2. TRIM.Expo: GENERAL OVERVIEW AND BACKGROUND

Human exposures to pollutants can result from contact with contaminated air, water, soils, and food, as well as with drugs and consumer products. Exposures may be dominated by contact with a single medium, or concurrent contacts with multiple media may be significant. The nature and extent of such exposures depend largely on two things: (1) human factors and (2) the concentrations of a pollutant in the exposure media. Human factors include all behavioral, sociological, and physiological characteristics of an individual or cohort (*i.e.*, a group of people within a population that can be aggregated because the variation in exposure within the group is much less than the group-to-group variation across the population) that directly or indirectly affect a person's contact with the substances of concern. Important behavioral factors are contact rates with food, air, water, and soils. Activity patterns, which are defined by an individual's or cohort's allocation of time spent in different activities at various locations, are also significant because they directly affect the magnitude of exposures to substances present in different indoor and outdoor environments. Information on activity patterns are taken from measured data collected during field and telephone surveys of individuals' daily activities, the amount of time spent engaged in those activities, and the locations where the activities occur.

EXPOSURE

The contact between a target organism and a pollutant at the outer boundary of the organism. Exposure may be quantified as the amount of pollutant available at the boundary of the receptor organism per specified time period.

From an exposure assessment standpoint, the principal goal is to estimate or measure exposure as a function of both the relevant human factors and the measured or estimated pollutant concentrations in the contact, or exposure, media.

2.1 RATIONALE AND NEED FOR TRIM.Expo

The models currently being used by OAQPS for estimating human exposure to criteria air pollutants and HAPs do not include multimedia exposures. Furthermore, the models that estimate exposures to HAPs do not adequately estimate the spatial and temporal patterns of exposures for all of the HAPs listed in section 112(b) of the CAA. In addition, a review of currently available exposure models and modeling systems revealed that no single model or modeling framework meets the needs of OAQPS, or could function effectively by itself as part of the TRIM modeling system for estimating multimedia exposures for a population. Most models are constrained by the types of media and environmental processes that can be addressed. Furthermore, no model was identified that addresses the broad range of pollutants and environmental fate and transport processes that are anticipated to exist for HAPs and criteria air pollutants. Therefore, OAQPS concluded that the currently available exposure models and modeling frameworks are not sufficiently integrated multimedia systems that can provide the temporal and spatial resolution needed for estimating human exposures.

EXPOSURE ASSESSMENT

Measurement or estimation of the magnitude, frequency, duration, and route of exposure of biological organisms to pollutants in the environment for a specified time period. An exposure assessment also describes the nature of exposure and the size and nature of the exposed populations.

The TRIM exposure assessment process relates pollutant concentrations in the larger environmental media to pollutant concentrations in the immediate exposure media with which a human population has direct contact. TRIM.Expo simulates the movement of an individual and/or cohorts according to activity patterns through locations (called microenvironments) in a defined physical or political region (*i.e.*, exposure districts). The movement of individuals or cohorts coincides with pollutants at varying concentrations. This creates the potential for contact between individuals or cohorts and pollutants, thus allowing the estimation of exposures of various individuals and cohorts within the population to the pollutants of interest.

TRIM'S EXPOSURE ASSESSMENT PROCESS

TRIM.Expo relates pollutant concentrations in the larger environmental media to pollutant concentrations in the immediate exposure media with which a human population has direct contact.

While OAQPS supports and recognizes the value of collecting pollutant monitoring data for a variety of tasks (*e.g.*, assessment of trends, determination of attainment of standards for criteria pollutants, evaluation of exposure models), exposure modeling is clearly needed for several reasons. First, it is very difficult to monitor the exposure of humans to low concentration mixtures of a large number of environmental pollutants. Direct monitoring of exposure (*i.e.*, personal monitoring) has been carried out for a number of airborne pollutants, but only limited direct monitoring studies have been used to assess ingestion and dermal exposures. Furthermore, direct monitoring is a resource intensive process. This is especially true for large populations, where the planning, conduct, and evaluation of such direct monitoring studies can be a lengthy and costly process.

In addition, the use of modeling is required or preferred to address the following regulatory assessment needs.

- **Consideration of hypothetical situations.** Modeling can address situations such as impacts of planned facilities, proposed controls on existing facilities, exposure upon attainment of ambient standards, and accidental releases.

- **Temporal flexibility.** Modeling can be performed for a future time period.

