What are the Next Steps in Developing a Mercury Externalities Model?

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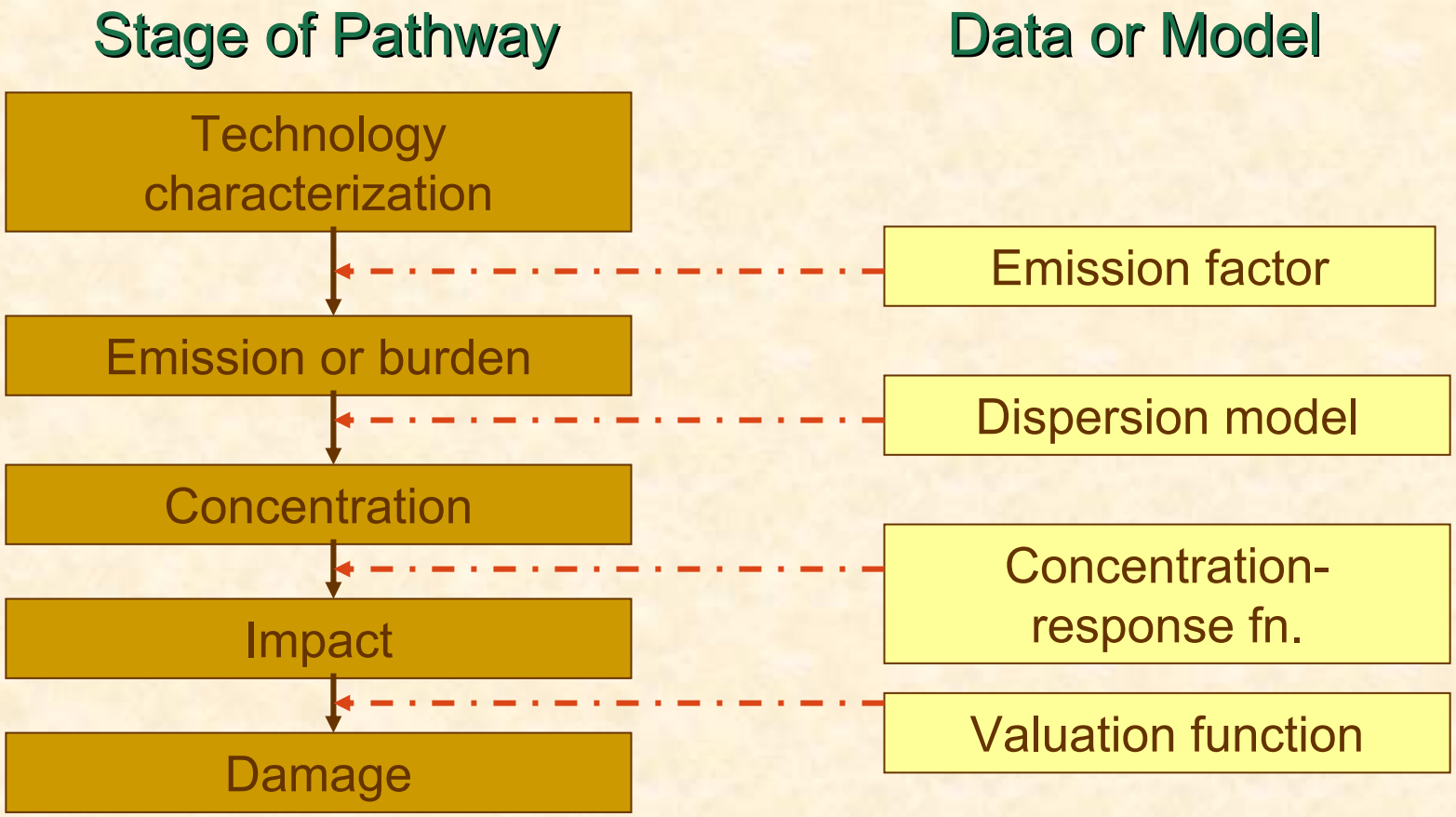
February 21, 2003

