AN EVALUATION OF ENVIRONMENTAL, BIOLOGICAL AND HEALTH DATA FROM THE ISLAND OF VIEQUES, PUERTO RICO

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ATSDR recognizes that Viequenses[1] are concerned about the health of everyone who lives on their island. ATSDR further recognizes that Viequenses are concerned about whether past military exercises[2] on Vieques might have contributed to health conditions some on the island have reported.

ATSDR wants to be responsive to those concerns. We have worked to ensure that this analysis of Viequense environmental data is thorough; that it considers all readily available investigations and research, especially research completed since release of our 2001–2003 public health assessments (PHA).[3] Simply stated, this report's nine chapters endeavor 1) to assess critically all of the available exposure and health information relevant to Viequense public health issues, 2) to draw conclusions—albeit often with some degree of uncertainty—and 3) to make recommendations for environmental and public health agencies as well as for scientific researchers that will assist in reducing that uncertainty.

The circumstances on Vieques typify many of the difficulties faced by the public and by public health officials when responding to concerns about the effects of hazardous substances. Although numerous questions arise regarding exposures and people's health, the means are limited to answer such questions definitively. When reaching conclusions about hazardous waste and public health, some degree of uncertainty will always remain. Thus in this evaluation, ATSDR identifies the available data as well as the data gaps.

This report's principal focus is to review and update environmental data on Vieques air, water, soil, seafood, and locally grown foods. In addition, this report adds human biomonitoring and health outcome data. It begins with a review and update of ATSDR's 2003 Fish PHA data on consumption of fish caught off the Vieques coast. Next are two chapters on human biomonitoring data and health outcome data. These are the chapters whose subject matter was not included in previous ATSDR reports on Vieques. At the end of each chapter, we provide conclusions, recommendations, and references specific to that chapter. Four chapters are dedicated to examination of exposure pathways from food, air, soil, and water. Chapter 9 summarizes all the conclusions and recommendations from each chapter.

The public health question in the chapters on food, air, soil, and water is whether residents were or are exposed to bombing-related contaminants and whether there were or are any public health

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[1] Throughout this document, the Spanish noun form "Viequenses" refers to the residents of Vieques, and the adjectival form "Viequense" refers to Viequenses and Vieques.

[2] The term "military exercises" subsumes all forms of naval, Marine, and other military service operations—including aerial bomb and naval gunfire practice—on and in the vicinity of Vieques.

[3] A public health assessment (PHA) is an ATSDR document that examines hazardous substances, health outcomes, and community concerns at a hazardous waste site to determine whether people could be harmed from coming into contact with those substances. The PHA also lists actions that need to be taken to protect public health.

consequences. The chapter on seafood consumption focused on mercury in seafood because Puerto Rican scientists and Viequenses raised that as a concern. Mercury in seafood is not from bombing-related activities.

The public health question addressed in the biomonitoring and health outcome chapters is different. We could not use these data to assess whether bombing-related contaminants are present in Viequenses or are causing morbidity or mortality. The purpose of the biomonitoring chapter is to identify whether excessive exposure to metals is occurring in Vieques residents and whether there is a risk of harmful effects from metal body burdens. The purpose of the health outcome chapter is to assess the overall health status of the Viequenses population. Finally, the report includes three appendices. Appendix A summarizes the studies reviewed previously by ATSDR or for this report. Appendix B contains summaries of ATSDR's previous documents evaluating Vieques-related environmental data, as well as summaries of two ATSDR-funded panel reviews: heart echocardiograms and elemental hair analysis. Appendix C contains the peer review comments received and ATSDR responses to those comments.

Background

Isla de Vieques, or Vieques Island, is a 55-square mile tract of land 7 miles off the Commonwealth of Puerto Rico's east coast. Approximately 10,000 persons live in the central 7,000 acres or about 20% of the island, mostly in the towns of Isabel Segunda and Esperanza.

In 1941, as the United States entered World War II, the U.S. Navy began to acquire Vieques property by condemnation of private lands. By 1950, the Navy owned the island's entire eastern and western portions. With its wide beaches, shallow approaches, and warm water temperatures, as well as its distance from commercial air and shipping lanes, the Navy believed that Vieques was not only ideal for naval and Marine warfare training, it was one of the few locations in the Western Hemisphere that met all the Navy's requirements.

The Navy's Atlantic Fleet Weapons Training Facility (AFWTF) established its so-called Inner Range on Vieques, comprising the Eastern Maneuver Area (EMA), and the Live Impact Area (LIA) (see Figure 1-2). Marines conducted live-fire exercises in the EMA. Aerial explosive-ordnance and naval gunfire practice were limited to the 900-acre LIA, on the island's easternmost end. Camp Garcia,[4] the principal Marine Corps encampment on Vieques, was also within the EMA's southern section.

For decades—particularly after the mid-1970s—ships and aircraft fired, launched, and dropped live bullets, artillery rounds, rockets, missiles, and bombs into the LIA. In the years following World War II, Viequenses, other Puerto Ricans, scientists, and activists increasingly opposed the Navy's activities on Vieques, contending that those activities deprived many residents of their livelihood (primarily fishing), exposed them to injury and, because of chemicals in the explosives, to long-term illness.

[4] Named for Puerto Rican native and Marine PFC Fernando Garcia, a Korean War Medal of Honor recipient.

Opposition increased after April 1999, when an F-18 pilot mistook an observation tower outside the LIA for a target. The exploding bomb killed the civilian observer inside the tower and prompted protestors to occupy the LIA. All live-fire exercises ceased. After protracted negotiations between the federal government and the Commonwealth of Puerto Rico, in early 2003 then-President George W. Bush ordered cessation of all military activities on Vieques. Former Navy properties on the eastern and western ends of the island, now mostly under U.S. Fish and Wildlife Service (FWS) jurisdiction, are national wildlife refuges. In August 2005, the U.S. Environmental Protection Agency (USEPA) added sites in the former AFWTF Inner Range to the National Priorities List, making the area subject to federally supervised remediation, which continues today.

Site investigations and environmental assessments began while the Navy still operated on Vieques. After the Navy's departure, a thorough, in-depth evaluation of the current and long-term human health risks posed by exploded and unexploded ordnance was initiated.[5] The Navy also looked at the risks military exercises generally might pose in Viequense air, water, biota, and in Viequenses themselves. The latest of these evaluations is ATSDR's review of environmental data that began in 2009. This report describes and discusses the results of our review. In addition, ATSDR examines some biomonitoring studies and health outcome data not available in our previous investigations.

Previous Site Investigations and Assessments

From 2001 to 2003, ATSDR released four Vieques-related PHAs. To investigate possible exposure to chemicals emanating from exploded and unexploded ordnance, each PHA assessed a specific exposure pathway: seafood (e.g., fish, shellfish, and land crabs), drinking water, air, and soil. After analyzing data and after extensive modeling, each PHA concluded that with one specific exception involving a single local well, contaminants in the evaluated pathways were not at levels expected to cause health effects. But these PHAs did not evaluate the risk of physical injury from unexploded ordnance or consider cumulative effects of exposure to multiple contaminants through multiple pathways. Unfortunately, current science does not adequately support a robust analysis of multiple chemical exposures and their interactions. Debate continues in the scientific community about how best to evaluate exposure to a chemical mixture both from a single pathway and from multiple, combined pathways. In addition, estimating combined doses from multiple pathways on Vieques is hampered by a lack of knowledge of the levels of chemicals residents are exposed to through various pathways (e.g., eating seafood, ingesting soil, drinking water, and breathing air).

Viequenses and other Puerto Ricans—together with some scientists, elected officials, and citizen groups—disagreed with ATSDR's findings. They believed the Navy's decades-long island presence left behind residual environmental hazards that directly and indirectly affected Viequenses' health. Scientists in Puerto Rico, for example, produced heart and hair studies that challenged ATSDR's findings. For this current site review, ATSDR not only revisited available data used in the previous ATSDR

[5] Throughout this document, "exploded or unexploded ordnance" refers to naval gunfire projectiles, aerial bombs, and projectiles from other weapons fired, launched, or dropped primarily into the Vieques Live Impact Area (LIA).

reports—and revisited Vieques itself—but also identified new environmental, biomonitoring, and health outcome data.[6] In November of 2009, ATSDR hosted a meeting in Atlanta in which interested scientists discussed available scientific data concerning Vieques. The scientists suggested how ATSDR could look at the data in additional ways. For example, the group suggested that ATSDR reconsider exposure scenarios for fish consumption. They also expressed concern about the lack of information about potential exposure to contaminants through consumption of locally grown produce. Discussions such as these resulted in some new analyses for this report. A summary of the November 2009 meeting is available at http://www.atsdr.cdc.gov/sites/vieques/notes_vsc_toc.html.

This Report's Conclusions and Recommendations

As part of this evaluation, ATSDR reviewed many of its previous conclusions and recommendations and identified some new findings. Again, Chapter 9 contains all of this report's conclusions and recommendations according to the topics described in each chapter. Certain conclusions and recommendations are highlighted in this Executive Summary.

Conclusions and Recommendations from Environmental Data

Consumption of Fish from Reefs off the Vieques Coast

- ATSDR has identified mercury exposure from frequent consumption of marine seafood as a potential public health hazard. Mercury is present in most seafood; it is particularly high in some fish species and low in other species. Due to mercury, children born to women who eat fish daily from waters surrounding Vieques are at increased risk of language, attention, and memory deficits, and to a lesser extent visual/spatial and motor function deficits. Children who frequently eat the same fish that their mothers eat are also at risk of similar harmful effects. That said, we could find no relationship between mercury in fish and military operations on Vieques. A more plausible explanation for the mercury levels found in fish is that they resulted from the global reservoir of mercury circulating through the environment.
- Due to the many nutritional benefits, women and young children in particular should include in their diets fish or shellfish that are low in mercury. Fish and shellfish are a part of a healthy diet. They contain high-quality protein, omega-3 fatty acids, other essential nutrients, and are low in saturated fat. A well-balanced diet that includes a variety of fish and shellfish can contribute to heart health and children's proper growth and development.
- Statistical analysis showed that some fish and shellfish had higher levels of some metals and lower levels of other metals—iron, aluminum, copper, zinc, arsenic, barium, potassium and selenium were all slightly higher. These metals are found in bombs and metal ships, suggesting possible localized contamination. But the levels were only slightly higher and the difference was only statistically significant when compared with a few other locations.

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[6] In this regard, note that the Navy is still involved in remedial activities on Vieques and these activities should be conducted in a way that ensures public health is protected from contaminant exposure.

- ATSDR recommends the following for consideration by environmental and public health agencies and scientists:
    - People who frequently consume marine seafood should follow available fish advisories and fishing restrictions in Vieques. Maintain the fishing restrictions in the waters adjacent to the LIA.
    - Conduct a survey of Vieques residents to determine the types, frequency, and quantity of fish consumed.
    - Conduct additional risk assessments and statistical analyses using new information gathered from the previously recommended fish consumption survey.
    - Should the proposed survey and statistical analysis not provide sufficient public health information, collect and analyze additional fish samples from Vieques.
    - Collect sufficient fish samples to allow analysis by species and by location.

Biomonitoring

- The data from biomonitoring studies in Vieques showed elevated levels of some metals in residents' blood, urine, hair, or feces. While cigarette use, seafood consumption, or hair dyes might explain some of these elevated levels in their study, the Puerto Rico Department of Health (PRDOH) manuscript reported they do not explain all. Because the source of these metals could not be identified, the biomonitoring results do not permit any conclusions about whether these elevated levels resulted from exposure to military exercise-related contaminants.
- Viequenses may be exposed to mercury in fish and cadmium in pigeon peas. These exposures may warrant additional environmental investigations , such as sampling locally grown produce for cadmium and gathering more information about fish consumption and possibly mercury in fish. The information could be used to decide whether to undertake human testing for mercury and cadmium in blood or urine. If other environmental exposures are identified, additional human biomonitoring investigations may be considered. More detailed information about ATSDR's recommendations concerning fish and locally grown produce can be found in Chapter 2, Section 2.3.2 and Chapter 5, Section 5.3.2, respectively.
- Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation.
- Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis.

- CDC/ATSDR can provide a list of qualified laboratories that can perform the tests. And if requested, CDC/ATSDR can provide information to healthcare providers about tests for metals in biologic samples.

Health Outcome Data

- Elevated morbidity and mortality in Vieques, coupled with problems accessing health care, paint for Viequenses a complex health picture.
- Data indicate elevations in chronic disease prevalence, cancer incidence, and cancer mortality among the Viequense population relative to the rest of Puerto Rico. The limitations associated with these analyses, particularly the methodological concerns discussed in this report, introduce considerable uncertainty and make interpretation difficult.

Local Produce and Livestock Pathway

ATSDR evaluated the available data and information on contaminants detected in locally raised garden produce and in livestock.

- The overall data are insufficient to quantify human exposures or draw health conclusions. Limited sampling data suggest cadmium toxicity may be a concern for excessive consumption of pigeon peas, but not for typical consumption rates of pigeon peas.
- A preliminary data evaluation completed for this report has concluded that the level of cadmium reported in a few samples of locally grown pigeon peas would not contribute excess dietary cadmium to preschool children who eat less than five of the largest (6 ounces) servings per week of locally grown pigeon peas. Adults who eat the largest serving sizes (12 ounces) should limit intake to 11 servings per week. Typical serving sizes for preschool children (1.5 ounces) do not contribute excess cadmium below 20 meals per week and adults who eat a typical serving (3 ounces) may eat up to 44 meals per week without exceeding recommended cadmium intake levels.

ATSDR Recommends

- Developing an educational program about mercury in fish that incorporates local habits and information about Viequenses' seafood consumption.
- Maintaining fishing restrictions near the former bombing range.
- That Viequenses talk to their healthcare providers about the need for biologic testing.
- Additional sampling of locally grown foods to better evaluate this exposure pathway.
- Sampling surface soil in the island's residential areas to address uncertainties regarding residential soil contamination issues.
- Clean-up activities continue in the LIA and other former military exercise areas to prevent human exposures to harmful contaminants.

- The significant uncertainty in the evaluation of cadmium in pigeon peas stresses the need for further sampling. Preliminary evaluation suggests a potential for uptake of metals from soil into food crops. These results warrant further investigation.

Air

- We reviewed the data on airborne contaminants from military exercises at the former Vieques Naval Training Facility. This review confirmed our previous findings and indicated that airborne contaminants from past military operations were very unlikely to have had health effects on Viequenses

Soil

- Sufficient data are available to conclude that people who lived on the LIA during the 1999–2000 protests were not exposed to soil contaminants at levels high enough to cause adverse health effects.
- Recent data, and the presence of unexploded ordnance at the LIA, support the need for continued, restricted access to the LIA and to other potentially contaminated former military exercise areas. Environmental assessment and remediation activities should continue.
- In the island's residential areas, no soil data are adequate to characterize potential exposures fully. To address remaining uncertainties about residential soil contamination issues, ATSDR recommends surface-soil sampling in the island's residential areas.

Drinking Water

- With the possible exception of one private well found to contain harmful nitrate-nitrite levels, all drinking water supplies in Vieques are acceptable for their current uses. ATSDR recommends no one drink from the one private well until further testing confirms its water is safe.
- Ongoing monitoring of the current pipeline-source water is required to ensure the supply meets drinking water standards. Repeating previous sampling of storage tanks, residential taps, and wells still in use would address any remaining uncertainty.

Peer Review and Public Comment

Scientists from the Commonwealth of Puerto Rico and from the United States reviewed the Vieques Summary Report. Appendix C of this report contains their comments and ATSDR's responses. The next step in the report process is for ATSDR to release the report for public comment. Members of the public will then have an opportunity to review the report and to comment. ATSDR will review all such comments and, if appropriate, will revise the text before releasing this report as a final document. During the public comment period for this report, CDC/ATSDR will consult with environmental and public health agencies to determine how our recommendations may be implemented, by whom, and timelines for implementation. The final report will include conclusions and recommendations that will provide guidance for future work on Vieques.

1. Introduction

1.1. Island Overview

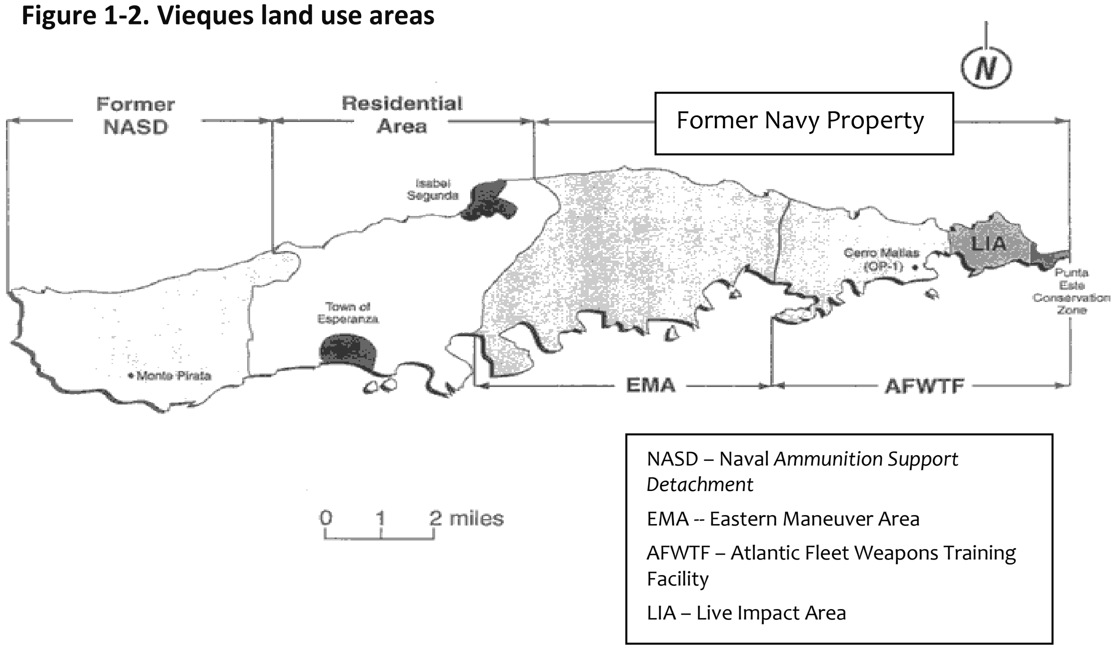
Figure 1-1. Puerto Rico and Vieques Island

Vieques is the Commonwealth of Puerto Rico's largest offshore island (see Figure 1-1). Twenty miles long and 4.5 miles wide at its widest point, Vieques comprises some 33,000 acres, or 51 square miles. Puerto Rico, the easternmost island in the Greater Antilles chain, is approximately 7 miles west of Vieques. The U.S. Virgin Islands, including St. Thomas, St. John, and St. Croix, are 20 miles or more northeast and southeast. Drinking water for the island is supplied by pipeline from the main island of Puerto Rico—Vieques groundwater is not used for drinking purposes. Figure 1-3 contains a topographic map showing groundwater flow on the island.

1.2. Vieques and the U.S. Navy

From 1941 until 2003, the U.S. Navy owned much of Vieques; residents were largely confined to areas slightly west of the of the island's center (see Figure 1-2). On the island's eastern half, the Navy's Atlantic Fleet Weapons Training Facility (AFWTF) administered the Eastern Maneuver Area (EMA) and, at the island's easternmost end, the Live Impact Area (LIA). Major training was generally restricted to two 90-day periods each year. Operating from Camp Garcia in the EMA's southern section, U.S. Marines rehearsed amphibious assaults on Vieques beaches, maneuvered inland with armored and other vehicles, and generally worked with naval task forces to ensure combat-readiness before embarking on major deployments.

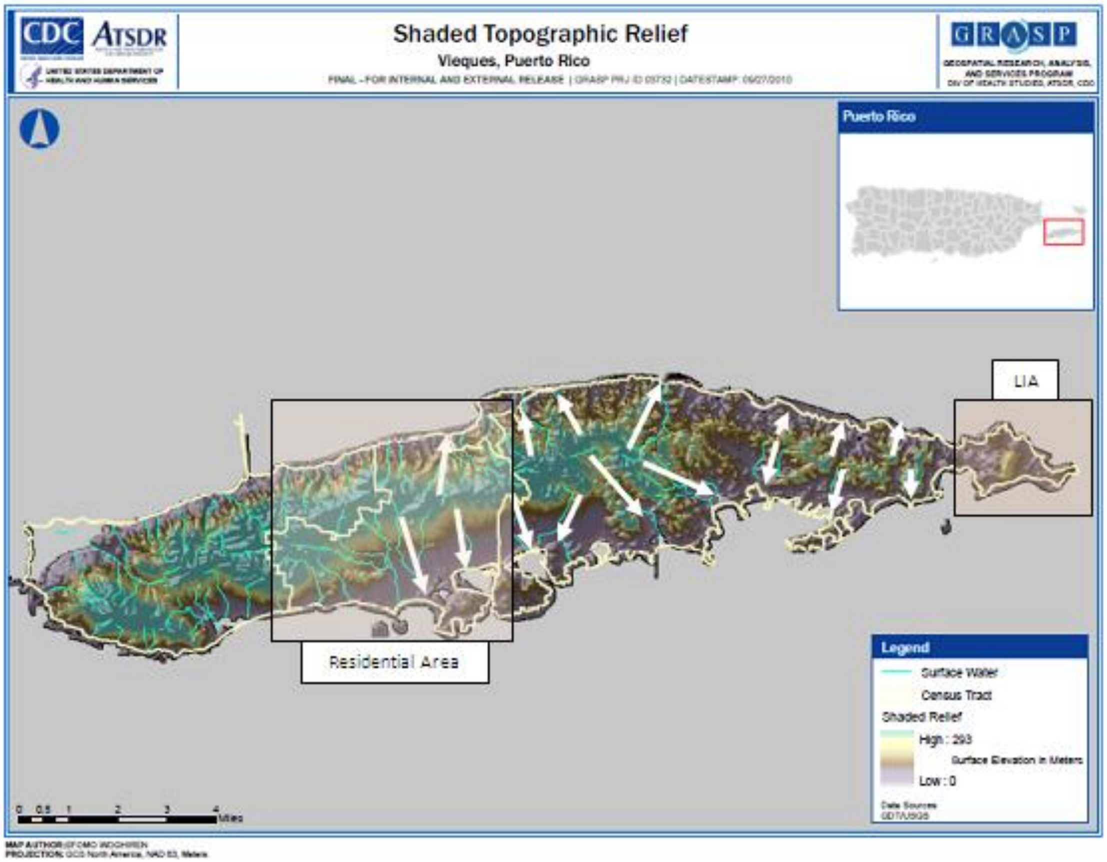
Figure 1-2. Vieques land use areas



Over and off the Vieques east coast, the Navy used the LIA for naval gunfire training. Arrows in Figure 1-3 below show directions of surface water, stream, and shallow for air-to-ground, explosive-ordnance exercises (CH2MHILL and Baker 1999). After the Culebra Island range closed in the mid-1970s (see Figure 1-1), air-to ground and ship-to-shore training activities increased in the LIA. Major exercises were usually in the spring and fall, but smaller exercises occurred throughout the year (IT 2000). Unexploded ordnance (UXO), that is, bombs or explosive ordnance and other waste military munitions, were treated and detonated in the LIA. Today, when UXO are identified, they are transported to an authorized area and detonated with a remote control charge. UXO that cannot be transported safely to the open burning/open detonation area are detonated on site in accordance with prescribed procedures.

Figure 1-3. Topographic map of Vieques showing directions of water flow.

Arrows show directions of surface water, stream, and shallow groundwater flow. Waterborne contaminants cannot flow from LIA to residential area.



The Navy is still involved in remedial activities on Vieques. These activities should be conducted in a way that ensures public health is protected from exposure to contaminants. In 2001, the Navy transferred ownership of approximately 7,500 acres of land on the west end of the island to the municipality of Vieques, the Puerto Rico Conservation Trust, and the U.S. Fish and Wildlife Service (FWS) but retained about 100 acres of the former Naval Ammunition Support Detachment (NASD) lands for radar and communication facilities (Navy 2001). Some NASD areas were leased to local farmers for cattle grazing and other agricultural purposes (USEPA 2004). On May 1, 2003, after civilian protests and negotiations between the federal and Puerto Rican governments, all military operations ceased on and around the island. The Navy transferred its remaining 14,500-acre property on the eastern end of the island to the FWS (USEPA 2004). Lands on the eastern and western ends of the island are now a national wildlife refuge. The Navy has initiated site investigations and cleanup actions pursuant to the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), sometimes referred to as the Superfund Act.

1.3. Chemicals in Munitions and Detonation Byproducts

During the peer review process for this report, several peer reviewers pointed out that the report failed to discuss any link between historical, military activity-related contaminates that might have entered the Viequense environment and any resultant human exposure from those contaminants. Previous PHAs looked at this issue; their findings are summarized in the following statements.

- ATSDR's Water PHA acknowledged that very low levels of RDX, tetryl, ammonia, and nitrate plus nitrite might have been present in drinking water samples taken by the Navy in 1978, but also expressed doubts about the validity of these data. Additionally, water samples from the Esperanza aquifer contained metals, high levels of total dissolved solids (TDS), and high salt. Two of the metals found in the Sun Bay wells (iron and manganese) and the TDS in all wells were above their secondary maximum contaminant levels (SMCL) established by U.S.EPA as a national secondary drinking water regulation. SMCLs are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. TDS—including iron, manganese, and sodium—are commonly found in groundwater. The presence of these metals was considered directly related to the high levels of TDS in the water and probably reflected the natural geology of the island, given that the igneous and volcanic rocks that make up the bedrock of Vieques are a common source of iron and manganese (ATSDR 2001).
- ATSDR's Soil PHA concluded that the soils of the LIA appeared to be influenced by Navy activities. The concentrations of heavy metals found at the LIA were 1.4 to 2.9 times higher than background concentrations collected from the west end of the island. Current soil data from the residential area of Vieques were not available, therefore, ATSDR conducted a very conservative health evaluation that included concentrations of metals detected in areas where access was restricted (i.e., land previously owned by the Navy, including the LIA) (ATSDR 2003a).
- ATSDR's Air PHA stated the Navy's past military exercises at Vieques released contaminants to the air, including dusts, chemical byproducts of explosions, and metals. Using particulate ambient air monitoring data from the residential areas of the island, the PHA concluded that wind-blown dust from the LIA was not a health hazard on days without bombing exercises and that the Navy's past military training exercises with practice bombs did not pose a health hazard. The modeling analysis of the Air PHA predicted that chemicals emitted from live bombing exercises dispersed to extremely low levels over the 7.9 miles that separate the emissions source (the LIA) and the residential area of Vieques. For a majority of the contaminants released, the estimated concentrations in the residential areas are so low that even highly sensitive air sampling devices would likely not be able to measure them (ATSDR 2003b).
- As a part of ATSDR's Fish and Shellfish PHA, fish and shellfish were analyzed for explosive compounds and heavy metals. Some evidence showed that explosive compounds might have

contaminated the marine environment. HMX and a chemical similar to RDX[7] were detected in fiddler crabs collected on the LIA. Because the fiddler crabs had not been rinsed before sampling, whether the explosive residues were present in the fiddler crabs or were due to external sand and dirt contamination was unclear. One trunkfish from the fish market was found to contain trace amounts of a chemical similar to RDX.[7] Explosive compounds were not detected in any of the other 142 edible fish or shellfish samples. Several heavy metals were detected in the fish and shellfish. Nevertheless, ATSDR could not confirm whether the metals found in Vieques fish and shellfish were related to military activity; seafood tends to accumulate metals that are naturally present in the environment (ATSDR 2003c).

The subsections that follow briefly describe 1) the organic and inorganic compounds and elements present in munitions and detonations, 2) what is known about these constituents in the Vieques environment, and 3) whether these constituents can be linked to human exposure on the island.

1.3.1. Organic Compounds in Munitions and Detonation Byproducts

In Vieques' eastern region, various branches of the U.S. military used many different ordnance types (e.g., firebombs, parachute flares, rockets, inert rockets, machine guns, practice bombs, and live explosives) (Young 1978). Organic compounds are typically found in the explosive charge of the military ordnance, and not in the casings. The explosive components of bombs varied over the years, but usually included some combination of

- 2,4,6-trinitrotoluene (TNT),
- Cyclotrimethylene trinitramine (RDX),
- Methyl-2,4,6-trinitrophenylnitramine (tetryl),
- Cyclotetramethylene tetranitramine (HMX), or
- Ammonium picrate (explosive D).

When ordnance detonates, the organic explosives are rapidly consumed and release large amounts of energy. In the process of detonation, the organic explosives are largely—but not completely—destroyed. Thus, they form other compounds. The scientific understanding of detonation byproducts of explosions has advanced over the years. For example, some early Navy publications (Young 1978) listed various detonation byproducts anticipated for the types of organic explosives used at Vieques. These estimates included the following compounds and compositions: carbon dioxide (35%), nitrogen (27%), carbon monoxide (16%), water (8%), ethane (5%), carbon (6%), propane (2%), plus several minor by products (e.g., ammonia, hydrogen, hydrogen cyanide, methane, methanol, formaldehyde) formed in trace quantities (<1%). These estimates are based on theoretical calculations, not on field-testing of actual detonations.

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[7] The laboratory that conducted the analyses could not confirm a conclusive identification.

Scientists have since developed more sophisticated and rigorous testing procedures for identifying and measuring detonation byproducts. "BangBox" studies (e.g., US Army 1992) have been particularly useful for directly measuring organic chemicals released following detonations. The BangBox refers to a flexible structure in which ordnance is detonated. Because the BangBox is completely enclosed, byproducts formed during the detonation do not escape the structure. Air sampling equipment can measure them. Scientists have used the BangBox to estimate emission factors for various types of ordnance, many of which are similar or identical to those used at Vieques. The BangBox studies have identified more than 50 organic compounds expected to be emitted to the air in trace quantities as detonation byproducts. In addition to the byproducts listed in the previous paragraph, the BangBox studies found the following byproducts in greatest quantities (but all were less than 0.1% of the total emissions): sulfur dioxide, benzene, naphthalene, acetylene, di-butyl phthalate, and various aromatic compounds. The modeling analysis in the Air PHA considered emission rates for every organic byproduct identified in the BangBox studies for the types of ordnance most similar to those the Navy used at Vieques.

1.3.2. Inorganic Compounds in Munitions and Detonation Byproducts

Inorganic compounds in munitions, including metals, are found in the metal bomb casings and sometimes in the explosive charge. Both sources of inorganic compounds (primarily metals) are reviewed here.

