Modeling Exposures
What Is A Mathematical Model?

- A mathematical model is an equation, or set of equations, that predicts the behavior of a system given specified values for model parameters.

- In our context, a mathematical model predicts the airborne concentration of a contaminant at different times and/or at different positions in a room.
Reasons for Mathematical Modeling

- To estimate exposure prospectively for a process being planned or for an accident scenario:
  - engineering control design, respirator selection,
  - consumer product liability concerns

- To prioritize exposure monitoring efforts:

- To estimate exposure retrospectively for a process that no longer exists:
  - legal case, epidemiology study
Steps to build an Exposure Scenario

- Identify, explore and structure the use(s) of the substance
  
  • Compile one or more tentative Exposure Scenarios covering the typical, actual conditions of use of the substance. Identify core determinants of exposure.

  • Assess exposure and risk.

  • Determine the effect of assumptions.
Three Elements of an Exposure Model

- The contaminant mass emission rate function
- The contaminant dispersion pattern in room air
- The exposed individual’s time-activity pattern
The Mass Emission Rate Function

- Common emission rate functions for a contaminant source in the room:
  - constant mass emission rate
  - exponentially decreasing vapor/gas mass emission rate
- Any time-varying function can be modeled
The Contaminant Dispersion Pattern in Room Air

- **Well-mixed room** – the concentration is uniform throughout the room.
- **Near field/far field** – the concentration is highest in the near field of the source, and lower in the far field (the remainder of the room); within each respective field or zone, the concentration is uniform.
- **Turbulent diffusion** – the concentration continuously decreases with distance from the source symmetrically or asymmetrically.
- **Computational fluid dynamics modeling.**
The Individual’s Time-Activity Pattern

- A worker may be in a room with one or more emission sources for only part of the shift, or the source(s) may emit for only part of the shift.

- A worker may spend time at different locations relative to the same emission source. Need to account for spatial variation in the airborne contaminant level.

- The time-activity pattern must be determined to estimate the 8-hr TWA exposure level.
Key Parameters in Mathematical Models

- The room or space volume $V$ (e.g., m$^3$)
- Supply/exhaust air rate $Q$ (e.g., m$^3$/min)
- Emission rate function $G(t)$ (e.g., mg/min)
- Dispersion factors:
  - Random air speed in room $s$ (m/sec or feet/min)
  - Advective air flow speed $U$ (m/sec or feet/min)
  - Turbulent eddy diffusion coefficient $D_T$ (m$^2$/sec)
Deterministic Versus Probabilistic Models

- **Deterministic**
  A value is specified for each model parameter. If each respective value is always the same, the model output is always the same.

- **Probabilistic**
  A distribution of possible values is specified for some or all model parameters. A distribution of possible outcome values is obtained.
A Quote Attributed to Albert Einstein

“Things should be kept as simple as possible, but not simpler.”

In our context, we should use the simplest model that provides the detail required for the exposure assessment scenario.
A Tiered Approach to Mathematical Modeling (from Simple to Complex)

- Saturation Vapor Pressure Model
- Well Mixed Room Model with Constant Emission
- Well Mixed Room Model with Variable Emission
- Near Field/Far Field Model with Constant Emission
- Near Field/Far Field Model with Variable Emission
- Turbulent Eddy Diffusion Model with Constant Emission
- Computational fluid dynamics models
Tier 1 - Simplest Model
Saturation Vapor Pressure Model

- Consider a sealed container half-filled with the liquid of a pure chemical, and half-filled with pure air in the headspace above the liquid.

- Liquid-phase chemical molecules with sufficient kinetic energy escape the liquid and enter the headspace air.

- As chemical molecules collect in the headspace, some strike the surface of the liquid and condense back into the liquid phase.
Saturation Vapor Pressure Model

- When the rate of evaporation equals the rate of condensation the system is at equilibrium, and the headspace air is saturated with chemical vapor.

- The partial pressure exerted by the gas phase chemical molecules in the headspace at equilibrium is alternatively termed the chemical’s vapor pressure, equilibrium vapor pressure, or saturation vapor pressure - $P_v$. 
Saturation Vapor Pressure Model

According to the ideal gas law, the mole fraction of a constituent, denoted \( Y_i \) for the \( i^{th} \) constituent, is equal to its partial pressure divided by \( P_{TOTAL} \):

\[
Y_i = \frac{P_i}{P_{TOTAL}}
\]

The airborne concentration of the \( i^{th} \) constituent in ppm is equal to its mole fraction multiplied by one million:

\[
C \text{ in ppm} = Y_i \times 10^6
\]
The “worst case” assumption is that the chemical’s partial pressure in air will equal its vapor pressure value. This is equal to saying that the chemical’s airborne concentration is the same as its saturation concentration in air.

