A Brief Reminder

- **WHAT IS THE MENTOR PROJECT**
  - MENTOR is not a single model; it is an evolving open environment - or computational toolbox - intended to support consistent multiscale source-to-dose modeling for human exposures to contaminants
  - Objective of the MENTOR project is to develop, apply and evaluate scientifically defensible mechanistic approaches and state-of-the-art computational tools for a wide range of environmental applications, that initially include:
    - analysis of exposure and dose to (potentially co-occurring) fine particles and gaseous air toxics and photochemical pollutants
    - studies of exposures to selected multimedia contaminants (such as arsenic and certain pesticides)
  - The computational tools being developed (or adapted) for MENTOR include both
    - models for environmental, microenvironmental, and biological processes and for related activities/operations, and
    - tools that facilitate the application and evaluation of process/operations models
  - Emphasis on integrating methods for prognostic and diagnostic analyses through:
    - implementation and evaluation of “data/model fusion” methods (primarily Bayesian)
    - development of state-of-the-art methods for systematic model reduction and efficient sensitivity/uncertainty analysis
Presentation Summary

"Top Ten" Developments in MENTOR Effort 2000-2001

1. On-going integration with CMAQ/Models-3; development of compatible components
2. Incorporation of receptor/activity variability and pollutant dynamics in biological dosimetry
3. "Proof-of-concept" demonstration of population source-to-dose assessment for PM$_{1.5}$
   - Case study: Philadelphia, 2 weeks in July 1999* (Integration of SHEDS with MENTOR-OPERAS): combined application of MM5, SMOKE, CMAQ, STRFM, PM-SHEDS_2
4. On-going integration of many environmental and of receptor attributes/activities databases in MENTOR framework; evaluation of visual modeling approaches (UML, state machines)
5. Integrated individual source-to-dose (environmental/microenvironmental/biological) model for multimedia/multipathway arsenic exposures*
7. User-oriented implementation of HDMR_α; multiple applications (atmospheric chemistry; groundwater transport; PBPK model)
8. User-oriented implementation of Bayesian MCMC; application to PBPKM*
9. First combined application of SRSM and MCMC to a complex environmental transport model (the finite element FACT groundwater model)
10. On-going comparative application/testing of pattern recognition (CART, cluster analysis, SVD) methods to exposure databases (NHEXAS)
On-Going Integration of MENTOR/SHEDS with CMAQ/Models-3; Development of Compatible Components

- "Seamless" integration of
  - Emission inventory processing (with SMOKE and or EMS-HAP)
  - Meteorological inputs development (with MM5)
  - Regional-to-urban air quality modeling (with CMAQ/Models-3)
  - Potential (outdoor) population exposure estimation (from regional to census-tract level) for comparative control strategy evaluation available for ozone, size-resolved PM, air toxics
  - Local source gas/aerosol chemistry/dispersion modeling (with RPM-AERO)
  - Neighborhood or census-tract level air quality assessment (with STRF or BME)
  - Indoor gas/aerosol chemistry and physics (with µE–AERO, µE–UDAERO; µE–3 compatible with Models-3 is currently under development)
  - Human exposure for individuals and populations using realistic activity patterns (from CHAD) and flexible (high resolution) version of SHEDS
  - Deposited fine PM dose for individuals and populations using new age/gender specific modules (fully integrated in the MENTOR/SHEDS) framework

- Application – and on-going development of refinement methods for – as well as development of local gas/aerosol physics and chemistry modules compatible with CMAQ/Models-3 are presented here
  - New dosimetry modules and first demonstration of population source-to-dose are discussed next

Consistency Across Scales: The Internally Mixed Aerosol Dynamic Equation from Regional Air Quality to Dosimetry