ATSDR's Air PHA characterized the composition of ordnance dropped onto the LIA and emitted into the air because of the training exercises. The most abundant elements in bomb casings were iron (93%), aluminum (5%), copper (2%), manganese (2%), and zinc (0.5%). The percentages shown total more than 100%—not uncommon when expressing metal content in alloy mixtures (i.e., an upper bound concentration is often used when characterizing the composition of individual constituents). Numerous other metals were present in bomb casings at concentrations less than 0.02%, including boron, chromium, molybdenum, nickel, and titanium (ATSDR 2003b). The predominant metal in explosive charges was aluminum, which accounted for as much as 21% of the explosive charge in some live bombs (ATSDR 2003b).

The emission factors for the BangBox studies identified the following five metals as having the highest emissions—in decreasing order: copper, zinc, aluminum, calcium, and lead. Eleven other metals were detected in these studies, but at lower levels. It should be noted that these studies did not measure concentrations of certain metals (e.g., iron, manganese) found in highest concentrations in the bomb casings (ATSDR 2003b).

Given the previous review, iron, aluminum, copper, manganese, zinc, and lead are the metals most likely to be elevated in LIA soils from military activity, though other metals were also found in bombs. It should be noted that all of these metals are also naturally present in the soils and rocks of Vieques (ATSDR 2003a, Learned 1973, USGS 1997 and 2001).

Because mercury was historically used in certain detonators, mercury has been mentioned as a contaminant of concern (Garcia et. al. 2000). Bomb casing composition data originally provided by the Navy indicated that casings did not contain mercury, which is consistent with information on Material

Safety Data Sheets available for steel. The Air PHA indicated that the total annual estimated mercury emissions from high explosive ordnance used at the LIA were very low (i.e., less than 1 pound per year). Following detonation, the mercury was presumably a trace constituent in the explosive charge and in the soil ejected into the air. Therefore, the live ordnance dropped on the LIA does not appear to be a significant mercury source in the Vieques environment.

1.3.3. What Bomb-related Constituents Were Found in Vieques

Vieques has seen numerous environmental sampling efforts over the past few decades. This section reviews the evidence for ordnance-related constituents in the local environment. Information is first presented for explosive compounds, then for metals.

What follows is a summary of explosive compounds found in various media from Vieques. Because explosive compounds do not occur naturally, the presence of these contaminants in environmental media point to the past military activities as the most likely source.

- In 2000, surface soil samples collected from the LIA showed rare detections of HMX, RDX, 2-amino-DNT, and TNT (CH2MHill 2000).
- In 2003, seawater samples from inside and near a 2000-lb bomb in Bahia del Sur showed explosive compounds, but explosives were not detected in samples near the sunken target vessel, the former USS Killen (Barton and Porter 2004).
- In 2003, sediment samples collected from within 2 meters of a 2000-lb bomb in Bahia Salina del Sur showed TNT. Farther away, the concentration declined to nondetectable. Sediment samples collected from the vicinity of the former USS Killen contained no detectable explosive residues (Barton and Porter 2004).
- In 2001, fish and shellfish were collected and their tissues analyzed for explosive compounds. No explosive residues were detected in fish tissues from any species or sample location, except for trunkfish. One trunkfish from the fish market was found to contain trace amounts of a chemical similar to RDX. Of the four shellfish species sampled, only fiddler crabs were shown to contain the explosive compound HMX. A chemical similar to RDX[8] was also detected in fiddler crabs, but the level was so low that an accurate determination could not be made. Because the fiddler crabs had not been rinsed prior to sampling, it was unclear whether the explosive residues were present in the crabs or were due to external sand and dirt contamination (ATSDR 2003c).
- In 2003, other marine organisms (one damselfish, one feather duster worm, and one sea urchin) collected near a 2000-lb bomb in Bahia Salina del Sur showed explosive residues. 1,3,5-trinitrobenzene was detected in a damselfish sample; TNT was found in a feather duster worm and in a sea urchin. Explosive residues were not detected in fish and lobster samples collected

[8] The laboratory that conducted the analyses could not confirm a conclusive identification.

near the former USS Killen. One coral sample from the USS Killen area contained detectable TNT residues (Barton and Porter 2004).

The previous results show that small amounts of explosive compounds remain in the Vieques terrestrial and marine environments. While explosives have been detected in or on some organisms (e.g., feather duster worm, sea urchin, fiddler crabs), nearly every fish tissue sample to date has failed to contain detectable levels of explosives, with the only exception being a single damselfish tissue sample—a species not typically consumed by people—and possibly one trunkfish sample.

The remainder of this section evaluates the presence of munitions-related metals in the Vieques environment. Metals were clearly present in the bombs the Navy dropped on the island and into the nearby ocean. The metals that landed in the Vieques environment might change chemical form over time, but the metals themselves will not decay or decompose. Nevertheless, because many metals occur naturally in soil and sediment, distinguishing is often difficult between naturally occurring concentrations and concentrations that represent human-activity contamination. The text that follows considers whether metals in the LIA soils have been found at levels believed above background.

In 2006, the Navy's contractor (CH2MHILL) conducted a survey of soil inorganics in east Vieques (CH2MHILL 2007). The survey's goal was to establish background levels within the naval training areas that could be used to determine whether other soil samples from suspected contaminated areas exceeded background levels. In cases where sampling results exceed background ranges, a logical inference is that the elevated measurements reflect contributions from past military activities or some other manufactured source. For each metal and element in the report, an upper tolerance limit (UTL) was developed for the various soil types in east Vieques. The UTL is a statistically derived value, with the exact derivation depending on the shape of the distribution of the sampling results (e.g., normal versus lognormal). The inference to be drawn from the UTLs is that measured soil concentrations below these values are indistinguishable from background concentrations. Not surprisingly, the UTLs were highest for the predominant elements in soil, including aluminum (35,000 ppm for all soil types), iron (38,100 - 43,200 ppm, depending on soil type) and magnesium (3,710 - 22,200 ppm, depending on soil type). Other elements in soil had UTLs with the following ranges depending on soil type (CH2MHill 2007):

- Arsenic 1.6–9.2 ppm
- Beryllium 0.27–0.95 ppm
- Cadmium 2.2–2.4 ppm
- Chromium 70–72 ppm
- Cobalt 16–26 ppm
- Copper 53–94 ppm
- Lead 5.4–16 ppm
- Mercury 0.057–0.31 ppm
- Nickel 22–41ppm

- Vanadium 56–144 ppm
- Zinc 32 ppm for all soil types

To identify metals possibly associated with military exercises, ATSDR compared soil samples collected in 2000 at the LIA (CH2MHILL 2000) to the above-listed UTLs. For the following metals, at least 30% of the measured concentrations exceeded background levels in LIA soils, as characterized by the UTLs. The maximum soil concentration for each metal follows:

- Arsenic 20 ppm
- Beryllium 0.48 ppm
- Chromium 120 ppm
- Cobalt 32 ppm
- Iron 59,000 ppm
- Lead 33 ppm
- Vanadium 220 ppm
- Zinc 180 ppm

Mercury was also considered in this data comparison. Still, the average mercury levels in LIA soils from the 2000 dataset was 0.02 ppm and the highest level was 0.086 ppm (CH2MHILL 2000). Only one of 29 soil samples had a mercury level that could be considered above naturally occurring levels when compared with the background UTLs (0.057–0.31 ppm; CH2MHILL 2007).

In May and October 2007, the National Oceanic and Atmospheric Administration (NOAA) randomly collected 78 sediment samples and 35 coral samples from near shore waters and a number of inland lagoons (sediments only) on Vieques (Bauer and Kendall 2010). The samples were grouped according to adjacent land use. A series of statistical tests were carried out to understand the distribution of the chemicals in the sediments. The concentrations of cadmium collected from sediments on and near the LIA were significantly higher than in sediments collected from the residential area of the island. The concentrations of cadmium were also found significantly higher in coral tissues than in sediments (Bauer and Kendall 2010). In addition, sediment concentrations of arsenic, copper, and chromium from the inland lagoons at the LIA were, on average, higher than sediment concentrations of these metals found in the other inland lagoons sampled elsewhere on Vieques.

In conclusion, soil or sediment concentrations of arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, vanadium, and zinc appear above naturally occurring levels in some areas in and around the LIA. The presence of these metals above background concentrations could reflect the influence of military activity, given the lack of other contamination sources at the LIA.

1.3.4. Linking Contaminants in Vieques with Human Exposure Pathways

ATSDR's soil PHA evaluated how elevated metals in LIA soils could affect Viequenses. Those living in the residential portion of the island do not have direct contact with LIA soils 7 to 8 miles away. Thus, exposures from any elevated metals in LIA soils cannot affect their health. Specific environmental sampling showed that Viequenses who camped on portions of the LIA in 2000–2001 were not exposed to metals (or other contaminants) in soil at levels that could harm their health. Similarly, the Air PHA concluded that metals in air from military activities could reach residential areas of the island, but not at levels that could harm people's health.

Some migration of contaminants from the soils to the marine environment undoubtedly occurs at Vieques, just as weathering of soils naturally occurs in virtually any shoreline setting. Precipitation and wind can carry soils from the LIA—and chemicals found in these soils—either directly into marine waters or into inland lagoons. And those lagoons have the potential to overflow into the marine environment. Environmental decay processes can gradually transform explosives at the LIA into other substances over time and thus reduce the potential migration of these chemicals into marine waters. But these chemical decay processes do not decompose the metals at the LIA. From an environmental health perspective, although migration of contaminants clearly occurs, the rate and amount of chemical migration is more important.

Military activities on Vieques have directly contaminated the marine environment. Some of the ordnance previously fired at the LIA landed in the ocean rather than hitting onshore targets. Dr. James Porter provided direct evidence of this in photographs depicted during a meeting at ATSDR in November 2009. Some ordnance found in Vieques waters apparently included unexploded material. While explosive organic compounds were found in some marine species, these species are not consumed by humans; therefore, the available sampling data indicate that elevated human exposures are not occurring. Explosive compounds were not found in the 104 edible fish sampled in 2001 except for a chemical similar to RDX in one trunkfish collected from the fish market.

Two observations suggest that the LIA is not currently the primary source of mercury in fish tissues. First, most mercury levels in LIA soils appear to be at naturally occurring levels, with no significant spatial variation to suggest that mercury levels are higher at the LIA. Second, ATSDR's fish sampling study did not find unusually elevated tissue concentrations of mercury in Vieques reef fish. A more plausible explanation for the mercury levels found in fish is that they resulted from the global reservoir of mercury circulating through the environment and not from mercury in some bombs and other munitions.

In conclusion, ATSDR evaluated the known environmental data associated with military activities. Our evaluation shows that residents living in the central portion of the island did not have direct contact with LIA soils at levels that could harm their health. Nor were residents likely to be exposed to contaminants in air at levels that could harm their health. While explosive compounds were found in a few sampled marine animals, residents did not consume these animals. Therefore, the available data indicate that no exposure occurred at levels that would harm health. ATSDR has concluded in this report that some residents who frequently ate reef fish were exposed to mercury at levels that could harm a developing fetus (see Chapter 2). But this mercury appears associated with global mercury circulating in the environment and not with the small amount of mercury in some military ordnance.

1.4. The Vieques Civilian Population

The entire, approximately 10,000-member civilian population of the island—referred to here as Viequenses—resides in the island's central 7,000 acres, mostly in the towns of Isabel Segunda and Esperanza. The residential areas are about 7 miles from the LIA. The civilian areas comprise residences and agricultural, commercial, and industrial activities. In the past, sugarcane was the principal crop; other crops have included coconuts, grains, sweet potatoes, avocados, bananas, and papayas. Construction of a General Electric plant in 1969 spurred manufacturing employment in the 1970s and released 1,1,1 trichloroethane and small amounts of copper to outdoor air (Bermudez 1998, ATSDR 2003b). Currently, however, the island is home to only minimal manufacturing activity. Commercial fishing fleets are home-ported at Isabel Segunda and Esperanza. Tourism has recently increased in economic importance. The 2000 Census indicates that 65% of residents of Vieques live in poverty compared with 48% for all of Puerto Rico. The 1990 Census results were similar, with 73% of the residents of Vieques living in poverty compared with 59% in all of Puerto Rico.

1.5. ATSDR's Evaluation of Vieques

The agency's evaluation of public health concerns on Vieques is the latest in a series of Vieques investigations. In 1999, a Vieques resident petitioned ATSDR for a determination of whether the Navy's use of live and inert ordnance resulted in health risks. From 2001 to 2003, ATSDR released four public health assessments (PHAs). Each PHA assessed a specific pathway for possible exposure to chemicals: seafood (e.g., fish, shellfish, and land crabs), drinking water, air, and soil. Each of these evaluations is available at http://www.atsdr.cdc.gov/sites/vieques/publications.html. ATSDR followed the public health assessment procedures described in its Public Health Assessment Guidance Manual.[9] Scientific experts peer-reviewed each PHA before its final release. After analyzing data and modeling, each PHA concluded that with one specific exception, no health hazard was associated with any pathways evaluated. The exception: drinking water from one local well was contaminated with nitrates and not fit to drink.

But some scientists from the University of Puerto Rico, the University of Georgia, and Yale University, as well as some Viequenses, disagreed with ATSDR's findings. Most scientists and residents believed the Navy's decades-long island presence left residual environmental hazards that affected public health on Vieques.

ATSDR has since 2009 gathered more than 75 documents relating to environmental sampling, health outcomes, and biomonitoring. Most of these documents were available when ATSDR released the 2001–2003 public health assessments, but some were completed later.

[9] Available at: http://www.atsdr.cdc.gov/HAC/PHAManual/index.html.

In August 2009, ATSDR scientists and staff visited Vieques and met with community leaders, Puerto Rican scientists, and health officials. From those meetings emerged a commitment to involve local experts in ATSDR's review of Vieques environmental data. ATSDR invited Puerto Rican scientists and others who had studied Vieques to meet in Atlanta, Georgia, on November 5–6, 2009. Participants engaged in a thorough review of multiple studies, identified the strengths and limitations of many of them, and made recommendations for further work. The group suggested that ATSDR reconsider its fish consumption exposure scenarios. The group also expressed its concern about potential exposure to contaminants through consumption of locally grown produce. Discussions such as these resulted in ATSDR performing new analyses for this report. A summary of that meeting is available at http://www.atsdr.cdc.gov/sites/vieques/notes_vsc_toc.html.

1.6. The Report

ATSDR prepared this report after review of all relevant, available data and related information and after the November meeting with invited scientists. We have divided the report into sections on environmental data (i.e., air, soil, drinking water, and food consumption), human biomonitoring data, and health outcome data. Conclusions and recommendations are made in each chapter and are summarized again in Chapter 9.

ATSDR observes here that the circumstances on Vieques typify many of the difficulties faced by the public and by officials concerned about the effects of hazardous substances. Numerous questions arise regarding exposures and people's health, and at times, relatively few measurements are available to answer those questions directly. The point is that environmental data are often limited in spatial coverage, number, or analytical quality control documentation. Consequently, some degree of uncertainty always exists. That means a key part of any review is to consider, before drawing public health conclusions, the adequacy of the available data. Note, however, that public health conclusions often can be drawn from limited data as long as uncertainties are recognized. ATSDR's conclusions can be reevaluated if new, improved information becomes available. Thus in this evaluation, ATSDR identifies the available data as well as the data gaps.

In contrast to environmental data, human biomonitoring can demonstrate how much of a chemical has entered the human body. Blood and urine levels of metals and organic chemicals can be useful in the comparative sense where potentially exposed groups can be compared to nonexposed or lesser-exposed groups to assess whether the target group has unusual or higher than expected exposure. Limitations to biomonitoring include the appropriate timing and collection of samples that will affect data interpretation. Also, in most situations, biomonitoring provides information about current or recent exposures; only in certain situations where a chemical may persist in the body (e.g., lead in bone) does biomonitoring provide information about exposures long past.

The November 2009 Atlanta meeting resulted in ATSDR performing new analyses, as detailed in the chapters of this report. Appendix A includes short summaries of each report analyzed as a part of this evaluation. After careful examination of previously reported data, new data, and new science, ATSDR has arrived at the conclusions and recommendations contained at the end of each environmental data chapter, the health-outcome data chapter, the biomonitoring data chapters, and in Chapter 9.

Because outside peer review is now complete, the document will become available for public comment. After comments are reviewed and addressed, the report will guide the future work of environmental and public health agencies and scientists on Vieques.

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2. Consumption of Fish from Reefs off the Vieques Coast

Chapter 2 Summary

At the request of scientists who visited ATSDR in 2009, ATSDR evaluated the risk from mercury in fish and shellfish by comparing the estimated mercury intakes with guidelines recommended by the National Academy of Sciences and by the U.S.EPA.

ATSDR has identified mercury exposure from frequent consumption of marine seafood as a potential public health hazard. After a review of estimated mercury intakes from seafood consumption, ATSDR concludes that children born to women who eat fish daily from waters surrounding Vieques are at increased risk of adverse health effects. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions. In addition, even if children were not exposed in utero, some children who frequently eat the same fish as their mothers eat are also at risk of harmful effects. This conclusion about the risk of harmful effects to the fetus and to children is somewhat uncertain, primarily because a person's mercury response is itself somewhat uncertain. Contributing to that uncertainty is how the body handles mercury, and the sex, genetics, health, and nutritional status of the person who eats the fish, or how mercury is handled in the body. Estimating mercury intake from eating reef fish is likewise uncertain. The intake could vary depending on the type, frequency, and quantity of fish eaten. Contemporary information about Viequenses fish-eating habits and mercury levels in fish could reduce this uncertainty.

Statistical analysis showed that some fish and shellfish had higher levels of some metals and lower levels of other metals—iron, aluminum, copper, zinc, arsenic, barium, potassium and selenium were all slightly higher. These metals are materials found in bombs and in metal ships, suggesting possible localized contamination. But the levels were only slightly higher and the difference was only statistically significant when compared with a few other locations.

ATSDR recommends the following for consideration by environmental and public health agencies and scientists:

Following available fish advisories and maintaining fishing restrictions near the LIA;

Conducting a survey to determine the type, frequency, and quantity of fish consumed;

Conducting additional risk assessments and statistical analyses using information gathered from the previously recommended fish consumption survey;

Collecting and analyzing additional fish samples from Vieques should the proposed survey and statistical analysis not provide sufficient public health information. Collect sufficient fish samples to allow analysis by species and by location; and

Developing an educational program about mercury in fish that incorporates local habits and information about Viequenses' seafood consumption.

2.1. Introduction to Viequense Fish Consumption

Many Viequenses remain concerned that the U.S. Navy's past military exercises might have contaminated fish and other marine life near the island. Locally harvested fish and other species are an important part of the Viequense diet. High contaminant levels in fish and other marine animals could affect the health of those who eat them. But heavy metals in fish and shellfish are not unusual. Depending on an area's geology and chemical composition, fish and shellfish will assimilate a variety of metals in varying concentrations. Thus in populations who eat substantial quantities of fish, evaluation of heavy metal exposure is quite reasonable.

During ATSDR's November 2009 meeting in Atlanta, several scientists raised questions about mercury levels in fish. They reported finding residents with elevated mercury levels in hair. Were these mercury levels indicative of mercury body burdens generally, they might put a developing fetus at risk for neurological effects. The scientists questioned whether the conclusions in ATSDR's 2003 Fish PHA contradicted the 2004 U.S.EPA/FDA national fish advisory for mercury. They were also concerned that ATSDR did not use the National Academy of Sciences' recommendations to U.S.EPA concerning mercury toxicity. ATSDR therefore is reevaluating its 2003 conclusions and recommendations about mercury in fish from reefs surrounding Vieques.

ATSDR's evaluation of mercury in the Vieques environment indicates that the mercury is most likely coming from the global reservoir of mercury in the environment and not from past military exercises. A more thorough discussion of this topic occurs in Chapter 1, Section 1.3. Nevertheless, because of continued public health concerns, ATSDR continues its evaluation of mercury in fish.

2.1.1. A Brief Review of Mercury

Mercury is found in several chemical forms: elemental mercury, inorganic mercury, and methylmercury. Elemental mercury is the familiar silver material found in some thermometers. Mercury in soil is often inorganic mercury, while mercury in fish and shellfish is predominantly methylmercury, with small amounts of inorganic mercury. When elemental or inorganic mercury enters freshwater and saltwater environments, some of it is transformed into methylmercury, which accumulates in fish and seafood. It is the methylmercury form in fish that is harmful to the developing fetus and to young children. Tests for mercury in fish, however, often measure all forms of mercury. We refer to these tests as total mercury concentration or just mercury concentration. Identification of just the methylmercury or inorganic mercury concentrations in fish requires specific tests.

2.1.2. Summary of ATSDR's 2003 Fish PHA

In July 2001, ATSDR collected 104 fish and 42 shellfish samples. ATSDR analyzed the edible tissue for metals and explosive compounds. The 42 shellfish samples consisted of 20 conch, 7 lobster, 11 blue land crab, and 4 fiddler crab. Twenty-five blue land crabs comprised 11 composite samples, and 146 fiddler crabs comprised four composite samples. All samples were analyzed individually except the blue crab (combined into 11 composite samples) and the fiddler crabs (combined into four samples). As expected, the results showed various metals in fish and shellfish tissue. Therefore, in its 2003 Fish PHA, ATSDR evaluated whether fish and shellfish muscle tissues contained levels of heavy metals that would pose a health risk. In its 2003 Fish PHA, ATSDR used fish intake rates that focused on people who ate large amounts (i.e., 8 ounces for adults and 4 ounces for children) and who ate fish daily. The agency also used standard body weights of 70 kilograms (kg) (or 154 pounds) for adults and 16 kg (35 pounds) for children. ATSDR further assumed that all the mercury detected in fish and shellfish was methylmercury—numerous fish studies support this (ATSDR 1999; Grieb 1990; Bloom 1992). In the 2003 Fish PHA, the estimated doses were compared with ATSDR's chronic Minimal Risk Level (MRL) for methylmercury. In June 2003, ATSDR released its evaluation of these data as a public health assessment with these conclusions:

- A variety of fish and shellfish were safe to eat every day;
- Fish and shellfish were safe to eat from any of the locations sampled, including from around the LIA and the sunken navy target vessel USS Killen; and
- Snapper, the most commonly consumed species, was safe to eat every day.

These recommendations were based on the low level of mercury and other metals detected in fish collected from reefs, from the sunken target vessel, and from a commercial fish market on the island. Organic chemicals associated with past military activities were rarely detected in the seafood samples and then only at low levels.

2.1.3. U.S.EPA and FDA Joint National Fish Advisory

In March 2004, a year after the public health assessment, the U.S.EPA and the Food and Drug Administration (FDA) released a joint national fish advisory. It emphasized that fish and shellfish were an important part of a healthy diet. The advisory pointed out that fish and shellfish contained high-quality protein and other essential nutrients, were low in saturated fat, and provided omega-3 fatty acids, a heart healthy chemical. A well-balanced diet that included a variety of fish and shellfish could contribute to heart health and to children's proper growth and development. The advisory concluded that in particular, women and young children should include fish or shellfish in their diets (USEPA 2004; FDA 2004).

The joint FDA/USEPA advisory acknowledged that nearly all fish and shellfish contained traces of mercury. For most people, the risk of mercury-related health effects from eating fish and shellfish was not a concern. Yet some fish and shellfish may contain levels of mercury considered unhealthy. Women and young children are advised not to eat them, especially in large quantities. The risks from mercury in fish and shellfish depend on the mercury levels in, and the amount of, fish and shellfish eaten. The FDA and the U.S.EPA advised women who might become pregnant, women already pregnant, nursing mothers, and young children to avoid some types of fish and to eat fish and shellfish known to have lower mercury levels (USEPA 2004; FDA 2004).

The joint advisory said that by following these recommendations for selecting and eating fish or shellfish, women and young children would receive dietary benefits. At the same time, they would reduce their exposure to mercury's harmful effects. U.S.EPA and FDA made the following recommendations and statements:

- Do not eat shark, swordfish, king mackerel, or tilefish—they contain high levels of mercury.
- Eat up to 12 ounces (2 average meals) a week of a variety of fish and shellfish lower in mercury.
- In the continental United States, five of the most commonly eaten fish low in mercury are shrimp (0.012 ppm),[10] canned light tuna (0.12 ppm), salmon (0.01 ppm), pollock (0.04 ppm), and catfish (0.05 ppm). Another commonly eaten fish in the continental United States, albacore ("white") tuna (0.36 ppm), has more mercury than does canned light tuna. U.S.EPA and FDA recommend limiting albacore tuna to only one 6 ounce-meal (one average meal) per week.
- U.S.EPA and FDA recommend checking local advisories about the safety of fish caught by family and friends in local lakes, rivers, and coastal areas. In the absence of a local advisory, eat only up to 6 ounces (one average meal) per week of fish caught in local waters but do not consume any other fish during the week.
- U.S.EPA and FDA advise following these same recommendations when feeding fish and shellfish to young children, but serve smaller portions (USEPA 2004; FDA 2004).

Note that the FDA currently compares the risk from mercury in fish with the benefits of eating fish (FDA 2009). According to its draft risk and benefit assessment, the FDA estimated the net effect of consumption of different amounts of fish. The results indicated that as measured by verbal development, consumption of fish species low in methylmercury was likely to result in a modest net benefit. When FDA modeled actual consumption for the range of methylmercury concentrations (low to high) in fish, the likelihood was small of an adverse effect in children. In addition, FDA concluded that fish consumption prevented a significant number of deaths from coronary heart disease and stroke each year in adults. FDA pointed out, however, that its risk and benefit assessment should not be construed as altering the agency's then-existing fish advisory (FDA 2009). More information about FDA's risk and benefit assessment is available at http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm088794.htm.

2.1.4. The Vieques Marine Environment

The following brief descriptions provide some insight into the ecological effects to the coral reefs around Vieques.

- In July 2001, the U.S.EPA's Environmental Response Team (USEPA/ERT) collected fish and shellfish from near-shore reefs around Vieques for ATSDR's public health assessment. The divers conducting the sampling reported that unexploded ordnance (UXO) was a common sight around the former USS Killen (a Navy target vessel intentionally sunk to the south of the LIA) and was occasionally seen in a seagrass bed to the north of the LIA. Despite the presence of UXO, the divers observed that all sample locations supported diverse, healthy populations of marine organisms and that the reefs visited were in good condition. The divers also noted that with very few exceptions, the fish and shellfish collected appeared healthy (USEPA 2001).

[10] Average mercury level as reported by FDA (FDA 2004).

- In November 2001, a Navy contractor (Geo-Marine) characterized the biological organisms on and around the former USS Killen. The purpose was to assess the health of the marine species and to assess potential effects on the surrounding biota. The overall conclusion was that the sunken vessel and its contents had no negative effects on the coral reef ecosystem; rather, they acted as a productive artificial reef habitat (Geo-Marine 2002).
- In June 2003, researchers from the University of Georgia and Underwater Ordnance Recovery collected data on the environmental integrity and ecosystem health of Vieques coral reefs. They reported the presence of underwater UXO and numerous 55-gallon drums in Bahia Salina del Sur (the bay to the southwest of the former LIA) and documented damage to the coral reefs (Barton and Porter 2004).
- In May and October 2007, the National Oceanic and Atmospheric Administration (NOAA) conducted an ecological characterization of the marine resources of Vieques. They found little evidence of any differences in marine resources, nutrients, or contaminants among the different former land-use zones. Biota, nutrients, and contaminant levels around Vieques generally match those of other coral reef ecosystems (Puerto Rico and U.S. Virgin Islands) and appear shaped by regional-scale processes rather than local factors. The results of their study did not support the hypothesis that military activities negatively affected the marine environment around Vieques. Nor did their study support the opposite hypothesis: that the lack of development on two-thirds of the island positively influenced the marine environment (Bauer and Kendall 2010).
- In July 2008, the National Coral Reef Institute published the results of a study that investigated whether the coral reefs around Vieques were in better or worse shape than the reefs around St. Croix. Even though the researchers observed evidence of past military activity at Vieques (e.g., unexploded bombs, casing, and ammunition shells to the north and south of the LIA), they found no differences in living benthic cover and coral assemblage structure between the two islands. They concluded that the effects of Caribbean-wide natural disturbances (disease and storms) had a greater impact on the coral reefs than did the former military activities on Vieques (Riegl et al. 2008).

2.2. Assessment of Available Fish Data

Two sets of data are available on metal levels in fish. One is from the Metropolitan University in Puerto Rico, and the other is from ATSDR. Both sets of data originate from sampling events conducted from 1999–2000 or in 2001.

2.2.1. Fish Data from Metropolitan University

From December 1999 to April 2000, Dr. Doris Caro with the Metropolitan University (i.e., Universidad Metropolitana), School of Environmental Matters, collected 52 fish from two markets in Vieques (northern Vieques and Esperanza) and compared the results with 26 fish collected from fish markets from the Parguera area on Puerto Rico's mainland (Caro 2000). She also conducted a survey of 51 Vieques residents and fishers to determine the most frequently consumed fish. Among the 51 residents surveyed, Dr. Caro reported the following fish consumption frequencies:

- 20% never eat fish,
- 47% eat fish 1–2 times a week,
- 18% eat fish 3–4 times a week, and
- 16% eat fish five or more times a week[11] (Caro 2000).

Dr. Caro thus reported that 34% of Viequenses ate fish 3–4 or more times a week. The more extensive, random PRDOH survey in 2004 supported her findings. The PRDOH manuscript reported that 38% of Viequenses ate fish three or more times a week. Both of these surveys show that a significant portion of Viequenses eat fish regularly. ATSDR's assumption that a significant proportion of Viequenses eat fish daily therefore seems reasonable, although the precise percentage is not known.

Dr. Caro also provided information about the type of fish the 51 respondents ate. Table 2-1 shows these results from Dr. Caro's survey along with the number of responders who ate certain fish (Caro 2000).

Dr. Caro concluded that the detected metal concentrations in Vieques fish did not show that metals in fish bioaccumulate, pointing to the absence of any clear relationship between fish weight, size, and metal content (Caro 2000). ATSDR's data, however, did show bioaccumulation in some species.

Mercury concentrations in fish collected by Dr. Caro are shown in Table 2-2 as ppm, although whether the reported concentrations are dry weight or wet weight is uncertain. We have attempted to contact the laboratory to ascertain how the data were reported, but we have not received a response. The described method produces raw results in dry weight. The mercury concentrations were extremely low (lower than ATSDR's results on wet or dry weight basis), but this latter fact could be explained by the very low weights of the fish. Uncertainty thus remains about whether the results are wet weight or dry weight. Regardless, Dr. Caro concluded that the results show that mercury concentrations are higher in fish from markets in Vieques compared with the control population from Parguera (Caro 2000).

