Most important, the operators are responsible for the process on a day-to-day, even a minute-by-minute, basis. Simply because they are not there to observe it, the line supervisors may not have full knowledge or recollection of exactly how frequently a spill, a malfunction, an off-specification product, or other events occur that can lead to high exposures. Operators usually have an accurate perspective on the frequency of such events.

Of course, such perspectives can be tainted by any operator bias. An operator who does not like the job and thinks it is dirty or may be harming his or her health (regardless of the truth) may be biased to think that spills occur much more often than they do. On the other hand, a supervisor who thinks that work is available to those who wish to get paid, and that people should not complain about their jobs, may believe that spills are very infrequent, and that those that do occur are of no important consequence when, in fact, this is far from the truth. The hygienist must sort out the various perspectives. The hygienist must be a communicator, and communication requires not only getting your point across, but adequately interpreting the points made by others.

Questions to Ask

When the various workplace personnel are being interviewed, the hygienist should anticipate the kinds of questions that must be asked to obtain needed information. It is best to make a list of the questions prior to interviewing the personnel. Some questions will be asked repeatedly of line management, staff management, and workers, as well as safety and health professionals; other questions will be more specific to a particular group of personnel. What follows is a partial listing of the kinds of questions that one should ask. It is not meant to be an exhaustive list, but a review of it should remind anyone conducting a walkthrough survey for a particular situation that there are other relevant questions.

1. What is the status of current production rates? Are they normal? Are changes expected in the near future or have changes occurred recently?

2. Is the process currently operating as it normally does? Have modifications been made recently or are they planned in the future? Are the current raw materials the same as have always been used? When were recent changes made? Are the temperature, pressure, and other critical operation parameters at normal status?

3. Are the number of workers associated with the particular process at normal levels? Is anyone absent? Are there unusual rates of absenteeism for the particular process?

4. Does the process operate similarly on all shifts? Are maintenance or other activities carried out on one particular shift? Are all shifts fully staffed?

5. What is the maintenance schedule for the equipment? How is maintenance performed?

6.   How are special procedures carried out? How is sweeping performed? How is spill response conducted?

Using the Senses

Most of us are endowed with the ability to taste, smell, see, hear, and touch. Although it seems like a relatively simple and straightforward idea that one should use these senses when conducting a walkthrough survey, it is amazing how often something will be overlooked in a plant because the senses did not detect it. Efficient use of the senses often comes only with experience. However, even the most inexperienced hygienists will conduct a more thorough walkthrough survey if they concentrate particularly hard on using the various senses at each juncture in the survey. Such a focus is particularly important because it is easy for one of the senses to be so overwhelmed that the others are not used. For example, in an industrial situation where noise is particularly high, the hygienist may be so overwhelmed with the noise that the other senses do not detect a particular odor in the area, or the hygienist does not see a particular work practice that could lead to a significant exposure or an improperly operating ventilation system. Therefore, it is important that the hygienist be cognizant of the ability of strong stimuli to overwhelm a particular sense at the expense of others. Take your time and allow all of the senses to survey the situation.

ODOR THRESHOLDS

Although sight and hearing certainly are two of the more important senses to use in the workplace, the hygienist has historically relied upon the combined senses of taste and smell. These two senses are closely related, as they can both be stimulated by airborne molecules. In 1958, Patty went so far as to recommend that hygienists be able to detect the odors of the major industrial gases and vapors, and even to be able to estimate their concentrations by odor. It is possible to do this; some persons are trained to recognize odors and their concentrations. However, even the senses of trained persons are subject to the day-to-day variability caused by environmental fluctuations (temperature, humidity, etc.), and changes in the person's biology. For example, a simple cold or allergic reaction can completely change one's ability to detect a particular odor.

Historically, the detection of odors was relied on fairly heavily to estimate workplace concentrations of gases and vapors. Fifty years ago, instrumentation for such purposes was either nonexistent, inaccurate, or cumbersome. Though instrumentation has vastly improved, odor detection continues to be used as a means of recognition (identification) and even evaluation (quantitation) of gases and vapors.

Quantitating gas/vapor concentrations by using odor detection relies mainly on the concept of odor threshold. If the odor of a chemical can be detected only at concentrations above 100 ppm, then if the exposure limit is 500 ppm and the odor cannot be detected in the work-

place, the concentration that exists must be below the odor threshold and thus acceptable. Unfortunately, this inexact concept is the concept of odor threshold that too many occupational health professionals still use. Because of individual variability, in reality there is no single concentration for a given chemical that can be said to be the odor threshold for a population of individuals. The same is true for an individual. What may be a person's odor threshold today will change tomorrow due to weather, biological variables, and changes in the setting in which the odor exists.

