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I am Dr. Leonard Levin, technical executive at the Electric Power Research Institute (EPRI). EPRI is an independent nonprofit organization carrying out research on technology, operations and the environment for the global electric power industry. EPRI brings together scientists and engineers, along with experts from academia, industry and other research centers, to address the major issues facing the electric sector. The various research groups at EPRI have been conducting investigations of environmental. mercury sources, fate, human health effects, and emissions controls for more than twenty years, spending between $10 million and $20 million per year on that research.

EPRI appreciates the opportunity to provide testimony to the Senate Committee on Environment and Public Works on the topic of mercury sources, health effects, and controls. The recent court decision by the D.C. Circuit Court of Appeals is leading to a re-evaluation of necessary mercury control regulations on electric utility coal-fired power plants. If utility mercury regulation moves back to Section 112 of the Clean Air Act, that change is likely to entail future risk-related studies under provisions for evaluating residual risk (risk remaining after full implementation of the initial regulatory control steps) and urban air toxics. For that reason, EPRI and others are now re-examining the mercury exposure and health impacts under different utility emissions scenarios. The lessons from those re-examinations are instructive in informing the community about the role of emissions controls in protecting public health, and the breadth of effort necessary to stem exposure to a global pollutant such as mercury.

SUMMARY OF OUR CURRENT UNDERSTANDING OF MERCURY SOURCES, HEALTH EFFECTS, AND CONTROLS

1. Increasingly, observations, measurements, and sophisticated modeling studies have demonstrated the significant role played by various mercury sources located in other countries to US mercury deposition.

2. Emissions of mercury in most countries outside the industrialized west are increasing at a rate of about 5 to 8% per year. This is especially true in China where emissions are growing rapidly despite application of new control technology which captures some mercury.

3. U.S. deposition of mercury has measurably declined in recent years in the northern tier of states from the Midwest to Maine, although such a decline is not evident in the southeastern U.S.

4. Sources as far away as 600 miles have been shown to contribute to mercury deposition at Steubenville, Ohio. This data-based finding tends to contradict modeling results attributing deposition only to nearby power plants.

5. Repeated studies by EPRI and by EPA have shown that health-related benefits from controls on power plant mercury emissions will not change significantly between a scenario in which all power plants are controlled to levels up to 90% vs. a cap and trade scenario in which the average reduction industry-wide is about 70%.

MERCURY IN THE U.S. ENVIRONMENT

Recent studies on mercury from all sources – natural and industrial, distant and domestic – have reinforced the complex nature of mercury input to the U.S. environment. The improvement in instrument and analytical methods, airborne and ground measurement protocols, and process modeling allows a more effective integration of data, the "gold standard" in any scientific endeavor, with computer simulations to provide an integrated understanding of mercury in the environment. Though many aspects of the substance are still poorly understood, the bounds on our understanding are narrowing and allowing us to more confidently link mercury concentrations in precipitation and in waterways to particular source areas and source categories.

Mercury as a Global Pollutant

- *Background Sources of Mercury.*

  Because mercury is a mass-conserved chemical element associated with geological formations in the earth's crust, it has long been ubiquitous in trace amounts in the human environment. This presence and potential impact were evidently common even prior to the Industrial Revolution. There is, for example, good archeological evidence that Native American peoples in the pre-European era set wildfires for land clearing and herding of wild animals. Geological cores from peat bogs and lake sediments show extended periods of elevated mercury in the atmosphere from these occurrences. There are many areas in the rural western United States with fish populations in local stream and lake systems bearing mercury at or above health advisory levels, even though no current or prior atmospheric or surface sources of the metal are evident nearby.

  It is useful to categorize mercury's sources broadly into human, or anthropogenic, sources (such as fossil fuel combustion), and background sources (such as emissions from geothermal vents or from abandoned mine tailings). The category of background sources – natural emissions of native mercury, mercury re-emitted from the surface after earlier deposition, and geological mercury exposed to the atmosphere by human disturbance – has assumed increasing importance in the global and regional mass balances of the substance. Recent findings have indicated that, globally, natural sources of mercury may be twice as large as previously thought, further reducing the significance of anthropogenic sources in the global mass flow.

