CHAPTER SEVEN

Mercury

IN 2003, CARMIN ORTIZ-ROQUE, an obstetrician in San Juan, Puerto Rico, led a study of the concentration of mercury among Puerto Rican women. She made a troubling discovery: women of childbearing age living on Vieques had mercury levels nearly nine times higher than their counterparts living in northeastern Puerto Rico, and nearly seven times higher than levels found in the United States. Ortiz-Roque reported that eleven of the forty-one Viequense women tested had levels of mercury "sufficient to cause neurological damage in their future children." She then noted a correlation between mercury levels and fish intake, and that Viequense women reported consuming fish at nearly twice the frequency of their counterparts in Puerto Rico, all of which suggested that the mercury levels might be explained by the fish the women were eating.[1] Consumer response on Vieques was immediate. Many residents stopped buying fish of all types, fearing for the future health of their children. Fish prices dropped, and commercial fishermen lost considerable revenue.

Studies such as Ortiz-Roque's may be valuable first steps in answering questions about environmental contamination on the island, but they also raise many more questions than they answer. The implication is that Vieques fish are contaminated, but what species of fish were consumed? Where were they caught? What other sources of mercury exposure are plausible? And did the women involved in the study respond accurately to the study's questions?

ABOUT MERCURY

Mercury is a naturally occurring element, a component of the earth's crust that is released to the environment from volcanic eruptions, forest fires, the weathering of rocks, and soil emissions. Nearly 158 tons of mercury are emitted annually into the air from the United States. The EPA recently estimated that four human activities account for 80 percent of emissions: coal fired boilers (33 percent), municipal waste combustion (19 percent), commercial or industrial boilers (18 percent), and waste incinerators (10 percent).[2] (Incinerators are included in this list because many people simply throw away mercury-containing batteries, thermometers, blood-pressure meters, fluorescent lamps, compact fluorescent bulbs, and electronic switches.) Throughout much of the twentieth century, organic mercury was also widely used as a pesticide and fungicide. By 2000, however, many of these uses had been restricted in wealthier nations due to concern over mercury's persistence in marine and aquatic ecosystems, and its toxicity.[3]

Ice cores collected from the Upper Fremont Glacier in Wyoming contain a record of atmospheric mercury deposition that geologists have studied to estimate natural versus anthropogenic mercury sources over the past 270 years. Overall, human activity contributed 52 percent, volcanic emissions 6 percent, and preindustrial background levels 42 percent. Over the last hundred years, however, human activities have accounted for nearly 70 percent of the total mercury measured in the cores.[4]

Once mercury is released to the atmosphere, it can move long distances attached to fine dust particles or water vapor before settling to earth. Its airborne movement and eventual descent to earth is similar in many respects to nuclear fallout. The length of time it spends airborne depends upon its "species" or chemical form.[5]

Mercury tends to exist in one of its inorganic forms, such as Hg(II), and once on the earth's surface tends to be quite mobile, traveling with surface water. It can bind to organic compounds—those containing carbon—through a process called methylation that occurs in the presence of microorganisms. The product, methylmercury (MeHg), is easily absorbed by aquatic species and makes up nearly 95 percent of the mercury found in fish. As larger organisms eat contaminated smaller ones, the methylmercury concentrates, so that very large predatory fish may have mercury levels 1 to 10 million times higher than surrounding waters.[6] Humans are exposed to methylmercury predominantly by consuming fish, and the levels of mercury in fish vary significantly by species, age, and location. In general, larger (and older) predatory fish such as swordfish, shark, and tuna have higher levels than smaller (and younger) fish and shellfish like shrimp, salmon, scallops, and oysters. The low levels in salmon are explained in part by their young age when caught, but also by the fact that many are raised in hatcheries, where they are fed fish meal to promote rapid growth.

Studies of methylmercury levels in other foods including meats, poultry, vegetables, fruits, and cereals have found levels to be 1,000 to 10,000 times lower than those found in fish and shellfish. Variation in diet, then, explains most of the differences noted in individuals' methylmercury concentrations.

Mercury has been known to be poisonous since the late nineteenth century, although today most people have little understanding of its danger or how they are exposed. Once inside the human body, methylmercury is readily absorbed into the bloodstream through the gastrointestinal tract. It is moderately lipophilic, meaning that it binds to fat, and it moves easily through cell walls where it attaches to proteins. It migrates to most human tissues, but concentrates in the brain, liver, and kidneys. Mercury moves easily across the placenta of pregnant women to circulate in the vascular system of fetuses, and it crosses the blood-brain barrier.[7]

