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Evaluating the Effectiveness of Risk-Reduction Strategies for Consumer Chemical Products

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Communication about risks offers a voluntary approach to reducing exposure to pollutants. Its adequacy depends on its impact on behavior. Estimating those impacts first requires characterizing current activities and their associated risk levels, and then predicting the effectiveness of risk-reduction strategies. Characterizing the risks from chemical consumer products requires knowledge of both the physical and the behavioral processes that influence exposures. This article presents an integrated approach that combines consumer interviews, users' beliefs and behaviors, and quantitative exposure modeling. This model was demonstrated in the context of consumer exposure to a methylene chloride-based paint stripper, showing how it could be used to evaluate current levels of risk and predict the effectiveness of proposed voluntary risk-reduction strategies.

KEY WORDS: Consumer products; exposure modeling; risk reduction; communication; methylene chloride

1. INTRODUCTION

Consumers are regularly faced with risk-management decisions related to their exposures from chemical products used in the home. Cleansers, pesticides, solvents, and coatings all can aid consumers, but at the price of exposing them to volatile organic compounds (VOCs). In addition, present building standards include better insulation and lower ventilation rates in order to increase energy efficiency. These improvements cause VOCs to disperse more slowly, which increases consumer exposure and creates new concerns about products once considered relatively safe. Even without these changes in average ventilation rates, new research can increase or decrease concern about familiar chemicals.

Consumers can control their exposure levels by choosing which chemicals enter their homes, where they are stored, and how they are used.[(1)] Much advice—in the form of warning labels, articles in the consumer literature, pamphlets, and World Wide Web sites—has been given to consumers about how to reduce their risks. This article offers a systematic approach to determine the effectiveness of such information. This approach can be used to evaluate existing messages and possible alternatives, as well as to assess the limits of communication as a risk-reduction strategy—one that has, at times been proposed as an alternative to more coercive regulatory approaches.

The integrated approach presented in this article (Fig. 1) combined interviews, observational studies, and prevalent consumer mitigation behaviors with an exposure model adapted from studies of indoor air pollution, to incorporate human action. The opportunities for risk reduction were then estimated on the basis of general principles of information processing and consumers' mental models of how particular

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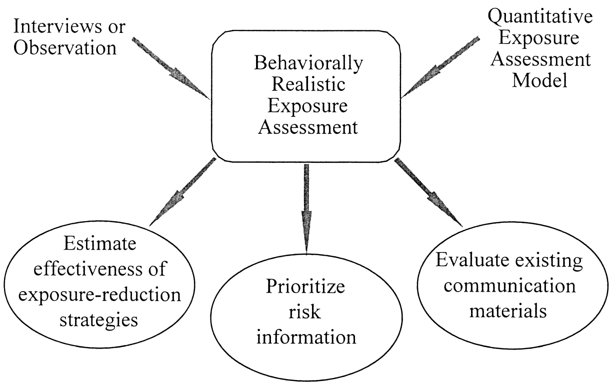

Fig. 1. Integrated approach for behaviorally realistic exposure and risk-communication analysis.

risks are created and controlled. The former constrain how much additional information consumers can absorb; the latter determines the effects of their actions. This method was demonstrated in the context of consumer exposure to the methylene chloride contained in paint stripper.

Magat and Viscusi,[2] among others, have demonstrated that information provision can induce risk-reducing behavior. If information provision can be shown to be sufficiently effective, then it may provide an alternative to top-down regulation, and would be an attractive alternative in that it would preserve freedom of choice, accommodate individual preferences, and allow manufacturers to seek the most efficient ways to achieve desired performance. The approach presented here affords a way to assess the viability of this form of voluntary self-regulation, by estimating the attendant exposure levels.

It is recognized that, although warning labels can afford protection to consumers, they also impose costs. Consumers must both acquire the information and comply with its directives.[3–5] They may reasonably not search very hard for information, if they do not expect their efforts to be rewarded; and may reject what they learn, if following that advice seems too costly.[6] Effective warning design should reduce both of these costs, by providing ready access to information regarding the most efficient precautions that consumers can take to reduce their risk.[7] That means prioritizing information according to the likelihood and impact of behavioral changes that would follow from it.[8] This study factored in the costs of information acquisition and compliance by considering "partial-compliance" behavior, assuming that individuals do what they deem beneficial to lower their risk, given their understanding of the information available to them. In this light, the modeling approach presented here can be used to evaluate the effectiveness of existing labels, and design more effective ones. This is achieved by identifying the "best buys" in exposure reduction (and risk communication), along a marginal risk-reduction curve.

2. CHEMICAL EXPOSURE MODEL

The quantitative exposure model was adapted from one developed by Van Veen[9] to predict respiratory and dermal uptake of VOCs. To it was added human actions potentially affecting indoor concentrations and exposures (e.g., opening windows, spending less time close to sources). The model was also adapted to accommodate the imperfect mixing of VOCs in a room by creating a virtual subchamber around the work area, which has rapid, but not perfect, mixing with the rest of the room (Fig. 2). The model is described in detail in Riley[10] and Riley, Small, and Fischhoff,[11] including its validation with observational data collected by Girman *et al.*[1]

Model parameters are of three kinds: (1) physical constants (e.g., volatilization rates), (2) physical measurements (e.g., room size, air exchange rates), and (3) behaviors. The latter two can be estimated either by observing people at work or by asking them to describe their actions and work conditions. In this study, interview data was used. The effects of a behavioral intervention (e.g., a warning label) are

