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Agreement between two methods for retrospective assessment of occupational exposure intensity to six chlorinated solvents: Data from The National Birth Defects Prevention Study

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ABSTRACT

The wide variety of jobs encountered in population-based studies makes retrospective exposure assessment challenging in occupational epidemiology. In this analysis, two methods for estimating exposure intensity to chlorinated solvents are compared: rated (assigned by an expert rater) and modeled (assigned using statistical models). Estimates of rated and modeled intensities were compared for jobs held by mothers participating in the National Birth Defects Prevention Study with possible exposure to six chlorinated solvents: carbon tetrachloride, chloroform, methylene chloride, perchloroethylene, 1,1,1-trichloroethane, and trichloroethylene. For each possibly exposed job, an industrial hygienist assigned (1) an exposure intensity (rated intensity) and (2) determinants of exposure to be used in a statistical model of exposure intensity (modeled intensity). Of 12,326 reported jobs, between 31 (0.3%) and 746 (6%) jobs were rated as possibly exposed to each of the six solvents. Agreement between rated and modeled intensities was low overall (Spearman correlation coefficient range: −0.09 to 0.28; kappa range: −0.23 to 0.43). Although no air measurements were available to determine if rated or modeled estimates were more accurate, review of participants' job titles showed that modeled estimates were often unexpectedly high given the low-exposure tasks found in these jobs. Differences between the high-exposure jobs used to create the statistical models (obtained from air measurements in the published literature) and the low-exposure jobs in the actual study population is a potential explanation for the disagreement between the two methods. Investigators should be aware that statistical models estimating exposure intensity using existing data from one type of worker population might not be generalizable to all populations of workers.

KEYWORDS
Agreement; chlorinated solvents; expert raters; exposure assessment; statistical models

Introduction

Estimating exposure intensity to chemical agents in epidemiologic studies is one of the most difficult steps in retrospective exposure assessment. The wide variety of industries and occupations found in population-based studies and the lack of comprehensive exposure information on the worksites of interest (which are crucial to exposure assessment) in these types of studies create additional challenges.[1] Individualized exposure assessment methods are considered to be better than methods based solely on industry and occupation or job-exposure matrices.[2] One common method for individualized exposure assessment typically uses expert raters, such as industrial hygienists, who assign exposure intensity scores after reviewing participants' job information and comparing it with exposure data from the literature.[3] However, experts might not be equally familiar with all jobs, exposure information in the literature might be limited, and exposure information provided by participants might be insufficient to allow an accurate assessment.[3,4] In this approach, expert raters presumably consider exposure determinants in their assessment, but documentation of the determinants considered by expert raters are generally not provided.

Another method for exposure assessment that provides clearer documentation involves two steps: an industrial hygiene expert identifying exposure determinants of participants' jobs and then applying a previously con-

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structed exposure determinants model to each job in the work history to estimate exposures. Exposure determinants models are often constructed by harvesting the industrial hygiene literature for exposure measurements and associated exposure determinants data and creating explicit algorithms to statistically model exposure intensity. Thus, the method produces the same exposure estimate for each combination of exposure determinants associated with each job.[1] However, if literature-based measurements are available on only a limited number (or a non-representative subset) of jobs or insufficient details are available to develop the models, accurate exposure assessment can be challenging and estimates could be biased.[1]

Assessments of exposure intensity from expert raters and from statistical models have their respective strengths and limitations and, as a result, might produce different estimates of exposure intensity. When validation data are unavailable on a similar population, the choice of which method to use will depend on the investigator's understanding of the strengths and limitations of each method in the context of the specific study.

In this analysis, two estimates of exposure intensity to chlorinated solvents are compared: one set developed from an experienced industrial hygienist's expert ratings and one set estimated from statistical models previously created by investigators from the National Institute for Occupational Safety and Health (NIOSH) and the National Cancer Institute.[5]

Methods

Data source

The source of job data to be assessed was the National Birth Defects Prevention Study (NBDPS), a population-based case-control study of risk factors for birth defects.[6] During a computer-assisted telephone interview, mothers provided information on jobs they held from three months prior to conception through the end of pregnancy, including job title, employer's name, service or product the employer provided or manufactured, main job activities and duties, and job start and end dates.[7] Industry and occupation were coded using the 1997 North American Industry Classification System (NAICS) and 2000 Standard Occupational Classification system (SOC), respectively. Institutional review board approvals were granted for all NBDPS study sites.

