Evaluation of Potential Exposure to Metals in Laundered Shop Towels

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Overview

In 2003, Gradient analyzed the results of lab tests conducted on samples of laundered shop towels, which had been used and then laundered, from 23 locations in 14 States throughout the United States; the towels were analyzed for 27 metals, grease and oil. Gradient's analysis was published by The Association of the Nonwovens Fabrics Industry (INDA) in the Winter 2003 issue of the *International Nonwovens Journal*. This report is a similar, but more recent analysis, evaluating the analytical results of new towel samples collected from 26 companies in the US and Canada.

Gradient estimated oral intake of metals in clean laundered shop towels for two potential exposure pathways: one involving hand contact with laundered shop towels and subsequent transfer to the mouth, and one involving direct contact of laundered shop towels with the lips. We estimated potential exposure to metals for both of these pathways, based on metal loading on the laundered shop towels, and estimates of transfer efficiencies for towel-to-hand, hand-to-mouth, and towel-to-lip.

Metal loading on the laundered shop towels returned as clean to the user was evaluated by TestAmerica Incorporated.[1] Concentrations were reported for 29 metals and oil/grease. Some sample concentrations were considered outliers (as determined using statistical testing). The results presented here are based on a dataset that does <u>not</u> include the outliers. Removing outliers decreased the number of exceedances found when exposures to metals in towels were compared with toxicity criteria.

Some shop towel samples had high concentrations of certain constituents, especially for oil/grease which ranged from 3,700 to 180,000 mg/kg. Copper, calcium, and iron concentrations were also high with maximum concentrations of 2,100, 8,800, and 15,000 mg/kg, respectively. The calculated 95% Upper Confidence Limits on the Mean (UCLMs) ranged from 0.14 (beryllium) to 7,686 (iron) mg/kg for metals and 107,646 mg/kg for HEM (oil and grease).

Gradient reviewed the quality control (QC) sample results, including matrix spikes/matrix duplicates, laboratory control samples, and method blanks, to determine whether the data required qualifications based on exceedances of TestAmerica's QC criteria. Gradient's QC analysis determined that all of the metals data were usable, with only minor data qualifications.

Data were gathered on the frequency of towel use in a survey administered shortly after the towels were collected for analysis. Safety and/or purchasing managers for each company were asked how many towels were used per week, and the number of employees using them. From these data, the average number of towels used per day per employee was calculated. Usage information from 24 companies was included in the study; we received towel samples from 21 of these companies (and 5 additional companies for which no usage information was available). We estimated exposure to metals on laundered shop towels assuming either typical or high-end use of towels, represented by the mean (12 towels) and the 95% UCLM (26 towels), respectively, as estimates of daily use per employee.

Based on our analysis with typical usage of 12 laundered shop towels per day, the estimated exposure to antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum in laundered shop towels exceeds at least one toxicity reference value (non-cancer and cancer). When evaluating the magnitude of the exceedances, lead intake was much higher than its respective toxicity criteria. Lead intakes for typical towel usage and maximum intake were almost 3,600-fold higher than California Environmental Protection Agency's (CalEPA's) Maximum Allowable Dose Level (MADL) for reproductive toxicity. As estimated in our analysis, even using one towel a day with the average (mean) lead concentration would result in an exceedance of the MADL. For cadmium, however, the metal with the next highest exceedances (43-fold greater than the MADL for maximum intake, typical use; and 93-fold greater than the MADL for maximum intake, high-end use), using two towels a day with the average (mean) cadmium concentration would <u>not</u> result in an exceedance of the MADL, but using three towels would result in an exceedance.

With high-end use of 26 laundered shop towels per day, our analysis indicates that the same compounds exceed the same toxicity criteria but with higher exceedances and with the addition of iron and nickel. Again, the highest exceedance was found with the maximum lead concentration. Assuming high-end use of 26 towels per day, the maximum lead intake is 7,700-fold higher than the MADL. In comparison to cancer toxicity criteria, lead intake was 146-fold higher than the No Significant Risk Level (NSRL) using the maximum intake concentration.

When estimating exposure *via* towel-to-mouth contact representative of personal wiping habits, a toxicity criteria exceedance was observed for lead for the maximum intake concentration, which exceeded the MADL by 3.5-fold. We assumed that a worker would wipe their lips with a laundered shop towel two times a day, regardless of whether we assumed typical usage of 12 towels per day, or high-end use of 26 laundered shop towels per day.

We also evaluated uncertainties associated with our exposure assumptions that could result in our estimated intakes of metal from contact

[1] *Each participating company sent approximately 10-15 towels directly to TestAmerica Incorporated (Pensacola, FL) following the laboratory's chain-of-custody procedures. At the laboratory, 10 towels were randomly selected for analysis from the bundles received.*

with the shop towels being either less than or greater than actual intakes. Although use of alternative exposure assumptions could result in lower estimated intakes, intake of metals from the shop towels would likely still exceed toxicity criteria.

Specifically, the overall conclusions of this analysis are:[2]

- Due to the wide range of detected concentrations in 2010 dataset, outlier concentrations were identified at the 1% and the 5% significant level. To ensure our estimates of exceedances were not based on a single high concentration, the outliers (all of which were at the high end of the distribution) were not included in the data used to generate the results presented in this report.
- When comparing the 2010 data without the identified outlier samples, six metals (barium, calcium, copper, lead, magnesium, and molybdenum) had mean concentrations in 2010 that were 1.5 – 2.8 times higher than the concentrations observed in 2003 (Beyer *et al*., 2003).
- Metals on shop towels can get onto hands and then potentially be ingested, as evaluated in the 2003 report and as developed in this evaluation.
- For typical use of 12 towels a day per person, exceedances of Proposition 65 limits, and US EPA and ATSDR toxicity criteria may occur for antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum. Calculated intakes for these metals were up to 3,600-fold higher (based on maximum intake concentration for lead) than their respective toxicity criterion.
- If the number of towels used increases to 26 a day per person, additional exceedances of US EPA and ATSDR toxicity criteria for iron and nickel may occur. Assuming maximum intake concentrations, intakes were up to 7,700-fold higher (lead) than their respective criterion.
- Although independent of the number of towels used, exposure *via* mouth contact may result in exceedances of the Proposition 65 MADL limits for lead assuming that a person wipes their mouth with an RST twice a day.
- The number of compounds with toxicity criteria exceedances is higher in this evaluation than in the prior 2003 assessment due to higher detected concentrations, the availability of additional toxicity criteria, higher number of towels used per day reflecting actual usage data compared to the estimate made in 2003 of 2.5 towels per day, and higher towel-to-hand transfer efficiency.

Methodology

Gradient updated the estimated oral intake of metals in laundered shop towels using new data from washed, used, rental shop towels collected from 26 North American companies (***Table 1***). Each participating company sent approximately 10-15 towels directly to TestAmerica Incorporated (Pensacola, FL) following the laboratory's chain-of-custody procedures. At the laboratory, 10 towels were randomly selected for analysis from the bundles received. Each towel was visually divided into four quadrants. Using ceramic scissors, subsamples were cut from the center of the towel and from the center of each of the 4 towel quadrants so that ~45-60 grams of sample were collected from each laundered shop towel. The subsamples collected from the 10 towels were then "homogenized." The samples were analyzed for 29 metals, and oil and grease (***Table 2***).[3] In addition, three unused RSTs were analyzed for 28 metals[4] and oil/grease (***Table 3***).

Gradient reviewed the quality control (QC) sample results, including matrix spikes/matrix duplicates, laboratory control samples, and method blanks, to determine whether qualifications of the data were needed due to exceedances of TestAmerica's QC criteria. Gradient's analysis determined that all of the metals data were usable, with only minor data qualifications.

Due to the wide range of detected concentrations in the 2010 dataset, the data were evaluated to identify potential outliers. Using the Rosner's outlier test and one half the detection limit for analytes that were not detected, samples from the following samples, as indicated using Gradient identifiers, were identified as having at least one analyte with an outlier concentration at the 5% significance level: 2 (sodium 1,600 mg/kg), 3 (silver 51 mg/kg), 7 (iron 22,000 mg/kg), 21 (arsenic 2.3 mg/kg), and 28 (chromium 430 mg/kg). The following samples had at least one analyte with an outlier at the 1% and the 5% significant levels: 18 (zinc 1,600 mg/kg), 19 (hexavalent chromium 2.8 mg/kg and potassium 480 mg/kg), 21 (tin 55 mg/kg), 22 (beryllium 0.79 mg/kg), 23 (barium 2,400 mg/kg), 28 (cobalt 200 mg/kg and nickel 1,500 mg/kg), 7 (calcium 15,000 mg/kg and molybdenum 470 mg/kg), and 8 (boron 390 mg/kg, cadmium 1,700 mg/kg, lead 19,000 mg/kg, titanium 990 mg/kg). Outliers were not identified for aluminum, antimony, copper, magnesium, manganese, mercury, selenium, strontium, thallium, vanadium, and HEM (oil and grease). The outliers were not included in the data used to generate the results presented in this report. However, results generated using the outliers are presented and compared to the results generated without the outliers in the Discussion, at the end of the report.

Data were gathered on the frequency of towel use in a survey administered at the time the towels were collected for analysis. Safety and/or purchase managers for each company were asked how many towels were used per week, and the number of employees using them. From these data, the average number of towels used per day per employee was calculated. Usage information from 24 companies was included in the study; we received towel samples from 21 of these companies and 5 additional companies (for which no usage information was available). Companies using fewer than 750 towels per week were not surveyed. Companies providing usage data used between 750 and 17,000 towels a week. On average, 3-50 towels were used per day per employee.

[2] *DISCLAIMER: The conclusions in this report are derived from the exposure assumptions provided herein. Utilization of different exposure assumptions, or comparison to different laundered shop wipes (which may contain different concentrations of metals), could affect the conclusions.*

[3] *We should note that mercury was only analyzed in four laundered towel samples - Gradient identifiers 9, 13, 17 and 18. Mercury analyses were discontinued due to the low concentrations found in these four samples.*

[4] *Reference samples were not analyzed for mercury.*

Table 1					
Companies Providing Reused Shop Towels (RST) Information (Chemical Data and/or Usage Information)					
State/Providence	**Country**	**Chemical Data?**	**Industry**	**Use per Week**	**Avg Use/ Day/Employee**
British Columbia	Canada	X	Automotive		
Ontario	Canada	X	Automotive		
Texas	USA	X	Automotive	700-750	10
Missouri	USA		Automotive	2,400	10
Quebec	Canada	X	Aviation	2,500	3
Ontario	Canada	X	Aviation	1,200	20
Alberta	Canada	X	Construction Material Manufacturing	800	3.5
Ontario	Canada	X	Electronics	3,500	5
California	USA	X	Food/Beverage Packaging	1,000	5
Ontario	Canada	X	Heavy Equipment Manufacturing	2,500	10
Ohio	USA	X	Medical Device Manufacturing	10,000	5
Ontario	Canada	X	Metal Manufacturing	17,000	8
Quebec	Canada	X	Metal Manufacturing	1,000	3
Ontario	Canada	X	Military	1,200	5
Ontario	Canada	X	Packaging	5,000	20
South Dakota	USA	X	Packaging	1,500	3
Texas	USA	X	Painting	750	10
Alberta	Canada	X	Printing	3,000	5
Ontario	Canada	X	Printing	2,000	
Quebec	Canada	X	Printing	10,000	50
Calgary	Canada	X	Printing	1,200	25
Texas	USA	X	Printing	1,250	20
Pennsylvania	USA	X	Printing		
Wisconsin	USA	X	Printing	2,500	20
Tennessee	USA	X	Printing	3,000	20
Arizona	USA	X	Printing	1,200	10
Indiana	USA	X	Pump Manufacturing		
Ontario	Canada		Retail	14,800	5
Texas	USA		Transportation	800	26
		X	Reference1		
		X	Reference2		
		X	Reference3		

Similar to our previous effort (Beyer *et al*., 2003), two potential exposure pathways were evaluated: 1) hand contact with laundered shop towels and subsequent transfer from the hand to the mouth, and 2) direct contact of laundered shop towels with the lips, as would be expected in personal wiping that might take place when a worker wipes sweat from his or her face. We evaluated exposure for two different concentrations: the average (mean) and the maximum concentration. Then, we estimated exposure to metals on laundered shop towels assuming either typical or high-end use of towels. For the typical use scenario, we used the mean (12 towels) and for the high-end use scenario, we used the 95% UCLM (26 towels) as estimates of daily use per employee.