These points can be illustrated by odor threshold data, which were reviewed by a committee of AIHA (AIHA, 1989). The first part of the review consisted of screening those studies that met certain criteria. A portion of those acceptable studies was then used to determine a geometric mean air odor threshold. However, there are actually two odor thresholds that can be estimated, one based on detection of the odor and the other based on recognition of the odor as a specific chemical. Usually the detection threshold is lower than the recognition threshold.

Table 13-1 shows some examples of data from the AIHA publication. No attempt was made to select data that had particularly wide ranges. Nevertheless, it can be seen that the median (geometric mean) odor thresholds are difficult to pinpoint. Furthermore, it is important to point out that the ranges (last column) do not represent absolute maxima or minima for individuals. Rather they are ranges of medians taken from different test panels. Hence, the odor thresholds of some individuals can be expected to be above or below the *range of acceptable values* and even outside the *range of all referenced values*. The *geometric mean air odor threshold* is essentially a median of medians, so about 50% of persons will have odor thresholds greater than or less than this value. Furthermore, if the distribution of odor thresholds is skewed right, as is most likely, the 95th percentile will be farther from the median than the 5th percentile (see Chapter 7 for discussion of lognormal distribution).

The reliance on odor detection as a tool in walkthrough surveys is largely a choice of the individual hygienist. Several uses of odor thresholds are appropriate, and others are not so appropriate in light of Table 13-1. They can be classed as qualitative (i.e., what chemical is present) and quantitative (i.e., what concentration exists).

With respect to qualitative uses, some might argue that if the background survey is conducted properly, one will know about all of the materials in the workplace and not have to rely on odor to detect what is there. However, compounds are frequently found in the workplace that may not come to light in a background survey. For example, the material safety data sheet for a compound may be unavailable or inadequate to properly identify the compound. Finally, one may need to identify by-products or reactants as a result of an unusual episode or a previously undocumented process. Any of the above scenarios might be at least partially solved with odor detection.

Quantitatively, odors and odor thresholds may be used to help plan an in-depth survey, recommend controls, or declare a workplace in compliance with a PEL. The use of odors and odor thresholds to help plan an in-depth survey is generally appropriate, but the latter two uses could be a bit risky. However, any of the above are best accomplished if the hygienist deter-

Table 13-1
Representative critiqued odor threshold (thld) values[a]

Name	TLV®-1992 (ppm)	Geometric Mean Odor Thld[b] (ppm)	Type of Thld[c]	Odor Character	Range of Acceptable Values[d] (ppm)	Range of All Referenced Values (ppm)
Acetone	TWA = 750 STEL = 1000	62 130	d r	sweet fruity	3.6–653 33–699	0.40–800
Aniline	TWA = 2	2.4	d	pungent oily	0.58–10	0.012–10
Benzene	TWA = 0.1	61 97	d r	aromatic sweet	34–119	0.78–160
1,3-Butadiene	TWA = 10	0.45 1.1	d r	aromatic rubber	* *	0.099–76
Isoamyl Acetate	TWA = 100 STEL = 125	0.22	d	banana	0.0034–209	0.00075–209
Dichloropropane	TWA = 75 STEL = 110	0.26 0.52	d r	sweet	* *	0.26–0.52
Trichloroethylene	TWA = 50 STEL = 200	82 110	d r	ether solvent	* *	0.5–167

[a]　Taken from AIHA (1989).
[b]　Geometric mean based on AIHA critiqued work of Gemert and Nettenbraiter (1977).
[c]　Detection threshold indicated by d; recognition threshold indicated by r.
[d]　* indicates only a single accepted value, shown in column three.

mines his or her own odor threshold, something rarely done now. Even so, the hygienist should realize that the actual concentration at which he or she first detects an odor will vary from day to day and from place to place.

Odors can help in the planning of the in-depth or quantitative survey. In order to calibrate equipment for this survey, it is often necessary to first estimate the concentration that will be measured. The nature of the use of the chemical, its physical properties such as vapor pressure and odor information from the walkthrough survey, will help in this process.

The other quantitative uses of odors and odor thresholds relate to deciding to use controls – emergency controls or long-term controls – or that there is no need for controls (an in-compliance workplace). By examining the data in Table 13-1, examples for each of these decisions can be found.

