Textile Rental Services Association (TRSA)

Risk Assessment of Heavy Metal Residues in Shop Towels

Executive Summary

February 2013

Executive Summary

On behalf of the Textile Rental Services Association (TRSA) of America, ARCADIS performed a study to measure heavy metal residues in laundered shop towels and to provide a quantitative risk assessment based on exposures to workers using the towels. The study was prompted by a technical paper prepared by *Gradient* (Cambridge, MA) entitled, *Evaluation of Potential Exposure to Metals in Laundered Shop Towels (Gradient, 2010),* which concluded that the residual metals could pose a significant hazard. *A Quantitative Assessment of Risks of Heavy Metal Residues in Laundered Shop Towels and their Use by Workers (*the study) was performed by ARCADIS to provide a more refined assessment of worker exposure, utilizing data that represented the releasable quantity of each metal present in the shop towels. Based on the findings of this study, the residual concentrations of metals in laundered shop towels do not present a health hazard for workers using the towels. Worker exposures to 27 metals modeled in this assessment were not above regulatory thresholds for judging potential human health hazards. A summary of the study development, risk analysis results and conclusion is provided below.

Study Development

In analyzing the metal residue concentrations in the shop towels, a leachability testing procedure was employed to obtain data suited to the modeling of worker skin contact with shop towels. Leachable concentrations of 27 metals were measured in samples of laundered shop towels. This group of metals included those reported by Gradient (2010) to be of potential concern with respect to worker exposures, such as antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum. Towels were obtained from 10 different rental/laundering facilities for the purpose of this study. Composite samples representing each facility were incubated in synthetic human sweat for 1 hour and the concentration of each metal in the extract, or leachate, was determined with inductively-coupled plasma-mass spectrometry (ICP-MS). The unfiltered leachate concentrations were used to represent the releasable quantity of each metal that could be transferred to the skin of workers using the towels.

Risk Analysis

This exposure model was focused on the towel-to-hand transfer of the metals and subsequent hand-to-food or hand-to-mouth transfers and was developed within the risk assessment framework used by U.S.EPA and other authoritative agencies. Transfer efficiencies used to represent the degree to which metals from towels are expected to migrate to the hands and from hands to mouth (or food) were derived from published studies evaluating similar exposure scenarios. Other exposure factor values were adopted from U.S.EPA risk assessment guidelines. The choice of high-end values for towel contact frequency and towel-to-hand transfer efficiencies was initially considered, to accommodate a considerable degree of uncertainty in these values; however, to avoid implausible estimates of skin loading, these exposure factor values were chosen

based on the concept of a maximum skin load. Overall, the assumed conditions of towel use represented by this exposure model are conservative, such that the resulting exposure estimates would be likely to overstate actual exposure.

The estimated worker intakes resulting from the exposure model were compared against a regulatory threshold for each metal, which for nearly all metals was a USEPA Reference Dose (RfD). This comparison is represented as a Hazard Index. Representing the ratio of modeled dose to a regulatory (threshold) dose, e.g., Reference Dose, a Hazard Index above 1 indicates that exposures may be at unacceptable levels. The Hazard Index for each metal evaluated was below 1.0, indicating that the predicted exposures would not be expected to represent a health hazard. The incremental cancer risks estimated for arsenic, which is regulated as a carcinogen, was 1×10^{-6}, i.e., one-in-one-million. This risk estimate is at the lower end of the range of acceptable risks used by U.S.EPA (10^{-6} to 10^{-4}) in regulatory decision-making. The risk assessment for lead utilized the USEPA Adult Lead Model, an approach that is consistent with a standard risk assessment approach in the U.S. Use of the Adult Lead Model with the concentration data obtained for lead predicted lead intakes in workers that do not constitute a health hazard.

Conclusion

This study provides an independent analysis of laundered shop towel samples obtained from TRSA member service companies, with the resulting data supporting a more accurate assessment of the potential for exposures to workers than the assessment performed by Gradient (2010). The uncertainties that are part of this analysis are discussed in relation to the overall confidence in the exposure estimates developed for each exposure pathway. It is noted that the overall worker exposure to the same metals, apart from the use of shop towels, is not addressed by this assessment, and these exposures, occurring via direct contact with metal parts and equipment, grease, grease-based residues, engine oils, and/or metal shavings and filings could be much higher.

Therefore, based on the assessment, it is concluded that the health risks associated with metal residues in shop towels are below regulatory levels of concern. Understanding the actual towel-to-hand transfer in a "real-world" scenario and the role of towels in the overall worker exposures would require further study. At present, the possibility that towel use might cause a net removal of metals and other substances from the hands should be considered in the assessment of these worker exposures. These uncertainties are only likely to cause the exposure estimates to overstate actual exposures.

A Quantitative Assessment of Risks of Heavy Metal Residues in Laundered Shop Towels and their Use by Workers

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Abstract

This paper presents ARCADIS U.S. Inc.'s (ARCADIS) risk assessment of metal residues that have been measured in laundered shop towels and potential exposures to workers who use the towels on a regular basis. The concentrations of 27 metals measured in a synthetic sweat leachate were used to estimate the releasable quantity of the metals which could be transferred to the skin of workers using the towels. Worker exposure was evaluated quantitatively with an exposure model that focused on the towel-to-hand transfer of the metals and subsequent hand-to-food or hand-to-mouth contacts (and assumed transfers). The exposure model was developed based on reasonable, but conservative assumptions regarding towel use and other default exposure factor values from the published literature or regulatory guidance. Transfer coefficients were derived based on studies that were most representative of the exposure scenario under study. Contact frequencies were chosen based on assumed high-end use of shop towels, but constrained by a plausible maximum dermal loading. The risk estimates for workers developed for all metals were below applicable regulatory risk benchmarks. The risk assessment for lead utilized the USEPA Adult Lead Model and concluded that predicted lead intakes do not constitute a significant health hazard based on potential worker exposures. The uncertainties that are part of this analysis are discussed in relation to the overall confidence in the exposure estimates developed for each exposure pathway and the likelihood that the exposure model is under- or overestimating worker exposures and risk.

Introduction

The use of reusable, natural-fiber-based towels in the workplace as rags for wiping engine or mechanical parts, work surfaces, or equipment gives rise to the possibility for some residual presence of metallic constituents in the towels despite the laundering process. Concentrations of heavy metals in samples of laundered shop towels were reported previously, in a paper that also presented a screening risk evaluation for workers using the towels, with reported risk estimates that exceeded certain health benchmark values (Beyer et al., 2010, Beyer et al., 2003). On the basis of this earlier work, the present effort was undertaken by ARCADIS to perform a refined evaluation of the health risks associated with residual metals in laundered shop towels, using analytical methods that provide more relevant measures of the available metal concentrations and applying alternative models for evaluating exposure and risk.

Quantifying chemical exposures that may result from the handling of garments, tools, accessories, or other consumer products have typically been conducted using *ad hoc* models that are tailored to the chemical constituents of interest, the nature of the exposure medium and the circumstances of contact between the user (receptor) and article. No single model has been established that is intended to fit all types of situations, although several examples can be found in the published and grey literature—representing efforts prompted by consumer right-to-know initiatives (e.g., California's Proposition 65) and by consumer safety protection agencies.

A model that has been applied to quantifying dermal exposures across a broad range of scenarios and circumstances are so-called transfer models, whereby a releasable or dislodgable concentration of a constituent is assumed to transfer to the hands of the user at some assumed rate based on values obtained from the literature or experiments simulating the exposure conditions. Transfer models have been used extensively in modeling human exposures with pesticides, which have been impregnated into garments or applied to a carpet or other surface (Lu and Fenske, 1999, Zartarian et al., 2000, Zeilmaker et al., 1999).