Rated intensity

For births between 1997 and 2002, an industrial hygienist rated all mothers' jobs held during pregnancy for probability of exposure (0, 0.01–0.09, 0.10–0.49, 0.50–0.89, ≥0.90) for each of 6 chlorinated solvents: carbon tetrachloride, chloroform, methylene chloride, perchloroethylene, 1,1,1-trichloroethane, and trichloroethylene. All mothers' jobs with a probability >0, indicating possible exposure, were assigned determinants of exposure and an estimate of exposure intensity, among other exposure characteristics. Determinants of exposure were assigned by the rater and their values were later collapsed into broader analytic categories (in parentheses): primary and secondary mechanisms of release (evaporation, aerosolization, other active mechanism); local exhaust ventilation (absent, present but ineffective, present and effective); industrial mechanical dilution (absent, present); location (indoor, outdoor, both); proximity to source (near, far, both); process temperature (elevated, room temperature, both); process condition (closed, open, both); solvent usage rate (<380 L/month, 380–3800 L/month, >3800 L/month); and confined space (no, yes, both). Determinant information was not asked directly of mothers; therefore, assignment was based on a combination of the job information provided, published industrial hygiene data, and the rater's experience and knowledge. After assigning these determinants, the same expert rater considered the assigned determinants, a database of previous workplace exposure monitoring studies (described below), and her expert judgment to assign a "rated intensity" in parts per million (ppm) to each possibly exposed job for each solvent. Examples of rater assignment of intensity and determinants of exposure are shown in the Appendix.

Modeled intensity

Development of the statistical models used to estimate "modeled intensity" has been described previously.[5] Briefly, a database of previous industrial hygiene assessments of exposure intensity for methylene chloride, 1,1,1-trichloroethane, and trichloroethylene was created by abstracting air concentrations for each solvent and corresponding exposure determinants from the published literature, NIOSH Health Hazard Evaluation reports, and NIOSH Industry-wide Study reports. In many cases, determinant information was not provided in these publications, requiring rater judgment to determine these values. This database was used to create a predictive model for each solvent. Models were fit using air concentration (natural-log transformed) as the dependent variable and the determinant values as independent variables.

Of the determinants assigned, process condition, solvent usage rate, and confined space were not included in any of the statistical models and process temperature

Table 1. Jobs rated possibly exposed and distribution of probability of exposure as estimated by an expert rater, National Birth Defects Prevention Study, 1997–2002.

	N[a]	Probability of Exposure			
		0.01—0.09	0.10—0.49	0.50—0.89	≥0.90
Carbon tetrachloride	31	21 (68%)	10 (32%)	0	0
Chloroform	301	262 (87%)	5 (2%)	27 (9%)	7 (2%)
Methylene chloride	746	499 (67%)	100 (13%)	145 (19%)	2 (0.3%)
Perchloroethylene	423	220 (52%)	163 (39%)	39 (9%)	1 (0.2%)
1,1,1-trichloroethane	746	494 (66%)	198 (27%)	54 (7%)	0
Trichlorethylene	348	305 (88%)	35 (10%)	8 (2%)	0

[a]Number of jobs rated possibly exposed to each solvent, among 12,326 jobs assessed.

