3. SUMMARY REVIEW OF EXISTING EXPOSURE MODELS AND RATIONALE FOR DEVELOPING TRIM.Expo

This chapter provides a review of current exposure modeling approaches and an overview of several existing and emerging exposure assessment models. The exposure models and modeling frameworks described in this chapter are critically compared and their respective strengths and weaknesses are assessed. A more detailed comparison of the features for each of the different exposure models identified is provided in Appendix B.

This review revealed that none of the models described here adequately meets the exposure modeling needs of OAQPS (see Section 1.1 for a discussion of the needs of OAQPS). The review in this chapter highlights the unique features included in TRIM.Expo for meeting OAQPS' modeling needs.

3.1 RATIONALE FOR DEVELOPING TRIM.Expo

Current models used by OAQPS for estimating human exposure to criteria and hazardous air pollutants do not include multimedia exposures. Furthermore, the models currently in use for estimating 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. Adopting or integrating existing models into a framework that meets OAQPS' needs represents the most cost-effective means for developing the tools needed to support the regulatory decision-making activities related to hazardous and criteria air pollutants.

Based on the review of currently available exposure models and modeling systems, there is no single model or modeling framework that meets the needs of OAQPS, nor any that could function effectively by itself as part of the TRIM modeling system for estimating multimedia exposures for a population. Most models are limited in the type of media and environmental processes that they are capable of addressing. No model currently exists that addresses the broad range of pollutants and environmental fate and transport processes that are anticipated to be encountered by OAQPS and other stakeholders when evaluating the risks from the multitude of hazardous and criteria air pollutants.

To summarize, none of the currently available exposure models is a sufficiently integrated multimedia model that provides the temporal and spatial resolution needed for estimating human exposures. It is not known to what extent modeled exposure estimates would differ between the currently available models and a truly integrated multimedia exposure model, such as TRIM.Expo. 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.

3.2 REQUIRED ATTRIBUTES OF THE TRIM.Expo MODULE

In addition to the five features that are required of the TRIM Exposure-Event module (listed in Section 2.1), OAQPS determined that the module must also (1) address varying time-steps (*i.e.*, one hour or greater) and provide sufficient spatial detail at varying scales; (2) have the "transparency" needed to be practical for a large and diverse group of users; (3) be modular in design; and (4) be easily accessible.

A key element in the development of TRIM.Expo is the need for the exposure model system or framework to be modular in design. A modular design is one that partitions the various algorithms necessary for evaluating the different aspects of an exposure assessment into generally discrete packages, or modules, which are able to interact with each other. By creating an exposure framework that is modular, only those model components necessary for evaluating particular aspects of the exposure assessment and/or endpoints of interest need to be used for a particular application.

OAQPS has decided to separately characterize uncertainty and variability on a selective basis. In concordance with EPA's probabilistic modeling guidance (U.S. EPA 1997c), a staged approach (as described in Section 4.2.9.3) will be used in characterizing uncertainty and variability (*i.e.*, rather than attempting to characterize uncertainty and variability for all parameters, sensitivity analyses will be used to identify a limited number of critical parameters that most influence the exposure outcomes and, thus, will be subjected to further analysis). These parameters will be examined in more detail to determine whether it is appropriate to separately characterize uncertainty and variability based on available information. For some parameters, such as body weight, there are sufficient data to support the explicit characterization of variability. However, for other parameters where data may be insufficient to support the separate characterization of uncertainty and variability, a distribution will be defined to reflect overall parameter uncertainty, including inherent variability.

3.3 OVERVIEW OF CURRENT MODELS AND MODELING APPROACHES

Exposure modeling approaches have long been based on physical principles. They were developed using a concise physical interpretation of the factors affecting exposures, which were determined prior to the development of a particular model. Examples of this type of modeling approach are the NAAQS Exposure Model (NEM) (U.S. EPA 1983) and several different indoor air quality mass balance models (Nazaroff and Cass 1986, Ryan et al. 1983, Özkaynak et al. 1982). A major limitation of these models is that they do not capture the full variability of people's activities as part of the exposure simulation. In addition, uncertainty in the values of the parameters used to make the estimates is not included.

