1. INTRODUCTION

The Office of Air Quality Planning and Standards (OAQPS) of the U.S. Environmental Protection Agency (EPA) has the responsibility for the hazardous and criteria air pollutant programs described by sections 112 and 108 of the Clean Air Act (CAA). Several aspects of these programs require evaluation of the health risks and environmental effects associated with exposure to these pollutants.[1] In response to these risk-related mandates of the CAA, and the scientific recommendations of the National Academy of Sciences (NAS) (NRC 1994), the Presidential/Congressional Commission on Risk Assessment and Risk Management (CRARM) (CRARM 1997), as well as EPA guidelines and policies, OAQPS recognized the need for improved fate and transport, exposure, and risk modeling tools that:

- Have multimedia assessment capabilities;
- Have human health and ecological exposure and risk assessment capabilities;
- Can perform multiple pollutant assessments (*e.g.*, ability to assess mixtures of pollutants and track chemical transformations);
- Can explicitly address uncertainty and variability;
- Have the ability to easily perform analyses iteratively, moving from the use of simpler assumptions and scenarios to more detailed assessments; and
- Are readily available and user-friendly, so that they can be used by EPA, as well as by a variety of Agency stakeholders.

In 1996, OAQPS embarked on a multi-year effort to develop the Total Risk Integrated Methodology (TRIM), a time series modeling system with multimedia capabilities for assessing human health and ecological risks from hazardous and criteria air pollutants. The first developmental phase of TRIM, which included the conceptualization of TRIM and implementation of the TRIM conceptual approach through development of a prototype of the first TRIM module, TRIM.FaTE (U.S. EPA 1998b), was reviewed by EPA's Science Advisory Board (SAB) in May 1998 (U.S. EPA 1998c). The second developmental phase included refining TRIM.FaTE and developing a model evaluation plan, initiating development of the second module (TRIM.Expo), and conceptualizing the third module (TRIM.Risk). In addition, progress was made on developing overarching aspects, such as the computer framework and an approach to uncertainty and variability. Consistent with the integral role of peer review in the TRIM development plan, the draft Status Report and draft Technical Support Documents (TSDs) documenting this phase (U.S. EPA 1999a-f) were subjected to review by representatives from

[1] Hazardous air pollutants (HAPs) include any air pollutant listed under CAA section 112(b); currently, there are 188 air pollutants designated as HAPs. Criteria air pollutants are air pollutants for which national ambient air quality standards (NAAQS) have been established under the CAA; at present, the six criteria air pollutants are particulate matter, ozone, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead.

the major program offices at EPA and an EPA Models 2000[2] review team prior to this SAB advisory. Since review of the draft documents, TRIM.FaTE activities have focused on model evaluation, implementation of the uncertainty analysis feature, and documentation of associated libraries.

This Technical Support Document (TSD) provides technical documentation and support for TRIM.FaTE, the environmental fate, transport, and ecological exposure module of the TRIM modeling system. The TSD is divided into two volumes. Volume I provides a description of the terminology, model framework, and functionality of TRIM.FaTE. Specifically, Chapter 2 provides an overview of the development and features of TRIM.FaTE, Chapters 3 and 4 discuss the TRIM.FaTE terminology and conceptual design, Chapter 5 provides a general description of how the conceptual design is implemented in TRIM.FaTE, and Chapter 6 explains the treatment of uncertainty and variability in TRIM.FaTE. A glossary of key terms related to TRIM.FaTE is presented in Appendix A. Volume II of the TSD presents detailed descriptions of the equations used in the TRIM.FaTE module.

1.1 GOALS AND OBJECTIVES FOR TRIM

The TRIM modeling system is intended to represent the next generation of human and environmental exposure and risk models for OAQPS. For example, TRIM is expected to be a useful tool for performing exposure and/or risk assessments for the following CAA programs: the Residual Risk Program (CAA section 112[f]); the Integrated Urban Air Toxics Strategy (CAA section 112[k]); studies of deposition to water bodies and mercury emissions from utilities (CAA sections 112[m] and 112[n]); petitions to delist individual HAPs and/or source categories (CAA sections 112[b][3] and 112[c][9]); review and setting of the national ambient air quality standards (NAAQS) (CAA section 109); and regulatory impact analyses (RIA).