These conclusions were reached using averages calculated in a manner inconsistent with U.S.EPA methods. Dr. Caro states that the results clearly justify a need for further sampling. We agree with this last statement.

[11] Percentages are rounded to whole numbers.

Table 2-1. The type of fish that the 51 respondents ate as reported by Dr. Doris Caro in her survey of Viequenses.

Number of respondents	***Spanish Common Name***	***Scientific Name***	***English Common Name***
41	Colirrubia	*Ocyurus chrysurus*	Yellowtail snapper
32	Mero cabrilla	*Epinephelus guttatus*	Rock hind
29	Langosta	*Palinurus sp.*	Spiny lobster
26	Peje puerco	*Balistes vetula*	Queen triggerfish
24	Sierra	*Scomberomorus maculatus*	Spanish mackerel
23	Capitán	Unknown	Hogfish
21	Cotorro	*Sparisoma* sp.	Parrotfish
20	Chapin Gallina	*Lactophrys trigonus*	Trunkfish
13	Bonito	*Euthynnus alletteratus*	Little tunny
11	Negra	*Lutjanus bucanella*	Blackfin snapper
11	Dorado	*Coryphaena hippurus*	Dolphinfish (Mahi-mahi)
11	Chillo	*Lutjanus vivanus*	Silk snapper
11	Boquicolora'o	*Haemulon plumier*	Striped (white) grunt
10	Dentex (Corvina)	*Odontoscion dentex*	Reef croaker
8	Atun	*Thunnus*	Tuna
8	Tibarón	*Numerous genera (e.g.,* Etmopterus, Carcharhinus*)*	Shark
5	Sharpsnout*	*unknown*	Sharpsnout
4	Abanico†	*Makaira nigricans*	Blue marlin
4	Salmón	*Salmo* and *Oncorhynchus*	Salmon
3	Carrucho	*Strombus*	Conch
1	Robalo	*Centropomus*	Snook
1	Salmonete	*Mulloidichthys* or *Pseudupeneus*	Goatfish
1	Arrayao	*Lutjanus synagris*	Lane snapper
1	Jurel aleta amarilla	*Caranx hippos*	Crevalle Jack

*Because a genus name is not provided, whether "sharpsnout" refers to the sharpsnout stingray, sharpsnout seabream, or sharpsnout flounder is unclear.

†ATSDR is unsure of the Viequense Spanish common name for the blue marlin. Other possible names include *aguja, castero, prieta,* and *voladora*.

Dr. Caro further states that her report should be viewed as a starting point for a more comprehensive survey. She recommended the following:

1. Choose sentinel species, including some close to sediments.
2. Obtain fish samples in other areas of the island, mainly in ordnance-free areas.
3. Sample fish after the beginning of military exercises and analyze it accordingly.[12]
4. Sample and analyze crustaceans (e.g., crabs, lobster) and other aquatic life, such as snails.
5. Assign additional funds for the enhancement of the proposed study.
6. Perform a risk-assessment study of the species analyzed and the results obtained.

Table 2-2. Average fish-mercury levels from fish markets in northern Vieques, southern Vieques (Esperanza), and Parguera, Puerto Rico (Caro 2000).

Fish	*Northern Vieques (n) ppm**	*Southern Vieques (Esperanza) (n) ppm*	*Parguera (n) ppm*
Arrayao (lane snapper)	0.048 (3)	0.018 (2)†	0.000 (1)
Boquicolora'o (striped grunt)	0.029 (6)	0.024 (6)‡	0.008 (4)
Colirrubia (yellow tail snapper)	0.019 (7)	0.022 (3)	0.004 (2)
Cotorro Azul (blue parrotfish)	0.002 (3)	NA	0.001 (2)
Cotorro Rojo (stoplight parrotfish)	0.000	NA	0.001 (3)
Cotorro Verde (redband parrotfish)	0.010 (1)	NA	0.007 (5)
Salmonete de Altura (goatfish)	0.038 (1)	NA	0.001 (2)
Pluma (dogfish)	NA	0.018 (3)	0.008 (2)
Mero Cabrilla (Red hind)	0.010 (4)	0.015 (1)	0.011 (3)

n = number of samples

NA = No sample available.

*Whether the concentrations represent wet weight or dry weight is unknown; no indication has been provided by the laboratory or Dr. Caro's report. The table here uses the values calculated by Caro et al. 2000 from Appendix 10. Her averages include values below the detection level of the instrument.

† An apparent typographical error appears in the original table in the main text of Dr. Caro's report. Using data from Appendix 10 in the report shows that the average is 0.018 ppm, not 0.048 ppm.

‡ An apparent typographical error appears in the original table in the main text of Dr. Caro's report. Using data from Appendix 10 in the report shows that the average is 0.024 ppm, not 0.029 ppm.

[12] Note that sampling fish after the beginning of military exercises is no longer possible—all such exercises have ceased.

The Metropolitan University data have several strengths, but some limitations as well. To ensure that metal concentrations in fish were those that people were consuming, investigators collected their fish samples from two local markets. Investigators interviewed 51 residents and fishers about their fish-eating habits and where those fish were bought or caught. Investigators learned their Vieques fish market samples included fish from the reefs and the open ocean. Metal concentrations in Vieques market fish did not therefore necessarily represent metal concentrations in reef fish near Vieques. Also, the participants were not randomly selected, and a limited number of surveys were conducted. All this adds some uncertainty to identifying all the fish species that Viequenses eat and to the frequency of Viequense fish consumption. And as stated, with regard to the fish sampling results, the authors did not specify whether their results were wet or dry weight. This prevents a reliable estimation of human doses from eating fish. Despite these limitations, however, one peer reviewer of this report requested additional analysis of Caro's data.

Therefore, with qualification, after Dr. Caro's data are regrouped and reaveraged, Dr. Caro's data can be compared with ATSDR's data. Because Dr. Caro reported averages for fish according to species rather than fish family, some locations have just one or two fish to compare. Also, in calculating averages, Dr. Caro used values below the detection level.

ATSDR used the raw data reported in Appendix 10 of Dr. Caro's report to group fish species into families from both Vieques markets. In this way, the results provide statistically significant numbers comparable with ATSDR's data:

- Arrayo was combined with colirrubia to represent the snapper family at both Vieques markets,
- Cotorro rojo was combined with cotorro azul and cotorro verde to represent the parrotfish family at both Vieques markets,
- Mero mantequilla were combined with mero cabrilla to represent the hind family at both Vieques markets, and
- Boquicolora were combined with pluma to represent the grunt family at both Vieques markets.

To calculate averages, all laboratory results below the analytical detection levels were then set at one-half the detection levels. Table 2-3 shows average mercury levels in various fish families using Dr. Caro's (regrouped) 2000 data and using ATSDR's 2001 data. Dr. Caro's data show average mercury levels by fish family that are below the average levels reported by ATSDR for both wet weight and dry weight. Note that if Dr. Caro's data are dry weight, the wet weight concentration will be lower.

Although for Dr. Caro's data the mercury concentration basis (wet vs. dry weight) is unknown, the fish families' relative rankings provide insight for exposure assessments. The fish families shown in Table 2-3 are in order of increasing average mercury concentration (according to ATSDR's order). Three of five families in Dr. Caro study have similar relative ranking to ATSDR's ranking. Goatfish might have a higher relative ranking in Dr. Caro study because of the small number (4) of Goatfish samples. The snapper Dr. Caro collected might have a higher relative ranking, but grunt and hind fish she collected were much smaller than ATSDR's. Some conclusions from these combined data follow:

1. Parrotfish have low mercury levels.
2. All of Dr. Caro's fish families have average mercury levels below U.S.EPA's screening level of 0.049 ppm (wet weight)[13]. This conclusion is true whether Dr. Caro's average is wet weight or dry weight.
3. ATSDR identified three families (goatfish, hind, and grunt) above the U.S.EPA screening level of 0.049 ppm (wet weight).

Because Dr. Caro's grunt and hind were much (~30%) smaller than ATSDR's grunt or hind and because we know that mercury accumulates in larger fish, it is likely that all (these) Vieques fish have very low levels—that is, until they grow larger. In addition, grunt and hind are two families that accumulate more mercury when they are larger.

Table 2-3. Average fish-mercury levels: Vieques

Fish	***Caro et al. (ppm)****	***ATSDR (ppm-wet)***	***ATSDR (ppm-dry)***
Parrot	0.004	0.009	0.046
Snapper	0.026	0.048	0.218
Goatfish	0.038	0.080	0.344
Hind	0.016	0.116	0.551
Grunt	0.024	0.185	0.887
All fish (fin fish)	0.020	0.091	0.427

*Whether Dr. Caro's results are wet or dry weight is unknown

2.2.2. Fish and Seafood Data from ATSDR

ATSDR's 2001 sampling and analysis activities focused on whether muscle tissues from commonly consumed fish and shellfish contained levels of heavy metals and explosives compounds that would result in health effects. To assist in these activities, ATSDR sought advice and worked with the U.S.EPA's Environmental Response Team (EPA/ERT) to collect and analyze fish and shellfish from the coastal waters around Vieques and from land and beaches near the shore.

ATSDR collected fish and shellfish from five reefs surrounding Vieques and one local fish market. Two reefs were off the eastern portion of the island near the Live Impact Area, where military exercises formerly occurred and one of these locations included the area where the USS Killen is located. The three other reefs were off the central and western portions of the island. Land crabs were collected from two locations within the Live Impact Area and one location on the western portion of the island. Efforts were made to collect from each reef location and from the fish market five fish within a family

[13] Using the Reference Dose (RfD) for methylmercury, U.S.EPA established a fish screening level of 0.049 ppm mercury for recreational and subsistence fishers. More information about U.S.EPA's screening levels is located at this Web address: http://www.epa.gov/waterscience/fish/advice/volume2/v2cover.pdf.

(e.g., grunt and hind from the genus *Epinephelus* in the *Serranidae* family or snappers from the genera *Lutjanus* and *Ocyurus* within the family *Lutjanidae*). At most locations, ATSDR was able to collect five fish from each family (e.g., *Epinephelus, Sparisoma* and *Haemulon* families). But at several locations, five fish could not be collected for some families (see Table 2-4).

Table 2-4. Fish and shellfish collected by ATSDR

Common Name and Taxonomic Family	Genus and species	Species # and Family Total	Loc. #1 Reef North LIA	Loc. #2 Reef South LIA	Loc. #3 Reef South Esperanza	Loc. #4 Reef NW Isabel Segunda	Loc. #5 Fish Market	Loc. #6 West End
Red hind	*Epinephelus guttatus*	19	5	1	0	5	5	3
Rock hind	*Epinephelus adscensionis*	8	0	4	4	0	0	0
Graysby	*Epinephelus cruentatus*	1	0	0	1	0	0	0
Coney	*Epinephelus fulvus*	2	0	0	0	0	0	2
Total # *Serranidae* family		Total = 30	Total = 5	Total = 5	Total = 5	Total = 5	Total = 5	Total = 5
Schoolmaster snapper	*Lutjanus apodus*	5	0	3	2	0	0	0
Grey snapper	*Lutjanus griseus*	3	0	2	1	0	0	0
Yellowtail snapper	*Ocyurus chrysurus*	11	0	0	1	2	5	3
Total # *Lutjanidae* family		Total = 19	Total = 0	Total = 5	Total = 4	Total = 2	Total = 5	Total = 3
Stoplight parrotfish	*Sparisoma viride*	19	4	1	5	4	0	5
Redband parrotfish	*Sparisoma aurofrenatum*	5	1	3	0	1	0	0
Redfin parrotfish	*Sparisoma rubripinne*	1	0	1	0	0	0	0
Total # *Scaridae* family		Total = 25	Total = 5	Total = 5	Total = 5	Total = 5	Total = 0	Total = 5
White Grunt	*Haemulon plumieri*	7	0	2	0	0	5	0
Spanish Grunt	*Haemulon macrostomum*	1	0	0	1	0	0	0
Bluestriped Grunt	*Haemulon sciurus*	12	5	3	4	0	0	0
French Grunt	*Haemulon flavolineatum*	4	0	0	0	0	0	4
Total # *Haemulidae* family		Total = 24	Total = 5	Total = 5	Total = 5	Total = 0	Total = 5	Total = 4

Yellow Goatfish	*Mulloidichthys martinicus*	4	0	0	3	0	0	1
Spotted Goatfish	*Pseudupeneus maculatus*	1	1	0	0	0	0	0
Total # *Mullidae* family		Total = 5	Total = 1	Total = 0	Total = 3	Total = 0	Total = 0	Total = 1
Honeycomb Cowfish	*Lactophrys polygonia*	1	0	0	0	0	1	0
Queen Conch	*Strombus gigas*	20	5	5	5	0	0	5
Spiny Lobster	*Panulirus argus*	7	1	0	1	0	5	0
Blue Land Crab	*Cardisoma guanhumi*	11	5	5	0	0	0	1
Fiddler Crab	*Uca* sp.	4	2	2	0	0	0	0
Note: Blue land crabs and fiddler crabs are listed by the number of composite tissue samples analyzed, not by the number of individuals captured. The meat from several land crabs was composited until a sufficient quantity of meat was obtained. To ensure a sufficient sample was collected for analysis, the whole fiddler crabs were composited and were analyzed.								

Fish and shellfish tissues were analyzed for explosives compounds. No explosive residues were detected in fish tissues from any sample location. Of the four shellfish species, only fiddler crabs were shown to contain the explosives compound HMX. RDX was detected in fiddler crabs, but the level was so low that an accurate concentration could not be measured. We should note that the laboratory analysis identified trace levels of a chemical with the same characteristics (i.e., retention time) of RDX (hexahydro-1,3,5,-triazine) in two samples: the fiddler crabs and the trunkfish. These trace levels were well below the RDX detection level and estimated doses were well below the RDX health guideline. Furthermore, the natural toxins within the trunkfish have the same retention time on the gas chromatogram as RDX. Therefore, we cannot conclusively determine whether RDX was present in the trunkfish tissues. The 2003 Fish PHA concluded that because residents did not eat fiddler crabs, the fiddler crab HMX would not cause harmful effects in people. No explosives compounds were detected in conch, lobster, or land crab samples from any location. Fiddler crabs and land crabs were collected from locations 1 and 2 on the eastern end of the island, and land crabs were collected from location 6 on the western end of the island (see Figure 2-1).

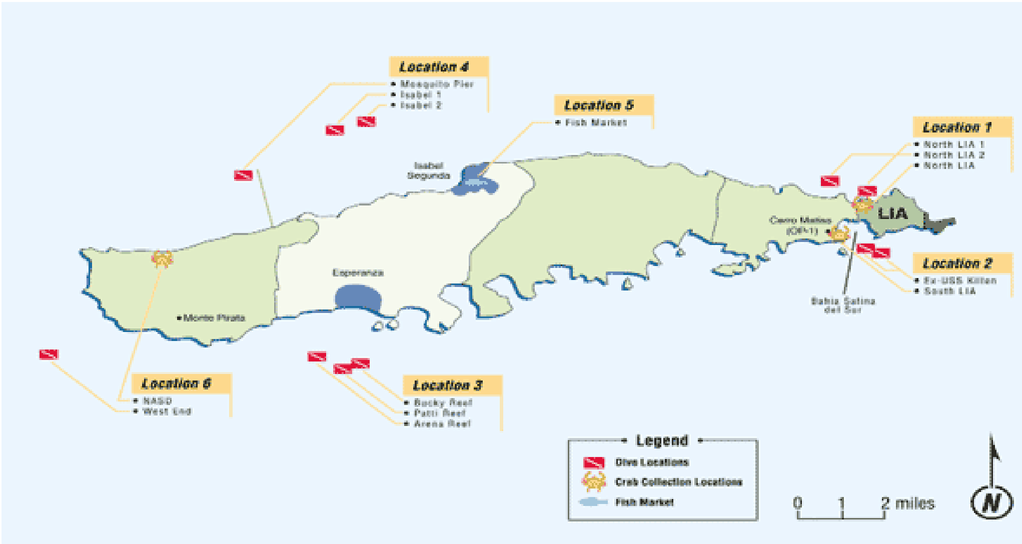

Figure 2-1. ATSDR fish and shellfish sample locations.

In addition to explosive compounds, ATSDR analyzed the same fish and shellfish tissues for heavy metals. ATSDR collected 104 fish and 42 shellfish samples and analyzed the edible tissue for metals and explosive compounds. The fish samples represent 17 different species and can be grouped into these fish families: 30 hinds (or groupers), 19 snappers, 25 parrotfish, 24 grunts, 5 goatfish, and 1 cowfish. The 42 shellfish samples consisted of 20 conch, 7 lobster, 11 composite, blue land crab, and 4 composite fiddler crab samples. Twenty-five blue land crabs comprised 11 composite samples and 146 fiddler crabs comprised four composite samples. All samples were analyzed individually except the blue crab (combined into 11 composite samples) and the fiddler crabs (combined into four samples). Here we refer to the individual and composite samples collectively as 42 shellfish samples.

2.2.3. Strength and Limitations of ATSDR's 2001 Fish and Seafood Data

ATSDR's 2001 sampling effort included several strengths:

- ATSDR used multiple information sources to identify the preferred types of fish and shellfish for collection. One important source was a Puerto Rican university report containing survey information about the frequency and types of fish eaten (Caro 2000). ATSDR substantiated the survey results with information from the petitioner and other residents, the Vieques Special Commission Report, and visits to the local fish markets on Vieques.
- ATSDR identified snapper (*Lutjanus* and *Ocyurus* species) as the most frequently eaten fish followed by hind (*Epinephelus* species) and grunt (*Haemulon* species).
- Fish and shellfish were collected from five marine locations and from one commercial fish market on the island. Land crabs were collected from three surface locations (see Figure 2-1).

- In designing the sample plan and in collecting the samples, ATSDR partnered with the U.S.EPA's Environmental Response Team, which has extensive experience in sampling and analyzing fish. The U.S.EPA recommended that ATSDR collect five fish per family group.
- ATSDR collected 104 fish and 42 shellfish samples. Although most samples represented one organism, crab samples represented a composite of three or more organisms.
- ATSDR used standard-default fish consumption intakes. These included intake rates that focused on high-end fish consumers as well as standard body weights for adults and children. ATSDR also used the agency's chronic, oral MRL for mercury. This MRL underwent rigorous scientific and peer review when it was developed.
- ATSDR followed many of the criteria described in the U.S.EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third Edition (USEPA 2000). These guidelines describe among other techniques how to identify those fish that should be sampled, how to identify the fish tissue that should be analyzed, and how to composite fish tissue.

But ATSDR's 2001 sampling effort also had limitations. Most notably, the 2001 sample design was not consistent with some important criteria found in current sample designs for fish advisories. The U.S.EPA and the State of California recommend these newer criteria when developing fish consumption advisories. Regarding the appropriate number of fish to sample, the State of California believes the sample design should include either 1) a minimum of three composite samples with each composite consisting of three fish, or, preferably, 2) nine individual fish samples for each species of concern from each water body. When a species has a large size range, fish samples, when feasible, should be collected from multiple legal or edible sizes. Following this sampling protocol allows estimation of the range and variation of contaminant concentrations at a particular site and derivation of a representative mean concentration for use in developing fish consumption advisories (State of California 2009). The U.S.EPA currently recommends a statistical analysis to determine the most appropriate number of fish in a composite sample and the most appropriate number of composite samples. At a minimum, U.S.EPA says the sample design should consist of three composite samples, with three fish per composite. If the contaminant concentration in a fish species is highly variable, more composite samples and more fish in each composite are needed to estimate the average concentration of the contaminant in that species. These recommendations were developed to determine whether average mercury levels in a fish species would exceed U.S.EPA's 0.049 ppm (wet weight) screening level for mercury in fish. When estimating human exposure to mercury, other sample designs might also provide reliable data.

2.2.4. Mercury Levels in Reef Fish from Vieques

Using ATSDR's 2001 fish sample results, the agency chose to analyze contaminant levels in individual fish—acceptable when a sufficient number of fish of each species or each family from each location are caught and analyzed. The maximum number of individual fish caught and analyzed for each species at each location was five. Table 2-4 summarizes the number of fish species and number of fish in each family analyzed at each location.

Although the U.S.EPA recommends against combining species when determining contaminant levels, the State of California says similar species can be combined (e.g., bass) because species within a family group are likely to have similar lifestyles. And because more than nine fish were collected within each family, sufficient samples were available to evaluate hind (*Epinephelus* species), snapper (*Lutjanu* and *Ocyurus* species), parrotfish (*Sparisoma* species), and grunt (*Haemulon* species)—if the data from all locations were combined. But grouping the data in this way introduced some uncertainty or bias. For example, certain species within a family had higher or lower contaminant levels than the average for that family. So having too many French grunt will create a high bias for all grunt. This was important for the fish ATSDR collected in Vieques—the mercury concentrations were highly dependent on species (and family). Grouping the data also limited evaluation of fish data by location. Table 2-4, above, identifies those locations with more samples of one species or another. This table helps identify where comparisons can be made by species and where comparisons are only possible by combining species within a family. For example, in Table 2-4, five red hind (first line of data) were collected from locations 1, 4, and 5—this suggests that red hind can be compared between locations 1, 4, and 5. Therefore, should we want to compare other locations, we would have to rely on other species of hind, which introduces added uncertainty due to the differences among the hind species.

ATSDR compensated for this uncertainty in part by a statistical analysis of the 2001 fish data. Table 2-5 provides the average concentrations for each species and family collected at the six locations.

Table 2-5 permits comparison of mercury levels in seafood by family, by location, and, in some cases, by individual species at a location. ATSDR's evaluation of the fish data resulted in new conclusions. A principal new conclusion was that the fish data represented enough fish to make numerous, statistically significant determinations. Statistical tests provided in Chapter 2, Section 2.5, Appendix 2A-1 indicate that mercury concentrations were highly dependent on family, on species within some families, and by size of fish within some species. But the fish-mercury levels near the LIA were not significantly higher than in the other locations.

Other new conclusions in this report include

- Mercury was lower in shellfish and higher in finfish.
- Mercury in fish was highly dependent on the family and on fish species. Mercury was higher in two fish families (i.e., grunt and hind, 0.18 ppm and 0.12 ppm, respectively) compared with other families sampled (e.g., parrotfish and snapper, 0.01 ppm, and 0.05 ppm, respectively).
- Mercury in hind was associated with fish weight; larger hind typically had more mercury.
- The average mercury concentration in grunt and hind was higher than U.S.EPA's 0.049-ppm screening level. Mercury levels in parrotfish were statistically lower than U.S.EPA's screening level of 0.049 ppm and lower than the overall average of 0.1 ppm.
- Snapper averaged less than, but not statistically different from, the U.S.EPA 0.049 ppm screening level, and statistically less than 0.1 ppm.

Table 2-5. Average total mercury in ATSDR-collected fish and shellfish

Common Name and Taxonomic Family	***Genus and species***	***Arithmetic Mean Mercury Levels (ppm wet weight)***						
		All Locations	***Loc #1 Reef North LIA***	***Loc #2 Reef South LIA***	***Loc #3 Reef South Esperanza***	***Loc #4 Reef Isabel Segunda***	***Loc #5 Reef Market***	***Loc #6 Reef West End***
Red Hind	*Epinephelus guttatus*	0.091	0.078	(0.038)	NS	0.10	0.12	0.057
Rock Hind	*Epinephelus adscensionis*	0.15	NS	0.13	0.17	NS	NS	NS
Graysby	*Epinephelus cruentatus*	(0.12)	NS	NS	(0.12)	NS	NS	NS
Coney	*Epinephelus fulvus*	0.21	NS	NS	NS	NS	NS	0.21
Total average *Serranidae* family		0.12	0.078	0.12	0.16	0.10	0.12	0.12
Schoolmaster snapper	*Lutjanus apodus*	0.045	NS	0.058	0.053	NS	NS	NS
Grey snapper	*Lutjanus griseus*	0.061	NS	0.032	(0.067)	NS	NS	NS
Yellowtail snapper	*Ocyurus chrysurus*	0.046	NS	NS	(0.048)	0.073	0.037	0.040
Total # *Lutjanidae* family		0.048	NS	0.055	0.045	0.073	0.037	0.040
White grunt	*Haemulon plumieri*	0.098	NS	0.068	NS	NS	0.11	NS
Spanish grunt	*Haemulon macrostomum*	(0.21)	NS	NS	(0.21)	NS	NS	NS
Bluestriped grunt	*Haemulon sciurus*	0.22	0.21	0.24	0.22	NS	NS	NS
French grunt	*Haemulon flavolineatum*	0.22	NS	NS	NS	NS	NS	0.22
Total # *Haemulidae* family		0.18	0.21	0.17	0.22	NS	0.11	0.22
Stoplight parrotfish	*Sparisoma viride*	ND*	ND*	(ND)*	ND*	ND*	NS	ND
Redband parrotfish	*Sparisoma aurofrenatum*	0.015**	(ND)*	0.020	NS	(ND)*	NS	NS
Redfin parrotfish	*Sparisoma rubripinne*	(0.016)	NS	(0.016)	NS	NS	NS	NS
Total # *Scaridae* family		0.023M	ND*	0.016	ND*	ND*	NS	ND
Yellow goatfish	*Mulloidichthys martinicus*	0.088	NS	NS	0.098	NS	NS	(0.059)
Spotted goatfish	*Pseudupeneus maculatus*	(0.045)	(0.045)	NS	NS	NS	NS	NS
Total # *Mullidae* family		(0.080)	(0.045)	NS	0.098	NS	NS	(0.059)

Common Name and Taxonomic Family	***Genus and species***	***Arithmetic Mean Mercury Levels (ppm wet weight)***						
		All Locations	***Loc. #1 Reef North LIA***	***Loc #2 Reef South LIA***	***Loc #3 Reef South Esperanza***	***Loc #4 Reef Isabel Segunda***	***Loc #5 Reef Market***	***Loc #6 Reef West End***
Honeycomb Cowfish	*Lactophrys polygonia*	(0.0082)	NS	NS	NS	NS	(0.0082)	NS
Queen Conch	*Strombus gigas*	0.016**	0.018M	0.020M	0.033	NS	NS	ND*
Spiny Lobster	*Panulirus argus*	0.031	(0.031)	NS	(0.047)	NS	0.028	NS
Blue Land Crab	*Cardisoma guanhumi*	0.028M	0.028M	0.021M	NS	NS	NS	(ND)*
Fiddler Crab	*Uca* sp.	ND*	ND*	ND*	NS	NS	NS	NS

NS = The species was not sampled at the given location
ND = Not Detected (range of detection levels in marine live varied 0.0039-0.0085)
(#) = Parenthesis around a value connote a single measurement rather than an average
*= All sample results for this species at this location were ND
**=The value was calculated with at least two samples that were ND
M =The preceding value represents the maximum collected at the given locations as most samples were ND

ATSDR's evaluation would improve by having more information about the consumption frequency of

- Reef fish, ocean-going fish, and canned fish by sex and by age group,
- Various fish species by sex and by age group, and
- Portion size by sex and by age group.

The 2001 U.S.EPA analytical report on the fish and shellfish samples provided chemical results and statistical metal analysis (USEPA 2001). U.S.EPA's statistical analysis of the fish and shellfish data identified that some fish and shellfish species had slightly higher levels of iron, aluminum, copper, zinc, arsenic, barium, selenium, potassium, and iron in the samples collected near the submerged bombs off the LIA coast. But the levels were only slightly higher and the difference was only statistically significant when compared with a few reef locations.

U.S.EPA's report did not study further the specific sources for these slight increases (USEPA 2001). The U.S.EPA report did provide results for many common explosive organic chemicals, but explosive chemicals rapidly decay into other chemicals that may not be as easily detected.

Nevertheless, the chemical results indicated the presence of HMX and the possible presence of RDX in fiddler crabs. Both of these chemicals are known to break down rapidly in the marine environment. For most fish, uptake of these chemicals is low; it is lowest in fish with higher oil content, and most species rapidly excrete the chemicals (Ownby et al. 2005; Yoo et. al 2002; Helene et al. 2003; Lotufo et al. 2005; Lotufo and Lydy 2005; Houston and Lutufo 2005; Blackburn et al. 2004). When reviewing information for a chemical that had not been ruled out, we identified picric acid as a possible bomb component at some bombing ranges; however, we could not verify that it was used in Vieques. Some samples were collected from groundwater and soil but picric acid was either not detected or the sample was rejected because of analytical problems. Picric acid is one explosive compound that does not decay rapidly in the marine environment. While picric acid is not typically used in bombs, it is an explosive compound used by the military. It does not quickly degrade in the sediment, but fish metabolize and excrete it rapidly (Yost et al. 2007; Nipper et al. 2001; Burton et al. 1983 and 1984; Cooper et al. 1984).

Slightly higher military exercise-related chemicals were found in some seafood in the southern LIA area compared with other areas, such as,

- HMX and trace levels of RDX explosives compounds were found in the LIA fiddler crabs;
- Aluminum and potassium were slightly higher in some LIA fish (grunts, parrotfish) compared with other reef locations:
  - Aluminum in south LIA grunt compared with west end and market,
  - Aluminum in north LIA parrotfish compared with west end,
  - Aluminum in south LIA parrotfish compared with all locations except Esperanza,
  - Potassium in south LIA gruntfish compared with west end,
  - Potassium in south LIA parrotfish compared with Isabel 2,
- Copper was slightly higher in some LIA species (grunts, conch) compared with other reef locations:
  - Copper in south LIA conch compared with North LIA, Esperanza, and west end,
  - Copper in north LIA conch compared with Esperanza and west end,
  - Copper in south LIA grunt compared with North LIA and Esperanza
- Iron was slightly higher in some LIA species (land crabs, snappers) compared with other reef locations:
  - Iron in snapper at south LIA compared with West End,
  - Iron in snapper at south LIA compared with North LIA,
  - Iron in crabs at south LIA compared with North LIA (USEPA 2001).