Based on the assumption of internally mixed aerosol: the particles of the same size have identical chemical composition, the relevant aerosol processes are described by

\[
\frac{\partial n_{\text{mix}}(D_p, x, t)}{\partial t} + \nabla \cdot n_{\text{mix}}(D_p, x, t) = H_i \left( D_p, x, t \right) n_{\text{out}} \left( D_p, x, t \right) - \frac{1}{3} \frac{\partial H_{\text{mix}} \left( D_p, x, t \right)}{\partial D_p} \nabla \cdot n_{\text{mix}} \left( D_p, x, t \right) + E_i \left( D_p, x, t \right) + R_i \left( D_p, x, t \right)
\]

where

- \( D_p \) = \text{log}(D_{p2}/D_{p1}) – log diameter
- \( n_{\text{mix}}(D_p, x, t) \) – mass concentration of species \( i \) between log diameters \( D_p \) and \( D_p + dD_p \)
- \( n_{\text{out}} \) = \( \sum_{i=1}^{m_{\text{mix}}} m_{i} \)
- \( H_i = (1/m)(dm/dt) \) – normalized condensation rate of species \( i \)
- \( H = \sum_{i=1}^{m_{\text{mix}}} H_i \)
- \( m_i \) – mass of species \( i \) in an individual particle of total mass \( m = \sum_{i=1}^{m_{\text{mix}}} m_i \)
- \( K(x, t) \) – is the turbulent diffusivity tensor
- \( E_i \) – emissions rate
- \( R_i \) – production rate due to chemical reactions in or on aerosol particles

The transport of volatile species between gas and particle phase is explicitly simulated by solving the following equation for condensational growth of the particles and their shift in size coordinate:

\[
\frac{\partial n_{\text{mix}}(D_p, x, t)}{\partial t} = H_i \left( D_p, x, t \right) n_{\text{out}} \left( D_p, x, t \right) - \frac{1}{3} \frac{\partial H_{\text{mix}} \left( D_p, x, t \right)}{\partial D_p} \nabla \cdot n_{\text{mix}} \left( D_p, x, t \right)
\]
Ambient & Microenvironmental Aerosol Models Currently in MENTOR-OPERAS

<table>
<thead>
<tr>
<th>Model Type</th>
<th>micro-environmental</th>
<th>(local) parcel trajectory</th>
<th>fixed grid (urban)</th>
<th>fixed grid (urban)</th>
<th>nested grid (regional)</th>
<th>nested grid (regional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorological model</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Layers in the vertical</td>
<td>N/A (MRI/option)*</td>
<td>5-12</td>
<td>5 (3+2)</td>
<td>5 (3+2)</td>
<td>21</td>
<td>6 to 30</td>
</tr>
<tr>
<td>Fog/cloud model</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gas-phase chemistry</td>
<td>CBM-IV or SAPRC</td>
<td>CBM-IV or SAPRC</td>
<td>CBM-IV or SAPRC</td>
<td>CBM-IV or SAPRC</td>
<td>RADM2</td>
<td>RADM2 or CBM-IV</td>
</tr>
<tr>
<td>Condensation/evaporation</td>
<td>under development</td>
<td>equilibrium</td>
<td>equilibrium</td>
<td>dynamic</td>
<td>dynamic</td>
<td>equilibrium</td>
</tr>
<tr>
<td>Nucleation</td>
<td>H₂O/ SO₄²⁻</td>
<td>H₂O/ SO₄²⁻</td>
<td>H₂O/ SO₄²⁻</td>
<td>none</td>
<td>H₂O/ SO₄²⁻</td>
<td>H₂O/ SO₄²⁻</td>
</tr>
<tr>
<td>Aerosol thermodynamics</td>
<td>SEQUILIB, AIM2 (i)</td>
<td>SEQUILIB</td>
<td>SEQUILIB</td>
<td>AIM2</td>
<td>AIM2 (with improved algorithm)</td>
<td>AIM2 (with improved algorithm)</td>
</tr>
<tr>
<td>Aerosol species</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
<td>SO₂⁺, NO₂⁻, NH₄⁺, D, Na⁺, EC, OC, H₂O, other PM</td>
</tr>
</tbody>
</table>

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Regional Aerosol Model Application/Testing Takes Place on the OTAG Domain
(Test Focus on Summers of 1995 and 1999)
Predictions Comparison between CMAQ and MAQSIP-UDAERO for 3:00 PM, July 11, 1995, EDT

PM2.5 Prediction

**MAQSIP-UDAERO**

*July 11, 1995*

![Map of PM2.5 predictions for 3:00 PM on July 11, 1995, using MAQSIP-UDAERO model.]

PM2.5 Prediction

**CMAQ**

*July 11, 1995*

![Map of PM2.5 predictions for 3:00 PM on July 11, 1995, using CMAQ model.]