was not included in the methylene chloride and 1,1,1-trichloroethane models because approximately half or more of the determinant values were assigned based on rater judgment. For the trichloroethylene model, location was not included because it was not statistically significant. Cross-validation of the modeling process was evaluated using data splitting and Monte Carlo techniques. For each solvent, 80% of the measurement data was used for modeling and 20% was set aside to validate this model. The process was repeated 1,000 times resulting in 1,000 models and 1,000 validation datasets for each solvent. For each repetition, the resulting model was applied to the observations in the validation dataset and a Spearman correlation coefficient (r_s) was calculated to compare the observed and predicted air concentrations. The mean r_s from these 1,000 repetitions was 0.21 for methylene chloride, 0.47 for 1,1,1-trichloroethane, and 0.61 for trichloroethylene, showing limited agreement.[5] Data were insufficient to create comparable statistical models for carbon tetrachloride, chloroform, and perchloroethylene; therefore, a vapor pressure conversion factor based on the Ideal Gas Law was applied to the exposure intensity obtained from the model for methylene chloride to estimate exposure intensity for these three solvents. For simplicity, the estimates obtained from these models will also be referred to as "modeled intensity." These models were then used to estimate exposure intensity for the NBDPS mothers' jobs. The exposure determinants earlier assigned to the mother's job were the input values used in the statistical models to predict exposure intensity for the job. The final statistical models, conversion factors used, and examples of calculations are shown in the Appendix.

Comparison of rated and modeled intensity

The median and range of rated and modeled intensities were calculated for each solvent and equality was assessed with a sign test. Agreement was assessed using Spearman correlation coefficients for continuous measures and kappa statistics for estimates dichotomized at the median.[8] Weighted kappa statistics were used when categorizing estimates into tertiles and quartiles. Analyses were performed in SAS version 9.3 (SAS Institute, Inc., Cary, NC).

Results

Of 12,326 jobs reported by 10,421 NBDPS mothers, 31 (0.3%) were classified as possibly exposed for carbon tetrachloride, 301 (2%) for chloroform, 746 (6%) for methylene chloride, 423 (3%) for perchloroethylene, 746 (6%) for 1,1,1-trichloroethane, and 348 (3%) for trichloroethylene.

Among jobs rated as possibly exposed, the probability of exposure for each of the 6 chlorinated solvents was low, with 52–88% of jobs rated as having a <0.10 probability of exposure and 80–100% of jobs having probability of exposure <0.50 (Table 1).

When directly comparing the rated exposure intensity to the modeled intensity, the median modeled intensity was greater than the corresponding median rated intensity for each of the 6 solvents ($p<0.001$ for each), and higher by over an order of magnitude for all except perchloroethylene (Table 2). Considering each job individually, the modeled intensity was higher than the rated intensity for 77% (trichloroethylene) to 100% (carbon tetrachloride) of jobs. The greatest agreement was observed between rated and modeled intensities for carbon tetrachloride ($r_s = 0.28$, kappa $= 0.43$) and perchloroethylene ($r_s = 0.21$, kappa $= 0.13$). No or slight agreement was observed for the other 4 solvents (r_s range: -0.09 to 0.01, kappa range: -0.23 to 0.12). Categorizing exposure intensity into tertiles or quartiles did not improve agreement (results not shown).

Among the NBDPS jobs rated possibly exposed to chlorinated solvents, the three most commonly reported occupations are shown in Table 3 along with the median and range of both rated and modeled intensities. The most common types of occupations held by NBDPS participants and rated as possibly exposed to chlorinated solvents were ones in which low exposure to chlorinated solvents is expected, such as maids and housekeeping cleaners, general and operations managers (most

Table 2. Comparison of rated and modeled occupational exposure intensity to six chlorinated solvents, National Birth Defects Prevention Study, 1997–2002.

	N[a]	Median (Range), ppm[b]		OSHA Ceiling, ppm	% Jobs with Modeled > Rated	Spearman Correlation	Kappa[c] (95% CI)
		Rated	Modeled				
Carbon tetrachloride[d]	31	0.06 (0.03, 0.08)	1.6 (0.08, 12.6)	25	100	0.28	0.43 (0.13, 0.73)
Chloroform[d]	301	0.03 (0.001, 15.8)	5.8 (0.12, 41.6)	50	94	0.01	−0.01 (−0.11, 0.10)
Methylene chloride	746	0.93 (0.05, 110.0)	22.8 (0.27, 91.7)	[e]	95	− 0.09	−0.23 (−0.30, −0.16)
Perchloroethylene[d]	423	0.08 (0.002, 5.0)	0.66 (0.01, 3.9)	350[f]	84	0.21	0.13 (0.05, 0.22)
1,1,1-trichlorethane	746	0.04 (0.002, 80.0)	8.5 (0.009, 36.3)	200	86	−0.09	0.11 (0.05, 0.17)
Trichloroethylene	348	0.24 (0.004, 71.6)	2.5 (0.21, 71.1)	200	77	−0.03	0.12 (0.02, 0.23)