The goal in developing TRIM has been to create a modeling system, and the components of that system, for use in characterizing human health and ecological exposure and risk in support of hazardous and criteria air pollutant programs under the CAA. The goal in designing TRIM has been to develop a modeling system that is: (1) scientifically defensible, (2) flexible, and (3) user-friendly.

(1) Characteristics of the TRIM components important to their scientific defensibility include the following.

C **Conservation of pollutant mass.** The modeled pollutant(s)' mass will be conserved within the system being assessed, wherever appropriate and feasible, including during intermedia transfers. For pollutants where transformation is modeled, the mass of the

[2] Following the report of the Agency Task Force on Environmental Regulatory Modeling (U.S. EPA 1994a), the Agency conducted the Models 2000 Conference in December 1997. This conference led to renewed emphasis on Agency-wide coordination of model development and the proposal for the implementation of a Council on Regulatory Environmental Modeling (CREM) to facilitate and promote scientifically-based, defensible regulatory computer models. The charter for CREM has been reviewed by SAB and is being updated for implementation by the Agency.

core substance (*e.g.*, mercury for methylmercury and divalent mercury) within the modeling simulation will be preserved.

C **Ability to characterize parameter uncertainty and variability.** For critical parameters, the impacts of parameter uncertainty and variability on model outputs will be tracked and, where feasible, differentiated.

C **Capability for multiple pollutant, multiple media, and multiple exposure pathway assessment.** The TRIM modeling system is being designed to facilitate assessment of risks posed by aggregate exposures to single or multiple chemicals from multiple sources and via multiple exposure pathways.

(2) To ensure flexibility, the features of TRIM include the following.

- **Modular design.** Major components of TRIM will be independent and can be used individually, with outside information or models, or in combination. Only those model components necessary for evaluating the particular pollutants, pathways, and/or effect endpoints of interest need be employed in an assessment.

- **Flexibility in temporal and spatial scale.** Exposure and risk assessments will be possible for a wide range of temporal and spatial scales, including hourly to daily or yearly time steps, and from local (10 kilometers (km) or less) to greater spatial scales, depending on the module.

- **Ability to assess human and ecological endpoints.** Impacts to humans and/or biota can be assessed.

(3) To ensure that TRIM will be user-friendly for a variety of groups, including EPA, state and local agencies, and other stakeholders, TRIM has the following characteristics.

- **Easily accessible.** The TRIM modeling system is accessible for use with a personal computer (PC). The system will be available for download from the Internet and accessible through an Agency model system framework (*e.g.*, Multimedia Integrated Modeling System (MIMS)).

- **Well-documented.** In addition to Technical Support Documents, Users Guidance is available to assist with setting up and running the model, and interpreting results.

- **Clear and transparent.** The graphical user interface of the TRIM computer framework provides transparency and clarity in the functioning of the TRIM modules, and output from the modules will include information on modeling assumptions, limitations, and uncertainties.