Presented at the *Valuing Externalities Workshop*, sponsored by the National Energy Technology Laboratory, U.S. Department of Energy

Recall the Impact Pathway/Damage Function Methodology for Valuing Externalities



Fate and Transport of Mercury Species in Atmospheric and Aquatic Environments are Complex and Our Understanding is Incomplete

- Mass balance studies have shown that atmospheric loading is the principal source of mercury in lakes
- The ORNL/RFF (1994) study quantification of ecological or health impacts of atmospheric mercury derived from coal combustion was not possible because of uncertainty about:
  - relationships between release rates and deposition rates,
  - relationships between sources and deposition,
  - water body characteristics and mercury bioaccumulation in fish

Can Apply Impact-Pathway or Damage Function Approach to Estimate Mercury-Related Externalities

Hagler, Bailly study considered:

- **Emissions**
- **Fate and transport**
- **Ambient concentrations and exposure pathways**
- **Uptake of mercury**
- **Estimates of health impacts**
- **Valuation of health impacts**

Coal-fired power plants are one of largest sources of U.S. anthropogenic mercury emissions.

Source: *Environment*, vol.44, no.9, p.37

Coal-Fired Power Plant *Emissions* of Mercury Depend on Amount of Mercury in Coal

- Volatization of mercury during combustion results in emissions of elemental, inorganic and organic forms of mercury
  - Elemental mercury, Hg^0, about 50%(?) of the emissions (estimates vary)
  - Inorganic mercury (divalent), Hg^{++}, accounts for remainder
- Quantity depends on amount of mercury in the coal and on pollution abatement equipment
  - 8 to 16 lb/10^{12} Btu's at coal plants with electrostatic precipitators
  - 1 to over 7 lb/10^{12} Btu's at coal plants with scrubbers

Airborne *Transport* Modeled Using Air Dispersion Model

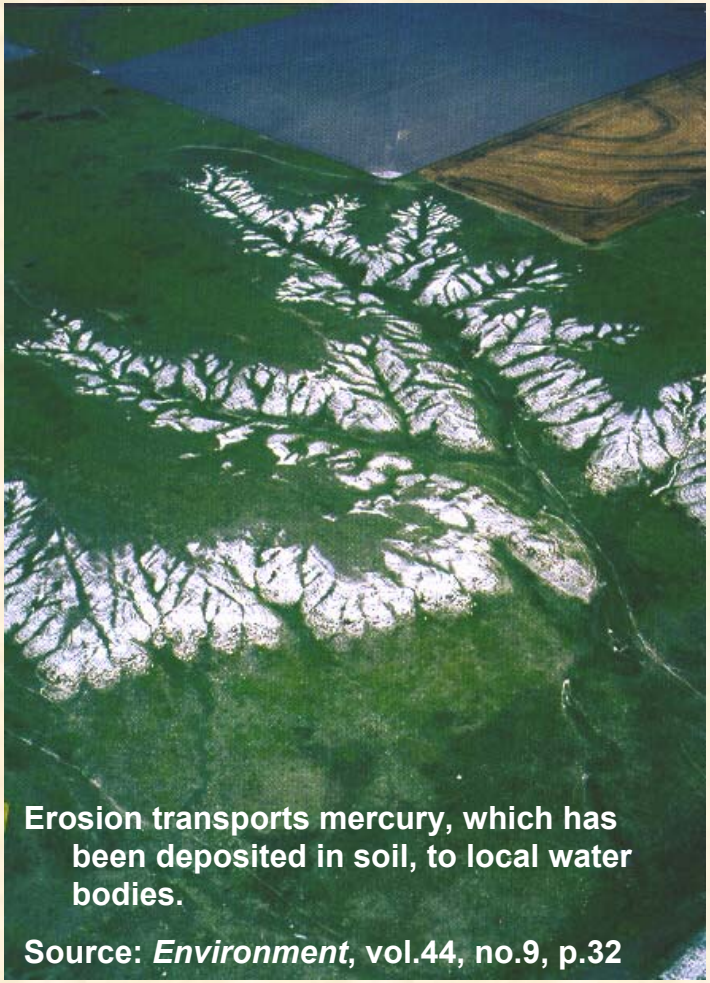
- Use simplifying assumption that emissions are inorganic in the form of soluble $HgCl_2$, both gaseous and bound to particles.
  - Inorganic mercury has shorter residence time in atmosphere –> assumption leads to higher impacts in local area
- Industrial Source Complex Long Term (ISCLT) model → estimate a *maximum* increase in ambient air concentrations of about 10^{-6} μg/m^3
- Long-range transport model used for regional concentrations
- Ambient concentrations of mercury and uptake from direct inhalation appeared to be quite small relative to ingestion exposures [the rest of this discussion focuses on ingestion]