Study Results

Industries providing RSTs for this evaluation included manufacturers of metals, heavy equipment, construction materials, pumps, medical devices, and chemicals, in addition to the military and painting, packaging, printing, aviation, automotive, electronics, transportation, and retail companies (***Table 1***). (Thirty samples were submitted to TestAmerica, but chemical concentration data for 4 of the 30 samples collected were not included in our analysis, because the towels had never been used or laundered.) ***Table 2*** lists the summary statistics (minimum detected, average, maximum detected, standard deviation, and 95% UCLM) for the laundered shop towels. Mean concentrations and the standard deviations were calculated using half the lower detection limit (method detection limit) for samples in which the analyte was not detected. The 95% UCLM was calculated using Pro-UCL, a US EPA software program (V. 4.00.04). Detected concentrations from the 26 laundered RST samples displayed a range of concentrations. Aluminum, barium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, silver, strontium,

Table 2										
Detected Concentrations without Outlier Data and Estimated Load										
Chemical	Detected Concentrations								Load Concentrations[2]	
	Total Detected	Total Sampled	% Detected	Minimum (mg/kg)	Average (mg/kg)	Standard Deviation	95% UCLM[1]	Maximum (mg/kg)	Average (mg/cm^2)	Maximum (mg/cm^2)
Aluminum	26	26	100%	50	566	342	681	1,500	7.1E-03	1.9E-02
Antimony	25	26	96%	1.9	13	7.4	16	30	1.7E-04	3.7E-04
Arsenic	23	25	92%	0.20	0.66	0.40	0.79	1.3	8.2E-06	1.6E-05
Barium	25	25	100%	4.7	387	397	565	1,700	4.8E-03	2.1E-02
Beryllium	8	25	32%	0.049	0.08	0.12	0.14	0.56	1.0E-06	7.0E-06
Boron	24	25	96%	0.32	7	8	14	39	8.5E-05	4.9E-04
Cadmium	25	25	100%	0.093	7	13	19	60	9.0E-05	7.5E-04
Calcium	25	25	100%	370	3,544	2,328	4,341	8,800	4.4E-02	1.1E-01
Chromium	25	25	100%	0.80	77	95	124	390	9.6E-04	4.9E-03
Chromium (VI)	14	25	56%	0.021	0.21	0.31	0.21	0.6	2.6E-06	7.9E-06
Cobalt	25	25	100%	0.34	32	35	48	120	4.0E-04	1.5E-03
Copper	26	26	100%	11	659	554	900	2,100	8.2E-03	2.6E-02
Iron	25	25	100%	110	5,083	4,598	7,686	15,000	6.3E-02	1.9E-01
Lead	25	25	100%	1.7	100	139	157	600	1.2E-03	7.5E-03
Magnesium	26	26	100%	97	705	568	937	2,000	8.8E-03	2.5E-02
Manganese	26	26	100%	5.3	91	44	105	190	1.1E-03	2.4E-03
Mercury	4	4	100%	0.015	0.065	0.059	--	0.15	8.0E-07	1.9E-06
Molybdenum	25	25	100%	0.64	56	55	86	220	7.0E-04	2.7E-03
Nickel	25	25	100%	0.65	68	80	110	290	8.5E-04	3.6E-03
Potassium	24	25	96%	18	78	55	96	250	9.7E-04	3.1E-03
Selenium	25	26	96%	0.24	1.0	0.81	1.7	3.2	1.3E-05	4.0E-05
Silver	25	25	100%	0.10	6.1	12	14	47	7.6E-05	5.9E-04
Sodium	24	25	96%	130	528	273	622	1,200	6.6E-03	1.5E-02
Strontium	26	26	100%	6.8	26	21	33	85	3.3E-04	1.1E-03
Thallium	0	26	0%							
Tin	23	25	92%	1.1	15	10	18	35	1.9E-04	4.4E-04
Titanium	25	25	100%	2.8	37	36	51	170	4.7E-04	2.1E-03
Vanadium	25	26	96%	0.12	4.3	4.2	7.9	13	5.4E-05	1.6E-04
Zinc	25	25	100%	69	441	277	536	960	5.5E-03	1.2E-02
HEM (Oil & Grease)	26	26	100%	3,700	76,446	59,875	107,646	180,000	9.5E-01	2.2E+00

Notes:
Average concentration and Standard Deviation calculated using ½ the lower detection limit (method detection limit - MDL) for samples where the analyte was not detected.
Outlier data were identified and removed for arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, hexavalent chromium, iron, lead, molybdenum, nickel, potassium, silver, sodium, tin, titanium, and zinc.
[1] Pro-UCL was used to calculate the 95% Upper Confidence on the Mean (UCLM)
-- the 95% UCLM was not calculated due to the small dataset.
[2] Load concentration (mg/cm^2) = [detected concentration (mg/kg) x weight of towel (kg)]/surface area of towel (cm^2)
Weight of towel (kg) = 2.83E-02
Surface area (cm^2) = 2,268 *Assume weight of towel = ~ 1 oz.*

titanium, zinc, and HEM (Oil & Grease) were detected in all samples. Mercury was only analyzed in four samples and detected in all four samples. Thallium was not detected in any of the samples. Some samples had high concentrations, especially for oil/grease which ranged from 3,700 to 180,000 mg/kg. Calcium and iron concentrations were also high with maximum concentrations of 8,800 and 15,000 mg/kg, respectively (***Table 2***). The calculated 95% UCLMs ranged from 0.14 (beryllium) to 7,686 (iron) mg/kg for metals, and 107,646 mg/kg for HEM (oil and grease) (***Table 2***).

Among the reference samples, beryllium, cadmium, cobalt, silver, thallium, and vanadium were not detected. Reference samples were not analyzed for mercury. The highest detected concentrations in reference towels were 3,900 mg/kg for HEM (Oil & Grease), 980 mg/kg for calcium, 770 mg/kg for potassium, and 670 mg/kg for sodium (***Table 3***). Potassium was the only analyte detected at a higher concentration among the reference samples than in the laundered RSTs. For the remaining analytes, the detected concentrations in the 26 RSTs were up to 2,245-fold (e.g., molybdenum) higher than the reference samples (***Table 3***).

Table 3										
Reported Concentrations *vs.* Reference Samples										
	Reference Samples					Laundered Rental Shop Towels				
Analyte	Total Detected	Total Sampled	Minimum Detected (mg/kg)	Average (mg/kg)	Maximum Detected (mg/kg)	Total Detected	Total Sampled	Minimum Detected (mg/kg)	Average (mg/kg)	Maximum Detected (mg/kg)
Aluminum	3	3	3.7	13	31	26	26	50	566	1,500
Antimony	2	3	5.0	5.4	11	25	26	1.9	13	30
Arsenic	2	3	0.24	0.20	0.26	23	25	0.20	0.66	1.3
Barium	3	3	0.52	1.8	2.8	25	25	4.7	387	1,700
Beryllium	0	3				8	25	0.049	0.081	0.56
Boron	3	3	0.65	2.1	4.2	24	25	0.32	6.8	39
Cadmium	0	3				25	25	0.093	7.2	60
Calcium	3	3	150	467	980	25	25	370	3,544	8,800
Chromium	2	3	0.15	0.18	0.34	25	25	0.80	77	390
Chromium (VI)	1	3	0.30	0.14	0.30	14	25	0.021	0.21	0.63
Cobalt	0	3				25	25	0.34	32	120
Copper	3	3	0.39	0.71	1.1	26	26	11	659	2,100
Iron	3	3	4.0	29	79	25	25	110	5,083	15,000
Lead	1	3	0.65	0.25	0.65	25	25	1.7	100	600
Magnesium	3	3	25	132	310	26	26	97	705	2,000
Manganese	3	3	0.49	2.0	3.9	26	26	5.3	91	190
Mercury						4	4	0.015	0.065	0.15
Molybdenum	1	3	0.098	0.066	0.098	25	25	0.64	56	220
Nickel	2	3	0.25	0.24	0.40	25	25	0.65	68	290
Potassium	3	3	24	277	770	24	25	18	78	250
Selenium	3	3	0.44	0.55	0.67	25	26	0.24	1.0	3.2
Silver	0	3				25	25	0.10	6.1	47
Sodium	3	3	200	370	670	24	25	130	528	1,200
Strontium	3	3	0.94	7.5	14	26	26	6.8	26	85
Thallium	0	3				0	26	0	0	0
Tin	3	3	0.30	0.55	0.76	23	25	1.1	15	35
Titanium	2	3	0.15	0.53	1.4	25	25	2.8	37	170
Vanadium	0	3				25	26	0.12	4.3	13
Zinc	3	3	0.90	2.8	5.3	25	25	69	441	960
HEM (Oil & Grease)	3	3	1,000	2,100	3,900	26	26	3,700	76,446	180,000

Notes:
Average concentration calculated using ½ the lower detection limit (method detection limit - MDL) for samples where the analyte was not detected.
Reference samples were not analyzed for mercury.
[highlighted] Reference concentrations higher than Laundered Rental Shop Towels

Fifteen samples were collected from Canadian companies, while eleven samples were collected from companies within the United States. Overall, despite the fact that the concentrations from Canadian samples were generally higher than the American samples (up to four times higher for cadmium), the mean concentrations for both countries were similar with no statistically significant differences (***Table 4***). Usage information came from 24 companies (11 US companies and 13 Canadian companies). Overall the average usage (expressed as per person per day) was comparable (13 towels for US companies and 12 towels for Canadian companies), however, the range of towels used was higher among the Canadian companies (3-50 towels *versus* 3-26 towels in the US) (***Table 1***).

When compared to the detected concentrations in 2003, overall, the concentrations observed in 2010 were higher than those observed in 2003 (***Table 5***). In fact, seven compounds (aluminum, barium, calcium, copper, magnesium, sodium, and oil/grease) had significantly higher mean concentrations (up to three times higher for barium) in 2010 than in 2003 (***Table 5***). In addition, the detection frequency was higher in the 2010 samples than in the 2003 samples. However, this could be the result of lower detection limits in 2010 than 2003. Maximum concentrations of aluminum, barium, beryllium, boron, cadmium, calcium, copper, lead, magnesium, molybdenum, silver, sodium, strontium, and titanium (14/27 or 52% of the metals) were higher in 2010, while maximum concentrations of antimony, arsenic, chromium, cobalt, iron, manganese, nickel, potassium, selenium, tin, vanadium, and zinc (12/27 or 44% of the metals) were lower in 2010 than in 2003. RSTs were not analyzed for chromium VI and mercury in 2003, and thallium was not detected in either 2003 or 2010.

Analysis

There are no standard methodologies for evaluating exposure to metals in laundered shop towels. We used the previously developed approach as a basis, updating it based on a current literature search. We used empirical data from the literature to estimate the amount of metal that could be transferred from the laundered shop towels either directly to the lips or to the lips from the hands, both ultimately leading to ingestion of metals.

For ingestion exposure *via* hand contact with the laundered shop towels, we estimated transfer of metals from laundered shop towels to hands based on empirical data regarding transfer of pesticide residues from surfaces to hands, updated data regarding the number of laundered shop towels used daily per person, as well as an estimate of the percentage of the towel surface area that would contact the hand. The amount of metal transferred to the hand that could ultimately be ingested was based on a hand-to-mouth transfer efficiency, using methodology developed by the U.S. Consumer Products Safety Commission (CPSC) for evaluating exposure to dislodgeable residues on treated wood surfaces (CPSC, 1990). ***Figure 1*** illustrates exposure occurring *via* hand contact with the laundered shop towels.

For exposure *via* direct contact with the lips, we estimated transfer of metals from laundered shop towels to the lips based on empirical data regarding transfer of pesticide residues from surfaces to hands, empirical data regarding surface area of the lips, as well as estimates of the fraction of the lip surface area contacting the laundered shop towels, fraction of the metal on the lip that is ultimately ingested, and the number of times per day that lips are wiped with laundered shop towels. ***Figure 2*** illustrates exposure occurring *via* direct contact of the laundered shop towels with the lips. The equations used for estimating intake, as well as the input parameters, are outlined and described below.