The half-life of mercury (that is, the time it takes the human body to reduce its concentration by 50 percent) ranges between 44 and 180 days. Mercury ingested from a single meal could remain in your body at some level for more than a year (Figure 7.1). If a pregnant woman weighing 50 kilograms ate a tuna fish sandwich with mercury at the high end of the range detected in 2001 (0.75 parts per million in canned tuna), and if the longer half-life of 180 days is assumed, her blood levels would not return to the maximum safe level recommended by the National Academy of Sciences for nearly three years. The average level of mercury detected in tuna by the FDA in 2001 was 0.17 parts per million. Assuming the more rapid excretion rate (half-life of 44 days), and this more average level of mercury, blood levels would not return to the recommended safe level for

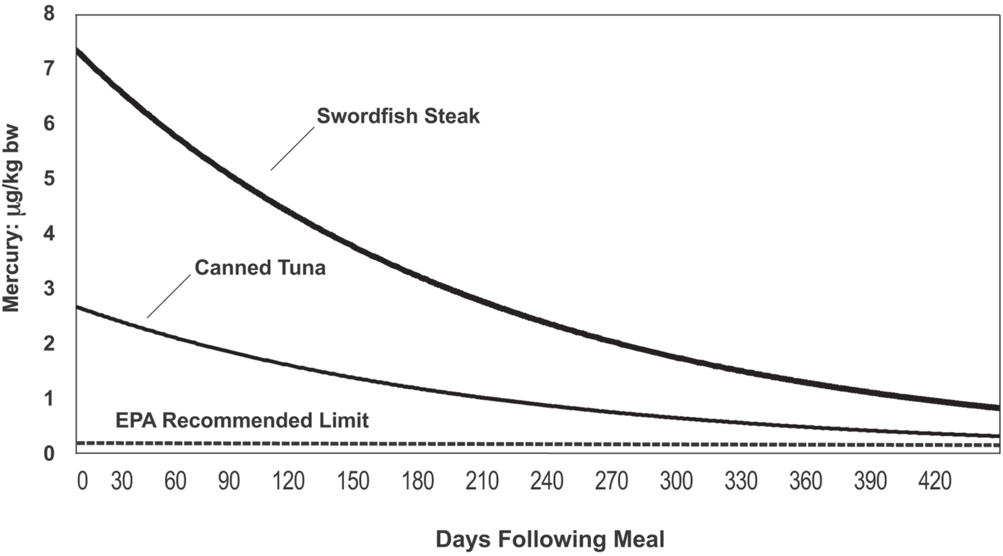

FIGURE 7.1. Mercury in human tissues. Eating a single serving of some species of fish can result in mercury concentrations that exceed the EPA's recommended limit. This example assumes that a 22-kilogram child consumes six ounces of fish at one serving. Mercury levels are derived from the U.S. FDA fish testing program for canned tuna fish and swordfish steaks. Mercury levels are normally far lower in smaller and less predatory fish such as shrimp, scallops, and salmon. *Source:* U.S. Food and Drug Administration.

nearly eight months. So mercury from a single sandwich might remain in your body between eight and thirty-six months.

Since mercury in a pregnant woman will cross the placenta, how long will it take for the fetus's blood to return to a safe level? Because of the similar blood concentration in mother and fetus, but the fetus's much smaller size, fetal exposure can be expected to be between 15 and 500 times higher than the mother's, depending on its age and weight. Given the earlier assumptions about half-life, then, some mercury from a single exposure could thus remain within the fetus (or newborn) for more than 400 days. Since the dominant routes of methylmercury excretion include lactation, the baby will also likely receive some additional exposure via breast milk after birth. Clearly, mercury exemplifies all of the traits of a very dangerous element: it is persistent, mobile, and toxic.

Intense accidental exposures to methylmercury have demonstrated its ability to cause mental retardation, cerebral palsy, deafness, blindness, and sensory and motor impairment in adults.[8] Exposure to mercury at lower levels has been associated with adverse effects on the cardiovascular system and a recent study has found that high blood mercury levels, possibly caused by eating seafood, are associated with infertility in both men and women.[9]

Methylmercury especially threatens normal growth and development of the human nervous system. At higher doses, the effects on fetuses in particular can be severe and include mental retardation, cerebral palsy, as well as visual and auditory deficits. More recently, subtle neurological effects including deficits in cognition, memory, and learning capacity are associated with early-in-life exposures.[10]

Several studies of island populations have contributed to an understanding that prenatal exposure to methylmercury can adversely affect a child's normal growth and development. The two largest have been controversial. One study conducted in the Faroe Islands in the North Atlantic Ocean found adverse neuropsychological effects (deficits in memory, language, and attention) associated with maternal consumption of pilot whale meat contaminated with mercury. The effects on brain function associated with prenatal methylmercury exposure were detectable at exposure levels commonly considered safe.[11] A second study, conducted in the Seychelles Islands in the Indian Ocean, reported no adverse developmental outcomes in children following both prenatal and postnatal exposure from fish.[12] In an effort to resolve differences in the results between the Faroe and Seychelles studies, the U.S. National Academy of Sciences convened a panel to review the evidence. The panel's experts concluded that on balance the evidence supported the more worrisome Faroe study findings.[13]

