LOW-CONCENTRATION AIR CONTAMINANTS AND MODELING OF THE NEAR ENVIRONMENT

G.M. Hutter, P.E.

ABSTRACT

The problems of personal injury and property damage from exposure to low-concentration air contaminants in the work place and near environment are presented. The usefulness of modeling to evaluate existing emission sources, to predict the effect of future spills or leaks, or to re-create past exposure conditions is examined.

INTRODUCTION

A motor bracket on an overhead crane fails and the motor falls, hitting an employee below. A small bolt becomes separated from a speeding airliner at 30,000 feet and smashes through the roof of a residence below after attaining a terminal velocity of 80 mph. An unknown white powder mysteriously settles on a car overnight and ruins its finish. Particles, ten microns in diameter, escape a collection hood at a work place, slowly migrate through the facility, and now permanently reside in an employee's lungs. All of these scenarios involve increasingly smaller objects, originating from increasingly more difficult to identify sources. The adverse effects are potentially more serious and more widespread in each case.

In the case concerning the falling motor, the time of occurrence is well-defined and a physical inventory can be taken to locate the motor's origin. In the case, however, of exposure to airborne contaminants in a work place, neither time nor the possibility of a physical inventory are allies in establishing the link between the source of the contaminant and the resulting injury or property damage. There are few practical means of identifying missing molecules of a gas or particles of dust from a process airflow. In addition, the injury or property damage may not become apparent until some considerable time after the exposure or after prolonged exposure. This is especially true when the exposure level (dose) is low and the extent of exposure (duration) is prolonged, thus making it difficult to determine where and when the exposure occurred, and how high the exposure level was. Some of these problems can be overcome by identifying suspect exposure/emission sources, determining personal exposure routes, performing an inventory of the materials and suspect pathways, monitoring to a limited degree, and by constructing an airborne-contaminant transport model.

Note: Mr Gary M. Hutter is Senior Safety and Environmental Engineer at Triodyne Consulting Engineers and Scientists Inc., Niles, Il

Occupational exposure or exposure to contaminants in the near environment is a growing problem in industry and has only recently been investigated. Currently only a few selected materials in the work place are regulated by OSHA, and the EPA regulates only six toxic materials. At the same time, personal injury and property damage from exposure to low-concentration air contaminants in the work place is escalating.

This paper attempts to describe the problem of airborne contaminants in the work place, or near work place, and how mathematical and computer transport models can be used to evaluate existing conditions, to recreate past exposures, and to predict future conditions.

THE PROBLEM OF LOW CONCENTRATION AIRBORNE CONTAMINANTS

Exposure Emission Sources

When discussing airborne contaminants, a common image is a colored, noxious cloud, complete with choking vapors, that causes exposed individuals to cough and become teary-eyed. However, the most prevalent form of exposure in this country comes from prolonged exposure to low-level concentrations of gases and particulates that either go undetected or are assumed to be harmless. The exposure may be at a residence, at the work place, or near an industrial emission source.

Exposure concentration levels and durations are the determining factors between acute and chronic toxicity. For some gases, such as hydrogen sulfide, long-term low-level exposures are relatively harmless. However, acute toxicity will occur after short-term exposures to elevated levels (for hydrogen sulfide, approximately 1500 ppm). Other gases cause chronic toxicity or are carcinogenic at low-concentration levels after long-term exposure, but are less toxic under short-term high concentration exposures. An example of such a gas is vinyl chloride. The types of materials involved and the corresponding exposure conditions are also important factors in establishing a chronic or acute exposure.

Acceptable exposure levels are sometimes difficult to ascertain. Murphy (1984) asserts that "adherence to current OSHA standards or even NIOSH recommended criteria for many solvents may not be sufficient to guarantee a healthy workplace."

Public buildings also contribute to potential exposure due to poor ventilation or to problematic heating and ventilating systems. A recent study conducted by researchers from the University of California, Berkeley, indicated that

> a number of [indoor] contaminants, such as
> CO_2, fine particulates, hydrocarbons and
> formaldehyde...were found to have higher in-
> door than outdoor concentrations
> (Turiel et al. 1983).

Measurements taken at the American Museum of Natural History in Manhattan found indoor levels of particulate lead in certain rooms adjacent to streets to be approximately the same as at street level (indoor range 0.45-0.981; outdoor 0.379 to 1.047 microgram/m3). In addition, the indoor levels of particulate lead remained elevated longer than the outdoor levels.

There is an ever-increasing understanding of the indoor environment, of indoor air-pollution sources, and of low-level concentration exposures. It is estimated that over 70% of our lives is spent indoors; exposure to household chemicals, emissions from kerosene heaters and appliances, and off-gassing of insulation and building products are some emission targets of concern. (Ritchie and Oatman 1983; Meckler 1985; Morris and Wiggin 1985). Other, less-studied commercial/residential sources include fireplace emissions, biological contamination of ventilation systems, and leakage of automotive exhausts into ventilation systems. Table 1 is an outline of common sources and causes for the contaminants in the work place, near work place sources (adjacent to sources), private residences, and public facilities.

Routes of Entry/Physical Attack

The major route of entry of airborne contaminants, either particulates or gases, is through the lungs:

> The human lung has an enormous gas-tissue
> interface (90 square meters total surface,
> 70 square meters alveolar surface). This
> large surface, together with the blood
> capillary network surface of 140 square
> meters...makes possible an extremely rapid
> rate of absorption of many substances from
> the air (U.S. Department of Health, Education
> and Welfare 1978).

