A Statistical Analysis of Factors Associated with Elevated Hair Mercury Levels in the U.S. Population:

An Interim Progress Report

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Foreward:

This report is intended to be an interim statement of progress and results of an on-going study of the mercury hair levels in the U.S. population and their statistical association with variables such as geographic location, gender, age, occupation, and fish consumption patterns. A final report on the completed study is scheduled for release in late February or early March 2005. With recent intense national interest in the issue of human exposure to mercury, prompted in part by U.S. Environmental Protection Agency reports that over 75 percent of 3,094 fish consumption advisories are caused by mercury contamination and that the extent of such consumption advisories has now increased to include about 35 percent of U.S. freshwaters, an interim progress report relating human mercury exposure to fish consumption patterns is appropriate.

It should be noted that the final study report will include a national statistical analysis geographically correlating mercury hair levels of the U.S. population with aerial mercury atmospheric deposition data from coal-fired power plants and other sources now becoming available as detailed dispersion models from the U.S. Environmental Agency. An assessment of this relationship between human mercury exposure and atmospheric deposition levels has not yet been performed to be included as part of this interim report.

Background and Introduction

Exposure to mercury has become increasingly recognized as a significant public health issue affecting the U.S. population, especially infants and young children. Fetal exposure to mercury is a special concern because it is now recognized that even very low mercury exposures cause significant cognitive developmental defects and other neurological development disorders in children (e.g. Bienenfeld et al, 2003; NRC, 2000; Castoldi et al, 2001). Other recent research (e.g. Steuerwald et al, 2000; Grandjean et al, 1999; Grandjean et al, 1997; Crump et al, 1998) has also repeatedly validated the fact that even moderate mercury exposure during pregnancy can cause measurable adverse effects on brain development, resulting in observed deficits in language development, memory, motor function, and visuospatial performance.

Although people in the U.S. can be exposed to mercury through many routes including inhalation of ambient mercury-containing air, ingestion of terrestrial animal products such as eggs, meat, and butter, consumption of water, and hand-to-mouth contact with surfaces where fly ash and mercury have deposited, it has become clear that the primary route of mercury exposure to the U.S. population is through fish consumption (e.g. Mahaffey et al, 2001; McDowell et al, 2004). Many fish species, especially those higher in the trophic web such as bass, salmon, walleye, and pike, are known to concentrate mercury to tens of thousands of times higher concentrations than found in the water column.

While permanent neurological damage to infants and young children continues to be the primary public health concern from mercury exposure, some studies have also found increases in male heart disease associated with moderately elevated mercury exposure (e.g. Gualla et al, 2002; U.S. Environmental Protection Agency, 2004). Although not yet adequately documented in the scientific literature, there is increasing evidence that many U.S. individuals of all ages have developed greatly increased sensitivities to periodic mercury exposure resulting in vision impairments, circulatory system problems, and other neurotoxic symptoms from even low mercury levels (eg. Snider, 2004; Wright and Wilson, 2004).

The U.S Environmental Protection Agency (EPA) has set a "reference dose" (as measured by the mercury content of hair) of 1.0 μg/g (or one part-per-million, i.e. ppm) to assess human mercury exposure. At this level women of child-bearing age are advised to stop consumption of fish that may have elevated mercury levels. In a large national study conducted previously to our study, McDowell et at. (2004) measured the hair mercury levels of 2564 randomly selected U.S. individuals (838 children and 1726 women of child-bearing age) from the 1999-2000 National Health and Nutrition Examination Survey (NHANES). The geometric mean for the entire study population in 1999-2000 was 0.12 μg/g in children and 0.20 μg/g in women aged 16-49. Among frequent fish consumers the geometric mean increased to 0.38 μg/g, again further reinforcing the fact that fish consumption is the major pathway of mercury exposure in U.S.

Approximately 12% of the women studied had hair mercury levels above the 1.0 μg/g EPA health advisory, and about 23% had levels that were greater than one-half the EPA advisory level (ie.> 0.5 μg/g). According to the NHANES data, between 300,000

and 600,000 newborns in the U.S. in the year 2000 were prenatally exposed to in utero methylmercury levels above the USEPA health advisory limits (Mahaffey et al, 2004).