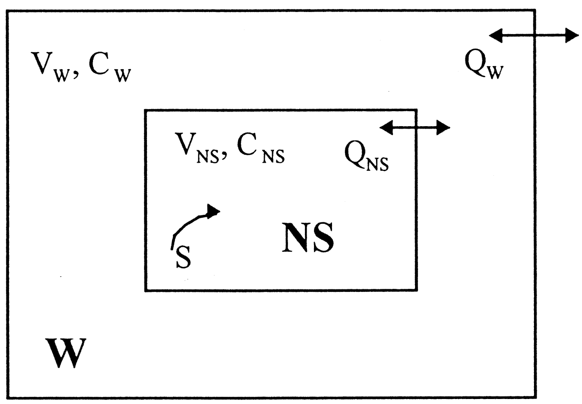

Fig. 2. Schematic of two-compartment indoor air quality model.[6,7] The model predicts room concentrations of methylene chloride (C_W, C_{NS}), based on a source S in a virtual compartment NS (near source, volume V_{NS}) located in a larger room W (workroom, volume V_W), with known air-flow rates between the near-source compartment and the workroom, Q_{NS}, and between the workroom and the outside environment, Q_W.

reflected in changed model parameters. How much change occurs depends, in part, on how well consumers understand how their actions affect their exposure levels. That understanding was assessed in this study with semi- structured, open-ended mental-models interviews, which could serve as the basis for structured surveys, suitable for administration to larger samples.[12,13]

3. INTERVIEWS

Interviews were used to gather two types of information from participants: (1) their suite of beliefs, or "mental models," regarding how risks are created and controlled; and (2) descriptions of their work environment and habits, in terms that allowed for the estimation of model parameters (e.g., size of workroom, quantity of product used, length of breaks). Even though people do some things that they know are risky and other things without very clear reasons, it is thought that beliefs and actions are at least somewhat related.

Subjects were recruited inside a Pittsburgh home-improvement center and offered a $10 gift certificate to the store for participating in a 20-minute interview, recorded on audiotape. Subjects were screened for prior experience with paint strippers. Eleven women and 9 men were interviewed; 17 were homeowners and 16 had completed college.

Subjects were first asked open-ended questions in five areas paralleling the formal (or "expert") model for VOC exposure associated with furniture stripper use. After eliciting general beliefs about paint strippers, the interviewer asked about specific usage patterns, beliefs, and concerns about the effects of paint strippers, risk-mitigation strategies, and beliefs about exposure and effects processes. Follow-up questions were asked to ensure that the consumers' frame of reference was understood.

3.1. Quantitative Information

Participants were asked how, where, and when they used paint stripper, in terms of a typical job (or their most recent one). These questions targeted the variables that influenced exposure, so that they could be included in the expert model. The variables were: size and type of room, position of windows and doors, time spent on different parts of the job, location and duration of breaks, and amount of paint stripper used. Table I summarizes subjects' estimates. In order to accommodate the heterogeneity of response values, separate models were created for three of the tasks described by our interviewees.

Table I. Subjects' Quantitative Estimates of Paint Stripping Activities

	Mean	Median	*SD*	Minimum	Maximum
Amount used (ounces)	82	32	93	12	384
Applying time (min)	18	10	20	"seconds"	60
Curing time (min)	29	15–20	37	1	180
Scraping time (min)	44	25	42	5	120
Cleaning time (min)	24	30	16	10	60
Break time (min)	19	15–20	13	5	30
Room volume (m^3)	51	61	31	4.5	92

Note: $N = 20$.

3.2. Precautionary Measures

Every participant reported reading the label on the can. This rate (like that for some other precautionary behaviors) was probably overreported, in response to normative expectations. For example, Kovacs, Small, Davidson, and Fischhoff[14] found that fewer than 5% of subjects even looked at the precautionary statement on the back label of a chemical cleaner in an experimental setting. Nonetheless, in a postexperiment questionnaire, 18% of their subjects reported having read the label during the experiment, while 76% reported that they "normally read" labels. Given the inefficiency of many reported work practices and precautionary measures in our study (described later), it is possible that even if all these consumers read the labels, they may not have extracted the necessary information.

Every interviewee described taking some precautions while working with paint stripper, including using at least one method to reduce inhalation exposure. However, not all these measures were effective ones. Table II shows their reported behaviors, categorized by scientific assessments of their effectiveness. Most participants reported doing something to improve ventilation, including working outside (60%), opening windows (55%), using a fan (20%), and taking breaks outside the work area (65%). The fact that these precautions were taken is consistent with 18 of the 20 participants reporting an awareness of health effects associated with poor ventilation. Break length varied from 5 minutes to several days, and typically involved a specific break activity and location, such as going to the kitchen and making a sandwich, or going outside to do yard work. One participant reported smoking during the breaks.

Table II. Reported Precautionary Behaviors

Behavior	No. of participants (%)
Reading the label	20 (100)
Effective behaviors	
Taking breaks (outside of work area)	13 (65)
Working outside [exclusively]	12 [5] (60 [25])
Using "safer" formulation	10 (50)
Wearing goggles	7 (35)
Working inside with open windows, no fan	7 (35)
Working inside with open windows and fan	4 (20)
Less effective/ineffective behaviors	
Wearing gloves	18 (90)
Taking breaks (inside work area)	4 (20)
Wearing dust mask	3 (15)
Wearing organic-vapor cartridge respirator	1 (5)
Wearing army gas mask	1 (5)

Note: $N = 20$.

Seven participants reported using (or planning to use) goggles, which guard against splashes into the eyes, and six participants mentioned eye irritation or blindness as a possible effect of paint stripper use; but only three mentioned both. The fact that three participants reported concerns, yet stated that they did not use goggles, suggests that the respondents did not feel compelled to invent appropriate behaviors. The four who used goggles, but mentioned no explicit concerns, show the possibility of important information going without saying, that is when asked about health effects, participants didn't think to mention eye injury even though (or perhaps because) they wore protective equiptment. The semistructured interview protocol was designed to reduce unarticulated or assumed knowledge by approaching the topic from different perspectives, and adapting the interview to participants' personal formulations.

Some participants reported taking precautions that likely had little effect, such as wearing a dust mask, organic-vapor cartridge (OVC) respirator, or army-issue gas mask. Dust masks do nothing to reduce exposure to methylene chloride; even OVC respirators only work for the first 20 minutes or so,[15] until the cartridge is saturated. Similarly, four people reported taking breaks inside the work area, which would not significantly reduce exposure to methylene chloride (unless they went to the far side of a large room).