Exposure *via* Hand Contact

Intake of metals in laundered shop towels *via* hand contact was estimated using the following equation:

$$Intake\ (mg/kg\text{-}day) = \frac{[Load_{towel} \times SA_{towel} \times F_{towel} \times N \times T_{t/h} \times HTE \times EF \times ED]}{BW \times AT}$$

Figure 1

ORAL EXPOSURE TO METALS IN LAUNDERED SHOP TOWELS *VIA* HAND CONTACT

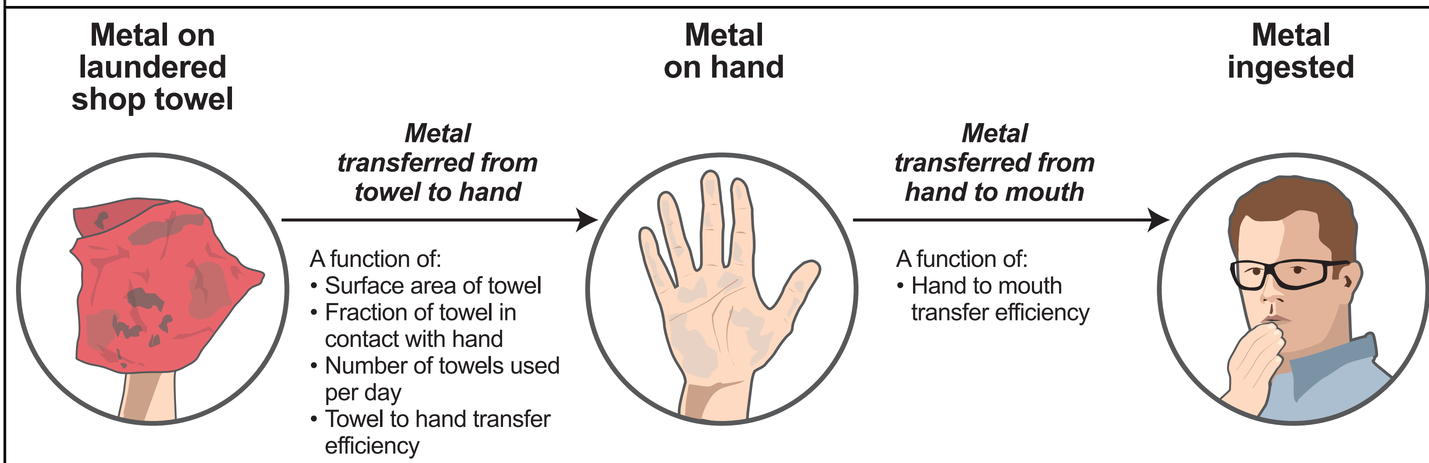
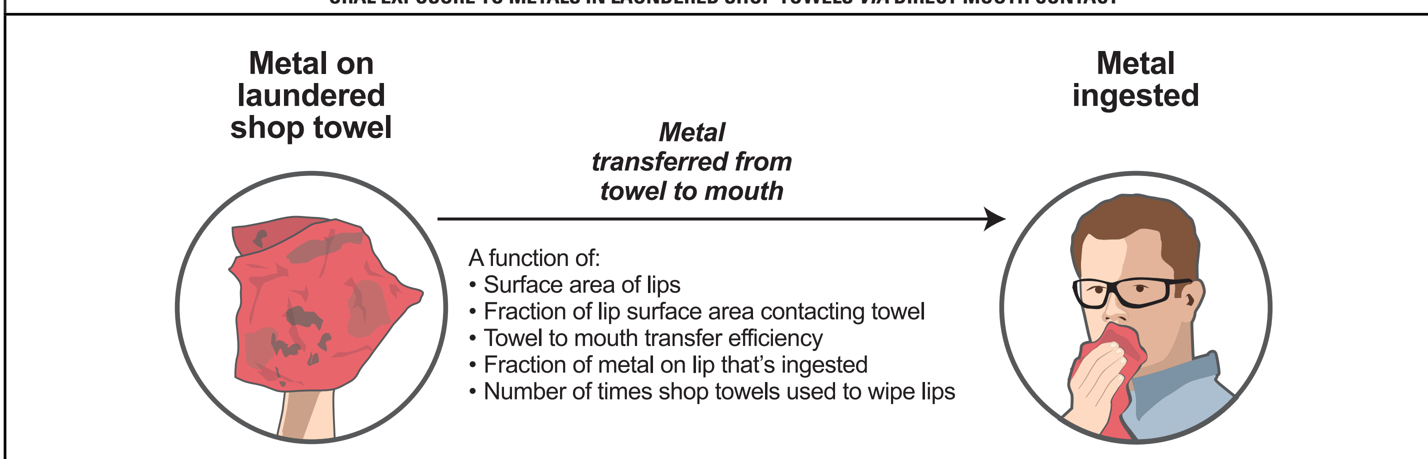


Figure 2

ORAL EXPOSURE TO METALS IN LAUNDERED SHOP TOWELS *VIA* DIRECT MOUTH CONTACT



where:

$Load_{towel}$ = Metal loading on towel surface (mg/cm^2);
SA_{towel} = Surface area of towel (cm^2);
F_{towel} = Fraction of towel in contact with hand (unitless);
N = Number of towels used daily per person;
$T_{t/h}$ = Towel to hand transfer (unitless);
HTE = Daily hand-to-mouth transfer efficiency (day^{-1});
EF = Exposure frequency (days/year);
ED = Exposure duration (years);
BW = Average adult body weight (kg);
AT = Averaging time (days).

This equation assumes that metals are transferred from the towels to the mouth in a two-step process. First, metals are transferred from the towels to the hands as a function of the metal loading on the laundered shop towels, the surface area of the towel in contact with the hands, and a towel-to-hand transfer efficiency. Once the metals are on the hands, they are transferred to the mouth, as estimated by a daily hand-to-mouth transfer efficiency. The parameters used in the above equations are described below and presented in ***Table 6***.

Metal Loading on Towel Surface. The concentration of the metals in the rental shop towels was based on metals analysis for 26 used RSTs, from 26 different companies – see ***Table 1***, at the end of the report. Average (mean) and maximum metal concentrations were calculated using an estimate of the weight of the laundered shop towels of 1 oz. (0.0283 kg),

Table 4

Observed Concentrations of Samples Received from USA *vs.* Canadian Companies

Chemical	Detected Frequency		Mean		Standard Deviation		Detected Range	
	US	Canada	US	Canada	US	Canada	US	Canada
Aluminum	100%	100%	489	623	432	260	50-1,500	140-1,000
Antimony	91%	100%	9.1	17	7.2	5.9	1.9-19	6.9-30
Arsenic	90%	93%	0.41	0.82	0.30	0.39	0.2-1.1	0.23-1.3
Barium	100%	100%	403	375	515	295	4.7-1,700	100-1,000
Beryllium	27%	36%	0.072	0.088	0.096	0.14	0.084-0.32	0.049-0.56
Boron	90%	100%	4.7	8.3	5.3	9.2	0.32-16	0.41-39
Cadmium	100%	100%	2.6	10	2.3	17	0.093-5.7	0.13-60
Calcium	100%	100%	2,500	4,364	2,244	2,119	370-6,400	1,900-8,800
Chromium	100%	100%	73	80	127	64	0.8-390	4.9-190
Cobalt	100%	100%	35	30	41	31	0.34-120	2.2-120
Copper	100%	100%	496	777	415	624	11-1,400	150-2,100
Chromium (VI)	70%	47%	0.14	0.26	0.19	0.38	0.021-0.63	0.065-0.46
Iron	100%	100%	3,552	6,286	4,863	4,160	110-14,000	1,100-15,000
Lead	100%	100%	38	141	33	166	1.7-94	4.4-600
Magnesium	100%	100%	449	893	472	573	97-1,700	240-2,000
Manganese	100%	100%	77	100	52	35	5.3-190	27-170
Mercury	100%	100%	0.083	0.047	0.095	0.012	0.015-0.15	0.038-0.055
Molybdenum	100%	100%	30	76	37	60	0.64-110	5.9-220
Nickel	100%	100%	59	75	91	73	0.65-290	5.1-230
Potassium	90%	100%	77	78	70	46	18-250	18-150
Selenium	100%	93%	1.1	0.99	1.0	0.66	0.24-3.2	0.32-2.3
Silver	100%	100%	6.7	5.6	14	11	0.1-47	0.42-43
Sodium	100%	93%	648	448	273	251	330-1,200	130-810
Strontium	100%	100%	18	33	11	25	6.8-34	13-85
Thallium	0%	0%	ND	ND	ND	ND	ND	ND
Tin	90%	93%	13	16	12	8.0	1.1-35	2.8-30
Titanium	100%	100%	28	44	27	40	2.8-88	8.2-170
Vanadium	91%	100%	3.1	5.2	4.8	3.6	0.12-13	1.6-13
Zinc	100%	100%	323	535	285	240	69-960	74-900
HEM (Oil & Grease)	100%	100%	54,055	92,867	61,030	55,303	3,700-180,000	12,000-180,000

Note:
Number of samples: USA = 11, Canada=15. All concentrations reported in mg/kg.
Based on the Wilcoxon-Mann-Whitney Test, detected concentration between the US and Canada were similar with no statistically significant difference (p<0.05).
ND = Not Detected

Table 5														
2003 *vs.* 2010 Detected Concentrations														
Chemical	**2003 *vs.* 2010 Detected Concentrations (mg/kg)**													
	Detection Frequency		**Mean**			**Standard Deviation**			**95% UCLM**			**Maximum**		
	2003	**2010**	**2003**	**2010**	**2010> 2003?**	**2003**	**2010**	**2010> 2003?**	**2003**	**2010**	**2010> 2003?**	**2003**	**2010**	**2010> 2003?**
Aluminum*	100%	100%	399	566	Y	338	342	Y	700	681		1,210	1,500	Y
Antimony	43%	96%	23	13		14	7.4		35	16		44	30	
Arsenic	4%	92%	2.7	0.66		N/A	0.40		N/A	0.79		2.7	1.3	
Barium*	100%	100%	137	387	Y	240	397	Y	370	565	Y	1,140	1,700	Y
Beryllium	0%	32%	ND	0.081		ND	0.12		ND	0.14		ND	0.56	Y
Boron	9%	96%	29	6.8		4.3	8.0	Y	33	14		33	39	Y
Cadmium	78%	100%	5.3	7.2	Y	4.8	13	Y	8.7	19	Y	17	60	Y
Calcium*	100%	100%	1,618	3,544	Y	1,041	2,328	Y	1,700	4,341	Y	4,800	8,800	Y
Chromium	91%	100%	87	77		146	95		330	124		608	390	
Chromium (VI)	NT	56%		0.21			0.31			0.21			0.63	
Cobalt	74%	100%	97	32		170	35		330	48		681	120	
Copper*	100%	100%	285	659	Y	302	554	Y	1,000	900		1,010	2,100	Y
Iron	100%	100%	4,074	5,083	Y	4,327	4,598	Y	8,000	7,686		15,700	15,000	
Lead	91%	100%	53	100	Y	39	139	Y	94	157	Y	138	600	Y
Magnesium*	100%	100%	441	705	Y	453	568	Y	570	937	Y	1,940	2,000	Y
Manganese	100%	100%	131	91		302	44		630	105		1,490	190	
Mercury	NT	100%		0.065			0.059			--			0.15	
Molybdenum	87%	100%	38	56	Y	34	55	Y	95	86		145	220	Y
Nickel	87%	100%	108	68		210	80		330	110		878	290	
Potassium	30%	96%	272	78		263	55		180	96		830	250	
Selenium	35%	96%	2.8	1.0		1.0	0.81		3.6	1.7		5.3	3.2	
Silver	48%	100%	6.1	6.1		6.6	12	Y	16	14		24	47	Y
Sodium*	100%	96%	381	528	Y	234	273	Y	540	622	Y	899	1,200	Y
Strontium	39%	100%	20	26	Y	8.6	21	Y	27	33	Y	36	85	Y
Thallium	0%	0%	ND	ND		ND	ND		ND	ND		ND	ND	
Tin	61%	92%	31	15		29	9.6		46	18		126	35	
Titanium	65%	100%	29	37	Y	20	36	Y	41	51	Y	75	170	Y
Vanadium	9%	96%	97	4.3		116	4.2		180	7.9		179	13	
Zinc	96%	100%	421	441	Y	419	277		1,000	536		1,940	960	
HEM (Oil & Grease)*	100%	100%	52,916	76,446	Y	74,916	59,875		85,467	107,646	Y	362,000	180,000	

Notes:
Average concentration and Standard Deviation calculated using ½ the lower detection limit (method detection limit - MDL) for samples in which the analyte was not detected.
Number of samples: 2003 - 23 samples; 2010 - 26 samples
Pro-UCL was used to calculate the 95% Upper Confidence on the Mean (UCLM)
-- the 95% UCLM was not calculated due to the small dataset.
ND - Not detected
Blank - Not analyzed
NT - Samples not tested for this compound
** 2010 concentrations are statistically higher than 2003 concentrations based on Wilcoxon-Mann-Whitney test (p<0.05).*

based on the previous evaluation, which calculated the average weight for three laundered shop towels. An average surface area of 2,268 cm^2 was based on measurements from five laundered shop towels from the previous evaluation.