1.2 TRIM DESIGN

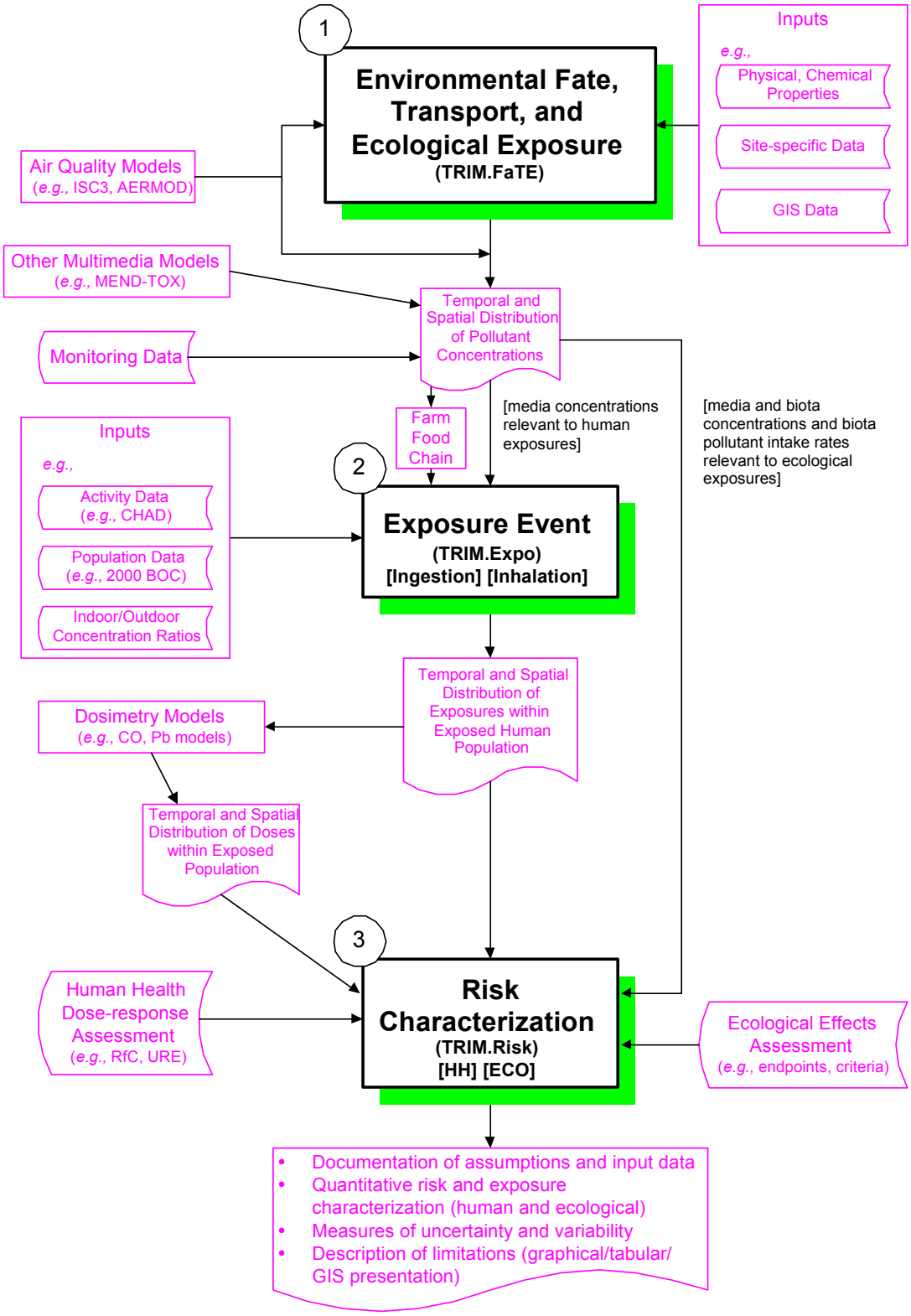
The TRIM design (Figure 1-1) includes three individual modules. The *Environmental Fate, Transport, and Ecological Exposure* module, **TRIM.FaTE,** accounts for movement of a chemical through a comprehensive system of discrete compartments (*e.g.*, media and biota) that represent possible locations of the chemical in the physical and biological environments of the modeled ecosystem and provides an inventory, over time, of a chemical throughout the entire system. In addition to providing exposure estimates relevant to ecological risk assessment, TRIM.FaTE generates media concentrations relevant to human pollutant exposures that can be used as input to the *Exposure-Event* module, **TRIM.Expo.**[3] In TRIM.Expo, human exposures are evaluated by tracking either randomly selected individuals that represent an area's population or population groups referred to as "cohorts" and their inhalation and ingestion through time and space. In the *Risk Characterization* module, **TRIM.Risk**, estimates of human exposures or doses are characterized with regard to potential risk using the corresponding exposure- or dose-response relationships. The TRIM.Risk module is also designed to characterize ecological risks from multimedia exposures. The output from TRIM.Risk is intended to include documentation of the input data, assumptions in the analysis, and measures of uncertainty, as well as the results of risk calculations and exposure analysis.