A transfer model was applied to the assessment of exposure to the residual metals in shop towels, which only addresses dermal contact as potential pathway of subsequent oral exposures via hand-to-mouth or hand-to-food contact. The first reason for this choice is that the dermal absorption of metals is very low, particularly when in a non-aqueous medium or in an elemental, non-ionic form and even metal salts have dermal absorption factors that are generally much less that 1%, or even less than 0.1% (EBRC, 2007, EPA, 2004). In addition, the conventional migration models, which address dermal absorption, would focus on the soluble fraction of the metals; however, if the metal concentrations detected in the shop towels are associated with small particles or shavings, or part of an oily residue, a focus on the soluble fraction could ignore the bulk of the metal present. Typically, in cases where contact with a material is intermittent, but there is the chance that the transferred substance can remain on the skin after contact, hand-to-mouth transfers (and subsequent ingestion) are more important than dermal absorption. Such exposures are typically evaluated with transfer models (Cal-EPA, 2011, CPSC, 2010, Dube et al., 2004). However, to test this assumption, a migration model was run for select metals using leachability data and the USEPA (2004) model for estimating a dermal applied dose (DAD), with corresponding dermal permeability coefficients (Kp) for constituents in an aqueous medium. The results confirmed that dermal absorption as an exposure pathway would represent a negligible (<1%) contribution to overall dose in workers, as compared with hand-to-mouth transfer. Therefore, dermal contact is only used in this assessment as a pathway to incidental oral exposure, through hand-to-mouth, or hand-to-food contact.

The most convenient analysis of the metal concentrations in an article is the measurement of total mass by weight ("bulk analysis"), using acid digestion. These data may provide useful baseline information on the bulk concentrations in the towels. However, for the purposes of risk assessment, these data fail to capture a measure of the available surface concentration of each metal that is relevant to human exposure. In some cases, it must be simply assumed that all of the metal content inside the fabric is available at the surface. As the basis for a more refined risk assessment, data on the available metal concentrations were obtained via leachability tests using a synthetic sweat to simulate conditions of human contact of skin with a towel.

The leachability data are the input for the transfer model, providing a measure of each metal that is available for transfer to the skin. Leachability testing protocols have been used as the basis for risk assessment by evaluations of medical devices such as bandages, first aid dressings, and gloves (Seibersdorf, 1998), flame retardants in upholstered materials (CPSC, 2006), cadmium and lead in children's toys (CPSC, 1997), and benzidine dyes contained in toys and other articles handled by children (Zeilmaker et al., 1999), among others.

The exposure model for workers focused on three potential exposure pathways: exposure via towel-to-hand contact and subsequent hand-to-mouth contact, towel-to-hand contact and subsequent hand-to-food contact, and direct contact of the towel with the mouth. The direct towel-to-mouth pathway addresses the use of a towel by a worker to wipe his or her face, wherein some incidental contact with the mouth could occur, giving rise to some small amount of the metal being ingested. An exposure model for workers was developed that aimed to be conservative, but reasonable and representative of a high-end, but foreseeable level of towel use and contact frequency. Exposure factor values and other assumptions were chosen to represent a mix of average- and upper-bound levels of anticipated worker exposure.

Toxicity reference values were obtained from authoritative sources, such as U.S.EPA, or the ATSDR. For lead, risk assessment has traditionally been conducted based on predicted change in blood lead concentration; accordingly, the USEPA Adult Lead Model (ALM) and a threshold blood lead concentration of 10 ug/dL were used.

A brief uncertainty analysis was carried out to evaluate the effect of using alternative exposure factor values and assumptions regarding worker exposure on the estimated risks and hazard indices. This analysis focused on several elements of the risk assessment that could be seen to make the predominant contribution to uncertainty in the results. These were related to both the methods used to obtain and interpret the analytical data and the model used to quantify exposure.

Methods

Data Collection

Laundered shop towels were obtained from ten (10) different rental/laundering facilities and forwarded to Exova laboratories (Santa Fe Springs, CA) for analysis of heavy metals. Each facility provided a bundle of 10 towels from which a composite sample was prepared, such that a single analytical result would be obtained for each towel bundle. Composite samples were obtained by collecting large cut-outs (approximately 8 x 10" in size and representing approximately 50% of the towel area) from individual towels. These sections were minced into small (~1 cm^2) bits with ceramic scissors and mixed thoroughly prior to the collection of subsamples for the analyses of metals.

Leachability tests were performed on the composite towel samples using synthetic sweat. The synthetic sweat solution was prepared by adding sodium chloride (10 g), lactic acid (1 g), disodium phosphate (1.875 g), and histidine (0.25 g) to 1 L of deionized water. A 200 mL volume of this solution was mixed with 20 grams of the homogenized sample and placed in a water bath at 37˚C for 1 hour with mild agitation. Leachates were treated with nitric acid (0.1 mL into 10 grams of leachate) to solubilize the substances leaching from the samples. Internal standards were added to these leachates and concentrations of twenty-seven (27) metals see (Table 1) were measured by inductively-coupled plasma-mass spectrometry (ICP-MS), based on an Exova Standard Operating Procedure (SOP; No. 7040, Revision 12). Similarly obtained samples were also analyzed with ICP-MS following a complete acid digestion to obtain a bulk (wt:wt) metal concentration.

Available Metal Concentrations in Towels

The leachable concentration of each metal was determined by multiplying the reported leachate concentration (in µg/g) by the leachate volume (200 mL) and dividing by the towel sample weight (20 g). Multiplying this value by the towel density (measured to be 0.026 g/cm^2) results in a leachable concentration per unit surface area of towel (in µg/cm^2). Based on these data (Table 1), a 95 percent upper confidence level (UCL) on the mean concentration was developed to represent the average exposure concentration for use in the risk assessment. Where a metal was detected in fewer than 3 samples, the maximum detected concentration was used *in lieu* of a 95%UCL. The concentration term is represented as C_{towel} in the exposure model presented below. A reference towel sample, which represented a new, unlaundered towel was similarly analyzed; results of this analysis are presented in Table 2.

Exposure Model

The basic approach to the modeling of exposure could be characterized as a *transfer* model, which uses transfer coefficients to describe the towel-to-hand or hand-to-face transfer of metals, together with estimates of the expected frequency and/or duration of each contact. The chosen model was adapted from models found in the open literature and in regulatory guidance, based on all foreseeable exposure pathways (calculated as dose) for workers using shop towels. An available (as leachable) concentration of each metal in the towels served as the source term for the exposure model. The model used elements of exposure models published by authoritative agencies or working groups and applied to risk assessments for various consumer products and varied impurities or residues (Cal-EPA, 2011, CPSC, 2006, EBRC, 2007, Zeilmaker et al., 1999).

Three different exposure pathways were evaluated, all of which culminated in the eventual ingestion of a small amount of a metal contained in the towels. These pathways include: 1) towel-to-hand-to-mouth contact, 2) towel-to-hand-to-food transfers, and 3) towel-to-mouth contact. In modeling hand-to-mouth transfer, contact with the face is based on the incidental but predictable hand-to-face contact that occurs throughout the day. The towel-to-mouth pathway addresses the possible contact of the towel directly with the face, specifically the lips, although the use of a shop towel to wipe the face is an uncertain practice, which may not occur on a regular basis. It is further assumed that these three exposure pathways could occur simultaneously throughout a work day, and therefore, a total exposure estimate was evaluated based on all three pathways.

The exposure model for each of the three exposure pathways is represented by the generalized equation below, which results in a daily dose in units of mg/kg-day. Exposure factor values may be defined differently for each exposure pathway; for example, the skin surface area (SA) used in the model of towel-to-hand contact is that of the hands, while the SA used to model the hand-to-face transfers is that for the mouth or lips.

$$\text{Dose} = C_{towel} \times STE_{TH} \times CF_{towel} \times SA_{hand\ or\ mouth} \times [CF_{face\ or\ food} \times TC_{HM/HF} \times FI] \times EF \times ED / AT \times BW$$

[ ]: Only applicable for two-step pathways, towel-to-hand/hand-to-mouth and towel-to-hand/hand-to-food.