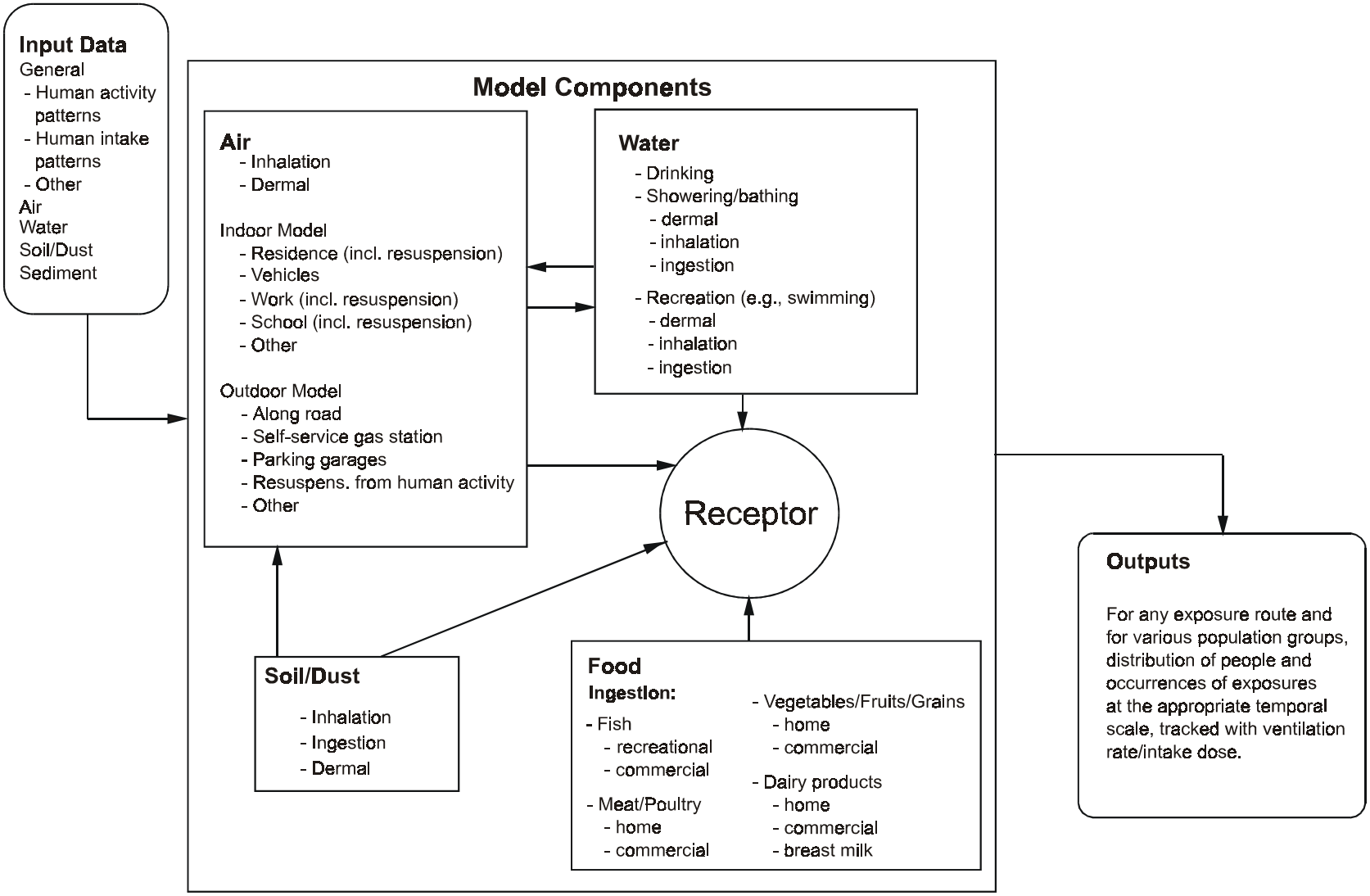
- **Source attribution.** Individual sources and/or source categories can be tracked throughout the modeling process to yield estimates of the relative contribution or importance of each source or source category to overall exposures.

- **Inclusion of more chemical species.** Personal monitoring techniques do not exist for all pollutants at the present time.

- **Representation of long-term conditions.** Modeling can address long-term time scales needed for assessment of chronic exposures. Personal monitoring studies are generally short-term studies, since wearing the monitoring equipment is too burdensome for long-term studies to be practical.