Abbreviations: CI, confidence interval; N, number of possibly exposed jobs; OSHA, Occupational Safety and Health Administration; ppm, parts per million. [a]Jobs with possible exposure to each solvent. [b]$p < 0.001$ for each solvent using sign test for equalities of medians for rated and modeled intensities. [c]Dichotomized exposure intensity (<median and ≥median). [d]Methylene chloride model used, result transformed using Ideal Gas Law to estimate exposure intensity. [e]No ceiling value. [f]National Institute for Occupational Safety and Health (NIOSH) ceiling.

commonly representing women in janitorial services or beauty salon industries), and janitors and cleaners. Modeled intensities were higher than rated intensities for most occupations, except for perchloroethylene for which both estimates were fairly similar.

Discussion

In this study, rated and modeled intensities were not comparable when using either continuous or categorized values. In the absence of actual exposure intensity measure-

Table 3. Median and range of rated and modeled intensities for the three most commonly exposed jobs per solvent in the National Birth Defects Prevention Study, 1997–2002.

Occupation[a]	n (%)	Rated Intensity Median (Range), ppm		Modeled Intensity Median (Range), ppm	
Carbon tetrachloride (N = 29)					
Pressers, textile, garment, and related materials	5 (17%)	0.06	(0.06—0.06)	11.6	(7.8—11.6)
Biological technicians	4 (14%)	0.06	(0.04—0.08)	1.6	(1.6—1.6)
Chemists[b]	3 (10%)	0.08	(0.08—0.08)	1.6	(1.6—1.6)
Chloroform (N = 295)					
Dental assistants	22 (7%)	0.02	(0.02—0.02)	10.3	(2.8—10.3)
Sewing machine operators	18 (6%)	0.06	(0.06—0.08)	13.7	(5.8—21.6)
Radiologic technologists and technicians	16 (5%)	0.02	(0.02—0.02)	3.3	(3.3—10.3)
Methylene chloride (N = 732)					
Maids and housekeeping cleaners	161 (22%)	0.6	(0.5—3.1)	91.7	(29.5—91.7)
General and operations managers[c]	78 (11%)	1.2	(0.5—31.0)	91.7	(1.9—91.7)
Janitors and cleaners	41 (6%)	3.1	(0.5—3.1)	47.7	(15.3—47.7)
Perchloroethylene (N = 413)					
Manicurists and pedicurists	23 (6%)	0.5	(0.5—0.5)	1.0	(0.7—2.1)
General and operations managers[d]	22 (5%)	0.4	(0.03—1.0)	1.0	(0.1—2.1)
Sewing machine operators	18 (4%)	0.5	(0.3—0.5)	1.3	(0.5—2.1)
1,1,1-trichloroethane (N = 732)					
Maids and housekeeping cleaners	161 (22%)	0.04	(0.01—0.2)	22.4	(4.9—22.4)
General and operations managers[e]	76 (10%)	0.03	(0.01—12.9)	22.4	(0.1—22.4)
Janitors and cleaners	41 (6%)	0.01	(0.01—0.2)	8.5	(2.4—10.8)
Trichloroethylene (N = 342)					
Manicurists and pedicurists	25 (7%)	0.03	(0.03—0.03)	4.5	(2.1—20.8)
Hairdressers, hairstylists, and cosmetologists	24 (7%)	0.03	(0.03—0.03)	2.1	(2.1—20.8)
General and operations managers[f]	23 (7%)	0.03	(0.03—3.0)	4.5	(0.8—20.8)

Abbreviations: N, number of jobs possibly exposed to each solvent; n, number of jobs possibly exposed to each solvent, by job title; ppm, parts per million. [a]Excludes jobs with missing Standard Occupational Classification (SOC) code. [b]Tied with "Laundry and dry-cleaning workers" and "Packers and packagers, hand" with n = 3. [c]Most common industry: janitorial services (n = 50, 67%). [d]Most common industry: beauty salons (n = 6, 30%). [e]Most common industry: janitorial services (n = 50, 68%). [f]Most common industry: beauty salons (n = 8, 38%).

ments, it is not possible to validate either estimate of intensity. However, characteristics of the NBDPS mothers' jobs (namely, that the majority have expected low chlorinated solvent exposure) suggest that the lower exposure intensity estimates obtained using the expert rater model might have provided a more accurate estimate of exposure intensity than the higher estimates obtained from the statistical models in this specific study population.