Eighteen out of the 20 participants reported using gloves while they worked. Although some cited glove materials ranging from latex to plastic, most were unsure of the type they used. No one mentioned using chemical-resistant gloves, which are designed for use with organic solvents. The effectiveness of gloves varies by material. However, almost all gloves available to consumers will eventually be penetrated by methylene chloride. Some gloves can even trap the chemical, preventing evaporation and increasing the likelihood of skin burns.[16] Although agencies such as the Occupational Safety and Health Administration (OSHA)[17] continue to recommend specific gloves as protection against dermal exposure to methylene chloride, it appears that their stipulation of agency-approved material is not being followed by all consumers.

4. BEHAVIOR-SENSITIVE MODELING

Going beyond these informal analyses requires formal modeling of the exposures associated with various patterns of consumer behavior. Such modeling allows for the determination of the magnitude of current risks and the reductions possible with different interventions. To that end, the behaviors described by interview participants were incorporated into the exposure model.[10,11] As a form of sensitivity analysis, three individuals with very different behavior patterns are discussed. Analyses that produce similar conclusions, increase the chances of producing general recommendations. When only one message is possible (e.g., with a fixed product label), then the frequency of different behavior patterns and the aggregate impact of possible messages on these behaviors should be considered before choosing that message.

4.1. Exposures Based on Individual Responses

Figure 3 shows the model's predictions of short-term (or acute) exposure over time for three interview participants. Subjects 14 and 10 represent low-

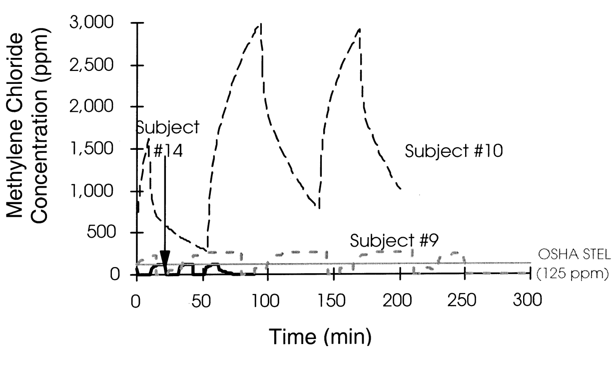

Fig. 3. Model predictions for short-term (acute) individual exposure for Subjects 9, 10, and 14, shown against the Occupational Safety and Health Administration (OSHA) short-term exposure limit (STEL) for methylene chloride.

and high-exposure single-session scenarios, respectively, while Subject 9 represents an intermediate case.

- Subject 9 stripped an antique spinning wheel of six to eight coats of paint plus a stain on the bottom layer, working in a 26′ × 14′ × 7′ garage with windows and doors open. The subject used more than 1 quart of paint stripper for the job over a 5-hour period, taking breaks about once an hour.
- Subject 10 reported stripping window woodwork in an 8′ × 13′ × 9.5′ kitchen with open windows and doors, using 1 quart of stripper in over 3 hours, taking breaks in the work area itself.
- Subject 14 reported stripping parts of a grandfather clock, working for 90 minutes each day with regular breaks for several weeks, 45 days in all. Although he used 6 to 8 quarts of stripper for the entire job, on any given day he reported using only about 6 ounces. This subject also reported suffering from emphysema and, therefore, took 10-minute breaks about every 20 minutes, working in a garage with windows and doors open and a fan on.

The exposure level of Subject 10 was very high, because a large amount of stripper was used in a small kitchen. Air exchange rates in an open garage, like the one in which Subject 9 worked, are assumed to be about five times higher than those of a room in a house.[18,19] Therefore, the predicted exposures are much lower for Subject 9, who used the same amount of stripper as Subject 10, but over a longer period of time. Each of Subject 14's short sessions, which were punctuated by his long breaks, produced much lower exposures.

The absolute magnitude of these exposures can be considered from both short- and long-term perspectives. The workplace short-term exposure limit (STEL) set by OSHA[17] requires that the average concentration not exceed 125 ppm, as a 15-minute time-weighted average. Based on the STEL, even Subject 9 may experience lightheadedness or drowsiness, such as that observed in individuals exposed to concentrations as low as 100 to 300 ppm.[16] Paint stripper users with a usage pattern similar to that of Subject 10 may experience more severe acute effects. A documented case of a heart attack (in a sensitive individual) was reported at 1,300 ppm.[20] Above 500 ppm, mild effects such as central nervous system depression, headaches, and lightheadedness have been observed.[16]

Figure 4 shows a measure of long-term (cumulative) exposure, potential inhalation dose (PID). This is an upper-bound estimate of the amount absorbed, defined by Wilkes, Small, Davidson, and Andelman.[21] as the total mass of the chemical entering the outer respiratory system of the individual, assuming a breathing rate of 8.3 l/min. More refined estimates are possible with physiologically based pharmacokinetic modeling, which considers the percentage of the PID that is actually taken up by the bloodstream and different tissues of the body. As seen in Fig. 4, there are dramatic differences between the maximum possible doses for the three depicted sessions, with Subjects 10, 9, and 14 potentially receiving 8.8, 1.3, and 0.11 g, respectively. Because Subject 14 distributed his work over 45 days, his total PID is about 5 g—higher than Subject 9, but still well below Subject 10, distributed over a period of more than 4,000 minutes. According to OSHA, a worker exposed to its 8-hour standard of 25 ppm of methylene chloride in a workday has a PID of 3.5 g (or about 900 g year), which is equivalent to an increased lifetime risk of death due to cancer of 10^{-3}. The horizontal lines translate these OSHA estimates into the equivalents for these individuals, were they to repeat the described project once a year for 45 years.