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1. Workplace in compliance. In the case of dichloropropane, the ACGIH® TLV® is 75 ppm, the range of all referenced odor threshold values is 0.26 to 0.52. (These data came from only one study.) If this study is reliable, then the workplace is very likely to be in compliance with the TLV® if no chemical odor can be detected. However, the data for acetone represent what is more often the norm, that is, the TLV® is within or close to the range of all referenced values. When using this approach, the hygienist should be confident of at least two pieces of information: the adequacy of the TLV® and that the workplace conditions were average or normal on the day of observation (odor detection).

2. Need for emergency respirator. The data in Table 13-1 for benzene indicate an emergency or out-of-control situation if an odor can be detected. In this case, if the process producing the benzene odor is frequent or continuous, and benzene can be smelled, then an average concentration greatly exceeding 0.1 ppm is likely.

3. Need for long-term controls. In this example, if one were certain that the long-term average concentration of benzene was greater than 0.1 ppm, then emergency use of respirators would be appropriate; but, in addition, plans for reducing the concentration by using engineering controls should be prepared. Odor thresholds do not provide the degree of certainty necessary for a large expenditure. Instead, while respirators are being used, an in-depth survey should be completed to ascertain, more certainly, the workplace concentrations. In essence, odor should not be used for recommending long-term controls unless abatement of an unpleasant, but not necessarily hazardous, odor is warranted.

The use of odors and odor thresholds requires a few more words of caution. The ability to detect an odor and to gauge its concentration at levels above the odor threshold, if reliably determined by the hygienist, represents only a snapshot of the concentration that exists at that particular time. For this reason, a decision not to conduct an in-depth survey for a particular compound simply because the hygienist cannot smell an odor is not, by itself, justifiable. The propensity of a compound to enter the air as a result of its physical properties and how it is used in the process should also be considered.

The sense of smell is easily fatigued if it is continuously stimulated or overstimulated. It is well known, for example, that hydrogen sulfide has a rotten-egg odor and that, at low concentrations, it can be smelled relatively easily. However, as concentrations increase, the sense of smell becomes overstimulated, and the brain blocks the stimulus, thereby causing the person to think that there is no longer any hydrogen sulfide. Similarly, workers who work day after day with a particular compound suffer odor fatigue as a result of their continuous exposure. Exposures from the day before can cause a two- to threefold increase in odor thresholds the next day (Ahlstrom et al., 1986). Therefore, the odor thresholds can be considerably higher than those of a population that has not been continuously stimulated by the chemical.

Finally, when the AIHA publication was prepared (1989), odor thresholds could be des-

ignated according to the AIHA criteria for only 110 compounds. Although other publications may contain odor threshold lists, at present only this limited AIHA listing can be used reliably. Other lists often report only a single value, and Table 13-1 shows that single values are very misleading representations of odor thresholds.

Looking for the Unexpected

In order to expand the space and time framework associated with a particular walk-through survey, the hygienist must be particularly alert. With respect to expanding the time framework, the hygienist must ask questions about future and past operations in order to determine how they compare to current status. With respect to the space framework, the hygienist will see what he or she is taken to see, or what he or she asks to see. Consequently, what one asks to see is extremely important, since very often workplace personnel will not take the hygienist to particular areas, either because they simply forget, or because they do not think that those areas are particularly important. In some cases, there may even be an attempt to hide certain areas from the hygienist. The hygienist should be particularly keen to ask questions about intermittent and discontinuous operations that may not be occurring during the walk-through. Maintenance is one of the most common and important operations. In some large plants (particularly in the petrochemical and metals industries) a full-scale maintenance operation requiring days to weeks (a *turn-around*) will take place approximately yearly. Exposures (at least to benzene) are often highest at these times (OSHA, 1987). Other maintenance activities are more frequent but also more subtle. A good example is the replacement of empty gas cylinders that may have once contained chlorine or ethylene oxide. Very specific procedures are commonly needed regarding the closing of valves and the removal of hoses if high exposures are to be avoided.

In some processes, the hygienist must be aware of pre-treatment and batch activities. For example, a particular operation that occurs in the beginning of a process may be performed repeatedly over a period of time until a certain amount of raw material has been stockpiled. The stockpile is then used for weeks until it is almost depleted, at which time the repeated batch process takes place again. Consequently, upon observing the process, the hygienist may assume that the raw material is prepared somewhere else. This assumption should not be made.