To overcome these limitations, subsequent exposure models were developed that used a stochastic approach. This made it possible for estimates of population exposure to be characterized as distributions rather than point estimates. One of the first models developed to use this "probabilistic" approach was the Simulation of Human Activities and PollutantExposure, or SHAPE, model (Ott 1982, Ott 1984, Ott et al. 1988). Shortly afterward, a probabilistic version of NEM was developed. The model (there were actually several pollutant-specific versions) was referred to as the probabilistic NAAQS Exposure Model, or pNEM (McCurdy and Johnson 1989). While it would be difficult to accurately represent the activities of an individual due to day-to-day variation, the general behavior of groups or subsets of the population can be well represented using stochastic processes. By explicitly including variability and uncertainty in the models, the effects of the uncertainty on the modeled exposure values can be evaluated.

Many of the early models stressed exposures to industrial and mobile sources and attempted to account for the variability in those exposures. Some of the earliest work in exposure modeling attempted to simulate human exposures to lead and carbon monoxide. With the periodic review and revision of the NAAQS, models were developed to assess the exposures of the population to the air pollutants for which ambient standards had been established.

Over time, it has become clear that there are important outdoor sources other than large industrial facilities and mobile sources, that exposures can occur both indoors and outdoors, and that the sources of the pollutants can likewise be found both indoors and outdoors. Over the past decade, increasingly sophisticated methodologies have been developed for modeling and evaluating exposures. However, there is currently no single exposure model that can estimate all pollutants, all sources, and all routes of exposure. The models that have emerged are largely still restricted to single-medium exposure assessments. In recent years, emphasis has been placed on developing modeling frameworks that can assess multimedia, multipollutant human exposures within a unified framework. This type of approach is relatively new, and a usable framework for conducting multipathway exposure assessments has yet to emerge. This chapter provides a general overview of modeling approaches used to date to estimate exposures.

Table 3-1 identifies numerous air quality and exposure models and modeling systems. More detailed information is given in Appendix B. that are currently publicly available along with the agency or group who was its major developer. Some exposure models are proprietary (*i.e.*, they are not "public domain") and therefore must be purchased from the developer. To facilitate public access, EPA has decided that no proprietary models will be considered in the development of TRIM.Expo. Examples of proprietary models include RISK*ASSISTANT® and LifeLine®.

The EPA's Office of Research and Development (ORD) is currently developing a number of exposure models and modeling systems. The development is on-going and therefore is not included in Table 3-1 at this time. However, since these models represent a major effort by ORD, a description of each has been included in Appendix B. Examples of new and continuing exposure modeling efforts at ORD include the development of the Stochastic Human Exposure and Dose Simulation (SHEDS) Model (see Section B.7.7). The SHEDS Model is a probabilistic, physically-based model that simulates aggregate exposure and dose for population cohorts and multimedia pollutants of interest. Initial applications of the model have assessed children's exposures to pesticides (SHEDS-Pesticides) and population exposures to PM (SHEDS-PM). Another effort within ORD is the development of the Modeling ENvironment for TOtal Risk (MENTOR) project. The objective of the on-going MENTOR project is to develop, apply through case studies, and evaluate state-of-the-art computational tools, that will support multipathway, multiscale source-to-dose studies and exposure assessments for a wide range of environmental pollutants. More detail about MENTOR can be found in Appendix B. The EPA's ORD is also engaged in the development of the MODELS-3/Multimedia Integrated Modeling System (MIMS). The MIMS will have capabilities to represent the transport and fate of nutrients and pollutants over multiple scales. The system will provide a computer-based problem solving environment for testing our understanding of multimedia (atmosphere, land, water) environmental problems, such as the movement of pollutants through the hydrologic cycle, or the response of aquatic ecological systems to land-use change.