Where:
Dose = Average daily dose (ADD); Lifetime ADD (LADD) for carcinogens
C_{towel} = available concentration of metal on surface of towel (µg/cm^2)
STE_{TH} = skin transfer efficiency, towel-to-hand (fraction)
CF_{towel} = towel contact frequency (number of contacts per day)
SA_{hand} = surface area of skin (hand) in contact with face, or with food (cm^2)
SA_{mouth} = surface area mouth in contact with towel (cm^2)

[CF_{face} = face contact frequency (number of contacts between hand & face per day)]
[CF_{food} = food contact frequency (events per day)]
[TC_{HM} = transfer coefficient, hand-to-mouth (fraction)]
[TC_{HF} = transfer coefficient, hand-to-food (fraction)]
[FI = fraction of constituent actually ingested]

EF = exposure frequency (days per year)
ED = exposure duration (years)
AT = averaging time (days)
BW = body weight (kg)

Dose is averaged over a 70-year lifetime (AT) when assessing cancer risk and termed a lifetime average daily dose (LADD), while the AT is set to the same value as the exposure duration (ED) in calculating an average daily dose (ADD) for noncancer hazard assessment. The exposure factor values used in the modeling each of the three exposure pathways are described in Tables 3 and 4 and the cumulative ADD/LADI for all three pathways is presented in Table 5. The basis for these values is described in detail below.

STE, skin transfer efficiency, towel-to-hand and towel-to-mouth

With each contact between the hands and a towel there is an assumed transfer of some fraction of the metal concentration from that towel. The skin transfer efficiency (STE) is used to describe the degree to which this transfer will occur. USEPA (2011) provides summaries of some key studies providing these skin transfer factors (or coefficients); however, this guidance also notes that because use of residue transfer depends on the specific conditions under which exposure occurs (e.g., activity, contact surfaces, age), the risk assessor should refer to the available data from which appropriate values may be selected. No data are available specifically representing the transfer of metals from shop towels to the hands; however, a number of STE estimates have been published in the literature based on studies measuring the transfer of various chemicals from a variety of consumer products, e.g., garments, carpeting, toys. Many of these studies are focused on pesticides; however, in most cases the contact was with a residue that had been applied to the surface of a material; and therefore, the chemical properties of the substance being studied is not likely the key factor in the observed transfer efficiency.

Based on a review of the literature values, the U.S. EPA Office of Pesticide Programs (OPP) recommends a default STE value of 5-10% for contact with various surfaces, although the transfer efficiencies observed with soft surfaces were towards the lower end of this range. As part of a risk assessment of perfluorooctanoate exposures in garments and apparel, Washburn et al. (2005) also reviewed transfer factors for various consumer products/household materials having soft surfaces and chose to use a value of 5% for infants and 2.5% for adolescents and adults. Additionally, dermal migration factors have been measured by several studies (Snodgrass, 1992, Wester et al., 1996, Yang and Li, 1993) and range from 0.13 to 6%. These values consider the overall transfer of chemicals (mostly pesticides) from clothing to skin. Some of these values are of questionable applicability to the transfer of metal residues from shop towels as assessed herein, since our model begins with an assumed available concentration (or leachable concentration) of metal.

Additional studies reviewed include Cohen Hubal et al. (2005) who observed an average STE of 7.2% based on moist hand data using an organic fluorescent tracer as a surrogate for pesticide residues. Hubal et al. (2008) also used fluorescent tracers and had volunteers perform several contact trials without washing their hands in between tests, which is likely more representative of a real-world scenario. For the dry hand condition, the STE estimate from this study was 3.6% and, for the moist hand conditions, 8.7%. Lu and Fenske (1999) evaluated the transfer of the pesticide chlorpyrifos from carpeting based on removal by human skin, cloth wipes, and polyurethane foam rollers. According to the study, skin removed between 0.04 and 0.26% of the chlorpyrifos from carpeting for an average STE of 0.13%. Camann et al. (1996) developed STE estimates based on the transfer of pesticides from carpet to saliva-moistened hands resulting in an average STE of 2.5%. Additionally, this study reported on data from a previous study representing the same tests conducted with dry hands in which he observed a mean transfer efficiency of 0.1%. Yang and Li (1993) measured the frictional transfer of three different pesticides from cotton, polyester, and blended fabrics to silk (imitating skin) and observed the highest average transfer to be about 6% (averaged for dry, water-wetted, and perspiration-wetted fabrics). Looking only at cotton, the average transfer efficiency for the three pesticides was 1.8%. Clothier (2000) evaluated the transfer efficiency of pesticides from vinyl flooring to dry and wetted palms and reported an STE of 5.1%; however, this STE represented the use of a smooth surface rather than a textured such as a towel, which could result in a higher STE than is applicable to this study. Two additional studies were reviewed, but not considered towards the selection of an STE. Rodes et al. (2001) measured the transfer of dust particles from carpeting to hands, however dust particles are likely to be a poor measure of the transfer of heavy metals (or oil and grease) from cloth fabrics to the skin. Wester et al. (1996) measured the transfer and absorption of pesticides from cotton fabrics into culture skin cells *in vitro,* and is therefore unlikely to be applicable for calculating a dermal transfer coefficient for intact human skin in a real-world setting. A summary of the various skin transfer efficiencies is presented in Table 4. A reasonable best estimate STE value based on this review would be between 3 and 5%.

Based on these findings, the U.S. EPA default of 5% was chosen to represent the STE for this assessment. This value is used to represent the fractional transfer of the metal present on the towel surface to the skin of either the hands or the mouth, per a specified surface area. It is noted that the same transfer efficiency value is applied to direct towel-to-mouth exposures, if it assumed that the towel contacts the skin of the lips and not the interior of the mouth, where an increased transfer based on contact with saliva might occur.

CF_{towel}, hand to towel contact frequency

The frequency of towel contact by workers is another key component of the exposure model. However, this exposure factor value is likely to be highly variable among workers, being dependent on the nature of towel use and the personal habits of an individual worker. Moreover, if towel number and contact frequency are used as the basis of exposure, the exposures predicted by this model would increase linearly with towel use, i.e., greater hand loading will accompany more frequent towel use. In reality, the opposite is likely to be true: a worker replacing his/her towel more often would be expected to have cleaner hands, since towel use in most instances is aimed at removing grease from the hands. In addition, studies on the pesticide exposures have shown that the pickup by hands from various surfaces is a saturable process, wherein the removal of a residue on the skin eventually becomes as important as the pickup (Brouwer et al., 1999). The maximum load can even be reached within several contacts (Cohen Hubal et al., 2005). The concept of a maximum dermal loading has been incorporated into some of the most advanced dermal exposure models (Zartarian et al., 2000). In an assessment of surface-to-hand transfers in pesticide workers, EPA (1997) applied a model that did not permit dermal loading to continue beyond the point where the skin concentration exceeded the concentration on the contacted surface.

Therefore, a contact frequency was chosen that is based on the maximum reasonable skin loading that could occur with towel usage. In this manner, skin loading was not allowed to exceed the concentrations on the towels themselves. Where an STE of 5% is used to represent the towel-to-hand transfer per contact event, an assumed number of 20 contacts per day will result in a transfer of 100% of the entire available metal content of a towel (per surface area contacted). Thus, a value of 20 contacts per day was chosen as a reasonable maximum for the number of towel contacts in a typical work day. Since the concentration typically found on the hands of workers would probably not equal the concentrations in the towels, this set of assumptions should be regarded as a “worst case” scenario.