Secondary routes of entry include: the mucous membranes and normally moist parts of the body which are susceptible to hygroscopic materials; exposed and unprotected skin areas; and the mouth. Skin absorption is especially important when dealing with substances which can penetrate the skin through wounds or are soluble through the skin and can thereby directly enter the blood stream. The American Conference of Governmental Industrial Hygienists (1977) estimates that approximately one-fourth of the materials listed in its "Threshold Limit Values" can be absorbed through the skin.

In cases where property damage is the result of these airborne contaminants, corrosive or galvanic reactions are often involved. These reactions may be caused by moisture from the atmosphere or from certain pH conditions. Often, crevices or locations that are difficult to inspect within a structure are the most prone to damage because they can trap contaminants that remain undetected.

Materials/Airborne Contaminants

Airborne contaminants may be water soluble, fat soluble, acidic, or non-reactive or chemically reactive physical irritants. Generally, fine particles are more invasive to the respiratory system than larger ones; odoriferous gases are not necessarily more dangerous than gases with no odors.

The EPA considers particles with aerodynamic diameters less than 5 microns in diameter and larger than 0.2 microns in diameter as inhalable particles; that is, they are small enough to penetrate deep within the lungs, but are large

enough that they are not quickly exhaled like a gas molecule. This size category is considered the most harmful size range of particles.

Gases, on the other hand, usually are harmful because of a specific toxic property, or, if non-toxic, because they displace the oxygen in the atmosphere or block the oxygen-carrying capability of the blood. Carbon monoxide, which is odorless, is not chemically toxic but blocks the oxygen-carrying capacity of the blood. In contrast, hydrogen sulfide is toxic and directly attacks the lung tissue. Hydrogen sulfide has the unusual property that, at low concentration levels, it has a strong odor but, at the more toxic levels, it paralyzes the sense of smell and may not be detected (National Safety Council 1982; Sittig 1981).

These gases and particles may be any of the approximately 95,000 chemicals which are listed in standard chemical references or their intermediates, their decomposition products, or the reaction products of combustion. The materials may be sparsely used, like beryllium, or ubiquitous, like cleaning solvents. They may act singularly or synergistically with other materials which, by

themselves, are not considered injurious. An example of the synergistic effect with lethal potential is the production of phosgene gas from freon gas passing through an internal combustion engine.

Monitoring the Near Environment

Monitoring performed around many industrial facilities identifies the increased exposure to individuals living nearby. Maximum levels of 37.8 micrograms/m3 of antimony were measured in air samples taken near the perimeter of a metallurgical plant (Vanderborght et al. 1983). It has also been reported that living near a vinyl chloride plant results in the same increased health risk as smoking 1.4 cigarettes per day (Fischhoff 1981). Measurements in urban air for benzene, a recognized carcinogen, revealed concentration levels of 114 micrograms benzene/m3 (Wathne 1983). Working in cotton processing facilities has been linked to bysinnosis, a lung disease (Merchant 1981). The work place is such a common source of disease and toxic exposure, that the federal government publishes a listing of work-related illnesses entitled "Occupational Diseases -- A Guide to Their Recognition" (U.S. Department of Health, Education and Welfare 1978).

A variety of devices are available to monitor air contaminants; a classification-type monitor (i.e., measures total hydrocarbon concentration) or a chemical-specific (i.e., measures for benzene only) may be used. Equipment may be installed at a specific site or worn by an employee to measure the cumulatve exposure while moving through a facility.

Monitoring a work place or near work place can only establish concentration levels for the conditions under which the monitoring was performed. If those conditions existed at a previous time, then, with some certainty, the emission levels will be equivalent. Present conditions most often are either known to be different than those from a previous exposure time, or it is unknown if the conditions have changed.

It is unreasonable to release toxic material into the atmosphere to allow monitoring of emission concentrations under possible future accidental release conditions. Present time monitoring can be used, however, to verify an air contaminant transport model that can simulate known previous conditions, to determine what previous conditions would have been required to produce a harmful concentration level, or to predict future exposure concentration levels. Hence, modeling allows one to look through a simulation window to the past or future,

and monitoring establishes the hallmarks to that view. These are the same principles upon which the EPA bases its requirement that modeling be performed and used in conjunction with monitoring to ensure environmental compliance.

PRECEDENTS AND THEORETICAL BASIS FOR MODELING

Precedents

A model is a scientific tool used to describe a multivariant system, to show the interplay of variables upon each other, and to allow for simulation of various conditions to enable predictions. Grodins (1981), for example, lists a sampling of 14 models of the dynamic respiratory control function which have been developed from 1954 through 1978. In air quality studies, modeling has been useful in understanding atmospheric chemistry, in predicting air pollution episodes, in determining dispersion of air contaminants, and in confirming compliance with standards. Most recently, models and monitoring have been the basis for new strategies concerning acid rain and in establishing exposure assessments.

In Wisconsin Power vs. Anne M. Gorsuch (No 82-1724, Aug. 17,1983) the U.S. Court of Appeals for the Seventh Circuit concluded that monitoring by itself was insufficient and that

> Models, on the other hand, predict air
> quality under a wide range of conditions.
> The Clean Air Act authorizes nonattainment
> designation based on such [model] predic-
> tions (Bureau of National Affairs 1983).