Table 3-1
Air Quality and Exposure Models and Modeling Systems and Their Developers

Model	Developer
INDOOR AIR EXPOSURE MODELS	
INDOOR, EXPOSURE, and RISK	EPA/Office of Research and Development (ORD)
MAVRIQ (Model for Analysis of Volatiles and Residential Indoor Air Quality)	EPA/ORD
AMEM (ADL Migration Exposure Model)	EPA/Office of Pollution Prevention and Toxics (OPPT)
CPIEM (California Population Indoor Exposure Model)	California Air Resources Board (CARB)/Indoor Program
INDOOR / OUTDOOR AIR EXPOSURE MODELS	
pNEM (probabilistic NAAQS)	EPA/OAQPS
HAPEM4 (Hazardous Air Pollutant Exposure Model)	EPA/OAQPS
AirPEx (Air Pollution Exposure Model)	National Institute of Public Health and the Environment (RIVM) [Netherlands]
HEM (Human Exposure Model)	EPA/OAQPS
SHAPE (Simulation of Human Activities and Pollutant Exposure)	EPA/ORD
BEAM (Benzene Exposure Assessment Model)	EPA/ORD
pHAP (probabilistic HAP Exposure Model)	EPA/OAQPS
CONSUMER PRODUCT EXPOSURE MODELS	
CONSEXPO (CONSumer EXPOsure Model)	National Institute of Public Health and the Environment (RIVM) [Netherlands]
SCIES (Screening Consumer Inhalation Exposure Software)	EPA/ OPPT/Economics, Exposure, and Technology Division (EETD)
DERMAL	EPA/OPPT/EETD
MCCEM (Multi-Chamber Concentration and Exposure Model)	EPA/OPPT; updated by EPA/ORD
DIETARY EXPOSURE MODELS	
DEPM (Dietary Exposure Potential Model)	EPA/ORD
MULTIMEDIA EXPOSURE MODELS	
The Exposure Commitment Method	National Radiological Protection Board (NRPB) [United Kingdom]
Layton et al. (1992) Indoor/Outdoor Air/Soil Transport Model	U.S. Department of Energy (DOE)
CalTOX (California Total Exposure Model for Hazardous Waste Sites)	California Environmental Protection Agency/Department of Toxic Substances Control (DTSC)

Model	Developer
MMSOILS (Multimedia Contaminant Fate, Transport, and Exposure Model)	EPA/ORD
RESRAD (RESidual RADiation)	DOE and Argonne National Laboratory
USES (Unified System for the Evaluation of Substances)	National Institute of Public Health and the Environment (RIVM) [Netherlands]
BEADS (The Benzene Exposure and Absorbed Dose Simulation)	EPA/ORD
DERM (Dermal Exposure Reduction Model)	Stanford University/Environmental Engineering and Science Group
SCREAM2 (South Coast Risk and Exposure Assessment Model, Version 2)	South Coast Air Quality Management District
Integrated Spatial Multimedia Compartmental Model (ISMCM)	University of California (Los Angeles)/School of Engineering and Applied Science
EXPOSURE SIMULATION MODEL SYSTEMS	
GEMS (Graphical Exposure Modeling System)	EPA/OPPT
THERdbASE (Total Human Exposure Risk database and Advanced Simulation Environment)	EPA/ORD
MEPAS (Multimedia Environmental Pollutant Assessment System)	DOE and Battelle Pacific Northwest Laboratory

In general, the models that most closely meet the design goals for TRIM development are the focus of this chapter. Generally, these include models that are able to calculate short-term exposures (*i.e.*, 1 hour or shorter in duration), because they can be adapted to evaluate long-term exposures as well. They may also be able to explicitly treat variability and uncertainty. Other desirable model attributes are the utilization of a mass balance approach for estimating indoor air concentrations and the ability to track potential intake rates concurrent with exposure. For inhalation, this means providing estimates of the respiration rate (also called ventilation or breathing rate) for various activities. Additional useful features include accounting for indoor air emission sources and the ability to include geographic mobility (*e.g.*, commuting) in the exposure simulation.