SA_{hand}, surface area fingertips in contact with face

The skin surface area (SA) of the hands that is relevant to hand-to-mouth contact is 19 cm^2 and this SA is used as a basis for estimating the towel-to-hand and hand-to-mouth transfer of heavy metals. Similar risk evaluations conducted by regulatory agencies or authoritative bodies for these types of exposures commonly use the skin surface area that makes contact with the article (Cal-EPA, 2011, CPSC, 1997, 2010, Washburn et al., 2005). As much as one-third to one-half of the total surface area for both hands is typically assumed to make contact with a surface, which is 180 to 270 cm^2 for adults (EPA, 2011). However, where dermal absorption itself is a *de minimis* exposure, the transfer model can focus on the skin surface area that is likely to make contact with the mouth.

In a recent interpretive guideline for exposure assessments under California's Proposition 65 (Cal-EPA, 2011), the recommended surface area for direct hand-to-mouth contact is that of the palmar surface area of a hand, counting each finger as 10% of the palmar surface area of the hand and counting each fingertip as 30% of the finger. It is further assumed that the part of a hand that is in contact with the mouth is three fingertips (i.e., the tip of a thumb and two fingertips). The resulting values are 19 cm^2 for men and 17 cm^2 for women. The higher value of 19 cm^2 is chosen to represent the surface area of the hands that is assumed to contact the mouth. It is noted that this value is equivalent to about 3 times the surface area of the lips (see below).

CF_{face}, face contact frequency (number of times worker touches face with hands each day)

The number of expected hand-to-mouth contacts is the rate-limiting step in the overall model of worker exposure to towel constituents, assuming that the hands carry a given load from the use of shop towels throughout the day. The review by Cherrie (2006) reported that adults in occupational settings are likely to touch their face approximately 5 times per hour on average, although contacts can increase under stressed situations. Cherrie (2006) also cited the data from Zainudin (2004), to point out that workers who used their hands to perform their jobs, such as manufacturing or laboratory workers, made much lower hand-to-face contact frequencies, as compared with those who did not (e.g., office workers). The highest contact frequencies reported by Zainudin (2004) among these groups was 6 contacts per hour. A contact frequency of 5 per day is also supported by age-dependent behaviors summarized in Xue et al. 2007 (as cited by USEPA 2011), which focused on children, but found evidence of a rapid decline in contact frequencies with age and that children age 6 -11 years had a mean contact frequency of 7 contacts per hour, which was 3 to 4-fold lower than those exhibited by younger children.

Based on these data, a hand-to-face contact frequency for adults of 5 contacts per hour is reasonable. However, not all hand-to-face contacts will represent a contact between the hands and lips. Nicas and Best (2008) provided one of the only studies of adults which recorded the hand-to-face contacts according to the area of the face contacted. As summarized by USEPA (2011), this study found that roughly 50% of the hand-to-face contacts included the lips or mouth. Therefore, the hand-to-face contact frequency of 5 contacts per hour (or 40 contacts per day), as estimated by Cherrie (2006), was halved to estimate a hand-to-mouth contact rate of 20 contacts per day.

$TC_{h/m}$, hand-to-mouth transfer efficiency

Typical contact between the hands and mouth would not result in the transfer of 100% of a chemical that is present on the hands. In fact, even with the most rigorous conditions of dermal contact, a transfer coefficient ($TC_{h/m}$) of more than 50% is difficult to conceive, at which point the concentration of the transferred substance on the lips would equal that of the hands. Transfer coefficients ($TC_{h/m}$) of 50% have been used in risk assessments evaluating lead exposure via dermal contact (Cal-EPA 2011 and CPSC 1997), referencing the transfer studies of Camann et al. (2000) and models that simulated the conditions of mouthing behavior in children. The $TC_{h/m}$ representing the much more incidental nature of hand-to-mouth contacts in adults is likely to be much less than 50%. A $TC_{h/m}$ value of 25% is used as the default choice in USEPA pesticide assessments, and an USEPA Region 3 (1996) assessment addressing dermal exposures to indoor surfaces used a value of 10%. Based on the lack of relevant data characterizing the hand-to-mouth transfers for adults, a value of 25%, which is an intermediate choice among the HME values used by others for this same purpose, was used in the risk assessment. The value of 25% also represents the value of 50% developed for young children, adjusted by a factor of 50%, which is a very minimal adjustment based on the substantial differences between children and adults with respect to hand-to-mouth contact.

FI, fraction of contacted metal ingested

Subsequent to the transfer of a chemical residue to the lips, some amount of incidental ingestion is typically assumed to occur. The amount of a material applied to the lips that is actually ingested has received recent attention as part of assessments for lipsticks and the trace levels of lead found in lipsticks (FDA, 2010; Cal AG, 2008). These assessments have concluded that, while there are no data quantifying the exact amount of lipstick (or similar product) that is ingested by users, this amount is likely to be small. Nonetheless, it was assumed for the purpose of this assessment that 50% of the metal transferred to the lips will be ingested. The same value for this exposure factor value was used by the assessment of shop towels by Beyer et al. (2010), citing professional judgment.

SA_{hand}, surface area hands in contact with food

The surface area of the hands that may come into contact with food is assumed to be 210 cm^2. A conservative model was evaluated assuming that the palmar surface of all ten fingers might come into contact with food. This values was derived from an assessment by Cal-EPA (2010), wherein each finger was assumed to comprise 10% of the palmar surface of the hand; conservatively assuming that all ten digits can will make contact with food during a meal, the surface area of all ten fingers will be equivalent to 50% of the surface area of both hands (420 cm^2), or 210 cm^2.

TC_{HF}, hand-to-food transfer coefficient

In the assessment of indirect contacts that accompany the hand-to-mouth exposure pathway, Cal-EPA (2011) assumed a transfer factor of 25%, attributable to a 50% hand-to-mouth transfer and a loss fraction of 50% of the skin load that remains on the hands. The loss fraction accounted for the removal of a substance from the hands that is presumed to occur outside of contact with the mouth, including the handling of foods. The same hand-to-food transfer efficiency (TE) of 25% is used in this assessment, in part based on the Cal-EPA (2011) analysis, but also based on the on the previous discussion of towel-to-hand transfer efficiency, where 50% is a reasonable upper limit on this transfer (whereby 50% of the available metal is transferred), but transfer efficiencies nearer to 5% might be expected.

CF_{food}, Hand to Food Contact Frequency

Hand-to-food transfers will occur when a worker who has not washed his or her hands will eat food items such as a sandwich, cracker, or raw vegetables, which are eaten with the hands. While some finger foods, such as chips will involve multiple contacts, the degree of contact made with these foods is also very small, as compared to larger items. Therefore, given that each contact “event” is assumed to involve a substantial skin surface area (including the palmar surface of the hands), it is assumed that 2 contact events will occur per day on average. It is noted that a contact event must involve a food item eaten with the hands, where the handled part of the food is consumed. It also assumes no amount of loss from hand-washing, which would likely occur before a meal in a shop setting.

$CF_{Hand\text{-}face}$, face contact frequency (number of times worker touches face with towel each day)

The frequency with which an adult worker might bring a towel to his lips was estimated to be 2 times per day. This is in part based on the assumption that towel-to-face contacts, if these contacts do occur, would likely involve other parts of the face. The previous discussion that led to a hand-to-face contact rate of 20 times per day was also considered; however, the nature of these contacts may be quite different and aimed more at wiping sweat from a forehead. It is therefore assumed that 10% of these contacts would include the lips, as it is unlikely that an adult worker would use a shop towel for the express purpose of wiping his mouth. Nonetheless, an average contact frequency is assumed to be 2 per day for this assessment.

SA_{mouth}, surface area mouth in contact with towel

The relevant skin surface area for evaluating towel-to-mouth contact is that of the lips, which has been estimated to be 6 cm^2 for adult males (Ferrario et al., 2000). The surface area of the lips in contact with the towel is regarded as the limiting factor in the transfer of towel-based constituents which might ultimately be ingested. It is likely that only half the surface area of the lips would come into contact with the towel. Therefore, a value of 3 cm^2 is used to represent the surface area of the lips that comes into contact with a shop towel.