This worst case assumption requires that:

1. The chemical is continually exposed to room air.
2. There is no room ventilation, or $Q = 0\ m^3/min$.
3. Room and liquid temperature is constant.
4. There is sufficient time to reach equilibrium.
5. There is a sufficient mass of chemical in the room such that liquid (or solid) chemical remains at equilibrium.
6. The ideal gas law holds.
A perchloroethylene \( (C_2Cl_4) \) container is left open in a nonventilated chemical storage cabinet. An employee opens the door and gets exposed to the cabinet air. To what ppm concentration of perchloroethylene is the employee exposed in the first couple of breaths?

The following values are known:

\[
T = 20 \, ^\circ\text{C}, \quad P_v = 14 \, \text{mm Hg} \text{ (at } 20 \, ^\circ\text{C)}
\]

Initial pressure = 760 mm Hg in the cabinet
We assume that the employee was exposed to a saturated concentration of perchloroethylene at 20 °C. We are implicitly assuming that equilibrium vapor pressure was attained in the cabinet, and that the contaminated air was not significantly diluted by room air prior to inhalation.

\[
C_{sat \ in \ ppm} = \frac{14}{760} \times 10^6 = 18,420 \ ppm
\]
### Exposure Potential Vapors: Rule-of-10

<table>
<thead>
<tr>
<th>Level of Control</th>
<th>Fraction of Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confined Space – Virtually no circulation</td>
<td>1/10(^{th}) of Saturation</td>
</tr>
<tr>
<td>Poor – Limited Circulation</td>
<td>1/100(^{th}) of Saturation</td>
</tr>
<tr>
<td>Good – General ~ 6 air turnovers/hr</td>
<td>1/1,000(^{th}) of Saturation</td>
</tr>
<tr>
<td>Capture</td>
<td>1/10,000(^{th}) of Saturation</td>
</tr>
<tr>
<td>Containment</td>
<td>1/100,000 of Saturation</td>
</tr>
</tbody>
</table>
Container filling operation

- Consider the air displaced from the headspace of a container being filled with a pure liquid chemical. If we assume the headspace air is saturated with the chemical’s vapor, the volumetric rate at which the container is filled provides a worst-case vapor mass emission rate into the airspace outside the container.

- \( V_{\text{CONT}} = \) container volume (m\(^3\))

- \( F = \) volumetric filling rate (m\(^3\)/min)

- \( C_{\text{sat}} = \) saturated vapor concentration (mg/m\(^3\))

- The vapor mass emission rate (mg/min) during filling is \( G_{\text{FILL}} \):

\[
G_{\text{FILL}}, \text{mg/min} = C_{\text{sat}} (\text{mg/m}^3) \times F (\text{m}^3/\text{min})
\]
First Principle Model – Box Model Basic

\[ G = \text{rate of contaminant going into box (wt/time)} \]
\[ Q = \text{ventilation rate (V/time)} \]

**Core set of working assumptions, hypotheses, and key beliefs**

- Amount of air going into box = amount of air coming out.
- Amount of contaminant in the box = amount going in minus the amount that leaves (in the exhaust air) or is destroyed within the box.
Summary of Gain and Loss Terms

Gain Terms

- In-room source: $G$, in mg/min
- Supply Air: $C_{IN} \text{ (mg/m}^3\text{)} \times Q \text{ (m}^3\text{/min)}, \text{ in mg/min}$

Loss Terms

- Exhaust Air: $C_{ROOM} \text{ (mg/m}^3\text{)} \times Q \text{ (m}^3\text{/min)}, \text{ in mg/min}$
- Other Pathways:

  \[ k_L \text{ (min}^{-1}\text{)} \times C_{ROOM} \text{ (mg/m}^3\text{)} \times V \text{ (m}^3\text{)}, \text{ in mg/min} \]
If $C_{IN} > 0$ (contaminant in the supply air), and