4.2. Measuring Room for Improvement

The impacts of possible interventions on these exposures can be estimated by changing the appro-

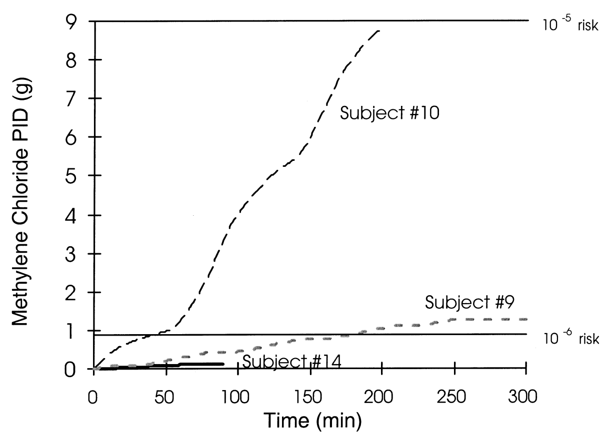

Fig. 4. Model predictions for long-term (cumulative) individual exposure for Subjects 9, 10, and 14, shown against Occupational Safety and Health Administration lifetime cancer death risk estimates (assuming that the subject repeats the same job once a year for 45 years). Potential inhalation dose (PID) is the total mass of methylene chloride that enters the body through inhalation (in grams). Risk = lifetime risk of cancer death for person engaging in one stripping job per year at this PID for 45 years.

priate parameters in the model. The way in which this can be done is seen most easily through an example. Figure 5A considers the case of Subject 10, who reported stripping window woodwork in a 8′ × 13′ × 9.5′ kitchen with open windows and doors, using 1 quart of stripper in 3+ hours, with no outside breaks. Holding the amount of stripper and working time constant, Figure 5A considers the effects on PID of three alternative measures for reducing exposure: taking breaks, using a fan, and changing the workspace to a two-car garage. Taking breaks reduces cumulative exposure by nearly half, while the new workspace or exhaust fan reduces it by almost one order of magnitude (the latter two are indiscriminable in the figure).

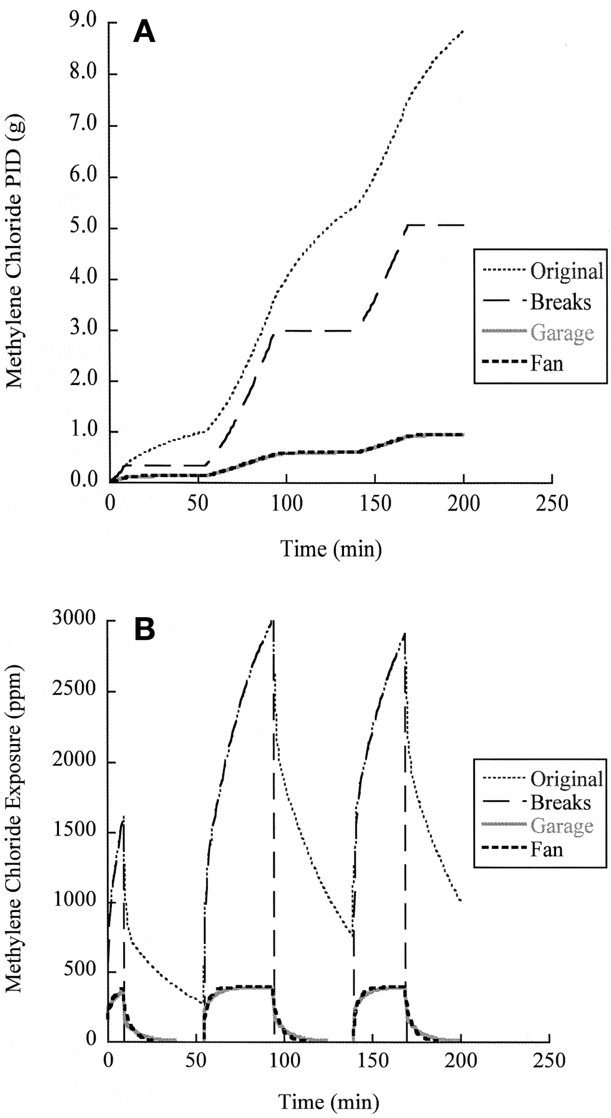

Fig. 5. (A) Cumulative exposure reduction options for Subject 10. (B) Short-term exposure reduction options for Subject 10. PID = potential inhalation dose.

Figure 5B shows the corresponding acute exposure patterns. Again, using a fan in the open kitchen and moving to a large open garage (with no fan) have similar, large effects, throughout the job. Taking breaks maintains the same high peak exposures, but they drop periodically to zero. For acute exposures, it is, of course, the peaks that matter.

Thus, there are significant opportunities for both peak and cumulative exposure reduction, by using either the garage or fan strategy. However, breaks are only marginally effective for cumulative exposure reduction. A combined strategy, such as moving the job to a garage with an exhaust fan, would further reduce exposure. An individual who compared these residual risks with absolute standards, however, might decide that the fan or garage was enough. The advice would then be to pick the one that involved the least effort—and not to waste too much time taking breaks.

4.3. Imperfect Compliance

The analyses in Fig. 5 assume that each mitigation action has 100% compliance. Realistically, though, users may be unwilling or unable to execute a course of action.[22] For example, partial compliance with opening windows can affect the fraction of windows opened (only one open window [or door] would fail to create a cross-current), the size of the window opening, or the percentage of work sessions, during which any one was opened. Partial compliance with breaks can mean that users stop less often than intended or they get distracted and fail to leave the room on their breaks.

"Costs" can also reduce compliance. For example, wearing gloves, goggles, or long sleeves can be uncomfortable, especially in warm weather. In cold weather, ventilation (or working outdoors) can also create discomfort or incur additional heating costs. As a trade-off, some interview subjects reported stripping paint only in the summertime; others reported such practices as ventilating with open doors and windows in warm weather, but working with a respirator in a closed basement in cold weather.