Other Exposure Factor Values (EF, ED, AT, and BW)

Several other exposure factor values used to quantify exposure (as dose) are based on default values commonly recommended by U.S. EPA, including exposure frequency (EF), exposure duration (ED), averaging time (AT), and body weight (BW). These values and the source of these values are summarized in Table 3. Exposure duration is chosen to represent job tenure for workers and a default value recommended by U.S. EPA (2002) of 25 years is chosen conservatively for this assessment. It is noted that this is a 95th percentile value representing for job tenure in the manufacturing sector for men. U.S. EPA (2011) states that the 25-year default value is likely to be protective of workers “across a wide spectrum of industrial and commercial sectors.”

Blood Lead Model

The hazard assessment lead exposures was based on the conventional approach using blood lead (PbB) levels as the dose metric for assessing risk. This assessment utilized the USEPA Adult Lead Model (ALM), which is based on a biokinetic slope factor of 0.4, relating a daily lead intake to a predicted PbB levels. ALM was used with embedded defaults, expect that an exposure frequency for workers was input as 250 days per year and the default bioavailability factor of 12% was changed to 20%. This value reflects the GI absorption of soluble lead, rather than an oral bioavailability of lead in soil, which is typically represented by an additional adjustment of 60% to reflect soil matrix effects.

Toxicity Values

Toxicity data were selected based on the recommended hierarchy presented in U.S. EPA (2003b) Human Health Toxicity Values in Superfund Risk Assessments. The U.S. EPA Integrated Risk Information System (IRIS) is used as the primary source for toxicity values, which are reference doses (RfDs) for the assessment of noncancer hazards and cancer slope (potency) factors (CSFs) for cancer risk assessment. The USEPA Office of Solid Waste and Emergency Response (OSWER) Provisional Peer-Reviewed Toxicity Values (PPRTVs) and the ATSDR Minimal Risk Levels (MRLs) are used as a second tier of toxicity values. The selected toxicity values are presented in Table 6

Results

Summary statistics for the 27 metals evaluated are presented in Table 1 and include the detection frequency, minimum and maximum detected concentrations, mean and standard deviation, and 95% UCL (on the mean) concentration. The mean and 95% UCL concentrations were calculated using the U.S. EPA Pro-UCL software (v4.00.05) and using a substitution equal to one-half of the detection limit for samples/analytes with undetectable results. As shown in Table 1, the majority of metals evaluated were detected in all 10 samples. Beryllium boron, silver, thallium, titanium and vanadium were detected in 5 to 9 of the 10 samples, whereas mercury was detected in just two samples, and selenium was detected in one of the 10 samples analyzed. Reference samples, which were comprised of new, unlaundered towels, were also found to contain measureable levels of aluminum, antimony, arsenic, barium, boron, cadmium, calcium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, potassium, strontium, tin titanium, and zinc. For magnesium, potassium, strontium, and titanium, the concentrations (as 95% UCL or maximum concentrations) in the reference towels were not different from those in the laundered ("in-use") towels, although it was more common for the laundered towels to have much higher (as much as 100-fold) concentrations of the metals than the reference towels (Table 2).

Noncancer Hazard Assessment

The assessment of noncancer hazards was judged on the basis of a Hazard Index (HI, as average daily dose (ADD)/RfD) and HIs for 22 metals are summarized in Table 7. Metals that are considered essential minerals or for which no toxicity criteria exist were not carried through the risk assessment, including calcium, magnesium, potassium, and titanium. Lead was evaluated separately using the USEPA Adult Lead Model (ALM). Hazard indices were calculated for each of the three exposure pathways and for the summed dose resulting from all three exposure pathways. The HI values for the 22 metals were below 1, ranging from 5×10^{-6} to 0.2. The highest HIs were those for cadmium (HI = 0.4) and cobalt (HI = 0.2), and the HIs for all other metals were at least 10X lower than 1. Each HI is based on the protection of the most sensitive toxicological endpoint, termed the critical effect, or endpoint. For metals that share a common critical effect, the HI values were summed to assess the cumulative hazard associated with simultaneous exposure to these metals. The assessment of cumulative risk is more important as the estimated exposure levels start approaching actual effect levels. However, the toxicity values are developed in a manner than assures a margin of safety of at least 100 to >1000; which means that while the HI for cadmium (0.4) may be just more than 2X less than 1.0 , the predicted cadmium doses are still hundreds or thousands times lower than the dose levels where adverse effects might be observed.

Cancer Risk

Among the metals evaluated, only arsenic is regulated as a potential human carcinogen and is commonly assessed on the basis of cancer as the endpoint. The U.S. EPA considers cancer risks to be generally acceptable when in the range of 1 $\times 10^{-6}$ to 1 $\times 10^{-4}$. The total risk estimated for arsenic and all three exposure pathways was 1×10^{-6}, which is the lower bound of the range of risk considered acceptable by the U.S. EPA (Table 7).

Adult Lead Model

U.S. EPA Adult Lead Model (ALM) uses a biokinetic slope factor (BKSF) relating blood lead level to ingested lead and data on the background exposures and blood lead levels for the general population. Using this model, lead risk is expressed as a probability that the blood lead levels among a receptor population will exceed 10 µg/dL, the threshold level established by the Center for Disease Control (CDC). USEPA (2003) considers a probability of 5% as the point of departure for assessing lead risks, which is consistent with a level of protection at the 95th percentile of exposure and risk.

An estimate of the daily lead dose (0.008 µg/kg-day) was calculated with the same exposure model used for other metals and was the starting point for the ALM. Based on this lead dose, the ALM predicts a 0.4% probability of exceeding the 10 µg/dL PbB threshold, indicating a *de minimus* risk for lead-related effects. The average estimated lead intake, as estimated in this assessment, would cause no measurable change in blood lead levels. Based on the results of the ALM modeling, predicted changes in blood lead to female workers of child-bearing age who are using the shop towels do not exceed EPA's target (*de minimis*) risk levels.

Discussion

Available Metal Concentrations on Towels

Ideally, dermal exposure is assessed on the basis of a "surface loading" concentration, which is based on an application rate (per unit surface area) to a material's surface. For substances that are part of the composition of an article, the estimation of a surface concentration requires data representing some measure of the available, or dislodgable mass of the substance. In the case of laundered shop towels, residual metal concentrations may in fact be most concentrated near the interior of the towels, because grease and oily residues at the surface of soiled towels are more susceptible to removal during laundering.

Wipe sampling is the conventional approach to measuring surface concentrations and, for example, has been the standard approach for measuring pesticide residues on surfaces (USEPA 2011). Other test methods that more closely simulate human contact, such as methods that use polyurethane foam (PUF) rollers or "drag sleds" are making advances. However, these methods are most commonly applied to firm or fixed surfaces to sample residues that are present on the surface, such as a pesticide or a dust (USEPA 2007). Nonetheless, wipe testing could be implemented on a loose fabric such as a shop towel and a more innovative method, such as a gloved hand approach, should likely be considered; however, it is not clear whether these methods would provide better measures of the releasable metal, where that metal is contained within the fabric. Leachability testing likely represents a more aggressive approach akin to an extraction method and therefore better representing the potential for a sweaty hand to remove some of the metal, which might not be captured with a wipe test. There are little data available for comparing the results of saline extractions versus wipe tests; however, CPSC (2010) applied both approaches for the measurement of phthalate releases from a children toys and apparel. The results, when expressed on a mass per surface area basis were comparable for both methods. In some instances, the saline extraction indicated higher releasable concentrations than the wipe tests. Since the CPSC was testing a constituent of plastics that is an integral part of the material, these results are of uncertain relevance to the case of metals in shop towels; however, the metals of interest make be more susceptible to extraction, since they are not part of the composition of the towels.

Towel-to-Hand and Towel-to-Mouth Transfer Coefficient

The skin transfer efficiency (STE) of 5% is an important factor in the model of towel-to-hand contact. The confidence in this value is increased by the large number of studies evaluating this factor and the use of similar values by regulatory agencies, which characterize them as conservative.