On the opposite end of the process, the hygienist should be particularly concerned about the disposal of unwanted by-products. Particularly, the hygienist should be aware that all control efforts typically lead to the accumulation of contaminants for disposal. For example, ventilation systems used for control of aerosols will accumulate aerosols within the ductwork, in settling bins, or in other types of air cleaners, such as filtration units. Someone must maintain these units and consequently encounter the accumulated contaminants. Solid and liquid contaminants may be disposed of on-site (although, at least in the U.S. and Europe, this is uncommon today) or may be accumulated on-site and then shipped off to another site. Particular workers are often associated with the waste operations. The hygienist should be aware of regulations regarding hazardous waste and should inquire particularly about workers who may

have to handle hazardous waste at the work site.

Laboratory facilities are also often overlooked. Most industrial plants have quality control laboratories, each with its own set of hazards, that the hygienist must examine. In addition, many industrial plants have small-scale versions of processes or proposed processes. These pilot plants are often laboratory-scale. Very often adequate measures for controlling exposures are not taken; pilot plants are often permanent, but operations change frequently, and therefore, expenditures for a control that may be needed only for a few weeks may be limited.

Warehouses for storing both raw and end products can be important sources of exposure, particularly if spill procedures are not adequate, or if the product *cures* or *off gases* during storage. In addition, many warehouses utilize forklifts or other motorized conveyances that can cause contamination of the air with carbon monoxide or other important contaminants. Battery-operated forklifts are not without their problems, as the batteries must be recharged, and the charging rooms can be hazardous if evolving gases (e.g., H_2) are not controlled.

The hygienist should seek out unusual places. In essence, anywhere that human beings go, the hygienist should also go or at least take a peek. Furthermore, even places where workers do not commonly go, but that nevertheless are places that may be associated with the overall *health* of the workplace, should be examined. For example, for many buildings the roof is not a place where workers commonly go. However, the roof is often the point at which ventilation systems exit the building, and where *fresh* air is taken into the building. Therefore, the possibility exists that contaminants being exhausted from the building can be reentrained in the building. The hygienist can only determine this by going onto the roof and examining the ventilation systems. The hygienist should also enter basement and attic areas and, if it is appropriate, look inside tanks or other confined spaces where workers may enter. It may not be necessary that the hygienist do exactly what the workers do, but the hygienist should at least see all areas where workers enter in order to spot any potential hazards that he or she could not otherwise find. To simply ask workers or other personnel what the inside of something looks like or what is on the roof is not good enough, as these personnel are not trained hygienists and consequently may not know what is important.

SETTING PRIORITIES FOR IN-DEPTH SURVEYS

The ultimate decision to be made from the hygiene survey process is whether controls are adequate for each of the hazards found in the workplace. After the walkthrough survey, it may be obvious to the hygienist that controls are not adequate for certain disease agents, and therefore, no further evaluation is necessary before certain control procedures are put into place. Simple control procedures such as retraining of workers and enforcement of or changes in standard operating procedures can be initiated at minimum expense. However, for some contaminants, further evaluation must take place in order to determine whether more controls are necessary. Further evaluation usually requires the use of instrumentation to quantitate the concentrations of airborne contaminants. Even when controls seem to be in order, and exposures

appear to be acceptable, documentation of airborne concentrations is often necessary for future reference and legal considerations.

With respect to those contaminants that may need further evaluation, and where resources are limited (often the case), the hygienist must set priorities for the contaminants that are to be considered in the in-depth survey. For the plant hygienist, often the most important contaminants are surveyed first, and those thought to be of less importance are surveyed as time and resources permit. But how can priorities for the in-depth survey be set? What factors should one consider in determining how to select potential hazards for the in-depth survey? The hygienist must perform a qualitative risk evaluation. Those compounds of higher perceived hazard should be surveyed first. The difficult part is to determine how to assess qualitative risk and what factors should be considered in qualitative risk formulation.