Likewise, in the EPA bubble policy, modeling can be a criteria for acceptance (Bureau of National Affairs 1984). The EPA (Federal Register 1984) has also acknowledged the usefulness of modeling in its "Proposed Guidelines for Exposure Assessment," "Proposed Guidelines for the Health Assessment of Suspect Developmental Toxicants," and "Proposed Guidelines for Carcinogen Risk Assessment." In discussing exposure assessment, for example, the EPA states that

> In general, the exposure assessment describes
> the magnitude, duration, schedule, and route
> of exposure. This information is developed
> from monitoring data and from estimates based
> on modeling of environmental exposure.
> (Federal Register 11-23-84)

While the EPA discusses the use of modeling in establishing exposure-risk relationships, it also acknowledges the need for appropriate modeling techniques to support modeling.

Early Mathematical Models

Early mathematical models applicable to atmospheric simulation originated in the 1800s. In 1827 Robert Brown reported that when an aqueous solution containing fine-size lightweight particles was closely examined, the particles were found to follow an unusual zigzag pattern. This random motion, today called Brownian Motion, was later determined to be the result of the fluid molecules hitting the lightweight particles in a random pattern. (Figure 1) This same momentum transfer between air and fine dust particles can cause long-

term suspension and dispersion of certain size particles in an environment. The terminal settling velocity, or the Stokes' settling velocity, to determine the rate at which these particles will settle or if they will remain suspended by naturally occurring upward air movement, can be calculated by using the equation:

$$Vs = \frac{2gr^2(d1-d2)}{9u}$$

Where

Vs = Stokes' settling velocity
g = gravitational constant
r = radius of particle
$d1$ & $d2$ = density particle and gas
u = gas viscosity.

In 1855, Adolf Fink proposed a mathematical relationship for the diffusion, or self-mixing, of one gas within a second gas. This relationship can be described by:

$$Nab = -Dab*\frac{\partial[Ca]}{\partial(z)}$$

Where

Nab = rate of diffusion
Dab = diffusion coefficient
Ca = concentration of "a"
z = distance.

Qualitatively, this relationship is based on the normal thermal agitation of molecules and on a concentration gradient. The thermal agitation causes the molecules to be in continuous motion in all directions, and the concentration gradient, $\partial[C]/\partial(z)$, causes more molecules of a gas to be driven in the direction of lower concentrations (Figure 2).

The rate of intermixing of gases will also be affected by temperature differences or temperature gradients existing between the two gases. It has been demonstrated that a thermal gradient can cause one constituent of a gaseous mixture to flow relative to the whole (Encyclopedia of Science and Technology 1971). This thermal diffusion is described by:

$$Na = Dtp\frac{\partial(lnT)}{\partial(z)}$$

Where

Na = rate of diffusion
Dt = coefficient of thermal diffusion
p = mass density
T = absolute temperature
z = distance.

Buoyant effects due to temperature and density differences may be present.

In addition to these gradient-driven mixing mechanisms, the atmosphere in which the gas or particulate matter may be located may produce various flow conditions which increase or inhibit mixing and transport. Turbulent flow or forced flow conditions may exist at the opening to a hood or due to a natural airflow pattern that may influence the concentration and distribution of an airborne material.

Turbulent diffusion of nonreacting airborne contaminants is described by the relationship (Clark 1979; Veigele and Head 1978):

$$\frac{\partial [C]}{\partial t} = \{k\}*[c] - \{V\}[c] + \{s\}$$

Where

c = concentration
k = diffusion tensor
V = average wind velocity
s = source function.

When combined with appropriate assumptions and boundary conditions, this relationship lead to the development of the Gaussian Plume Dispersion Model used by the EPA in evaluating emission sources.

Within buildings, the driving forces distributing a vapor, aerosol, or gas cloud may be pressure gradients or gravity forces. Pressure differences may cause infiltration of exhaust gases through cracks. Here the flow rate is proportional to one-half the power of the ratio of pressure differential and characteristic flow resistance, as expressed in the equation:

$$Q = (\Delta P/R)^{1/2}$$

Where

Q = mass flow rate
ΔP = pressure drop
R = flow resistance; $k(A)^2/(.5*p)$
A = area
p = mass density
k = flow coefficient.

Gravity spreading velocities may be represented by:

$$\frac{dx}{dt} = \frac{[2g(p1-p2)H]^{1/2}}{p2}$$

Where

$\frac{dx}{dt}$ = gravity spread rate

p1 = density gas
p2 = density air
 H = height of cloud
 g = gravity constant

In general, modeling of airborne emission concentrations and transport can be considered a two-dimensional continuum bounded by a source or receptor perspective and a transport distance scale (Figure 3). Source models predict transport and concentrations based on knowledge about the emission source, whereas receptor models are generally based on levels at an observer's location and "model" back to the source. The transport distance scale is the distance between the source and receptor. The work place, or near work place, would be considered a microscale model because the distances are relatively small. Models describing transport over distances of more than a few kilometers are considered mesoscale, and models describing transport on a global scale are described as macroscale models. Figure 3 depicts how both large and small sources can affect microscale models, but usually only large sources are considered in meso or macroscale models.

With this backround, a description of various modeling considerations and modeling approaches based on diffusion, forced ventilation, gravity effects and pressure gradients will be discussed.