Table 2 lists the calculated average (mean) and maximum metal loadings (mg/cm^2) for the laundered shop towels. Metal loading on the surface of the laundered shop towels was estimated as the concentration of metals in the towel (mg/kg) times the weight of the towel (kg), divided by the total surface area (front and back) of the towel (cm^2). We calculated intakes using both average and maximum metal loadings. For our analysis we assumed that half of the total metals detected in the laundered shop towel would be available for transfer to hands on each side of the towel.

Surface Area of Towel. The total surface area of the laundered shop towels (front and back) was assumed to be 2,268 cm^2, based on the average surface area (length x width) of five laundered shop towels measured in the previous evaluation.

Fraction of Towel in Contact with Hands. Similar to the previous evaluation, we assumed, based on professional judgment, that the hands would contact approximately 75% of the total surface area of a laundered shop towel, under typical laundered shop towel usage.

Number of Towels Used Daily Per Person. Based on the surveys conducted at the time the RSTs were collected in 2008-2009, data (total number of towels used, number of employees) from 24 companies were used to calculate an average daily towel use per employee. The average daily use ranged from 3-50 towels per employee. For the typical and high-end use scenarios, we used the mean (12 towels) and the 95% UCLM (26 towels) as estimates of daily use per employee.

Towel to Hand Transfer. Previously, we estimated a towel to hand transfer of 5% based on Camann *et al.* (1996), Lu and Fenske (1999), and Clothier (2000), who investigated the transfer of pesticides from various hard surfaces to hands. Gradient conducted an updated literature search and identified more recent studies assessing hand transfer of chemicals from soft surfaces, which are more relevant than hard surfaces to the scenario in which RSTs contact workers' hands. We used transfer efficiencies from the following studies: Hubal *et al*. (2008); Lu and Fenske (1999); Wester *et al*., 1996, as cited in Babich (2006); Rodes *et al*. (2001); Cohen Hubal *et al*., (2005); Camann *et al*. (1996) (see Attachment A).

Towel to hand transfer is dependent on the amount of pressure and movement of the hand against the towel, duration of each skin to towel contact, affinity of the contamination to the hands, the surface area of the hand in contact (palm *vs*. entire hand – front and back), and degree of skin hydration. Several studies looked at multiple compounds and found different transfer efficiencies depending on the compound being evaluated. For example, Caman *et al*. (1996) reported mean transfer efficiencies of 1.1%, 4.8%, and 2.8% for chlorpyrifos, pyrethrin I, and piperonyl butoxide. Similarly, Hubal *et al*. (2008) found higher transfer efficiencies for uvitex OB tracer than riboflavin, and Wester *et al.* (1996, as cited in Babich, 2006) reported a higher mean transfer for malathion than glyphosate (see Attachment A). Within each study, we averaged the various relevant transfer percentages; they were averaged separately for studies conducted with dry *vs*. wet hands. In reviewing the current literature, transfer to moist hands (average 20%) is four times higher than transfer to dry hands (average 5%). Workers are likely to come into contact with RSTs with both dry and moist hands. Therefore, we averaged the transfers to moist hands and dry hands separately before averaging the two averages, to equally weight the results from both categories. This value (13%) is more than double the transfer efficiency used in the 2003 evaluation (5%).

Daily Hand-to-Mouth Transfer Efficiency. Gradient conducted a literature search for more recent studies to use in determining the hand-to-mouth transfer efficiency (HTE). The HTE parameter quantifies the fraction of material on the hands that is likely to be transferred to the mouth and ultimately ingested. DiBiasio and Klein (2003) calculated a hand-to-mouth transfer efficiency of 4% based on adults, and Babich (2006) recommended a value of 43% based on children. Both studies calculated a transfer efficiency using the HTE method originally developed by the Consumer Products Safety Commission (CPSC, 1990), and used again by the CPSC in 2003 (CPSC, 2003). We chose to retain the prior value of 0.13 or 13% as the most relevant value for our scenario. Specifically, the 4% value from DiBiasio and Klein (2003) assumed a very high value of 8 complete loading and unloading events throughout the course of the day and is based on fingers only. The Babich value is based on children only and assumed loading on both hands. Using the same method, we calculated and applied the same hand transfer efficiency of 0.13 as in the previous evaluation. Gradient adapted the HTE for estimating exposure to dislodgeable residue on treated wood surfaces (Gradient, 2001). The HTE transfer is based on estimates of the amount of soil transferred by children from the surface of their hands to the mouth, where it is subsequently ingested, but is adapted for adults, based on a lower HTE value, to be consistent with the lower ingestion rate of adults.

Exposure Frequency. We used an exposure frequency of 245 days per year, as recommended by CalEPA for occupational exposures (OEHHA, 2003). This exposure frequency assumes exposure would occur 5 days/week, for 49 weeks/year.

Exposure Duration. We used an exposure duration of 40 years, as recommended by CalEPA for occupational exposures (OEHHA, 2003).

Body Weight. We used a body weight of 70 kg, which is average adult body weight, as recommended by CalEPA for occupational exposures (OEHHA, 2003).

Toxicity Criteria. Estimated average and maximum intakes from exposures *via* hand contact were then compared to the toxicity criteria presented in ***Table 7***. The following toxicity criteria are dose-response derived values that can be used to estimate the potential for health risks from exposure.

- Reference Dose (RfD) - "an estimate of daily exposure level for human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime" (US EPA, 1989).
- Minimum Risk Level (MRL) - "an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure" (ATSDR, 2009),
- No-Significant Risk Level (NSRL) - is the daily intake level that would result in one excess cancer case in an exposed population of 100,000 assuming lifetime exposure (CalEPA, 2009).
- Maximum Allowable Dose Level (MADL) - is the maximum allowable dose level that would result in no observable reproductive toxicity effect assuming exposure at 1,000 times that level (CalEPA, 2009).

The toxicity criteria in the tables include RfDs from US EPA's Regional Screening Level (RSL) Tables (US EPA, 2010), oral MRLs from the Agency for Toxic Substances and Disease Registry (ATSDR, 2009), and NSRLs and MADLs from CalEPA's (2009) Proposition 65 criteria. Multiple forms of some metals are included in US EPA's RSL Table

Table 6					
Exposure Parameters					
Parameter	**Acronym**	**Typical Use**		**High End Use**	
Exposure *via* Hand Contact					
Surface area of towel (front and back).	SA_{towel} (cm^2)	2,268	Based on average dimensions for 5 rental shop towels.	2,268	Same as the typical use.
Fraction of towel in contact with hand.	F_{towel} (unitless)	75%	Professional judgment.	75%	Same as the typical use.
Number of towels used daily per person.	N	12	Average daily use per employee based on telephone surveys.	26	95th percentile daily use per employee based on telephone surveys.
Towel to hand transfer.	$T_{t/h}$ (unitless)	13%	Based on a range of transfer rates from carpet (Lu and Fenske, 1999; Wester *et al*., 1996 as cited in Babich, 2006; Camann *et al*., 1996; Cohen Hubal *et al*., 2005; Hubal *et al*., 2008; Rodes *et al*., 2001). Averaged mean transfer rates from moist/wet hands and mean rates from dry hands.	13%	Same as the typical use.
Hand to mouth transfer efficiency.	HTE (day^{-1})	13%	Based on Calabrese *et al*. (1989), Stanek and Calabrese (1995), and Roels *et al*. (1980).	13%	Same as the typical use.
Exposure *via* Mouth Contact					
Towel to mouth transfer.	$T_{t/m}$ (unitless)	13%	Same as towel to hand transfer.		
Surface area of lips.	SA_{lips} (cm^2)	5.2	Ferrario *et al*., 2000; Average for men/women.		
Fraction of lip surface area contacting towel.	F_{lip} (unitless)	50%	Professional judgment.		
Fraction of metal on lips that's ingested.	F_{ing} (unitless)	50%	Professional judgment.		
Number of times shop towels used to wipe lips.	WL (day^{-1})	2	Professional judgment.		
General Exposure Parameters					
Exposure frequency.	EF (days/year)	245	49 weeks a year, 5 days a week (OEHHA, 2003).	245	Same as the typical use.
Exposure duration.	ED (years)	40	Recommended value under Prop 65 (OEHHA, 2003).	40	Same as the typical use.
Body weight.	BW (kg)	70	Based on OEHHA recommendation (2003).	70	Same as the typical use.
Averaging time - non-cancer.	AT-NC (days)	14,600	Exposure duration x 365 days/yr.	14,600	Same as the typical use.
Averaging time - cancer.	AT-C (days)	25,550	70 years x 365 days/yr.	25,550	Same as the typical use.

(2010). The form of the metals used in our evaluation is presented in ***Table 7***; the duration associated with the MRLs is also presented.

Averaging Time. Estimated average and maximum intakes from exposures *via* hand contact were then compared to the toxicity criteria presented in ***Table 7***. For comparing intakes with the MADL or NSRL we had to adjust exposures. For the MADL, we used an averaging time of 14,600 days (40 years x 365 days/year). For comparing intakes with the NSRL, we averaged exposures over a 70-year lifetime, as recommended by OEHHA (2003), for an averaging time of 25,550 days.

Table 8 lists the estimated intake, assuming typical use of 12 towels per day, for non-cancer health effects and cancer for exposure occurring *via* hand contact. Average and/or maximum intake exceedances of cancer or non-cancer criteria were found for antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum. When evaluating the magnitude of the exceedances, lead and cadmium maximum intakes were much higher than their respective toxicity criteria. Lead intakes were up to 3,600-fold higher than a toxicity reference value (maximum intake *versus* MADL), while cadmium intakes were up to 43-fold higher than a toxicity criterion (maximum intake *versus* MADL) (***Tables 8*** and ***8a***).

With high-end use of 26 laundered shop towels per day, our analysis indicates that the same compounds exceed the same toxicity criteria but with higher exceedances with the addition of iron and nickel (***Tables 9*** and ***9a***). Again, the highest exceedances are found with the maximum cadmium and lead concentrations. For non-cancer toxicity criteria, assuming high-end use of 26 towels per day, the maximum intake of cadmium is 93-fold higher than the MADL, and the maximum lead intake is 7,700-fold higher than the MADL. For cancer toxicity criteria, lead intakes were 24-fold and 146-fold higher than the NSRL using average and maximum concentrations, respectively (***Tables 9*** and ***9a***).

In both exposure scenarios, calcium, magnesium, potassium, and sodium were not evaluated due to absence of toxicity criteria. US EPA identifies these compounds as essential nutrients, which do not need to be evaluated in a risk assessment (US EPA, 1989).

Exposure *via* Direct Mouth Contact

Exposure to metals in laundered shop towels *via* direct mouth contact was estimated using the following equation:

$$Intake\ (mg/kg\text{-}day) = \frac{[Load_{towel} \times T_{t/m} \times SA_{lips} \times F_{lip} \times F_{ing} \times WL \times EF \times ED]}{BW \times AT}$$

Table 7

Toxicity Reference Values

Chemical	EPA RSLs			ATSDR		CalEPA	
	RfD (mg/kg-d)	Rfd Key[1]	Notes	Oral MRL (mg/kg-day)	Duration	MADL[2] (mg/kg-day)	NSRL[3] (mg/kg-day)
Aluminum	1.0E+00	P		1.0E+00	Chronic		
Antimony	4.0E-04	I					
Arsenic	3.0E-04	I		3.0E-04	Chronic		2.9E-04
Barium	2.0E-01	I		2.0E-01	Chronic		
Beryllium	2.0E-03	I		2.0E-03	Chronic		1.4E-06
Boron	2.0E-01	I	Boron and borates only	2.0E-01	Intermediate		
Cadmium	1.0E-03	I	Cadmium diet	1.0E-04	Chronic	5.9E-05	
Calcium							
Chromium	1.5E+00	I	Chromium III insoluble salts				
Chromium (VI)	3.0E-03	I		1.0E-03	Chronic		
Cobalt	3.0E-04	P		1.0E-02	Intermediate		
Copper	4.0E-02	H		1.0E-02	Intermediate		
Iron	7.0E-01	P					
Lead						7.1E-06	2.1E-04
Magnesium							
Manganese	1.4E-01	I	Manganese (diet)				
Mercury	1.6E-04	C	Mercury (elemental)				
Molybdenum	5.0E-03	I					
Nickel	2.0E-02	I	Nickel soluble salts				
Potassium							
Selenium	5.0E-03	I		5.0E-03	Chronic		
Silver	5.0E-03	I					
Sodium							
Strontium	6.0E-01	I		2.0E+00	Intermediate		
Thallium							
Tin	6.0E-01	H		3.0E-01	Intermediate		
Titanium							
Vanadium	5.0E-03	I		1.0E-02	Intermediate		
Zinc	3.0E-01	I		3.0E-01	Chronic		
HEM (Oil & Grease)							

Notes:
Blank - Not available
[1] P - PPRTV, I - IRIS, H - HEAST, C - CalEPA as presented in the EPA RSL table (US EPA, 2010).
[2,3] CalEPA's MADL and NSRL in μg/day converted to mg/kg-day, using body weight of 70 kg (CalEPA, 2009).

where:

$Load_{towel}$ = Metal loading on towel surface (mg/cm^2);
$T_{t/m}$ = Towel-to-mouth transfer (unitless);
SA_{lip} = Surface area of lips (cm^2);
F_{lip} = Fraction of lip in contact with towel (unitless);
F_{ing} = Fraction of metal on lip that is ingested (unitless);
WL = Number of times shop wipes used to wipe lips per day (day^{-1});
EF = Exposure frequency (days/year);
ED = Exposure duration (years);
BW = Average adult body weight (kg);
AT = Averaging time (days).