In a study of 149 children on the island of Madeira, off the coast of Morocco, children were exposed to methylmercury due to their mothers' high intake of black scabbard fish while pregnant. Maternal hair mercury concentrations on the island ranged from 1.1 to 54.1 micrograms per gram. Children of mothers with hair mercury concentrations higher than 10 micrograms per gram experienced auditory and visual deficits.[14]

Additional research has found that elevated levels of mercury in hair are associated with neurodevelopmental abnormalities among populations in Morocco and Iraq, along the Amazon River, and in Greenland.[15] An Iraqi study that analyzed eighty-four mother-child pairs poisoned by consuming mercury-contaminated grain in the winter of 1971–72 confirmed that mercury in mothers' hair at levels over 10 parts per million appeared to be related to neurodevelopmental abnormalities in their children.[16]

A 1999 study of three villages along the Tapajós River, a tributary of the Amazon, found that more than 80 percent of 246 children had hair-mercury concentrations of about 10 micrograms per gram, and were experiencing associated neuropsychological declines in motor function, attention, and visual-spatial performance.[17] Similarly, a 2002 study of Inuit children supports evidence that "prenatal or early postnatal exposures to methylmercury may cause subtle neurobehavioral deficits."[18]

Babies exposed to methylmercury in utero may also experience changes to their blood pressure. A study published in 1999 found in a birth cohort of a thousand children from the Faroe Islands that their prenatal methylmercury concentrations were correlated with higher blood pressure at age seven. Among those children who had lower birth weights, the effect was even greater.[19]

Elevated levels of mercury in humans have been found throughout the world. In addition to the studies already cited:

- A 2001 study of the Wayana population from French Guiana (where fish are known to have high levels of methymercury) found that 57 percent of the Amerindians had mercury levels higher than the World Health Organization's recommended maximum safe concentration (10 micrograms/gram); all those tested over one year of age exceeded this level.[20]
- In March 2001, the U.S. Centers for Disease Control and Prevention found that one in ten women of childbearing age in the United States is exposed to mercury at levels that could be harmful.[21]
- In 2002, researchers at the Chinese University of Hong Kong found that high blood levels of mercury are associated with infertility in men and women.[22] These findings are worrisome for any population that depends on fish as a major source of protein. Often poor coastal and island populations consume more fish than others. A recent study in California too, found that older

Americans with cardiovascular disease may purposely increase their intake of fish to obtain the vascular benefits of omega-3 oils, and so may inadvertently augment their mercury intake, and perhaps their blood pressure.

- A Finnish study of 2,005 men with coronary heart disease found that those 25 percent with the highest hair mercury levels faced a 60 percent increased risk of death from cardiovascular disease, and a 70 percent higher risk of having coronary heart disease.[23] A separate study in the United States, however, found that although mercury levels were highest among those eating the most fish, after controlling for smoking, age, and other risk factors, mercury was not associated with an increased risk of coronary heart disease.[24]

One of the most important problems in the field of environmental health is how best to understand the dose that damages human health. Identifying a threshold between safe and harmful doses has been elusive for mercury. Over the past several decades, scientists and government officials have lowered the "acceptable daily intake" of mercury in response to increasingly sensitive studies demonstrating more subtle effects at lower concentrations than previously tested. This process of discovery and regulation follows a pattern much like that which occurred with many pesticides—including some containing mercury and licensed by the government for much of the past century.

On the basis of the advances in research in this area, in 2001 the EPA recalculated the "benchmark dose" for prenatal exposure to mercury to 58 micrograms per liter of umbilical cord blood. This benchmark dose is also the maximum level recommended by the U.S. National Research Council panel in 2000. The benchmark was selected because it was the dose at which the number of children with subnormal scores on neurobehavioral tests doubled.[25]

The EPA also has developed a "reference dose" for mercury, which is defined as that level of exposure that is "likely to be without risk of deleterious effects during a lifetime." The EPA recommended that this level be set at 0.1 micrograms per kilogram of body weight per day, based on the agency's concern that methylmercury in human tissues has a long half-life and threatens children's neurological development. This means that a 50-kilogram woman should not consume more than 5 micrograms of methylmercury per day. The World Health Organization set its exposure limit recommendation five times higher than this EPA health goal, but its recommendation was designed to protect adults from such extreme effects as developing paresthesia, numbness, and tingling of the extremities and lips.[26]

Some researchers worry about variation in susceptibility among children. There is some evidence to suggest that umbilical cord blood levels are 70 percent higher than maternal levels, and differences in body weight mean that tissue concentrations are likely to be far higher in fetuses than mothers. After analyzing data from an Iraqi mercury poisoning incident, for example, several scientists estimated that susceptibility may vary by a factor of 10,000 across the population of children and adults who were exposed.[27]