The extent to which modeled exposure estimates would differ between the currently available models and a truly coupled source-to-dose, multimedia modeling system, such as TRIM, is unknown. However, models that are not fully coupled have long been considered to lack scientific credibility. Therefore, OAQPS has determined that it is necessary to undertake efforts to develop a truly coupled multimedia exposure modeling framework. Figure 2-1 illustrates the selected modeling features of TRIM.Expo. Because TRIM.Expo will be developed using a phased approach, future development of the model may include model components in addition to those shown in Figure 2-1.

Figure 2-1
Conceptual Diagram of TRIM.Expo



2.2 IMPORTANT DEFINITIONS

To enhance understanding throughout this document, the following discussions define various terms relevant to exposure modeling. These definitions are based primarily on the guidelines published by EPA (U.S. EPA 1992a).

2.2.1 BASIC DEFINITIONS RELATED TO EXPOSURE

BASIC DEFINITIONS RELATED TO EXPOSURE

Environmental media	Components of the physical environment that carry a pollutant, and through which pollutants can move and reach organisms (*e.g.*, ambient air, ground water, surface water, surface soil, root zone soil, vadose zone soil, and several classes of vegetation).
Exposure	The contact between a target organism and a substance at the outer boundary of an organism. Exposure may be quantified as the amount of substance available at the boundary of the receptor organism per specified time period. For inhalation, exposure over a period of time can be represented by a time-dependent profile of the exposure concentration.
Exposure district	A geographic location within a defined physical or political region, where there is potential contact between an organism and a pollutant, and for which environmental media concentrations have been estimated either through modeling or measurement.
Exposure factor	A normalizing or standardizing factor used in an exposure assessment as a surrogate for specific information that is not available for a particular subject, cohort, or demographic group. These factors often are drawn from a distribution or range of data; see, for example, EPA's *Exposure Factors Handbook* (U.S. EPA 1997b).
Exposure medium	The part of the physical environment that surrounds or contacts organisms at the time of an exposure. The exposure media in TRIM.Expo include: outdoor air, indoor air (multiple microenvironments), tap water, home-grown food, locally-produced food, prepared food, breast milk, house dust, soil, swimming pools, and other recreational surface water.
Exposure pathway	The physical course a pollutant takes from the source to the organism exposed. An exposure pathway describes a unique mechanism by which an individual or population is exposed to pollutants or physical agents at, or originating from, a site. Each exposure pathway includes a source, or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (such as air) or media (in cases of intermedia transport, such as water to air) is also included.
Exposure route	The way a pollutant or physical agent comes in contact with an organism (*e.g.*, inhalation, ingestion, dermal contact).