An overarching feature of the TRIM design is the analysis of uncertainty and variability. A two-stage approach for providing this feature to the user has been developed. The first stage includes sensitivity analyses that are useful in identifying critical parameters, while more detailed uncertainty and variability analyses using Monte Carlo methods (*e.g.*, for refined assessment of the impact of the critical parameters) are available in the second stage to assess the overall precision of the model. The uncertainty and variability feature augments TRIM capability for performing iterative analyses. For example, the user may perform assessments varying from simple deterministic screening analyses using conservative default parameters to refined and complex risk assessments where the impacts of parameter uncertainty and variability are assessed for critical parameters.

Additionally, the modular design of TRIM allows for flexibility in both its development and application. Modules have been developed in a phased approach, and refinements can be made as scientific information and tools become available. Furthermore, the user may select any one or more of these modules for an assessment depending on the user's needs. For example, when performing a human health risk assessment for an air pollutant for which multimedia distribution is not significant, TRIM.Expo may be applied without the need to run TRIM.FaTE, using ambient concentration data or the output from an air quality model external to TRIM. The output from TRIM.Expo may then be used as input to TRIM.Risk to perform the desired risk analyses. In the case of a multimedia air pollutant, such as mercury, the user may choose to run all three TRIM modules to assess both human and ecological risks posed by multipathway exposures from multiple media.

[3] A farm food chain (FFC) model is also available as a method for deriving livestock and produce contaminant concentrations from soil and air concentrations and air deposition outputs from TRIM.FaTE.

Figure 1-1
Conceptual Design of TRIM



1.2.1 DESCRIPTION OF TRIM.FaTE

The first TRIM module to be developed, TRIM.FaTE, is a spatial compartmental mass balance model that describes the movement and transformation of pollutants over time, through a user-defined, bounded system that includes both biotic and abiotic components (compartments). The TRIM.FaTE module predicts pollutant concentrations in multiple environmental media and in biota and pollutant intakes for biota, all of which provide both temporal and spatial exposure estimates for ecological receptors (*i.e.*, plants and animals). The output concentrations from TRIM.FaTE also can be used as inputs to a human exposure model, such as TRIM.Expo, to estimate human exposures.

Significant features of TRIM.FaTE include: (1) the implementation of a truly coupled multimedia model; (2) the flexibility to define a variety of scenarios, in terms of the links among compartments as well as the number and types of compartments, as appropriate for the desired spatial and temporal scale of assessment; (3) the use of a transparent approach to chemical mass transfer and transformation based on an algorithm library that allows the user to change how environmental processes are modeled; (4) an accounting for all of the pollutant as it moves among the environmental compartments; (5) an embedded procedure to characterize uncertainty and variability; and (6) the capability to provide exposure estimates for ecological receptors. Additional details regarding TRIM.FaTE are covered in the chapters that follow.

1.2.2 DESCRIPTION OF TRIM.Expo

The TRIM.Expo module, similar to most human exposure assessment models, provides an analysis of the relationships between various chemical concentrations in the environment and exposure levels of humans. Because multiple sources of environmental contamination can lead to multiple contaminated media, including air, water, soil, food, and indoor air, it is useful to focus on the contaminated environmental media with which a human population will come into contact. These media typically include the envelope of air surrounding an individual, the water and food ingested by an individual, and the layer of soil and/or water that contacts the surface of an individual. The magnitude and relative contribution of each exposure pathway must be considered to assess total exposure to a particular chemical. Currently, the focus of TRIM.Expo development is on inhalation and ingestion exposure; however, dermal exposure may be added in the future.

The exposure analysis process consists of relating chemical concentrations in environmental media (*e.g.*, air, surface soil, root zone soil, surface water) to chemical concentrations in the exposure media with which a human or population has contact (*e.g.*, air, drinking water, foods, household dusts, and soils).