$k_L > 0$ (loss mechanisms other than exhaust air)

$$C(t), \text{mg/m}^3 = \frac{G + C_{IN} \cdot Q}{Q + k_L \cdot V} \left[1 - \exp\left(-\frac{Q + k_L \cdot V}{V} \cdot t\right)\right]$$

$$+ \quad C_0 \cdot \exp\left(-\frac{Q + k_L \cdot V}{V} \cdot t\right)$$

$C(t) =$ contaminant concentration at time $t$ (min)

$G =$ contaminant mass emission rate (mg/min)

$Q =$ room supply/exhaust air rate (m$^3$/min)

$V =$ room volume (m$^3$)

$C_0 =$ contaminant concentration at $t = 0$
- There is a room with $V = 200 \text{ m}^3$ and $Q = 20 \text{ m}^3/\text{min}$ (6 ACH for this room).

- Starting at time zero, $G = 1000 \text{ mg/\text{min}}$ of solvent vapor is emitted into room air.

- Supply air contains no vapor, $C_{IN} = 0$, and there are no vapor removal mechanisms other than exhaust air, $k_L = 0$. The vapor level in room air at time zero is $C_0 = 0$. We want to find the equation for $C(t)$. 
\[ C(t) = 50 \cdot [1 - \exp(-0.1 \cdot t)] \]
The Steady State Room Concentration

- If the in-room emission rate is a constant value $G$, and emission continues for a long time, the contaminant concentration will reach a steady-state value, $C_{SS}$.

$$C_{SS}, \text{ mg/m}^3 = \frac{G + C_{IN} \cdot Q}{Q + k_L \cdot V}$$

- In the previous figure, it appears that the concentration is reaching a steady-state value of 50 mg/m$^3$. This is expected because:

$$C_{SS} = \frac{1000 + 0.20}{20 + 0.200} = 50 \text{ mg/m}^3$$
A Two Zone Dispersion Pattern

- To this point, we have assumed that contaminant is dispersed instantaneously and uniformly throughout a room containing an emission source. In effect, a room is treated as a perfectly mixed zone, yet we know this condition is physically unrealistic.

- The next level of complexity is a near field/far field dispersion pattern. We view a room as containing two contiguous zones – a “near field” zone surrounding the emission source, and a “far field” zone comprising the rest of the room.

- We treat the air within each zone as perfectly mixed, but with a limited air exchange between the two zones.

- This condition means that the contaminant concentration is uniform throughout the near field zone, and is uniform throughout the far field zone. In general, the near field concentration is higher than the far field concentration.
A Visual Perspective

- If the contaminant emission source is on a flat surface, the near field zone can be conceived as a hemisphere with its base on the surface and with its center at the source.

![Diagram of a hemisphere and a cube with arrows indicating air flow.]  

- The hemisphere radius is sized to contain the breathing zone of the individual whose exposure level is to be estimated.

- Air flows into and out of the near field at rate $\beta$ in $\text{m}^3/\text{min}$.

- Room supply/exhaust air flows into and out of the far field at rate $Q$ in $\text{m}^3/\text{min}$. 
An Example of Estimating $\beta$

- A person works at arm’s length ($r = 0.8$ m) from an emission source located on a table. The random air speed near the operation is: $s = 3.0$ m/min (10 fpm).
Change in Mass = Mass Gain − Mass Loss

Near Field: \( V_{NF} \cdot dC_{NF} = \left[ G \cdot dt + \beta \cdot C_{FF} \cdot dt \right] - \beta \cdot C_{NF} \cdot dt \)

Far Field: \( V_{FF} \cdot dC_{FF} = \beta \cdot C_{NF} \cdot dt - \left[ \beta \cdot C_{FF} \cdot dt + Q \cdot C_{FF} \cdot dt \right] \)

\( C_{NT} \) = the near field concentration (mg/m³)

\( C_{FF} \) = the far field concentration (mg/m³)

\( V_{NF} \) = the near field volume (m³)

\( V_{FF} \) = the far field volume (m³)

\( G \) = constant mass emission rate (mg/min)

\( \beta \) = air flow rate (m³/min) between the near and far fields

\( Q \) = room supply/exhaust air rate (m³/min)
Near Field: \[ C_{NF}(t) = \frac{G}{Q} + \frac{G}{\beta} + \]
\[ G\left(\frac{\beta \cdot Q + \lambda_2 \cdot V_{NF}(\beta + Q)}{\beta \cdot Q \cdot V_{NF}(\lambda_1 - \lambda_2)}\right) \exp(\lambda_1 \cdot t) - G\left(\frac{\beta \cdot Q + \lambda_1 \cdot V_{NF}(\beta + Q)}{\beta \cdot Q \cdot V_{NF}(\lambda_1 - \lambda_2)}\right) \exp(\lambda_2 \cdot t) \]