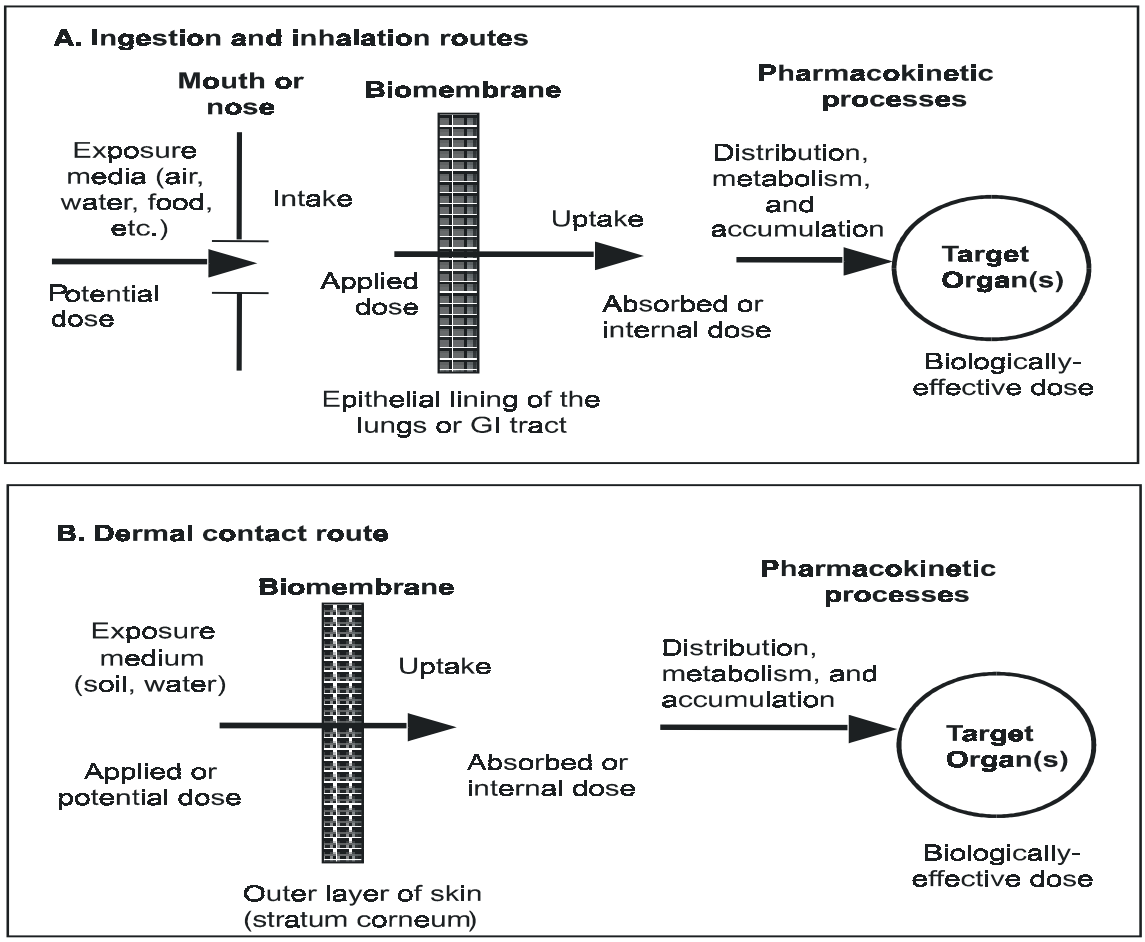
2.2.2 BASIC DEFINITIONS RELATED TO DOSE

TRIM.Expo will focus on the estimation of exposure only; estimation of dose, where appropriate, will need to be addressed by dosimetry modeling. Nevertheless, it is useful to review some concepts related to dose to create a context for understanding how the outputs of TRIM.Expo are likely to be used. This section contains definitions for several of these terms and clarifies the terminology used in this document. Figure 2-2 illustrates the relationships among many of these terms for the inhalation, ingestion, and dermal contact routes.

BASIC DEFINITIONS RELATED TO DOSE

Absorbed dose	The amount of a pollutant crossing the exchange boundaries of an organism after contact, usually expressed as the mass of pollutant absorbed into the body per unit body mass per unit time, such as mg/kg/d. Absorbed dose is calculated from the intake and absorption efficiency. For inhalation exposure, absorbed dose is the amount of material that passes from the gas volume of the lung into the blood. For ingestion exposure, absorbed dose is the quantity of pollutant that passes from the gastrointestinal tract across the gut wall and into the blood stream. For dermal exposure, absorbed dose is the quantity of material that passes through the stratum corneum into the living cells of the epidermis and dermis and then into the blood stream. In some cases, the absorbed dose is referred to as the internal dose.
Applied dose	The amount of a pollutant given in mg/kg/d that comes in contact with the living tissue of an organism by entering into the lungs, by entering the gastrointestinal tract, and/or by crossing the stratum corneum into the living cells of the epidermis. In some experimental designs, the applied dose is referred to as the administered dose.
Average Daily Dose (ADD)	Dose rate within a population averaged over body weight and an averaging time and typically expressed in terms of mg/kg/d.
Intake	The process by which a pollutant is physically moved through an opening in the outer boundary (usually the mouth or nose) of the human body, typically via ingestion or inhalation.
Lifetime Average Daily Dose (LADD)	The average daily dose within a population when the averaging time is the expected individual lifetime. The LADD is usually expressed in terms of mg/kg/d. The LADD is used for compounds with carcinogenic or chronic effects.
Potential dose	An approximation of applied dose that is simply the amount of pollutant in the food or water ingested, air inhaled, or material applied to skin. The potential dose for ingestion and inhalation is analogous to the administered dose in a dose-response experiment. For the dermal route, the potential dose is the amount of pollutant applied or the amount of pollutant in the medium applied to skin.
Uptake	The process by which a substance crosses an absorption barrier and is absorbed into the body. Although the chemical is often contained in a carrier medium, the medium itself is typically not absorbed at the same rate as the chemical.