Maids and housekeeping cleaners exposed to methylene chloride (Table 3) illustrate why rated intensity might better reflect the true exposure over the modeled intensity in this population. The rated intensities ranged from 0.5–3.1 ppm (median = 0.6 ppm), whereas the modeled intensities ranged from 29.5–91.7 ppm (median = 91.7 ppm). Given the usual job tasks of maids and housekeepers, it seems unlikely that they would typically be exposed to these relatively high exposures to chlorinated solvents. As a result, one might suspect that the rated intensity more accurately estimated their exposure than the modeled intensity (i.e., 91.7 ppm) which approaches the Occupational Safety and Health Administration short-term exposure limit of 125 ppm.[9]

The possibly biased higher exposure intensities estimated by the statistical models might have resulted from differences in the types of jobs and tasks performed between the jobs used to create the statistical model and those in the NBDPS study population. First, for example, a review of the literature on exposure to trichloroethylene in U.S. workplaces found that the majority of published measurements were taken in industrial settings of often high-exposed metal degreasing operations.[10] This is not surprising: air measurements in the published literature often come from high-exposure workplaces and not from low-exposure jobs where exposure levels are less likely to be monitored or less likely to be published. In contrast, the NBDPS jobs most commonly reported as possibly exposed to trichloroethylene were in the service industry and included manicurists and pedicurists; hairdressers, hairstylists, and cosmetologists; and general and operations managers (most commonly in the beauty salon industry)—jobs in which relatively low chlorinated solvent exposure would be expected. Second, women may perform different tasks than men, even if they share the same job title. In a combined analysis of three case-control studies, more women in janitors/cleaning jobs reported cleaning and polishing furniture than men, and more men in that same category reported stripping floors than women.[11] Therefore, a statistical model created from either male-dominated jobs or from a mixture of male and female jobs might not apply to this all-female study population. This discordance between the jobs and tasks used to create the statistical models and those in the NBDPS study population could result in the models estimating higher exposure intensity than were being experienced in these mothers' jobs.

In this study, a discrepancy between the jobs used to create the statistical models and the jobs held by individuals in the study population may have caused the statistical models to provide less accurate estimates of exposure intensity than the rater estimates. Despite this, statistical models retain some advantages over expert rater judgement for exposure assessment: they can provide quantitative and more reproducible methods for exposure assessment, removing reliance on the rater's experience, education, or judgements.[1]

Creating a single valid model for estimating exposure intensity across the variety of jobs found in population-based studies remains challenging. An expert rater might account for the use of (essentially) pure methylene chloride to degrease large metal parts compared to the use of a spray can of furniture polish containing a small percentage of methylene chloride. In contrast, the statistical models could not distinguish between these two situations because the modeled determinants did not include the concentration of the solvent in the product being used. Volume (solvent usage rate) was originally considered for inclusion in the models, but was ultimately not included because information on usage rate was rarely available in the literature. While higher concentrations of solvent and higher volumes of use might result in higher air concentrations or exposure intensity, they also might be associated with lower concentrations or intensity due to increased, or more effective, use of exposure control measures. Differences in the determinants used by raters compared to the models and the complicated relationship between solvent concentration and volume of use and exposure controls might explain why rated and modeled intensities were not comparable. Additionally, the statistical models used for this analysis did not include industry or occupation as variables. Using models that included these variables might have helped to provide more accurate exposure estimates by better distinguishing high-exposure jobs from low-exposure jobs. However, because air measurements from low-exposed jobs are less likely to be collected and published, accumulating sufficient data to create statistical models applicable to the wide variety of jobs and industries in a population-based case-control study might be challenging.