- *Anthropogenic Mercury Emissions.*

  Table 1 shows a recently published inventory[1] of global mercury emissions. The notable point is that, not only are total Asian emissions about an order of magnitude greater than those of North America, but Asian sources are the "nearest" upwind sources to North America at mid-latitude in the Northern Hemisphere. Following a recent global emissions re-evaluation by the United Nations Environment Program, emissions from China are believed to total more than half of all those from Asia, while Indian emissions may be half of what was earlier estimated. Country-by-country inventory estimates, when available, indicate that emissions on all populated continents except Europe and North America are increasing over time.

Country/continent	Hg annual emissions (Mg/y)	$Hg^0/Hg^{II}/Hg_p$
United States	104	60/31/9
Canada	8	54/35/11
Mexico	26	71/20/9
Asia	1204	57/34/9
Europe	239	61/32/7
South & Central America	92	71/23/6
Africa	407	65/28/7
Oceania	125	55/36/9

Table 1. Global anthropogenic emission inventory for total mercury (datum year 2000)

- *Trends in Mercury Concentrations.*

  Mercury, as a global pollutant, can exhibit significant fluctuations in concentrations due to local meteorological and environmental factors. Day-night cycles can bring oxidized mercury down to near the earth's surface by nocturnal cycling, displacing some of the normally prevalent elemental form. Nearby industrial areas can provide oxidizing agents, such as ozone, to convert ambient elemental to divalent mercury, while surface vegetation and porous soils can serve as temporary mercury reservoirs.

  These shorter term cycles tend to be smoothed out when examined from a global perspective using data from locations distant from emission sources and less subject to diurnal cycles. These global data will be more reflective of long-term trends in concentration, for example, driven by shifts in emission sources. Work by Franz Slemr et al.[2], shown in Figure 1, reveals that, over the past thirty years, global atmospheric mercury levels have apparently varied substantially. Those data indicate an apparent increase in emissions until about 1970-1980, then a decline for about 20 years or so, followed by a leveling-off in the past 10 years.

[1] K Lohman, C Seigneur, M Gustin, S Lindberg; 2007; **"**Sensitivity of the Global Atmospheric Cycling of Mercury to Emissions," *Applied Geochemistry 23* (2008) 454–466

[2] F Slemr, E-G Brunke, R Ebinghaus, C Temme, J Munthe, I Wängberg, W Schroeder, A Steffen, T Berg; 2003; "Worldwide trend of atmospheric mercury since 1977," *Geophysical Research Letters, 30,* 10, 1516, Doi:10.1029/2003gl016954.

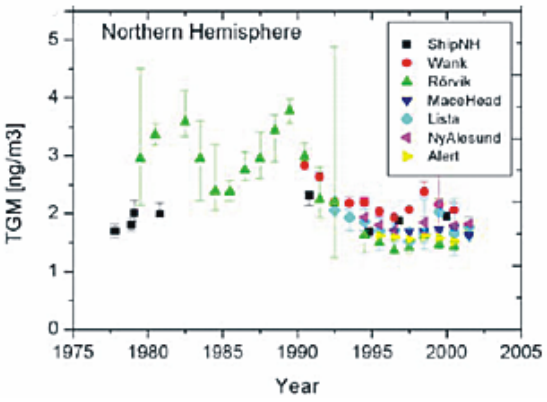


Figure 1.
From: "Worldwide trend of atmospheric mercury since 1977," F. Slemr et al., 2003; *Geophysical Research Letters, 30*, 10.