Airborne Mercury is *Deposited* to Soil and Water

- Total deposition is sum of wet and dry deposition rates
- Wet deposition rate
  - Average mercury concentration in air
  - Washout ratio that reflects the concentration of soluble mercury in rainwater
  - Annual average rainfall rate
  - Annual hours of precipitation
- Dry deposition rate
  - Average mercury concentration in air
  - Fraction of year during which dry deposition occurs
  - Deposition velocity

Mercury Concentration in *Sediment*

- Mercury deposited to soils finds its way into stream and lake sediment through runoff and erosion
- Total sediment concentration of mercury is sum of:
  - concentration from runoff, and
  - from wet deposition



Erosion transports mercury, which has been deposited in soil, to local water bodies.

Source: *Environment*, vol.44, no.9, p.32

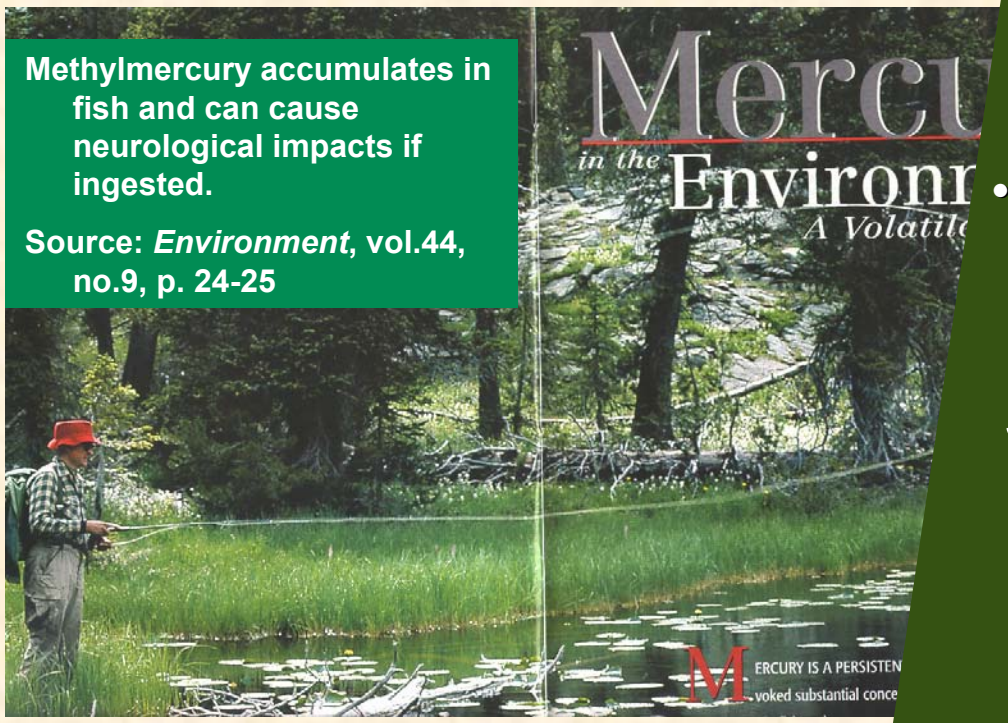
Mercury Concentration from Runoff

- Soil loss rate per unit area watershed depends on:
  - Rainfall erosion index
  - Soil erodability factor
  - Slope length factor
  - Cover and management factor
  - Sediment delivery factor
- Watershed area
- Mercury concentration in soil
- Accumulation time
- Sediment mixing depth
- Water body area receiving runoff

Mercury Concentration from Wet Deposition

- Wet deposition rate (previously estimated)
- Evasion
- Flux to sediment
- Sediment mixing depth
- Sediment bulk density
- Accumulation time

Mercury *Concentration in Fish* Tissue



Methylmercury accumulates in fish and can cause neurological impacts if ingested.