Additional studies reviewed include Cohen Hubal et al. (2005) who observed an STE of 7.2% based on moist hand data using an organic fluorescent tracer as a surrogate for pesticide residues. Hubal et al. (2008) also used fluorescent tracers and had volunteers perform several contact trials without washing their hands in between tests, which is likely more representative of a real-world scenario. For the dry hand condition, the STE estimate from this study was 3.6% and, for the moist hand conditions, 8.7%. Lu and Fenske (1999) evaluated the transfer of the pesticide chlorpyrifos from carpeting based on removal by human skin, cloth wipes, and polyurethane foam rollers. According to the study, skin removed between 0.04 and 0.26% of the chlorpyrifos from carpeting for an average STE of 0.13%. Camann et al. (1996) developed STE’s based on the transfer of the pesticides from carpet to saliva-moistened human hands resulting in an average STE of 2.5%. Additionally, Camann et al. (1996) reported on data from a previous study representing the same tests conducted with dry hands in which he observed a mean transfer efficiency of 0.1%. Yang and Li (1993) measured the frictional transfer of three different pesticides from cotton, polyester, and blended fabrics to silk (imitating skin) and observed the highest average transfer to be about 6% (averaged for dry, water-wetted, and perspiration-wetted fabrics). Looking only at cotton, the average transfer effieicny for the three pesticides was 1.8%. Clothier (2000) evaluated the transfer efficiency of pesticides from vinyl flooring to dry and wetted palms, and noted an STE of 5.1%, however this the use of a smooth surface rather than a textured such as a towel one may result in a higher STE than is applicable to this study. Two studies were reviewed but excluded from our selection of an STE. Rodes et al. (2001) measured the transfer of dust particles from carpeting to hands, however dust particles are likely to be almost 100% dislodgeable and a poor measure of the transfer of heavy metals (or oil and grease) from cloth fabrics to the skin. Wester et al. 1996 measured the transfer and absorption of pesticides from cotton fabrics into culture skin cells *in vitro,* and is therefore unlikely to be applicable for calculating a dermal transfer coefficient to intact human skin in a real-world/occupational setting.

It is further important to note that used in conjunction with a contact frequency of 20 events per day, it is being assumed that 100% of the available concentration in the towels is transferred to the hands. As applied to the subsequent modeling of hand-to-mouth transfer, this maximal dermal loading is assumed to be present on the hands throughout the day. In reality, the load from 20 transfers would only likely be present after a substantial fraction of the work day, at which point, a worker is likely to have washed his hands at least once, in preparation for a meal, after use of the bathroom, or because of the end of a shift. A more refined model might account for time-dependent hand loading, as it is likely to fluctuate over the course of the work as a function of loading and loss (from wiping, washing, etc.).

Hand-to-Mouth Transfer Coefficient

The review of the available literature supports an assumed hand-to-mouth transfer efficiency of 25% based on the typical nature of hand-to-mouth contacts in adults. This value is, for example, the recommended default in USEPA guidance for assessing incidental ingestion of pesticides. However, values of approximately 10% have also been used to represent the $TC_{h/m}$ for adults. Dubé et al. (2004) proposed a $TC_{h/m}$ value for adults of 13% as the fraction of a single hand loading necessary to equal the average daily soil ingestion rate for adults. Cal-EPA (2008), in an assessment of dermal exposure to lead-bearing fishing tackle, was critical of the $TC_{h/m}$ value by Dubé et al. (2004) and the assumed connection between soil ingestion and dermal contact with soil. On the other hand, the $TC_{h/m}$ value by Dubé et al. (2004) may be overstated, not having accounted for inhalation of dust as another significant route of soil ingestion and not having divided the soil ingestion rate into multiple contact events. Thus, the value of 25% used in this assessment is a high end value, chosen to represent the uncertainty in this parameter value for adults. It is important to note that a large percentage of hand-to-mouth contacts likely involve a transfer of chemical residues that is either minimal or even negligible.

Face Contact Frequency

Of the exposure pathways evaluated in this assessment, hand-to-mouth transfers are the most difficult to model, because contact frequency is highly variable among individuals. Cherrie et al. (2006) recognized that there are no suitable methods available to measure the potential for ingestion exposure where the underlying processes are unintentional. While there is a large body of work documenting the role of hand- and object-to-mouth contact in children, there are limited data in adults. Many of these studies note a decrease in mouthing behaviors with age, although there is a substantial variation in behaviors (Tulve et al. 2002 as cited in Cherrie et al. 2006). The available studies examining adult behavior do indicate that adults touch their face much less often than children. A study of 44 university students found that adults touched their face an average of 3.9 times per hour and mouthed objects 1.6 times per hour (Woods and Miltenberger, 1996 as cited in Cherrie et al. 2006). Zainudin (2004) hypothesized that those engaged in work requiring the use of their hands were less likely to touch their face.

The decision to apply a conservative hand-to-mouth contact rate of five times per hour is based on the available research for adults and common use of this value in other exposure model (Cherrie et al. 2006).

According to the EPA Exposure Factors Handbook (2011), 10-12 year olds can be expected to mouth objects once an hour on average and display hand-to-mouth contacts four times per hour. These findings are consistent with the value of 20 hand-to-mouth contacts per day (2.5 contacts per hour) used in this assessment, which is focused on adult workers.

The stated variability in this exposure factor value could prompt the use of a more conservative, higher-end value. However, each of the 20 transfer events is assumed to represent a full contact event, that is, each contact is assumed to transfer the entire amount, in accordance with the transfer coefficient of 25%. Further, some skin transfer factors that are intended for the cumulative exposure over the course of a day are in the same range, indicating that the 25%, as discussed previously is a very conservative assumption.

Toxicity Assessment

The metal with the highest HI of the metals evaluated was cobalt, and this metal provides an interesting case study, which might provide additional perspective on the risks estimated by this assessment. In the absence of a USEPA Reference Dose (RfD) for cobalt, the assessment used the USEPA provisional RfD (p-RfD) of 3E-4 mg/kg-day. Provisional toxicity values do not receive the same level of peer-review as more formally established toxicity values from USEPA and often contain a higher level of conservatism by comparison. Therefore, an analogous toxicity value available through the Agency for Toxic Substances and Disease Registry (ATSDR) Minimum Risk Level (MRL) of 0.01 mg/kg-day for intermediate-duration exposures is also considered. ATSDR used a LOAEL of 1 mg cobalt/kg-day for polycythemia observed in a study with humans and applied an uncertainty factor of 100 (10 for use of a Lowest Observed Adverse Effect Level (LOAEL) and 10 for potential human variability susceptibility to these effects), recognizing the vast experience with human exposure. Polythemia, measured as an increase in erythrocyte (red blood cell) counts, has been very well characterized in animal studies as well as studies in human volunteers, with doses of 0.16–1.0 mg cobalt/kg/day being used to achieve certain therapeutic effects in humans and with the LOAELs observed in animal studies being in a similar dose range, including studies as long as 9 months in duration.

However, USEPA rejects the use of hematological effects as the critical effects, e.g., polycythemia, because they are reversible effects which are not an adverse consequence. However, USEPA developed the p-RfD of 3E-4 mg/kg-day for cobalt based on effects on iodine uptake by the thyroid and a LOAEL observed at 1 mg/kg-day. These effects are observed at lower doses that the dose eliciting polycythemia, even when normalizing for the differing exposure periods. Conservatism in the USEPA p-RfD is further added with the use of a combined uncertainty factor (UF) of 3000 (10 for the use of subchronic data, as noted, plus 10 for the use of a LOAEL, 10 for potential human variability, and 3 for the deficiencies in the available data characterizing cobalt toxicology.) Application of a full factor of 10 for use of a subchronic study (rather than a chronic study) is particularly questionable, since chronic studies are available.