Far Field: \[ C_{FF}(t) = \frac{G}{Q} + \frac{G}{\beta} \left(\frac{\lambda_1 \cdot V_{NF} + \beta}{\beta} \right) \left(\frac{\beta \cdot Q + \lambda_2 \cdot V_{NF}(\beta + Q)}{\beta \cdot Q \cdot V_{NF}(\lambda_1 - \lambda_2)}\right) \exp(\lambda_1 \cdot t) \]

\[ - \frac{\lambda_2 \cdot V_{NF} + \beta}{\beta} \left(\frac{\beta \cdot Q + \lambda_1 \cdot V_{NF}(\beta + Q)}{\beta \cdot Q \cdot V_{NF}(\lambda_1 - \lambda_2)}\right) \exp(\lambda_2 \cdot t) \]

\[ \lambda_1 = 0.5 \left[ -\left(\frac{\beta \cdot V_{FF} + V_{NF}(\beta + Q)}{V_{NF} \cdot V_{FF}}\right) + \sqrt{\left(\frac{\beta \cdot V_{FF} + V_{NF}(\beta + Q)}{V_{NF} \cdot V_{FF}}\right)^2 - 4 \left(\frac{\beta \cdot Q}{V_{NF} \cdot V_{FF}}\right)} \right] \]

\[ \lambda_2 = 0.5 \left[ -\left(\frac{\beta \cdot V_{FF} + V_{NF}(\beta + Q)}{V_{NF} \cdot V_{FF}}\right) - \sqrt{\left(\frac{\beta \cdot V_{FF} + V_{NF}(\beta + Q)}{V_{NF} \cdot V_{FF}}\right)^2 - 4 \left(\frac{\beta \cdot Q}{V_{NF} \cdot V_{FF}}\right)} \right] \]
Steady State Concentrations

- Because emission is at a constant rate, steady state concentration values are reached:

\[
\text{Near Field: } C_{NF,SS} = \frac{G}{Q} + \frac{G}{\beta}
\]

\[
\text{Far Field: } C_{FF,SS} = \frac{G}{Q}
\]
$$C_{NF,SS} = \frac{G}{Q} + \frac{G}{\beta} \quad \text{versus} \quad C_{FF,SS} = \frac{G}{Q}$$

- If $\beta \leq Q$, it follows that $C_{NF,SS} \geq 2 \times C_{FF,SS}$. This condition pertains in a room with a low air speed near the source, or in a large room with large $Q$.

- In general, $Q$ increases relative to $\beta$ as the room size increases. In turn, the model predicts relatively higher exposure intensity near the emission source compared to the well mixed room model.

- Therefore, using the well mixed room model leads to more substantially underestimating exposure near the source as the room size (and $Q$) increases.
FIGURE 17.5 Predictions of the near-field far-field model for $G = 105$ mg/min, $V_{FF} = 240$ m$^3$, $Q = 15$ m$^3$/min, $V_{NF} = 1.1$ m$^3$, $\beta = 7.25$ m$^3$/min.
You may have guessed it!
Feeding the Model is the Real Task

- Feeding the model means that you understand or at least have addressed the variables that will drive the concentration and exposure.
- Getting at Q and V (and even Beta is pretty easy).
- G (or emission rate) is typically the tough one to get.
There are ways of getting $G$

- For evaporating volatiles it can be done with submodels. See references.
  - It can also be done by measuring weight loss during evaporation of a known amount, volume, and surface area of a pure liquid.

- For airborne generated particulates it is more complicated.
  - The simplest way is to put the source in a well mixed box with known $Q$, measure the concentration and calculate the $G$. 
Uncertainty Analysis
Nature of Probability

Classical or Frequentist View:

The probability of an event’s occurring in a particular trial is the frequency with which it occurs in a long sequence of similar trials.

For example, repeat weighings of a filter.

Or, repeat measurements of the air concentration of a pollutant in a steady state environment using an instrument.
Personalist of Bayesian View:
In many cases, it is not clear what the relevant population of trials should be.