One model that has many of the desirable attributes is pNEM/CO (Johnson et al. 1992b, Johnson et al. 1999). Although this model is for a single medium only (air), it already incorporates nearly all of the features needed for the inhalation component of TRIM.Expo (see Appendix B, Table B-1). In addition to the criteria listed above, pNEM/CO is well documented and is already being used by OAQPS as an input to regulatory decision-making. Furthermore, the 1992 version of pNEM/CO has undergone review by the Clean Air Scientific Advisory Committee.

For modeling the non-inhalation routes of exposure, the CalTOX model (McKone 1993a, b, c), developed at the Lawrence Berkeley National Laboratory (LBL), already includes many of the features needed. CalTOX has the ability to calculate multipathway exposures for organic chemicals and some metals. In addition, the model is stochastic and can quantify the variability and uncertainty in the exposure calculations. CalTOX, pNEM/CO, and several other models for estimating non-inhalation and inhalation exposures are discussed in the following sections.

3.3.1 INHALATION EXPOSURE MODELS

Perhaps the largest number of exposure models have been developed to assess the relationship between chemical releases to outdoor air and human exposure to these pollutants both indoors and outdoors. The early "indoor/outdoor" exposure models were the first to use newly collected information on activity patterns and microenvironmental concentrations. They simulated the microenvironmental concentrations based on empirical data derived from field measurements.

The EPA played a major role in developing exposure models that addressed the air pathway. The original purpose of these models was to assist in setting the ambient air quality standards by estimating the population exposure to air pollutants when alternative air quality standards were just met. One of the first models developed for this purpose was the NEM. The NEM was pollutant-specific and included versions for estimating exposures to ozone, carbon monoxide, and particulate matter. Later, a stochastic method for randomly selecting values for important variables was incorporated into the models. These models were referred to as "probabilistic" and hence are known as probabilistic NEM, or pNEM. Groups outside of EPA have used the NEM approach and developed variations of the NEM for specific applications. These models include SAI/NEM (Hayes et al. 1984, Hayes and Lundberg 1985), REHEX (Winer et al. 1989, Lurmann et al. 1990, Lurmann et al. 1992), and the Event Probability Exposure Model (EPEM) (Johnson et al. 1992a). All three of these models are related to the NEM approach, although significant variations now exist among the models (McCurdy 1994).

The EPA also developed exposure models for specific sources or types of sources. In 1985, EPA's Office of Mobile Sources (OMS) in conjunction with EPA's Office of Research and Development (ORD) developed a model for estimating human exposure to non-reactive pollutants emitted by motor vehicles. This model, named the Hazardous Air Pollutant Exposure Model for Mobile Sources, or HAPEM-MS, is similar in methodology to the pNEM models (Johnson 1995). However, it differs from pNEM in the averaging time for exposure concentrations. Instead of the hourly resolution of pNEM, HAPEM-MS aggregates the hourly exposure concentrations to 3-month averages, because HAPEM-MS is designed to address exposures to pollutants with carcinogenic and other long-term effects. Subsequently, HAPEM-MS has been enhanced and now is able to model exposures to numerous air toxics from different sources through the use of the air dispersion module of the Assessment System for Population Exposure Nationwide (ASPEN) model (SAI 1999). Given the model's ability to estimate exposures from different types of sources (*i.e.*, not just mobile sources), the Mobile Sources, or "MS," designation has been dropped from the model's name. The latest version of the model is called HAPEM4.

Agencies in other countries have developed exposure models that are specific to their population. The Dutch, for example, have developed an inhalation exposure model based on the pNEM approach which is used for estimating exposures of people in the Netherlands (although the model may be adapted for any location). The model, called the Air Pollution Exposure Model, or AirPEx (Freijer et al. 1997), works on a personal computer (PC) using Windows®.

The PC platform enhances the accessibility of the model to various stakeholder groups that do not have extensive programming expertise. Several new exposure models are being designed to run on PCs, and some existing models, previously run on large machines, are being modified to run on PCs and via the Internet.