While mercury can enter the environment from various natural and industrial sources, at least 40% of total U.S. mercury emissions come from coal-fired power plants. This percentage is increasing as other Hg sources such as medical incinerators and municipal waste combustors are greatly reduced (USEPA, 2004; NESCAUM, 2003). Also, in a large percentage of U.S. watersheds, coal-fired power plants are recognized to be the majority source of mercury emissions (NESCAUM, 2003). Without regulatory requirements and the installation of mercury control technologies, emissions from coal-fired power plants can be expected to increase as more plants are built and/or existing plants expanded (NESCAUM, 2003).

Thus, the purposes of the current study were to: 1) Determine from a large study sample the percentage of people in various age/gender categories with excessive mercury exposure as measured by hair levels in 2004. 2) Examine statistical relationships for the study population between mercury exposure and age, gender, occupation, and fish consumption habits. 3) Develop statistical relationships between hair mercury levels and atmospheric mercury deposition rates across the United States.

Methodology

Study participants were recruited by Greenpeace, Aveda, and various nonprofit organizations in various areas of the U.S. through national internet notices, regional media coverage of the research project, special local awareness events, and other publicity efforts. As of the September 23, 2004 cut off date for receiving samples, over 3000 hair sampling kits had been sent to volunteer study participants, and 1449 were returned in time to be included in this interim project analysis. It is anticipated that over 5000 participants will eventually be included in the statistical analysis for the final report on this research project in February or March of 2005. The study sample population areas are not intended to be statistically representative of the entire U.S. population, since participants were self-selected, and recruitment of study participants was focused more strongly in some areas of the country than others. The study population is clearly weighted towards particular geographic areas, towards individuals who might be more concerned about this particular health issue, and towards individuals better able to afford the small fee to participate in the study. It is unclear whether these selection factors would tend to inflate or reduce average hair mercury levels related to the general population. It is very unlikely, however, that the statistical relationships we examined between hair levels and other variables including age, gender, geographic area, and fish consumption levels would be different for our study population than for the general U.S. population.

Each volunteer was sent a hair sampling kit by the Environmental Quality Institute (EQI) consisting of gloves, ziplock sample bags, labels, a cardboard weighing balance designed to tip when approximately 0.5g of hair was added, detailed instructions for cutting, weighing and labeling hair samples, and a return postage-paid mailer. After washing their hair, each volunteer participant was instructed (complete with illustrations) on how and where to cut and weigh their sample. Each sampling kit also included a detailed research questionnaire which requests information on age, gender, pregnancy

status, hair color, occupation, dental amalgams and removal, flu shot history, and, several questions regarding specifics of fish consumption habits. (See Appendix A).

Upon receipt at the EQI laboratory, samples were logged in and questionnaire data was transferred to a computerized database. Hair samples were weighed to the nearest 0.0001 gram on an analytical balance and digested using EPA Method 3050B with concentrated nitric acid and 30% hydrogen peroxide on a SCP Science Digiblock™ graphite block digestor. Final volume of the digestate was 50ml.

Mercury determination was performed using EPA Method 7470A. Either a Thermo-Jarrel-Ash 22 graphite furnace atomic absorption spectrometer (AAS) with deuterium arc background correction or a Thermo M6 AAS with a V90 vapor system were used to determine mercury concentration in the digestates. Mercury levels in the original hair sample were determined by back-calculation according to the formula:

[Hg Hair in ppm]= (Hg concentration (μg/L) x 0.05 L digestate volume)/(wt. of hair (g))

Each volunteer participant was sent a confidential letter with their individual results along with explanatory information regarding USEPA advisory levels.

Results and Discussion

Of the 1449 individual hair samples completed for the interim report 20.3% (slightly over one-fifth) were found to have mercury levels above the USEPA advisory level of 1.0 μg/g. An additional 20.6% of participants had levels between 0.5 and 1.0 μg/g, also indicating significantly elevated mercury exposure. As noted earlier, the 1999-2000 NHANES study found that about 12% of the U.S. population of children 0-5 years and women 16-49 years had mercury hair levels above the advisory level. It is unclear at this point to what extent this difference may be due to the self-selection procedure used for our study as opposed to the extent that mercury exposure of the U.S. population has actually increased since 1999-2000. It is very possible that overall fish consumption in the U.S. has increased over the past 4-5 years with the national health trend away from red meat and the widespread emphasis on the health value of the omega oils contained in fish. In our study we include males and females of all ages, and we found virtually no differences in the mercury hair levels between genders. Thus, we find nearly identical percentages above 0.5 μg/g and 1.0 μg/g regardless of whether we consider both men and women or just women as was done in the NHANES study. In any case the data from both studies clearly show that a high percentage of Americans (estimated range 30 to 60 million) have been exposed to mercury at levels above the levels deemed to be safe (especially for pregnant women), and that an additional 30-60 million Americans have exposure levels approaching these official cautionary levels. Thus, there is clearly no other human-produced toxin that is causing officially-recognized elevated exposures to anywhere near this high a percentage of the U.S. population.