Mercury levels in LIA fish were not significantly different from mercury levels in fish from other Vieques reefs. Mercury has been mentioned as a contaminant of concern because mercury was historically used in detonators (Garcia et. al. 2000). The data originally provided by the Navy on the composition of the bomb casings indicated the casings did not contain mercury. This is consistent with information on the Material Safety Data Sheets available for steel. The Air PHA indicated that the estimated total annual emissions of mercury to the air were very low (i.e., 0.14 pounds per year). The source of mercury air emissions was trace amounts in the explosive charge of some bombs and naturally occurring mercury in the soil ejected into the air following detonation. Therefore, past military exercises do not appear to be a significant source of mercury in the Vieques environment.

Average mercury levels in LIA soils was 0.02 ppm, with the highest level detected at 0.086 ppm. NOAA determined that one of 29 soil samples had a mercury level that could be considered above naturally occurring levels (NOAA 2010). But two observations suggest that the LIA is not currently the primary source of mercury in fish tissues. First, most mercury levels in LIA soils appear to be at naturally occurring levels with no significant spatial variation to suggest mercury levels are higher in the LIA. Second, ATSDR's fish sampling study did not appear to find unusually elevated tissue concentrations of mercury in Vieques reef fish. A more plausible explanation for the mercury levels found in fish is that they resulted from the global reservoir of mercury circulating through the environment.

2.2.5. Toxicological Evaluation of Mercury in Vieques Fish

The wet-weight/dry-weight nature of the Metropolitan University fish data is unknown. Those data, then, provide only speculative insight into contaminant levels. That is, the data can be only compared with fish from Parguera, the study's control population. For quantitative dose estimates, the data are unusable;[14] doses calculated using these data would be unreliable. A toxicological evaluation will therefore incorporate ATSDR's fish data, which have been converted from dry weight in ppm to wet weight in ppm. Compared with Dr. Caro's data (see Table 2-3), ATSDR's data will provide a higher mercury exposure estimate as the fish were larger and the mercury concentrations are higher. Also compared with Dr. Caro's data, the higher mercury concentrations in ATSDR's data could possibly result from ATSDR having collected larger fish, which tend to accumulate higher mercury levels.

Several scientists attending ATSDR's November 2009 meeting on Vieques raised concerns about ATSDR not using U.S.EPA's Reference Dose (RfD) for methylmercury and not considering the National Academy of Sciences' (NAS) recommendations concerning methylmercury. The scientists noted that Puerto Ricans typically have lower body weights and that Viequenses have high fish consumption rates. They suggested, therefore, that ATSDR evaluate the risk for residents with lower body weights and with higher fish intake. ATSDR used the following parameters to recalculate the doses for women of childbearing age and for children:

1. A range of body weights from 4.5 to 100 kg (9.9 to 220 pounds):
    a. Children (1–2 years; 3–5 years; 6–8 years; 9–14 years; 15–18 years); and
    b. Adult women (18–54 years) (USEPA 1997).
2. A range of age-specific meal portion sizes, including the 50th, 95th, and 99th percentile.
    a. Adult women's portion sizes were 3 oz, 8 oz, and 13.9 oz.

[14] Laboratory results for chemicals in fish are initially measured as dry weight because the moisture is removed from fish tissue before analyzing for the chemical. Once the moisture is removed, a fish sample might contain 1 ppm of a chemical as dry weight. To estimate exposure, the dry-weight concentration is usually converted to a wet-weight concentration; fish consumption is usually measured as ounces of fresh (wet) fish consumed. Thus to know whether the results are reported as wet weight or dry weight is important.

   b. Children's portion size varied by age (see Table 2-6). For example, 3–5 year old girls have portion sizes of 2.5 oz, 6 oz, and 8.5 oz at the 50th, 95th, and 99th percentile, respectively (USEPA 1997).

3. Average mercury levels were recalculated using ½ the detection limit for the approximately 25% of fish that had nondetectable mercury levels (ATSDR 2005). Most of the nondetectable mercury levels were found in parrotfish. Average mercury level for all fish was 0.1066 ppm using the 95th upper confidence limit (UCL) of the mean with a maximum mercury level in a bluestriped grunt of 0.33 ppm.
4. Some scientists were concerned that the 2003 Fish PHA used national average weights to represent exposure dose. This report provides exposure estimates using a wide range of weights for various ages. Estimated doses also were calculated on a continuous weight profile from 9.9 to 220 pounds and increasing meal size up to the 99th percentile (See Table 2A-1 in Chapter 2, Section 2.6, Appendix 2A-2.)
5. The estimated doses were compared with U.S.EPA's RfD for methylmercury of 0.1 µg/kg/day. Chapter 2, Section 2.2.5 provides more information about methylmercury's toxic effects.

ATSDR also considered the National Academy of Sciences' recommendations to the U.S.EPA. The NAS recommended that U.S.EPA use the Faroe Islands study to develop the agency's Reference Dose. They also suggested the study and the effect levels that should be considered.

Table 2-6. 50th, 95th, and 99th fish portion size for women and girls of various ages.

	Meal size in ounces/portion		
Age group	50th	95th	99th
1–2 yr old girls	1.5	4.4	5.6
3–5 yr old girls	2	6	8.5
6–8 yr old girls	2.5	6	10.2
9–14 yr old girls	2.8	7.3	10.2
15–18 yr old girls	3	9.5	20
Adult women	3	8	13.9

Source: U.S.EPA's Exposure Factors Handbook (USEPA 1997).

Table 2A-1 (Chapter 2, Section 2.6, Appendix 2A-2) shows the estimated mercury doses for women and children who eat up to 20 ounces of fish daily and who weigh up to 220 pounds. Approximate age groups are provided for various body weights ranging from 10 to 220 pounds (4.5–100 kg). For example, for women who weigh 143 pounds (65 kg) and who eat 4 ounces of reef fish daily, the estimated dose is 0.19 µg/kg/day. Similarly, for women who weigh 121 pounds (55 kg) and who eat 4 ounces of reef fish daily, the estimated mercury does is 0.22 µg/kg/day. These estimated doses exceed U.S.EPA's RfD of 0.1 µg/kg/day. The 99th percentile portion size is used to estimate the maximum dose for each age group. Doses are not calculated beyond this point and appear as black in Table 2A-1. Table 2-6 shows the 50th, 95th, and 99th percentile fish portion size for various age groups. Precision is difficult regarding what constitutes average fish consumption for Viequenses. Using information from Dr. Caro's survey, a typical fish intake for an adult female might be three meals a week, with a portion size of 4 ounces and an average body weight of 55 kg (121 pounds). This person would have an estimated mercury dose of 0.094 µg/kg/day, which is below U.S.EPA's RfD of 0.1 µg/kg/day.

Estimated doses less than U.S.EPA's RfD (0.1 µg/kg/day) are shown with a white background. Residents with these estimated doses are not at risk of harmful effects from mercury in fish. Estimated doses that exceed U.S.EPA's RfD for residents who eat fish daily are shown in three shades of blue (light, medium, and dark). Women with estimated doses indicated as light blue (light gray in black and white) have a small increased risk of harming a developing fetus if they are pregnant. The risk is greater for those women with estimated doses indicated in medium blue. These estimated doses approach the dose of 1.1 µg/kg/day identified by the National Academy of Science as a dose that results in a 5% increase in the incidence of abnormal scores on the Boston Naming Test (a picture-naming, vocabulary test). The NAS effect level is consistent with the range of 0.85 to 1.5 µg/kg/day identified by the U.S.EPA as the benchmark dose lower limit (BMDL05.)

Similarly, most of the estimated doses in children exceed U.S.EPA's RfD as indicated by light, medium, and dark blue in Table 2A-1 (Chapter 2, Section 2.6, Appendix 2A-2). Young children with higher daily fish intake have estimated doses that exceed the effect level of 1.1 µg/kg/day. These doses are in dark blue. Whether children are as sensitive to the neurotoxic effects of mercury as is the fetus is uncertain. To be protective, U.S.EPA's and FDA's national fish advisory include a warning for children as well as women who are pregnant, who plan to become pregnant, and nursing mothers.

These conclusions about the risk of harmful effects are also somewhat uncertain; to know the exact dose that might cause harmful neurological effects in the fetus and in children is difficult. This uncertainty arises from limitations inherent in human studies and because a person's susceptibility may vary. Finally, estimating the mercury dose that someone might receive is similarly uncertain. If residents eat more snapper and parrotfish, which are lower in mercury, their estimated dose of mercury will be lower; they are likely to be at lower risk of harmful effects or at no risk at all. If residents eat more grunt and hind, which are higher in mercury, their estimated dose of mercury will be higher and they could be at greater risk of harmful effects.

The conclusions and recommendations from ATSDR's evaluation of fish and shellfish data appear at the end of this chapter (Section 2.3) and in Chapter 9 of this report.

2.2.6. Possible Mixtures Effects from Chemicals in Fish and Other Biota

In ATSDR's 2003 Fish PHA, the concentrations of individual metals in Vieques reef fish were not at levels of health concern. In its evaluation of these fish data for this report, ATSDR concluded that mercury in fish is a concern for children and for the developing fetus in women who frequently eat large amounts of fish. Unfortunately, current science does not adequately support a robust analysis of multiple chemical exposures and their interactions. Debate continues in the scientific community about the best methods by which to evaluate exposure to a chemical mixture both from a single pathway and from multiple, combined pathways. In addition, estimating combined doses from multiple pathways at Vieques is hampered by a lack of knowledge of the levels of chemicals residents are exposed to through various pathways (e.g., eating seafood, ingesting soil, drinking water, and breathing air). Because of this complexity and lack of knowledge, any additional risk from any possible, so-called mixtures effect assumed by residents eating seafood is likewise uncertain.

2.3. Conclusions and Recommendations

2.3.1. Conclusions

During ATSDR's November 2009 meeting, several scientists raised concerns about mercury levels in fish. In particular, they were concerned that the conclusions in ATSDR's 2003 Fish PHA were inconsistent with the 2004 U.S.EPA/FDA national advisory concerning mercury. Therefore, ATSDR reviewed its 2003 conclusions and recommendations about mercury in fish from reefs surrounding Vieques.

In its 2003 public health assessment regarding fish consumption, ATSDR used fish intake rates that focused on adults who ate 8 ounces of fish daily and who weighed 70 kg (or 154 pounds). Daily fish intakes rates for children were 4 ounces and children were assumed to weigh 16 kg (or 35 pounds). Estimated doses were compared with ATSDR's MRL of 0.3 µg/kg/day, which was derived from an analysis of the Seychelles Island and Faroe Islands studies. In ATSDR's evaluation as presented in this report, ATSDR used a broad range of daily fish intakes and body weights. Using information from U.S.EPA's Exposure Factor Handbook, ATSDR assumed that daily fish intakes for adult women were as high as 14 ounces—the 99th percentile—and that women weigh as little as 46 kg (or 100 pounds). For children, ATSDR assumed that daily fish intakes were as high as 6 ounces for 1- to 2-year old children, 8 ounces for 3- to 5-year old children, 10 ounces for 6- to 14-year old children, and 20 ounces for 15- to 18-year old children. The highest intakes for children represent the 99th percentile portion size for the stated ages. In addition, ATSDR used the NAS's recommendations and U.S.EPA's Reference Dose (RfD) concerning mercury as well as human toxicity studies from the Faroe Islands. From its evaluation of mercury in Vieques fish, ATSDR reached these new conclusions:

1. ATSDR has identified mercury exposure from frequent consumption of marine seafood as a potential public health hazard. Women with a varied fish diet who typically eat more than 2 oz of fish every day have estimated mercury doses that exceed U.S.EPA's chronic RfD. As portion size increases, the estimated doses approach the lowest level known to cause harmful effects to the developing fetus. ATSDR concludes that if these women are pregnant, their developing baby has a small increased risk of neurological effects later in life. The risk of harmful effects increases as portion size increases. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.

2. Women who eat grunt or hind more frequently than other reef fish and who typically eat more than 2 oz of fish every day have estimated mercury doses two times higher than women who eat a varied fish diet. As portion size increases, the estimated doses approach or exceed the lowest level known to cause harmful effects in the developing fetus. ATSDR concludes that if

these women are pregnant, their developing baby has a small increased risk of neurological effects later in life. The risk of harmful effects increases as portion size increases. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.

3. Children with a varied fish diet who typically eat more than 0.5 oz of fish every day have estimated mercury doses that exceed U.S.EPA's chronic RfD. These children have a small risk of neurological effects. But as portion size increases, the risk of harmful effects increases. Depending upon their age, children as young as 1 year who eat 3 to 4 ounces of fish every day have estimated doses that exceed doses known to cause neurological effects and have the greatest risk of harmful neurological effects. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.

4. Like women, children who eat grunt and hind more frequently than other reef fish have estimated doses two times higher than children who eat a varied fish diet. The estimated doses in these children exceed the doses associated with neurological effects.

5. Some uncertainty is associated with these findings because a person's mercury response is itself somewhat uncertain. The uncertainty could be due to sex, genetics, health and nutritional status, or how mercury is handled in the body. In the three human studies that focused on mercury exposure from eating fish and seafood, the identification of the lowest-effect levels was uncertain. Estimating the mercury dose from eating reef fish was likewise uncertain, given that the dose could vary depending on the type, frequency, and quantity of fish eaten.

6. While ATSDR supports the U.S.EPA's and the FDA's national fish advisory, portions of the advisory do not apply to the Viequenses who rely heavily on local seafood. For example, the advisory discusses fish that Viequenses do not eat, such as pollock, catfish, and tilefish. In addition, the advisory recommends that if a local advisory is not available, people should not eat more 6 ounces of local fish and should not consume any other fish during the week. We include links to the advisory for informational use and we recommend an educational program about mercury in locally consumed fish.

7. Residents need information so they can select local seafood lower in mercury over seafood higher in mercury. This will protect developing fetuses and young children from mercury in fish. For informational purposes only, the advisory and related information is available at: http://www.epa.gov/waterscience/fish/advice; http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm115662.htm, and Chapter 2, Section 2.7 of this report, Appendix 2A-3.

8. For the 104 fish samples collected from the marine areas near Vieques and from the commercial fish market, the average mercury level was 0.1 ppm and the range was nondetectable to 0.33 ppm. The mercury levels detected in Vieques reef fish are similar to levels reported by the FDA

(FDA 2010). The mercury levels are in the low (0.02–0.2 ppm) to mid (0.2–0.6 ppm) mercury range identified by FDA in its recent risk and benefit assessment (FDA 2009).

9. ATSDR also conducted a statistical analysis of the 2001 fish data and concluded the following:

    a. Mercury detected in the seafood is higher in two fish families (grunt and hind) compared with other families sampled (e.g., parrotfish and snapper). The average mercury concentration in grunt and hind was higher than U.S.EPA's 0.049 ppm screening level. In testing some of the hypotheses, ATSDR used the overall average of 0.1 ppm to determine which families of reef fish were likely to exceed the overall average.

    b. Mercury levels in parrotfish were statistically lower than U.S.EPA's 0.049-ppm screening level and lower than the 0.1-ppm overall average.

    c. All snapper were lower than U.S.EPA's 0.049 ppm screening value. But an insufficient number of snapper were collected to determine whether the average snapper-mercury level was statistically different from the U.S.EPA 0.049 ppm screening level. A sufficient number of snapper were collected to determine that the average mercury level is statistically lower than the 0.1-ppm overall average.

10. Mercury is present in most seafood and is particularly high in some fish species and low in other species. While mercury was a component of the detonators of some bombs, only small amounts of mercury were introduced to the Vieques environment from this source. This conclusion is supported by the low mercury levels in LIA soils, which appear to be at naturally occurring levels. Mercury levels in fish in and around the LIA are most likely the result of the global reservoir of mercury circulating in the environment.

11. Statistical analysis showed that some fish and shellfish had higher levels of some metals and lower levels of other metals—iron, aluminum, copper, zinc, arsenic, barium, potassium, and selenium were all slightly higher. These metals are materials found in bombs and metal ships, suggesting possible localized contamination. But the levels were only slightly higher and the difference was only statistically significant when compared with a few other locations.

2.3.2. Recommendations

ATSDR recommends environmental and public health agencies and scientists consider the following:

1. People who frequently consume marine seafood should follow available fish advisories and fishing restrictions in Vieques. Maintain the fishing restrictions in the waters adjacent to the LIA.

2. Conduct a survey of Vieques residents to determine the types, frequency, and quantity of fish consumed.

3. Conduct additional risk assessments and statistical analyses using new information gathered from the previously recommended fish consumption survey.

4. Collect and analyze additional fish samples from Vieques should the proposed survey and statistical analysis not provide sufficient public health information. Collect sufficient fish samples to allow analysis by species and by location.

5. Develop an educational program about mercury in fish that incorporates local habits and information about Viequenses' seafood consumption. Benefits accrue to the developing fetus with maternal intake of nutrients in seafood (FDA 2009) that can outweigh the concomitant intake of small amounts of mercury. The goal of this site-specific educational program should be to educate Viequenses about the benefits of eating seafood so they can choose fish lower in mercury and still maintain their healthy dietary customs of consuming local seafood.

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2.5. Appendix 2A-1: Statistical Analysis of ATSDR Fish Data

2.5.1. Addressing the Statistical Tests and Sample Numbers

Any investigation has strengths and weaknesses. The strengths of the 2001 sampling supported by ATSDR were

- It repeated the analysis of metals in market fish conducted by the Universidad Metropolitana, School of Environmental Matters (Caro et al. 2000).
- It provided previously unavailable, specific information about fish. Such information included measurements of explosive compounds in fish, measurements of contaminants in fish captured on specific reefs around the island (including reefs with visible signs of military presence), and measurements of contaminants in shellfish captured on and around the island.

The limitations were

- By collecting only larger specimens of the popular reef species, the average concentrations might have been biased high, which might have resulted in a mercury overestimate.
- Because larger fish were targeted and the reefs had only a few larger species, fish within the same family had to be combined to provide statistical significance. Consequently, these data could not establish differences in concentration between most species within a family. Fish within a family were grouped to provide sufficient number to represent each family at a sampling location. Although this was adequate to represent the concentrations of most metals in the families, more appropriate ways to address mercury were available. We determined that mercury concentrations were highly dependent on species within a family. For example, white grunt had lower mercury concentrations than the rest of the fish in the grunt family, and red hind had lower mercury concentrations than others in the hind family.

2.5.2. Sample Design

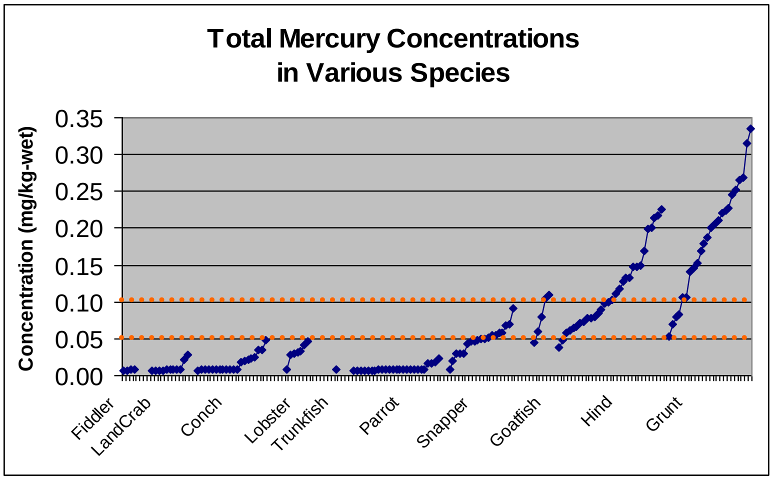
The original sample design did not focus only on mercury, but mercury was included. ATSDR and U.S.EPA proposed a sampling strategy to 1) evaluate many metals and explosive chemicals in fish, and 2) compare chemicals in fish caught in the various reefs with fish purchased at the market (USEPA 2001). From each location, the specimens collected were approximately the same size. The School of Environmental Matters collected 52 fish of varying sizes, with little variation in results. Each of these datasets provided unique and meaningful information about mercury and other metals.

Statistical tests confirmed sufficient fish for numerous evaluations. U.S.EPA provided statistical tests to compare fish by location and by family for all metals (USEPA 2001), and ATSDR provided statistics to compare fish family with health-related concentrations for mercury. A summary of ATSDR's testing is provided below.

2.5.3. Summary of Statistics for Health-Related Hypothesis Testing

Hypothesis tests were designed to determine whether mean mercury concentrations were above or below 0.1 ppm and above or below 0.049 ppm. Figure 2A-1 of total mercury in fish by family illustrates many of the results of the statistical tests.

Figure 2A-1. Total mercury in fish by family



Blue squares represent concentrations for individual fillet sample. The horizontal dotted line at 0.049 ppm (close to the 0.05 label) connotes the EPA screening value for subsistence populations and the horizontal dotted line at 0.1 ppm connotes a site-specific methylmercury value calculated using ATSDR's 2001 fish data.

A statistical analysis of the data supports the following conclusions:

1. Most of the goatfish, hind, and grunt were above the 0.049 ppm level;
    a. The mean goatfish concentration of 0.0797 ppm was statistically higher than 0.049 ppm;
    b. The mean hind concentration of 0.116 ppm was statistically higher than 0.049 ppm;
    c. The mean grunt concentration of 0.185 ppm was statistically higher than 0.049 ppm;
2. Many of the hind and grunt were above the 0.1 ppm level.
    a. But the mean hind concentration of 0.116 ppm was not statistically different than 0.1 ppm;
    b. Follow-up review of the species shows that red hind are lower (with a mean concentration of 0.091 ppm—also not statistically different from 0.1 ppm)
    c. The mean grunt concentration of 0.185 ppm was statistically higher than 0.1 ppm;
    d. Follow-up review of the species shows that Bluestriped grunt and French grunt were higher with mean concentrations of 0.22 ppm (each) and that white grunt averaged 0.098 ppm (therefore, white grunt were not statistically different from 0.1 ppm)
3. Many of the snapper and goatfish were between the two levels (i.e., 0.049 ppm and 0.1 ppm):

   a. The snapper concentration of 0.0478 ppm was not statistically different from 0.049 ppm, but was statistically lower than 0.1 ppm;
   b. The mean goatfish concentration of 0.0797 ppm was statistically higher than 0.049, but not statistically different from 0.1 ppm;

4. The remaining fish families were below the 0.049 ppm level (many of those results were statistically significant):
   a. The mean lobster concentration of 0.0317 ppm was statistically lower than 0.049 ppm.
   b. The highest mercury concentration in 25 parrotfish was 0.0231 ppm, less than half of the 0.049 ppm screening level. Because mercury was not detected in most samples, the concentrations were not normally distributed; we therefore performed nonparametric tests using the median. The median of 0.00767 ppm has 95% confidence limits of 0.00747 and 0.00801 ppm, with a coverage of 95.7%, lower than 0.049 ppm.
   c. The highest mercury concentration in 11 composite land crab samples was 0.0287 ppm—less than the 0.049-ppm screening level. The concentrations were not normally distributed; mercury was not detected in many samples. We therefore identified that the median 0.00823 ppm (with its 95% confidence limits of 0.00725 and 0.0216 ppm and 96.1% coverage) was lower than 0.049 ppm.
   d. The highest mercury concentration in 20 conch samples was 0.0486 ppm, lower than 0.049 ppm. The conch concentrations were not normally distributed—mercury was not detected in many samples. We therefore found that the median 0.008277 ppm (with its 95% confidence limits of 0.00803 and 0.0179 ppm and 95.9% coverage) was well below 0.049 ppm.
   e. Four composite fiddler crab samples were normally distributed, with a mean concentration of 0.0077 ppm—statistically lower than 0.049 ppm.
   f. We had only one trunkfish sample—insufficient for statistical analysis.

We could make more specific conclusions for families or species.

2.5.4. Testing Limitations

Testing of the thresholds had a high bias: larger fish were used, and total mercury was used to represent methylmercury. More samples in some locations would provide stronger results. But to collect enough samples for the test levels chosen (0.049 and 0.1 ppm) could be cost prohibitive, as some families had averages very close to those levels.

2.5.4.1. Summary of Statistics for Location Testing

Statistical analyses were conducted on the mercury (and other metals) levels in fish and invertebrate tissues to determine whether the locations were statistically different (USEPA 2001). Tissue from hind, grunts, parrotfish, snappers, conch, and land crabs were included in the analyses. Because of the limited numbers collected at most sampling locations, fiddler crabs, goatfish, and lobster were not tested.

The mercury statistical test found high influence of species and size. Even with these influences, the range of concentrations within families was relatively small. Thus any differences by location are hard to determine. Because the range of mercury concentrations was small and the influence of species and size was large, we cannot predict the number of samples needed to determine any differences between the levels found in the fish at each location. Further statistical tests are provided below.

2.5.5. Results of the Tests (Mercury focus)

A multivariate analysis of variance (MANOVA) was computed for mercury (and other metals). Individual analysis of variance (ANOVA) results indicated a statistical significance between several metals at several locations. But for mercury, little statistical difference appeared between the locations. Table C1 in Appendix C of U.S.EPA (2001) includes a complete summary of all comparisons between locations, parametric and nonparametric, for all families. The following is an abbreviated list of the summary of the mercury statistic tests provided by U.S.EPA in Appendix C of U.S.EPA (2001):

- Hind: A MANOVA was computed for mercury. Individual ANOVA results indicated a statistical significance between locations for other metals, but not for mercury. The statistical reports for hind are listed under “grouper” in U.S.EPA (2001) p C3.1.
- Grunt: A MANOVA was computed for mercury. Individual ANOVA results indicated a statistical significance between locations for some metals, but not for mercury.
- Snapper: A MANOVA was computed for mercury. Individual ANOVA results indicated a statistical significance between locations for some metals, but not for mercury.
- Parrotfish: Kruskal-Wallis’s nonparametric comparison of the locations indicated no significant difference ($p<0.05$) for mercury in comparisons between locations.
- Conch: Mercury at Esperanza was higher than the LIA North, LIA South, and the West End. Kruskal-Wallis’s nonparametric comparison of the locations resulted in significant probability values ($p<0.05$) from comparisons between locations for mercury. Tukey’s multiple comparisons on the ranks resulted in two distinct patterns for mercury: LIA-North (1), LIA-South (2), and the West End (6) were grouped together; Esperanza (3) was grouped separately.

  Land Crabs: Because more than 50% of mercury results were below the detection level, they were evaluated using nonparametric methods. Nonparametric testing indicated no significant difference between mercury levels at the locations.

Table C1 from U.S.EPA's report (USEPA 2001) for locations 1 through 6.

Table C1. Results of Statistical Comparisons Between Sampling Locations, Target Species, and Analytes
Vieques Fish Assessment
Vieques, Puerto Rico
November 2001

	Probability Values					
Species: Locations Compared:	Conch 1, 2, 3, 6	Grouper 1, 2, 3, 4, 5, 6	Grunt 1, 2, 3, 5, 6	Land Crab 1, 2	Parrot 1, 2, 3, 4	Snapper 2, 3, 4, 5, 6
Aluminum	**0.0103** *	**0.0013** *	**<0.0001**	0.0508	**<0.0001**	**0.0284** *
Antimony	NE	NE	NE	NE	NE	NE
Arsenic	**0.0001**	**0.0053**	**0.0039**	NE	**0.0089** *	0.1415 *
Barium	**0.0069**	**0.0132** *	0.6473	0.1802	0.3259	0.5276
Beryllium	**0.0102** *	**0.0042** *	**0.0036** *	NE	**0.0045** *	**0.0103** *
Cadmium	**0.0435**	NE	NE	NE	0.8510 *	NE
Calcium	**0.0452**	**0.0050**	0.1826	**0.0498**	0.6766	0.7062
Chromium	0.6119	0.2764	0.0695	0.1676	0.0921	0.0919
Cobalt	0.1436 *	0.6493 *	0.1645 *	0.9168 *	0.7840 *	**0.0213** *
Copper	**0.0103**	0.1008	**0.0073**	0.6475	0.2887	0.1939
Iron	NU	0.1862 *	0.2557	**0.0070**	**0.0085** *	**0.0008**
Lead	**0.0086** *	0.0238 *	0.0792 *	0.0758 *	0.4978 *	0.3115 *
Magnesium	**0.0413**	0.5051	**0.0060**	0.0683	0.3419	0.2079 *
Manganese	0.6318	**0.0072** *	**0.0119** *	**0.0053**	0.9230	**0.0405** *
Mercury	**0.0195** *	0.3412	0.0728	0.1745 *	0.2011 *	0.1599
Nickel	NE	0.1960 *	NE	NE	NE	0.239 *
Potassium	0.8085	0.3901	**0.0064**	NE	**0.0256**	0.6473
Selenium	0.1064	**0.0002**	**0.0066**	**0.0162**	**0.0002**	0.2604
Silver	0.0558	NE	0.4209 *	**0.0160** *	0.3060 *	0.3214 *
Sodium	**0.0028**	0.7279	0.9993	0.2840	0.1410	0.2308
Thallium	NE	NE	NE	NE	NE	NE
Vanadium	0.6715 *	NE	NE	0.0864	0.8214 *	NE
Zinc	0.4960	**<0.0001**	0.3596	**0.0315**	**0.0063**	**<0.0001**

* - Non-parametric analyses conducted
NE - not evaluated - 100% of analytical results were below the method detection limit
NU - Analytical results were not useable

Statistical analyses conducted at an alpha- level of 0.05. Probability values <0.05 listed in bold type.