These parameters are described below.

Metal Loading on Towel Surface. We used the same values as described above for exposure *via* hand contact.

Towel-to-Mouth Transfer. We assumed towel-to-mouth transfer would be similar to towel to hand transfer, and thus used the same value of 0.13, or 13%, as described above. This value is more than double that used in the previous 2003 evaluation (5%).

Surface Area of Lips. We used the previous surface area of 5.2 cm^2, based on a study by Ferrario *et al*. (2000). This study used a three dimensional facial morphometry method, which estimates surface area based on distances between specific landmarks, which for the lips includes the outermost portion of the upper and lower lips, and the outer right and left side of the lips. Using this method the estimated outer lip surface area for 105 men and 96 women (ages 18 to 32) was 5.59 and 4.80 cm^2, respectively. We used the average lip surface area for men and women, of 5.2 cm^2.

Fraction of Lip in Contact with Towel. We assumed that the laundered shop towel would contact 50% of the lip surface area, based on professional judgment.

Fraction of Metal on Lip that is Ingested. We assumed that 50% of metal on the lip would be ingested, based on professional judgment.

Number of Times Laundered Shop Towels Used to Wipe Lips Per Day. We assumed that a worker would wipe their lips with a laundered shop towel two times on any given day, based on professional judgment. Note that we used the same assumption regarding the number of times per day the laundered shop towels are used to wipe lips, regardless of whether we assumed typical usage of 12 towels per day, or high-end use of 26 laundered shop towels per day (for exposure *via* contact with hands and subsequent transfer to the mouth). Personal wiping of the face is commonly observed to dry sweat or remove grime while working.

Table 10 lists the estimated average and maximum intakes occurring *via* direct mouth contact. When estimating exposure *via* towel-to-mouth contact, a toxicity criteria exceedance was observed for lead. Using the maximum lead concentration, the estimated intake exceeded the MADL by 3.5-fold. Using the average concentration, the estimated intake for lead in the shop towels did not exceed the MADL (***Tables 10 and 10a***). In general, these exposures were lower than those occurring *via* hand contact, typical use.

Results

Current Analysis

Based on this analysis, the estimated typical-use exposure to antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum in laundered shop towels exceeds at least one toxicity reference value (non-cancer and cancer) with typical usage of 12 laundered shop towels per day (***Tables 8 and 8a***). When evaluating the magnitude of the exceedances, lead and cadmium maximum intakes were much higher than their respective toxicity criteria. Lead intakes were up to 3,600-fold higher than a toxicity reference value (maximum intake *versus* MADL), while cadmium intakes were up to 43-fold higher than a toxicity criterion (maximum intake *versus* MADL) (***Tables 8 and 8a***). As estimated in our analysis, even using one towel a day with the average (mean) lead concentration would result in an exceedance of the MADL (data not shown). For cadmium, however, the metal with the next highest exceedances (43-fold greater than the MADL for maximum intake, typical use; and 93-fold greater than the MADL for maximum intake, high-end use), using two towels a day with the average (mean) cadmium concentration would not result in an exceedance of the MADL, but using three towels would result in an exceedance (data not shown).

With high-end use of 26 laundered shop towels per day, our analysis indicates that the same compounds exceed the same toxicity criteria but with higher exceedances, and with the addition of iron and nickel (***Tables 9 and 9a***). Again, the highest exceedances are found with the maximum cadmium and lead concentrations. Assuming high-end use of 26 towels per day, the maximum intake of cadmium is 93-fold higher than the MADL, and the maximum lead intake is 7,700-fold higher than the MADL. In comparison to cancer toxicity criteria, lead intakes were 24-fold and 146-fold higher than the NSRL using average and maximum concentrations, respectively (***Tables 9 and 9a***).

When estimating exposure *via* towel-to-mouth contact, a toxicity criterion exceedance was observed for lead. Using the maximum lead concentration, the estimated intake exceeded the MADL by 3.5-fold. Using the average concentration, the estimated intake for lead in the shop towels did not exceed the MADL (***Tables 10 and 10a***).

Comparison to 2003 Analysis

In comparing the results using the 2010 data with the prior 2003 evaluation, more exceedances of criteria were observed in the towels (***Table 11***). The higher number of exceedances in 2010 can be attributed to higher metal concentrations in the towels, more available toxicity criteria, increased number of shop towels used daily per employee, changes in transfer factors, and a change in the use of reference concentrations.

As stated previously, the detected concentrations in 2010 were generally higher than in 2003 (***Table 5***). Another difference between 2010 and 2003 is the frequency of detection of the various metals. In 2010, all of the metals, with the exception of thallium (0%), beryllium (35%), and chromium VI (58%), were detected in over 90% of the samples, while in 2003 only 11 metals were detected over 90% of the time and many were detected at much lower frequencies. It is unlikely that the types of metals frequently found in the towels tested from the variety of industries in 2010 would be from any single industry or process.

Other differences between 2010 and 2003 include the number of towels used. In 2010, the majority of the industries used more than 750 towels a week (companies using fewer than 750 towels per week were not surveyed) and as many as 17,000 towels as week. In the 2003 study, industries used as few as 96 towels a week and as many as 8,000 towels a week. In 2003, all of the companies assessed were located in the United States, whereas in the present study about half of the companies were in the US (11 companies) and other half were in Canada (15 companies). In 2003, a wide variety of industries were assessed, but in the current study, 42% of the companies evaluated were in the printing industry; the majority of the maximum concentrations were in the printing industry.

In 2003, several toxicity values were not available for cobalt (oral RfD and MRL), copper (MRL), iron (oral RfD), and beryllium (CalEPA NSRL). Consequently, these compounds were not evaluated. Having more available criteria in 2010 increased the number of exceedances.

Table 8

Exposure *via* Hand Contact - Typical Use

Exposure *via* Hand Contact

INTAKE (mg/kg-day) = [$Load_{towel}$ (mg/cm^2) x SA_{towel} (cm^2) x F_{towel} (unitless) x N x $T_{t/h}$ (unitless) x HTE (day^{-1}) x EF (days/year) x ED (years)] / BW (kg) x AT (days)

$Load_{towel}$ (mg/cm^2) = Concentration of metal on towel surface, estimated from concentration (mg/kg) in towels, weight of towels, and surface area of towels.
Assume : *Half of total metal in towel is available on each side of towel surface.*

Parameter	Definition	Value	Basis
SA_{towel} (cm^2)	= Surface area of towel (front and back).	**2,268**	Based on average dimensions for 5 rental shop towels.
F_{towel} (unitless)	= Fraction of towel in contact with hand.	**75%**	Professional judgment
N	= Number of towels used daily per person.	**12**	Average daily use per employee based on telephone surveys
$T_{t/h}$ (unitless)	= Towel to hand transfer.	**13%**	Based on a range of transfer rates from carpet (Lu and Fenske, 1999; Wester *et al.*, 1996 as cited in Babich, 2006; Camann *et al.*, 1996; Cohen Hubal *et al.*, 2005; Hubal *et al.*, 2008; Rodes *et al.*, 2001). Averaged mean transfer rates from moist/wet hands and mean rates from dry hands.
HTE (day^{-1})	= Hand to mouth transfer efficiency.	**13%**	Based on Calabrese *et al.* (1989), Stanek and Calabrese (1995), and Roels *et al.* (1980).
EF (days/year)	= Exposure frequency.	**245**	Based on OEHHA recommendations of a 5 day work week for 49 weeks per year (2003)
ED (years)	= Exposure duration.	**40**	Based on OEHHA recommendation (2003)
BW (kg)	= Body weight.	**70**	Based on OEHHA recommendation (2003)
AT (days)	= Averaging time. non cancer hazard	**14,600**	Based on OEHHA recommendation (2003)
	cancer risk	**25,550**	Based on OEHHA recommendation (2003)

Chemical	Average Load Concentration (mg/cm^2)	Maximum Load Concentration (mg/cm^2)	Non-Cancer Endpoint					Cancer		
			Average Intake (mg/kg-day)	Maximum Intake (mg/kg-day)	US EPA Oral RfD (mg/kg-day)	ATSDR Oral MRL (mg/kg-day)	CalEPA MADL[1] (mg/kg-day)	Average Intake (mg/kg-day)	Maximum Intake (mg/kg-day)	CalEPA NSRL[2] (mg/kg-day)
Aluminum	7.1E-03	1.9E-02	2.4E-02	6.4E-02	1.0E+00	1.0E+00		1.4E-02	3.6E-02	
Antimony	1.7E-04	3.7E-04	5.7E-04	1.3E-03	4.0E-04			3.3E-04	7.3E-04	
Arsenic	8.2E-06	1.6E-05	2.8E-05	5.5E-05	3.0E-04	3.0E-04		1.6E-05	3.2E-05	2.9E-04
Barium	4.8E-03	2.1E-02	1.6E-02	7.2E-02	2.0E-01	2.0E-01		9.4E-03	4.1E-02	
Beryllium	1.0E-06	7.0E-06	3.4E-06	2.4E-05	2.0E-03	2.0E-03		2.0E-06	1.4E-05	1.4E-06
Boron	8.5E-05	4.9E-04	2.9E-04	1.7E-03	2.0E-01	2.0E-01		1.7E-04	9.5E-04	
Cadmium	9.0E-05	7.5E-04	3.1E-04	2.5E-03	1.0E-03	1.0E-04	5.9E-05	1.8E-04	1.5E-03	
Calcium	4.4E-02	1.1E-01	1.5E-01	3.7E-01				8.6E-02	2.1E-01	
Chromium	9.6E-04	4.9E-03	3.2E-03	1.7E-02	1.5E+00			1.9E-03	9.5E-03	
Chromium (VI)	2.6E-06	7.9E-06	8.9E-06	2.7E-05	3.0E-03	1.0E-03		5.1E-06	1.5E-05	
Cobalt	4.0E-04	1.5E-03	1.4E-03	5.1E-03	3.0E-04	1.0E-02		7.8E-04	2.9E-03	
Copper	8.2E-03	2.6E-02	2.8E-02	8.9E-02	4.0E-02	1.0E-02		1.6E-02	5.1E-02	
Iron	6.3E-02	1.9E-01	2.2E-01	6.4E-01	7.0E-01			1.2E-01	3.6E-01	
Lead	1.2E-03	7.5E-03	4.2E-03	2.5E-02			7.1E-06	2.4E-03	1.5E-02	2.1E-04
Magnesium	8.8E-03	2.5E-02	3.0E-02	8.5E-02				1.7E-02	4.9E-02	
Manganese	1.1E-03	2.4E-03	3.9E-03	8.1E-03	1.4E-01			2.2E-03	4.6E-03	
Mercury	8.0E-07	1.9E-06	2.7E-06	6.4E-06	1.6E-04			1.6E-06	3.6E-06	
Molybdenum	7.0E-04	2.7E-03	2.4E-03	9.3E-03	5.0E-03			1.4E-03	5.3E-03	
Nickel	8.5E-04	3.6E-03	2.9E-03	1.2E-02	2.0E-02			1.6E-03	7.0E-03	
Potassium	9.7E-04	3.1E-03	3.3E-03	1.1E-02				1.9E-03	6.1E-03	
Selenium	1.3E-05	4.0E-05	4.3E-05	1.4E-04	5.0E-03	5.0E-03		2.5E-05	7.8E-05	
Silver	7.6E-05	5.9E-04	2.6E-04	2.0E-03	5.0E-03			1.5E-04	1.1E-03	
Sodium	6.6E-03	1.5E-02	2.2E-02	5.1E-02				1.3E-02	2.9E-02	
Strontium	3.3E-04	1.1E-03	1.1E-03	3.6E-03	6.0E-01	2.0E+00		6.4E-04	2.1E-03	
Thallium										
Tin	1.9E-04	4.4E-04	6.4E-04	1.5E-03	6.0E-01	3.0E-01		3.6E-04	8.5E-04	
Titanium	4.7E-04	2.1E-03	1.6E-03	7.2E-03				9.1E-04	4.1E-03	
Vanadium	5.4E-05	1.6E-04	1.8E-04	5.5E-04	5.0E-03	1.0E-02		1.0E-04	3.2E-04	
Zinc	5.5E-03	1.2E-02	1.9E-02	4.1E-02	3.0E-01	3.0E-01		1.1E-02	2.3E-02	
HEM (Oil & Grease)	9.5E-01	2.2E+00	3.2E+00	7.6E+00				1.9E+00	4.4E+00	