The model allows for quantitative analysis of the effect of partial compliance on exposure. As examples, scenarios were developed for two room types, with air-exchange rates representing ventilation for rooms that were closed, open, or open with an exhaust fan. (These air-exchange rates were chosen based on values in Hodgson and Girman,[18] Consumer Product Safety Commission,[19] and Environ-

Table III. Assumed Air-Exchange Rates for Partial and Full Compliance

	Partial compliance	Full compliance
Small workroom		
Closed	0.13 ACH	0.13 ACH
Open	1.0 ACH	1.6 ACH
Open + fan	9.0 ACH	18.7 ACH
Basement		
Closed	1.6 ACH	1.6 ACH
Open + fan	3.0 ACH	4.7 ACH
Fan	6.0 ACH	11.0 ACH

Note: ACH = air changes per hour.

mental Protection Agency.[23]) Partial compliance was assumed to be half as effective as full compliance (Table III), and break time was reduced by half.

Figure 6 shows the results of this analysis, in the form of a "marginal-risk reduction curve," which is a graphical representation of the "best buys" in exposure reduction, for the small workroom example. It shows the marginal benefit for each step in reducing exposure (as well as their combinations). The gray lines show full compliance, while the black lines show partial compliance. Thus, for example, in this small room, full compliance with opening windows and taking breaks is equally effective. However, partially opening windows is much better than partially taking breaks. Full breaks add something to opening windows, while partial breaks do not. Adding a fan makes a big difference, even with partially opened windows. Thus, if (small-room) consumers cannot realistically be expected to take breaks diligently, that strategy should not be emphasized. Rather, instructions should stress ventilation, where imperfect efforts can make a big difference.

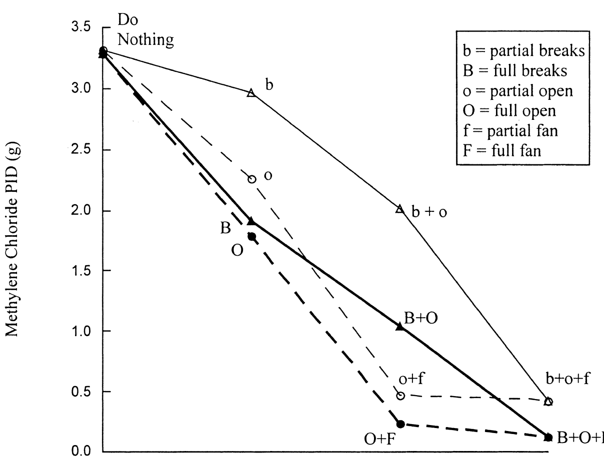

Fig. 6. Best buys in risk reduction: Marginal risk-reduction curves for cumulative exposure in a small workroom. Each curve shows the stepwise benefit of successive precautionary actions, for fully or partially compliant users. PID = potential inhalation dose.

The extent of compliance turns out to matter less for peak exposure (not shown), with opening windows being the clearly favored strategy from that perspective as well. In the basement case (also not shown), the exposures are much lower, even with windows closed, because the room has a much larger natural ventilation rate. Thus, while opening windows is still the best option, it achieves less in that work area.

As this model shows, opening windows creates cross-ventilation. In the case of paint stripper, estimating the effect of opening only one window would require a model considering the temperature gradient, among other factors. Depending on the specific conditions, methylene chloride might drift into other rooms or blow out the window, bringing air from other rooms into the work area. The latter outcome is desired, and the former is not, insofar as it could create exposure in other parts of the house.

5. EVALUATING RISK INFORMATION ON LABELS

After determining which risk mitigation strategies are most effective, one can prioritize information based on what consumers already know and do (e.g., if they already practice the most effective strategy, one can emphasize the second most effective one, while briefly reinforcing what they are currently doing). The interview participants reported a variety of beliefs and practices. However, none was sufficiently frequent to assume that it was common knowledge. Thus, for a population of consumers that is similar in nature to the study population, it seems appropriate to assume no prior knowledge about product safety. If so, then message priority is determined simply by working down the marginal risk-reduction curve. That is, consumers should first be told about the measure that would most reduce exposure, then about the second most-effective measure, and so on. If compliance level affects priorities, some assumptions are needed regarding what to expect. In the example given in Fig. 5, the order was (windows, fans, breaks) with either full or partial compliance. However, that may not always be the case.

Consumer response to warning labels is a complex process.[24,25] Consumers must decide which parts of a label to read, then how extensively to read them. This section discusses the effectiveness of labels' content, assuming that consumers have chosen to read them. Specifically, combinations of four different reading approaches and three different room types

Table IV. Location and Ventilation Strategies for Reading Scenarios

Product label	Label = reading scenario			
	1 (first five statements)	2 (bold only)	3 (directions)	4 (entire label)
A	Closed basement (0.5 ACH)	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)	Open garage with breaks (10.6 ACH)
B	Open workroom (3.0 ACH)	Partially open basement (0.75 ACH)	Open basement (1.0 ACH)	Open workroom (3.0 ACH)
C	Closed basement (0.5 ACH)	Closed basement (0.5 ACH)	Closed basement (0.5 ACH)	Closed basement (0.5 ACH)
D	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)	Open workroom (3.0 ACH)
E	Closed basement (0.5 ACH)	Partially open basement (0.75 ACH)	Closed basement (0.5 ACH)	Open workroom (3.0 ACH)
F	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)	Partially open basement (0.75 ACH)

Note: ACH = air changes per hour.

were considered, as summarized in Table IV. For each reading approach, it was assumed that users had no prior knowledge but retained and complied with all information that they read. It was further assumed that if the information was complete, then compliance would be also; and if information was incomplete, partial compliance would result. In Scenario 1, the user read the first five statements on the label. In Scenario 2, the user read only the bold-printed items. In Scenario 3, the user read only the directions for product use. Scenario 4 assumed that the user read (and complied with) all information found on the entire label.