Setting Priorities with Qualitative Risk Evaluation

Risk is the product of hazard and exposure. Hazard for airborne contaminants is essentially toxicity. A qualitative risk assessment involves estimating risk based upon qualitative estimates of hazard and exposure. The qualitative risks are then used to set priorities for quantitative assessment. A wide range of qualitative risk evaluation techniques have been formulated, largely for determining acute or safety hazards in workplace settings (see, e.g., Gressel and Gideon, 1991). By acute hazards we mean explosion, fire, etc. These techniques range from simple to complex, with the degree of complexity having a direct correlation with the difficulty of obtaining the data needed for the qualitative risk evaluation. Although these qualitative risk evaluation techniques do not have direct application to qualitative risk evaluation for exposure to chemical contaminants, they can be adapted to it, and a review of the techniques may be appropriate before one enters into a complex priority-setting procedure. However, for more simple priority-setting procedures, as might take place after a walkthrough survey, a procedure that considers the most important aspects of chemical risk is appropriate.

For a consulting or regulatory hygienist, the priority-setting process may often be cognitive only. However, a written description of the rationale for including or eliminating certain contaminants from the in-depth evaluation is warranted. If nothing else, ethical and future legal considerations make this a good practice. Obviously the contaminants for which there is the greatest risk should receive attention; however, what is the compound with the most health risk in a workplace setting? Is it the compound having the greatest toxicity? Is it the compound to which the greatest number of people are exposed? Is it the compound used with the greatest frequency? Or in the greatest tonnage? Is it the compound with the greatest vapor pressure? There are a number of factors that can be considered in the setting of priorities. Frequently, the three most important factors are the toxicity of the compound, its propensity to enter the workplace air, and the number of workers who are exposed to it. The latter two are exposure variables. Time of use is also a consideration, and if such data are gathered during a careful walkthrough, this can be considered in the priority setting.

TOXICITY

The toxicity of a compound can be roughly indexed with available exposure limits. In other words, for priority-setting purposes, a compound with an OEL of 400 ppm may be thought to be twice as toxic as a compound with an exposure limit of 800 ppm. TLVs® and other exposure limits can be used for such purposes if one realizes (1) the limitations of those exposure limits and (2) the limitations of the comparison process. The *TLV® and BEIs®* Book states that TLVs® are not a *relative index of toxicity*. Since further details are not given to explain this statement, we must try to interpret logically what constraints it places on the use of TLVs® in priority setting.

Regarding point (1) above, the risk of disease associated with exposure to two compounds at their respective TLV® concentrations, although not stated, should be presumed different. In theory, this should not be true (the acceptable risk level, such as 1 in 1,000, should be about constant), but in fact residual risk levels are not likely the same for two chemicals at their respective TLVs® (per discussion in Chapter 10). The risk is not stated in the TLV® *Documentation*; therefore, relative risk is probably not reflected in a ratio of two TLVs®.

Relative to point (2) above, the toxicities of acute and chronic toxins should not be compared. Comparisons should be made only for compounds having similar target organs or compounds from the same family (e.g., halogenated aliphatic hydrocarbons). Also, if two compounds do in fact have the same stated relative risks of 1 in 100 for a specific neurological disorder at TLVs® of 1 and 10 ppm, respectively, then we might say that the two compounds have a tenfold difference in neurological toxicity. However, one or both of the compounds may have effects on other organ systems, e.g., the reproductive system. It is likely that the relative risks of reproductive effects at the respective TLVs® would not be 1 in 100, nor would the reproductive risks for the two compounds likely be equal.

The Threshold Limit Values for Chemical Substances (TLV®-CS) Committee defines the TLV® for each compound to be that level of exposure which will protect *nearly all workers*. One would expect that for two compounds having similar effects (e.g., nephritis), their TLVs® would be good approximate indices of toxicity, i.e., the word *nearly* would have the same meaning for each TLV®, but we do not know this. For these reasons, the difficulties of using the TLVs® or PELs as relative indices of toxicity or of residual risk at the OEL are evident. Unfortunately, they are the only indices available.

Therefore, without having a quantitative baseline residual risk definition for TLVs®, their use as relative indices for toxicity in priority setting must be undertaken cautiously. A safety factor should be used. For example, compounds having TLVs® that differ by a factor of 4 or less might be considered to have equivalent toxicities.

TENDENCY TO BECOME AIRBORNE – VOLATILITY

The tendency of a compound to enter the air is directly related to its vapor pressure. For

example, a compound with a vapor pressure of 50 mm or mercury (~ 7000 Pa) at standard temperature, potentially would be twice as likely to become airborne as one with a vapor pressure of 25 mm of mercury, all else being equal. Under similar conditions, the first compound would be expected to form concentrations in the air approximately twice as high as those of the second compound. The potential for mixtures to form azeotropes and thereby reduce vapor pressures is a complicating factor. However, by assuming that volatility is proportional to pure compound vapor pressure, the actual volatilities of mixtures are at least overestimated in most cases. There are a few cases where the opposite is true (Glasstone, 1946). For a good listing of binary azeotropes see Gordon and Ford (1972).