3.3.2 MULTIMEDIA EXPOSURE MODELS

Ingestion is another important route of exposure; however, modeling ingestion exposures presents a different set of requirements than does inhalation. For example, exposure to a particular pollutant from a certain food source can occur in a single location or in many places over time. The actual location where the exposure takes place may not be the same as where the contamination of the exposure medium occurred. Another difference is the time period for exposure due to ingestion. There may be long lags between the contamination of the exposure medium (*e.g.*, food, water, soil) and the time that exposure occurs. Much of the exposure modeling that has been done for ingestion pathways has been conducted as part of multimedia modeling efforts. Hence, ingestion exposures discussed in the context of multimedia exposure models.

Efforts to assess human exposure from multiple media date back to the 1950s when the need to assess human exposure to global fallout from nuclear testing led rapidly to a framework that included transport through and transfers among air, soil, surface water, vegetation, and various paths of the food chain. Efforts to apply such a framework to non-radioactive organic and inorganic toxic chemicals have been more recent and have not as yet achieved the level of sophistication that exists in the radioecology field.

The CalTOX program was developed for the California EPA as a set of spreadsheet models and spreadsheet data sets to assist in assessing human exposures to toxic substances released in multiple media (McKone 1993a,b,c). CalTOX consists of two component models: a multimedia transport and transformations model that is based on both conservation of mass and chemical equilibrium, and a multipathway human exposure model that includes ingestion, inhalation, and dermal uptake exposure routes. It is a mass balancing model that also includes the ability to quantify uncertainty and variability. The exposure assessment process consists of relating pollutant concentrations in the multimedia model compartments to pollutant concentrations in the media with which a human population has contact (*e.g.*, personal air, tap water, foods, household dusts/soils).

The Integrated Spatial Multimedia Compartmental Model (ISMCM) has been under development for the past 15 years. The ISMCM considers all media, biological and non-biological, in one integrated system. The model includes both spatial and compartmental modules to account for complex transport of pollutants through the ecosystem. Assuming conservation of mass, ISMCM predicts transport by using estimates of intermedia transfer factors. A newer version of ISMCM, called MEND-TOX, is currently under evaluation by EPA.

The Indirect Exposure Methodology (IEM) is a significant current EPA methodology for multimedia, multipathway transport, fate, and exposure modeling. This methodology identifies procedures for estimating the indirect (*i.e.*, non-inhalation) human exposures that can result from the transfer of emitted air pollutants to soil, vegetation, and water bodies. The IEM addresses exposures for a variety of receptor scenarios (*e.g.*, subsistence fisher) via inhalation, ingestion of food, water, and soil, and dermal contact. The most up-to-date version of the IEM methodology is scheduled to be published in late 1999 (U.S. 1999h). The updated documentation no longer refers to the methodology as IEM; it is now referred to as the Multiple Pathways of Exppsure (MPE) methodology. Appendix B provides a more detailed discussion of the IEM model.

3.4 STRENGTHS AND LIMITATIONS OF EXISTING MODELS

TRIM development is designed to focus on the processes that have the greatest impact on pollutant fate and transport and on human exposure. In order to have the same scientific basis as the rest of the TRIM system, TRIM.Expo needs to incorporate the same attributes, including: (1) mass conservation to the extent feasible and appropriate; (2) ability to characterize uncertainty and variability; (3) capability to assess multiple pollutants, multiple media, and multiple exposure pathways; and (4) ability to perform iterative analyses. Hence, these four design attributes serve as the basis for critically comparing the strengths and limitations of existing exposure models.

By assessing the strengths and limitations of publicly available exposure models and modeling systems in regard to the needs defined for TRIM development, a determination can be made regarding the features of the various models that may be incorporated into TRIM. Table B-2 in Appendix B compares the strengths and weaknesses of some of the most commonly used EPA and non-EPA exposure models. The models in this table are included because they each have one or more of the desirable attributes identified above needed for TRIM.Expo.