Investigators are still unable to determine whether this most recent change in trend is real and long-term, or an artifact of data coverage and time intervals. Inventories compiled on mercury emissions from China by Wu et al.[3] of Argonne National Laboratory have shown Chinese mercury emissions growing by up to 10% per year, and on average about 3% per year, since the 1990s. The Slemr et al. results match up with the decline in background mercury levels underway since the 1950s or 1960s, shown in data by Benoit et al.[4] and Engstrom and Swain[5]. Growth in mercury emissions on continents other than Europe and North America (where emissions are declining) may now be impacting the global balance of the substance.

- *Mercury Deposition Trends.*

  Mercury emitted to the atmosphere can be carried to great distances, and globally, by atmospheric circulation. Eventually some of this mercury will be deposited to the earth's surface, in part by dissolving in atmospheric precipitation and in part by simply contacting the earth's surface and being sequestered temporarily into soils and vegetation, or onto constructed surfaces. There are at present no field-capable means of consistently measuring this second form of deposition, referred to as dry deposition. The first type, wet deposition, is regularly measured around the United States in a network of precipitation collection stations termed the Mercury Deposition Network (MDN). This network is maintained and its samples analyzed for mercury by a voluntary system of sponsors, including state and federal agencies, universities, and private institutions such as EPRI. The samples are collected weekly, then analyzed for both the rate of mercury transfer to the surface in precipitation and the concentration of the mercury (all divalent form) in the precipitation itself. Figure 2 shows the most recent annual compilation of these national data.

  Trends in the MDN data sets have been difficult to discern statistically, because the network itself is generally growing in coverage with time and the first of its stations has only been in operation since 1995. Two recent analyses by Han et al.[6] and by Butler et al.[7] have found by both modeling and data analysis that, in recent years, mercury deposition in the northeast,

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[3] Y Wu, S Wang, D G Streets, J Hao, M Chan, J Jiang, 2006; "Trends in Anthropogenic Mercury Emissions in China from 1995 to 2003," *Environ. Sci. Technol., 40,* 5312-5318

[4] JM Benoit, WF Fitzgerald, AWH. Damman. 1994. "Historical atmospheric mercury deposition in the mid-continental United States as recorded in an ombrotrophic peat bog." In: C. Watras and J. Huckabee (eds.), *Mercury Pollution: Integration and Synthesis*.Lewis Publ., Boca Raton, FL, pp. 187-202.

[5] DR Engstrom, EB Swain, 1997; **"**Recent Declines in Atmospheric Mercury Deposition in the Upper Midwest," *Environ. Sci. Technol., 31*, 960-967

[6] Y-J Han, TM Holsen, DC Evers, CT Driscoll, 2008; "Reduced mercury deposition in New Hampshire from 1996 to 2002 due to changes in local sources," *Env. Poll.* (prepub.)

[7] TJ Butler, MD Cohen, FM Vermeylen, GE Likens, D Schmeltz, RS Artz, 2008; "Regional precipitation mercury trends in the eastern USA, 1998–2005: Declines in the Northeast and Midwest, no trend in the Southeast," *Atmosph. Env. 42*, 1582–92

and specifically southern New Hampshire has declined significantly. Importantly, the latter paper is a re-investigation of deposition trends in the same area of New England modeled in a 2006 paper by some of the same authors. That earlier paper attributed most of the deposition and fish levels of mercury in southern New Hampshire to nearby utility coal-fired power plants, including sources no further from the receiving waters than western Massachusetts from the receiving waters in New Hampshire. The new paper by Butler et al. interestingly notes the difficulties in that approach, by remarking upon the lack of inclusion in either study of any mercury sources more distant than the adjoining state. The authors found an incommensurate decline in deposition with their modeled emissions cuts: emissions cuts of 50% and 90% in their scenarios led to general declines in deposition of 5% and 9% respectively, in their regional-scale domain, with greater proportional declines in deposition at finer scale closer to their largest modeled power plant source (in that case, they found a 23% deposition drop for a 50% emission cut).