MODELING THE WORK PLACE OR NEAR WORK PLACE ENVIRONMENT

Many of the existing air-contaminant transport models have been designed to address macro or mesoscale conditions. One reason for this is that the resulting model can be more general as to the contours of the pathways traced by

the model, and unique geometries that may occur within a building or at a particular site do not have to be addressed. A microscale model must account for the geometry of its location and is, therefore, often considered site-specific. A microscale model does, however, have the following advantages over its larger scale relatives:

1. The boundaries of the microscale model are often well defined.
2. Air movement can be well documented.
3. Rain washout generally does not occur.
4. Time dimensions are shorter.
5. Generally, photochemical reactions can be ignored.
6. Monitoring can be more supportive of the model.
7. The effect of unexpected weather conditions can be minimized.

A model of the work place or near work place relies on an identification of the contaminants to be modeled, a mass balance of contaminants, an accounting for any chemical reactions, a mapping of the flow paths at the location, and a physical identification of the boundaries of the location to be modeled. It may utilize some of the theories used in meso and macroscale models, but must be tailored for the specific site.

Once the suspect contaminant has been identified for modeling, a mass balance and an accounting of all such sources and sinks must be determined. There may be a single source or multiple sources and they may contribute either continually or intermittently. A common example of this would be a facility with two or more identical batch process lines where the volume of off-gassing varies throughout the individual batch line cycles. When any one of the batch sources is vented, the collection system can accommodate the flow; but, when multiple sources are all in sequence, producing large amounts of off-gas, the collection system is inadequate (Figure 4). In the case of particulates, the material may vary in particle size consistency throughout a process cycle, thus allowing small-size particles to escape collection only during some portions of a cycle. Although process flow sheets should allow for a total mass balance, conditions have to be evaluated with these types of variations in the process cycle.

In Table 2, "mass out" VII represents the mass of a particular contaminant available for distribution in a specific work place. Obviously there are many other conditions that may influence these mass balance considerations, and many of these conditions may not have a linear effect (as used in Table 2 for simplicity). Where these effects are not linear, with respect to time or position, a nonlinear simulation, including discontinuities, may be set up using a computer version of the model. Monitoring can be used to account for the total effect of these sources and sinks, and to verify various physical constants. Whether or not this final "mass out" arrives at the suspect location depends on the transport mechanism.

CONSIDERATIONS OF TRANSPORT

The driving mechanism for transport might be simple diffusion, thermal or mass bouyant conditions, forced ventilation, natural convection currents, pressure gradients, and/or wind conditions. Air movement measurements and monitoring are the simplest means of establishing these flow patterns within a facility. Figure 5 shows a simple flow pattern in a facility where emissions escape a hood and, due to the high density and relatively low temperature of the material, follow a ground-level path. Because the example building is under positive pressure, a majority of the uncollected gas at ground level is the first to escape to the outside through poor sealing under a nearby door. The placement of return air ducts in this area or additional sealing of the door during winter months would diminish the escape of this unwanted contaminant and could result in higher indoor concentration levels. Computer modeling of these conditions allows simulation of these two different flow patterns and their resulting

different concentration levels.

In the outdoor near environment, ground-level terrain, in addition to wind direction, may play an important role in determining the progress of an airborne contaminant. Buildings or gulley-like surface features may act as conduits for the material. Such structures may inhibit dispersion and allow high concentrations to move long distances. Likewise, the low surface roughness of paved parking lots and streets can enhance the speed of a gaseous flow. Subsurface sewers and other tunnelways may also act as conduits for heavy gases.

TYPICAL MODELS

Some of the early models, applicable to the near environment, were developed by simulating spills or leaks from a single source and from the resulting vapor cloud. Concern about fires and explosions resulting from spills and leaks of liquid natural gas while in transit or in storage facilities prompted much of this model research. These studies and models were sponsored with funding from governmental agencies and various shippers and producers of Liquid Natural Gas. (U.S. Nuclear Regulatory Commission 1981; Havens 1979; Boyle 1973; Byggstoyl and Saetran 1982).

These models can accommodate calm or low forced-convection conditions and allow for calculation of the gas concentration in the air. The resulting "pool" of liquid natural gas and the air-gas cloud are both simulated as a function of time. These models assume a relatively constant spread geometry, a relatively uniform thermodynamic state throughout the pool, limited variations in heat transfer among components, and a spread rate that is not significantly affected by dilution. This last assumption does not mean that the cloud size at the lower flammability limit condition is invariant, but that the cloud growth history in time will be similar.

The primary driving potential for these models is gravity. This type of model is useful in situations where a relatively heavy gas or vapor is released into the atmosphere and the major transport phenomena is due to the density of the gas. This could be the case with LNG, cryogenically-cooled gases, or other low vapor pressure liquids released in an industrial spill. These models are commonly applied during the simulation of accidental releases of selected materials during rail or highway transport. Modifications to these kinds of models, to allow their use inside a facility, would include defining the

location's interior boundaries and routing the pathways.

Other models exist for the short-term release of gases based on diffusion relationships (Palazzi 1982; Trinity Consultants). One typical model, called "Puff,"(U.S. Environmental Protection Agency, 1982) simulates the release and resulting dispersion of a gas with relatively short escape periods, as might occur from inadvertent releases from a pressure relief valve, reactor rupture disk, malfunctioning emission control device, or spill. This model estimates the concentration of the airborne contaminant at multiple locations, under various atmospheric conditions, and for any time duration after the release. "Puff" can accommodate variations in wind speed, atmospheric stability, molecular weights of the contaminant, and initial concentration levels. This type of model can be used, in its present form, to simulate releases in the near environment outside, or it may be modified to represent the interior of a facility where an intermittent release can occur. Sequencing such a model allows for the simulation of multiple batch sources as discussed previously.