Table 1 shows a breakdown of hair exposure levels by frequency of fish consumption. As seen from Table 1 even those who consume a low to moderate amount of fish have nearly a 10 % probability of exceeding the EPA Advisory Level, while nearly 50 % of heavy fish consumers exceeded this level.

Especially concerning is the finding that the highest 10 % of the heavy fish consumer group typically show mercury exposure several times greater than the Advisory Level.

Table 2 shows that for the heavy fish consumption group, almost three-fourths of the individuals were found to have levels above 0.5 µg/g. Even for the moderately high fish consuming group 28.5 % exceed the Advisory Level, and a total of almost 60 % of this group exhibit mercury hair exposures of at least 0.5 µg/g.

Tables 3, 4, and 5 show a further detailed analysis of fish consumption habits. Table 3 shows that the more frequently individuals consume canned tuna, the higher their hair mercury levels become. For people who consumed canned tuna four or more times per month, nearly one-third have mercury exposures exceeding the EPA Advisory Level. Table 4 shows that over half the people who consume either fresh store-bought or restaurant fish at least seven times per month have mercury exposures exceeding the EPA Advisory Level. As shown in Table 5 consumption of locally caught fish seems especially to be a problem, with over half of individuals exhibiting exposures of at least 0.5 µg/g from consumption of just one of two servings per month.

The USEPA Reference Dose (i.e. Health Advisory) of 1.0 µg/g was set for children and women of childbearing age. No Reference Dose has yet been established for adult males, but given the documented health effects, it can only benefit both genders to try to keep their mercury exposure as low as possible.

Table 1. Summary of Hair Mercury Concentrations (µg/g) by Total Fish Consumption (Note: The Result of 32.0 was Removed to Reduce Effect on Mean and Standard Deviation).

Fish Consumed Per Month	N	Mean	Stand. Dev.	Median	75%- ile	90%-ile
0 - 4	701	0.35	0.42	0.19	0.43	0.87
5 - 9	420	0.89	1.03	0.60	1.08	1.82
10 +	166	1.35	1.30	0.97	1.92	2.68

Table 2. Percentages of Individuals with Hair Mercury Concentrations of 0.5 µg/g or Above and of 1.0 µg/g or Above, Broken Down by Total Fish Consumption

Fish Consumed Per Month	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
0 - 4	702	78.5	13.4	8.1
5 - 9	420	41.9	29.5	28.5
10 +	166	26.5	25.3	48.2

In Table 6 the results are broken down by region of the U.S. From this table it can be seen that the study participants are relatively evenly distributed geographically. The most obvious trend noticeable from Table 6 is that mercury exposures are significantly lower overall for individuals in the Midwest. This trend may be due to any combination of factors including lower fish mercury levels in the Midwest, lower per-capita fish consumption, or other age/ gender differences in the study population from this versus the

other three regions. One factor which would tend to damp out differences between regions is the reality that fresh, frozen, and canned fish products are now shipped over very wide geographic regions.

In Table 7 we have further broken down the geographic regions by individual states for which we had at least 50 study participants. From Table 7 it can be seen that a significant percentage of individuals from all six states listed had moderately elevated mercury exposure levels. Participants from New York State were particularly high with over 45 % of study subjects exhibiting mercury exposures above the EPA Advisory Level. Florida and California were also well above the national percentage exceeding the EPA Advisory Level. These percentages may change substantially as the study continues, and we obtain larger and more representative study populations from each state.

Consistent with the 1999-2000 NHANES study (Mahaffey et al, 2004), it is shown in Table 8 that children and teens tended to have significantly lower mercury exposure levels than adults. This trend is probably because children and teens tend to eat less fish than adults, which in terms of mercury toxicity is probably fortunate, given the greater neurotoxicity effects of mercury on children.