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PM2.5 Predictions of CMAQ for 10:00 AM, July 19, 1999, EDT

PM2.5 CMAQ Predictions

*Grid Resolution: Arc x Arc*

**July 19, 1999 10:00 AM EDT**

![Map of PM2.5 predictions for 10:00 AM on July 19, 1999, using CMAQ model.]

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The MENTOR Project
Computational Chemodynamics Laboratory
HEADSUP Meeting, August 2001
EMAD - EOHSI
Comparison of CMAQ Predictions with Hourly Observations of PM2.5 in New Jersey for July 11 - 24, 1999

Camden

Middlesex

Comparison of CMAQ Predictions with Hourly Observations of Ozone in New Jersey for July 11 - 24, 1999

Camden 1

Camden 2

Middlesex
On-going Efforts to Refine Application of Regional/Local Air Quality Modeling

- Emission Inventories
  - MARAMA
  - NEI (10/2001)

- Met Inputs
  - Expanded data assimilation (collaborative effort with MCNC)

Ozone and PM2.5 Potential Outdoor Exposure Predictions based on CMAQ for July 18, 1999
A Major Issue in Implementing Consistent Source-to-Dose Modeling is Going to Local/Neighborhood/Indoors Resolution

Examples of Indoor Levels Predicted by μE-AERO and μE-UDAERO
Top - Total PM10 & PM2.5; Bottom: NH₄⁺ Content of PM10 & PM2.5

Source: Georgopoulos et al., ES&T, 1997, 31(1)
2. Incorporation of Receptor/Activity Variability and Physicochemical Pollutant Dynamics in Biological Dosimetry

- The new biological dosimetry modules in MENTOR have been implemented using a flexible design, and are interactively linked with CHAD (the Consolidated Human Activities Database), to account for:
  - physiological variability due to age, gender, weight, etc.
  - continuous temporal variability due to physical activity (expressed through metabolic expenditure)
- Both respiratory PM deposition and multimedia/multipathway PBPK models have been implemented with flexible design (as described above)
- The receptor activity modules are fully integrated with the microenvironmental modules (to reflect modifications of microenvironmental qualities from the receptor’s presence and activities)
- “High-level” (i.e. detailed) modules for respiratory PM deposition can account dynamically for various size-specific physicochemical properties of inhaled particles (such as hygroscopicity) and the changes occurring in the lungs (particle growth, etc.)
  - Two peer-reviewed articles presenting new developments in "non-ideal" (i.e. hygroscopic, reactive, etc.) aerosol dosimetry modeling were published in 2001 (in Aerosol Science and Technology and in Environmental Science and Technology)

Three Levels of Inhalation Dosimetry Modeling in MENTOR - I: Levels A & B: Macro- and Micro- Modules
Three Levels of Inhalation Dosimetry Modeling in MENTOR - II: Level C: Semiempirical (Population-Oriented) Module

CHAD database
METs value for time spent in each microenvironment

PM-SHEDS output: age/gender, particulate matter concentration in air

ICRP databases: age/gender specific body mass

ICRP databases: deposition fractions and efficiencies

Empirical physiological model: calculates inhalation rate using METs value (regression equations)

Metabolic model: simplified kinetic model for inhalation, calculates deposition to 3 regions of lung and total pulmonary burden, time-dependent dosage for each microenvironment

Plot results as a function of duration of exposure to particulate matter

Particle matter deposition to nasal-pharyngeal, tracheobronchial, and pulmonary regions of lungs, time-dependent dosage for each microenvironment

3. “Proof-of-Concept” Demonstration of Integrated Population Source-to-Dose Assessment for PM$_{2.5}$

First demonstration (“proof-of-concept”) of a complete, integrated, population source-to-dose analysis for PM$_{2.5}$

Case study

Philadelphia, 2 weeks in July 1999*

The study involved the combined application of MM5, SMOKE, and CMAQ with a new census-tract-level population exposures/dose model which merged approaches and tools of SHEDS and MENTOR

The revised/expanded SHEDS code (MENTOR version of PM-SHEDS_2 in MATLAB) is interactively linked with CHAD and allows exposure and dose calculation for each activity event (flexible time implementation)

A sample of 500 individuals developed to match the demographic characteristics of each census tract is used to extract activity information from CHAD and drive the exposure and dose modules

A detailed presentation of the case study is given separately; a brief summary is included here
The MENTOR Project
Computational Chemodynamics Laboratory
HEADSUP Meeting, August 2001
EMAD - EOHSI