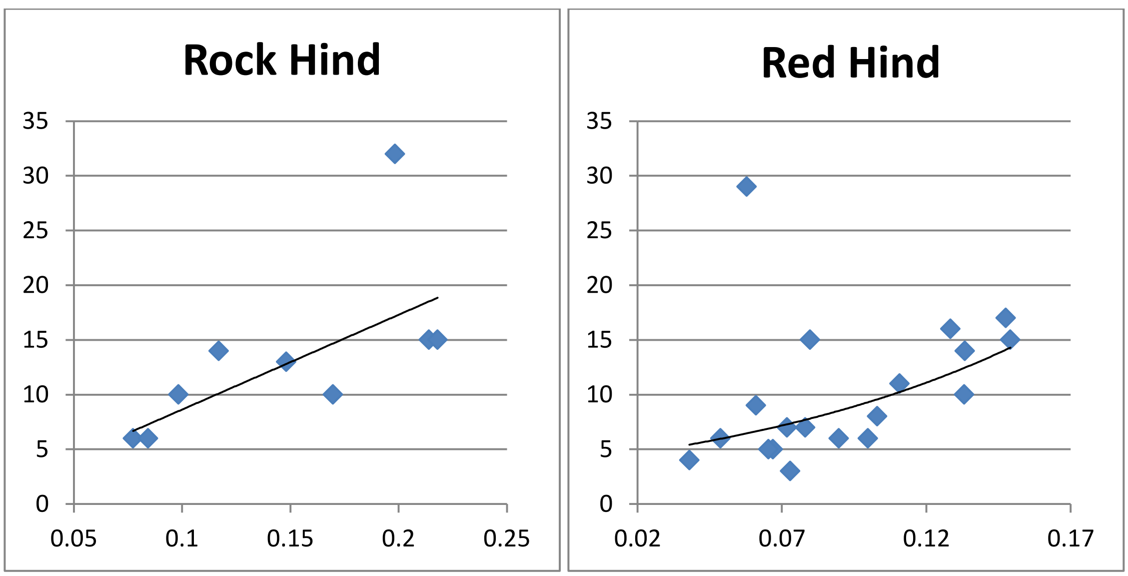
2.5.6. Testing Limitations

Because of peer-review comments, we performed additional tests. Because the grunt family averaged higher than 0.1 ppm, we tested to determine whether all grunt species were higher. Four French grunt were caught near the west end and nowhere else; all were over 0.1, with the lowest sample having 0.14 ppm and the 95% confidence interval being 0.13 ppm. These French grunt were much smaller than the other species of grunts. French grunt, even at full size, are small and tend to forage more near sand than near grasses at night when they leave the reef, resulting in different exposures from other grunt. Because French grunt had relatively high mercury levels for their size, they introduce a bias into the grunt family. This reduced our ability to compare all grunt at all reefs. Bluestriped grunt were caught at three reefs, North LIA, South LIA, and Esperanza, with similar averages (between 0.21-0.24 ppm). Furthermore, White grunt were statistically lower than Bluestriped grunt and French grunt. The market only had white grunt for the investigation. We found no statistical difference between the Bluestriped grunt at the two LIA locations compared with those caught at Esperanza.

In Chapter 2, Section 2.2.2 we discussed the hind family as one case where it appeared that a location (location 1) had different (in this case lower) concentrations than other locations. We also mentioned additional statistical tests to determine other reasons for location 1 having lower levels. Looking into this family, we want to compare other species factors and to determine whether weight could have influenced the results.

We had sufficient samples within the hind family only to evaluate further the red hind and the rock hind. The red hind from the market, from Isabel Segunda, and from the North LIA averaged less than the rock hind from Esperanza and the South LIA (from Table 2-5). The three rock hind from the west end had the lowest average mercury levels for that species (0.057 ppm). Rock hind were found at two reefs, South LIA (averaging 0.13 ppm) and Esperanza (averaging 0.16 ppm). After accounting for species differences, we can determine whether weight influences the concentration by looking at concentrations within one species. Figure 2A-2 is a scatterplot of all the rock hind weights compared with their mercury concentrations.

Figures 2A-2a and 2A-2b. Weight (in oz) vs. mercury concentration (ppm)



The graphs suggest a relationship between fish size and mercury concentration. This was not evident in the fish Caro collected. Because ATSDR intentionally selected larger fish, the size variation is insufficient to make this comparison for all fish.

From the mercury tests, we concluded that only conch showed statistical differences by location. Those differences were that conch on the LIA-North, the LIA-South, and the West End had statistically less mercury than the conch collected in Esperanza. Even the Esperanza conch, however, were below screening levels.

2.5.7. Mercury: Three Human Studies and U.S.EPA's Reference Dose

Several human studies have evaluated the neurological effects of methylmercury exposure in children. A long-term human study of children from the Faroe Islands, a small group of islands in the North Atlantic Ocean affiliated with Denmark, began in 1986 and focused on children born to women who lived on the islands. This population relies heavily on seafood and whales as a protein source. The investigators used various tests that monitor child development. They concluded that at birth, cord blood mercury levels in the mother were associated with harmful effects in children at age 7 years involving language, attention, and memory, and to a lesser extent visual/spatial and motor functions (Grandjean et al 1997). Follow-up studies at age 14 years showed similar findings (Debes et al 2006).

In 1978, New Zealand was the site of another human study. It focused on 61 children who were exposed *in utero* to high mercury levels that resulted from their mother's consumption of four or more fish meals a week. If the authors omitted one outlier, the data showed a decrease in children's intelligence quotient (IQ) at age 6 with increasing exposure to methylmercury as measured by their mother's hair mercury levels at birth (Crump 1998). The third study came from the Republic of Seychelles, where 85% of the population relied on local seafood for protein. Average ocean fish consumption in this population was 12 meals a week (Davidson 1998). The Seychelles study initially did not find harmful effects in children as they grew older. In one recent publication, the investigators reported that two of 21 endpoints (one positive and one negative) were associated with prenatal methylmercury exposure. The authors stated that these outcomes were probably due to chance. They concluded that their data did not support a neurodevelopment risk from prenatal methylmercury exposure from eating fish (Myers 2003). In another paper, the authors reported that they found several associations between postnatal methylmercury exposure and children's developmental endpoints. However, the investigators concluded that no consistent pattern of associations emerged to support a causal relationship (Myers 2009). In some cases in which several tests were used to evaluate a single domain, and only one of those tests was positive, the Seychelles investigators did not believe they could base a firm conclusion on only one of several tests for that domain. Rather, they believed that if a domain was adversely affected, more than one test should show it (Risher 2010).

More information about the harmful effects of methylmercury is available in ATSDR's Toxicological Profile for Mercury (ATSDR 1999).

U.S.EPA developed a methylmercury Reference Dose using a mathematical model that estimated a 5% adverse response in children for neurological effects.[15] Using the Faroe Islands study, U.S.EPA concluded that the methylmercury concentration in maternal cord blood that caused a 5% adverse response in children ranged from 46 to 79 ppb. This methylmercury concentration in maternal blood equated to a range of 0.8 to 1.5 µg methylmercury per kilogram per day (µg /kg/day) as a dietary intake. The doses were divided by an uncertainty factor of 10 to arrive at the Reference Dose of 0.1 µg/kg/day. The

[15] More precisely, U.S.EPA estimated the lower 95th confidence limit of the concentration of methylmercury in maternal blood that gave a 5% response for neurological effects in offspring at 7 years of age.

U.S.EPA's approach is consistent with the approach used by the National Academy of Sciences. The NAS recommended that U.S.EPA use the Faroe Islands Study and 58 ppb methylmercury in cord blood for deriving its health guideline (NRC 2000). U.S.EPA's methods for deriving the agency's RfD are described in detail at http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?IRIS (IRIS 2009).

The National Academy of Sciences concluded that some risk is possible regarding anticipated harmful effects in children exposed *in utero* to 58 ppb methylmercury in cord blood. The cord blood concentration of 58 ppb methylmercury equates to 12 ppm methylmercury in maternal hair (NRC 2000).

2.6. Appendix 2A-2. Estimated Doses in Residents from Eating Vieques Fish

Table 2A-1. Estimated mercury dose for women and children of various body weights from eating Vieques reef fish. +

Approximate Age			Body Wt lbs	Body Wt kg	Estimated Mercury Dose in µg/kg/day													
18 yr and older	A		220	100	0.02	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.30	0.36	0.42		
18 yr and older			198	90	0.02	0.03	0.07	0.10	0.13	0.17	0.20	0.24	0.27	0.34	0.40	0.47		
18 yr and older	D		176	80	0.02	0.04	0.08	0.11	0.15	0.19	0.23	0.26	0.30	0.38	0.45	0.53		
18 yr and older			154	70	0.02	0.04	0.09	0.13	0.17	0.22	0.26	0.30	0.35	0.43	0.52	0.60		
18 yr and older	U		143	65	0.02	0.05	0.09	0.14	0.19	0.23	0.28	0.33	0.37	0.46	0.56	0.65	0.74	0.93
17 yr and older		C	132	60	0.03	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.71	0.81	1.01
16 yr and older	L		128	58.1	0.03	0.05	0.10	0.16	0.21	0.26	0.31	0.36	0.42	0.52	0.62	0.73	0.83	1.04
15 yr and older	T		121	55.1	0.03	0.05	0.11	0.16	0.22	0.27	0.33	0.38	0.44	0.55	0.66	0.77	0.88	1.10
14 yr and older		H	121	54.8	0.03	0.06	0.11	0.17	0.22	0.28	0.33	0.39	0.44	0.55				
13 yr and older	S		112	50.9	0.03	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.47	0.59				
12 yr and older			102	46.4	0.03	0.07	0.13	0.20	0.26	0.33	0.39	0.46	0.52	0.65				
11 yr		I	92	41.8	0.04	0.07	0.14	0.22	0.29	0.36	0.43	0.51	0.58	0.72				
10 yr			79	36.1	0.04	0.08	0.17	0.25	0.33	0.42	0.50	0.59	0.67	0.84				
9 yr			70	31.9	0.05	0.09	0.19	0.28	0.38	0.47	0.57	0.66	0.76	0.95				
8 yr		L	61	27.9	0.05	0.11	0.22	0.32	0.43	0.54	0.65	0.76	0.87	1.08				
7 yr			55	25	0.06	0.12	0.24	0.36	0.48	0.60	0.73	0.85	0.97	1.21				
6 yr			49	22.1	0.07	0.14	0.27	0.41	0.55	0.68	0.82	0.96	1.09	1.37				
5 yr		D	43	19.6	0.08	0.15	0.31	0.46	0.62	0.77	0.93	1.08	1.23					
4 yr			37	17	0.09	0.18	0.36	0.53	0.71	0.89	1.07	1.24	1.42					
3 yr		R	33	14.9	0.10	0.20	0.41	0.61	0.81	1.01	1.22	1.42	1.62					
2 yr			29	13	0.12	0.23	0.46	0.70	0.93	1.16	1.39							
1 yr			24	10.8	0.14	0.28	0.56	0.84	1.12	1.40	1.68							
< 1 yr		E	19.4	8.8	0.17	0.34	0.69	1.03	1.37	1.72	2.06							
< 1 yr		N	9.9	4.5	0.34	0.67	1.34											
				fish kg/day	0.014	0.028	0.057	0.085	0.113	0.142	0.170	0.198	0.227	0.284	0.340	0.397	0.454	0.567
				fish oz/day	0.5	1	2	3	4	5	6	7	8	10	12	14	16	20

+ Men with the same weight and fish intake have the same estimated dose as women. *These estimated doses are for teenagers 15 to 18 years who have a 99th percentile fish-meal portion of 20 ounces. The 99th percentile fish meal portion for adult women is 14 ounces.

2.7. Appendix 2A-3. The Joint U.S.EPA and FDA National Fish Advisory

*What You Need to Know About Mercury in Fish and Shellfish***,** *March 2004:*

2004 EPA and FDA Advice for Women Who Might Become Pregnant, Women Who Are Pregnant, Nursing Mothers, and Young Children

Fish and shellfish are an important part of a healthy diet. Fish and shellfish contain high-quality protein and other essential nutrients, are low in saturated fat, and contain omega-3 fatty acids. A well-balanced diet that includes a variety of fish and shellfish can contribute to heart health and children's proper growth and development. So, women and young children in particular should include fish or shellfish in their diets due to the many nutritional benefits.

However, nearly all fish and shellfish contain traces of mercury. For most people, the risk from mercury by eating fish and shellfish is not a health concern. Yet, some fish and shellfish contain higher levels of mercury that may harm an unborn baby or young child's developing nervous system. The risks from mercury in fish and shellfish depend on the amount of fish and shellfish eaten and the levels of mercury in the fish and shellfish. Therefore, the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) are advising women who may become pregnant, pregnant women, nursing mothers, and young children to avoid some types of fish and eat fish and shellfish that are lower in mercury.

By following these three recommendations for selecting and eating fish or shellfish, women and young children will receive the benefits of eating fish and shellfish and be confident that they have reduced their exposure to the harmful effects of mercury.

1. Do not eat shark, swordfish, king mackerel, or tilefish because they contain high levels of mercury.
2. Eat up to 12 ounces (2 average meals) a week of a variety of fish and shellfish that are lower in mercury.
    a. Five of the most commonly eaten fish that are low in mercury are shrimp, canned light tuna, salmon, pollock, and catfish.
    b. Another commonly eaten fish, albacore ("white") tuna has more mercury than canned light tuna. So, when choosing your two meals of fish and shellfish, you may eat up to 6 ounces (one average meal) of albacore tuna per week.
3. Check local advisories about the safety of fish caught by family and friends in your local lakes, rivers, and coastal areas. If no advice is available, eat up to 6 ounces (one average meal) per week of fish you catch from local waters, but do not consume any other fish during that week.

Follow these same recommendations when feeding fish and shellfish to your young child, but serve smaller portions.

3. Biomonitoring

Chapter 3 Summary

The following chapter describes and evaluates the available biomonitoring studies of Vieques residents. These studies were conducted since 1999 by Puerto Rican scientists and physicians or by the Commonwealth's Department of Health. They consist of measurement of various metals in residents' blood, urine, hair, or feces. Data from these studies reported elevated levels of some metals in residents' blood, urine, or hair. While some of these elevated levels might be explained by cigarette use, seafood consumption, or hair dyes, they did not account for all the elevated levels. These studies were unable to investigate each person's environment to identify the metals' source

for those residents who had excessive levels in hair, urine, or blood. The PRDOH study came closest to identifying possible sources but acknowledges an inability to identify the source or sources for all residents with excessive metals exposure.

Viequenses may be exposed to mercury in fish and cadmium in pigeon peas. These exposures may warrant additional environmental investigations, such as sampling locally grown produce for cadmium and gathering more information about fish consumption and possibly mercury in fish. The information could be used to decide whether to undertake human testing for mercury and cadmium in blood or urine. If other environmental exposures are identified, additional human biomonitoring investigations may be considered. More detailed information about ATSDR's recommendations concerning fish and locally grown produce can be found in Chapter 2, Section 2.3.2 and Chapter 5, Section 5.3.2, respectively. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation.

Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis. CDC/ATSDR can provide a list of qualified laboratories that can perform the tests. And if requested , CDC/ATSDR can provide information to healthcare providers about tests for metals in biologic samples.

3.1. Introduction to Biomonitoring

Biomonitoring is the measurement of metals or chemicals in a biological matrix such as blood, urine, or hair. It can sometimes be a useful method of evaluating environmental chemical exposure in people. Biomonitoring examples include measuring lead in blood, cadmium in urine, and mercury in hair. The concentration of environmental chemicals in a biological matrix may allow assessment of excessive exposure. In some cases, the levels of environmental chemicals could be predictive of the risk of harmful effects occurring in the population. Depending on the chemical, biomonitoring studies can provide insight into a population's exposure over the previous days, weeks or months, or even years. Scientists usually use biomonitoring to assess populations at risk for exposure (e.g., average exposures or the prevalence of unusually high exposures). Less often, biomonitoring can be useful in assessing the exposure of a single person.

But like all exposure assessments, biomonitoring has limitations and requirements. These fall into five categories:

- Many chemicals are not measureable with current technology.
- Measurements require defined precision and accuracy to be applicable.

- Proper timing and collection techniques are required. In fact, they are essential to interpretation, appropriate comparison, or identification of reference groups.
- Although biomonitoring can assist in exposure assessment, the toxicological significance of biomonitoring results is sometimes not possible.

Biomonitoring results from Vieques can be compared with national data, such as the Fourth National Report on Human Exposure to Environmental Chemicals (CDC 2009). But more appropriate comparisons should include comparison with biomonitoring data from residents of the main island of Puerto Rico. These limitations are described in more detail later in this chapter.

3.2. Assessment of Available Vieques Human Biomonitoring Studies Data

Because ATSDR's previous public health assessments did not review biomonitoring data from Vieques, this chapter and its appendices describe the biomonitoring data in detail. Because of confidentiality issues, ATSDR does not have access to individual results. Thus our evaluation relies on information reported by the investigators. The important fact is, however, that biomonitoring data available for Viequenses cannot be used to determine whether residents of Vieques were exposed to past, military exercise-related constituents.

Since 1999, either the Puerto Rico Department of Health or Puerto Rican scientists and doctors have conducted several human biomonitoring studies in Vieques. These studies have focused on measuring metals in hair, urine, blood, or stool samples. They are listed in Table 3-1 (Colón de Jorge undated; Ortiz Roque 2004; Ortiz Roque 2002; PRDOH 2006; Rodríguez Sierra 2009). Highlights are provided here. The studies are described in more detail in Appendix 3-A.

Dr. Carmen Colón de Jorge conducted one of the first studies. She analyzed hair samples from 30 residents with preexisting health conditions and analyzed seven stool samples for metals. At about the same time, Dr. Carmen Ortiz Roque's study analyzed hair samples from about 200 Viequenses for various metals. The doctors concluded their data showed Viequenses had heavy metal exposure and that the exposure had resulted in harmful health effects (Colón de Jorge; Ortiz Roque 2002, 2004).

Dr. Colón de Jorge reported numerous metals in hair. That report stated that based on the ranges provided by the service laboratory that made the measurements (i.e., Doctor's Data, Chicago, Illinois) a sizeable percentage of the 30 tested residents exceeded the reference range established by Doctor's Data. Dr. Colón de Jorge noted that in about 70% of the 30 tested residents, arsenic and antimony in hair were above the reference ranges selected by the reporting laboratory. Dr. Colón de Jorge's report stated that because antimony levels in bombs are high, the antimony exceedences proved residents were exposed to metals from munitions. But the report did not explain how residents could have been exposed to antimony or to other metals.

Table 3-1. Vieques human biomonitoring studies

Source	***Title***
Puerto Rico Department of Health	Executive summary of the prevalence study of heavy metals in Vieques, 2006, draft unpublished manuscript
Dr. Carmen Ortiz Roque	Mercury contamination in reproductive age women in a Caribbean island: Vieques. J. Epidemiol Community Health 58:756-757, 2004
Dr. Carmen Ortiz Roque	Heavy metal exposure and disease in the proximity of a military base. Unpublished manuscript, 29 January 2002
Dr. Carmen Colón de Jorge	Innocence battered on Vieques, scientific investigation of toxic metals present in the biological terrain of Vieques children and adults and their effects on nutrient minerals utilizing hair and feces analysis (preliminary report). Unpublished manuscript, no date
Dr. Carlos Rodríguez Sierra	Webcast, October 30, 2009, New look at the opening of the case of Vieques, www.telecoque.net

Most commercial laboratories that report results will develop their own reference range for what they consider normal or typical concentrations of a chemical in a biological matrix. But such ranges can vary with the populations tested. Inevitably, exposures will vary from population to population based on factors such as age, sex, race/ethnicity, and underlying health conditions. Laboratories will sometimes develop a concentration that they consider above the expected range or that they sometimes even consider toxic. Often for these ranges (and, if reported, for the toxic levels) the basis is the company's own cumulative experience from many years of laboratory testing. Such reference ranges or identified toxic levels are not regulated by the government nor are they approved by a medical or scientific organization.

Dr. Ortiz Roque's study identified several residents with hair-mercury levels above 12 ppm—the level the National Research Council identified as causing a 5% increase in abnormal results on a neurocognitive test (i.e., the Boston Naming test) for children who were exposed *in utero* (NRC 2000).

Dr. Ortiz Roque showed that higher mercury levels were associated with Viequenses' higher fish consumption (Ortiz Roque 2002, 2004). But the patients in this investigation were not randomly selected. Thus insofar as the prevalence of Viequenses' elevated mercury levels is concerned, any firm conclusions are difficult to draw. That said, Dr. Ortiz Roque's identification of three residents with hair mercury levels above 12 ppm is an important finding. A major limitation of hair analysis in a free-living population is the difficulty in discerning whether the metal was *internally* deposited from the blood stream or *externally* deposited from the air or the use of products on the hair. While hair measurements for mercury have been used in previous population studies, efforts to understand or control external deposition are usually investigated.

From 2006 to 2008, Dr. Carlos Rodríguez Sierra collected hair, nail, and urine samples from 52 Viequense adults. He divided the study subjects into high and low fish-consumption groups. This division is necessary because persons who eat fish regularly will have high levels of urinary arsenic. This arsenic is predominantly arsenobetaine—a nontoxic arsenic form. An October 30, 2009 Webcast sponsored by Casa Pueblo de Adjuntas carried a report that high levels of arsenic in hair, nails, and urine were not detected at the time of sampling. Hair and nail sample levels were below 1-µg/g (microgram per gram), which Dr. Rodríguez Sierra used as a reference value (Rodríguez Sierra C. 2009). The Webcast further reported that the sum of inorganic arsenic species and their metabolites in urine was less than 50 µg/g creatinine, which Dr. Rodríguez Sierra also used as a reference value. This value likely comes from occupational exposure studies; they might have used the value to assess excessive exposure to arsenic (ACGIH 2000; WHO 2001). The American Conference of Governmental Industrial Hygiene (ACGIH) currently recommends 35 µg/g creatinine as an action level of the sum of inorganic arsenic species and their metabolites for occupational testing (ATSDR 2007).

Dr. Rodríguez Sierra reported that the median and 95th percentile of total inorganic arsenic (As V, As III, DMA, MMA) levels in Viequenses' urine were slightly above the respective levels reported in the 2003–2004 Fourth National Report on Human Exposure to Environmental Chemicals.[16] Dietary sources of inorganic arsenic include chicken as well as rice, particularly when rice is grown in arsenic-contaminated soils (Lasky et al. 2004; Potera 2007; Williams et al. 2007). Whether these slightly higher levels of inorganic arsenic in urine are associated with harmful effects, however, is impossible to determine.

As a follow up to these studies, PRDOH conducted a comprehensive biomonitoring study in which it collected hair, urine, or blood samples from 500 randomly selected Viequenses. The results were shared with some of those who participated, but no public report was ever released (PRDOH 2006). In August 2009, ATSDR obtained a draft of the unpublished manuscript. ATSDR found that inappropriate units were used for some of the results, thus rendering some measurements uncertain.

Nevertheless, the PRDOH manuscript reported that in 20% of the participants, either aluminum, lead, or mercury in blood; uranium, cadmium, or nickel in urine; or nickel or arsenic in hair exceeded Quest Laboratories' reference range.[17] For some—but not all—of the elevated levels, the PRDOH manuscript identified as possible sources cigarettes, hair dyes, and seafood consumption. For other residents, the origin of high metal levels in urine, hair, and blood could not be identified. As mentioned previously, the elevated levels of metals (except mercury) in hair are difficult to interpret. Hair analysis leaves unanswered whether the metals were ingested and were bound to the hair from direct contact. Note also that the PRDOH manuscript stated that they did not test children 4 years and younger.

[16] The basis for CDC's Fourth National Report on Human Exposure to Environmental Chemicals is an ongoing national survey that samples the U.S. population every 2 years. Each 2-year sample consists of about 2,400 persons. The *Fourth Report* includes findings from national samples for 1999–2000, 2001–2002, and 2003–2004. The data are analyzed separately by age, sex, and race/ethnicity groups. The Fourth Report is available at www.cdc.gov/exposurereport/.

[17] While the draft PRDOH manuscript states that Quest Laboratories in San Juan, PR conducted the clinical analyses, the correct name is most likely Quest Diagnostics.

All that said, however, Dr. Colón de Jorge's and Dr. Ortiz Roque's biomonitoring studies did support the conclusions in the PRDOH manuscript.

3.3. Strengths and Limitations of Human Biomonitoring for Vieques

The use of biomonitoring results to assess public health issues requires consideration of biomonitoring's previously enumerated strengths and limitations. Biomonitoring data will allow an investigator to look at markers of exposure and markers of effect. When toxicological information is available, markers of effect allow an investigator to determine whether harmful consequences might result from the measured level of a chemical or its metabolite. Extensive toxicologic data support current research on lead in blood, cadmium in urine, and mercury in hair. Once the concentration is known, health scientists can draw conclusions about the presence or absence of risk. For other metals in blood or urine, toxicological data and research are limited, thus reducing the ability to draw firm conclusions. For example, no human toxicity data are available for urine levels of antimony, beryllium, cesium, molybdenum, platinum, and tungsten. Thus while biomonitoring might identify populations with excessive exposure, assessing the risk of that exposure's harmful effects might not be possible (CDC 2009).

But a particular biomonitoring strength is the availability of comparison data for a representative sample of the U.S. population. Those comparison data are in the National Reports on Human Exposure to Environmental Chemicals at http://www.cdc.gov/exposurereport/ (CDC 2009). National data are also available on mercury in hair (McDowell 2004).

An important consideration when using National Health and Nutrition Examination Survey (NHANES) biomonitoring data is that differences in levels between populations (e.g., regional, cultural, and ethnic) are likely due to differences in exposures, pharmacokinetics, and other factors. Thus U.S. population data can only be cautiously applied to the Commonwealth of Puerto Rico. If any future biomonitoring investigations are undertaken for the Vieques population, a comparison population from the Commonwealth of Puerto Rico or another nearby island-based population may be more appropriate.

To understand possible exposure sources, subjects with an elevated metal or chemical concentration should be subsequently investigated for attributable sources of exposure.

3.4. The Special Case of Hair Analysis for Metals and Other Elements

3.4.1. ATSDR's 2001 Hair Panel

During ATSDR's November 2009 meeting with invited scientists, we were asked to reconsider the agency's position on testing metals in hair. In 2001, ATSDR sponsored a workshop and invited researchers in the medical, environmental, and toxicological fields to advise the agency of the utility of measuring metals and organic chemicals in hair. The workshop panelists agreed on the following summary statement related to the overall usefulness of hair analysis in evaluating environmental exposures:

> For most substances, insufficient data currently exist that would allow the prediction of a health effect from the concentration of the substance in hair. The presence of a substance in hair may indicate exposure (both internal and external), but does not necessarily indicate the source of exposure (ATSDR 2001).

The panelists agreed that a relationship between contaminant concentrations in hair and any kind of measurable outcome—provided external contamination could be ruled out—have only been established for methylmercury and, to a limited extent, for arsenic (e.g., segmental analysis for forensic analysis). Unique forensic settings might be available for other substances (ATSDR 2001).

The panelists identified several factors that limit interpretation of even the most accurate, reliable, and reproducible laboratory results. These include

- A lack of reference (or background) ranges in which to frame the interpretation of results.
- Difficulties in distinguishing endogenous (internal) from exogenous (external) contamination in hair.
- Some panelists thought the then-current literature suggested the absence of any reliable washing method capable of separating external contamination from internal element deposition. One potential remedy was that where possible, identifying metabolites—or other unique markers of internal exposure—for substances of interest would be most helpful in distinguishing internal and external contamination.
- A lack of understanding of how and to what extent environmental contaminants are incorporated into the hair.
- A lack of correlation between levels in hair and blood and other target tissues, as well as the lack of epidemiologic data linking substance-specific hair levels with adverse health effects.
- Little pertinent information is available for the study of environmentally relevant organic compounds in hair. The panel recommended taking advantage of what is known about hair analysis for testing for drugs of abuse (ATSDR 2001).

3.4.2. Current Status of Hair Analysis Validity

ATSDR staff checked with several sources to determine the current validity of hair analysis. The American Medical Association (AMA) supports the conclusions of those panelists who participated in ATSDR's 2001 workshop. The German Federal Environment Agency (GFEA 2005) has a similar recommendation. One exception is carefully tested hair specimens for mercury. The NHANES survey includes mercury in hair from a national population for one 2-year period (1999–2000). Therefore, comparison of hair mercury levels with a national group is possible. This might help in identifying those with excessive mercury exposure.

3.5. Conclusions and Recommendations

3.5.1. Conclusions

1. Since 1999, Vieques has hosted at least five human biomonitoring investigations. Puerto Rican scientists, physicians, or the Puerto Rico Department of Health (PRDOH) conducted all of them. The PRDOH has conducted the most extensive sampling effort, collecting biological specimens from 500 randomly selected Viequenses. The PRDOH manuscript reported that in 20% of the participants, either

   - Aluminum, lead, or mercury in blood;
   - Uranium, cadmium, or nickel in urine; or
   - Nickel or arsenic in hair

   exceeded the laboratory's reference range. The PRDOH manuscript identified cigarette use and hair dyes, as well as the consumption of seafood, as possible sources for some but not all the elevated levels. The PRDOH manuscript acknowledged that for some residents, it could not identify the source of high metal levels in urine, hair, and blood. The PRDOH manuscript did not report mercury levels in hair. Results from Dr. Ortiz Roque's investigations showed that some residents had elevated levels of mercury in hair, and that the most likely source was fish consumption; other possible sources, however, were not completely ruled out.

2. Data from these studies showed that in blood, urine, hair, or feces, some residents of Vieques had elevated levels of various metals. While some of these elevated levels might be explained by cigarette use, seafood consumption, or hair dyes, they did not account for all the elevated levels. In particular, biomonitoring results from Dr. Ortiz Roque showed that some Viequenses had elevated mercury in hair above 12 ppm, the level identified by the NAS to cause harm in 5% of fetuses exposed in utero. Dr. Ortiz Roque also showed that mercury in hair was associated with fish consumption. In contrast, the PRDOH study did not find excessive mercury levels in blood, although the study either did not measure for or did not report mercury level in hair. Thus some uncertainty exists about the prevalence of high mercury levels in Viequenses. Except for mercury, metal content in hair is difficult to interpret. Metals can bind directly to hair from the use of commercial hair products, making difficult any distinction between internal metal exposure via ingestion and inhalation versus external exposure resulting from contact with the metal in the environment (e.g., shampoo, dyes, dirt).

3. These studies were unable to investigate each person's environment to identify the source for those who had excessive metals in hair, urine, or blood. The PRDOH study came closest to identifying possible sources (e.g., cigarette and hair dye use, seafood consumption) but acknowledged an inability to identify the source or sources for all residents with excessive metals exposure. Either through the survey instrument or through an in-home visit, it may be possible to identify other sources that increase metal exposure, such as cooking utensils, metal

residues in foods (e.g., tea and vegetables), consumption of drinks with metallic packaging, antacid formulations and antiperspirant formulations.

4. ATSDR remains cautious in making decisions about using hair as an indicator of exposure to environmental contaminants and as an indicator of risk of harmful effects. A major problem in interpreting metal concentrations in hair is whether the metal content resulted from internal exposure (e.g., from ingestion or inhalation) or from external exposure (e.g., the hair coming in contact with a metal-containing product). Currently, no washing method is capable of removing exogenous metal contaminants while leaving endogenous metals undisturbed. Chemicals such as methylmercury, which originate generally from dietary sources, suffer less from this drawback, provided unusual sources of inorganic mercury do not complicate the picture, (e.g., mercury vapor in occupational or home settings).