Uncertainty in scientific evidence and subjectivity in government interpretation of evidence also are common—and seem to become more of a factor in setting limits for exposure to hazardous chemicals as the economic consequences for polluters, or for those responsible for hazardous site restoration, increases. If one wished to be cautious given the uncertain evidence, the acceptable daily intake level would be set very low. When the costs of precaution are high, and the evidence highly uncertain, however, a common government tactic is to set the acceptable exposure levels higher, at least until the evidence is stronger. Uncertainty such as this is often managed by applying "safety factors" when setting acceptable levels of exposure. In practice, this is accomplished by looking at the most sensitive population and discovering the lowest concentration that induces any adverse health effect. This level would then be divided by the safety factor to identify a "safe" level of exposure. The effect of this precautionary method may be to remove products from the marketplace due to "excessive contamination," depending on the magnitude of safety factor chosen. Within the United States the longest history of experience with this regulatory approach has occurred in the area of pesticide management. EPA, however, chose to employ only a tenfold safety factor for methylmercury and this level corresponds to an allowable intake of 0.1 microgram per kilogram of body weight per day, a level the U.S. National Academy of Sciences agreed with.

MERCURY LEVELS IN ADULTS AND CHILDREN

If mercury exposure can retard normal growth and development of fetuses and small children, why has the public not been warned about the threat? The Food and Drug Administration is responsible for setting allowable limits for mercury in fish, and these have been set at 1 part per million. The National Academy of Science in 2000 examined all available studies of the health effects of methylmercury exposure and concluded that neurodevelopmental abnormalities occurred at doses lower than any other adverse effects. They identified the lowest level of exposure that was associated with measurable neurodevelopmental problems (58 parts per billion of methylmercury in maternal cord blood) and agreed that a tenfold safety factor should be used to set the acceptable daily intake at a level that would assure that cord blood levels would not exceed 5.8 parts per billion. Based on these evaluations, the NAS found that the EPA's recommended limit of 0.1 microgram per kilogram of body weight per day would protect public health. The NAS also called for harmonization of policies of the EPA, FDA, and other regulatory agencies to adhere to this standard. The FDA continued to employ a limit of 0.4 micrograms per kilogram of body weight per day, thereby allowing exposures from fish four times higher than the EPA or NAS suggested, at levels corresponding to 1 part per million in fish.[28]

Assume, for example, that you purchase a swordfish steak that contains mercury at the 1 part per million government recommended limit for pregnant women. (The mean detected level reported by the FDA in 2006 was 0.97 parts per million.) If the steak is half a pound (226 grams of fish), and 1 microgram is allowed for every gram (1 microgram of mercury per gram of fish is 1 part per million), this meal would result in the consumption of 226 micrograms of mercury. For a 50-kilogram (120 pound) pregnant woman, this would result in an exposure of about 4.5 micrograms per kilogram of body weight for every day the legally allowed limit is consumed, an exposure forty-five times higher than the level that the National Academy of Sciences considers to be safe.

Given these data and the government's analysis, what should you do to keep your blood levels of mercury beneath the EPA recommended limit? Consume at most one normal meal of swordfish or tuna every forty-five days. This suggested guideline assumes an average level of fish contamination; it also takes for granted that forty-five days after the meal, your mercury level will have dropped to zero, even though it may take far longer to fully clear a single dose of methylmercury from the body (Figure 7.1).

Body weight is crucially important for determining exposure. If a child ate the same fish steak, but weighed only 25 kilograms (55 pounds), the concentration per kilogram would be double or triple that of the mother. For a fetus weighing only 1 kilogram, the concentration per kilogram of fetal body weight would generally be at least fifty times higher than the mother.

How much mercury has been found in human tissues? The levels are surprisingly high. One recent study of eighty-nine patients visiting a private internal medicine practice in California found an average level of mercury of 15 micrograms per liter of whole blood, ranging between a low of 2.0 to high of 89.5 micrograms per liter. On average, blood levels were three times higher than the NAS- and EPA-recommended levels of 5 micrograms per liter; surprisingly 89 percent of all those tested had levels above this ceiling. The patients reported consuming nearly thirty different species of fish; swordfish consumption, however, was most strongly correlated with elevated mercury levels.[29]

For several decades the fishing industry and food processors have convinced Congress and the FDA to manage mercury levels in fish by advising the public of the problem. Instead of banning sales of fish contaminated with mercury and regulating air emissions from power plants to reduce mercury emissions, the government relies on an end-of-the-food-chain warning system known as "fish advisories." The FDA's system relies on individual states to monitor their water and fisheries; states also have the responsibility for issuing public advisories. By 2008, forty-one states had issued advisories warning the public about the presence of mercury in fish. But the absence of advisories within the other ten states simply indicates the absence of testing, not that mercury was undetected. Advisories may be issued for entire lakes or rivers, or specific areas or segments. Statewide advisories have been issued for mercury in freshwater fish in only thirteen states; eleven others have issued statewide advisories for coastal fisheries.[30]