The pNEM/CO and pNEM/O_3 (for ozone) models have been used extensively by OAQPS in its reviews of the CO and ozone NAAQS, respectively (see Table B-3 in Appendix B for a descriptive overview of many of the features of pNEM/CO). The pNEM/CO uses a stochastic approach for selecting input variables. This stochastic approach allows both sensitivity and uncertainty to be incorporated into the model operation. Many of the model's input variables come from measured data, thereby decreasing the uncertainty associated with the model's estimates. The pNEM/CO treats human exposure as a time series of the convergence of (1) human activities occurring in a particular microenvironment and (2) air quality in those microenvironments. The model is also designed to provide estimates of the intake dose associated with exposures. The focus on time series modeling and intake dose allows analysts to produce estimates of the "dose profile" of exposed people (McCurdy 1995). A disadvantage of the pNEM/CO model in its current form is that it is difficult to execute. The pNEM/CO model, as with all of the pNEM models, is a single pollutant, single media model.

The CalTOX model (see Table B-4, Appendix B) consists of two main components: a multimedia transport and transformation model and a multipathway human exposure model. The multimedia transport and transformation model is based on both the conservation of mass and chemical equilibrium. The multimedia transport model is a dynamic model that can be used to assess time-varying concentrations of pollutants introduced initially into the soil or released to the air, soil, or water. The exposure model has 23 exposure pathways encompassing all three environmental routes of exposure, which are used to estimate average daily doses within a human population in the vicinity of a hazardous air pollutant release site. The exposure assessment process consists of relating pollutant concentrations in the multimedia model compartments to pollutant concentrations in the media with which a human population has contact (*e.g.*, personal air, tap water, foods, house dust). This explicitly differentiates the environmental media pollutant concentrations from the pollutant concentrations in the exposure media to which humans are exposed. In addition, all input variables are taken from distributions.

The CalTOX model is limited in the extent of the environmental settings for which it can be applied. For example, it has limited effectiveness for settings where there is a large ratio of land area to surface water area. In addition, it was developed for a limited range of pollutants (*i.e.*, non-ionic organic chemicals in a liquid or gaseous state). As a result, CalTOX does not provide adequate flexibility in the environmental settings or the chemical classes it models. Also, CalTOX does not allow spatial tracking of a pollutant, hence it is not directly applicable to the TRIM approach.

HAPEM has undergone many enhancements in recent years. The most recent of these is the ability of the model to use air quality concentration estimates from the ASPEN. This latest version of HAPEM is designated HAPEM4 (see Table B-5, Appendix B).. It allows exposure to population cohorts to be simulated at the census tract level. This is a much finer spatial resolution than was previously possible. It also means that calculation of population exposures no longer needs to rely solely on data from fixed-site monitors. This is important for estimating exposures to HAPs because widespread monitoring networks for these pollutants are not available.

The HAPEM4 calculates long-term average exposure concentrations in order to address exposures to pollutants with carcinogenic and other long-term effects. Thus, HAPEM4 does not preserve the time-sequence of exposure events when sampling from the time/activity database. This means that information to evaluate possible correlations in exposures to different pollutants due to activities that are related in time is not preserved. Also, the model does not include any measures of the ventilation rate associated with an activity, so that there is no ability to calculate the potential dose received when engaging in various activities.

The IEM has been used by EPA in a variety of applications and has undergone extensive scientific peer review. The methodology includes fate and transport algorithsms, exposure pathways, receptor scenarios, and dose algorithms. It also includes procedures for estimating the indirect (*i.e.*, non-inhalation) human exposures and health risks that can result from the transfer of pollutants to soil, vegetation, and water bodies.

The IEM is limited, relative to OAQPS's needs, because the methodology, as currently implemented, can be applied only to pollutants that are emitted to air. While IEM is a significant current EPA methodology for multimedia, multipathway exposure modeling, it does not fully satisfy the needs of OAQPS. An important limitation of IEM, relative to the needs of OAQPS, is that it consists of a one-way process through a series of linked models, using as inputs the annual average air concentrations and wet and dry deposition values from external air dispersion modeling. As a result, it is not a truly coupled multimedia model and does not have the ability to maintain a full mass balance or model "feedback" loops between media or secondary emissions, nor can it provide a detailed time series estimation of media concentrations and resultant exposures. The methodology does not provide for the flexibility OAQPS needs in site-specific applications or in estimating population exposures. Significant site-specific adjustments must be made to allow for spatially tracking the relationship between concentrations and exposures. Much of the focus of the methodology is on evaluating specific receptor scenarios (*e.g.*, recreational or subsistence fisher) that may be indicative of high-end or average exposures rather than on modeling the range of exposures within a population (*i.e.*, IEM cannot estimate population exposure distributions). Appendix B provides more detailed discussion of the IEM model.