Figure 2-2
Illustration of the Relationships among Exposure and Dose for the Inhalation, Ingestion, and Dermal Contact Routes



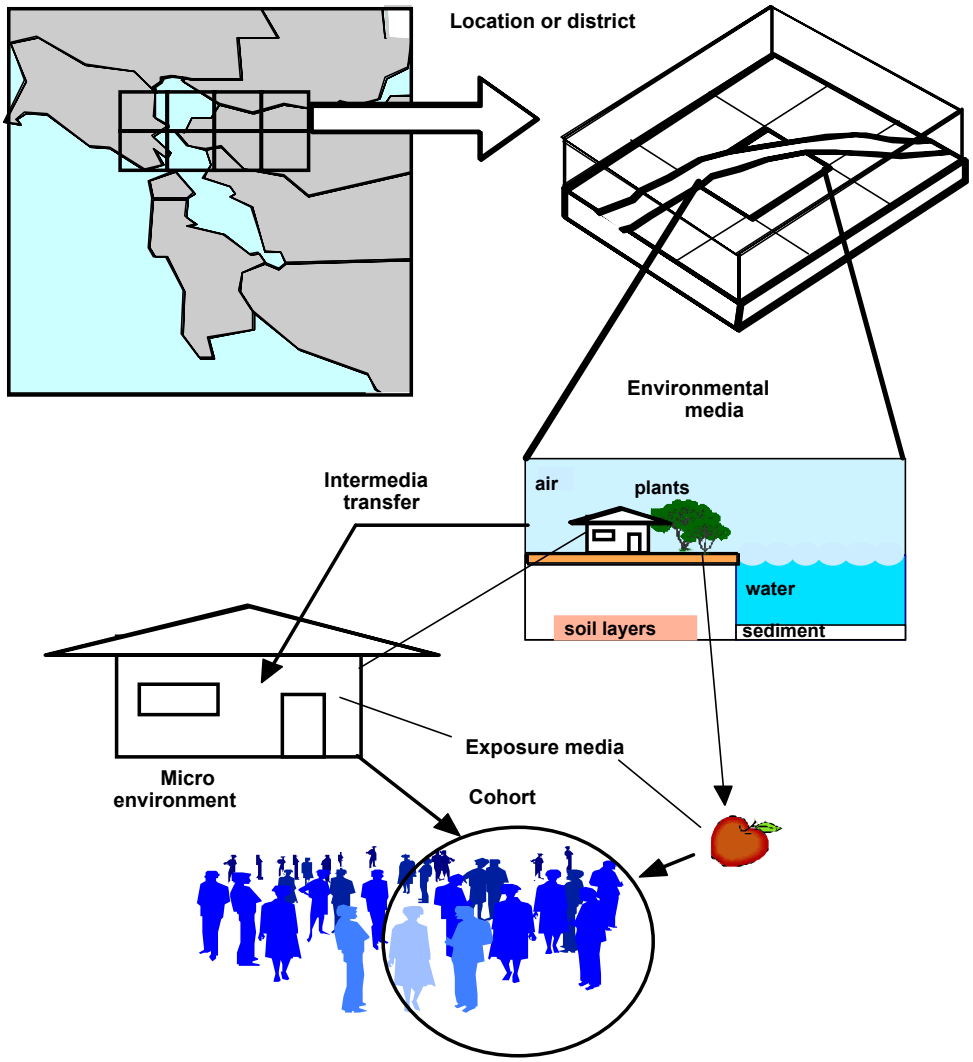
2.2.3 OTHER IMPORTANT TRIM.Expo DEFINITIONS

Figure 2-3 illustrates the interconnected nature of the relationships among location (districts), environmental media, microenvironments, intermedia transfers, exposure media, and cohorts as defined in this section.

OTHER IMPORTANT TRIM.Expo DEFINITIONS

Cohort	A group of people within a population with the same demographic variables who are assumed to have similar exposures. Individuals within a cohort can be aggregated for exposure assessment purposes because the variation in exposure within the cohort is much less than the cohort-to-cohort variation across the broader population.
Intermedia transfer	An algorithm for "linking" the environmental media with the microenvironmental media that exposed individuals occupy (*e.g.*, air compartments) or the exposure media with which they come in contact (*e.g.*, air, water, food, soil). An intermedia transfer algorithm relates the pollutant concentration in a microenvironmental medium to the concentration in an ambient environmental medium that provides pollutant inputs to that microenvironment.
Microenvironment	A defined space in which human contact with an environmental pollutant takes place and which can be treated as a well-characterized, relatively homogeneous location with respect to pollutant concentrations for a specified time period. Microenvironments include spaces within buildings (*e.g.*, rooms, household volumes, restaurants, schools), spaces inside vehicles (*e.g.*, cars, buses, trains), and other spaces within which humans have contact with environmental pollutants (*e.g.*, swimming pools, bathtubs, lakes, rivers).