Again, fish are not prevented from being sold in the marketplace, regardless of their mercury content. Instead, the FDA assumes that the public has the ability to read signs posted near lakes and rivers, and limit consumption to levels that would prevent dangerous levels of mercury from entering the human body. Realistically, however, how many people read these signs and make the calculations to understand whether—based on their weight, gender, age, and if they are pregnant—they should eat the fish they just caught?

One way the FDA could ban the sale of contaminated fish is by using its authority to set and enforce "action levels" for food contaminants that threaten public health. When action levels are exceeded, the FDA can remove these "adulterated" foods from the marketplace, although they rarely do so. In practice, action levels have been nonbinding informal guidelines. Furthermore, action levels for mercury have undergone dramatic changes over the years. The first action level set for mercury in fish was 0.5 parts per million in 1969. Ten years later, the agency doubled the allowable contamination level to 1 part per million, and in 1984, it changed the way that it measured mercury, reporting only methylmercury, rather than total mercury. This change brought more fish into compliance with the 1 part per million standard, even though other forms of mercury can be transformed into methylmercury once inside the human body. The FDA fish sampling program was further restricted in the late 1990s. In 1998 and 1999, after testing only eighteen samples of swordfish and shark and finding that 50 percent contained methylmercury at or above the 1 part per million action level, the FDA stopped its mercury testing program for fish, leaving consumers to rely on fisheries and fish-processing firms to help them avoid what is now well-recognized in the scientific literature to be one the most important chemical hazards in our food supply.

This reliance on the private sector to monitor itself, and to report violations to the government, has long been standard procedure among environmental and health protection programs in the United States. The seafood inspection program is no different. The FDA's regulations require that private seafood processing firms sufficiently test their products to identify important health hazards, and to develop a plan to manage these risks. But the regulations are generally not followed. By 1999, 54 percent of fish processing firms did not have a plan in place to identify and manage human health threats from their products or suppliers. The FDA is even unable to estimate how many large fishing ships should also be subject to its regulations because the vessels process the fish on board.[31]

The lack of information about the scale of the problem is startling. The

U.S. Government Accountability Office reported that it took the understaffed FDA two years to visit all registered processing plants once. This was an improvement from previous years, when a processing firm could expect a visit from FDA inspectors only once every four years. And when the FDA inspectors finally do arrive for an unannounced visit, 48 percent of the time they cannot conduct their review because seafood is not being processed at that time. When the inspectors do directly inspect products, they have found one or more serious violations of their hazard control plans in 55 percent of the cases.[32]

In March 2001, the FDA issued an advisory warning pregnant women and women of childbearing age to stop eating shark, tilefish, swordfish, and king mackerel. Tuna was noticeably absent from the FDA warning, although oddly enough, FDA officials did draft a separate health advisory warning consumers against eating more than three meals of tuna fish per month, to limit mercury exposure. In fact the March 2001 advisory encourages continued fish intake by women, stating: "FDA advises these women to select a variety of other kinds of fish—including shellfish, canned fish, smaller ocean fish or farm-raised fish—and that these women can safely eat 12 ounces per week of cooked fish." But an average 50-kilogram woman, consuming 12 ounces of canned tuna per week, containing mercury at the average detected level of 0.17 ppm, would exceed by 65 percent the maximum average daily intake recommended by the NAS and EPA. A 25-kilogram child consuming this amount of tuna in a week would consume three times the agencies' recommended safe limit. Perhaps significantly, between September and November 2000, only four months before releasing the final version of the health advisory that did not mention tuna, FDA regulators had met privately with representatives of the Bumble Bee, Starkist, and Chicken of the Sea corporations.[33]

Given this history, it is perhaps not surprising that FDA inspectors have routinely advised industry managers and FDA inspectors "not to identify methylmercury as a hazard reasonably likely to occur."[34] With this loophole, the seafood industry truly has no incentive or requirement to self-test for mercury.

The problem may be underreported, but it has not been solved. The EPA in 2004 doubled its estimate of children at risk, noting that "about 630,000 children are born each year at risk for lowered intelligence and learning problems caused by exposure to high levels of mercury in the womb."[35]

A 2003 study of fish intake by women and children by Susan Schober and her colleagues estimated that 7.8 percent of U.S. women consume mercury-tainted fish above the recommended daily intake level.[36] Mercury levels were significantly higher among those women who consumed three or more meals of fish per week. Nearly 4 million children are born each year in the United States and this same study found little difference between the blood mercury levels of pregnant women when compared to women who were not pregnant. If 7.8 percent of pregnant women have levels of mercury above the recommended blood level, and if mercury concentrations in cord blood are 70 percent higher than maternal levels, then more than 300,000 fetuses are receiving exposures that are likely to be approaching the dose where neurobehavioral deficits have been reported.