The justification for these particular scenarios is as follows: Studies have found that consumers are most likely to read the first few sentences at the top of the back panel (Scenario 1),[26] or in the directions section (Scenario 3).[28] Bolded words add emphasis and draw readers' attention (Scenario 2).[28] Explicitness and understandability increase the likelihood of compliance with instructions.[24,27] Because manufacturers tend to treat safety information similarly on all their products, these scenarios were examined for just one product from each manufacturer, labeled A through F. Tables V, VI, and VII document the specific information found on each product label.

The three room types were: (1) A worst-case basement, small and tight (base air-exchange rate of 0.5 air changes per hour [ACH]) with only one small window, which limited the potential for increasing ventilation. The air-exchange rate increased to just 1.0 ACH when

Table V. Location of Mention of Health Effects on Labels of Strippers Containing Methylene Chloride

Product[a]	Skin/eye	Cancer	Headache	Phosgene	Cap	Linoleum	Fire	CO	Heart
A 1	Front & back	Back	Back	Back	Back	Side	Front & back		
A 2	Front & back	Back	Back	Back	Back	Side	N/A		
A 3	Front & back	Back	Back	Back	Back	Side	N/A		
A 4	Front & back	Back	Back	Back	N/A	Side	N/A		
A 5	Front & back	Back	Back	Back	N/A		Front & back		
B 1	Front	Back	Back	Back	Back	Side	Front & back		
B 2	Front	Back	Back	Back	Back	Side	N/A		
B 3	Front	Back	Back	Back	Back	Side	N/A		
B 4	Front	Back	Back	Back	Back	Side	Front & back		
C 1	Front	Side	Side		Side	Back	Front		Side
C 2	Front	Side	Side		Side	Back	Front		Side
D 1	Back	Back	Back	Back	N/A		Back	Back	
E 1	Front & back	Back	Back	Back			Back	Back	
F 1	Front	Back			Back		Back		

Note: Health effects are skin/eye irritation, cancer, headache, phosgene poisoning, injury from over-pressurized cap, damage to linoleum, fire, carbon monoxide poisoning, and heart attack.
[a] A through F represent six manufacturers.

Table VI. Precautions Mentioned on Methylene Chloride Paint-Stripper Labels (on Back Panel Except Where "Side" Indicated)

Product[a]	Wear gloves	Ventilate (explicit)	Indoor location advice	Work outside	Wear goggles	Cover skin	Avoid flames	Dust mask not protective	Take breaks
A 1	Side	•	•••	•	•	Avoid	•	•	
A 2	Side	•	•••	•	•	Avoid		•	•
A 3	Side	•	•••	•	•	Avoid		•	•
A 4	•	•	•••	•	•	Avoid		•	
A 5	•	•	•••	•	•	Avoid	•	•	
B 1	•	•	••	•	•	•	•		
B 2	•	•	••	•	•	•	Phos		
B 3	•	•	••	•	•	•	Phos		
B 4	•	•	••	•	•	•	•		
C 1	Side	Side	(•)	(Side)	•		Side		
C 2	Side	Side	(•)	(Side)	•	•	Side		
D 1		•	••	(•)			•	•	
E 1	Side	•	••	•	•	Avoid	•	•	
F 1	•		•	•		•	•		

Note: • = well-ventilated area, •• = avoid basements and other enclosed areas, ••• = avoid basements, bathrooms or small enclosed areas. ( ) = contradictory messages (e.g., "good for interior use" with "work outside"). Avoid = instruction to avoid skin contact as opposed to positive recommendation to cover skin.
[a] A through F represent six manufacturers.

the window was open. (2) A small workroom, the same size as the basement and similarly tight (0.5 ACH), but with more windows. Its air-exchange rate increased to 3.0 ACH when doors and windows were open. (3) A large garage that was leaky to begin with (2.1 ACH), and had great potential for increased ventilation when the garage door and windows were open (10.6 ACH). The room evaluated for each label and reading scenario reflects a preliminary screening of the label content. Room 1 is used in the model when an individual pursuing that reading scenario would encounter no room-choice information; Room 2, when the reader would encounter a warning against basements, but not against small enclosed areas, and Room 3, when such a reader would see (and follow) advice for an airy space. None of the six manufacturers' labels recommended using an exhaust fan to increase ventilation; as a result, no scenario with a fan was included.

Table VIII shows peak exposures for the different paint strippers (A–F) for each scenario (1–4), as an indicator for acute health effects resulting from

Table VII. Incidence of Precautionary Information Placed in Directions for Use

Product[a]	Wear goggles	Wear gloves	Ventilate (vague)	Cover skin	Work outside	Cap pressure	Take breaks	Avoid flame	Eye irritant
A 1	•	•						•	
A 2	•	•					•		
A 3	•	•					•		
A 4	•	•							
A 5	•	•							
B 1	•	•	•	•	•	•			
B 2	•	•	•	•	•	•			
B 3	•	•	•	•	•	•			
B 4	•	•	•	•	•	•			
C 1	•								
C 2	•	•		•					
D 1			•						
E 1	•	•							
F 1		•	•	•	•				•

[a] A through F represent six manufacturers.

Table VIII. Predicted Peak Methylene Chloride Levels (ppm, Short-Term Exposure) for Six Paint-Stripper Product Labels, and Four Reading Scenarios

	Label-reading scenario			
Product label	1 (First five)	2 (Bold only)	3 (Directions)	4 (Entire label)
A	1,860	1,600	1,600	270
B	710	1,600	1,400	710
C	1,860	1,860	1,860	1,860
D	1,600	1,600	1,600	710
E	1,860	1,600	1,860	710
F	1,600	1,600	1,600	1,600

short-term exposure. As can be seen, those who read just the bold information or just the usage directions faced high peak exposures, well above those associated with acute health effects. Except for label B, the same would be true for those reading the first five label items. Label B gave prominence to specific and explicit ventilation instructions (e.g., the product should be used outdoors when possible, or with open windows and moving fresh air across the work area). However, readers who read the entire label would not learn anything else of value in reducing exposures. Those who read all of labels D and E would reach equivalent protection, while those who read all of label A would achieve an even higher level of protection. Labels C and F contained no useful information regarding reducing exposures.