Figure 2-3
Relationships among Districts, Environmental Media, Microenvironments, Intermedia Transfers, Exposure Media, and Cohorts



2.3 APPROACH USED IN DEVELOPING TRIM.Expo

Based on a review of currently available exposure models and modeling systems (discussed in Chapter 3 of this report), no single model was identified that would exclusively satisfy all of the modeling features and requirements that TRIM.Expo will satisfy. However, several components of existing models were found to meet certain requirements of TRIM.Expo, and these components will be adapted for use in TRIM.Expo. For example, EPA is developing the Air Pollutant Exposure Model (APEX), which is based on EPA's human exposure models, probabilistic NAAQS Exposure Models (pNEM), and Hazardous Air Pollutant Exposure Model (HAPEM4). The APEX framework will be adapted to address both short- and long-term

exposures for the inhalation pathways modeled by TRIM.Expo. It also includes the incorporation of activity patterns to track cohorts and individuals as they move among exposure media. The pNEM model also includes a mass balance treatment of the relationship between environmental medium (*i.e.*, outdoor air) and exposure medium (*i.e.*, indoor air), as well as the characterization of uncertainty and variability.

For the ingestion pathways, exposure algorithms from the California Total Exposure Model for Hazardous Waste Sites (CalTOX) will be incorporated into TRIM. Expo. The CalTOX framework is capable of modeling multimedia transport and transformation of pollutants, and multipathway exposure for humans.

For the first prototype of TRIM.Expo, the exposure routes will be limited to inhalation and ingestion. However, TRIM.Expo will eventually be capable of modeling exposures from all three main routes of environmental exposure: inhalation, ingestion, and dermal contact.

2.4 TAXONOMY OF EXPOSURE ATTRIBUTES FOR MULTIMEDIA POLLUTANTS

Despite the large amount of data and the numerous variables used in an exposure assessment, a relatively small subset of these variables actually significantly influences the estimated exposures (Morgan and Henrion 1990). However, little is known about how to isolate this defining set of variables and data. One potential method of sorting and organizing the complex web of exposure information that is collected during a modeling study is to develop a taxonomy of exposure-related questions that an exposure model is expected to answer. The purpose of this taxonomy is to first identify the relevant characteristics or properties as *building blocks*, and then rank the attributes of exposure that are important to both analysts and decision-makers. The taxonomy of exposure-related questions derived during TRIM.Expo's development is presented in the following sections.

2.4.1 EXPOSURE CHARACTERIZATION PROCESS AND EXPOSURE ATTRIBUTES

Most of the inhalation pollutant exposures addressed by TRIM.Expo are location-specific and the individual's or cohort's locations and activities need to be tracked over time and space. Accounting for time and space is an important factor in determining exposure because of the spatial and temporal differences in pollutant concentrations among different exposure media. A log of the time- and activity-specific locations of individuals or cohorts and the time-specific concentrations of pollutants in the relevant exposure media is needed to create such an *exposure characterization process.* A critical issue in the exposure characterization process is to identify appropriate and transparent methods to combine pollutant concentration data with activity tracking information to assess both short- and long-term exposures. To develop the exposure characterization process for TRIM.Expo, the following attributes that define an exposure event (*i.e.*, human activities that bring people in contact with one or more pollutants in a microenvironment) were identified:

- Route of exposure;

- Temporal and spatial scale of the pollutant concentration;
- The seasonality of human activities and pollutant concentrations;
- Time scale of the health effects;
- Duration of the exposure event;
- Contributing environmental media;
- Exposure media; and
- Demographic characteristics of the exposed individual/cohort (*e.g.*, age, gender).