[1]*CALEPA's MADL in µg/day converted to mg/kg-day, using body weight of 70 kg.*

[2]*CALEPA's NSRL in µg/day converted to mg/kg-day, using body weight of 70 kg.*

(yellow) *Intake exceeds toxicity criterion* (blue) *Criterion exceeded*

Table 8a								
Exposure *via* Hand Contact - Typical Use (12 Towels) - Exceedance Ratios of Individual Toxicity Reference Values								
	Average Intake				**Maximum Intake**			
Chemical	**US EPA Oral RfD (mg/kg-day)**	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**	**US EPA Oral RfD (mg/kg-day)**	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**
Antimony	1.4				3			
Beryllium				1.4				10
Cadmium		3	5		3	25	43	
Cobalt	5				17			
Copper		3			2	9		
Lead			591	11			3,566	68
Molybdenum					2			

Exceedance ratios are only presented for chemicals with at least one exceedance of a toxicity reference value.
Blank - Intake did not exceed respective toxicity reference value or toxicity reference value was not available.

In the prior evaluation, we assumed a typical use and high-end use of 2.5 and 10, respectively. In 2010, we obtained more reliable information and used the mean and 95% UCLM for the typical and high-end RST usage, respectively. The values used in 2010 are 4.8 times higher for the typical use and 2.6 times higher for the high-end use, compared to the values used in 2003. As a result, the intakes were higher, resulting in more criteria exceedances.

A higher towel to hand transfer was used in 2010. Previously, we based the towel to hand transfer on studies using hard surfaces due to limited data. We applied a modifying factor of 50% to account for the porous nature of the towels. Based on our literature review, additional studies were found that assessed soft surfaces to hand transfers. We used the values for soft surfaces to eliminate the uncertainties associated with the arbitrary modifying factor applied in 2003 to account for the porous nature of towels. Increasing the transfer efficiency from 5% in 2003 to 13% in 2010, doubled the intake, contributing to the additional exceedances observed in 2010.

Finally, it should also be noted that in 2003, we subtracted the reference concentrations before calculating the load. This approach was not used in 2010, because the total concentration was deemed to be more representative of actual exposure.

Discussion

Because calculation of exposure requires the use of assumptions, there are uncertainties inherent in the exposure estimates, which could result in the actual exposures being either greater or less than the estimated values presented here. For example, due to a lack of empirical data, there is significant uncertainty regarding the transfer of metals from the towel to the hands, and from the hands to the mouth. Additional areas of uncertainty include (but are not limited to) the surface loading of metals on the shop towels, number of towels used daily per person, the fraction of towels in contact with the hands, and suitability of the toxicity criteria for evaluating potential risks associated with metals on the shop towels. These areas of uncertainty, and their potential impact on our analysis, are discussed in more detail below.

Metal Loading on Towel Surface. The number of shop towels analyzed by a laboratory is relatively modest. Thus, the representativeness of the estimates of metal concentrations on these shop towels with respect to shop towels from the same or other laundries is uncertain. Nonetheless, the use of the maximum and the average concentrations of metals in the towels provides an estimate of a plausible range of values, although it is possible that analysis of a larger number of shop towels could yield both higher and lower metal concentrations, and hence surface loadings.

Number of Towels Used Daily Per Person. In general, purchasing managers of the companies provided information regarding the number of towels used and the number of employees; the total number of towels used was divided by the number of employees to calculate the mean number of towels per employee, but actual towel usage by employees could differ. We estimated exposure to metals on laundered shop towels assuming either typical or high-end use of towels. For typical usage, we used 12 laundered shop towels per day, the average number of towels used. We used 26 towels as a plausible number of towels used daily by the high-end user based on the 95% UCLM of the average number of towels used (12).

Although various industries are represented in this study, not all industries are represented. In addition, some industries use more or less than the number of towels we used to represent typical and high-end use. Based on the compiled surveys, companies in the transportation industry used an average of 26 towels, followed by the following industries: printing (21 towels), painting and automotive (10 towels), manufacturing (7.5 towels), military and retail (5 towels), and packaging (4 towels). Daily towel use can also vary by employee based on job position and personal preference.

Many factors can affect the manner in which the towels are used, resulting in more or less metals in the towels. We assumed, for example, that exposure increases proportionately (linearly) as the number of shop wipes used increases. However, this might not be the case. It is possible that using more towels per day results in less metals on each towel. If exposure does not increase linearly as the number of towels used increases, intake would be less than we calculated. Alternatively, using more towels per day could indicate a dirtier work environment. Regardless, the intake associated with 26 towels per day would still, in all likelihood, exceed that associated with 12 towels per day.

Fraction of Towel in Contact with Hands. Another area of uncertainty in this analysis is the fraction of the towel in contact with the hands. For this analysis, we assumed 75% of the total surface area of the towel would contact the hands, based on professional judgment. According to information provided by an INDA member, women use between 30-60% of the towel surface area in any given hand drying event, and men use approximately 25% more of the towel surface area than women, or between 38 and 75%. Thus, 75% could be considered a maximum estimate for the fraction of towel in contact with hands. However, other uses of the towel, such as cleaning shop equipment, may involve contact with different portions of the towel, such that the fraction of the towel in contact with the hands for all uses throughout the day may be greater than the fraction contacted for drying hands. In addition, using a towel multiple times would likely increase the total surface area used.

Towel-to-Hand Transfer. For this analysis, we estimated transfer of metals from the towel to the hands based on data regarding transfer of pesticides from surfaces to hands. We chose these data, because they were the most reliable data we found regarding transfer of substances to hands. However, use of the pesticide transfer data introduces considerable uncertainty, notably potential differences in transfer rates for organics (pesticides) *vs*. inorganics (metals); differences in transfer rates for the relatively small sized pesticide residues *vs.* the larger sized metal particles; as well as differences in adherence of recently applied pesticide residues *vs.* metal particles on a laundered shop towel. In spite of these uncertainties, there is a precedent for estimating transfer rates for inorganics based on pesticide data. For example, US EPA used pesticide transfer data to estimate transfer (to hands) from arsenic on wood structures treated with copper chromated arsenic (ManTech and US EPA, 2002). Basing the towel to hand transfer rate on data for carpets also introduces uncertainty for estimating transfer from a shop towel.

An additional area of uncertainty for this factor is use of the entire range of transfer rates, including transfer rates to water-wetted hands, and including transfer rates at 4 hours post-application. Transfer rates were greater to water-wetted hands than to saliva-wetted hands, and greater at 4 hours post-application than at 24 hours post-application. Although use of transfer rates at 4 hours post-application may overestimate transfer of metals from the shop towels, it is conceivable that some usage of the shop towels may involve hands that are water-wetted (*e.g.*, for drying hands).

Daily Hand-to-Mouth Transfer Efficiency. This parameter was based on data regarding lead loading onto hands and soil ingestion rates in children, to estimate the amount of dislodgeable material on the hand surface that is transferred to the mouth, throughout the entire day. The estimate for children ages 1-6 years is 0.26, which means that 26% of the mass of dislodgeable material on the surface of a child's hand would be transferred to the mouth, and subsequently ingested. Because Agency-recommended soil ingestion rates for adults are approximately 50% of soil ingestion rates for children (US EPA, 1997), we used a hand-to-mouth transfer efficiency of 0.13, which means that 13% of the mass on an adult's hand is estimated to be transferred to the mouth and subsequently ingested. It should be noted that the surface area of a typical adult's hand is greater than that of a child's hand by a factor of 1.6 (904 *vs*. 550 cm^2), and that typical soil loadings (when expressed on a per cm^2 basis) on an adult's hand are about 0.29 of those of a child's (0.19 *vs*. 0.66 mg/cm^2) (US EPA, 1997). This means that the total mass of soil on the adult's hand is about half of the total mass on the child's hand (*i.e.*, 1.6 x 0.29 = 0.46). To achieve an estimated soil ingestion rate for adults (50 mg/day) which is half that of the child (100 mg/day), implies using the same hand-to-mouth transfer efficiency for both adults and children. Using a lower transfer rate for adults as was assumed in this analysis could potentially underestimate actual intake of metals by approximately two fold (0.29/0.13). On the other hand, there are also data that suggest that the average soil ingestion rate of the adult may be less than half that of the child (see Calabrese and Stanek, 1993, for example), so it unlikely that we underestimated adult intake of metals.

An additional aspect of uncertainty regarding the HTE parameter is the time frame of exposure. The HTE parameter integrates exposure due to hand-to-mouth activity occurring throughout a 12-hour day (approximately). Although hand-to-mouth activity may be more likely to occur at work, it will also occur while away from work. Using the HTE parameter without adjusting for the length of a typical 8-hour workday could overestimate actual intake of metals from the shop towels, by approximately 50% (12 hours/8 hours). Note that inherent in use of this hand-to-mouth transfer efficiency for this analysis, is the assumption that transfer of metals from hands to mouth is comparable to transfer of soil from hands to mouth.

Bioavailability. Because no data are available regarding the bioavailability[5] of metals on laundered shop towels, our analysis assumes that the bioavailability of the metals in the shop wipes is comparable to the bioavailability of metals in the studies used as the basis for the toxicity criteria. However, the metals present in the laundered shop towels may be in a relatively insoluble, metallic form, and hence may be less bioavailable than the more soluble forms of metals typically used in studies that serve as the basis for most toxicity criteria, including those used in this analysis. To directly compare estimated intakes with toxicity criteria, both the estimates and the toxicity criteria should be adjusted to represent an absorbed dose. Reduced bioavailability would result in a lower absorbed dose and hence reduced likelihood of exceeding the EPA RfD, ATSDR MRL, and Proposition 65 toxicity criteria, if adjusted to represent an absorbed dose.

Table 12 summarizes the impact of the uncertainties discussed above on the likelihood of exceeding the toxicity criteria (EPA RfD, ATSDR MRL, CalEPA's Proposition 65). Taking the uncertainties into

[5] In evaluating the potential for toxicity, it is important to consider the amount of a chemical that is absorbed into the bloodstream, since it is the absorbed form of the chemical that is typically of toxicological concern. Following ingestion, a chemical may not be completely absorbed into the bloodstream; some fraction of the dose may pass through the gastrointestinal tract unabsorbed. This phenomenon is reflected in the term relative bioavailability. Bioavailability is dependent on a number of factors, including chemical form, solubility, and particle size (Valberg et al., 1997).