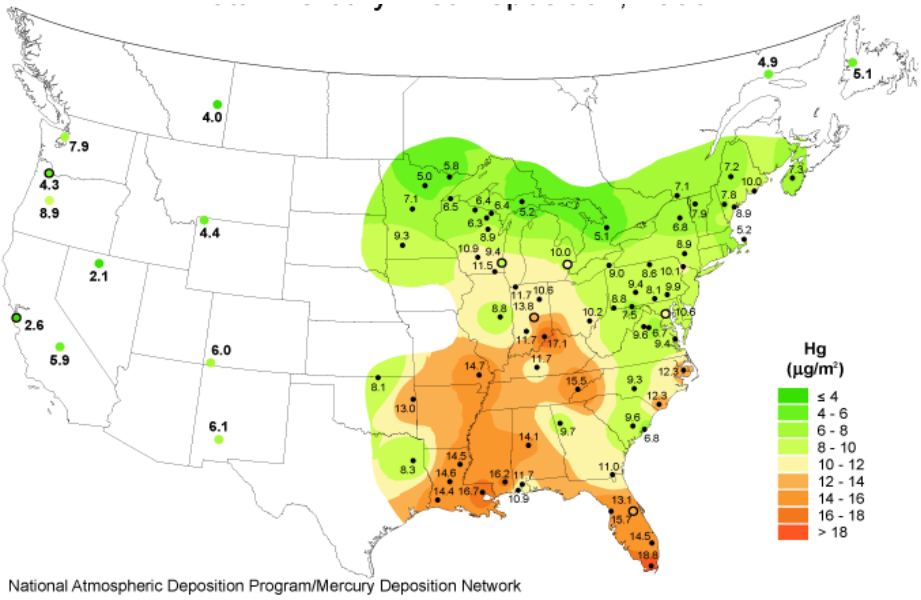


Figure 2.
Annual Mercury Wet Deposition, 2006.
From: National Atmospheric Deposition Program at
http://nadp.sws.uiuc.edu/mdn/maps/map.asp?imgFile=2006/06MDNdepo.gif

These findings, in a limited modeling study, reflect the conclusions of earlier emissions-deposition scenario calculations carried out for the entire United States. In those simulations, reductions in utility mercury emissions of 75% and 83% (the equivalent of about 25% and 27% national mercury emissions cuts, respectively, with other U.S. sources assumed to remain unchanged) both resulted in U.S. national average deposition drops of about 6%[8]. The differences between these national modeling simulations and the more constrained New Hampshire simulations lies primarily in the inclusion of many other (unchanged) sources, nationally and globally, in the U.S. simulation. But the general trend –

[8] C Seigneur, K Vijayaraghavan, K Lohman, P Karamchandani, C Scott, 2004; "Modeling the atmospheric fate and transport of mercury over North America: power plant emission scenarios," *Fuel Proc Tech. 85*, 441-50.

a small "payback" in deposition reduction for relatively large cuts in utility emissions – leads to the possibility of further investigation of how potential cuts in utility mercury emissions may play out in changes in local-scale deposition.

Mercury Deposition under Regulatory Scenarios

- *Pathways of Human Exposure to Mercury.*

  Nearly all community exposure to mercury occurs via consumption of food fish that may contain mercury levels of concern. These fish may be self-caught by anglers, individually distributed from anglers to family and community, or (in most instances) purchased in commerce. A number of studies have shown that the most sensitive individuals to mercury exposure are unborn fetuses, for whom mothers' consumption of fish represents the likely route of exposure through the umbilical blood system. Several studies of children in island nations, where consumption of locally caught fish is a major portion of the diet for young and old alike, have indicated that there is a threshold for (mothers') mercury exposure above which decrements in neurobehavioral achievement (ages of walking and talking; attention span; reaction time) are likely.

  It is this critical link, through fish consumption, that leads to the evaluation of mercury deposition in current and future policy scenarios as an indicator of how public health might benefit from willful control of source emissions. More importantly, current data and numerical tools allow us to study the marginal benefits of marginal source control strategies: what additional public health benefit (in lowered levels of fish mercury due to lowered levels of mercury input to waterways because mercury deposition has been reduced) can be expected if emissions are increasingly reduced from current emissions levels?