For example, estimating the air flow rate (air changes per hour) through a room in the absence of any measurements.

An ‘expert’ can estimate it to be between 5 and 9 air changes/hr, with each value being equally likely.

But, there is NO population of air flow measurements.

This is a subjective description of the state of information or knowledge of the expert.
Sources of Uncertainty

1a. Random error and statistical variation
Most studied and best understood kind of uncertainty arises from random errors in direct measurement of some quantity. E.g., repeat measurements of a blank filter can determine the error associated with gravimetry.

1b. Variability
Quantities vary over time and space, and can be represented by a probability distribution. E.g., the exposure of a worker category can vary from day to day or from worker to worker. It can change seasonally.

2. Incomplete scientific or technical knowledge
“We don’t know what we don’t know”
(1a.) and (1b.) type of uncertainties can be represented by sampling statistics.
(2.) type of uncertainty can be large, and dominate the overall uncertainty.
Common and Useful Probability Distributions

Uniform Distribution

Its use is appropriate when we are able and willing to identify a range of possible values for some variable, but unable to decide which values within this range are more likely to occur than others.
Normal Distribution

Arises in many applications. Quantities formed by adding many uncertain quantities tend to be normally distributed. The PDF takes on values over the entire range of real numbers. Evaluation of the CDF can be done using statistical tables. The parameters of the distribution are related to the first and second moments.
Triangular Distribution

This describes a situation where you know the minimum, maximum, and values most likely to occur.
For example, we might describe the gallons of a particular chemical used per week in a workplace.
Past records might indicate that a minimum of 3,000 gallons to a maximum of 7,000 gallons are used per week, with most weeks showing usage of 5,000 gallons.
Propagation of Uncertainty

Suppose we have constructed a model to predict some quantity such as the concentration or a worker’s exposure.

- Suppose we have identified various uncertainties in the inputs.
- How can we propagate these uncertainties through the model to discover the uncertainty in the model output?
  - Can provide insights about the relative importance to our conclusions of our various assumptions and uncertainties in the model inputs.
  - Can help us decide whether it is worthwhile gathering more information to reduce uncertainty.
Consider a model represented by a function \( f \), with two uncertain inputs \( x_1 \) and \( x_2 \), and one output \( y \).

\[
y = f(x_1, x_2)
\]

Let us consider three values for each input - low, medium, and high.

To investigate the possible interactions between the effects of all the inputs at various levels, we will have to look at all possible combinations of input values.
Limitations of this approach:

Two variables with 3 levels each = \(3^2 = 9\)

Ten variables with 3 levels each = \(3^{10} = 59,049\)

Very often the uncertain quantities are continuous and not discrete. Then we may more naturally use probability density functions to represent the input parameters.

Usually difficult to obtain analytical expressions for the output in such cases.

One way out of this quandary is to select a moderate-sized, random \textit{sample} of scenarios for evaluation. This is called \textbf{Monte Carlo sampling}.

Each scenario is generated by selecting each branch at a node according to its assigned probability. The branch values are generated from the underlying continuous probability distribution.
Example from Jayjock (1997)

Simple indoor air concentration model

\[ C = \frac{G}{Q} \]

C = equilibrium air concentration (mg/m³)

G = steady generation rate (mg/hour)

Q = steady ventilation rate (m³/hour)

G: Assume that data is available on the source. The data is normally distributed with mean of 50 mg/hour and a standard deviation of 5 mg/hour

Thus, worst case might be \( 50 + 3 \times 5 = 65 \text{ mg/hr} \)

Best case might be \( 50 - 3 \times 5 = 35 \text{ mg/hr} \)

Q: No measurements available. But we can estimate from existing literature that the ventilation rate will not be below 0.2 air changes per hour (ACH) and will not be greater than 30 ACH.

Worst case = 0.2 ACH
Best case = 30 ACH
Exposure Estimate Example:

Simple Model:

\[ C = \frac{G}{Q} \]

Worst Case

\[ C = \frac{65 \text{ mg/hour}}{36 \text{ m}^3/\text{hour}} = 1.8 \text{ mg/m}^3 \]

Best Case

\[ C = \frac{35 \text{ mg/hour}}{540 \text{ m}^3/\text{hour}} = 0.065 \text{ mg/m}^3 \]

Agent “X” OEL = 1 mg/m³

\[ G = \text{steady generation rate (mg/hour)} \]

35 to 65 mg/hour

\[ Q = \text{steady ventilation rate (m}^3/\text{hour)} \]

3.6 to 540 m³/hour
Monte Carlo Analysis

Generation Rate (mg/hour)

Ventilation Rate $m^3/hr$
10,000 independent samples (sets of values of G and Q) are obtained randomly from their respective probability distributions.

