Exposure Science in the 21\textsuperscript{st} Century: A vision and a strategy

A report of the
Committee on Human and Environmental Exposure Science in the 21st Century
Statement of Task

• Develop a long-range vision for the field, and an implementation strategy for the next 20 years.
  ➢ Revise the conceptual framework for advancement of exposure science
• Examine the continuum from sources of stressors, fate in environment, contacts with human and ecologic systems, and the exposures that lead to doses relevant to health outcomes
• Provide a vision that also recognizes the goals of: *Toxicity Testing in the 21st Century* (NRC 2007) and *Science and Decisions: Advancing Risk Assessment* (NRC 2009).
Can be a mathematically sound system with Source to Dose Modeling.
Numerous state-of-the-art methods and technologies measure exposures, from external concentrations to personal exposures to internal exposures.

- Geographic information technologies
- Ubiquitous sensing techniques
- Biomonitoring for assessing internal exposures
- Model and information-management tools
Scientific and Technologic Advances

Sources
Environmental
Intensity
Outcomes
Remote Sensing
Geographic Information Systems
Participatory Assessment
Nanosensors
Geolocation Global Positioning System
Biomonitoring

Expanded view of the Core Elements of Exposure Science

And Internal Exposures

Sources

Environmental
Intensity

Stressors

Outcomes

Receptors

Integrated by Source to Dose Models

Contact

Dose

Time-Activity & Behavior

Upstream Human & Natural Factors

Participatory Assessment

Remote Sensing

Geographic Information Systems

Nanosensors

Biomonitoring

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• New challenges and new scientific advances - require us to revise and improve the vision for the field.

• Historical origins— move them from typically addressing discrete exposures to an integrated approach that considers exposures
  ➢ from source to dose
  ➢ on multiple levels of integration (including time, space, and biologic scale)
  ➢ to multiple stressors
  ➢ scaled from molecular systems to individuals, populations, and ecosystems.
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Vision for exposure science – an expansion

• Defined an “eco-exposome”: A reaffirmation that exposure science from the point of contact between stressor and receptor inward into the organism and outward to the general environment, including the ecosphere.

➢ Adoption and validation of the eco-exposome concept within exposure science should lead to the development of:

➢ a universal exposure-tracking framework that allows creation of an exposure narrative, prediction of biologically relevant human and ecologic exposures

➢ a generation of improved exposure information for making informed decisions on human and ecosystem health protection.

• Premised on scientific developments of the last two decades.
Vision for exposure science

• To advance this broader vision, exposure science needs to deliver knowledge that is effective, timely, and relevant to current and future environmental-health challenges.

• Exposure science needs to continue to build capacity to

  ➢ Assess and mitigate exposures quickly in the face of emerging environmental-health threats and natural and human-caused disasters.

  ➢ Predict and anticipate human and ecologic exposures related to existing and emerging threats.

  ➢ Customize solutions that are scaled to identified problems.

  ➢ Engage stakeholders associated with the development, review, and use of exposure-science information, including regulatory and health agencies and groups that might be disproportionately affected by exposures.
Motivation for Study

• Advances in tools and technologies to better implement the principles of exposure science.

  ➢ Increasing development and collection of different types of biological markers of exposures information and the need to evaluate of source-exposure and exposure-disease relationships

  ➢ Introduction of the “exposome” concept

• Scientific and technologic advances provide potential for

  ➢ More accurate and more comprehensive exposure datasets

  ➢ Development of an integrated systems approach to exposure science that
    ▪ More fully coordinates with other fields of environmental health
    ▪ Better Address scientific, regulatory, and societal challenges
    ▪ Provides exposure information to a large swath of the population
    ▪ Embraces both human and ecosystem protection
Overarching research needs –
• Characterize exposures quickly and cost-effectively at multiple levels of integration – including time, space, and biologic scales – and for multiple and cumulative stressors
• Scaling up methods and techniques to detect exposure in large human and ecologic populations of concern

Strategy to achieve this…
• Develop new tools for today’s urgent demands collaboratively creating infrastructure (including educational)
• Using these data and this infrastructure, especially informatics, environmental-health-related hypotheses could be tested and the basis for a more predictive approach built.
Exposure Science

• The Field: examines intensity and duration of contact of humans or other organisms with agents (chemical, physical, or biologic stressors) and their relationship to the health of living systems.