The National Bureau of Standards has funded considerable research for the development of modeling techniques for estimating the generation, transport, and dispersion of smoke within facilities. In "Design of Smoke Control Systems for Buildings"(U.S. Department of Commerce 1983), researchers discuss a computerized model that allows determination of airflows and smoke distribution within a building. This model simulates individual rooms in a single or multi-story building, the effects of pressurizing various locations, and the effects

of changing pressure from outside the building. Where definition of physical parameters is poor, a series of verification tests are recommended to complete a simulation model. This model is extremely useful in conditions when the source contaminant is buoyant and a complex ventilation system may be in place.

A second model called "FAST - A Model for the Transport of Fire, Smoke and Toxic Gases," is designed to "predict the evolution of a fire in a room and the subsequent transport of the smoke and toxic gases which evolve" (Jones, 1984). Features of the model provide a logical means of simulating the dispersion of smoke or toxic materials throughout a facility by a forced ventilation system and by natural dispersion mechanisms. These modeling situations may have thermal gradients, density differences, and forced ventilation, as driving forces.

The Fire Research Station of England, a governmental body concerned with reducing fire-related injuries, produced a model for the movement of the products of combustion within buildings. Its report, "A Computer Model for Analysing Smoke Movement in Buildings" (Evers and Waterhouse 1978), addresses the distribution of combustion-produced contaminants, including the "stack effect" from vertical openings within buildings, exterior wind effects on pressure distribution within buildings, ventilation system and buoyant flow effects, and flow along corridors. This computer approach, in many ways, follows finite element stress analysis mapping techniques by employing nodes at selected points throughout a structure. At each node, information concerning mass conservation and flow conditions is defined. This would be analogous to applying Kirchhoff's first and second laws of electric circuit theory to an airflow network. By iterative processes, the directions and the concentrations of contaminants can be mapped as they progress through a facility.

Two additional kinds of models address more localized airborne contaminants within a facility: those resulting from infiltration from outside sources and those resulting from internally-generated sources. Both of these modeling efforts grew out of concern over the effects of living and working within airtight homes and buildings. Increased heating and cooling costs have resulted in newer buildings having fewer leaks and a reduction in the normal rate of replacement air in a ventilation system. These models address the problems of

leaks or infiltration between the inside and outside atmospheres. Using the previously discussed relationship for infiltration rate based on pressure differential and flow resistance, information about exterior wind and pressure conditions, and the geometry and number of the pathways, a site-specific infiltration model can be produced. Likewise, the dilution of internally-generated emissions can be modeled, based on air-exchange rates. Such modeling and verification tracing techniques are discussed in "Manual on Indoor Air Quality" (Electric Power Research Institute 1984).

These are just a few of the existing models which address transport of contaminants in a work place or near work place environment. Other models can be produced. As work place or near work place environments are often unique, models usually are site-specific and may contain empirical coefficients to simulate conditions at a particular location.

CONCLUSION

Occupational exposure to airborne contaminants has become a growing problem which needs to be addressed to reduce its potential hazards. Monitoring airborne contaminants can provide vital information about present conditions, but monitoring cannot recreate previous exposures or predict the possible results of future accidents. Modeling techniques can be used in conjunction with established monitoring procedures to explore past or possible exposures. Several types of models, which can be adapted to specific sites and particular conditions, are available to assure a reasonably safe and healthy environment.

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TABLE 1

I) Workplace / near workplace
   a) Inadequate ventilation
      1) Dilution ventilation for exposure control
      2) Stagnation points within facility
      3) Bouyancy effects
      4) Thermal layering
      5) Recirculation of contaminated air
   b) Inadequate hooding or capture equipment
      1) Original design not sufficient
      2) Additions to exhaust system resulting in degrading
      3) Leaks in hooding or dusting
      4) Loss of efficiency of fan or air handler
      5) Undetected blockages in ducting
   c) Process changes/conditions
      1) New materials produce volumes of fumes in excess exhaust equipment capacity
      2) Synergistic effects of materials
      3) Careless handling of materials
      4) Highly diffusive materials
   d) Intermittent releases
      1) Safety release valves
      2) Rupture disks

      3) Continued operation when collection equipment is off-line
      4) Seasonal conditions
II) Residence/ public buildings
   a) Inadequate ventilation (recent problem due to energy conservation practices)
      1) "Tight- house" effect
      2) Recirculation of normally-vented appliances
      3) Interior combustion heating devices
   b) Household chemicals
      1) Cleaning chemicals
      2) Paints
      3) Aerosols
      4) Off-gassing of certain materials
   c) Biologically-contaminated or active HVAC systems
   d) Household appliances
      1) Leaking heating equipment
      2) Improper exhausted