Table 9

Exposure *via* Hand Contact - High End Use

Exposure *via* Hand Contact

INTAKE (mg/kg-day) = [$Load_{towel}$ (mg/cm²) x SA_{towel} (cm²) x F_{towel} (unitless) x N x $T_{t/h}$ (unitless) x HTE (day⁻¹) x EF (days/year) x ED (years)] / BW (kg) x AT (days)

$Load_{towel}$ (mg/cm²) = Concentration of metal on towel surface, estimated from concentration (mg/kg) in towels, weight of towels, and surface area of towels.
Assume : *Half of total metal in towel is available on each side of towel surface.*

Parameter	Definition	Value	Basis
SA_{towel} (cm²)	= Surface area of towel (front and back).	2,268	Based on average dimensions for 5 rental shop towels.
F_{towel} (unitless)	= Fraction of towel in contact with hand.	75%	Professional judgment
N	= Number of towels used daily per person.	26	95th percentile daily use per employee based on telephone surveys
$T_{t/h}$ (unitless)	= Towel to hand transfer.	13%	Based on a range of transfer rates from carpet (Lu and Fenske, 1999; Wester *et al.*, 1996 as cited in Babich, 2006; Camann *et al.*, 1996; Cohen Hubal *et al.*, 2005; Hubal *et al.*, 2008; Rodes *et al.*, 2001). Averaged mean transfer rates from moist/wet hands and mean rates from dry hands.
HTE (day⁻¹)	= Hand to mouth transfer efficiency.	13%	Based on Calabrese *et al.* (1989), Stanek and Calabrese (1995), and Roels *et al.* (1980).
EF (days/year)	= Exposure frequency.	245	Based on OEHHA recommendations of a 5 day work week for 49 weeks per year (2003)
ED (years)	= Exposure duration.	40	Based on OEHHA recommendation (2003)
BW (kg)	= Body weight.	70	Based on OEHHA recommendation (2003)
AT (days)	= Averaging time. non cancer hazard	14,600	Based on OEHHA recommendation (2003)
	cancer risk	25,550	Based on OEHHA recommendation (2003)

Chemical	Average Load Concentration (mg/cm²)	Maximum Load Concentration (mg/cm²)	Non-Cancer Endpoint: Average Intake (mg/kg-day)	Non-Cancer Endpoint: Maximum Intake (mg/kg-day)	Non-Cancer Endpoint: US EPA Oral RfD (mg/kg-day)	Non-Cancer Endpoint: ATSDR Oral MRL (mg/kg-day)	Non-Cancer Endpoint: CalEPA MADL[1] (mg/kg-day)	Cancer: Average Intake (mg/kg-day)	Cancer: Maximum Intake (mg/kg-day)	Cancer: CalEPA NSRL[2] (mg/kg-day)
Aluminum	7.1E-03	1.9E-02	5.2E-02	1.4E-01	1.0E+00	1.0E+00		3.0E-02	7.8E-02	
Antimony	1.7E-04	3.7E-04	1.2E-03	2.7E-03	4.0E-04			7.0E-04	1.6E-03	
Arsenic	8.2E-06	1.6E-05	6.0E-05	1.2E-04	3.0E-04	3.0E-04		3.4E-05	6.8E-05	2.9E-04
Barium	4.8E-03	2.1E-02	3.5E-02	1.6E-01	2.0E-01	2.0E-01		2.0E-02	8.9E-02	
Beryllium	1.0E-06	7.0E-06	7.4E-06	5.1E-05	2.0E-03	2.0E-03		4.2E-06	2.9E-05	1.4E-06
Boron	8.5E-05	4.9E-04	6.2E-04	3.6E-03	2.0E-01	2.0E-01		3.6E-04	2.0E-03	
Cadmium	9.0E-05	7.5E-04	6.6E-04	5.5E-03	1.0E-03	1.0E-04	5.9E-05	3.8E-04	3.1E-03	
Calcium	4.4E-02	1.1E-01	3.2E-01	8.0E-01				1.8E-01	4.6E-01	
Chromium	9.6E-04	4.9E-03	7.0E-03	3.6E-02	1.5E+00			4.0E-03	2.0E-02	
Chromium (VI)	2.6E-06	7.9E-06	1.9E-05	5.7E-05	3.0E-03	1.0E-03		1.1E-05	3.3E-05	
Cobalt	4.0E-04	1.5E-03	2.9E-03	1.1E-02	3.0E-04	1.0E-02		1.7E-03	6.3E-03	
Copper	8.2E-03	2.6E-02	6.0E-02	1.9E-01	4.0E-02	1.0E-02		3.4E-02	1.1E-01	
Iron	6.3E-02	1.9E-01	4.6E-01	1.4E+00	7.0E-01			2.7E-01	7.8E-01	
Lead	1.2E-03	7.5E-03	9.1E-03	5.5E-02			7.1E-06	5.2E-03	3.1E-02	2.1E-04
Magnesium	8.8E-03	2.5E-02	6.4E-02	1.8E-01				3.7E-02	1.0E-01	
Manganese	1.1E-03	2.4E-03	8.3E-03	1.7E-02	1.4E-01			4.7E-03	9.9E-03	
Mercury	8.0E-07	1.9E-06	5.9E-06	1.4E-05	1.6E-04			3.4E-06	7.8E-06	
Molybdenum	7.0E-04	2.7E-03	5.1E-03	2.0E-02	5.0E-03			2.9E-03	1.1E-02	
Nickel	8.5E-04	3.6E-03	6.2E-03	2.6E-02	2.0E-02			3.5E-03	1.5E-02	
Potassium	9.7E-04	3.1E-03	7.1E-03	2.3E-02				4.1E-03	1.3E-02	
Selenium	1.3E-05	4.0E-05	9.3E-05	2.9E-04	5.0E-03	5.0E-03		5.3E-05	1.7E-04	
Silver	7.6E-05	5.9E-04	5.5E-04	4.3E-03	5.0E-03			3.2E-04	2.5E-03	
Sodium	6.6E-03	1.5E-02	4.8E-02	1.1E-01				2.8E-02	6.3E-02	
Strontium	3.3E-04	1.1E-03	2.4E-03	7.8E-03	6.0E-01	2.0E+00		1.4E-03	4.4E-03	
Thallium										
Tin	1.9E-04	4.4E-04	1.4E-03	3.2E-03	6.0E-01	3.0E-01		7.8E-04	1.8E-03	
Titanium	4.7E-04	2.1E-03	3.4E-03	1.6E-02				2.0E-03	8.9E-03	
Vanadium	5.4E-05	1.6E-04	3.9E-04	1.2E-03	5.0E-03	1.0E-02		2.3E-04	6.8E-04	
Zinc	5.5E-03	1.2E-02	4.0E-02	8.8E-02	3.0E-01	3.0E-01		2.3E-02	5.0E-02	
HEM (Oil & Grease)	9.5E-01	2.2E+00	7.0E+00	1.6E+01				4.0E+00	9.4E+00	

[1] *CALEPA's MADL in μg/day converted to mg/kg-day, using body weight of 70 kg.*

[2] *CALEPA's NSRL in μg/day converted to mg/kg-day, using body weight of 70 kg.*

(yellow) *Intake exceeds toxicity criterion*

(blue) *Criterion exceeded*

Table 9a								
Exposure *via* Hand Contact - High End Use (26 Towels) - Exceedance Ratios of Individual Toxicity Reference Values								
Chemical	**Average Intake**				**Maximum Intake**			
	US EPA Oral RfD (mg/kg-day)	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**	**US EPA Oral RfD (mg/kg-day)**	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**
Antimony	3				7			
Beryllium				3				20
Cadmium		7	11		5	55	93	
Cobalt	10				37	1.1		
Copper	2	6			5	19		
Iron					2			
Lead			1,271	24			7,666	146
Molybdenum	1.0				4			
Nickel					1.3			

Exceedance ratios are only presented for chemicals with at least one exceedance of a toxicity reference value.
Blank - Intake did not exceed respective toxicity reference value or toxicity reference value was not available.

consideration as a whole, they are unlikely to change the conclusions regarding lead, the metal with the highest exceedances. This is due to the relatively large exceedance of the Proposition 65 Maximum Allowable Dose Level (MADL) for reproductive toxicity for lead, where, assuming high-end use of 26 towels per day, the maximum lead concentration is 7,666-fold higher than the MADL. This exceedance is likely greater than the combined magnitude of the uncertainties (which could be quantified). In addition, we compared estimated intake from hand contact (and subsequent ingestion) and mouth contact (and subsequent ingestion) to the toxicity criteria separately. However, under risk assessment guidance, risk is often evaluated by combining exposures for multiple pathways. If the estimated exposures (intakes) were combined prior to comparing them to the toxicity criteria, additional exceedances would likely result.

Outliers. As mentioned earlier, we evaluated the data to identify outliers, and we removed them from the database that form the basis of the results presented in this report. We did this to ensure that our estimates of exceedances were not based on single high concentrations, even though the data are believed to be reliable. Had we based the comparisons to regulatory criteria on data including the outliers, additional exceedances and larger exceedances would have been noted (***Table 11***). For example, for typical average use of 12 towels per day, additional exceedances of EPA RfDs would have resulted for cadmium (average intake exceedance of 3.1-fold and maximum intake exceendence of 73-fold), iron (maximum intake exceedance of 1.4-fold), and nickel (maximum intake exceedance of 4.1-fold) (data with outlier data not shown). In addition, for high-end use of 26 towels per day, additional EPA RfD exceedances would have resulted for cadmium (average intake exceedance of 6.6-fold and maximum intake exceedance of 155-fold) and barium (maximum intake exceedance of 1.1-fold). For mouth contact, exceedances of the Cal EPA MADL would have been 1.2-fold higher for cadmium assuming maximum intake, and 4.8-fold and 111-fold greater for lead assuming average and maximum intakes, respectively. In addition, the estimated maximum lead intake exceeded the Cal EPA NSRL by 2.1-fold. Overall, the exceedances were higher with the inclusion of the outliers. For example, by removing the outlier concentrations, the lead and cadmium high-end use Cal EPA MADL exceedances were reduced from 240,000 to 7,666-fold and from 2,650 to 93-fold, respectively.

Conclusion

Concentrations of metals in laundered shop wipes can result in exposures (as evaluated using the methodology presented in this report) which exceed toxicity criteria for certain metals.

Specifically, the overall conclusions of this analysis are[6]:

- Due to the wide range of detected concentrations in 2010 dataset, outlier concentrations were identified at the 1% and the 5% significant level. To ensure our estimates of exceedances were not based on a single high concentration, the outliers (all of which were at the high end of the distribution) were not included in the data used to generate the results presented in this report.

- When comparing the 2010 data without the identified outlier samples, six metals (barium, calcium, copper, lead, magnesium, and molybdenum) had mean concentrations in 2010 that were 1.5 – 2.8 times higher than the concentrations observed in 2003 (Beyer *et al.*, 2003).

- Metals on shop towels can get onto hands and then potentially be ingested, as evaluated in the 2003 report and as developed in this evaluation.

- For typical use of 12 towels a day per person, exceedances of Proposition 65 limits, and US EPA and ATSDR toxicity criteria may occur for antimony, beryllium, cadmium, cobalt, copper, lead, and molybdenum. Calculated intakes for these metals were up to 3,600-fold higher (based on maximum intake concentration for lead) than their respective toxicity criterion.

[6] *DISCLAIMER: The conclusions in this report are derived from the exposure assumptions provided herein. Utilization of different exposure assumptions, or comparison to different laundered shop wipes (which may contain different concentrations of metals), could affect the conclusions.*

Table 10

Exposure *via* Mouth Contact

Exposure *via* Mouth Contact

INTAKE (mg/kg-day) =[$Load_{towel}$ (mg/cm^2) x $T_{t/m}$ (unitless) x SA_{lips} (cm^2) x F_{lip} (unitless) x F_{ing} (unitless) x WL (day^{-1}) x EF (days/year) x ED (years)]/BW (kg) x AT (years)

$Load_{towel}$ (mg/cm^2) = Concentration of metal on towel surface, estimated from concentration (mg/kg) in towels, weight of towels, and surface area of towels.
Assume : *Half of total metal in towel is available on each side of towel surface.*

Parameter	Definition	Value	Basis
$T_{t/m}$ (unitless)	= Towel to mouth transfer.	**13%**	Based on a range of transfer rates from carpet (Lu and Fenske, 1999; Wester *et al.*, 1996 as cited in Babich, 2006; Camann *et al.*, 1996; Cohen Hubal *et al.*, 2005; Hubal *et al.*, 2008; Rodes *et al.*, 2001). Averaged mean transfer rates from moist/wet hands and mean rates from dry hands. Note: this is the same value as towel-hand transfer.
SA_{lips} (cm^2)	= Surface area of lips.	**5.2**	Ferrario *et al.* 2000; Average for men/women
F_{lip} (unitless)	= Fraction of lip surface area contacting towel.	**50%**	
F_{ing} (unitless)	= Fraction of metal on lips that's ingested.	**50%**	Professional judgment
WL (day^{-1})	= Number of times shop towels used to wipe lips.	**2**	Professional judgment
EF (days/year)	= Exposure frequency.	**245**	Based on OEHHA recommendations of a 5 day work week for 49 weeks per year (2003)
ED (years)	= Exposure duration.	**40**	Based on OEHHA recommendation (2003)
BW (kg)	= Body weight.	**70**	Based on OEHHA recommendation (2003)
AT (days)	= Averaging time. non cancer hazard	**14,600**	Based on OEHHA recommendation (2003)
	cancer risk	**25,550**	Based on OEHHA recommendation (2003)