• Instrumental to:
  - forecasting, preventing, and mitigating exposures
  - identifying populations that have high exposures
  - assessing and managing human health and ecosystem risks
  - protecting vulnerable and susceptible populations.
Exposure science is defined by this committee as: the collection and analysis of quantitative and qualitative information needed to understand the nature of contact between receptors (such as people or ecosystems) and physical, chemical, or biologic stressors. Exposure science strives to create a narrative that captures the spatial and temporal dimensions of exposure events with respect to acute and long-term effects on human populations and ecosystems.

For this report, the committee focuses on environmental risk factors and excludes behavioral or lifestyle and social risk factors but does consider them as modifying influences on exposures to stressors.

A central theme is the interplay between the external and internal environments and the opportunity for exposure science to exploit novel technologies for assessing biologically active internal exposures from external sources.
Applications for Exposure Science

• Has a fundamental role in development and application of many fields to addressing environmental and occupational health problems.

• Has the ability to play an effective role in the activities of other fields -- environmental regulation, urban and ecosystem planning, and disaster management.
Demands for exposure science

- Societal Demands
- Health and Environmental Science Demands
- Market Demands
- Policy/Regulatory Demands
Demands for Exposure Science

• Need information on contact with thousands of new chemicals entering the market each year.

• Need to address health effects of low-level exposures to chemical, biologic, and physical stressors over years or decades.

• There is need for more rapid response of exposure science to assist in the aftermath of natural and human-caused disasters.

• Market demands require identification and control or prevention of exposures resulting from manufacture, distribution, and sale of products.

• Societal demands—for example, to maintain local environments, personal health, health of workers and global environment.
Figure 1-1 The classic environmental-health continuum.
Exposure science is relevant to the mission of many federal agencies, and transagency collaboration would accelerate progress in exposure science and transform application to addressing multiple issues.

Tox21—a collaboration among EPA, NIEHS, the National Human Genome Research Institute, the National Institutes of Health Chemical Genomics Center, the FDA, and international partners—was established to leverage resources to advance the recommendations in *Toxicity Testing in the 21st Century: A Vision and A Strategy* serves as a relevant model.

- Model could be extended to exposure science and to creation of Exposure21

Exposure 21 would need to be extended to other federal agencies

- Such as USGS, the CDC, NOAA, NSF, DOD, DOE, and NASA.
- Promote greater access to and sharing of data and resources on a broader scale.
Enabling resources

- As the collaborative partnerships among agencies are expanded, there will be opportunities to share research results, to demonstrate the value of exposure-science research to other agencies and decision-makers, and to generate additional resources.

- The committee recommends that intramural and extramural programs in EPA, NIH, the Department of Defense, and other agencies that advance exposure-science research be supported as the value of the research and the need for exposure information become more apparent.
• Much of the human-based research in environmental-health sciences is funded by NIEHS. However, none of the existing NIH study sections that review grant applications has substantial expertise in exposure science, and most study sections are organized around disease processes.

• In light of the role that an understanding of environmental exposures can play in disease prevention, a rethinking of how NIH study sections are organized that incorporates a greater focus on exposure science would allow a core group of experts to foster the objectives of exposure-science research.

• Increase in collaborations between agencies should be explored; for example, collaborations between EPA, NIEHS, NSF and other agencies could support integrative research between ecosystem and human-health approaches in exposure science.

  ➢ Many other agencies engaged in exposure-science research could be included in collaborations.
Enabling resources – education/training

• Implementing the committee’s vision will depend on development and cultivation of scientists, engineers, and technical experts with experience in multiple fields to
  • educate the next generation of exposure scientists and to provide opportunities for members of other fields
  • cross-train in the techniques and models used to analyze and collect exposure data.
  • collaborate closely with other fields of expertise, including engineers, epidemiologists, molecular and system biologists, clinicians, statisticians, and social scientists.