TRIM.Expo is currently comprised of two components, one for inhalation exposure and one for ingestion exposure. The inhalation component of TRIM.Expo predicts inhalation exposures of many individuals randomly selected to represent an area's population by tracking the movement of each individual through locations where chemical exposure can occur according to specific activity patterns. In a typical application, the inhalation component can combine either processed air monitoring data or air dispersion modeling results with the activity

patterns of the individuals and micro-environment concentration relationships to estimate exposures. The movements of an individual are defined as an exposure-event sequence that can be related to time periods for which exposure concentrations are estimated. Each exposure event places the individual in contact with one or more environmental media within a specified microenvironment (*e.g.*, inside a home, along a road, inside a vehicle) in an exposure district for a specified time interval. In addition to the location assignments, the exposure event also can provide information relating to the potential for pollutant uptake (*e.g.*, respiration rate). Exposures associated with these events are aggregated to predict an exposure concentration for the time period of interest.

TRIM.Expo KEY TERMS

Cohort - A group of people within a population with the same demographic variables who are assumed to have similar exposures.

Activity pattern - A series of discrete events of varying time intervals describing information about an individual's lifestyle and routine. The information contained in an activity pattern typically includes the locations that the individual visited (usually described in terms of microenvironments), the amount of time spent in those locations, and a description of what the individual was doing in each location (*e.g.*, sleeping, eating, exercising).

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.

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.

The primary purpose of the ingestion component of TRIM.Expo is for the assessment of ingestion exposure to air pollutants that are persistent and/or bioaccumulative. The ingestion component calculates the ingestion exposure (in units of mg of constituent per kg of body weight per day) to human receptor groups from media and food concentrations. In a typical application, the ingestion component can accept TRIM.FaTE output data or other pollutant concentration data for media and biota to estimate human exposure. TRIM.FaTE can be used to provide an inventory of chemical concentrations in environmental media and in biota across the ecosystem at selected time intervals (*e.g.*, days, hours). A farm food chain module is also available to provide livestock and produce contaminant estimates from air and soil concentrations and air deposition estimates provided by TRIM.FaTE or from an external file.

In addition to directly providing human population exposure estimates, the TRIM.Expo module is intended to contribute to a number of health-related assessments, including risk assessments and status and trends analyses.

1.2.3 DESCRIPTION OF TRIM.Risk

Risk characterization is the final step in risk assessment and is primarily used to integrate the information from the other three key steps (*i.e.*, hazard identification, dose-response assessment, exposure assessment). Within the TRIM framework, TRIM.Risk, the risk characterization module, will be used to integrate the information on exposure (human or ecological receptor) with that on dose-response or hazard assessment and to provide quantitative

descriptions of risk and some of the attendant uncertainties. The TRIM.Risk module will provide decision-makers and the public with information for use in developing, evaluating, and selecting appropriate air quality standards and risk management strategies. The purpose of TRIM.Risk is to integrate information from other TRIM modules and to facilitate the preparation of a risk characterization. The TRIM.Risk module and associated tools will provide the capability to summarize or highlight the major points from each of the analyses conducted in the TRIM modules. In general, this will include: (1) documentation of assumptions and input data, (2) risk calculations and data analysis, and (3) presentation of results and supporting information.

Current and proposed EPA guidance on risk characterization will guide the development of TRIM.Risk and associated tools. The TRIM.Risk module will be developed in a phased approach similar to other TRIM modules. Ideally, TRIM.Risk will provide all of the information required to prepare a full risk characterization. However, the types and variability of information needed for this purpose are vast. Therefore, the type of information generated by TRIM.Risk will evolve over time as the Agency gains experience and has the resources to implement more flexibility. For example, early versions of TRIM.Risk will be limited to preparing summaries of input data and results, without supporting text. However, as the Agency gains experience, it may be possible to incorporate generic language to more fully describe the information required for a full risk characterization. Many EPA risk assessments will be expected to address or provide descriptions of: (1) individual risk,[4] including the central tendency and high-end portions of the risk distribution; (2) population risk; and (3) risk to important subgroups of the population such as highly exposed or highly susceptible groups or individuals, if known. Some form of these three types of descriptors will be developed within TRIM.Risk and presented to support risk characterization. Because people process information differently, it is appropriate to provide more than one format for presenting the same information. Therefore, TRIM.Risk will be designed so that the output can be presented in various ways in an automated manner (*e.g.*, similar to the Chart Wizard in Microsoft® Excel), allowing the user to select a preferred format.