Other limitations of the statistical models chosen for this study might also have contributed to the differences between estimates in this population. As previously mentioned, the models showed limited agreement with air measurement samples when they were initially created and validated.[5] In addition, information on exposure determinants were not directly asked of NBDPS participants, nor were they available in many published air measurement reports, requiring rater judgment. However, this is a limitation of all exposure assessments in population-based case-control studies, and the expert rater method is preferred over other exposure assessment methods, such as self-report or use of job-exposure matrices, for this study type.[3] The statistical models were created from measurements of individuals who were exposed, whereas the majority of jobs held by NBDPS mothers had <0.10 probability of exposure, a variable not taken into account in the statistical models. Additionally, a single rater determined which jobs had a >0 probability of chlorinated solvent exposure, which determined which jobs were included in this analysis. Error is possible, but reliability of the assessment of exposure probability could not be determined.

The ability of the expert rater method to incorporate her own knowledge into exposure assessments is both an advantage and a disadvantage: the expert rater can make more nuanced estimations than statistical models, but the assessment can be difficult to reproduce across studies because of differences in raters' experience and knowledge of the jobs represented.[12] In this study, it is possible that the expert raters took probability, and other exposure variables such as frequency of exposure, into account during their evaluation (either systematically or subconsciously), assigning a lower exposure intensity to jobs with lower exposure frequency and contributing to the differences between rated and modeled intensities. It should be noted that in this study, the same rater considered the same reference measurement data, provided the estimates of rated intensity, and assigned the determinants of exposure, meaning that the two sets of estimates were not independent. Despite this, the results from the two methods were mostly uncorrelated. Although the expert rater approach is a preferred approach for population-based studies, their assessments are subject to error.[3] If different raters had been used for assignment of exposure determinants and of exposure intensity, it is possible the results might have been even more discordant. However, a recent study showed that accuracy and reliability greatly increases when industrial hygienists have been trained using a specific checklist, which could greatly improve exposure assessment in epidemiologic studies in which different raters are used.[4] If other methods to assess exposure determinants had been used, such as participant self-reports, the rated and modeled intensities would have been more independent. However, the quality of the information might have been worse if participants were unable to self-report some of the determinants, such as primary and secondary mechanisms of release.

To date, exposure intensity has not been a metric used in studies of maternal occupational chlorinated solvent exposure in NBDPS and so the results of the present study do not affect any previously published results from NBDPS.[13,14] Based on the results of this comparison of rated and modeled intensities, NBDPS investigators might consider using rated intensities over modeled intensities in future analyses. Investigators using these statistical models with other study populations should consider how generalizable these models might be to their own study populations and determine if rated or modeled estimates of exposure intensities would be more likely to provide an accurate estimate of exposure.

Conclusions

Exposure intensity to six chlorinated solvents estimated by expert rater and statistical models did not produce comparable results. Based on results of this analysis, exposure intensities estimated from the statistical models used in this study seemed too high given the types of jobs found among study participants, and rated intensity was likely the better estimate of exposure intensity in the NBDPS study population, although it is recognized that experts may not develop accurate estimates reliably and no evidence was available to determine which estimates were the most accurate. Differences might be the result of using high exposure jobs to create the models, which are not representative of the types of jobs worked by women of reproductive age in this study.

Recommendations

Researchers should be aware that exposure data generated for a specific purpose, such as for assessing compliance or evaluating hazardous exposures, may not be representative of the exposures experienced by workers in different jobs, meaning that statistical models based on higher exposed jobs might not be generalizable to all workers. Researchers using existing exposure models or job exposure matrices should consider conducting validation studies to evaluate if use of these methods is appropriate for their specific population.