As shown in Figure 2-2, the route of exposure refers to the way the pollutant can enter the receptor during the exposure event (*i.e.*, inhalation, ingestion, dermal contact) and lead to actual absorption of the pollutant into the body (referred to as the route of potential uptake, *i.e.*, the process by which a pollutant crosses an absorption barrier and is absorbed into the body). The health effects resulting from an exposure may vary significantly among these three routes of exposure. Moreover, both the exposure media and exposure activity tend to be strongly associated with the route of potential uptake. For example, air is associated with the inhalation route, and the inhalation rate varies significantly with the type of activity. Water, food, and soil are associated with the ingestion route and with eating and hand-to-mouth related activities.

Pollutant concentrations over time and space are needed to construct an exposure event. If a pollutant shows little spatial variation in concentration over a large region, even if there is time variation in that region, there is little need for large numbers of separate geographic regions in an assessment. Similarly, for pollutant concentrations that do not vary significantly in time, even if they show large spatial variation, using longer time steps may be possible than that needed for a pollutant whose concentrations vary more greatly with time. TRIM.Expo will be flexible with regard to level of spatial resolution.

The interplay between the periodicity of human activities and pollutant levels is an important attribute for tracking by the exposure-event model. The often cyclic nature of human activities and pollutant levels is typically expressed in terms of seasonality in exposure modeling. Seasonality also affects people's habits such as whether they leave windows open or closed. This has a strong influence on the ability of outdoor pollutants to penetrate indoors. Another important attribute related to time that can affect exposure levels is the difference in activity patterns generally observed between weekdays and weekends. A person's activities, particularly those who work, are usually significantly different on weekends than they are on weekdays. It is important for an exposure model to distinguish between weekdays and weekends when constructing exposure-event sequences. TRIM.Expo will retain this information so that it is available to an analyst performing an exposure assessment. It should also be noted that in addition to a weekday/weekend effect in activity patterns, the emissions of many pollutants have a discernable weekday/weekend difference. The combination of effects caused by the day of the week, particularly weekdays versus weekends, makes this an important factor in exposure assessments.

The time scale of exposure associated with health effects for a particular pollutant also strongly affects the temporal resolution required of the exposure event-model. For some pollutants, including most of the criteria air pollutants and those HAPs associated with health effects due to short-term exposures, exposures may need to be assessed for periods as short as one hour or less. For many HAPs, only long-term cumulative exposure may need to be

characterized. TRIM.Expo will have the capability of aggregating exposures up from small time increments so that the subsequent time profile of exposure can match the time pattern or period of concern from a health perspective.

The durations of the exposure events and human activities are also important considerations in the structure of the exposure-event model. Other factors that affect the structure of the exposure-event model are the demographic characteristics of an exposed individual or cohort, such as age or gender, that may influence both the activity pattern and the health response to exposure. Proximity to particular emission sources, or health status, may also be important factors that affect the structure of the exposure event.

Cohorts are subsets of a population grouped so that the variation of exposure within a cohort is much lower than the variation between/among cohorts. The reason for using this approach is because the available data are not adequate to estimate the exposure of each individual in a population. Therefore, information about people who are expected to have similar exposures is aggregated together to make more efficient use of the limited data. The cohorts are assumed to contain people with exposures that can be characterized by the same probability distributions for key characteristics. The demographic variables used to describe a cohort are selected to minimize the differences between individuals within the cohort. The model selects an individual from the appropriate cohort and uses that individual's activity pattern data to create an exposure-event sequence for that day. The exposure event sequence represents the exposure pattern for the entire cohort. TRIM.Expo account for within cohort variability through multiple runs of the model for the exposure duration under study. As new statistical techniques are developed, future versions of TRIM.Expo will be modified to use the best available approaches for characterizing time/activity data. At the present time, however, the current method of using cohorts is a useful technique for modeling the exposures of a large population in the absence of complete time/activity pattern data.

TRIM.Expo is being designed to allow flexibility in the user's ability to select a cohort's characteristics. The demographic variables (*e.g.*, age, gender, work status) that characterize a cohort can be modified by a user of TRIM.Expo providing that the appropriate data are available. The level of stratification in the identification of the cohorts' characteristics depends on the particular problem being addressed and on the availability of data. Typically, input data for the demographic variables of a cohort are taken from census data. However, TRIM.Expo can be run using data supplied by the analyst as long as it is formatted correctly and provides sufficient information to execute the model. Hence, the cohorts' characteristics can be chosen for individualized studies on a site-specific or case-specific basis.