1.3 TRIM DEVELOPMENT

In the development of TRIM, existing models and tools are being relied upon where possible. Consequently, review of existing models and consideration of other current modeling efforts has been an important part of TRIM development activities. Reviews of relevant models existing at the initiation of development activities for TRIM.FaTE are described in Chapter 2 of this document. Additionally, EPA has incorporated TRIM into EPA's MIMS, which is essentially a modeling framework that accommodates linkages among multiple models and the sharing of common tools and data.

Consistent with Agency peer review policy (U.S. EPA 1998d) and the 1994 Agency Task Force on Environmental Regulatory Modeling (U.S. EPA 1994a), internal and external peer review has been an integral part of the TRIM development plan. Following the first phase of TRIM development, OAQPS submitted TRIM (U.S. EPA 1998a, U.S. EPA 1998b) to SAB under their advisory method of review. In May 1998 in Washington, DC, the Environmental

[4] The phrase individual risk as used here does not refer to a risk estimate developed specifically for a single member of a population. Rather, it refers to the estimate of risk for a subgroup of a population that is presented as an estimate of the risk faced by a person rather than by the population as a whole.

Models Subcommittee (Subcommittee) of the Executive Committee of SAB reviewed the TRIM project, assessing the overall conceptual approach of TRIM and the specific approach of TRIM.FaTE. The Subcommittee reported that the development of TRIM and the TRIM.FaTE module was conceptually sound and scientifically based (U.S. EPA 1998c) and provided specific recommendations related to six specific charge questions. These recommendations are detailed in Chapter 2 of the 1999 TRIM Status Report (U.S. EPA 1999b), along with brief responses. Changes to TRIM.FaTE based in part on the SAB recommendations are highlighted in Chapter 4 of the 1999 TRIM Status Report.

TRIM was again submitted to SAB advisory review in December 1999, when the Subcommittee met to review progress on TRIM (U.S. EPA 1999a,b, U.S. EPA 1999g,h). In providing comments and recommendations the Subcommittee found "ongoing efforts to develop TRIM as a flexible, state-of-the-art system for evaluation multimedia chemical fate, transport, exposure and risk, to be effective and innovative" (U.S. EPA 2000). In consideration of SAB's comments and recommendations, TRIM.FaTE was refined, including the development of new and updated capabilities and the development and limited testing of methodologies for model set-up, uncertainty and variability analysis, and evaluation. This TRIM.FaTE documentation has also gone through internal Agency peer review, involving reviewers across the Agency from major program offices, the Office of Research and Development, and staff involved in the Agency's Models 2000 efforts, as well as the SAB reviews described above.

In addition to consulting with Agency scientists during future TRIM development (*i.e.,* peer involvement), OAQPS will, as appropriate, seek peer review of new aspects in TRIM development. In addition to the SAB, which provides the Agency with reviews, advisories, and consultations, other external peer review mechanisms consistent with Agency policy (U.S. EPA 1998d) include the use of a group of independent experts from outside the Agency (*e.g.,* a letter review by outside scientists), an *ad hoc* panel of independent experts, and peer review workshops. The OAQPS intends to seek the peer review mechanism appropriate to the importance, nature, and complexity of the material for review.

1.4 PHASING TRIM INTO OAQPS' SET OF MODELING TOOLS

As mentioned earlier, TRIM is intended to support assessment activities for both the criteria and hazardous air pollutant programs of OAQPS. As a result of the greater level of effort expended by the Agency on assessment activities for criteria air pollutants, these activities are generally more widely known. To improve the public understanding of the hazardous air pollutant (HAP) (or air toxics) program, the Agency published an overview of the air toxics program in July 1999 (U.S. EPA 1999e). Air toxics assessment activities such as National Air

Toxics Assessments (NATA) are described as one of the program's key components.[5] NATA include both national- and local-scale activities. The TRIM system is intended to provide tools in support of local-scale assessment activities, including multimedia analyses.