Figures 7A–D show the cumulative exposure for each reading strategy, measured as PID. Qualitatively, the results parallel those for peak exposure, although the magnitude of the effects requires explicit modeling. Figure 7A shows that B's label brought greater exposure reduction to readers of the first five statements because more critical information was placed at the top. Figures 7B and 7C show small differences in exposure for readers who read emphasized text or directions only. This is because these brand labels used bold text (Fig. 7B) primarily for section headings, and because their directions (Fig. 7C) lacked explicit precautionary instructions. For readers who naturally follow these reading strategies, effective, explicit instructions for exposure reduction would have to be boldfaced and included in product-use directions. Figure 7D shows label A's form of superiority; it contained the most information for people who read and processed the entire label. B, D, and E all have good information, but the information presented on labels D and E was not placed optimally for less-thorough readers, as shown in Figures 7A and 7C.

These analyses could be repeated with different assumptions, including prior knowledge of consumers. For example, all of the labels would have elicited high compliance rates, had it been assumed that basic information about work location did not need to be specified. However, the interviews showed that this was not the case for a significant portion of consumers.

6. RECOMMENDATIONS AND CONCLUSIONS

The research presented here demonstrates an integrated approach for assessing consumer exposure to household chemicals, combining users' behavior with chemical fate-and-transport information. The approach can be used to characterize individual exposures, assess the relative effectiveness of existing risk-mitigation strategies (e.g., labels), and design better interventions. The approach is flexible enough to consider alternative behavior patterns and different levels of compliance with risk-reduction strategies.

This approach represents the first known attempt to assess label effectiveness by predicting associated exposure outcomes. It would be possible to extend the approach to include factors such as prior knowledge and experience, attitude toward risks, and costs of compliance. Converting these results to population estimates (and aggregate impacts of interventions) would require more systematic sampling of consumers, in order to estimate the prevalence of various beliefs, behaviors, and attitudes. If this study's sample was any indication, there are not many important messages regarding exposure risk that most users know well enough to assume that they will take the associated precautions.

This formal model focused on inhalation. It showed the critical importance of providing clear messages about ventilation, especially with regard to the choice of workspace, the opening of windows, and the positioning of fans. Overall, it appears that consumers understand the importance of ventilation, but not necessarily how best to achieve it. Given consumers' level of concern with health risks, simple messages about fans may find a receptive audience. Moreover, the modeling[11] presented here indicates that it could be one of the single most effective measures of reducing exposure risk. Given the flammability of some formulations of paint removers, this information would have to specify a nonsparking fan.

In the model, exposure depended strongly on the quantity of chemical being used. However, it was difficult to determine the appropriateness or accuracy of the amounts that were given by the inter-