e) Leakages into building
   1) From combustion sources
   2) Other sources

TABLE 2

An Example of Particulates Modeling
Mass Balance Considerations

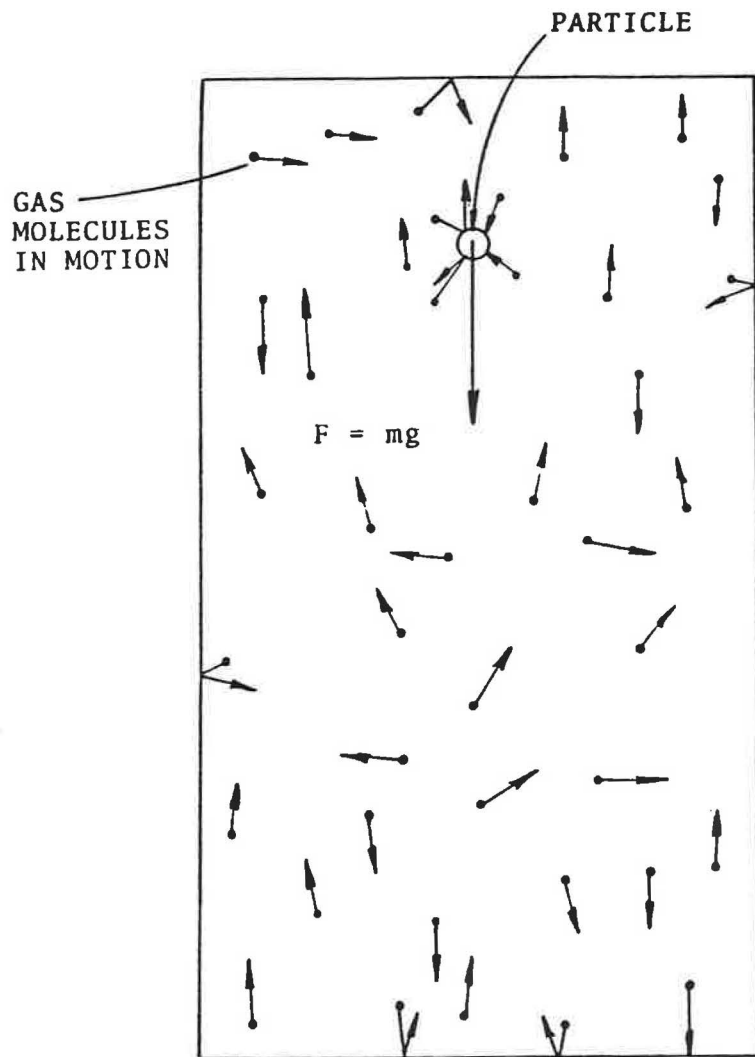|			
1) General	" mass in"	=	"mass out" I
2) Refined for size	W% "mass in" of a particular size	=	"mass out" II
3) Timing considerations	batch #1 + X% batch #2 "mass in" of a particular size	=	"mass out" III
4) Collection considerations	Y% of above escapes collection system	=	"mass out" IV
5) Chemical or physical reactions	100%-(Z% of above which combines with available moisture)	=	"mass out" V
6) Deposition	100%-(D% of above settle out or are attracted to surfaces)	=	"mass out" VI
7) Other considerations	110% of above to account for reintrainment by air handler	=	"mass out" VII

Figure 1. Random motion results in
multiple impacts on particle
by gas molecules resulting in
net forces which may resist
or compete with vertical force
due to gravity. Normal
convection currents may be of
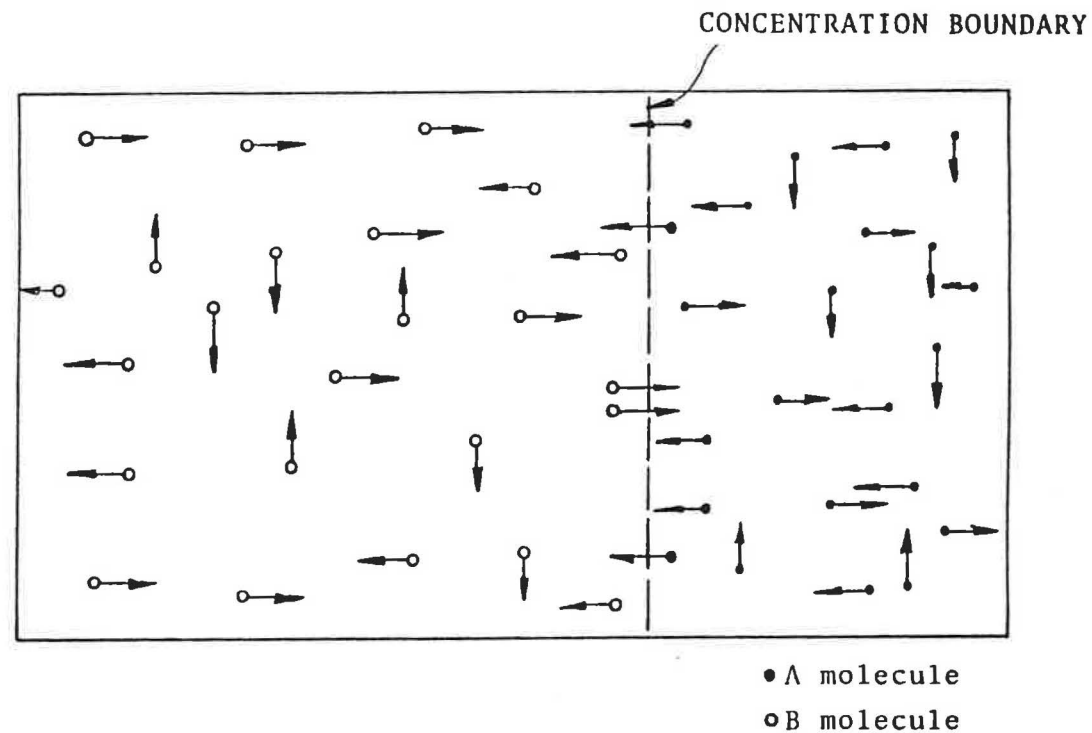same magnitude as vertical
force