EXAMPLES OF TRIM APPLICATIONS

- A human health or ecological assessment of multimedia, multipathway risks associated with mercury emissions from one or several local sources could be performed using all three modules in the TRIM system.
- An assessment of human health risks associated with air emissions of a criteria air pollutant (*e.g.*, ozone) or one or several volatile HAPs in a metropolitan area could be developed using an external air model or ambient concentration data from fixed-site monitors coupled with TRIM.Expo and TRIM.Risk.

One of the Agency's most immediate needs for TRIM comes in the Residual Risk Program, in which there are many upcoming statutory deadlines for risk-based emissions standards decisions. As described in the *Residual Risk Report to Congress* (U.S. EPA 1999f), TRIM is intended to improve upon the Agency's ability to perform multipathway human health risk assessments and ecological risk assessments for HAPs with the potential for multimedia environmental distribution. Another important upcoming use for TRIM is in exposure assessment in support of the review of the ozone National Ambient Air Quality Standards (NAAQS). The TRIM.Expo and TRIM.Risk modules augmented with external air quality monitoring data and models are intended to support this type of criteria pollutant assessment as well as risk assessments for non-multimedia HAPs.

Consistent with the phased plan of TRIM development, the application of TRIM will also be initiated in a phased approach. The EPA will begin to use the modules to contribute to or support CAA exposure and risk assessments. These initial applications also will contribute to model evaluation. The earliest TRIM activities are expected to include the use of TRIM.FaTE side-by-side (at a comparable level of detail) with the existing multimedia methodology[6] in risk assessments of certain multimedia HAPs (*e.g.*, mercury) under the Residual Risk Program. As TRIM.Expo is developed to accommodate inhalation modeling of HAPs and after it has undergone testing, OAQPS plans to initially run it side-by-side (at a comparable level of detail) with EPA's existing inhalation exposure model, HEM (Human Exposure Model (U.S. EPA

[5] Within the air toxics program, these activities are intended to help EPA identify areas of concern (*e.g.*, pollutants, locations, or sources), characterize risks, and track progress toward meeting the Agency's overall air toxics program goals, as well as the risk-based goals of the various activities and initiatives within the program, such as residual risk assessments and the Integrated Urban Air Toxics Strategy. More specifically, NATA activities include expansion of air toxics monitoring, improvements and periodic updates to emissions inventories, national- and local-scale air quality modeling, multimedia and exposure modeling (including modeling that considers stationary and mobile sources), continued research on health effects of and exposures to both ambient and indoor air, and use and improvement of exposure and assessment tools. These activities are intended to provide the Agency with improved characterizations of air toxics risk and of risk reductions resulting from emissions control standards and initiatives for both stationary and mobile source programs.

[6] In support of the *Mercury Report to Congress* (U.S. EPA 1997) and the *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units !Final Report to Congress* (U.S. EPA 1998e), the Agency relied upon the Indirect Exposure Methodology, which has recently been updated and is now titled the Multiple Pathways of Exposure methodology (U.S. EPA 1999d). This methodology is being used in initial assessment activities for the Residual Risk Program (U.S. EPA 1999f).

1986)). When TRIM.Risk has been completed, it will be used, as appropriate, in both criteria and hazardous air pollutant risk assessments.

In later years, OAQPS intends to use TRIM and the TRIM modules in a variety of activities including: (1) residual risk assessments using TRIM.FaTE, TRIM.Expo, and TRIM.Risk, in combinations appropriate to the environmental distribution characteristics of the HAPs being assessed; (2) urban scale assessments on case study cities as part of the Integrated Urban Air Toxics Strategy; and (3) exposure and risk assessments of criteria air pollutants (*e.g.*, ozone, carbon monoxide) in support of NAAQS reviews.

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