- *Patterns of Mercury Deposition.*

  Modeling studies over the past five years by the U.S. EPA, EPRI, and by others have shown quite clearly that, beyond a certain national level of emissions control, the net change in human health benefits (as measured by a decline in mercury deposition) becomes quite small. There are several reasons for this "declining marginal benefit." The primary reason is due to the two primary forms of mercury emitted by power plants, and their differences in both capacity for being captured before emissions and in atmospheric behavior.

  The divalent form of mercury, Hg(II), makes up roughly 40% of U.S. utility emissions, while elemental or metallic mercury, Hg(0), constitutes, on average, the remaining 60%. For an individual coal-fired power plant, these relative fractions can range from nearly 0 to nearly 100% for each (in addition to the differences in absolute amounts emitted). But divalent mercury is more easily captured within power plant facilities by existing and newly introduced control devices, such as flue gas desulfurization (FGD) systems or "scrubbers." Elemental mercury, conversely, is very difficult to capture by existing commercial control devices, primarily due to its very low chemical reactivity and its insolubility in water.

  These differences in ability to be captured at the source are, in a sense, counterbalanced by the two forms' behavior in the atmosphere once emitted. Divalent mercury, whose combined forms are generally water-soluble, is more readily removed from the atmosphere and from stack plumes by atmospheric precipitation, in which it will dissolve. Even though precipitation occurs only about 3-4% of the time in most of the United States, this small

fraction of time is very effective in removing the divalent mercury then present in the atmosphere in the areas of precipitation. The remainder of the time for divalent mercury, and all of the time for the elemental form, represents atmospheric transport away from the source points and dispersion into large volumes of the atmosphere. Simultaneously, atmospheric chemistry can oxidize elemental to divalent mercury, or reduce divalent to the elemental form.

Generally, this atmospheric dispersion carries elemental mercury thousands of miles from its source before, eventually, some of it becomes oxidized and entrained into precipitation carrying it to the earth's surface. Remembering that, like any plume of emitted material, longer transit time from the source point equals longer distance from the source and more mixing and dilution in the surrounding atmosphere, the picture emerges that elemental mercury plays little role in overall mercury deposition at locations close its atmospheric sources, while the divalent form plays a larger such role.

When this information is combined with the general pattern of mercury emissions from U.S. power plants, where power plants in the east generally emit higher fractions and higher mass flows of divalent mercury than those further west, a picture emerges that helps explain in part the deposition patterns seen in Figure 2. Mercury deposition generally increases from west to east in the United States for three primary reasons: first, rainfall is generally higher moving from west to east, and from northwest to southeast; second, there are increasing numbers of U.S. mercury emissions sources upwind, or generally west, of locations as one traverses from west to east, adding to the input of mercury at each location; and third, more of those sources may be preferentially emitting the more easily deposited divalent mercury.

- *Performance and Cost of Advanced Mercury Controls*

  The effectiveness and cost of mercury control technologies, such as activated carbon injection (ACI), are determined by both the coal a power plant burns and a plant's existing or planned air pollution control equipment.

  For many plants burning bituminous coal, removal of mercury at levels of 90% or more is potentially feasible with a combination of flue gas desulfurization (FGD) device, or "scrubber," for removing SO_2 and selective catalytic reduction (SCR) systems for NOX. However, this mercury removal can be affected by conversion of a portion of the captured mercury to elemental mercury, which escapes from the control device. Thus, the net removal may be less than 90%.

  Plants that do not have an FGD and SCR system would be likely to use ACI for their mercury control. However, those plants that burn a medium-to-high sulfur coal can have the mercury reduction effectiveness of an introduced ACI system degraded by sulfur trioxide present in their flue gases, driving up the costs due to their need for increased carbon use. For higher sulfur coals, most plants can achieve mercury removal of about 50% even at high levels of carbon injection.