Table 3. Percentages of Individuals with Hair Mercury Concentrations of 0.5 μg/g or Above and of 1.0 μg/g or Above, Broken Down by Canned Tuna Fish Consumption

Tuna Fish Servings Per Month	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
0 - 1	835	66.8	17.0	16.2
2 - 3	327	52.0	25.4	22.6
4 +	219	41.6	25.6	32.9

Table 4. Percentages of Individuals with Hair Mercury Concentrations of 0.5 μg/g or Above and of 1.0 μg/g or Above, Broken Down by Store or Restaurant Fish Consumption

Fish Servings Per Month	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
0 - 2	754	76.8	14.7	8.5
3 - 7	445	42.7	28.3	29.0
7 +	170	22.9	26.5	50.6

Table 5. Percentages of Individuals with Hair Mercury Concentrations of 0.5 μg/g or Above and of 1.0 μg/g or Above, Broken Down by Local Fish Consumption

Local Fish Servings Per Month	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
0	954	65.6	18.0	16.4

1 - 2	247	47.4	25.1	27.5
3 +	109	33.0	31.2	35.8

Table 6. Percentages of Individuals with Hair Mercury Concentrations of 0.5 µg/g or Above and of 1.0 µg/g or Above Broken Down by Region.

Region	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
Northeast	357	53.5	19.6	26.9
Southeast	491	61.9	18.9	19.1
Midwest	323	75.9	15.2	9.0
West	271	40.2	31.7	28.0

Table 7. Percentages of Individuals with Hair Mercury Concentrations of 0.5 µg/g or Above and of 1.0 µg/g or Above for States with More Than 50 Samples.

State	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
California	148	37.8	31.8	30.4
District of Columbia	58	62.1	20.7	17.2
Florida	72	45.6	20.3	34.2
New York	73	30.1	24.7	45.2
Ohio	243	79.0	12.8	8.2
Pennsylvania	289	77.2	13.5	9.3

Table 8. Percentages of Individuals with Hair Mercury Concentrations of 0.5 µg/g or Above and of 1.0 µg/g or Above, Broken Down by Age Category.

Age	N	Percentage 0.00 - 0.49	Percentage 0.50 - 0.99	Percentage 1.00 or Greater
0 - 19	169	87.0	8.9	4.1
20 - 40	768	56.1	21.2	22.7
50 +	478	54.2	23.9	22.0

In Table 9 we have summarized the statistical significance of various potential factors which might influence peoples' overall mercury exposure. The results are based on a linear regression model, and each factor in Table 9 is adjusted for all the other factors. Factors with P-values of less than 0.05 would be considered statistically significant, which means that the association is almost certainly real as opposed to being a statistical coincidence. As seen from the first three rows of data, the more store-bought fish, canned tuna fish, or locally caught fish a person consumes, the higher their hair mercury level will tend to be. As noted previously, mercury exposure clearly increases

with age, and the mercury hair levels vary significantly with geographic region. The geographic region analysis is particularly interesting because the result is adjusted for frequency of fish consumption. This means that there remain differences in mercury exposure for the different geographic regions after adjusting for the amount of each type of fish consumed.

As shown in Table 9, none of the other potential variables including occupation, gender, the presence or removal of mercury-containing dental amalgams, recent flu shots (which contain mercury as a preservative), or a recent hair dying (a few dyes still contain some mercury) were found to be statistically significant factors when adjusted for all the other factors. As the study sample size continues to increase, it is possible that some of these variables (especially the mercury amalgam variables) may become statistically significant.

Table 9. Statistical Significance of Various Factors Associated with Hair Mercury Levels Based on 1109 Completed Questionnaires

Factor	DF	F	P-Value
Store Fish Servings	1	233.1	< 0.001
Tuna Fish Servings	1	33.5	< 0.001
Local Fish Servings	1	14.2	< 0 .001
Age Category	2	28.5	< 0.001
Geographic Region	3	14.5	< 0.001
Gender	1	0.2	0.685
Work Exposure	1	0.4	0.513
Have Amalgams	2	1.5	0.230
Amalgams Removed Recently	1	0.8	0.374
Flu Shot	1	0.2	0.637
Hair Dyed	1	0.0	0.892

Summary and Conclusions

The preliminary results of this large nationwide study indicate that approximately 20 % of the U.S. population may have been exposed to mercury at levels above the U.S. EPA's Advisory Level for public health protection. This is an increase from the 12 % found in 1999-2000 by other researchers, and this difference may be due to an upward bias in our self-selected sample and/ or the fact that mercury exposures to the U.S. public have increased in the past five years. In either case both studies clearly indicate that a substantial percentage of the U.S. population, representing 30-60 million people, and 300,000 to 600,000 newborn infants per year, have been exposed to mercury at levels above the US EPA health Advisory Level.