Population Exposure to PM2.5: Source-to-Dose Assessment
PM-SHEDS_2 Prototype that Incorporates MENTOR Tools

Example Results from the First Source-to-Dose Population Exposure Assessment for PM2.5 (Case Study: Philadelphia, 7/11-24/1999)

Maps of City of Philadelphia (and Adjacent) Census Tracts, Showing 95th Percentiles of 24-Hour Aggregated Total Exposure and Dose, 18 July 1999

The MENTOR Project
Computational Chemodynamics Laboratory
HEADSUP Meeting, August 2001
EMAD - EOHSI
Example Results from the First Source-to-Dose Population Exposure Assessment for PM2.5 (Case Study: Philadelphia, 7/11-24/1999)

Percentile Plot for 24-Hour Aggregated Total Dose, Dose due to Outdoor Sources, and Dose due to Indoor Sources (All Days: 7/11-24/1999).

24-Hour Aggregated Total Dose, Dose due to Outdoor Sources, and Dose due to Indoor Sources on 18 July 1999

4. On-Going Integration of Many Macro/Micro-Environmental and of Receptor Attributes/Activities Databases in MENTOR

- Integration of Relational and Geospatial Data in a consistent, user-oriented framework
  - This integration provides the infrastructure for comprehensive Exposure Information Systems (EXIS)
    - Examples include: PM-GIS_1999, US Arsenic EXIS
- Evaluation of approaches for interactive database/model linking
  - ODBC compatibility
    - MATLAB toolboxes
  - visual representation employing “standard” languages
    - Unified Modeling Language (UML)
    - Statecharts (Staflow/Simulating for finite state machines modeling)

5. Assessing Individual Exposure to Arsenic: A New Coupled Source - to - Dose (Environmental/μEnvironmental/PBPK) Modeling
Schematic Depiction of Human PBPK Model for Arsenic Currently Integrated in the Source-to-Dose Framework

Microenvironmental – PBPK Model Test: Indoors Inhalation Exposure/Dose to Arsenic (Sources: Tap Water Use, Outdoor Air)

(Outdoor air: 100 pg/m³; Tap water: 50 ppb)
6. Population Exposure to Arsenic: A Source-to-Dose Assessment with a New Multimedia MENTOR/SHEDS Prototype

- **START**
- **Census tract demographic data**
- **Outdoor air concentrations**
- **CHAD database**
- **CSFI**
- **AOED**

**Online data importing module**

**Select a census tract and generate a hypothetical population comprised of N individuals that match the characteristics of the population in census tract**

**Outcome exposure simulations of individual parameters**

**Select an activity event for each individual**

**Calculate inhalation rates for each activity event of an individual based on age, gender and METs values**

**Calculate microenvironmental air concentrations in each activity location of the activity event sequence using the exposure model parameters**

**Calculate dose for each activity event of an individual based on concentration inhalation rate and time duration of each activity event**

**Obtain PM dose estimate for all census tracts in area of interest?**

**Obtain PM dose estimate for all individuals in population?**

**Calculate drinking water consumption**

**Calculate drinking water concentration**

**Obtain estimates of 1-hr averaged outdoor concentrations in census tract**

**CHAD database**

**Obtain the matching diary record for each individual in the generated population from variability distributions (specified by uncertainty statistical parameters)**

**Calculate the matching diary record for each individual based on uncertainty distributions of statistical parameters**

**Calculate PM dose for all individuals in population?**

**Completed all uncertainty iterations?**

**END**

---

**Population Exposure to Arsenic: Source-to-Dose Assessment Preliminary Test Application of Multimedia MENTOR/SHEDS**

This test application involved comparison of population exposures due to inhalation (from outdoor sources) and ingestion (from drinking water) in two counties with reported groundwater arsenic problems: Pima, AZ and Hunterdon, NJ
Population Exposure to Arsenic: Source-to-Dose Assessment Preliminary Test Application of Multimedia MENTOR/SHEDS

Inhalation dose in the above figures: dose from arsenic component in outdoor PM estimated using the MENTOR gender/age/activity specific population inhalation dosimetry module (outdoor concentrations calculated using EPA’s 1996 NATA approach with the 1996 NTI inventory and the ASPEN model).