Figure 2. Diffusion representation of molecules of A and B
crossing a boundary line of high concentration
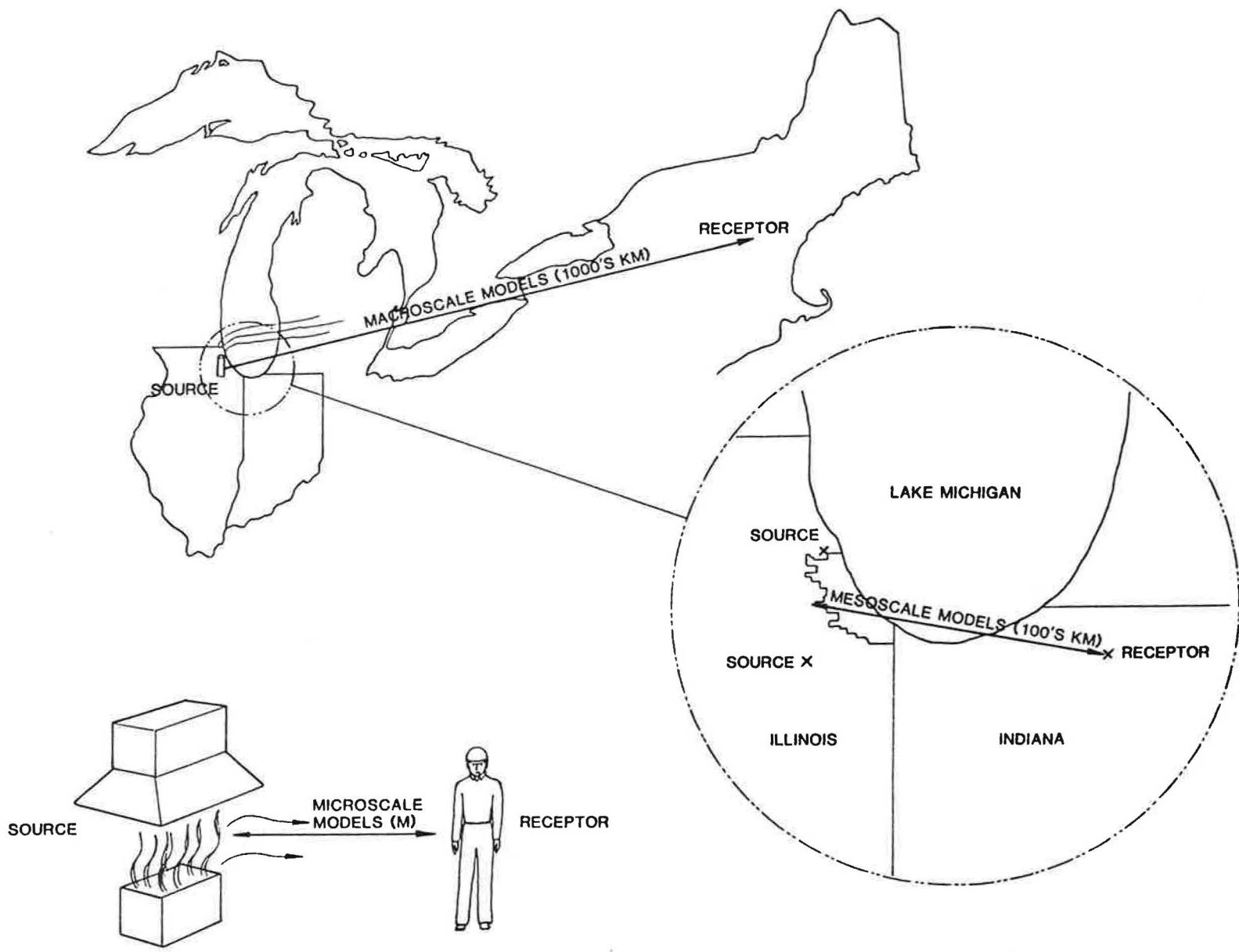separating A and B

● Λ molecule
○ B molecule

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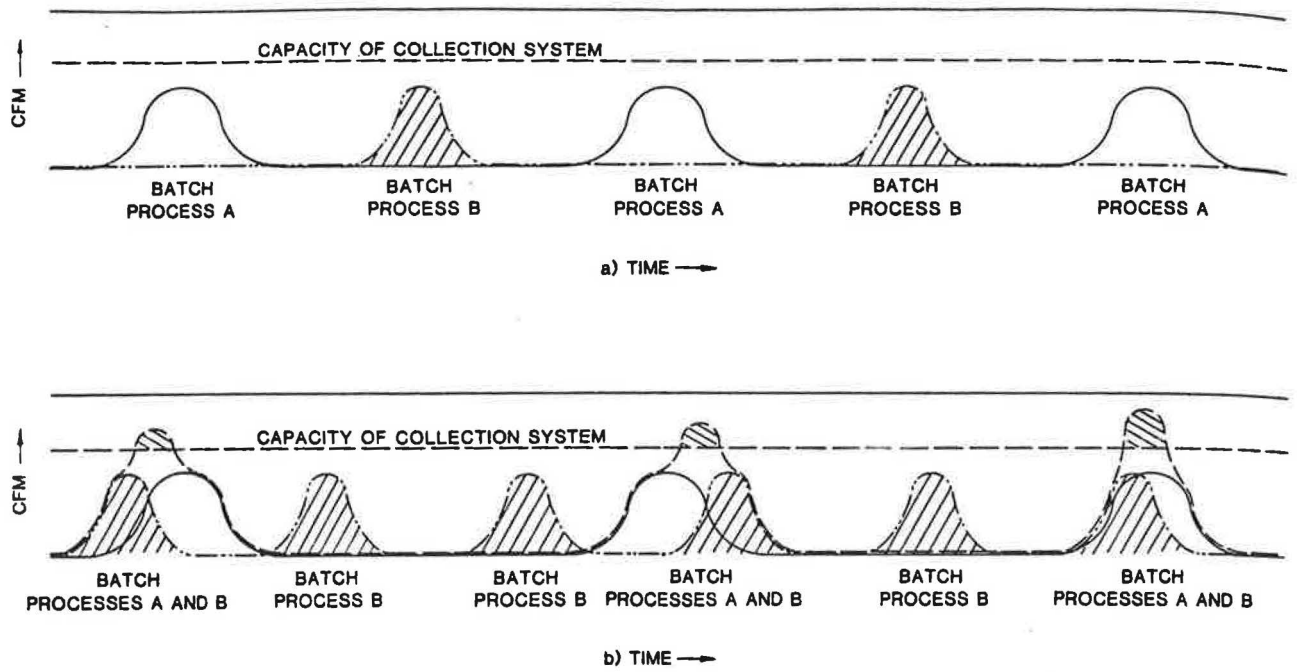Figure 3. *Relationship between distance/source receptor models and various model scales*