Chemical	Average Load Concentration (mg/cm^2)	Maximum Load Concentration (mg/cm^2)	Non-Cancer Endpoint					Cancer		
			Average Intake (mg/kg-day)	Maximum Intake (mg/kg-day)	US EPA Oral RfD (mg/kg-day)	ATSDR Oral MRL (mg/kg-day)	CalEPA MADL[1] (mg/kg-day)	Average Intake (mg/kg-day)	Maximum Intake (mg/kg-day)	CalEPA NSRL[2] (mg/kg-day)
Aluminum	7.1E-03	1.9E-02	2.4E-05	6.2E-05	1.0E+00	1.0E+00		1.3E-05	3.6E-05	
Antimony	1.7E-04	3.7E-04	5.6E-07	1.2E-06	4.0E-04			3.2E-07	7.1E-07	
Arsenic	8.2E-06	1.6E-05	2.7E-08	5.4E-08	3.0E-04	3.0E-04		1.6E-08	3.1E-08	2.9E-04
Barium	4.8E-03	2.1E-02	1.6E-05	7.1E-05	2.0E-01	2.0E-01		9.2E-06	4.0E-05	
Beryllium	1.0E-06	7.0E-06	3.4E-09	2.3E-08	2.0E-03	2.0E-03		1.9E-09	1.3E-08	1.4E-06
Boron	8.5E-05	4.9E-04	2.8E-07	1.6E-06	2.0E-01	2.0E-01		1.6E-07	9.3E-07	
Cadmium	9.0E-05	7.5E-04	3.0E-07	2.5E-06	1.0E-03	1.0E-04	5.9E-05	1.7E-07	1.4E-06	
Calcium	4.4E-02	1.1E-01	1.5E-04	3.7E-04				8.4E-05	2.1E-04	
Chromium	9.6E-04	4.9E-03	3.2E-06	1.6E-05	1.5E+00			1.8E-06	9.3E-06	
Chromium (VI)	2.6E-06	7.9E-06	8.8E-09	2.6E-08	3.0E-03	1.0E-03		5.0E-09	1.5E-08	
Cobalt	4.0E-04	1.5E-03	1.3E-06	5.0E-06	3.0E-04	1.0E-02		7.7E-07	2.9E-06	
Copper	8.2E-03	2.6E-02	2.7E-05	8.7E-05	4.0E-02	1.0E-02		1.6E-05	5.0E-05	
Iron	6.3E-02	1.9E-01	2.1E-04	6.2E-04	7.0E-01			1.2E-04	3.6E-04	
Lead	1.2E-03	7.5E-03	4.1E-06	2.5E-05			7.1E-06	2.4E-06	1.4E-05	2.1E-04
Magnesium	8.8E-03	2.5E-02	2.9E-05	8.3E-05				1.7E-05	4.8E-05	
Manganese	1.1E-03	2.4E-03	3.8E-06	7.9E-06	1.4E-01			2.2E-06	4.5E-06	
Mercury	8.0E-07	1.9E-06	2.7E-09	6.2E-09	1.6E-04			1.5E-09	3.6E-09	
Molybdenum	7.0E-04	2.7E-03	2.3E-06	9.1E-06	5.0E-03			1.3E-06	5.2E-06	
Nickel	8.5E-04	3.6E-03	2.8E-06	1.2E-05	2.0E-02			1.6E-06	6.9E-06	
Potassium	9.7E-04	3.1E-03	3.2E-06	1.0E-05				1.9E-06	5.9E-06	
Selenium	1.3E-05	4.0E-05	4.2E-08	1.3E-07	5.0E-03	5.0E-03		2.4E-08	7.6E-08	
Silver	7.6E-05	5.9E-04	2.5E-07	2.0E-06	5.0E-03			1.4E-07	1.1E-06	
Sodium	6.6E-03	1.5E-02	2.2E-05	5.0E-05				1.3E-05	2.9E-05	
Strontium	3.3E-04	1.1E-03	1.1E-06	3.5E-06	6.0E-01	2.0E+00		6.2E-07	2.0E-06	
Thallium										
Tin	1.9E-04	4.4E-04	6.2E-07	1.5E-06	6.0E-01	3.0E-01		3.6E-07	8.3E-07	
Titanium	4.7E-04	2.1E-03	1.6E-06	7.1E-06				8.9E-07	4.0E-06	
Vanadium	5.4E-05	1.6E-04	1.8E-07	5.4E-07	5.0E-03	1.0E-02		1.0E-07	3.1E-07	
Zinc	5.5E-03	1.2E-02	1.8E-05	4.0E-05	3.0E-01	3.0E-01		1.0E-05	2.3E-05	
HEM (Oil & Grease)	9.5E-01	2.2E+00	3.2E-03	7.5E-03				1.8E-03	4.3E-03	

[1]CALEPA's MADL in μg/day converted to mg/kg-day, using body weight of 70 kg. *[2]CALEPA's NSRL in μg/day converted to mg/kg-day, using body weight of 70 kg.*

(yellow)	*Intake exceeds toxicity criterion*
(blue)	*Criterion exceeded*

Table 10a								
Exposure *via* Mouth Contact - Typical Use - Exceedance Ratios of Individual Toxicity Reference Values								
Chemical	**Average Intake**				**Maximum Intake**			
	US EPA Oral RfD (mg/kg-day)	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**	**US EPA Oral RfD (mg/kg-day)**	**ATSDR Oral MRL (mg/kg-day)**	**CalEPA MADL[1] (mg/kg-day)**	**CalEPA NSRL[2] (mg/kg-day)**
Lead							3.5	

Exceedance ratios are only presented for chemicals with at least one exceedance of a toxicity reference value.
Blank - Intake did not exceed respective toxicity reference value or toxicity reference value was not available.

- If the number of towels used increases to 26 a day per person, additional exceedances of US EPA and ATSDR toxicity criteria for iron and nickel may occur. Assuming maximum intake concentrations, intakes were up to 7,700-fold higher (lead) than their respective criterion.
- Although independent of the number of towels used, exposure *via* mouth contact may result in exceedances of the Proposition 65 MADL limits for lead assuming that a person wipes their mouth with an RST twice a day.
- The number of compounds with toxicity criteria exceedances is higher in this evaluation than in the prior 2003 assessment due to higher detected concentrations, the availability of additional toxicity criteria, higher number of towels used per day reflecting actual usage data compared to the estimate made in 2003 of 2.5 towels per day, and higher towel-to-hand transfer efficiency.

Table 11									
Metals with Exceedances - 2003 *vs.* 2010									
Using Average Intake (*i.e.*, mean concentrations)									
Criterion	**2003**			**2010 Without Outliers**			**2010 With Outliers**		
	Hand Contact		**Mouth Contact**	**Hand Contact**		**Mouth Contact**	**Hand Contact**		**Mouth Contact**
	Typical (2.5 towels)	**High End (10 towels)**		**Typical Towel Usage (12 towels)**	**High End Towel Usage (95% UCLM, 26 towels)**		**Typical Towel Usage (12 towels)**	**High End Towel Usage (95% UCLM, 26 towels)**	
Oral RfD/ Heast				Sb, Co	Sb, Co, Cu, Mo		Sb, **Cd**, Co	Sb, **Cd**, Co, Cu, Mo	
ATSDR MRL				Cd, Cu	Cd, Cu		Cd, Cu	Cd, Cu	
Cal-EPA MADL	Pb	Cd, Pb		Cd, Pb	Cd, Pb		Cd, Pb	Cd, Pb	**Pb**
Cal-EPA NSRL		Pb		Be, Pb	Be, Pb		Be, Pb	Be, Pb	
Using Maximum Intake (*i.e.*, maximum concentrations)									
Criterion	**2003**			**2010 Without Outliers**			**2010 With Outliers**		
	Hand Contact		**Mouth Contact**	**Hand Contact**		**Mouth Contact**	**Hand Contact**		**Mouth Contact**
	Typical (2.5 towels)	**High End (10 towels)**		**Typical Towel Usage (12 towels)**	**High End Towel Usage (95% UCLM, 26 towels)**		**Typical Towel Usage (12 towels)**	**High End Towel Usage (95% UCLM, 26 towels)**	
Oral RfD/ Heast		Sb		Sb, Cd, Co, Cu, Mo	Sb, Cd, Co, Cu, Fe, Mo, Ni		Sb, Cd, Co, Cu, **Fe**, Mo, **Ni**	Sb, **Ba**, Cd, Co, Cu, Fe, Mo, Ni	
ATSDR MRL		Cd		Cd, Cu	Cd, Co, Cu		Cd, Cu	**Ba**, Cd, Co, Cu	
Cal-EPA MADL	Cd, Pb	Cd, Pb		Cd, Pb	Cd, Pb	Pb	Cd, Pb	Cd, Pb	**Cd**, Pb
Cal-EPA NSRL	Pb	Pb		Be, Pb	Be, Pb		Be, Pb	Be, Pb	**Pb**

Notes:
Sb - antimony, Ba - barium, Be - beryllium, Cd - cadmium, Co - cobalt, Cu - copper, Fe - Iron, Mo - molybdenum, Ni - nickel, Pb - lead
Blank - no exceedances
BOLD: Exceedances that were dropped when the outliers were subtracted

Table 12	
Impact of Alternative Exposure Assumptions on Likelihood of Exceeding Toxicity Criteria	
Parameter with Uncertainty	**Likelihood of Exceeding Toxicity Criteria**
Metal loading on towel surface	Increase or decrease
Fraction of towel in contact with hands	Slightly decrease
Towel to hand transfer	Increase or decrease
Hand-to-mouth transfer efficiency	Increase or decrease
Bioavailability	Decrease

Attachment A						
Hand-to-Towel Transfer Studies						
Soft Surface (Wet and Dry)						
Reference	**Value**	**Pathway**	**Compound**	**Hand Condition**	**Surface**	**Basis**
Cohen Hubal *et al.*, 2005	2.6%	Surface to hand	Tracer	Dry	Carpet	1st contact transfer - mean of smudging and pressing results (Expt 1-4) presented in Table 3 of the study.
Hubal *et al.*, 2008	4.8%	Surface to hand	Pesticide-tracers	Dry	Carpet	1st contact - mean of pressing and smudging using riboflavin and uvitex OB tracer results (Trails 3, 8, 12 and 13) presented in Table S1 of the study.
Lu and Fenske, 1999	5.9%	Surface to hand	Pesticides	Dry	Carpet	After 3.5 hours, hand press, mean of aerosol (4.2% and 8.9%) and broadcast (4. 5%) applications presented in Table 4 of the study.
Rodes *et al.*, 2001	6.1%	Surface to hand	Dust particles	Dry	Carpet	Mean of no embed (8.7%) and embed (3.4%) mean surface loading presented in Table 4 of the study.
Wester *et al.*, 1996 as cited in Babich, 2006	6.2%	Textile to hand	Pesticide	Dry	Cloth	Based on mean of malathion and glyphosate results presented in Table 8 of the study.
Camann *et al.*, 1996	2.9%	Carpet to hand	Pesticides	Moistened	Carpet	Mean of chlorpyrifos, pyrethrin I and piperonyl butoxide results based on moistened "hand condition" presented in Table 5 (mean of 9 numbers).
Cohen Hubal *et al.*, 2005	8.7%	Surface to hand	Tracer	Moist/Sticky	Carpet	1st contact transfer- mean of smudging and pressing results (Expt 9-12 and 17-20) presented in Table 3 of the study.
Hubal *et al.*, 2008	10%	Surface to hand	Pesticide-tracers	Moist	Carpet	1st contact - mean of pressing and smudging using riboflavin and uvitex OB tracer results (Trials 2, 5, 9 and 16) presented in Table S1 of the study.
Rodes *et al.*, 2001	18%	Surface to hand	Dust particles	Damp	Carpet	Mean of embed (16.9%) and no embed (19%) mean surface loading results presented in Table 4 of the study.
Wester *et al.*, 1996 as cited in Babich, 2006	55%	Textile to hand	Pesticide	Moist	Cloth	Mean of malathion and glyphosate results presented in Table 8.
Mean	5%	Dry hands only				
	20%	Moist hands only				
	13%	Average of the means (moist and dry separately)				
	12%	Mean of all studies				
	Indicates Studies reviewed in the previous evaluation					

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