Children are not the only ones in danger of health loss from mercury. The average U.S. resident consumes about fifteen pounds of seafood per year (18 grams per day), 80 percent more than the EPA and NAS recommend. And the NAS committee in 2000 estimated that 5 percent of the U.S. population (15 million people) consumed enough fish to place their blood levels of mercury above the NAS recommended maximum concentration.[37]

The United States imports nearly 3.9 billion pounds of seafood from 160 different nations, and monitoring and surveillance pose a formidable problem. Consequently, it pays to ask where your fish come from. The answer is likely to be Canada, China, Chile, Equador, or Thailand, which account for more than 50 percent of all fish imports. If the U.S. FDA is lax in regulating fish contaminants, what is likely happening with food safety in more polluted nations that have weaker laws and more limited resources to ensure food safety?

THE LATEST WARNINGS

The EPA and FDA in 2004 jointly issued a notice advising pregnant and nursing women, women who may become pregnant, and young children to consume no more than twelve ounces of fish per week, but albacore tuna should be limited to six ounces per week, approximately one modest meal. The agencies suggested that intake of canned light tuna should not exceed two average meals per week.[38] Tuna companies vigorously fought the new advisory, and their influence resulted in the following addition to the press advisory: "FDA and EPA want to ensure that women and young children continue to eat fish and shellfish because of the nutritional benefits and encourage them to follow the advisory so they can be confident in reducing their mercury exposure as well." The California attorney general filed suit against major tuna processing companies in 2004 based on their failure to warn consumers of the presence of mercury, recognized by the state to be both a carcinogen and reproductive toxin. The attorney general also sued sixteen supermarket chains for failing to warn consumers in markets about the presence of mercury in fresh and processed fish.[39]

The EPA regulates pesticides very differently than the FDA regulates mercury. For example, human exposure to pesticides found to be developmental neurotoxins (including some mercury compounds) must be restricted to 1,000 times lower than the dose found to induce adverse health effects, under provisions of the Food Quality Protection Act of 1996. Under pesticide law, the government must also assume additional sources of exposure to the active ingredient—perhaps from indoor, lawn, and garden use or contaminated water supplies—when setting maximum daily limits for food. Further, all exposures to pesticides allowed by law must provide health protection for children, infants, and fetuses.[40]

By contrast, the government only recommends that the public limit their fish intake to control against the health threat of fish-derived exposure to mercury. Why should one standard be used for methylmercury in meat, poultry, vegetables, and fruits, while another less protective standard is used for the same toxic substance in fish?

During the waning days of the George W. Bush administration, in December 2008, the FDA issued a draft report proposing to recommend increased fish intake by women; for example, it proposes overturning the EPA-FDA warning to limit albacore tuna intake to six ounces per week with a recommendation to consume at least twelve ounces a week. The EPA, however, is challenging the claim by the FDA that the health benefits from fish-derived omega-3 fatty acids outweigh the dangers to fetuses from methylmercury.[41]

METHYLMERCURY TESTING AROUND VIEQUES

Standing on the stern of the *Pumba,* about to dive into the turquoise waters of Bahia Salina del Sur, Carlos Ventura made a fist and pounded his chest as he described his family's diet. "Fish give you a strong heart. We will live a long time, unless our fish absorbed too many of the Navy's chemicals." Given the study by Carmin Ortiz-Roque that found elevated levels of mercury among Vieques women, who eat large amounts of fish, and the consequent increase in concern among Vieques residents, scientists from the U.S. Agency for Toxic Substances and Disease Registry, within the CDC, sought to understand whether contaminated fish may be responsible for the abnormally high disease incidence among islanders.

Researchers from the ATSDR converged on the island for several days in 2001 to collect and test area fish for contamination. They chose fish from several different locations near the island's shore, and collected some samples directly from one of the island's fish markets. After testing the fish for numerous chemical elements and explosives residues, the agency concluded: "There is no apparent health hazard from fish consumption. . . . It is safe to eat a variety of fish and shellfish every day. . . . It is safe to eat fish and shellfish from any of the locations sampled, including from around the LIA and the two sunken Navy target vessels. . . . It is safe to eat the most commonly consumed species, snapper, every day."[42]

These are clear and confident statements meant to reassure Vieques residents about their health, and the future of the island's productive fishing industry. A closer look at the government study demonstrates that the ATSDR collected fish samples at six different sites on the island: two off the east end of the island in close proximity to the live impact area; one near the village of Esperanza on the south coast, nearly ten miles from the live impact area; one northeast of the village of Isabel Segunda, twelve miles from the bombing range; Johnny's Pescadoria, the local fish market; and one off the largely undeveloped western end of the island, the site of weapons storage bunkers.