Ingestion dose refers only to the component due to consumption of drinking water (concentration distributions for Pima, AZ and Hunterdon, NJ were derived respectively from the Arsenic Occurrence and Exposure Database and from NJDEP’s Water Quality Database). The bimodal distribution in NJ reflects the different source quality (municipality system vs private wells – the latter are arsenic contaminated).

7. Model Reduction and Sensitivity/Uncertainty Analysis: HDMR (High Dimensional Model Representation) Based Tools

A "Fast Equivalent Operational Model" (FEOM) that can substitute the original, complex, model in calculations
Formal Model Reduction and Sensitivity/Uncertainty Analysis: HDMR Applied to Atmospheric Photochemistry Models

In this example HDMR was used to derive a computationally efficient FEOM (Fast Equivalent Operational Model) of alkane atmospheric chemistry, starting from a "master chemical mechanism" that included the complete reaction schemes of 33 alkanes (in addition to inorganic components such as ozone, NOx etc.)

This formally derived FEOM provides significantly better agreement with the master mechanism compared with "standard" atmospheric chemistry lumping schemes (CB4 and SAPRC)

(Other applications of HDMR by CCL included 3D fate/transport models as well as PBPK models)


Stochastic Response Surface Method (SRSM)

Representation of Inputs:

\[ X_i = f(\xi_1, \xi_2, \ldots, \xi_n), \quad i = 1, \ldots, n \]

Approximation of Outputs:

\[ y = a_0 + \sum_{i_1=1}^{n} a_{i_1} \Gamma_1(\xi_{i_1}) + \sum_{i_1=1}^{n} \sum_{i_2=1}^{n} a_{i_1i_2} \Gamma_2(\xi_{i_1}, \xi_{i_2}) + \ldots \]

\[ + \sum_{i_1=1}^{n} \sum_{i_2=1}^{n} \sum_{i_3=1}^{n} a_{i_1i_2i_3} \Gamma_3(\xi_{i_1}, \xi_{i_2}, \xi_{i_3}) + \ldots \]

\[ \text{where, } \Gamma_p(\xi_{i_1}, \ldots, \xi_{i_p}) = \left(-1\right)^{p} \frac{\partial^p}{\partial \xi_{i_1} \cdots \partial \xi_{i_p}} e^{-\frac{1}{2} \xi^T \Sigma^{-1} \xi} \]

(Multi-dimensional Hermite Polynomials)

Input Transformations in terms of Standard Random Variables (srvs)

Normal (μ, σ) → μ + σξ; Lognormal (μ, σ) → exp(μ + σξ); Weibull (α) → y^{1/α}

Uniform (a, b) → a + (b - a) \left( \frac{1}{2} + \frac{1}{2} \text{erf}(ξ/\sqrt{2}) \right); Gamma (a, b) → ab \left( \frac{1}{b} + 1 - \frac{1}{b} \text{erf}(ξ/\sqrt{2}) \right); Extreme Value → -\log(y)

where, ξ is normal (0,1) [which is the selected srv] and y is exponential (1) distributed

HDMR and SRSM for Efficient Uncertainty Analysis: Application to the FACT Groundwater Model

This example shows the comparative application of the new state-of-the-art uncertainty tools in MENTOR [the High Dimensional Model Representation (HDMR), and the Stochastic Response Surface (SRS) methods], and of "classical" Monte Carlo analysis, to the propagation of uncertainties in the variables of a 3-dimensional finite element Flow and Contaminant Transport (FACT) groundwater model.

In the above figure HDMR and SRSM reproduce probability density functions of two outputs from FACT, derived from 1,000 Monte Carlo runs, using only 45 and 51 model runs, respectively.

Bayesian methods offer unique advantages for incorporating information from (often evolving) data sets into complex mechanistic models that employ a multitude of physically-based parameters. Markov-Chain Monte Carlo (MCMC) has been implemented as a user-oriented tool in MENTOR: it can be used with a variety of complex models to reduce uncertainty in their parameters by “fusing” available observational information.

A separate presentation demonstrates application of the MCMC approach with a PBPK model.

Combined Implementation of the SRSM and MCMC Methods for Data Fusion with a Complex Environmental Model (FACT)

This example represents a first combined application of the Stochastic Surface Response Method (SRSM) with the Markov Chain Monte Carlo (MCMC) Bayesian data fusion method, to simultaneously optimize the values of six uncertain (and “mildly” correlated) parameters in the FACT model, using observational data for predicted model outputs.