The estimated cobalt dose associated with worker exposures, as estimated in this assessment was 7×10^{-5} mg/kg-day. While the margin of safety may appear small when comparing to the p-RfD, it is worth nothing that this conservatively estimated dose is certainly several-thousand-times lower than cobalt doses that have been used for medical purposes and where the risk adverse effects would have been observed if EPA's RfD were an accurate estimate of human risk.

Conclusions

An assessment of heavy metal exposures through the use of shop towels was carried out based on previous reports of residual concentrations in laundered towels. The results indicate that there is no increased health risk for workers who routinely use shop towels, from a variety of exposure pathways. The exposure model was based on the premise that dermal absorption of metals will be negligible as compared to indirect exposure pathways that lead to the incidental ingestion of a the metals; however, this was confirmed by a brief analysis of the potential dermal absorbed dose using USEPA permeability constants for inorganic metal salts. Several worker studies evaluating conditions of high exposure in an occupational setting reported that the skin load of substances encountered in the workplace can predict an increase in the total intake of certain heavy metals (reviewed in Cal-EPA, 2008).

A leachate analysis was performed as a measure of the "releasable" concentration of residual metals from a standard shop towel. This was used as a moderately aggressive extraction method to estimate the concentrations of heavy metals that could be transferred onto the skin of workers. Exposures were quantified with standard U.S. EPA-type models and scientifically-based inputs, focused on towel-to-hand, and towel-to-mouth exposure pathways. The conclusions of this assessment apply to normal, foreseeable towel use and conditions of worker exposure, as described in this risk assessment.

Hazard indices calculated for 26 metals (excluding lead) were below 1.0, indicating that predicted worker exposures were below levels which would indicate a potential health risk. The incremental cancer risks estimated for metals that are regulated as carcinogens (arsenic only) was $1x10^{-6}$, near the lower end of the range of risks generally considered to be acceptable by U.S.EPA (10^{-6} to 10^{-4}). Additionally, lead risks as evaluated by U.S. EPA ALM were below levels of a significant health concern as evaluated in this assessment. Based on our findings, the residual concentrations of metals in laundered shop towels do not present a health hazard for workers using the towels.

In the context of such an evaluation, workers who use shop towels are likely to have substantial, regular contact with the same substances found as residues in the towels, via direct contact with metal parts and equipment, grease, grease-based residues, engine oils, and/or metals shavings and filings. Thus, it is noted that any evaluation focused on laundered shop towels as a source of worker exposure to heavy metals will fall short of assessing the total exposure to these metals through the sum of work-related activities. In fact, focusing the assessment on the transfer of metal residues from a towel to a clean hand is somewhat artificial and in many instances towel use is more likely to cause a net removal of metals and other substances from the hands. This consideration was applied in the development of a model of worker exposure in this assessment, but only to a limited extent.

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Table 1. Data Summary for Synthetic Sweat Leachate Analysis: Selected Metals

Chemical	Total Detected	Detected Concentrations (µg/g)				
		Minimum	Maximum	Mean	Standard Deviation	95% UCL
Aluminum	10/10	0.024	0.5	0.131	0.045	0.358
Antimony	10/10	0.014	0.2	0.0567	0.043	0.0958
Arsenic	10/10	0.0013	0.01	0.00332	0.00205	0.00511
Barium	10/10	0.015	1.4	0.434	0.335	0.801
Beryllium	6/10	0.00009	0.001	0.000337	0.00024	0.000478
Boron	8/10	0.05	0.76	0.196	0.135	0.469
Cadmium	10/10	0.0078	1.6	0.27	0.057	0.94
Calcium	10/10	24	77	47.4	42	57.9
Chromium	10/10	0.002	0.19	0.0251	0.005	0.105
Cobalt	10/10	0.005	0.33	0.109	0.069	0.173
Copper	10/10	0.35	6	2.48	1.75	3.43
Iron	10/10	0.057	3.3	0.564	0.19	1.95
Lead	10/10	0.0012	0.028	0.0105	0.00755	0.0205
Magnesium	10/10	3.6	25	11.5	11.5	15.3
Manganese	10/10	0.21	0.81	0.449	0.39	0.555
Mercury	2/10	0.0002	0.0003	0.00025	0.00025	NA
Molybdenum	10/10	0.00615	0.68	0.11	0.0555	0.389
Nickel	10/10	0.044	1.4	0.261	0.0715	0.87
Potassium	10/10	0.6	8.4	2.86	2.2	4.21
Selenium	1/10	0.006	0.006	0.006	0.006	NA
Silver	5/10	0.00011	0.00048	0.000299	0.000315	0.0000292
Strontium	10/10	0.19	2	0.56	0.395	0.938
Thallium	5/10	0.0001	0.00018	0.000122	0.00011	0.000127
Tin	10/10	0.00058	0.019	0.00405	0.0019	0.00806
Titanium	6/10	0.002	0.008	0.004	0.003	0.0045
Vanadium	9/10	0.0004	0.0022	0.00101	0.0009	0.00125
Zinc	10/10	1.6	11	5.23	4.7	6.91

Notes:

UCL = Upper Confidence Limit

NA = UCL was not calculated for metals with less than five detected samples. Maximum detected concentration was used.

< = metal detected below laboratory detection limit

A substitution equal to 1/2 of the detection limit was used for samples/analytes with undetectable results for the purpose of calculating a mean, standard deviation, and 95% UCL.

All summary statistics and 95% UCLs were calculated using ProUCL Version 4.1.

Laboratory Method: Synthetic Sweat Leachate by SOP 7040, Rev 12

Duplicate sample processing was performed as follows:

- Both values non-detect: select the minimum value
- One detect / one non-detect: select the detected value
- One non-detect / one non-reported: select non-detect value
- One detect / one non-reported: select detect value
- Both detects: compute arithmetic mean

Table 2. Reference Data Summary for Synthetic Sweat Leachate Analysis: Selected Metals

Chemical	Total Detected	Reference Sample (µg/g)
Aluminum	10/10	0.14
Antimony	10/10	0.008
Arsenic	10/10	0.0057
Barium	10/10	0.18
Beryllium	6/10	<0.00004
Boron	8/10	0.07
Cadmium	10/10	0.0004
Calcium	10/10	67
Chromium	10/10	<0.001
Cobalt	10/10	0.00047
Copper	10/10	0.012
Iron	10/10	0.13
Lead	10/10	0.00054
Magnesium	10/10	26
Manganese	10/10	0.36
Mercury	2/10	<0.0001
Molybdenum	10/10	0.0009
Nickel	10/10	0.0034
Potassium	10/10	9.2
Selenium	1/10	<0.001
Silver	5/10	<0.00005
Strontium	10/10	2.2
Thallium	5/10	<0.00006
Tin	10/10	0.013
Titanium	6/10	0.004
Vanadium	9/10	<0.0002
Zinc	10/10	0.049

Notes:

< = metal detected below laboratory detection limit

Laboratory Method: Synthetic Sweat Leachate by SOP 7040, Rev 12

Table 3. Exposure Factor Values

Variable	Unit	Value	Source	Notes
STE_{TH}	unitless	5%	U.S. EPA OPP 2007	
$TC_{HF/HM}$	unitless	25%	Cal-EPA 2011; see text	
SA_{hand}	cm^2	19 or 210	U.S. EPA OPP 2007; see text	
CF_{towel}	unitless	20	See text	
CF_{face}	contact/day	20 or 2	Cherrie 2006; see text	
FI	unitless	50%	Professional judgment; see text	
CF_{food}	unitless	2	Professional judgment; see text	
SA_{mouth}	cm^2	3	Ferrario 1999	50% of surface area of lips for adult male
EF	days/year	250	U.S. EPA OSWER 2002 default	
ED	years	25	U.S. EPA OSWER 2002 default	
AT	days	NC: 9,125 Cancer: 25,550	U.S. EPA OSWER 1989 default	
BW	kg	70	U.S. EPA 2011 Exposure Factors Handbook	