Yellowtail snapper is the fish most consumed by Viequense, but only six were caught and tested. None were collected from the contaminated east end sites, one was collected off of Esperanza, two were taken north of Isabel, and three were found off the west end, farthest from the range. Five were then collected at the local fish market, with no understanding of where they were caught. Lobsters are also favored among Viequense fishermen, but in this case, too, only one was collected near the live impact area, while five were collected at a local fish market, again with no knowledge of where they were collected. The choice of six different sampling locations demonstrates the government's interest in understanding spatial variability in contamination levels. But the scientists undermined any potential for comparison by collecting too few fish of the same species at each site. For example, twenty species of fish and shellfish were sought at five different sites, creating one hundred distinctive interpretative possibilities. No fish were collected for 54 percent of the combinations, and two or fewer fish of the same species were collected 75 percent of the time, far too small a number to generalize about safety or hazard.

And why would the government test fish collected from a fish market, with no knowledge of where they were caught? This might make sense if fish markets were the primary source of fish consumed on the island. If so, samples taken from that source could provide a representative sample of average fish intake, and be a legitimate basis to estimate human exposure to contaminants. But many Viequense consume fish they catch themselves, or that they purchase directly from professional fishermen.

What would be the best sampling design to explore the hypothesis that Navy chemicals contaminated fish consumed by the Viequense? One would need to know which fish are most consumed by the Viequense, and these fish should be tested, if they are known to inhabit coastal waters near Vieques. (Large predatory fish such as swordfish, tuna, shark, and barracuda migrate long distances, and have little chance of absorbing chemicals originating on or near Vieques, so should not be tested.) Fish should be collected as close as possible to the live impact area, with additional fish of the same species collected both two miles away and ten miles away. This strategy would provide information on whether concentrations decline with distance from the bombing range. (The ATSDR sampling design followed this pattern, with the exclusion of intermediate sites.) The sampling sites should also be known favored fishing grounds for Vieques fisherman. Ideally, too, fish would be collected during different times of the year, because the species of fish caught often vary with the seasons. Finally, a similar sample size should be collected for each species at each location, and a control population of fish should be collected around a distant island, one with no chance of being contaminated with chemicals similar to those released on Vieques.

A new study would also benefit from including the extensive knowledge of the local fishermen. Most Vieques fishermen know the life histories of at least several dozen species of commercial fish, when and where they are most likely to be found. Many have a mental map of the island's reefs, Spanish shipwrecks, fallen Navy fighter planes, sunken Navy vessels, and areas of the sea floor littered with bombs and piled with artillery shells. They also recognize that some species like the whelks, snails that grow to the size of a softball and are prized as a local delicacy, tend to remain close to shore and move slowly across short distances. Barracuda, in contrast, will spend much of their early life near shore, but then cruise through much of their adulthood in open ocean waters. Shorter-lived fish or those that move over larger distances are less likely to pick up local contaminants than longer-lived fish that spend more time closer to shore. Working with twenty species of marine life daily, the island fishermen are ecologists, with deep knowledge of those species they depend on for economic survival; this knowledge should be put to use for the community's own benefit.

Are levels of mercury in Vieques fish dangerous? Do they result in exposures that exceed the maximum levels recommended by the NAS? As we learned earlier, in 2000 the NAS concluded that the most scientifically defensible limit for human intake of methylmercury is 0.1 microgram per kilogram of body weight per day.[43] ATSDR for some unexplained reason assumed that a level three times higher than the NAS recommendation should be the appropriate safety threshold. Using average concentrations of mercury detected in fish collected at all six locations, all exceed the NAS recommended limit by six- to elevenfold for children, and by three- to fivefold for adults.[44]

In response to criticism that it had failed to test yellowtail snapper, the islanders' favorite fish, the ATSDR did test eleven of the fish for mercury concentrations and concluded, "It is safe to eat snapper every day." Yet in its own tables, it has highlighted its findings with the caution that some detected concentrations result in exposures that exceed the NAS recommended intake. Had ATSDR employed the lower, more health-protective limit, the exposures may well have been deemed to constitute a health threat to children and others depending on their age, body weight, and fish consumption, as well as fish contamination levels.[45]

The government eventually did address the implications of its study for the health of children, but here too the finding is more reassuring and optimistic than cautionary. "ATSDR recognized that infants and children can be more sensitive to contamination of their food than adults because children are smaller; therefore childhood exposure results in higher doses of chemical exposure per body weight. Because children can sustain permanent damage if these factors lead to toxic exposure during critical growth stages, ATSDR as part of its public health assessment process is committed to evaluation of their special interests at sites such as Vieques. ATSDR specifically evaluated the exposure to children and determined that they can safely eat fish and shellfish from Vieques."[46]