TENDENCY TO BECOME AIRBORNE – DUSTINESS

For aerosols, particularly those derived from solids, vapor pressure is not of great importance, and it can be misleading.[1] If the vapor pressure of solids were used in priority setting, no doubt most solids would be of low priority. Dustiness is the property of solids that best relates to potential exposure; but unfortunately it is dependent on several factors, and thus little information is available on it. However, in some situations, particularly where two solid materials are being evaluated for future use in a process, or where differing formulations of a product are being evaluated for consumer use, it may be appropriate to evaluate dustiness. Several techniques are available, as the idea has received renewed interest (Elder et al., 1974; Heitbrink et al., 1989; Cowherd et al., 1989; Plinke et al., 1991; Carlson et al., 1992; Breum, 1999; and Brouwer et al., 2006). Reist and Creed (1994) have proposed a method for determining the respirable mass fraction of a bulk dust sample. Liden (2006) has reviewed pertinent issues and attempts on the part of the UK HSE and the CEN to devise dustiness standard methods.

VHI

The concepts of toxicity and volatility can be combined to give an index of the risk posed by a compound. The highest, or saturated, concentration (C_s) of a particular compound that can be reached in workplace air can be calculated from its vapor pressure (P^o) at a given temperature and ambient atmospheric pressure (P_a):

$$C_s = \frac{P^\circ}{P_a}$$

[Equation 13-1]

If C_s is less than the TLV® for a compound, that would indicate that the TLV® concentra-

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[1] See Chapter 24 for greater detail. Solids can have vapor pressures that make them semi-volatile and of presumed low vapor concentration. However, they may also be aerosolized in processing and thus exposures to vapor and aerosol occur.

tion could not be reached unless the compound were heated to temperatures above ambient, or somehow physically or mechanically divided such that solid particulate matter or liquid droplets were formed. Similarly, two compounds having a similar TLV® but with one having a vapor pressure five times that of the other would have different potential risk levels.

The concepts have been combined into an index. A vapor hazard[2] index (VHI), as proposed by Popendorf (1984), considers vapor pressure and toxicity. The vapor hazard index is calculated as:

$$VHI = \log_{10}\left(\frac{C_s}{TLV}\right)$$
[Equation 13-2]

This index can be multiplied by the number of workers exposed and further adjusted by the time of exposure in order to set priorities. Table 13-2 shows vapor hazard indices that have been calculated for fictitious chemicals representing a wide range of industrial compounds. When the VHI is less than zero, the TLV® concentration of the vapor cannot be reached unless the compound is heated above ambient temperature. (Note: Remember the vapor pressure is temperature-dependent, and so Table 13-2 assumes that ambient conditions are 25°C. If other conditions exist, the vapor pressure should be adjusted accordingly.)

An important caution about the use of vapor pressure for assessing airborne propensity should be noted. It is best illustrated with an example. The vapor pressures of polychlorinated biphenyls are quite low («1 mmHg), and so airborne levels are also quite low («10 µg/m³) in jobs related to electric transformer repair. Yet serum PCB levels can be elevated (Christiani et al., 1986). The exposure is coming via the skin from contaminated surfaces. Thus even though the fugitive emissions are small for such compounds, the emissions appear to condense on surfaces and accumulate. Other compounds in this class would include, for example, pentachlorophenol, some insecticides, and plasticizers. In addition, higher molecular weight compounds that are aerosolized and sprayed (pesticides for example) will drift to both desired and undesired surfaces. Their transferability to the skin of an operator from those surfaces may contribute substantially to exposure (see e.g., Ramwell et al., 2006). The use of surface wipe samples is a technique for assessing the relative contamination of surfaces (ASTM, 2003 and OSHA, 1999).

NUMBER EXPOSED AND FREQUENCY OF EXPOSURE

In order to set priorities for an in-depth survey, the VHI can be modified by using the number of workers exposed and the time of exposure. Consider again the data in Table 13-2. Chemical A has the highest VHI because it also has the highest vapor pressure and lowest

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[2] This is better thought of as a risk index since toxicity is hazard, i.e., the potential to cause disease, and volatility is an indicator of exposure potential. Risk is the product of exposure and hazard (see Chapter 10 and Chapters 11 and 12 of Volume 3).