  In the case of subbituminous and lignite-fueled power plants, test results to date have shown capture at levels of 90% or beyond when halogens such as bromine are either injected in the boiler or on the coal or are present in the activated carbon. However, additional issues arise regarding bromine in wastewater streams or the ability to use the coal ash in construction applications. These additional issues can add significantly to the true costs of ACI even

when capture efficiency is at high levels, for which the average capital cost for an ACI system is $4 per kilowatt.

- *Mercury Deposition under Utility Regulation.*

Because of the "co-benefit" of capturing divalent mercury with current (and planned) control equipment, every simulation run of control strategy economics and timing has indicated that the utility sector will significantly reduce mercury emissions as more plants are retrofit with SO_2 scrubbers and selective catalytic reduction (SCR) systems for NOx control (SCR systems can oxidize elemental mercury to the divalent form in some instances). Reductions in elemental mercury will require either in-plant oxidation to the divalent state for removal in FGD systems or application of additional technology such as activated carbon injection (which removes both forms of mercury). The tradeoff is that the elemental form plays very little role in nearby deposition, requiring some 3000 km before even half of an emitted amount of elemental mercury is removed from the atmosphere by chemical or physical processes. Thus we can see that most of the elemental mercury emitted in the United States is likely to disperse into the prevailing westerly wind patterns and pass out of national airspace before being removed from the atmosphere. Modeling studies have accounted for this behavior by tracking all the mercury to its eventual removal, even following repeated circumglobal transects before oxidation and precipitation to the surface.

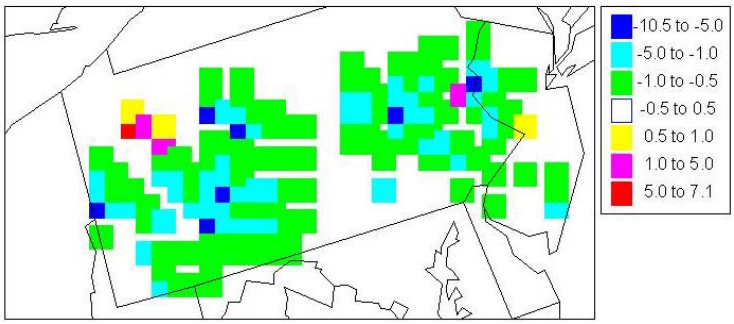


Figure 3
Differences in deposition, micrograms per square meter per year (µg/m^2-yr), Pennsylvania and New Jersey, for 90% utility controls vs. national 70% controls

The impacts of this differing behavior can be seen in Figure 3, a simulation of the differences in deposition in the states of Pennsylvania and New Jersey for two power plant control scenarios: a 90% cut from baseline (2004) emissions applied equally at each power plant, vs. state-designated "CAMR" levels under the former EPA control regulation (a 70% mercury reduction with the capability for emissions trading).

The patterns of differences seen between the two simulations are somewhat surprising but understandable once the data are carefully analyzed. We find that for most locations, in going from the 70% to the 90% control scenario, mercury deposition is incrementally reduced by 5 micrograms per cubic meter per year (µg/m^2-yr) or less. Some locations drop by up to 7 µg/m^2-yr. From Figure 4 below, it is evident that these additional reductions are only about 1/10th of current deposition in that region. (A few locations show a modest increase in deposition for a further cut in emissions. This is due to the 70% scenario including a provision for emissions trading. Since a 90% across-the-board reduction would leave no "excess" emissions for trading, power plants would have no economic incentive to cut emissions beyond 90% as they might under a 70% cap and trade.)

For the entire eastern US, the results are much the same. Going from a 70% average reduction as part of a cap and trade program to 90% control at all coal-fired power plants

results in a rather small change in mercury deposition (again typically about 5 µg/m^2-yr) which is a reduction of about 5-10% compared to the average deposition in the region, depicted in Figure 4.