FACT (the Flow and Contaminant Transport model) is a 3-dimensional finite element groundwater model. The figure shows the marginal pdf’s of the six uncertain variables (along the diagonal) along with the combined SRSM/MCMC optimization.
10. Tools for Mining and Analysis of Exposure-Related Data

- Evaluation of data mining tools
  - Pattern recognition in environmental and exposure databases
  - Comparison of patterns in observational databases versus model predictions for diagnostic evaluation purposes
  - On-going application of various alternative methods (and of specific software implementations)
    - Cluster, factor, CART, SVD analysis

Example: CART characterization of the 90th percentile of blood benzene concentration (error rate is estimated to be 4%). The most important five attributes that separate the top 10% group from the rest (in order of importance) are: number of cigarettes smoked per day (numerical), indoor air benzene concentration (numerical), job in contact with plastic fumes (categorical) time spent on highway (numerical), and time spent outside at home (numerical).

On-Going Work and Research Plans

- Refinement and testing of MENTOR modules for PM and Arsenic
  - Food ingestion module (population-based) for arsenic
  - Receptor activity and biology modeling
    - Variability issues (focus on biochemical); improved parameterizations
  - Microenvironmental modeling
    - CMAQ compatible indoor aerosol dynamics modules
    - Implementation of new data and mechanistic information on aerosol formation and evolution; testing with EOHSI CEF data
    - Implementation and testing of mixing modeling options such as mixer-reactor networks and CFD (collaborative with ISPRA)
  - Ambient modeling
    - New data assimilation techniques
    - Examine potential of utilizing annual OAQPS simulation outputs (CMAQ, REMSAD)
  - Expand data mining and analysis (environmental, exposure, biomarker)
- Collaborative testing (and interface development) of diagnostic tools
- Increased focus and effort on pesticides and dermal absorption pathway
  - Testing/adaptations of Residential SHEDS; coupling with MENTOR modules
  - Development of prototype Pesticides Exposure Information System
THE MENTOR MODELING TEAM 2001

- **EOHSI (UMDNJ & Rutgers)**
  - Faculty: Panos Georgopoulos, Natalie Freeman, Paul Lioy, Amit Roy, Vikram Vyas, A. Chandrasekar (visiting), Eric Vowinkel (adjunct), Charlie Weschler (adjunct)
  - Senior Research Associates: Ming Ouyang, Qing Sun, Sheng-wei Wang
  - Research Specialists: Srinivas Bandi, Linda Everett, Samir Goel, Hao-Chen Tan
- **Rutgers University, Department of Statistics**
  - Faculty: Bill Strawderman
- **Princeton University, Departments of Chemistry and Applied Mathematics**
  - Faculty: Hersh Rabitz; Research Associate: Genyuan Li
- **Harvard School of Public Health**
  - Faculty: Petros Koutrakis; Research Associate: George Allen
- **TRJ, Inc.**
  - Ted Johnson, Tom Long
- **INTERACTIONS/LINKS/COLLABORATIONS**
  - Amherst, UNC, Vanderbilt, MCNC, STI, ISPRA (Italy), U. Athens & U. Crete (Greece)

Sources of Support for the MENTOR Efforts

- **MAIN SUPPORT: US EPA NERL**
  - primarily through the Center for Exposure and Risk Modeling (CERM) at EOHSI, a component of EPA NERL's HEADSUP (Human Exposure and Dose Simulation – University Partnership) Program
  - through other Grants and Cooperative Agreements
    - Outdoor/Indoor PM Relationships Project
    - NE-OPS Modeling and Data Analysis Component (Penn State Subcontract)
- **OTHER (SUPPLEMENTARY) SUPPORT: projects that “feed” results into MENTOR**
  - US DOE
    - through the Consortium for Risk Evaluation with Stakeholder participation (CRESP) at EOHSI (focus on modules for PM emissions, resuspension, transport, fate)
  - NIEHS
    - through the Environmental Health Sciences Center at EOHSI
  - NJ DEP
    - through the Ozone Research Center (ORC) at EOHSI
  - Industrial
    - PSE&G (Ozone PM, Air Toxics)
    - ICA (Multimedia Heavy Metals with focus on Copper, including PM; EXIS tools development)