5. These biomonitoring results do not permit any conclusions about exposure to the bombing-related contaminants.

3.5.2. Recommendations

1. Viequenses may be exposed to mercury in fish and cadmium in pigeon peas. These exposures may warrant additional environmental investigations, such as sampling locally grown produce for cadmium and gathering more information about fish consumption and possibly mercury in fish. The information could be used to decide whether to undertake human testing for mercury and cadmium in blood or urine. If other environmental exposures are identified, additional human biomonitoring investigations may be considered. More detailed information about ATSDR's recommendations concerning fish and locally grown produce can be found in Chapter 2, Section 2.3.2 and Chapter 5, Section 5.3.2, respectively.
2. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation.
3. Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare providers to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis.
4. CDC/ATSDR can provide a list of qualified laboratories that can perform the tests. And if requested, CDC/ATSDR can provide information to healthcare providers about tests for metals in biologic samples.

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3.7. Appendix 3-A. Biomonitoring

3.7.1. Vieques, Puerto Rico-Related Human Biomonitoring Study Summaries

Several biomonitoring investigations have been conducted on Vieques, with the first samples collected in 1999 (see Table 3A-1). These investigations are summarized in Table 3A-1 and described in detail in the text of this appendix (Colón de Jorge; Ortiz Roque 2004; Ortiz Roque 2002; PRDOH 2006; Rodriquez Sierra 2009).

Table 3A-1. Vieques human biomonitoring studies

Source	***Title***
Puerto Rico Department of Health	Executive summary of the prevalence study of heavy metals in Vieques, 2006, draft unpublished manuscript
Dr. Carmen Ortiz Roque	Mercury contamination in reproductive age women in a Caribbean island: Vieques. 2004. J. Epidemiol Comm Health 58:756–57
Dr. Carmen Ortiz Roque	Heavy metal exposure and disease in the proximity of a military base. Unpublished manuscript, 29 January 2002
Dr. Carmen Colón de Jorge	Innocence battered on Vieques, scientific investigation of toxic metals present in the biological terrain of Vieques children and adults and their effects on nutrient minerals utilizing hair and feces analysis (preliminary report). Unpublished manuscript, undated
Dr. Carlos Rodriquez Sierra	Webcast, October 30, 2009, New look at the opening of the case of Vieques, www.telecoque.net

3.7.2. PRDOH Biomonitoring Study

The most extensive human biomonitoring study conducted to date is a two-phase study of 500 Vieques residents conducted by the Puerto Rico Department of Health starting in May 2004. This study was conducted after ATSDR's public health assessments were published and so represent new data to consider. For this reason, the study is described in detail.

In the first phase, the PRDOH manuscript reported interviewing 500 Vieques residents, collecting biological samples, and analyzing for the following:

- Arsenic, cadmium, and nickel in hair and urine,
- Aluminum, lead, and mercury in blood, and
- Uranium in urine.

As stated in the PRDOH manuscript, the second phase involved collecting and analyzing blood samples from Phase 1 participants with metal concentrations deemed toxic according to the reference values provided by the analytical laboratory. Phase II was from December 2005 to March 2006. In PRDOH manuscript stated that the information obtained from this study would be used to determine the magnitude and scope of the problem, generate hypotheses and identify areas that warrant intervention from a public health perspective. The PRDOH report includes recommendations for follow-up activities.

3.7.2.1. PRDOH Study, Phase 1

Five hundred persons were randomly chosen from residents 5 years of age or older who lived in Vieques before 2000. The interview collected information about age, sex, residence history, smoking status, employment, water consumption and use, food preparation and consumption, medicines, hobbies, and chemicals/solvent use. In particular, information was collected about fish and shellfish consumption 3 days before the sample collection.

To reduce external contamination from the environment, hair samples were collected from the pubic region or, if that was not possible, a 1-inch hair sample from the scalp was collected near the root. Table 3A-2 provides a summary of metal concentrations in blood, urine, and hair from Phase 1. Note that comparing pubic hair results with scalp hair may not be appropriate.

Table 3A-2. PRDOH Phase 1 results of heavy metal analysis of Vieques residents.

Note: The geometric means for some metals (e.g., uranium) in the study population appear to be the average of detectable concentrations. For other metals (e.g., mercury), nondetectable levels were replaced by zero while for other metals (e.g., aluminum), nondetectable levels were replaced by 1 µg/L. For cadmium, the report states that nondetect levels were replaced by a value but did not specify the value. The treatment of nondetects is very important when calculating means and comparing those means to either a reference or toxicity value or to a national average. Complicating the comparisons even further is that for some metals, the detection limit was high. When nondetectable levels are part of the database, the calculation of a geometric mean could be biased high or low depending upon what value was substituted for the nondetect. Therefore, caution is warranted when comparing these study population means to means from reference populations, who are likely to have handled nondetectable concentrations differently or had lower detection limits. For example, the NHANES means replace nondetectable concentrations with the detection limit divided by the square root of two. For some metals, the limitations of the detection limit are acknowledged in the PRDOH report.

	% Detection	***Geometric Mean of PRDOH Sample (n=500)[1]***	***Geometric Mean General Population Selected by PRDOH***	***Geometric Mean 2003-2004 NHANES[2]***	***Level of Possible Toxicity (as reported by service laboratory)***	***Comments***
Aluminum in blood µg/L	93	17.6 (unreliable, see comment)	1-4[3]	NA	≥ 60[5]	Quest Laboratories reports a high detection limit (10 ug/L), which adds uncertainty to the reported geometric mean of 17.6 because 1 µg/L was used for non-detect values. Nevertheless, some persons appear to have elevated Al in blood; 109 persons ≥ 40 µg/L ; 10 persons ≥ 60 µg/L
Lead in blood µg/dL	99	3.53	1.66[4]	1.43	20 µg/dL[5]	Six persons ≥ 10 µg/dL; 2 persons ≥ 20 µg/dL Median age = 56 years; All males; 3 work with petroleum products No safe level identified; CDC case management level for children, 10 ug/dL
Mercury in blood µg/L	99	5.02 (unreliable, see comment)	1.02[6]	0.797	46-79[7]	The PRDOH report states that the detection limit (5 ug/L) was too high to estimate a reliable population mean; Maximum level detected was 13 µg/L. While the draft report states that zero was used for non-detects, it is uncertain if this is actually the case for the average of 5.02 ug/L as reported in the PRDOH manuscript.
Total arsenic in urine µg/L	95	33.6	38.2[4]	8.3	> 50 µg/L[5]	23% > 50 µg/L (117 of 500) 39 of 257 persons who did not eat fish had urine arsenic > 50 µg/L. Another

	% Detection	**Geometric Mean of PRDOH Sample (n=500)[1]**	**Geometric Mean General Population Selected by PRDOH**	**Geometric Mean 2003-2004 NHANES[2]**	**Level of Possible Toxicity** (as reported by service laboratory)	**Comments**
						possible source of urinary arsenic is rice.
Arsenic in hair ppm	65	0.15	0.15[4]	NA	--	One person > 3 ppm
Uranium in urine µg/L	1	0.14 (6 individuals)	0.007[4]	0.008	--	Six women with detectable levels. Mean of these 6 women is 0.14 µg/L. Nondetectable concentrations were not included in calculating the mean.
Cadmium in hair ppm	82	0.14	<0.15[4]	NA	>3.4[5]	No participant exceeded 3.4 µg/L
Cadmium in urine µg/g	87	0.43	0.307[6,8]	0.211	>2[5]	Eleven persons >1.03 ug/g Two persons >lab's toxicity levels of 2 µg/g—for some persons, probably smoking-related
Nickel in urine	79	2.05	< 2[4]	NA	>100[5]	Three persons exceeded the lab's threshold reference range. No participant exceeded the lab's toxicity levels of 100 µg/g creatinine
Nickel in hair	97	0.64	0.39[4]	NA	--	

1 Nondetectable samples were handled in different ways for various averages. For aluminum, 35 missing values were replaced by 1, which is the minimum concentration expected in a population. For cadmium in urine, 64 values were replaced by a value, although the actual value was not stated in the report. For uranium, the average consists of just the six samples with detectable concentrations. A low percent detection indicates that many people had nondetectable levels, thus the mean of the detectable levels is uncertain

2 NHANES National Survey, 2003-2004. This 2-year period was chosen because Phase I of the PRDOH study was conducted in May 2004.

3 PRDOH 2006 report. Levels reported by Poison Line of Puerto Rico

4 PRDOH 2006 report, source not identified

5 Source = Quest Laboratories

6 Source = 1999-2002 NHANES

7 $bmdl_{05,}$ Source = U.S.EPA (IRIS, Methylmercury)

8 The value 0.307 ug/L could not be confirmed from NHANES

NA = not available

Aluminum: The geometric mean blood aluminum was 17.6 µg/L (95% CI 17.02–18.34); Quest Laboratories reported, however, the detection limit for aluminum in blood was 10 µg/L. Because the PRDOH manuscript reported using 1 µg/L for 35 nondetectable levels, some uncertainty exists in the geometric mean of 17.6 µg/L. The PRDOH manuscript reported using a geometric mean for aluminum in blood in the United States of 1 to 4 µg/L, which was provided by the Poison Line of Puerto Rico. Twenty-two percent (109 persons) showed levels of 40 µg/L or greater—the laboratory's upper threshold level of the reference range for a population. Two percent (10 persons) had levels greater than 60 µg/L, the laboratory's toxicity threshold. Persons between the ages of 20 and 44 were five times more likely to have aluminum levels above 40 µg/L than those 65 and older (PRR=4.99, $p<0.05$). Medicines and occupation were not identified as possible sources.

Lead: The geometric mean blood lead level for all ages in the study population was 3.53 µg/dL compared with the geometric mean of 1.66 µg/dL from the 1999-2000 NHANES survey (as reported in the PRDOH manuscript) and 1.42 µg/dL from the 2003-2004 NHANES survey. In addition, 16% (81/500) of participants (all ages) had blood lead levels greater than 5 µg/dL compared with 5% from NHANES. Older participants (46–64 years and 65+) were more likely to have levels greater than 5 µg/dL than were the youngest age group tested (5 to 19 years). Participants who worked with metals and with petroleum-derived products, and those lacking a water purification system were more likely to have elevated blood lead levels. For example, the following occupations or hobbies showed a high prevalence risk ratio for elevated blood lead levels: car/truck maintenance, electrical repair, metal work, solvent use, petroleum product use, or metal use. Smokers and participants who consumed seafood within 3 days of the test showed a higher probability of elevated blood lead levels. The PRDOH manuscript stated, however, that smoking did not account for all participants with elevated blood lead levels. This conclusion is supported by the observation that the geometric mean of blood lead levels for nonsmokers was twice the national average. ATSDR agrees with this conclusion.

Mercury: A comparison of average blood mercury levels in Vieques residents to other populations is not reliable—the detection limit for mercury in blood was too high (i.e., 5 µg/L). The NHANES survey finds the average blood mercury level for the U.S. population is 1 µg/L. But coastal populations have higher fish intake and a higher frequency of women with elevated blood mercury levels compared with the national average and inland areas. For example, 8% of women in coastal areas have blood mercury levels greater than 5.8 µg/L compared with 2% of women from inland areas (Mahaffey 2009). Interestingly, Mahaffey reported blood mercury levels by race/ethnicity as well: almost 16% of women whose ancestry is Asian, Native American, Pacific Islands, and the Caribbean Islands have blood mercury greater than 5.8 µg/L. The highest blood level detected in the PRDOH study was 13 µg/L.

To provide perspective, U.S.EPA estimated a benchmark-dose, lower confidence limit of a 5% ($BMDL_{05}$) adverse response rate in fetal development. U.S.EPA identified the $BMDL_{05}$ cord blood mercury level in women to be between 46–79 µg/L (USEPA 2009). U.S.EPA derived this range of blood mercury levels using human data from the Faroe Islands fish-eating study and the agency's benchmark dose methods (USEPA 2009). U.S.EPA's values are similar to those derived by the National Academy of Sciences' (NAS) Committee on the Toxicological Effects of Methymercury. Using a similar benchmark dose approach, the NAS identified the 5% adverse effect level (i.e., a benchmark dose, BMD) at 85 µg/L as a cord blood mercury level and estimated a 5% lower confidence limit of 58 µg/L ($BMDL_{05}$). NAS stated that corresponding values in hair result in a benchmark dose of 17 ppm and $BMDL_{05}$ of 12 ppm (NRC 2000).

Arsenic: The PRDOH manuscript stated that the geometric mean for arsenic in urine was below what was expected (see Table 3A-2, 33.6 vs. 38.2 µg/L). The report did not state the source of the reference levels. The geometric mean of the study population is higher than the geometric mean from the 2003-2004 NHANES survey (33.6 vs. 8.3 µg/L. Total urine arsenic levels were above 50 µg/L in 25% of the participants (i.e., 117/473). The median age of participants with levels greater than 50 µg/L was 50 years (range = 5 to 90 years). The PRDOH manuscript stated that risk factors associated with elevated urine arsenic were the age groups 45–64 and over 65, smokers, seafood eaters, seafood consumption within 3 days of the test, regular contact with animals, and those who worked with metals.

Still, the urine arsenic test did not distinguish between inorganic arsenic and organic arsenic. When people eat fish a few days before providing a urine sample, nonharmful organic arsenic arsenobetaine is often found in urine at high levels. Freshwater and saltwater fish contain the organic arsenicals, arsenobetaine, and to a much lesser extent, arsenocholine.

Whenever total arsenic levels exceed 50 µg/L and people eat fish, the high levels of total arsenic are probably the result of measuring arsenobetaine and arsenocholine and thus do not indicate toxicity (Caldwell et al. 2009). Arsenobetaine and arsenocholine are excreted very quickly through the kidneys without being metabolized and are relatively nontoxic to humans. Some shellfish contain small amounts of inorganic arsenic in addition to organic arsenic; consequently, the arsenic levels reported in the PRDOH study are likely to be mostly organic arsenic with some inorganic arsenic

The PRDOH report stated that 267 participants did not eat seafood and that 39 of these participants had urine total arsenic levels above 50 µg/L. This result points to another source of arsenic, or it points to dietary recall problems. Other dietary sources of arsenic in the human diet include chicken as well as rice, particularly when rice is grown in arsenic-contaminated soils (Lasky et al. 2004; Potera 2007; Williams et al. 2007).

Uranium: Six of the 500 participants had detectable levels of uranium in urine. The geometric mean uranium level in urine in these six participants was 0.14 µg/L, which is greater than the 2003-2004 NHANES geometric mean of 0.008 µg/L and the 95^{th} percentile of 0.031 µg/L. All six participants are women, and five were not employed when interviewed. The median age was 57. No uranium levels exceeded Quest Laboratories' threshold level or toxic level. The source of uranium is unknown.

Cadmium: The geometric-mean hair-cadmium level in the study population (n=429) was 0.14 ppm. The PRDOH report states that this value is similar to its reference value of less than 0.15 ppm. But the report does not identify the source of the reference value of less than 0.15 ppm. In any event, no participant exceeded Quest Laboratories' hair toxicity threshold of 3.4 ppm.

The PRDOH report stated that the geometric mean cadmium level in urine in the study population was higher than the 1999-2000 NHANES geometric mean (0.43 vs. 0.31 µg/g). Because of interference from molybdenum oxide, CDC has since corrected the 1999-2000 NHANES value. The corrected geometric mean from the 1999-2000 NHANES is 0.181 µg/g. The geometric mean from the 2003-2004 NHANES is 0.21 µg/g. Eleven participants had cadmium urine levels above 1.03 ug/g, the 95th percentile from the 1999-2000 NHANES (uncorrected for molybdenum oxide). Two participants showed urine cadmium levels above the laboratory's toxic level of 2 µg/g creatinine. OSHA's worker action level is 3 µg/g creatinine. The median age for participants with urine cadmium levels above 1.03 µg/g creatinine was 55. Smokers showed urine cadmium levels five times higher than did nonsmokers.

Nickel: Participants' geometric mean nickel levels in urine (2.05 µg/g creatinine) was similar to the reference value (less than 2 µg/g creatinine). The report does not identify the source of the reference value. Three participants (2 women and 1 man) had urine nickel levels that exceeded Quest Laboratories' threshold of 6.2 µg/g creatinine in women and 10.2 µg/g creatinine in men. No urine nickel levels exceeded the Quest Laboratories' 100 µg/g- creatinine toxicity threshold.

The geometric mean for hair-nickel levels in participants (0.64 ppm) was much greater than the reference level (0.39 ppm) reported in the PRDOH manuscript. The PRDOH manuscript did not identify the source of this reference level. Sixty-three participants had hair nickel levels exceeding the laboratory's 2-ppm threshold level. Of these, 80% were women. In addition, participants in age groups 5–19 and 20–44 showed higher levels than did persons over 65 years. Risk factors associated with higher nickel hair levels included dyed hair, colorants and pigments use, and solvent use. Most of the elevated nickel levels in hair were probably from external contact via hair treatment.

3.7.2.2. PRDOH Discussion of Phase 1

At the total population level, the average concentration of some metals was above expected norms as established by Quest Laboratories (i.e., the laboratory's reference value) but the average concentrations for the population were not above toxic levels as also stated by Quest Laboratories. The PRDOH manuscript stated that this suggests the need for further investigation concerning the various risk factors, with particular emphasis on how smoking contributes to metal body burden. In addition, a better understanding is needed for how fish consumption affects metal body burdens, especially for arsenic and mercury. The PRDOH manuscript stated that eating fish within 3 days of a test or smoking could partly explain some but not all of the elevated metal body burdens in participants. The PRDOH manuscript stated that smoking was associated with lead in blood, and arsenic and cadmium in urine. In addition, seafood consumption was associated with mercury in blood, and arsenic in hair and urine.

The PRDOH manuscript pointed out that the percentage of people with high metal levels who were neither exposed to tobacco smoke nor exposed from eating seafood was still greater than expected. For example, the PRDOH manuscript stated that 10% of nonsmokers had urine cadmium levels above 5 µg cadmium per gram creatinine where only 5% was expected. The PRDOH report did not clarify whether these nonsmokers lived with smokers. Using information from the survey, the PRDOH manuscript identified factors or sources that were associated with elevated metals. These factors or sources include age, sex, hair dyes, and years living on Vieques, and soil contact, as well as working with petroleum products, solvents, metals, or animals. Table 9 from the PRDOH manuscript provides information about the estimated number of residents with elevated levels of metals in residents' blood, urine, or hair.

The PRDOH manuscript stated the following:

- Being an adult between the ages of 20 to 65 was associated with higher aluminum levels in blood.
- Being an adult over age 61 and working with animals was associated with higher arsenic in urine.
- Working with petroleum products was associated with higher blood lead levels.
- Contacting the earth's crust and working with solvents was associated with higher cadmium in urine.
- Being a female; dying hair; using colorants, pigments, and solvents; and years living in Vieques was associated with higher nickel in hair.

What follows is Table 9 from the PRDOH manuscript.

Table 9 from Heavy Metal Prevalence Study, Vieques, 2004

Table 9. Summary of heavy metal findings; estimate of persons affected in the population and their possible exposure factors, Heavy Metal Prevalence Study, Vieques, 2004.

METAL	Prevalence n (%)	Estimate of Persons with Above-Normal Levels in the Community Universe=9,106	Exposure
Aluminum in Blood	23(4.6)	419	Age 20-65
Lead in Blood	6 (1.2)	109	Petroleum products Smoking
Mercury in Blood	7 (1.4)	127	Consumption of fish
Arsenic in Urine	117 (23.4)	2.130	Older than age 61 Smoking Consumption of fish Working with animals Use of metals
Cadmium in Urine	22 (4.4)	401	Earth's crust Work with solvents Smokes > 10 cigarettes per day
Nickel in Urine	3 (0.60)	55	-
Uranium in Urine	6 (1.2)	109	-
Arsenic in Hair	1 (0.23)	21	Consumption of fish
Cadmium in hair	0	0	-
Nickel in hair	63 (12.7)	1,154	Female Hair dying Use of colorants and pigments Solvents Years living in Vieques

The PRDOH manuscript stated that further research was needed to understand how metal body burden in Vieques residents compared with Puerto Rico. In addition, research was needed concerning the possible long-term effects of high body burdens of metals in some Viequenses.

At the individual level, the PRDOH manuscript stated that according to Quest Laboratories, 15 persons showed toxic levels of metals:

- 10 had toxic levels of aluminum in the blood,
- Two had toxic levels of blood lead,
- Two had toxic levels of cadmium in the urine, and
- One had toxic levels of mercury in blood.

Quest recommended follow-up tests and medical examinations for these persons and investigation of their environments for possible metals sources.

It is not clear why the PRDOH manuscript did not include the 117 persons who had arsenic urine levels that exceeded 50 µg/L (see Table 3A-2).

3.7.3. PRDOH Study, Phase 2

In Phase 2, from December 2005 to March 2006, the PRDOH study undertook follow-up activities on 15 adults whose metal body burdens exceeded toxicity levels as identified by Quest Laboratories. Ten of 15 agreed to participate. Blood samples were collected and measured for aluminum (6 persons), arsenic (3 persons), lead (2 persons), and mercury (1 person)[18]. Arsenic blood tests included inorganic arsenic. Why the PRDOH study did not test urinary cadmium in the two persons with elevated urinary cadmium in Phase 1 is not clear. Why the PRDOH study did not measure speciated urinary arsenic in the 117 persons with elevated urinary arsenic in Phase 1 is similarly unclear. LabCorp conducted the tests and provided the reference levels.

Of the six persons in Phase 1 with elevated aluminum in blood who agreed to retesting, none were elevated in Phase 2. Similarly, the one person with elevated blood mercury in Phase 1 was not elevated in Phase 2. Of the two participants from Phase 1 with elevated blood lead levels, one was elevated in Phase 2. The PRDOH manuscript stated that a follow-up investigation of the home environment for this person would take place. Table 3A-3 shows the results of Phase 2, although because of confidentiality issues, the PRDOH manuscript did not report the specific values.

In addition to the 10 persons who participated in Phase 2 because they had high metal levels, the PRDOH manuscript included four additional residents who were not part of Phase I. These four residents volunteered for blood tests because they were interested in being tested. The PRDOH manuscript provides their results in the report but states that none showed levels considered potentially toxic.

[18] Note that the number of tests is 12—some persons were apparently tested for more than one metal.

Table 3A-3. PRDOH biomonitoring study Phase 2 biomonitoring results for 10 persons

Metal (Blood Samples)	*Reference Threshold Level*	*NHANES (4th Report)*		*Number of Persons Above Toxicity Level, Phase 1*	*Number of Persons Above Toxicity Level Phase 2*
		Geometric Mean	**95th Percentile**		
Aluminum	0 – 9 µg/L	Not measured	Not measured	6	0
Total Arsenic	< 50+ µg/L	Not measured	Not measured	3	2
Inorganic Arsenic	0 – 19 µg/L	Not measured	Not measured	Not available	0/3
Lead	0 – 19 µg/dL	1.2 µg/dL	3.7 µg/dL	2	1 (Class III)
Mercury	0 – 14.9 µg/L	0.77 µg/L	4.6 µg/L	1	0

+ Table 1 (Phase II) in the PRDOH report is the source of the Reference Threshold Levels reported in Table 3A-3. The value of 50 µg/L appears to be a mistake as this level is often used for total urinary arsenic.

3.7.4. PRDOH Findings

The PRDOH manuscript reported that the main findings of this study were

- In over 90% of the population, detectable levels were found of at least one heavy metal.
- In more than 20% of the study participants, the levels of aluminum in blood, arsenic in urine, or nickel in hair were over the laboratory reference threshold.
- Geometric means for uranium in urine, mercury in blood, lead in blood, aluminum in blood, nickel in hair, and cadmium in urine were significantly higher than the geometric means from the 1999 NHANES survey. But the geometric means for mercury and aluminum in blood reported in the PRDOH manuscript were unreliable because of the high detection limit reported by the laboratory.
- None of the identified geometric means were over the toxicity threshold identified by the reporting laboratory.
- Cigarette use, hair dye use, and seafood consumption were identified as risk factors for levels above the laboratory threshold for arsenic, cadmium, and nickel.
- Fifteen persons (3%) were identified with levels above the toxicity threshold for aluminum in blood (10 persons), lead in blood (2 persons), mercury in blood (1 person), and cadmium in urine (2 persons).
- In the follow-up study on 10 persons with metal body burdens that exceeded toxicity levels, only one person with levels above the toxicity threshold was identified.
- Fewer than 4% of the participants showed elevated metal levels associated with possible development of signs and symptoms related to acute exposure. Among the metals studied, levels of aluminum in blood, nickel in hair, and arsenic in urine were reported with the greatest

frequency as over the laboratory detection reference threshold. But the test for arsenic measured total arsenic, which includes nontoxic forms of arsenic from eating seafood (i.e., arsenobetaine and arsenocholine).

Multiple factors might account for these observations of elevated metals in blood, hair, and urine. For example, aluminum is abundant in soil worldwide. Average aluminum levels in LIA soils is 16,200 ppm compared with average aluminum in U.S. soils of 57,000 ppm. The absence of reference populations from Puerto Rico or information about aluminum levels in soils in Viequense residential areas limits interpretation of the aluminum results. The PRDOH manuscript also evaluated possible risk factors associated with elevated metal levels below the laboratory's toxicity level—significant risk factors were in fact found. The PRDOH manuscript, however, points out that the study did not consider possible risk factors such as exposures from explosives, armaments, use of metal cooking utensils, metal residues that might be in foods such as tea and vegetables, consumption of drinks with metallic packaging, antacid formulations, and antiperspirants.

In Phase 1, the PRDOH study measured total arsenic in urine, which consists of inorganic and organic arsenic. Because high levels of nontoxic organic arsenic are likely from seafood consumption, in Phase 2 the PRDOH study measured total and inorganic arsenic for the three persons who had elevated total arsenic in Phase 1. No evidence of inorganic arsenic was found. The PRDOH manuscript pointed out that hair arsenic levels in the study participants were similar to the national average.

Nickel levels in urine in the study participants were similar to the national average. Sixty-three (63) persons had nickel levels in hair above the laboratory reference threshold. Hair dye, used by 27 of these 63 persons (43%), and the use of colorants and solvents were identified as risk factors and thus possible sources of the nickel in hair. The PRDOH manuscript mentioned hair analysis's inability to provide information about internal (i.e., ingestion) exposure versus external contact with metals (except for mercury). In addition, nickel measurements in hair do not predict that exposure will produce adverse health effects.

The PRDOH manuscript also said the geometric means for aluminum (blood), mercury (blood), lead (blood), uranium (urine), cadmium (urine), and nickel (hair) were higher than the national average (using NHANES and other reference sources); average levels, however, were not above toxicity levels cited by Quest Laboratories. The PRDOH manuscript identified three factors associated with increased arsenic, cadmium, and nickel in hair, urine, or blood: cigarettes , hair dye , and fish consumption. At the time of the study, seventy (15%) participants self-reported as smokers. Elevated lead levels were 4.75% more likely in smokers, who were also nearly two times as likely to have elevated levels of arsenic and nickel. The PRDOH manuscript added that the percentage of people with elevated levels of these metals who were not exposed to cigarette use or consumption of seafood was still higher than expected.

The study design attempted to use a stratified random sample of Viequenses who would represent the island's population. But the PRDOH manuscript acknowledged the sample had a higher percentage of women, older persons, and the unemployed compared with the island's population. The PRDOH manuscript said this might have been due to interviews conducted during the day. Nevertheless, the

PRDOH study may have underrepresented fishers and island residents who worked during the day. The PRDOH manuscript agreed that the difference between the study population characteristics and the island characteristics limited generalizations of the data to all island residents.

The PRDOH manuscript also acknowledged that some of the tests failed to distinguish between the different forms of a metal. As mentioned previously, urine arsenic tests in Phase 1 failed to distinguish inorganic from organic arsenic. This also was the case for mercury. For uranium, laboratory tests failed to distinguish between natural uranium and depleted uranium.

3.7.5. PRDOH Actions Taken After Phase 1 and Phase 2

After completion of Phase 1, the following actions were taken:

- Dr. Luis Santiago gave a presentation of preliminary results to a group of about 15 Vieques community leaders.
- Participants' results were provided to Dr. Mackenzie at the Vieques clinic. Of the 500 participants, 182 collected their results.
- Dr. Braulio Jimenez, a toxicologist with the University of Puerto Rico, gave three talks in Vieques about the signs and symptoms associated with exposure to heavy metals.
- A Phase 2 sampling was conducted to follow up on residents with toxic levels of metals.
- A working group was formed to analyze the studies conducted by the health department. This group came up with the suggestions for continuity and follow-up activities listed here.

3.7.6. PRDOH's Suggested Follow-up Activities

The PRDOH manuscript suggested follow up with

- People identified with toxic levels of heavy metals,
- People with possible acute exposure to heavy metals,
- People with possible chronic exposure to heavy metals, and
- High-risk groups.

The PRDOH study used the CDC-provided recommendations to decide follow-up activities for the one remaining person with elevated blood lead levels after Phase 2 testing (CDC 1997; CDC 2002). The PRDOH study offered additional urine arsenic tests for those people who had elevated total urine arsenic in Phase 1. The follow-up tests measured inorganic arsenic. Inorganic arsenic levels in urine were within the laboratory reference levels (PRDOH 2006).

3.7.6.1. Follow up for people with possible acute exposure to heavy metals

The PRDOH manuscript stated that a protocol will be developed for the management of persons with suspected acute poisoning of heavy metals using CDC guidelines as a basis (CDC 1997; CDC 2002). It should be noted that CDC guidelines apply only to lead. The protocol will contain 1) training of local health care providers, 2) ways to promote additional testing using the Commonwealth's laboratory, 3) use of the poison center to provide recommendations for managing acute exposure victims, and 4) referral of suspected cases to the Medical Center of Puerto Rico.

3.7.6.2. Follow up for people with possible chronic exposure to heavy metals

The PRDOH manuscript suggested establishing a voluntary health registry for Vieques residents. A health registry would 1) allow for systematic documentation of factors related to potential risks, 2) identify people with early signs and symptoms that may be associated with illness, and 3) facilitate early care and health service access needs. The registry would gather demographic information, risk history, family history, past illness history, present status, and history of signs and symptoms associated with the chronic heavy metal exposure. A health registry could also provide comprehensive medical evaluations that include physical examinations with, among other tests, neurological examination and laboratory tests, including tests for kidney function, liver function, and CBC.