For each set of (G, Q), a value of C is predicted using the model equation.

Thus, we obtain 10,000 values of C. These can be plotted as a probability distribution for C.
Mean = 0.46 mg/m³

Median = 0.19 mg/m³

5th percentile = 0.09 mg/m³

95th percentile = 1.54 mg/m³
Sensitivity Analysis

Shows how much the uncertainty in each variable contributes to the overall variability. This can help decide where to allocate resources to reduce uncertainty.

![Sensitivity Chart](image-url)
Using Models in Scenarios
Scenario 1

- A spray adhesive ("Brand A+ Adhesive") is filled into aerosol cans on an automatic fill machine line.

- A task occurs about once per week which involves cleaning the filling equipment surfaces to remove the adhesive.

- The workers use a rag dipped in solvent containing xylene (OEL = 100 ppm) and wipes adhesive. They also use a scraper tool along with the rag and solvent.

- This cleaning task occurs once per week for about 4 hours. Around one gallon of solvent (maybe 50% xylene) is used.

- The room is 20 feet X 40 feet X 12 feet and has general ventilation at 6 ACH (air changes per hour). No local exhaust is used in this room.
WMR Model Parameters

- **Volume of room**
  - $20 \text{ ft} \times 40 \text{ ft} \times 12 \text{ ft} \times (0.3048 \text{ m/ft})^3 = 272 \text{ m}^3$

- **Ventilation Rate**
  - $6 \text{ air change/hour} \times 272 \text{ m}^3/60 \text{ min} = 27.2 \text{ m}^3/\text{min}$

- **Mass Rate of xylene**
  - $(1 \text{ gal} \times 3.78 \text{ l/gal} \times 1000 \text{ cc/l} \times 0.88 \text{ gm/cc} \times 1000 \text{ mg/gm} \times 0.25)/240 \text{ minutes} = 6930 \text{ mg/min}$
Well Mixed Room Model Prediction

TLV xylene = 435 mg/m³ = 100 ppm

TWA = 61 mg/m³
NF-FF Model Parameters

- Volume of room = 272 m³
- $Q = 6 \text{ air change/hour} = 27.2 \text{ m}^3/\text{min}$
- Mass Rate of xylene = 1732 mg/min (0.5 gal of 25% xylene)

Volume of NF = \[ \frac{2}{3} \pi r^3 = \frac{2}{3} \pi (0.8)^3 = 1.1 \text{ m}^3 \]

$\beta = 0.5 \times \text{surface area of hemisphere} \times \text{random air velocity} = 0.5 \times (2 \pi r^2) \times 3 \text{ m/min} = 6 \text{ m}^3/\text{min}$
Near Field Far Field Model

TLV xylene = 435 mg/m³ = 100 ppm

TWA = 348 mg/m³

TWA = 61 mg/m³
Effect of uncertainty in xylene used on Near Field concentration

![Graph showing concentration in mg/m^3 over time in minutes for different flow rates.]

- NF for 0.5 gal/hour
- NF for 0.1 gal/hour
Xylene NF Uncertainty Analysis

Uncertain Inputs

- Amount of xylene used for cleaning
  - Typically 200 ml used over 4 hours but very variable
  - Assume **Lognormal**: GM = 200 ml; GSD = 3

- Percent xylene in solvent
  - Assume **Uniform**: Min = 10%, Max = 50%

- Ventilation rate (ACH)
  - Assume **Triangular**: Min = 5, Mode = 6, Max = 7
Amount of xylene used for cleaning

Typically 200 ml used over 4 hours but very variable
Assume **Lognormal**: GM = 200 ml; GSD = 3
Percent xylene in solvent

Assume **Uniform**: Min = 10%, Max = 50%
Ventilation rate (ACH)

Assume **Triangular**: Min = 5, Mode = 6, Max = 7
4 hour TWA Distribution

GM = 38; GSD = 3.5
References


Papers and articles supplied with this PDC.
Mathematical Models for Estimating Occupational Exposure to Chemicals

2nd edition

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A Publication from the American Industrial Hygiene Association
Other References