The Integrated Spatial Multimedia Compartmental Model (ISMCM) has been undergoing development at the University of California's (Los Angeles) School of Engineering and Applied Science for the last 15 years. The latest version of ISMCM, called MEND-TOX, is currently under evaluation at EPA's Office of Research and Development. The ISMCM considers all media in a single integrated system. It includes both spatial and compartmental modules to account for complex transport of pollutants through the ecosystem. The model is mass conserving and is able to estimate intermedia transfer factors desirable for TRIM.

An important limitation of ISMCM for use in TRIM.Expo development is the lack of flexibility in the spatial configuration of the model. The links and compartments in ISMCM are predetermined, thus limiting its ability to be fully integrated into a system like TRIM. Another drawback to ISMCM is that it is not structured to incorporate uncertainty and variability directly into the model outputs.

The South Coast Risk and Exposure Assessment Model (SCREAM2) provides the ability to model both inhalation and multipathway non-inhalation exposures (see Appendix B, Table B-6) (Rosenbaum et al. 1994). The model can use both measured and modeled air quality data, thus increasing the spatial resolution and number of the pollutants being studied. The SCREAM2 also includes an indoor air model for calculating indoor air concentrations. An internal submodel, called MULTPATH, calculates population exposures from several non-inhalation pathways, including food ingestion, water ingestion, and dermal adsorption. The inhalation exposure module accounts for mobility patterns of the population, indoor-outdoor exposure concentration differences, and physical exercise levels.

The use of SCREAM2 in the TRIM.Expo framework is limited because it is a deterministic model, so that input and output data are represented as point estimates rather than ranges or distributions. This limitation also restricts the model's ability to explicitly characterize uncertainty. The SCREAM2 framework consists of a one-way process through a series of linked models, based on annual average air concentrations and wet and dry deposition values from air dispersion modeling. In contrast, TRIM.Expo will have the capability to report exposure results for both short-term and long-term averages and will allow for "feedback" loops and secondary emissions.

The California Population Indoor Exposure Model (CPIEM) was developed to evaluate indoor exposures for the general California population as well as certain subgroups such as individuals who may be highly sensitive to indoor pollutants (see Appendix B, Table B-7) (CARB 1998a). The CPIEM combines indoor-air concentration distributions with Californians' location and activity information to produce exposure and dose distributions for different types of indoor environments. This is achieved through a Monte Carlo simulation whereby a number of location/activity profiles that were collected in Air Resources Board (ARB) studies are combined with airborne pollutant concentrations for specific types of microenvironments (*e.g.*, residences, office buildings).

Concentration distributions for many pollutants and microenvironments are included in the CPIEM database. However, for pollutants and microenvironments not included in the database, CPIEM presents two alternatives. The first option is to estimate indoor air concentration distributions based on distributional information for mass balance parameters such as indoor source emission rates, building volumes, and air exchange rates. The second option is for the user to directly specify concentration distributions. The concentration values for a particular environment are then sampled from the distributions and multiplied by time durations of the population groups in the environment, based on results from Californians' location/activity profiles, to calculate time-integrated exposure.

Model limitations for CPIEM include the assumption that concentrations in different environments on the same day are independent. For example, if outdoor concentrations have a significant impact on indoor concentrations they may be correlated, so that the assumption of independence may misrepresent the shape of the exposure/dose distribution. The impact could be significant, particularly at the upper end of the distribution where the calculated exposures could be underestimated. Also, since CPIEM uses activity profiles from a limited number of studies (*i.e.*, only those conducted in California), the results may not represent small subgroups of the population or population groups in other regions of the U.S.