3.7.6.3. Follow up with a monitoring program for children under 6 years of age

Blood lead levels are unknown for the 1,000 Vieques children 6 years of age and younger—a high-risk group more vulnerable to lead exposure than are adults. This initial evaluation proposed in the PRDOH manuscript will include all children 6 years of age and younger and will subsequently incorporate in future years an evaluation of children 1 and 2 years of age as part of their primary care. In 2006, when the report was written, the PRDOH manuscript stated that an epidemiologist would be appointed to work towards establishing this program, and this program will follow CDC guidelines for case management (PRDOH 2006).

With funding from USEPA, PRDOH and CDC are currently conducting a prevalence study of blood lead levels in 1 to 5 year old children from mainland Puerto Rico.

3.7.7. Investigations by Dr. Carmen Ortiz Roque

Dr. Carmen Ortiz Roque is a physician who has treated patients and conducted investigations on Vieques. In 2000, she began collecting hair samples from residents and had the samples analyzed for various metals. She has reported some of her results in unpublished manuscripts. In 2004 she published one peer-reviewed journal article.

3.7.7.1. Summary of Dr. Ortiz Roque's 2004 Journal Article

In 2004, Dr. Ortiz Roque published the mercury data from her 2000/2001 hair study of Vieques residents (Ortiz Roque 2004). The study investigated hair mercury levels in women 16 to 49 years of age who lived on the island of Vieques and compared those levels with women from San Juan and Ceiba, Puerto Rico. Women with chemically treated hair within 3 months of the test were excluded. One of two licensed laboratories analyzed a 1.5-cm proximal hair sample.

Dr. Ortiz Roque reported statistics on 41 Viequense women together with information about seafood consumption and compared these data with mainland Puerto Rico and with results from the 1999 NHANES survey in the United States. Table 3A-4 summarizes her data. Dr. Ortiz Roque used margin of exposure (MOE) to define unsafe exposure levels. The MOE approach used by Dr. Ortiz Roque came from a 2001 MMWR article and the National Research Council. The formula for MOE is 5% effect level for mercury in hair / 90th percentile value for mercury in hair in the study population.

Table 3A-4. Mercury hair results in women published by Dr. Ortiz Roque in 2004.

	#	Age	*Mercury in ppm*			*Margin of Exposure*	*Seafood Consumption*			*% women > RfD*
			Median	*Mean*	*90th Percentile*		*Total*	*Local*	*Local fish*	
Vieques	41	31.8	0.66	4.4	8.96	1.3	4.9	2.9	1.9	26.8
PR	45	29.9	0.38	0.4	1	12	2.8	1.1	0.7	6.6
USA (1999 NHANES)	702	NA	0.2		1.4	8.6	NA	NA	NA	7

The National Research Council (NRC) recommended deriving the 5% effect level from the 95% lower confidence limit of a benchmark dose ($BMDL_{05}$) that resulted in abnormal scores on cognitive function tests in children exposed to methylmercury *in utero*. The NRC recommended that the U.S.EPA derive their Reference Dose using a $BMDL_{05}$ of 58 ppb methylmercury in cord blood, which was identified as the 5% effect level using statistical models from the Faroe Islands study. The 58-ppb cord blood translates to 12 ppm in hair (NRC 2000). Therefore, the MOE = 12 ppm / 90th percentile mercury in hair. A MOE less than 1 means that for 10% of the study population the mercury level in hair is above the 5% effect level of 12 ppm, while an MOE greater than 1 means that for 90% of the study population the mercury level in hair is below the 5% effect level of 12 ppm (Ortiz Roque 2004; MMWR 2001). It is important to note that Dr. Ortiz Roque found three women with hair mercury levels greater than 12 ppm, the level identified by the NAS as an effect level for the developing fetus.

Results showed that the 90th percentile mercury hair concentration in Vieques women was 8.96 ppm compared with 1 ppm in women from Puerto Rico and 1.4 ppm in women from the United States. With a MOE of 1.3, Dr. Ortiz Roque concluded that because hair mercury levels were close to the 5% effect level of 12 ppm, some Viequense women of reproductive age were exposed to mercury concentrations unsafe to their developing fetus. While ATSDR agrees with this conclusion, it should be noted that the percentage of Viequenses women with hair mercury levels above 12 ppm is uncertain because of the small and biased sample size in Dr. Ortiz Roque's investigation.

Dr. Ortiz Roque also has unpublished data showing other metal concentrations in hair of Vieques residents. These data are summarized in Chapter 2.

3.7.8. Summary of Dr. Ortiz Roque 2002 Unpublished Manuscript

3.7.8.1. Study Design

Dr. Carmen Ortiz Roque collected hair samples from 203 Viequenses from January 2000 to July 2001 along with an extensive residential, occupational, nutritional, and health survey. Hair samples were analyzed for mercury, aluminum, cadmium, lead, and arsenic. The group consisted of 110 females and

93 males and ranged in age from 0.8 to 81 years. Participants were distributed among 18 neighborhoods on the island and were later informed of their individual hair results. Scalp hair samples were obtained from most participants. However, when scalp hair was limited or not available or hair was treated chemically, pubic or chest hair was collected (Ortiz 2002). Note that comparing results from pubic hair or chest hair with scalp hair may not be appropriate. Hair analysis were conducted by either the Mayo Medical Laboratory (Rochester, MN) or the King James Medical Laboratory (Cleveland, OH).

3.7.8.2. Hair Study Results

Dr. Ortiz Roque reported the following results concerning metals in hair (Table 3A-5):

Table 3A-5. Results of metal analysis of hair samples collected from Viequenses from January 2000 to July 2001.

Metal (sample number)	***% elevated***	***Average in ppm***			
		Overall (95% CI)	***Females***	***Males***	***Children <10 years old***
Mercury N= 205	33% > 1 ppm	2.07 (0–8.9)	2.87	1.08	1.89
Aluminum N=145	56% > 17 ppm	25.74 (10.52–25.75)	26.45	24.18	34.94
Cadmium N=205	26% > 0.47 ppm	0.65 0–5.0)	0.75	0.55	Not available
Lead N=205	2.9% > 25 ppm	8.07 (0–19.0)	4.28	12.47	Not available
Arsenic N=205	0 > 1 ppm	0.18 (0–3.0)	0.141	0.233	Not available

Dr. Ortiz Roque stated that elevated levels of mercury (33%), aluminum (56%), cadmium (26%), and lead (2.9%) were found in hair samples from residents in Vieques. Hair arsenic levels were not elevated (Ortiz 2002).

Dr. Ortiz Roque provided additional information about hair mercury in women and children, shown in Table 3A-6. She stated that 22% of women and 60% of children sampled in Vieques had mercury levels above the 90th percentile in the United States as identified from the 1999 NHANES national survey (Ortiz 2002). Dr. Ortiz Roque further analyzed a subset of 22 Viequense matched pairs of mothers and their children 5 years of age or less. Dr. Ortiz Roque reported a significant correlation between mercury hair levels in mothers and their children (Pearson's correlation 0.93, p = 0.0001). Dr. Ortiz Roque published these matched pairs in 2003 (see Table 3A-4).

Table 3A-6. Viequense women and children mercury hair analysis compared with United States

Population	*Number*	*% Population Sampled 2000*	*75th percentile ppm hair*	*90th Percentile ppm hair*	*% above 90th percentile for U.S.*
USA Women 16–49 years*	702	702/146,250,000 0.00048%	0.5	1.4	10%
Vieques women	45	45/4,594 0.97%	1.14	7.54	22%
USA Children* 1–5 years	338	338/19,175,798 0.00256%		0.4	10%
Vieques Children 1–5 years	38	38/771 4.9%	1.31	2.67	60%

* Reference ranges were derived from the 1999 NHANES survey

Dr. Ortiz Roque stated that the average aluminum hair concentration for Viequenses was 25.74 ppm. She reported that this concentration exceeded the upper limit of a standard human population, although the manuscript does not report the source of the upper limit. Dr. Ortiz Roque pointed out that aluminum levels in children's hair was higher than in adults (Ortiz 2002). As stated previously, it is not possible to determine whether elevated levels of aluminum, cadmium, and lead in hair are from internal exposure via ingestion or inhalation or external exposure from direct contact of the hair with a metal-containing commercial product. While Dr. Ortiz Roque's data show that these metals are elevated in Viequenses at the 75th and 90th percentile, her population was not chosen randomly from the Vieques population. This nonrandom participant selection might account for some confounding factor elevating the rates. And for other metals, the nonrandom sample might account for the lower than expected metal concentrations.

3.7.8.3. Dr. Ortiz Roque's Conclusions

Dr. Ortiz Roque maintained her data showed that Viequenses had internal exposure to heavy metals, supported by the high percentage of women and children with hair mercury levels above the 90th percentile compared with the continental United States. While none of the women in the 1999 NHANES survey had mercury hair levels above 12 ppm, 3 of 45 Viequense women had hair levels above 12 ppm in Dr. Ortiz Roque's survey (i.e., 15.41, 25.26, and 101.3 ppm) (Ortiz 2002).

In her 2002 draft manuscript, Dr. Ortiz Roque stated further that the positive correlation between mother and offspring hair showed that mercury exposure was occurring *in utero;* Viequenses' exposure to mercury was too high to be considered safe; and mercury was used in explosive ordnance detonators (Ortiz 2002). The correlation between mother and offspring hair with seafood consumption is expected, has been shown in numerous human studies, and points to seafood as a major source of mercury in humans. The correlation of hair mercury levels in mother and children is not conclusive proof that these children were exposed *in utero*. A study of mothers and newborns would be needed to make that statement conclusively. Assuming that mothers maintained similar fish-eating habits before and during their pregnancy, the positive hair mercury correlation between mother and offspring suggests that *in utero* exposure to mercury occurred and could occur in future pregnancies. While Dr. Ortiz Roque's patients were not selected randomly, identifying several women with very high hair mercury levels is an important finding.

3.7.9. Investigations by Dr. Carmen Colón de Jorge

Dr. Carmen Colón de Jorge also conducted human biomonitoring of metals in hair and in addition analyzed several stool samples for metals. Dr. Colón de Jorge collected hair and stool samples from Vieques residents in 1999 and 2000 and wrote a manuscript describing her results and findings (Colón de Jorge, no date).

Dr. Carmen Colón de Jorge began her manuscript by describing the case history of one of her patients who lived on Vieques. A 1991 hair analysis in a sick patient showed toxic levels[19] of lead and aluminum according to the reporting laboratory. The patient was treated using naturopathic remedies, and the patient's health improved. The patient was tested again in 1993 and again in 1996 because the patient was again sick. The hair tests showed high levels of lead, aluminum, and antimony. Arsenic and mercury were also present in hair. In 1999, toxic levels of aluminum, antimony, arsenic, and mercury were much higher as well, now showing toxic levels of cadmium and bismuth. The patient also had low levels of zinc and selenium and increased boron. Dr. Colón de Jorge stated the low levels of zinc and selenium confirmed endogenous poisoning with heavy metals. Representing the Scientific Committee of the Association of Licensed Naturopaths of Puerto Rico, Dr. Colón de Jorge collected hair and stool samples from Vieques residents in 1999 and 2000. She stated that the nutritional imbalance in residents as shown by hair analysis was evidenced by deficiencies in calcium, phosphorus, and magnesium and excessive boron in hair. She further stated that the decline in selenium, resulting from heavy metal contamination, was a contributor to cancer development.

3.7.9.1. Dr. Colón de Jorge's Conclusions

Dr. Colón de Jorge stated that 45–50% of the people tested in Vieques were poisoned with mercury. Using results from stool samples, she found that 3 out of 6 children tested in Vieques had metal concentrations in stools[20] above the reference range provided by the clinical laboratory (i.e., Doctor's Data) that conducted the tests. She also reported that 5 out of 6 children tested had antimony and arsenic in stool samples that exceeded the laboratory's reference range. She pointed out that children

[19] Dr. Colón de Jorge's manuscript does not provide a definition for toxic level. Apparently Dr. Colón de Jorge used the term "toxic level" because it is used in the laboratory report provided by Doctor's Data for potentially toxic elements. Although Doctor's Data, Inc. also provides no "toxic level" definition, it appears to be any level above the 95th percentile and is based on the laboratory's observation of over 1 million hair samples.

[20] Determination of metals in stools samples is not a standardized or recommended means of determining exposure.

could not be exposed to metals in paint, cigarette paper, tobacco, old pots, make-up, and hair dye as adults might be.[21] Uranium levels in children's stool samples were below the reference range established by the laboratory.

Dr. Colón de Jorge reported that 30 hair samples were collected from Vieques residents with various health conditions:

- 50% of the people tested were contaminated with antimony compared with 29% from a control population,
- 50% of the people tested were contaminated with arsenic compared with 29% from a control population,
- 50% of the people tested had a selenium imbalance.
- Dr. Colón de Jorge pointed out that antimony levels were high because antimony was used in explosive ordnance on Vieques, thus making the case that military exercises were the reason antimony levels were high. No supporting evidence, however, was provided to show how residents were exposed.
- Dr. Colón de Jorge also summarized the results of seven control patients with the following statements:
    - None of the seven patients showed toxic levels.
    - Two cases had antimony above the reference range established by the laboratory compared with 29% of those investigated outside of Vieques. The selenium was normal for exogenous contamination.
    - Two cases had arsenic above the reference range compared with 29% of the cases outside Vieques. The selenium is normal for exogenous contamination.
    - The seven control patients exhibited no endogenous contamination with heavy metals—the selenium was normal and within the reference range. According to Dr. Colón de Jorge, heavy metal contamination in a patient will often result in lower levels of selenium.

In summary, Dr. Colón de Jorge collected hair samples from seven random persons in Rio Piedras, a community on the main island of Puerto Rico. These persons' health status remains unknown. None of the results show toxic levels of heavy metals, while 21 of 30 persons (i.e., 63%) from Vieques with known health conditions—and thus not randomly selected—showed toxic levels of various metals. As stated previously, current science is simply incapable of determining whether elevated levels of these metals in hair is from internal exposure via ingestion or inhalation, from external exposure via direct contact of the hair with a metal-containing commercial product, or due to accumulation secondary to an

[21] Note, however, that children can be exposed to lead in paint when they contact painted surfaces such as walls, doors, windows, stairs, and fences.

underlying disease. The exception is that current science can determine whether mercury in hair is from internal or external exposure.

Dr. Colón de Jorge provided a report section that described the relationship between metal toxicities, which can cause mineral deficiencies and excesses, and the risk of various diseases and health conditions. This relationship, or risk pattern, is described for 1) cardiac conditions, 2) cardiovascular, 3) emotional disturbances, 4) violence 5) poor absorption, and 6) cancer.

3.7.9.2. Sample Results and Interpretation

Dr. Colón de Jorge summarized elemental levels in hair (Table 3A-7) and in stool samples (Table 3A-8). Dr. Colón de Jorge's report contained several appendices with additional information, mostly focused on how to evaluate and interpret elemental results in hair. One of the appendices contained a report by Doctor's Data entitled Comprehensive Interpretations for Hair Elements from Al to Zn.

Table 3A-7. Summary of hair analysis of 30 samples as reported in Dr. Colón de Jorge's unpublished (Colón de Jorge undated).

Metal	***Range of levels in Dr. Colón de Jorge's patients in µg/g***	**Reference Range in Dr. Colón de Jorge's manuscript***	***Percent above reference***	***Percent below reference***
Aluminum	4.4 – 68	<7	90	
Antimony	0.016 – 2.7	<0.05	69	
Arsenic	0.028 – 2.8	<0.06	66	
Barium	0.23 – 4.7	0.026 – 3; 0.16 – 1.6	14 21	3
Beryllium	<0.001	<0.02	0	
Bismuth	0.011 – 2.4	<0.06; <0.1	48 41	
Boron	0.42 – 19	0.3 - 2 0.4 - 3	41 48	0
Calcium	145-2240	300 - 1200 200 - 750	17 24	24
Cadmium	0.024 – 0.98	<0.1 0.15	69 52	3
Zinc	64-630	140 - 220 130 - 200	21 24	28 14
Zirconium	0.012 - 0.76	0.02 - 0.42 0.02 - 0.44	7 7	3 0
Cobalt	0.008 – 0.16	0.013 - 0.05 0.013 - 0.035	14 28	21
Copper	8.9 – 110	12 - 35 10 - 28	31 35	21 3
Chromium	0.2 – 0.69	0.2-0.4	10	0
Tin	0.08 – 1.3	<0.3	66	

Metal	***Range of levels in Dr. Colón de Jorge's patients in µg/g***	**Reference Range in Dr. Colón de Jorge's manuscript***	***Percent above reference***	***Percent below reference***
Strontium	0.29 – 9	0.5 - 7.6 0.3 - 3.5	7 28	17 3
Germanium	0.022 – 0.082 (12 N/A)	0.045 - 0.0.65 (sic)	18	77
Iron	6.4 – 70	5.4 - 14 5.4 - 13	52 62	0
Lithium	0.005 – 0.056	0.007 - 0.023	7	66
Magnesium	23 – 560	35 - 120 25 - 75	31 52	21 3
Manganese	0.21 – 4.8	0.15 - 0.65	31	0
Mercury	0.06 – 3.1	<1.1	38	
Molybdenum	0.02-0.12		48 31	10 3
Nickel	0.05 - 2.9	<0.4	28	
Silver	0.01 - 1.7	<0.14; <0.12	21 35	
Platinum	<0.003	 <0.005	0	
Lead	0.34 – 26	 <0.1;<2	55 35	
Rubidium	0.018 – 0.38	 0.007 – 0.096; 0.11 – 0.12	28 24	0 0
Selenium	0.52 – 2.5	 0.95 – 1.7	3	
Thallium	<0.001 – 0.005	<0.01	0	

Metal	***Range of levels in Dr. Colón de Jorge's patients in µg/g***	**Reference Range in Dr. Colón de Jorge's manuscript***	***Percent above reference***	***Percent below reference***
Thorium	<0.001	<0.005	0	
Uranium	<0.001 – 0.021	(<0.06)	0	
Vanadium	0.013 – 1.2	(0.018 – 0.065)	38	3

* Reference values provided by Doctor's Data, Inc., St. Charles, IL. For several elements, the laboratory reported two reference ranges on different samples.

Table 3A-8. Summary of the results of feces analysis as reported in Dr. Colón de Jorge unpublished manuscript (Colón de Jorge undated).

Metal	***Range in Dr. Colón de Jorge's patients in µg/g (Reference range)***	***Reference Range****	***Percent above reference***	***Percent below reference***
Aluminum	43-750	130	57	42
Antimony	0.06 – 0.127	NA	83	16
Arsenic	0.098 – 0.866	NA	83	16
Beryllium	0.01 – 0.012 (2 < dl) *	NA	50	50
Bismuth	0.014 – 0.55	NA	50	50
Cadmium	0.14 – 1	0.47	14	86
Copper	17 – 68	50	14	86
Mercury	0.028 – 0.1 (0.02 with no amalgam) (0.26 with amalgam)	0.02 with no amalgam 0.26 with amalgam	100 0	0 100
Nickel	3.4 – 7.5 (4.4)	4.4	86	14
Platinum	2.92 (6< dl) [a]	NA	16	84
Lead	0.23 – 0.59	0.75	30	100
Thallium	0.005 – 0.015	NA	0	100
Tungsten	0.014 –0 0.475	NA	50	50
Uranium	0.025 – 0.061	NA	0	100

*Reference values provided by Doctor's Data, Inc., St. Charles, IL.

dl = detection limit

NA = not available

3.7.10. Investigations by Dr. Carlos Rodríguez Sierra

On October 30, 2009, Dr. Carlos Rodríguez Sierra gave a presentation at Casa Pueblo de Ajuntas that was broadcast via the Internet. Dr. Rodríguez Sierra discussed arsenic in fish and biomonitoring data concerning urine arsenic levels in Viequenses. Among the 162 fish from 8 species that he collected, he said only arsenic exceeded the international criterion of 2 µg arsenic per gram fish wet weight.

In July 2006, he also collected biological samples from 52 adults, whom he divided into two groups: a high fish-consumption group (n=30) and a low fish-consumption group (n=22). He collected hair, nail, and urine samples. Urine samples were measured for total arsenic and for various arsenic species:

- Trivalent arsenic (As III)
- Pentavalent arsenic (As V)
- Monomethylarsensonic acid (MMA),
- Dimethylarsenonic acid (DMA), and
- Arsenobetaine.

The inorganic arsenic species are AsIII and AsV and their organic metabolites (MMA and DMA). The following data were presented:

	Minimum	***Median***	***75th***	***95th***	***max[22]***
Total As	5.33	22.54	33.7	161.69	1414
Arsenobetaine ug/g creatinine	0	7.64	22.26	141.63	1373

Total inorganic arsenic was compared with the 2003-2004 NHANES results of the U.S. population:

	N	***Median***	***95th***
Vieques	52	10.3	35.3
NHANES	2557	6.0	18.9

Dr. Rodríguez Sierra announced these conclusions from his analysis of arsenic in residents of Vieques:

1. High levels of arsenic in hair, nails, and urine were not detected at the time of sampling
   a. Hair and nail sample levels were below the reference values of 1 ug/g,
   b. The sum of the inorganic arsenic species and its metabolites was less than 50 ug/g creatinine, which was used as a reference value.
2. Levels of inorganic arsenic in urine samples from Vieques are slightly above the median and 95th percentile levels reported in 2003–2004 NHANES.

Dr. Rodríguez Sierra has informed ATSDR that he plans to publish these data in 2011; more complete information should then become available.

[22] ATSDR is unsure of the maximum level of total arsenic and arsenobetaine reported during Dr. Rodríguez Sierra's presentation.

3.8. Appendix 3-B. Biomonitoring

The NHANES Fourth National Report on Human Exposure to Environmental Chemicals (The 4th Report) provides biomonitoring data for the U.S. population for the years 1999–2004. The 4th Report also provides geometric mean, 50th, 75th, 90th, 95th percentile as well as statistics by the following age groups, sex, race, and ethnicity:

- 6–11
- 12–19
- 20 years of age and older
- Mexican-American
- Non-Hispanic blacks
- Non-Hispanic whites

The 4th Report contains toxicological information about metals when available. The report is now available at: http://www.cdc.gov/exposurereport. The 4th Report also contains summary statistics from previous NHANES surveys that cover 1999–2000 and 2001–2002. Table 3B-1 provides a brief summary of statistics (CDC 2009).

Table 3B-1. Fourth National Report on Human Exposure to Environmental Chemicals: urine and blood levels toxicity

Metal	*Media*	*Year*	*Geometric Mean*	*95th Percentile*	*Age*
Antimony	Urine	99-00	0.132 ug/L	0.42 ug/L	6 and older
		01-02	0.134 ug/L	0.34 ug/L	
		03-04*	--	0.28	
		99-00	0.124 ug/g	0.382 ug/g	
		01-02	0.126 ug/g	0.364 ug/g	
		03-04*	--	0.277 ug/g	
Total Arsenic	Urine	03-04	8.3 ug/L	65.4 ug/L	6 and older
		03-04	8.24 ug/g	50.4 ug/g	
Arsenobetaine	Urine	03-04	1.55 ug/g	35 ug/g	6 and older
		03-04	1.54 ug/g	29.4 ug/g	
Barium	Urine	See report	See report	See report	
Beryllium	Urine	See report	See report	See report	
Cadmium	Urine	99-00	0.193 ug/L	1.2 ug/L	6 and older
		01-02	0.210 ug/L	1.2 ug/L	
		03-04	0.211 ug/L	1.15 ug/L	
		99-00	0.181 ug/g	0.993 ug/g	6 and older
		01-02	0.199 ug/g	0.917 ug/g	
		03-04	0.21 ug/g	0.94 ug/g	
	Blood	99-00	0.412 ug/L	1.3 ug/L	1 and older
		01-02*	--	1.3 ug/L	
		03-04	0.304 ug/L	1.6 ug/L	
Cesium	Urine	See report	See report	See report	
Cobalt	Urine	See report	See report	See report	
Lead	Blood	99-00	1.66 ug/dL	4.9 ug/dL	1 and older
		01-02	1.45 ug/dL	4.4 ug/dL	
		03-04	1.43 ug/dL	4.2 ug/dL	
	Urine	99-00	0.766 ug/L	2.9 ug/L	6 and older
		01-02	0.667 ug/L	2.9 ug/L	

Metal	**Media**	**Year**	**Geometric Mean**	**95th Percentile**	**Age**
		03-04	0.636 ug/L	2.29 ug/L	
		99-00	0.721 ug/g	2.37 ug/g	6 and older
		01-02	0.639 ug/g	2.03 ug/g	
		03-04	0.632 ug/g	1.97 ug/g	
Total Mercury**	Blood	99-00	0.343 ug/L	2.3 ug/L	1-5 year old
		01-02	0.318 ug/L	1.9 ug/L	1-5 year old
		03-04**	0.326 ug/L	1.8 ug/L	1-5 year old
		99-00	1.02 ug/L	7.1 ug/L females	16-49 years
		01-02	0.833 ug/L	4.6 ug/L females	16-49 years
		03-04	Not available	Not available	Not available For women 16-49
		03-04	0.979 ug/L	4.9	1 and older
	Urine	99-00	0.719 ug/L	5.0 ug/L	16-49 years
		01-02	0.606 ug/L	3.99 ug/L	16-49 years
		03-04	Not available	Not available	Not available for women 16-49
		03-04	0.447 ug/L	0.319 ug/L	1 and older
		99-00	0.71 ug/g	3.27 ug/g females	16-49 years
		01-02	0.62 ug/g	3.0 ug/g females	16-49 years
		03-04	Not available	Not available	Not available For women
		03-04	0.443 ug/g	2.35 ug/g	1 and older
Molybdenum	Urine	See report	See report	See report	
Platinum	Urine		<LOD	<LOD	
Thallium	Urine	99-00	0.176 ug/L	0.45 ug/L	6 and older
		01-02	0.165 ug/L	0.44 ug/L	
		03-04	0.155 ug/L	0.44 ug/L	

Metal	***Media***	***Year***	***Geometric Mean***	***95th Percentile***	***Age***
		99-00	0.166 ug/g	0.366 ug/g	6 and older
		01-02	0.156 ug/g	0.348 ug/g	
		03-04	0.154 ug/g	0.350 ug/g	
Tungsten	Urine	See report	See report	See report	
Uranium	Urine	99-00	0.008 ug/L	0.046 ug/L	6 and older
		01-02	0.009 ug/L	0.046 ug/L	
		03-04	0.008 ug/L	0.039 ug/L	
		99-00	0.007 ug/g	0.034 ug/g	6 and older
		01-02	0.008 ug/g	0.04 ug/g	
		03-04	0.008 ug/g	0.029 ug/g	

* A large percentage of participants had < LOD, thus preventing the calculation of an overall mean

** Additional information about mercury levels in blood for various age groups is now available from a 2003–2006 survey. These data are summarized in Caldwell KL et al, “Total blood mercury concentrations in the U.S. population: 1999–2006.” Int J Hyg Environ Health 2009 (Nov) 212;6:588–98.

Note: Total blood mercury was measured in children aged 1–5 years and in women aged 16–49 years in 1999–2002. Total blood mercury and inorganic blood mercury were measured in all participants aged 1 year and older in 2003–2004. Urinary mercury was measured in women aged 16–49 years in 1999–2002. For the 2003–2004 survey, urinary mercury was measured in a random one-third subsample of participants aged 6 years and older.

4. Health Outcome Data

Chapter 4 Summary

Assessing accurately the health status of Viequenses requires quantifying morbidity and mortality as well as identifying possible factors that may lead to adverse health outcomes. Quantifying morbidity and mortality and assessing possible contributing factors can help to identify specific opportunities for intervention in public health programs or delivery of health services. An understanding of public health data collection and reporting systems, public health programs, and the health care delivery system on the island of Vieques is required to determine future activities for improving the health status of Viequenses.

In this chapter we review public health data collection and reporting systems used in quantifying morbidity and mortality, review several reports published in the last 10 years that assess morbidity and mortality in Vieques, and provide a brief review of available health services on Vieques. All of these studies are descriptive in nature and provide some insight into the Vieques health picture. The studies do not contain analyses that relate potential environmental or other factors to the identified health conditions. Because of the small population, all studies suffer to some degree from a lack of statistical power and methodological limitations that make interpretation difficult. Despite these limitations, the studies are valuable for describing the health status of Viequenses. And in Vieques relative to the rest of Puerto Rico, the studies indicate elevations in the prevalence of chronic disease, cancer incidence, and cancer mortality.

4.1. Public Health Data Systems and Programs

The primary data systems supporting the estimation of incidence and prevalence of health outcomes in Puerto Rico are the Central Cancer Registry (RCCPR), Behavioral Risk Factor Surveillance System (BRFSS), Birth Defects Surveillance System (BDSS), and the Puerto Rico Vital Records Office. CDC helps to fund each of these data collection and reporting systems. Their strengths and weaknesses affect data quality and the resulting ability to develop appropriate public health actions based on this information.

The data reported by the RCCPR have several strengths. Cancer registries typically represent the best population-based dataset when compared with data collection systems and associated datasets for other chronic diseases. Most cancer cases are captured by registries due to legal reporting requirements, redundancies in the reporting system (i.e., reporting by labs, clinics, hospitals, and specific oncologists), and the clinical course of cancer that usually requires substantial follow up and repeat visits. The analysis of cancer registry data should then represent the most accurate assessment of cancer incidence in Vieques. Finally, through a cooperative agreement in place since 1998, CDC has continuously funded the cancer registry. And the registry's data accuracy has steadily improved.

That said, however, several weaknesses in the registry data should be noted. First, funding has been inconsistent throughout the life of the registry, but recently it has become more stable. The RCCPR was funded in part by the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program from 1973–1989. The contract between the RCCPR and SEER was not renewed, and until 1997 RCCPR operated on local funding. In 1997, the RCCPR applied for and received funding from the Centers for Disease Control and Prevention (CDC) through a cooperative agreement via the National Program of Cancer Registries. The RCCPR provided data to the CDC beginning with cancer cases diagnosed in calendar year 1998. Completeness and timeliness have also been problematic due to a shortage of trained personnel to perform cancer abstracting and delays in reporting by facilities because of lack of funds and lack of reporting requirements by some facilities. The RCCPR has made significant progress toward improving completeness. In 2003, a CDC review concluded that 95.3% of all cancer cases diagnosed or treated in hospital facilities in Puerto Rico were appropriately reported to the RCCPR; a result comparable to the US median (95%).