Figure 4. *Changes in sequencing of operations which can produce emissions that might exceed collection capacity of hooding system: (a) both batch process, A and B, have non-overlapping particulate generating cycles; (b) cycles overlap and collection system capacity is exceeded*
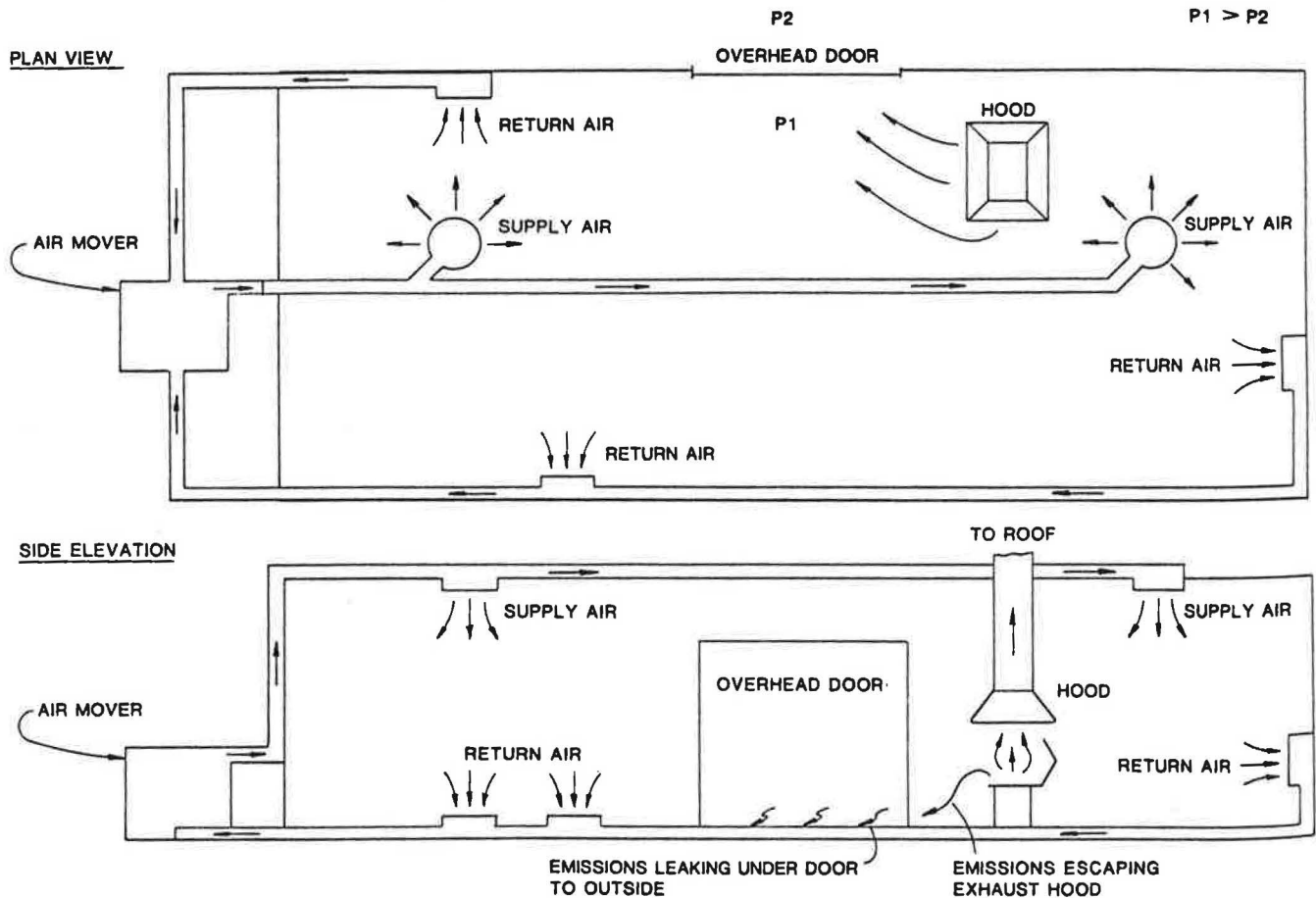

Figure 5

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