Source: *Environment*, vol.44, no.9, p. 24-25

- Methylation of inorganic mercury by microbial action forms the more toxic methylmercury, Me-Hg
- Mercury concentration in sediment due to runoff and direct wet deposition, as previously calculated
- Sediment-based bio-concentration factor that relates mercury concentration in fish to mercury concentration in sediment, e.g., 10:1(?)
  - Lake pH levels
  - Sulfate levels
  - Presence of humic acid
  - Trophic status
  - Conductivity
  - Size of catchment area

Ingestion of Mercury

- Consumption of fresh-water fish is primary source of methylmercury uptake
- For most non-fishermen, freshwater fish consumed is limited to occasional meal in a restaurant
- For fishermen and their families, average incremental daily absorption of methylmercury from freshwater fish ingestion depends on:
  - Methylmercury concentration in fish tissue due to power plant emissions, as previously calculated
  - Local freshwater fish ingestion rate – percentage of fishermen's families who consume fishermen's catch

Estimates of *Health Impacts* Depend on Dose-Response Relationships, Thresholds

- EPA has reference dose of 0.1 µg/kg body weight/day as estimate of lowest uptake level with observable adverse effects.
  - World Health Organization has previously used 0.5 µg/kg body weight/day
- Adults – symptom is prickling or itching of extremities (paraesthesia)
- Fetal impacts include child IQ loss and compensatory special-education costs
- Other effects such as low birth weight and associated risks, infant mortality, retardation and hearing loss risks were not quantified

Estimates of *Health Impacts* If Uptake Exceeds Thresholds for Effects

- Adults: Estimated increase in number of annual paraesthesia cases due to ingestion uptake of methlymercury
  - Incremental daily ingestion of methylmercury attributable to power plant emissions
  - Risk coefficient from dose-response function
  - Population exposed
- Fetal: Estimated increase in number of annual cases of fetal effects …
  - Incremental daily ingestion of methylmercury attributable to power plant emissions
  - Risk coefficient from dose-response function for fetal impacts
  - Fetal population exposed

Valuation of Health Impacts

- Estimated damage to adults
  - Increase in number of paraesthesia cases
  - Medical costs of treating these cases (e.g., diagnosis and monitoring, chelation therapy)
  - Lost productivity valued at median wage rate, times estimated lost work days
  - Ratio of willingness to pay to cost of illness
- Estimated damage of fetal impacts
  - Increase in number of cases of psychomotor retardation
  - Costs of diagnosis and treatment
  - Costs of compensating education
  - Present value costs associated with loss of IQ
  - Ratio of willingness to pay to cost of illness

Scientific Challenges to Developing a Mercury Externalities Model

- Considerable uncertainty about virtually all of the relationships and parameters used above
- Fate and transport are complex processes, especially for elemental mercury which has long residence time and is dispersed over long distances
- Understanding of deposition and geo- and biochemical processes that determine methylmercury concentrations in fish
- Dose-response relationships (including those for other health impacts not addressed in the study)

Integrated Modeling -- Challenges to Implementing a Mercury Externalities Model

- **What quantitative analysis can be justified and how to handle the uncertainty with so many parameters**
- **Nationwide analysis needed (not just plant-by-plant)**
- **Externalities estimated in Hagler, Bailly study – using the above-stated approach -- were small (not even accounting for discounting of time lag between emission and impacts) – 0.004 mills/kWh for a "typical" coal plant vs. 40 mill/kWh cost of generating electric power using coal**
  - → ***Still important to assess in rigorous way.***
    - ***c.f., proposed regulations***
  - → ***Are there aspects of the risks that are valued more highly?***
    - ***c.f., Eugene Smith Photo Essay on Minamata Disease***