• The following are needed:

  ➢ Increase in the number of academic predoctoral and postdoctoral training programs in exposure science supported by training grants.
  ➢ Short-term training and certification programs in exposure science for midcareer scientists in related fields.
  ➢ Development, by federal agencies that support human and environmental exposure science, of educational programs to improve public understanding of exposure-assessment research, including ethical considerations involved in the research.
Participatory and community-based research programs

- To engage broader audiences, including the public, the committee suggests
  - developing more user-friendly and less expensive monitoring equipment to allow trained people in communities to collect and upload their own data in partnership with researchers, and thereby
  - improving the value of the data collected and make more data available for purposes of priority-setting and to inform policy.

- One approach – implementing a system of ubiquitous sensors (for example, through the use of cellular telephones, GPS, or other technologies) in two American cities to evaluate the feasibility of such systems to develop community-based exposure data that are reliable.

  - Potential issues of privacy protection would need to be considered.
Concluding remarks

• Exposure science is critical for predicting, preventing, and reducing human health and ecosystem risks.

• Historically limited by the availability of methods, technologies, and resources, but recent advances present an unprecedented opportunity to develop more rapid, cost-effective, and relevant exposure assessments.

• Research supported by such federal agencies such as EPA and NIEHS has provided valuable partnership opportunities for building capacity to develop the technologies, resources, and educational structure and continued commitment will be needed to achieve the committee’s vision for exposure science in the 21st century.
QUESTIONS?
Research needs

- Providing effective responses to immediate or short-term public-health or ecologic risks requires research on observational methods, data management, and models:

  **Short term**
  - Identify, improve, and test instruments that can provide real-time tracking of biologic, chemical, and physical stressors to monitor community and occupational exposures to multiple stressors during natural, accidental, or terrorist events or during combat and acts of war.
  - Explore, evaluate, and promote the types of targeted population-based exposure studies that can provide information needed to infer the time course of internal and external exposures to high-priority chemicals.

  **Intermediate term**
  - Develop informatics technologies (software and hardware) that can transform exposure and environmental databases that address different levels of integration (time scales, geographic scales, and population types) into formats that can be easily and routinely linked with populationwide outcome databases (for humans and ecosystems) and linked to source-to-dose modeling platforms to facilitate rapid discovery of new hazards and to enhance preparedness and timely response.
  - Identify, test, and deploy extant remote sensing, personal monitoring techniques, and source to dose model-integration tools that can quantify multiple routes of exposure and obtain results that can, for example, be integrated with emerging methods (such as –omics technologies) for tracking exposures.

  **Long term**
  - Enhance tracking of human exposures to pathogens on the basis of a holistic ecosystem perspective from source through receptor.
• Supporting research on health and ecologic effects that addresses past, current, and emerging outcomes:

  Short term
  ➢ Coordinate research with human-health and ecologic-health scientists to identify, collect, and evaluate data that capture internal and external markers of exposure in a format that improves the analysis and modeling of exposure–response relationships and links to high-throughput toxicity testing.

  ➢ Explore options for using data obtained on individuals and populations through market-based and product-use research to improve exposure information used in epidemiologic studies and in risk assessments.

  Intermediate term
  ➢ Develop methods for addressing data and model uncertainty and evaluate model performance to achieve parsimony in describing and predicting the complex pathways that link sources and stressors to outcomes.

  ➢ Improve integration of information on human behavior and activities for predicting, mitigating, and preventing adverse exposures.

  Long term
  ➢ Adapt hybrid designs for field studies to combine individual-level and group-level measurements for single and multiple routes of exposure to provide exposure data of greater resolution in space and time.
Research needs

• Addressing demands for exposure information among communities, governments, and industries with research that is focused, solution-based, and responsive to a broad array of audiences:

  Short term
  ➢ Develop methods to test consumer products and chemicals in premarketing controlled studies to identify stressors that have a high potential for exposure combined with a potential for toxicity to humans or ecologic receptors.
  ➢ Develop and evaluate cost-effective, standardized, non-targeted, and ubiquitous methods for obtaining exposure information to assess trends, disparities among populations (human and ecologic), geographic hot spots, cumulative exposures, and predictors of vulnerability.

  Intermediate term
  ➢ Apply adaptive environmental-management approaches to understand the linkages between adverse exposures in humans and ecosystems better.
  ➢ Implement strategies to engage communities, particularly vulnerable or hot-spot communities, in a collaborative process to identify, evaluate, and mitigate exposures.

  Long term
  ➢ Expand research in ways to use exposure science to more effectively regulate environmental risks in natural and human systems, including the built environment.