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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 a risk assessment of exposure to metal residues in laundered shop towels by workers. The concentrations of 27 metals measured in a synthetic sweat leachate were used to estimate the releasable quantity of metals which could be transferred to workers' skin. Worker exposure was evaluated quantitatively with an exposure model that focused on towel-to-hand transfer and subsequent hand-to-food or -mouth transfers. The exposure model was based on conservative, but reasonable assumptions regarding towel use and default exposure factor values from the published literature or regulatory guidance. Transfer coefficients were derived from studies representative of the exposures to towel users. Contact frequencies were based on assumed high-end use of shop towels, but constrained by a theoretical 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 Adult Lead Model and concluded that predicted lead intakes do not constitute a significant health hazard based on potential worker exposures. Uncertainties 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.

1. 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 of some residual presence of metallic constituents in the towels despite the laundering process. Concentrations of 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 (Beyer et al., 2003, 2010). The present effort was undertaken 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. The study of these exposures was not prompted by any known or reported health effects in workers using shop towels. Rather, it was prompted by the publication of the previous work suggesting that metals may be present on used shop towels at levels that exceed established regulatory toxicity criteria. Since the current manuscript was drafted, Beyer and co-workers (Beyer et al., 2014) have additional analytical data using the same screening level analytical methods and have repeated their suggestions that metals are present at levels exceeding conservative toxicity criteria, but the chemical methods and risk assessment approaches used have not been refined and remain screening level approaches.

Quantifying chemical constituent exposures that may result from the handling of garments, tools, accessories, or other consumer products has 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 the consumer product. No single model has been established that is intended to fit all types of situations, although several examples can be found in the literature representing efforts prompted by consumer right-to-know initiatives (e.g., California's Proposition 65) and by consumer safety protection agencies (CPSC, 1997, 2006, 2010; Cal-EPA, 2008, 2011).

Exposure models that have been most commonly applied to the prediction of human exposures to organic chemicals that might be present in clothing or household materials across a broad range of scenarios and circumstances are often called transfer models. A transfer model begins with a surface concentration of a chemical that is assumed to be releasable or dislodgeable and assumes a fractional transfer to the hands of the user based on values obtained from the literature or experiments simulating the

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exposure conditions. Transfer models have been used extensively in modeling human exposures to 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) and other contacted surfaces, including fabrics (Snodgrass, 1992; Yang and Li, 1993; Camann et al., 1996; Brouwer et al., 1999; Rodes et al., 2001; Cohen Hubal et al., 2005, 2008). Transfer models are also used to estimated exposures to metals from hard surfaces like floors and office furniture (DiBiasio and Klein, 2003; USACHPPM, 2009). Similar to the Beyer et al. (2003, 2010, 2014) assessments, a transfer model was applied to the assessment of exposure to the residual metals in shop towels in this assessment. However, significant advancements to the overall transfer model are employed in this assessment of shop towel exposures, which include (1) employing methods of analysis that provide a concentration of the available (dislodgeable) concentration of each metal, and (2) placing limits on the concentration of metals that can possibly accumulate on the skin surface. The limiting assumption, based on measurement data, is that the concentration of a substance that may accumulate on a hand will not exceed the surface concentration on the contact material. For soft surfaces like carpet or garment fabrics, the pickup by a hand is never observed to exceed the concentration of the substance on the material itself, even after multiple contacts (Yang and Li, 1993; Camann et al., 1996; Brouwer et al., 1999; Rodes et al., 2001; Cohen Hubal et al., 2005, 2008).

The simplest screening-level analysis of the metal concentrations associated with fabric, such as shop towels, is the measurement of total mass by weight ("bulk analysis"), using acid digestion. For the purposes of risk assessment, such data fail to measure the available surface concentration of each metal that is relevant to human exposure. As the basis for a more refined risk assessment, data on the available metal concentrations were obtained using a leachability test protocol with a synthetic sweat solution to simulate conditions of contact of human skin with a towel.

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 dyes contained in toys and other articles handled by children (Zeilmaker et al., 1999), among others. The use of leachability data may raise the question of whether it is necessary to make an adjustment for the transfer efficiency governing the transfer of metals from towel to hand. The estimates of transfer efficiencies from the literature studies cited above have measured the transfer of chemicals that were 100% available. Thus, transfer efficiency is a relevant input parameter for available metals in shop towels. In addition, risk assessments of contact with metals on hard surfaces have used very similar transfer efficiency values (DiBiasio and Klein, 2003; USACHPPM, 2009).

This risk assessment of workers was developed to provide a conservative, but reasonable prediction of risks associated with the use of shop towels. It is based on a high-end, but reasonable level of towel usage. Exposure factors and other assumptions were chosen to represent a mix of average- and upper-bound levels of anticipated worker exposure as is consistent with a Reasonable Maximum Exposure scenario.

The uncertainties in this assessment are discussed in detail in the uncertainty section where the effect of using alternative exposure factor values and assumptions regarding worker exposure on the overall confidence in the estimated risks and hazard indices is evaluated. The discussion of uncertainties focuses on several elements of the risk assessment that make a substantial 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.

2. Methods

2.1. Data collection

Laundered shop towels were obtained from 10 different rental/laundering facilities and forwarded to Exova laboratories (Santa Fe Springs, CA) for analysis of 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 $8 \times 10''$ 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 solution per AATCC, 2011, a method for measuring the leaching of fabric dyes under simulated conditions of use and specifically, the effects of acidic perspiration. 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 (AATCC, 2011). A 200 mL volume of this solution was mixed with 20 g of the homogenized sample and placed in a water bath at 37 °C for 1 h with mild agitation. Leachates were treated with concentrated nitric acid (0.1 mL into 10 g of leachate) to solubilize the substances leaching from the samples. Internal standards were added to these leachates, and concentrations of 27 metals see (Table 1) were measured by inductively-coupled plasma-mass spectrometry, based on an Exova Standard Operating Procedure (SOP No. 7040, Revision 12). The solubilization step with nitric acid overestimates the available concentration if metal particles are present in the synthetic sweat solution, because these particles would not likely be available for transfer to skin during towel use.

2.2. Available metal concentrations in towels (C_{towel})

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 area 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% upper confidence level (UCL) on the mean concentration was developed to represent the average exposure concentration for use in the risk assessment. When a metal was detected in fewer than three 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 was a new, unlaundered towel, was similarly analyzed; results of this analysis are also presented in Table 1. These results overestimate the true available concentrations of metals per unit surface area of towel, because the leachate method solubilized metals from the surface of the fabric as well as metals from deeper in the nap of the towel. The latter would not actually be available for transfer to skin during towel use.

2.3. Exposure model

As described above, the basic approach to the modeling of exposure in this assessment is characterized as a *transfer* model, which uses transfer coefficients to describe the towel-to-hand or