The ATSDR's findings were not credible to many in the Vieques population. The islanders find it unthinkable that hundreds of millions of pounds of bombs and other weapons could be exploded on the island's land or within its coastal waters and be undetectable in its marine food webs. Some islanders believe the ATSDR is an apologist for the military's pollution history, and given the lack of a scientifically defensible study showing otherwise, are perhaps even more fearful and receptive to claims that mercury levels in fish are to blame for the high rates of illness on the island—claims that have frightened some Viequense from eating this high-protein, low-fat, and inexpensive food source. Even if they just ignore the ATSDR study, they are still left without essential advice regarding which species and locations yield clean fish.

The islanders' risk of exposure is almost certainly high. During the summer of 2003 Marina Spitkovskya and Laura Hess, two Yale College undergraduates, developed a food intake survey under my direction and administered it to nearly fifty Vieques fishermen. The results were surprising: the islanders ate fish for lunch, fish for dinner, fried fish, baked fish, grilled fish, fish stew, fish broth, fish paste, fish salad, fish tacos, fish pastries . . . endless variations on the theme. In fact, the Vieques fishermen sometimes consumed twelve pounds per week, thirty-two times more than the FDA and EPA had predicted. Consequently, even low levels of chemical contamination in these fish could result in significant chemical exposures for the fishermen.

Stock depletion of the most valuable species in the best fishing grounds haunts the fishing industry worldwide. Sophisticated technology such as dragnets, radar, sonar, and refrigeration all contribute to the increased rate of harvesting. Generally, however, no one knows the reproduction rates of the seafood until well after local or regional populations have crashed. Viequense fishermen, by contrast, rarely have any electronic equipment, even a VHF radio. They use small boats, often with single outboard engines. Many fishermen pull traps by hand, and those who are younger and can tolerate the water pressure spearfish for the largest and most valuable catch. On a recent research trip, I passed a fifteen-foot skiff with two island fishermen hauling traps several miles offshore. It is a risky business: steady twenty-five-knot trade winds had pushed up eight-foot swells. But their ability to fish successfully points to the remarkable abundance of fish near the island due to modest fishing pressure, low technology, and the absence of capital.

The Viequense fishing culture may be sustainable now in terms of fish abundance, but it faces an insidious chemical threat. Although little is known about the chemical content of Caribbean fish—they rarely have been tested—all fish on the planet contain pollutants produced by human activity. Tests of fish taken from remote Canadian lakes hundreds of miles from the nearest village demonstrate elevated levels of methylmercury. Whales taken from the far reaches of the Arctic Sea contain even higher levels of mercury, PCBs, and numerous pesticides such as DDT, which was banned in wealthier nations during the last quarter of the twentieth century.

Some Viequense fishermen do not wish to explore the issue. After all, the absence of evidence of hazardous chemicals is normally interpreted as proof of safety, especially among those who normally buy and consume fish. Other fishermen, however, want answers, in the hope of putting to rest the worries of those who purchase and consume Vieques fish. What chemicals do Vieques fish contain? How do they compare with levels found in fish elsewhere? What threat could they pose to human health? If some fish contain hazardous levels of chemicals, could the continued harvest of others that tend not to accumulate the toxins sustain the fishing economy? Still others understand a strategy long used by those who sell products vulnerable to contamination: market mixing. Finding contaminants in fish does not necessarily foretell the demise of the Vieques fishing industry. Fish, like coffee, vegetable oils, hamburger, and many other foods, are often mixed in the marketplace. Hormone-treated beef from the United States may be mixed with hormone-free beef produced in the European Union. Coffee grown using pesticides banned in the United States may be mixed with coffee grown using pesticides that are neither toxic nor persistent. And Viequense fish may be mixed with fish caught in nearby St. John or St. Thomas, where fish have not been tested. Consumers rarely ask where foods come from, and this form of product dilution in a very international marketplace provides an opportunity for hiding contaminated goods. Although an unsettling practice at best, it is a common survival tactic for businesses faced with the increasing chemical complexity of the environment, and it is often condoned by federal laws that demand testing of the marketed products, not their component ingredients.

Now that the Navy has left Vieques, the fishermen are free again to catch what they can. If government agencies can provide them with accurate, comprehensive information about what is in the fish they catch, the government could encourage the consumption of fish that are least contaminated, while strictly testing and regulating the sale of those species that are most risky. This strategy could go a long way to protect human health, and given the many delicious fish species in the Caribbean, it should not harm the fishing industry. If the Food and Drug Administration adopted this model, the safety of all seafood would be far greater, while the public would be assured access to the significant health benefits that toxin-free fish provide.