Disclaimer

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Appendix

1a. Statistical models

Methylene chloride

ln(MeCl) = 3.453 – 0.737(primary mechanism of release is evaporation) – 1.134(secondary mechanism of release is evaporation) – 0.931(local exhaust ventilation is present and effective) – 0.654(industrial mechanical dilution is present) – 2.717(location is outdoor or mixed outdoor/indoor) + 1.321(proximity to source is near or mixed near/far) – 0.027(year minus 1970)

1,1,1-trichloroethane

ln(TCA) = −1.101 + 1.964(primary mechanism of release is active) + 3.415(primary mechanism of release is aerosolization) + 1.281(secondary mechanism of release is active) + 1.519(secondary mechanism of release is aerosolization) – 1.334(local exhaust ventilation is present and effective) – 0.730(industrial mechanical dilution is present) – 3.026(location is outdoor or mixed outdoor/indoor) + 1.206(proximity to source is near or mixed near/far) – 0.036(year minus 1970)

Trichloroethylene

ln(TCE) = 1.246 + 0.749(primary mechanism of release is aerosolization) + 2.283(secondary mechanism of release is aerosolization) – 0.428(local exhaust ventilation is present but ineffective) – 1.286(local exhaust ventilation is present and effective) – 0.222(industrial mechanical dilution is present) + 1.436 (process temperature is elevated or mixed elevated/room temperature) + 1.032(proximity to source is near or mixed near/far) + 1.398(year minus 1970)

1b. Using the models to calculate exposure intensity

The determinants of exposure are assigned a value of 1 if they meet the condition in parentheses and 0 if they do not meet the condition.

When exponentiated, these models produce an estimate of the geometric mean. Arithmetic means are calculated using the following formula, assuming a geometric standard deviation of 2.5:

$$\text{Arithmetic mean} = \text{geometric mean} \times \exp\left[0.5(\ln(2.5))^2\right].$$

For carbon tetrachloride, chloroform, and perchloroethylene, the model for methylene chloride is used and the resultant arithmetic mean is multiplied by a vapor pressure conversion factor based on the Ideal Gas Law (equal to the vapor pressure of the solvent divided by the vapor pressure of methylene chloride) to obtain the final result. Conversion factors are:

Carbon tetrachloride : 2.64/10
Chloroform : 4.53/10
Perchloroethylene : 0.43/10

2. Examples of estimation of rated and modeled exposure to methylene chloride

Example 1: Rated intensity is lower than modeled intensity.
Example 2: Rated intensity is higher than modeled intensity.

	Example 1	Example 2
Questionnaire responses		
Job title	Cleaning lady	Glue shoes
Company name	A home	[Name provided]
What does company make or do	N/A	Makes sleeping shoes
Main activities or duties	Cleaning the house	Put glue on the shoes
Chemicals or substances handled	Cleaning products, bleach, laundry detergent	Glue
Expert rater assessment		
Industry	Janitorial Services	Footwear Manufacturing
Occupation	Maids and Housekeeping Cleaners	Shoe Machine Operators and Tenders
Methylene chloride exposure	Possible	Possible
Determinants of exposure		
Primary release mechanism	Spreading (Active)	Spreading (Active)
Secondary release mechanism	Aerosolization	Aerosolization
Local exhaust ventilation	Absent	Absent
Industrial mechanical ventilation	Absent	Present
Location	Indoors	Indoors
Proximity to source	Near	Near
Year[a]	1995	1995
Exposure intensity		
Expert rater	0.6 ppm	86.5 ppm
Statistical model	91.7 ppm	47.7 ppm

[a]All mothers were assigned 1995 as year in the statistical models. Data used to create the model were generally available through 1995 and this date was used to extrapolate the model data to the maternal jobs which were reported for 1997–2002.

Calculation for Example 1

$$\ln(\text{MeCl}) = 3.453 - 0.737\,(0) - 1.134\,(0) - 0.931\,(0) - 0.654\,(0) - 2.717\,(0) + 1.321\,(1) - 0.027\,(25) = 4.099$$

$$\text{Arithmetic mean} = \exp(4.099) \times \exp\left[0.5(\ln(2.5))^2\right] = 91.7\text{ppm}$$

Calculation for Example 2

$$\ln(\text{MeCl}) = 3.453 - 0.737\,(0) - 1.134\,(0) - 0.931\,(0) - 0.654\,(1) - 2.717\,(0) + 1.321\,(1) - 0.027\,(25) = 3.445$$

$$\text{Arithmetic mean} = \exp(3.445) \times \exp\left[0.5(\ln(2.5))^2\right] = 47.7\text{ppm}$$