2.4.2 DIMENSIONS OF THE EXPOSURE ASSESSMENT PROBLEM

The exposure attributes noted above were organized into a set of *key* exposure dimensions. The three most important dimensions of the exposure assessment problem were determined to be the (1) route of exposure, (2) time scale of an exposure event relevant to the pollutant's associated effects, and (3) degree of location dependence (*i.e.*, dependence of exposure on the location of the exposed subject). Addressing these three dimensions has a significant impact on the structure of the exposure model (*e.g.*, on the exposure media included, the degree of spatial resolution, and the level of temporal and spatial aggregation).

For example, consider a model used to assess inhalation exposures to pollutants with health effects that depend on the number and duration of contacts above some threshold concentration versus an exposure model used to assess ingestion contact with a pollutant that has health effects that depend primarily on a lifetime cumulative intake. The former model requires a compilation of short-term exposure events and must provide relatively detailed information on the location of the exposed individual. For the latter model, different temporal and spatial detail is required about the exposed individuals or cohorts (*i.e.*, a detailed time/location profile of the exposed cohort or individual is not as crucial as information on the location of the exposed cohort's/individual's food or water supply and the cumulative intake of food or water from a specific supply).

The primary time scales for exposure assessment models vary from short-term resolution (*e.g.*, minutes to hours and days) to long-term resolution (*e.g.*, days to months and years). Short-term resolution allows one to assess both cumulative intake as well as the number and duration of peak exposure events. Long-term resolution allows primarily for the assessment of cumulative intake. The quantitative distinction between short-term and long-term depends to some extent on the pharmacokinetics (*i.e.*, uptake and distribution) and toxicokinetics of the pollutants being considered.

Location-dependence specifies the level of detail required for the time-activity budget of an exposed individual. For example, to address inhalation exposures where pollutant concentrations vary significantly among several districts in which the exposed cohort or individual lives and differ strongly between indoor and outdoor microenvironments, location-dependence is high. However, if the properties of the pollutant are such that concentrations are similar in almost all microenvironments, then location-dependence is lower. For instance, for ingestion exposures to a pollutant in ground water that is distributed throughout a region, the location of the exposed cohort or individual is much less important than the source of the cohort's drinking water.

The above set of attributes gives rise to a broad range of exposure situations, such as short-term inhalation exposure with strong location dependence, long-term ingestion exposure with weak location-dependence, and short-term dermal contact exposure. The general exposure-event function used in TRIM.Expo can be adapted across the broad range of problems defined by these attributes. In some situations, combining two or more sets of exposure model attributes may be necessary (*i.e.*, combining long-term ingestion exposures that are weakly location-dependent with short-term inhalation exposures that are strongly location-dependent). TRIM.Expo will be designed to combine exposure model attributes, where possible.

2.5 TRIM EXPOSURE-EVENT CONCEPT

As stated previously, human exposures to pollutants may be dominated by contacts with a single medium, or concurrent contacts with multiple exposure media may be significant. The nature and extent of such exposures is mainly influenced by the pollutant concentrations in the exposure media and human factors (*i.e.*, behavioral, sociological, and physiological characteristics of an individual or cohort that directly or indirectly affect contact with pollutants). Therefore, from an exposure assessment standpoint the principal challenge is to estimate or

measure the individual or cohort exposure as a function of both the relevant human factors and the pollutant concentrations (measured and/or estimated) in the exposure media.

TRIM.Expo is built around the concept of simulating a series of exposure events. Exposure events are human activities that bring people in contact with a contaminated exposure medium within a specified microenvironment at a given geographic location for a specified period of time. In TRIM.Expo, exposure of each individual or cohort is determined by a sequence of exposure events specific to the individual or cohort. The exposure-event sequence is a chronologically ordered series of events that identifies the locations and amount of time spent in those locations. Each exposure-event sequence consists of a series of events with durations ranging from one to 60 minutes. Each exposure event assigns the individual or cohort to a particular combination of exposure district, microenvironment, and activity. To construct exposure events, an individual or cohort is linked with a series of time-specific activities and the exposure districts and microenvironments associated with those activities. The following important attributes of an exposure event are used to estimate the corresponding exposure concentrations and potential doses:

- Pollutant concentration in an environmental medium (*e.g.*, ambient air, surface water);
- Any significant intermedia transfer from environmental media to the exposure medium, (*e.g.,* from soil to house dust to air in an indoor microenvironment);
- Pollutant concentration in an exposure medium (*e.g.*, personal air, tap water);
- Duration of contact with the exposure medium; and
- Time scale of interest.