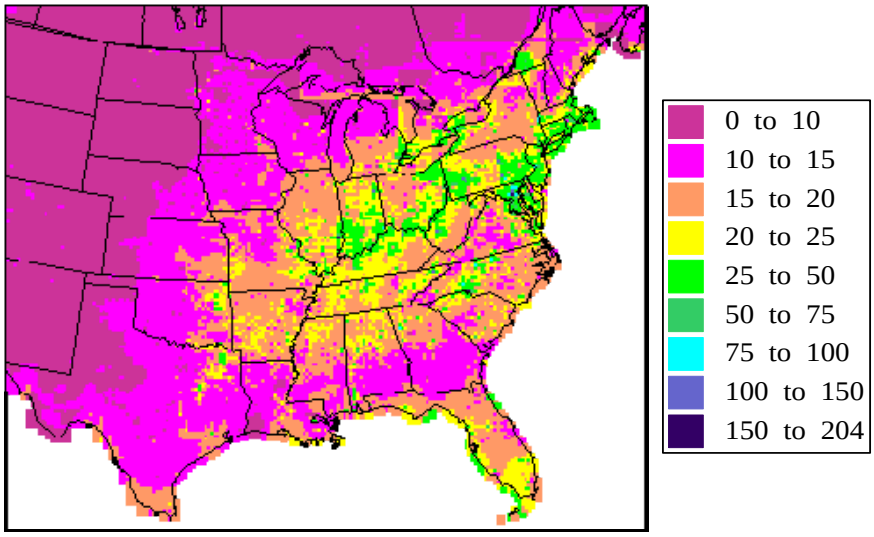


Figure 4
Total mercury deposition, micrograms per square meter per year (µg/m^2-yr), eastern United States, for 2004 mercury emissions from all sources U.S. and global

CONCLUSIONS REGARDING MERCURY FATE AND TRANSPORT

Based on these results we reach the following conclusions:

- Increasing required mercury emissions reductions from a 70% cap and trade scenario to a 90% plant by plant scenario results in very small marginal differences in mercury deposition. This is due to the fact that elemental mercury plays only a small role in U.S. mercury deposition as well as the continuing (and growing) role of non-U.S. mercury sources over time contributing to US deposition.
- The additional public health benefits that result in going from a 70% control strategy to 90% mercury controls on individual plants are minimal. The average decline in mercury exposure of U.S. women (as measured by projected drops in blood levels of mercury) is about 1%, with a maximum reduction of less than 7% under a 70% control strategy[9]. Going to 90% control, further reductions in exposures are insignificant. These findings closely match those of EPA, which found that the maximum decline in exposure was 15% under a roughly 70% decline in emissions.
- These relatively small drops in mercury exposure of U.S. women of childbearing age following large proportional cuts in U.S. utility mercury emissions are chiefly because

[9] L. Levin, 20 August 2004, "Mercury Research Update," U.S. EPA Headquarters, Washington, D.C.

consumption surveys by the Centers for Disease Control and Prevention have shown that women primarily consume fish purchased in commerce, of which about 70% come from the North Pacific, a region where mercury deposition is relatively insensitive to changes in U.S. mercury emissions. Due to prevailing wind patterns, that region is essentially upwind of American mercury sources, and their changes, so will reflect little change in resulting deposited mercury or mercury in fish native to the region.

- Current modeling tools allow the scientific community to effectively determine at which locations control of mercury emissions can have the greatest impact in reducing deposition of, and exposure to, mercury. By examining the major contributors to deposition in watersheds with the greatest sensitivity to changes in mercury input, effective management strategies can be designed. The complex relationships between water chemistry and aquatic ecosystems can be used to target particular sources that may strongly contribute to fish levels of mercury in those water bodies. An across-the-board reduction in mercury emissions of 90% from one source category appears, by all evidence, to have little additional benefit for human health compared to either focused reduction strategies or an average 70% emissions control approach.