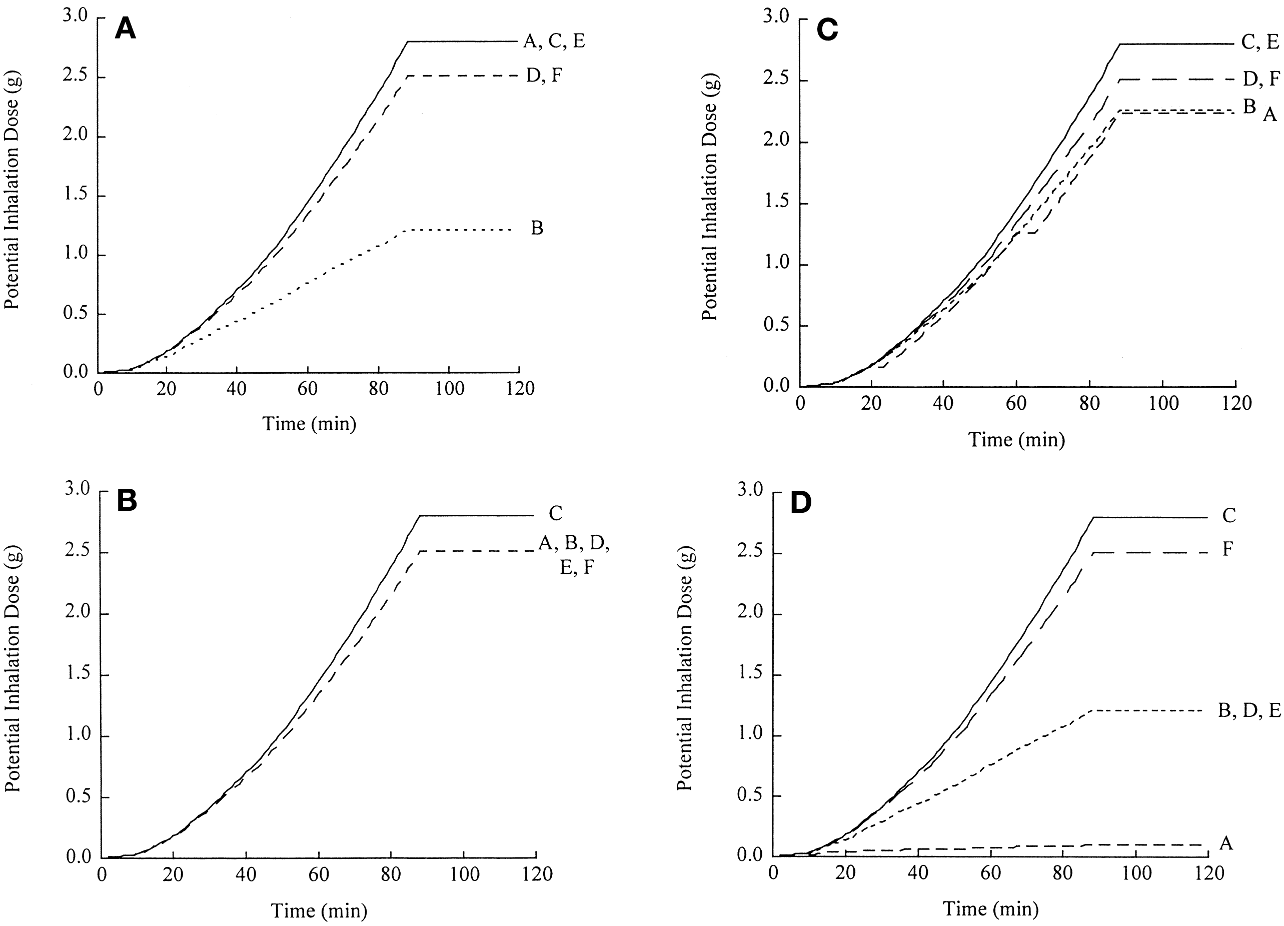

Fig. 7. (A) Cumulative exposure estimates for users reading first five statements on each product label, A–F (Scenario 1). (B) Cumulative exposure estimates for users reading emphasized text on each product label, A–F (Scenario 2). (C) Cumulative exposure estimates for users reading directions only on each product label, A–F (Scenario 3). (D) Cumulative exposure estimates for users reading each full product label, A–F (Scenario 4).

viewees. Excess usage implies unneeded exposure in a given session, as well as a waste of consumers' money (not to mention increased environmental burden, a topic beyond the present study, but subject to similar analyses). Insufficient or inefficient usage may mean extra sessions, unnecessary exposure, and added expense. Therefore, it would be useful to validate the existing label instructions relative to consumers' mental models of amount of product necessary to complete a particular job.

Another important message emerging from the interviews pertained to the use of goggles when working with specific products. The potential danger of not using goggles is easy enough to understand, once raised, and is bolstered by hospital admissions data showing a high rate of such accidents (R. Brown, personal communication, March 1996). Citing that rate as well as asking consumers to examine the splatter patterns on their own work clothing, may help get this message across. Goggles and gloves are usually recommended together on labels, but reported use of goggles is much lower than reported use of gloves, even though goggles are typically much more effective. Possible reasons include the fact that goggles are more expensive, less available, and less comfortable. At one of the home improvement centers where our label data were obtained, solvent-resistant gloves were available next to the paint strippers, but goggles were not. Packaging and sales strategies (emphasizing that goggles are suited for multiple uses, making them a much better investment than the gloves and breathing aids that most people buy) might encourage their use, even without explicit instruction.

Instructing consumers about the properties of different glove materials will be difficult. As a result, increasing the use of gloves may require engineering or marketing solutions. In order to match consumers, gloves, and tasks, strippers and appropriate gloves might be packaged together, while inappropriate gloves might be explicitly labeled "not suitable for paint stripping."

The information presented on the labels reviewed in this study varied considerably in terms of usefulness, for consumers making risk-management decisions regarding product use. Some manufacturers could enhance their labels by adding information; all could improve their effectiveness by arranging information more appropriately. These recommendations could be carried out in a manner consistent with the Consumer Product Safety Commission regulations for labeling under the Federal Hazardous Substances Act.[(29)]

6.1. Limitations of the Approach

This analysis assumed that consumers had come into contact with the information source and were deciding what to do with that information. Getting consumers to pay attention in the first place should depend on the perceived risk of the chemical and anticipated usefulness of the labels. Over time, improved label content should improve the accuracy of the former and the magnitude of the latter. Information regarding quantitative risk perceptions can be found in articles by Fischhoff,[(12)] Morgan, Fischhoff, Bostrom, Lave, and Atman[30] and Fischhoff, Riley, Kovacs, and Small.[(31)] Information on the effects of label design (e.g., lettering positioning, graphics) can be found in Wogalter and Cox[(32)] and Laughery, Vaubel, Young, Brelsford, and Rowe.[(24)]

It is recognized that individuals do not always accurately observe nor honestly report on their workspace conditions or behavior—just as they do not always behave naturally when someone is watching them. However, an open-ended interview approach, such as the one used in this study, should reduce normative expectations and provide better information than ad hoc assumptions regarding user label reading and product usage behavior.

With a heterogeneous consumer population, difficult trade-offs must be made in terms of whose needs are served. For example, with fixed space, addressing the needs of Spanish-speaking consumers means attending less to English-speaking consumers—or to illiterate consumers who might benefit from having space devoted to suitable icons. Similarly, using larger type for consumers who have reduced vision means providing less detail for those who can read smaller type. The impacts of these choices, too, could be modeled. Doing so would improve empirical estimates of the prevalence of different information-processing patterns and prior knowledge.

6.2. Future Work

The mental models interviews provided data for modeling low-, middle-, and high-exposure individuals. Characterizing the risks faced by consumers nationally would require an estimate of how many users fit into each exposure pattern (e.g., the percentage of users who work in drafty garages). Such estimates are needed to determine the risks of current use and the opportunities for risk reduction through consumer education. If consumers cannot realistically be guided to follow usage patterns that meet target risk levels, then other, nonvoluntary methods of risk reduction will be needed.

If labeling can be effective for methylene chloride paint strippers, then the next step is to determine how this integrated approach can be applied to the thousands of chemical consumer products on the market. In principle, this analysis would need to be repeated for each chemical and usage pattern. In practice, however, the indoor air-quality model developed here could be readily adopted to accommodate many usage patterns, exposures, and toxicities. As more products are modeled, it will become easier to tailor the approach for new products. Similarly, mental-models interviews are likely to discover recurrent belief patterns for classes of products. If that is indeed the case, then those beliefs would have similar characteristics and risks. It may be that lay users have one or just a few general mental models associated with chemical household products that can inform analyses of many products. Thus, with suitable adjustments, this approach could be applied to a variety of consumer, occupational, and environmental health problems. As such, it could help to identify the most cost-effective risk-mitigation strategies, as well as how effective the best communication-based strategies are in managing risks.

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