The greatest factor influencing mercury exposure of the U.S. public is the individual's frequency of fish consumption. Fish, especially higher trophic level species such as bass, salmon, walleye, tuna, and other larger marine species, are known to

generally concentrate mercury (which has entered water from atmospheric deposition or industrial discharges) in their muscle tissues. We found that nearly half of the high fish-consuming subjects had mercury levels exceeding EPA Advisory levels.

Mercury is well documented to cause measurable brain development deficits to children exposed to even relatively low levels prior to birth, and there is increasing evidence of neurological and cardiovascular illness in many mercury-sensitive adults as well.

Coal-fired power plants are the greatest source of mercury to the environment of the U.S. and are the only significant source which continues to be unregulated. Technologies (already installed on waste combustion and medical incinerators) exist to reduce mercury emission from coal-fired power plants by 90 %.

Our preliminary work, as well as that of other researchers, clearly indicate that virtually no other pollutant is affecting such a large percentage of the U.S. population at levels above established government healthy advisory levels. Thus, it would be reasonable and prudent that the United States should move quickly in the direction of greatly reducing mercury power plant emissions. Such action would substantially increase the safety of fish consumption and provide a much-needed public health protection to the nation's people, especially its children.

An official final report on the project, projected to include over 5000 nationally-distributed study subjects, and thus the largest and most current of its type, is scheduled to be completed by the Environmental Quality Institute by late February or early March, 2005.

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Attachment A.

Mercury Testing Questionnaire

Date:		
Name:		
Address:		
Phone Number:		
Email Address:		
Are you taking this sample because you believe that you have had an unusually high mercury exposure?	Y N	
If yes, explain why:		
Gender:	M F	
Race (optional):		
Age:		
Are you currently pregnant?	Y N	
Natural Hair Color: (please circle one)	Black	Dark Brown
	Light Brown	Blond
	Red	Grey
If you dye your hair, the date of your last dye:		
Color of dyed hair: (please circle one)	Black	Dark Brown
	Light Brown	Blond
	Red	Other
If you perm your hair, the date of your last permanent:		
Do you work in an industry that requires regular exposure to mercury?	Y N	

Mercury Testing Questionnaire

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If yes, which industry? (please circle)	Dentistry	Coal-fired Electricity Generation
	Or Manufacture of:	
	Thermometers	Mercury arc equipment
	Barometers	Fungicide
	Chlorine (Chlor-alkali process)	Insecticide
	Dry cell battery	Pigment

On average, how many servings of the following do you eat per month? (A standard serving is 6 oz.)	
Canned albacore (white) tuna:	0 1 2 3 4 5 6 7 more than 7 (servings per month)
Canned chunk light tuna	0 1 2 3 4 5 6 7 more than 7 (servings per month)
Any of the following store or restaurant fish: swordfish, shark, tilefish, king mackerel	0 1 2 3 4 5 6 7 more than 7 (servings per month)
Any other store or restaurant fish	0 1 2 3 4 5 6 7 more than 7 (servings per month)
What kinds of store or restaurant fish do you usually eat?	
Locally caught fish:	0 1 2 3 4 5 6 7 more than 7 (servings per month)
What kinds of locally-caught fish do you usually eat?	
Do you have dental amalgam (silver-colored) fillings? If yes, how many?	Yes No Don't Know
Have you had dental amalgam fillings removed in the last twelve months? If yes, please give the approximate date of the last removal.	Y N
Have you had a flu shot in the past twelve months?	Y N
Do you use mercury at home in any rituals or as a medicine?	

You may choose whether or not you would like to receive information about the study findings. By checking one or more of the following boxes, you can indicate the type of information you would like to receive.

- ❑ I would like to receive the individual results of my mercury test by mail.
- ❑ I would like to receive the general study findings by e-mail.
- ❑ I **do not** wish to receive the results of my mercury test, the general study findings or any other communication about this study.