Notes:

STE_{TH} = skin transfer efficiency, towel-to-hand (fraction)

$TC_{HF/HM}$ = transfer coefficient, hand-to-food/hand-to-mouth (fraction)

SA_{hand} = surface area of skin (hand) in contact with face, or with food (cm^2)

CF_{towel} = towel contact frequency (number of contacts per day)

CF_{face} = face contact frequency (number of contacts between hand and face per day)

FI = fraction of constituent actually ingested

CF_{food} = food contact frequency (events per day)

SA_{mouth} = surface area mouth in contact with towel (cm^2)

EF = exposure frequency (days per year)

ED = exposure duration (years)

AT = averaging time (days)

BW = body weight (kg)

EPA = Environmental Protection Agency

OPP = Office of Pesticide Programs

OSWER = Office of Solid Waste and Emergency Response

Table 4. Studies Providing an Estimate of the Skin Transfer Efficiency

Reference	Summary Values	Matrix	Compound	Skin Condition
Cohen Hubal et al., 2005	2.6%	Carpet	Fluorescent-tracers	Dry
Hubal et al., 2008	3.6%	Carpet	Fluorescent-tracers	Dry
Lu and Fenske, 1999	0.1%	Carpet	Pesticides	Dry
Camann et al., 1996	2.5%	Carpet	Pesticides	Dry
Cohen Hubal et al., 2005	7.2%	Carpet	Fluorescent tracers	Moist
Hubal et al., 2008	8.7%	Carpet	Fluorescent-tracers	Moist
Camann et al., 1996	0.1%	Carpet	Pesticides	Dry
Yang and Li, 1993	1.8%	Cotton Cloth	Pesticides	Dry/Wet/Perspiring
Clothier, 2000	5.1%	Vinyl Flooring	Pesticides	Dry/Wet/Wetted with Saliva

Notes:

Additional studies from Wester et al. and Rodes et al. were evaluated but excluded from consideration; see text.

Table 5. Average Lifetime and Daily Dose: Selected Metals

Chemical	Concentration Leachate Available (C_{towel}) µg/cm^2	Exposure Model: Hand-to-Mouth ADD (mg/kg-day)	Hand-to-Food	Towel-to-Mouth
Aluminum	9.31E-02	4.33E-05	9.56E-05	1.37E-07
Antimony	2.49E-02	1.16E-05	2.56E-05	3.66E-08
Arsenic	1.33E-03	6.18E-07	1.37E-06	1.95E-09
Barium	2.08E-01	9.68E-05	2.14E-04	3.06E-07
Beryllium	1.24E-04	5.78E-08	1.28E-07	1.82E-10
Boron	1.22E-01	5.67E-05	1.25E-04	1.79E-07
Cadmium	2.44E-01	1.14E-04	2.51E-04	3.59E-07
Chromium	2.73E-02	1.27E-05	2.80E-05	4.01E-08
Cobalt	4.50E-02	2.09E-05	4.62E-05	6.60E-08
Copper	8.92E-01	4.14E-04	9.16E-04	1.31E-06
Iron	5.07E-01	2.36E-04	5.21E-04	7.44E-07
Lead	5.33E-03	2.48E-06	5.48E-06	7.82E-09
Manganese	1.44E-01	6.71E-05	1.48E-04	2.12E-07
Mercury	6.50E-05	3.02E-08	6.68E-08	9.54E-11
Molybdenum	1.01E-01	4.70E-05	1.04E-04	1.48E-07
Nickel	2.26E-01	1.05E-04	2.32E-04	3.32E-07
Selenium	1.56E-03	7.25E-07	1.60E-06	2.29E-09
Silver	7.59E-06	3.53E-09	7.80E-09	1.11E-11
Strontium	2.44E-01	1.13E-04	2.51E-04	3.58E-07
Thallium	3.30E-05	1.53E-08	3.39E-08	4.85E-11
Tin	2.10E-03	9.74E-07	2.15E-06	3.08E-09
Vanadium	3.25E-04	1.51E-07	3.34E-07	4.77E-10
Zinc	1.80E+00	8.35E-04	1.85E-03	2.64E-06
Chemical		*LADD (mg/kg-day)*		
Arsenic	1.33E-03	2.21E-07	4.88E-07	6.96E-10

Notes

C_{towel} Loading concentration of metal

ADD Average Daily Dose (Noncancer)

LADD Lifetime Average Daily Dose (Cancer)

Table 6. Toxicity Values: Selected Metals

	EPA RSLs			ATSDR MRLs			
Chemical	**CSF**	**RfD_o** mg/kg-day	**Key**	**Oral MRL** mg/kg-day	**Duration**	**Critical Effect**	**Notes**
Aluminum		1	P	1	Chronic	Neurological effects	
Antimony		4.00E-04	I			Longevity, blood glucose, and cholesterol	
Arsenic	1.5	3.00E-04	I	3.00E-04	Chronic	Hyperpigmentation, keratosis and possible vascular complications	
Barium		0.2	I	0.2	Chronic	Nephropathy	
Beryllium		2.00E-03	I	2.00E-03	Chronic	Small intestinal lesions	
Boron		0.2	I	0.2	Intermediate	Decreased fetal weight (developmental)	
Cadmium		1.00E-03	I	1.00E-04	Chronic	Significant proteinuria	diet
Chromium		1.5	I			No effects observed	Chromium III
Cobalt		3.00E-04	P	1.00E-03	[Chronic]	Thyroid toxicity and polycythemia	
Copper		4.00E-02	H	1.00E-03	[Chronic]	Gastrointestinal effects	
Iron		0.7	P			Gastrointestinal effects	
Manganese		0.14	I			CNS effects	diet
Mercury		1.00E-04	I			Hand tremor, increases in memory disturbance; objective evidence of autonomic dysfunction	methyl
Molybdenum		5.00E-03	I			Increased uric acid levels	
Nickel		2.00E-02	I			Decreased body and organ weights	soluble
Selenium		5.00E-03	I	5.00E-03	Chronic	Clinical selenosis	
Silver		5.00E-03	I			Argyria	
Strontium		0.6	I	0.2	[Chronic]	Rachitic bone	
Thallium		1.00E-05	X			Hair follicle atrophy	soluble
Tin		0.6	H	3.00E-02	[Chronic]	Hematological effects	
Vanadium		5.00E-03	S	1.00E-03	[Chronic]	Kidney effects	
Zinc		0.3	I	0.3	Chronic	Cu, Zn-superoxide dismutase (ESOD) activity in healthy adult male	

Notes:

EPA = Environmental Protection Agency

RSL = Regional Screening Level

CSF = Cancer Slope Factor

RfD_o = Reference Dose, oral

ATSDR = Agency for Toxic Substances and Disease Registry

MRL = Minimal Risk Level

Key: I = IRIS; P = PPRTV; X = PPRTV Appendix; H = HEAST; S = see user guide Section 5.

Table 7. Hazard Indices and Cancer Risk: Selected Metals

Chemical	Kidney	Gastroinestinal	Thyroid	Develop/Neuro	Blood	Other	Cancer Risk
Aluminum				1.E-04			
Antimony					9.E-02		
Arsenic						7.E-03	1.E-06
Barium	2.E-03						
Beryllium		9.E-05					
Boron				9.E-04			
Cadmium	4.E-01						
Chromium						3.E-05	
Cobalt			2.E-01				
Copper		3.E-02					
Iron		1.E-03					
Manganese				2.E-03			
Mercury				1.E-03			
Molybdenum	3.E-02						
Nickel						2.E-02	
Selenium		5.E-04					
Silver						2.E-06	
Strontium						6.E-04	
Thallium						5.E-03	
Tin					5.E-06		
Vanadium	1.E-04						
Zinc						9.E-03	
TOTAL	**4.E-01**	**3.E-02**	**2.E-01**	**4.E-03**	**9.E-02**	**4.E-02**	**1.E-06**