BRFSS is the primary surveillance system for estimating the prevalence of chronic diseases and health behaviors in the United States and in Puerto Rico. BRFSS is the primary data source for prevalence estimates of asthma, diabetes, hypertension, and heart disease. One limitation of this system is the ability to provide accurate prevalence estimates in small populations. Vieques has a population of less than 10,000 residents. Providing accurate prevalence estimates is difficult in populations this small. This is particularly due to the complex survey design and the overarching goals of producing state and national prevalence estimates. The Selected Metropolitan/Micropolitan Area Risk Trends (SMART) project was initiated to develop prevalence estimates at the local level. The SMART project utilizes methods to develop prevalence estimates using BRFSS data for areas with 500 or more respondents. These methods may represent a viable option for using BRFSS to develop prevalence estimates for Vieques.

CDC funds the Puerto Rico BDSS, which tracks thirteen congenital conditions diagnosed at birth. Current program goals include expanding the capacity of the surveillance system to identify birth defects cases and developing legislation that mandates the reporting of birth defects in Puerto Rico to the BDSS. The BDSS is one of 14 CDC-funded birth defects surveillance systems. The population-based system uses active case ascertainment. Abstractors in each public health region visit hospitals and other facilities to review medical records to identify cases for each specific type of birth defect. Although this approach is considered the gold standard, it is resource-intensive. A limitation of birth defects surveillance in general is that some defects cannot be diagnosed at birth and thus go undetected.

Another morbidity and mortality data source is the Puerto Rico Vital Records Office. The Vital Records office collects data on births and deaths for the entire population. Advantages of birth and death data include low cost, availability, and, because of the statutory reporting requirements, near-complete coverage. Mortality data limitations include multiple causes of death, completeness of records, and changes in diagnostic practices from improvements in medical technology (Rothman and Greenland 1998). Birth certificate data limitations include changes to birth certificates over time, incomplete birth certificates, and self-reported information.

4.2. Assessment of Available Public Health Data

Several studies have evaluated morbidity and mortality in the Viequense population. All are descriptive in nature and provide some insight into the health of that population. But these studies do not contain analyses that relate potential environmental or other factors to the identified health condition. In addition, because of the small study population, all the studies suffer from a lack of statistical power. Despite their limitations, these studies are valuable for describing the health status of Viequenses and providing insight that will inform next steps. An evaluation of studies published within the past decade are summarized and discussed in this chapter. Conclusions and recommendations for further action are outlined below and in Chapter 9. These recommendations are viewed as a starting point for dialogue with the scientific community and Viequenses to develop an action plan that will help improve Viequenses' health.

4.2.1. Cancer

The RCCPR released reports in 2006 and 2009 detailing cancer incidence and mortality in Puerto Rico. The 2006 report evaluated cancer incidence and mortality from 1990–2001. In contrast, the 2009 report evaluated cancer incidence and mortality from 1990–2004. Both studies assessed whether, using similar methods, cancer incidence and mortality rates were higher in Vieques than in the main island of Puerto Rico. The standardized incidence and mortality ratios with 95% confidence intervals were calculated. The authors defined statistical significance as a 95% confidence interval that did not include 1. Similarly, the authors defined marginal statistical significance as a 90% confidence interval that did not include 1.

The analyses have several strengths. Most cancer cases are captured by registries. This is because of legal reporting requirements, redundancies in the reporting system (i.e., reporting by labs, clinics, hospitals, and specific oncologists), and the clinical course of most cancers that requires substantial follow up and repeat visits. The analysis of cancer registry data should then represent the most accurate assessment of cancer incidence on Vieques.

Although the analyses have several strengths, several limitations were also noted. As mentioned briefly in the PRDOH reports and confirmed by Dr. Figueroa (personal communication, July, 2009), some follow up to identify cases in Vieques occurred that was not uniformly applied across the rest of Puerto Rico. One example is related to the documentation of age for cases in the registry.

For both assessments, all cases indicating residence on the Island of Vieques were age-confirmed. This practice was not mirrored on the main island of Puerto Rico. If a case did not have a known age, it was not included in any rate calculations. In addition, cases were actively sought in Vieques and not in the rest of Puerto Rico. This potentially introduces bias; it omits cases from the reference population (i.e., Puerto Rico) and increases the proportion of cases captured by the registry in Vieques relative to Puerto Rico, thus potentially, artificially inflating standardized incidence ratios. Other differential methods for seeking out and reviewing cases in Vieques not applied on the main island would similarly bias the results (RCCPR 2006, 2009).

4.2.2. Noncancer

We reviewed two studies that evaluated noncancer data. The primary noncancer morbidity study was released in March 2000 by Yadiris Lopez and Crisarlin Carrosquillo (Lopez and Carrosquillo 2002). We also reviewed noncancer mortality in “Heavy metal exposure and disease in the proximity of a military base” by Dr. Carmen Ortiz Roque (Ortiz Roque 2002).

The Lopez and Carrosquillo survey was conducted because of growing concerns regarding environmental contamination from the past military activities and their potential adverse human health effects on Viequenses. The survey was a cross-sectional design with a sample size of 1,043. The field work for the study was conducted between April and November of 2000. Lopez and Carrosquillo attempted to include all residents in each neighborhood and allowed the head of a household, typically the matriarch, to provide proxy responses for all household members. The survey collected data on demographics, employment history, and dietary habits, along with self-reported disease prevalence.

The overall age distribution of the sample selected, based on 1990 and 2000 U.S. census data, appears older than the Vieques population. Lopez and Carrosquillo reported that 36% of the sample was ages 60 and older. Data from the 1990 U.S. Census indicated that 16% of the Vieques population was 60 years and older. Similarly, the 2000 Census indicated that 19.5% of the Vieques population was 60 years and older. Participants were selected from Lujan, Puerto Rico Reconstruction Administration, Santa Maria, and Esperanza. The 132 residents of Lujan reported an age range of 5–25, whereas the 306 residents of the Puerto Rico Reconstruction Administration (PRRA) reported an age range of 59–70. The age distributions of Santa Maria and Esperanza were not reported separately. These neighborhoods were collectively described as "representative” of the Vieques population but appear to be older.

The survey participants identified 28 medical conditions. These conditions are listed in Table 4-1. Of the 28 medical conditions identified by participants, the authors presented comparisons using risk ratios for six health conditions: cancer, heart disease, hypertension, diabetes, asthma, and arthritis. The prevalence of health conditions was compared with the expected number of cases, calculated by multiplying the population of Vieques by the percentage of cases that occurred in the 1994 Puerto Rico Chronic Morbidity Study (PRCMS). In addition to medical conditions, the authors described the frequency of cigarette use, alcohol consumption, eating habits, and abortions. The authors stated that cancer was not connected to cigarette smoking or alcohol consumption—the frequency of each factor in the survey was similar to the totality of Puerto Rico. The frequency of cigarette use and alcohol consumption among participants with the most prevalent health conditions was not presented (Lopez and Carrosquillo 2002).

Table 4-1. Viequenses-reported health conditions

Health Conditions	*Number of Cases*	*Percentage*
High Blood Pressure	189	18.1
Asthma	112	10.7
Diabetes	102	9.8
Arthritis	89	8.5
Heart Disease	77	7.4
Skin Conditions	61	5.8
Sinusitis	56	5.4
High Cholesterol	54	5.2
Muscular Spasms	52	5.0
Allergies	49	4.7
Other	36	3.5
Circulation	36	3.5
Stress	32	3.1
Migraine	24	2.3
Cancer	19	1.8
Anemia	16	1.5
Kidneys	14	1.3

Health Conditions	***Number of Cases***	***Percentage***
Uric Acid	13	1.2
Epilepsy	11	1.1
Tumor	10	1.0
Prostate	10	1.0
Fatigue	10	1.0
Nodules	5	0.5
Pneumonia	4	0.4
Lead in blood	4	0.4
Osteoporosis	3	0.3
Lupus	1	0.1
Spinal Column Deviation	1	0.1

Dr. Ortiz Roque briefly presented noncancer mortality and infant mortality in a report. In January 2002, Dr. Ortiz Roque, together with the College of Physicians and Surgeons in San Juan, PR, released a report entitled "Heavy metal exposure and disease in the proximity of a military base." This effort was initiated because of community concern that past military activities on the island may have adversely affected Viequenses' health. Ortiz Roque reported mortality statistics from the Puerto Rico Department of Health for 1991–1998. Age standardized mortality data between Vieques and mainland Puerto Rico were compared with total deaths and cause-specific deaths. Additionally, infant mortality rates in Vieques were also compared with those of Puerto Rico for 1975–1995 (Ortiz Roque 2002).

The mortality data presented did not enumerate all analyses performed—only those that were elevated. Finally, infant mortality is only briefly mentioned, and to ascertain specific times is difficult, especially those for specific causes.

Symptom-disease prevalence surveys of a population, such as the Lopez and Corrosquillo survey, are useful hypothesis-generating tools. This is especially true when little preexisting knowledge is available regarding the population's potential exposures and associated health effects. Another strength of the Lopez and Carrosquillo survey was its large sample size (n=1,043) relative to a population of approximately 10,000. Mortality data may also provide meaningful insight into the health status of Viequenses. Analyses of mortality patterns in a population can be useful for hypothesis generation; however, using these data to quantify potential relationships in exposure-disease relationships is difficult. Many potential confounding variables cannot be assessed (e.g., access to care, lifestyle factors, and dietary habits). Typically, mortality data are population-based, with near universal coverage, and are less prone to bias.

Despite such strengths, however, symptom-disease prevalence surveys and the mortality data reviewed have several limitations. Their ability is restricted to test inferences regarding associations between exposure and health status. They assess exposure and disease simultaneously; thus to determine whether the exposure preceded the disease is not possible. Because these surveys rarely contain quantitative exposure data—either through direct contaminant measurements in a participant's immediate environment or through biomonitoring—using this approach to understand the relationship between exposure and health status is inherently difficult. The Lopez and Carrosquillo symptom prevalence survey, for example, did not include environmental exposure information. In addition, cross sectional surveys of symptom-disease prevalence are often severely compromised by reporting bias from participants' real or perceived problems. For the Lopez and Corrosquillo survey, all data were self-reported or reported via proxy, with no attempt to validate the information using medical records. In such cases, the analysis would benefit from a medical records review to validate self-reported data.

A third limitation of this survey was a lack of statistical power. The sample was large relative to the population, but still may have lacked the power necessary to identify differences in the observed frequencies and, for many health conditions, in the expected frequencies. Confidence intervals, with risk ratio estimates to identify differences, were not presented.

4.3. Findings

- Access to oncology and other specialty services (e.g., neurology, cardiology) requires travel to the main island of Puerto Rico.
- Analyses of data from the RCCPR (cancer incidence) and the Vital Statistics office (cancer mortality) identified some statistically significant elevations. Statistically significant results ($\alpha=0.05$) from these analyses are presented in the following tables:

Table 4-2. Summary of Statistically Significant Standardized Incidence Ratios for Cancer

Outcome	***Period***	***Group***	***SIR, 95% CI***
All cancers	1990 – 1995	Men and Women together	1.19 (1.02, 1.39)
Lung and bronchus	1990 – 1995	Men and Women together	2.25 (1.35, 3.52)
Lung and bronchus	1990 – 1995	Men	2.24 (1.19, 3.83)
Prostate	1990 – 1995	Men	1.47 (1.03, 2.03)
All cancers	1995 – 1999	Men and Women together	1.26 (1.08, 1.47)
All cancers	1995 – 1999	Men	1.31 (1.07, 1.60)
Prostate	1995 – 1999	Men	1.53 (1.09, 2.09)

Table 4-3. Summary of Statistically Significant Standardized Mortality Ratios for Cancer

Outcome	***Period***	***Group***	***SMR, 95% CI***
All cancers	1990 – 1995	Men and Women together	1.26 (1.01, 1.57)
All cancers	1990 – 1995	Women	1.43 (1.01, 1.96)
Breast	1990 – 1995	Women	0.26 (0.03, 0.92)
Colorectal	1990 – 1994	Women	2.75 (1.11, 5.67)
Oral Cavity and Pharnyx	1990 – 1995	Men	3.96 (1.08, 10.0)
All cancers	1995 – 1999	Men and Women together	1.35 (1.08, 1.67)
All cancers	2000 – 2004	Men	1.40 (1.07, 1.80)
Prostate	2000 – 2004	Men	2.62 (1.66, 3.93)

- When compared with all of Puerto Rico, the Lopez and Carrosquillo survey indicated an increased occurrence in Vieques of hypertension, asthma, diabetes, heart disease, and some cancers. A key survey limitation is the lack of supporting medical record inspection to support self-reported claims and to reduce the possibility of information bias.
- An increase in infant mortality was also reported and increases in noncancer mortality for hypertension, cirrhosis, and diabetes.

Vieques has a population of approximately 10,000. Typically, around 30 new incident cases and 15 deaths for all cancers combined occur annually. Therefore, statistical power to detect any meaningful differences in cancer incidence on the island is low when evaluating specific anatomical sites, short time frames, or both. Assessing rates over a longer time span would be useful rather than the traditional 5 years, as in standard cancer surveillance publications. As differential ascertainment for the Vieques residents probably biased the presented, standardized incidence ratios, uniform case identification methods should be applied across all study and referent populations

4.4. Conclusions and Recommendations

4.4.1. Conclusions

1. The documents ATSDR reviewed paint a complex health picture for Viequenses. The findings of these reports indicate elevations in chronic disease prevalence, cancer incidence, and cancer mortality among the population between Vieques and the rest of Puerto Rico. In addition, increased mortality in Vieques particularly from cancer may indicate lack of access to appropriate medical care. The limitations associated with these analyses, particularly the methodological concerns discussed in this report, introduce considerable uncertainty and make interpretation difficult. Some of the methodological concerns previously noted include more exhaustive cancer case finding in Vieques than the rest of Puerto Rico, differential follow-up, chronic disease prevalence estimates based on a symptom disease prevalence survey without medical record confirmation of health outcomes, and limited noncancer mortality data. Differential follow up and exhaustive case finding may result in biased estimates of cancer incidence and mortality. Uncertainty is also evident in the wide confidence intervals reported indicating imprecise estimates of cancer incidence and mortality ratios in Vieques relative to the rest of Puerto Rico (RCCPR 2009). This is not unusual when calculating estimates for small populations.

2. These findings can nonetheless serve as a guide for future investigations of Viequenses' health status.

4.4.2. Recommendations

Assess the feasibility of applying the SMART BRFSS methods for generating stable Vieques specific prevalence estimates on asthma, diabetes, hypertension, and other chronic diseases.

4.5. References

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5. Local Produce and Livestock Pathway

Chapter 5 Summary

This chapter evaluates available data and information on contaminants detected in local garden produce and livestock; Chapter 7 considers the effects of direct contact with soil contaminants.

The overall data are insufficient to quantify adequately human exposures or draw any valid health conclusions about whether consuming locally grown produce and livestock would result in harmful health effects.

Limited sampling data are available for pigeon peas, a staple food among Viequenses. A preliminary data evaluation completed for this report has concluded that the level of cadmium reported in samples of locally grown pigeon peas would not contribute excess dietary cadmium to preschool children who eat no more than 5 of the largest (6 ounces) servings per week of locally grown pigeon peas. Adults who eat the largest serving sizes (12 ounces) should limit intake to 11 servings per week. Typical serving sizes for preschool children (1.5 ounces) do not contribute excess cadmium below 20 meals per week and adults who eat a typical serving (3 ounces) may eat up to 44 meals per week without exceeding recommended cadmium intake levels. Exceeding recommended levels of cadmium in the diet would not typically result in immediate health consequences. Excessive cadmium intake over decades, however, could contribute to harmful levels of cadmium accumulation in the kidneys, possibly resulting in kidney disease.

To be protective, these exposure estimates assumed that people consistently ate the largest portions typically consumed at a meal, and that the pigeon peas contained the highest level of cadmium measured. These assumptions, however, likely overestimate the extent of exposure for the majority of the population.

Whether the limited sampling results are representative of cadmium concentrations in other locally grown pigeon peas is unclear; but the significant uncertainty in the evaluation stresses the need to

conduct further sampling. Preliminary evaluation results and the totality of the available data suggest a potential for uptake of metals from soil into food crops—thus further investigation is warranted. To evaluate better this exposure pathway, ATSDR has recommended a collaborative effort to conduct additional sampling of locally grown foods.

5.1. Introduction

Many Viequenses remain concerned that past military training activities in the eastern portion of their island left elevated levels of heavy metals in the surface soil. Plants could take up these metals. And when people eat those plants, they could be exposed. Viequenses also question whether animals could accumulate heavy metals if they forage in areas where past military activities occurred, and whether this could result in exposure for people who consume meat and milk products from these animals. Viequenses depend on many local animal and vegetable products as food sources and for economic support. Thus, for Viequenses the safety of locally produced foods has both health and economic implications.

5.2. Assessment of Available Data

Since 2000, a number of independent studies have explored levels of heavy metals in Vieques vegetation and livestock. This section provides a brief summary of the results and discusses their strengths and limitations, together with ATSDR's evaluation and response to the findings.

The studies discussed in this section were prepared by scientists associated with the University of Puerto Rico and Casa Pueblo, a local community advocacy organization. Several of these studies were presented and discussed by the authors during the November 2009 meeting in Atlanta, GA.

5.2.1. Studies from 2000–2002

- In 2000, researchers from Casa Pueblo and the University of Puerto Rico sampled the prevailing vegetation in the Live Impact Area (LIA) (specifically Carrucho Beach, Monte David, and Gato and Icacos Lagoons) for heavy metals (Massol Deyá and Díaz 2000). Reference populations of the same species were also collected in Bosque Seco de Guánica and RUM Alzamora Ranch. The plants collected included *Urochloa maxima* (root and stem), *Sporobolus virginicus* (root and stem), *Syringodium filiform* (stem), *Ipomoea violaceae* (fruit), *Faidherbia albida* (stem), *Calotropis procera* (leaves), among other species. The authors reported that the concentrations of heavy metals such as lead, cobalt, and manganese in Vieques vegetation were significantly higher than concentrations detected in the reference locations.
- In 2001, the same researchers randomly collected agricultural and common vegetation from three sites within the residential section of Vieques: an agricultural area in Monte Carmelo, another area of Monte Carmelo that bordered the former Camp Garcia, and an agricultural farm in Barrio Monte Santo, Gobeo sector (Massol Deyá and Díaz 2001). In this paper, discussion was limited to the two farms sampled in the civilian area of Vieques and focused on plants grown for an agricultural economy. Sampling included leaves and stems of pumpkin, pepper, pigeon peas,

pineapple, and yucca. The study reported that the concentration of cadmium, cobalt, copper, lead, and manganese exceeded levels reported in typical vegetation in temperate zones (from Smith and Huyck 1999). The authors stated that roots, stems and leaf samples of pumpkin, pepper, pigeon pea, pineapple and yucca had elevated lead and cadmium concentrations while guamá and mango trees did not show any elevated metals concentrations. On August 18, 2001, the researchers from Casa Pueblo collected hair samples from goats that grazed in Mount Santos and Santa María on Vieques (Massol Deyá 2002). As a reference, samples were collected from goats that pastured in the main island of Puerto Rico. The publication reported that hair from goats grazing in Vieques contained higher levels of lead than did goats on the main island. No mercury was detected in the goat hair (detection limit was 0.03 µg/g).

Because of these results and other studies by the same researchers reporting elevated levels of heavy metals in plants and livestock, on August 7, 2001, the Puerto Rico Department of Agriculture (PRDA) placed an embargo on Vieques produce and livestock. The Puerto Rico Department of Agriculture, in cooperation with the Farmers Association of Puerto Rico, sampled grass, fruit-bearing trees, and bovine livestock from Monte Carmelo, Martineau, Monte Santo, Esperanza, Lujan, Gubeo, and western Vieques for cadmium, cobalt, copper, lead, manganese, and nickel. The Department of Agriculture and the Farmer's Association concluded that the agricultural products from Vieques were suitable for consumption and did not contain toxic levels of these metals (PRDA 2001). When the Department of Agriculture and the Farmer's Association could not duplicate the Massol Deyá and Díaz' studies, the embargo was lifted (El Nuevo Día 2001).

5.2.1.1. ATSDR Evaluation

During preparation of the public health assessment evaluating soil exposure (ATSDR 2003), ATSDR cited two of the studies (Massol Deyá and Díaz 2000, 2001). These studies reported elevated metals in local vegetation and agricultural areas. This issue was originally addressed as a community concern in the Soil Pathway Evaluation Public Health Assessment (ATSDR 2003).

ATSDR requested that an agronomist with the U.S. Department of Agriculture independently review the 2000 and 2001 Massol Deyá and Díaz studies. The agronomist determined (USDA 2002) that although the studies provided evidence that heavy metals were accumulating in plants, the study's limitations prevented estimation of a human exposure dose:

1. Humans do not eat many of the species sampled in this study. When edible species were sampled, the edible portions were not. Human exposures from locally grown foods are best estimated from the edible portions of the food source. In general, the edible portions of plants are less likely to accumulate metals from soil because of normal plant processes (e.g., physiological barriers that prevent contaminants from getting to the tops of plants) (ATSDR 2001).
2. The study lacked the use of standard reference materials to demonstrate that the results were accurate. It also lacked background corrections for lead, cobalt, nickel, and cadmium to eliminate the effect of light scattering by any nonelement materials in the samples, which can result in a concentration overestimate.

3. The metals analysis did not indicate whether the metals were in a bioavailable form (i.e., in a chemical form readily absorbed into plant tissues from the surrounding environment). This is important because vegetation samples include both contaminants taken up by the plant and soil particles from the surrounding environment. Even with a thorough washing, small soil particles will adhere to the plant materials and can actually carry more contaminants than those taken up by the plant from the soil (ATSDR 2001). The researchers did not determine how much of the chemical was adhered externally as soil and how much was in the plant tissue.

Because of these limiting factors, ATSDR could neither quantify human exposures appropriately nor draw any valid health conclusions about whether consuming Vieques plants would result in harmful health effects. ATSDR has recommended additional sampling of locally grown produce that would improve the evaluation of this exposure pathway. Details of ATSDR's recommendations are at the end of this chapter and in Chapter 9 of this report.

ATSDR was unable to evaluate human exposure to goat meat and milk products from the sampling data presented in Massol Deyá (2002). Information was missing on similarities and differences between the goats in Vieques and the reference population (e.g., goat species, age, whether differences were statistically significant) and how they might affect interpretation of the hair sampling results. The report was unclear regarding how the hair samples were prepared for analysis. Inadequate processing of the hair for chemical analysis can lead to misleading results and to difficulty in interpreting whether the data represent contamination internal to the hair shaft or incomplete removal of any external contamination. Additionally, limitations in interpreting the health significance of hair sampling data precluded ATSDR from using the goat hair data reported in Massol Deyá (2002). Three key limitations of hair analysis generally prevented further characterization of exposures:

1. Hair analysis results cannot pinpoint the sources of detected chemical contaminants. For instance, hair analysis results typically cannot distinguish substances deposited onto hair (e.g., dusts) from substances that might have distributed into hair following an environmental exposure, such as ingestion of contaminated drinking water or food. In other words, hair analysis generally cannot differentiate internal from external exposure.
2. Currently, the scientific community does not know the range of contamination levels typically found in hair. Without reliable data in the peer-reviewed literature on baseline or background hair contamination levels in the general population, and without hair samples collected from comparison populations, health agencies cannot determine whether hair analysis results from a given site are unusually high or low. In Massol Deyá (2002) a comparison population of goats was sampled, and the results supported the author's conclusion that the goats sampled on Vieques had higher concentrations of heavy metals in hair relative to the comparison population.
3. A critical input into public health assessments is an understanding of the dose—whether measured or estimated. Because we currently know so little about rates at which substances in human and animal bodies distribute into hair, calculation was not possible of internal doses from hair sampling results. Hair analysis, then, would provide no added insight into estimating

exposures to humans, but it does imply a need to sample directly meat and milk from these animals to determine whether the meat and milk are safe for consumption.

For most substances, insufficient data are currently available to support any prediction of adverse health effects from concentrations in hair. Detection of a substance in a hair sample generally will not tell how, when, or where exposure to that substance occurred. Data from plant and animal foods that people actually consume are best suited for determinations about the possible health implications for people who eat those foods. Accordingly, as part of its evaluation, ATSDR recommends additional sampling of local produce and livestock.

5.2.2. Studies from 2003

In 2003, researchers from University of Puerto Rico published a study discussing the same data the authors published in April 10, 2000—plant samples collected in February and March 2000 and analyzed for heavy metals (Díaz and Massol Deyá 2003). This paper compared concentrations found on Vieques with concentrations detected on the main island of Puerto Rico. The 2000 sampling included plant stems and leaves but did not include the edible portions of the plants sampled. This peer-reviewed publication provided more information on sampling, preparation, and analytical techniques than did the April 2000 report. In addition to the 2000 sampling data, this paper included new samples of *C. cajan* (pigeon peas) leaves and fruit taken August 18, 2001. It also discussed the ratio of contamination detected in the fruit to contamination in the leaves. The study compared concentrations detected in pigeon pea fruit and leaf samples collected August 18, 2001. For some metals, higher concentrations were found in the fruit (zinc, nickel, cadmium and cobalt). For other metals, higher concentrations were found in the leaves (copper and lead).

5.2.2.1. ATSDR Evaluation

In May 2009 ATSDR obtained a copy of the 2003 Díaz and Massol Deyá study. As part of its evaluation of Vieques, ATSDR reviewed the pigeon pea data in this study. The data reported in Díaz and Massol Deyá have significant limitations that restrict ATSDR's ability to interpret the study findings' significance. These limitations include no mention of comparison samples and no indication of statistical significance in the data reporting pigeon-pea metal concentrations. The sampling results from only one study are not representative of the extent of cadmium in local produce and do not represent the potential for cadmium exposure to the general population from consuming locally grown pigeon peas.

A preliminary evaluation concluded that the level of cadmium reported in a few samples of locally grown pigeon peas would not contribute excess dietary cadmium to preschool children who eat no more than 5 of the largest (6 ounces) servings per week of locally grown pigeon peas. Adults who eat the largest serving sizes (12 ounces) should limit intake to 11 servings per week.

To be protective, these exposure estimates assumed that people consistently ate the largest portions typically consumed at a meal, and that the pigeon peas contained the highest level of cadmium measured. These assumptions likely overestimate the extent of exposure for the majority of the population. Typical serving sizes for preschool children (1.5 ounces) do not contribute excess cadmium below 20 meals per week. Adults who eat a typical serving (3 ounces) may eat up to 44 meals per week without exceeding recommended cadmium intake levels. Still, excessive cadmium intake over decades could contribute to harmful levels of cadmium accumulation in the kidneys, possibly resulting in kidney disease. Table 5-1 provides details on the methodology used in this evaluation.

Table 5-1. Exposure dose for pigeon pea fruit (Díaz and Massol Deyá 2003 data)

	Percentile		*C mg/kg*	*IR kg/day*	*Portion size in Oz*	*Meals per week*	*Meals per Year*	*EF days/yr*	*ED Yrs*	*BW kg*	*AT days*	*FA unit less*	*DOSE (mg/kg/day)*	Target dose (mg/kg/day)
Chemical	IR													
cadmium	95th	adult	3.17	0.10	12	5	260	260	64	70	23360	0.05	0.00016	0.00036
	95th	child	3.17	0.05	6	5	260	260	6	16	2190	0.05	0.00035	
Number of weekly meals to reach tolerable daily intake level														TDI
	95th	child <6 yr	3.17	0.05	6	5	260						0.00036	0.00036
	50th	child <6 yr	3.17	0.01	1.5	20	1040						0.00036	
	95th	adult	3.17	0.10	12	11	572						0.00036	
	50th	adult	3.17	0.02	3	44	2288						0.00036	

Where

C Concentration (mg/kg)

IR Ingestion rate in percentile (e.g. 95th means that 95% of the population has an intake level below that amount): see below

EF Exposure frequency or events: 260 days/year = 5 days/week for 52 weeks/year; 156 days/year = 3 days/week for 52 weeks/year

ED Exposure duration over which exposure occurs: 64 years (adult); 6 years (child)

AT Averaging time: period over which exposures are averaged (expressed in days) for noncancer AT=ED*365 days/year

FA Food absorption factor: Assumes dietary cadmium absorption of 5%. (ATSDR Cadmium Toxicological Profile, Sep 2008)

BW Body weight in kilograms

TDI Tolerable daily intake, 0.00036 mg/kg-bw/day, European Food Safety Authority (EFSA) 2009

dry weight
rate

95th adult 98.7 g/day See EFH Chapter 9, Section 9.2.5 for conversion between as consumed and dry weight intake rates

50th adult 24.8 g/day used 71.8 percent water content for "beans –dry–black-eyed peas (cowpeas)–cooked," see Table 9-27

95th child 1.6 g/kg/day

50th child 0.4 g/kg/day

USEPA. 1997. Exposure Factors Handbook. August 1997. Available from: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=20563

Tolerable daily intake

TWI= tolerable weekly intake

2.5 ug/kg BW EFSA 2009

0.00036 mg/kg/day Converted to daily intake

5.2.3. Studies from 2004–2005

- In 2004, researchers from the University of Puerto Rico's Agricultural Extension Service in Vieques and the Land Authority of the Commonwealth of Puerto Rico collected a total of 72 samples of smooth cayenne pineapple fruit, leaf tissues, and soil. They collected these samples from two pineapple plantations (one located in Barrio Luján in the civilian zone in Vieques and a control located in Barceloneta on the mainland of Puerto Rico). The samples were to determine the total concentration of arsenic, cadmium, chromium, cobalt, and lead in the fruit. The author concluded that no contamination was found in the pineapple fruit or leaf samples from either plantation. In all fruit samples arsenic, cadmium, cobalt, and lead either were below levels of detection or were not detected. No contamination was observed in the pineapples from Vieques when compared with those from the Barceloneta plantation (Lopez Morales 2005). Higher levels of metals were, however, found in the soil at the Barceloneta plantation, which the author attributed to the soil's natural composition. The study concluded that the results were within accepted regulatory levels.
- In 2005, Massol Deyá et al. published a paper discussing the same data that the authors published in April 10, 2000, and again in 2003—plant samples collected in February and March 2000 and analyzed for heavy metals. The authors noted that "distinctive profiles are observed within the studied species thus reflecting differences in their physiological properties." In addition to the 2000 sampling data, this paper included new samples of *Syringodium filiforme* (Manatee grass) taken from the Atlantic Fleet Weapons Training Facilities (AFWTF) in 2004 and from Guánica State Forest in 2003 and 2004. Concentrations of heavy metals were higher at AFWTF. The authors proposed the hypothesis of bioaccumulation through the food chain: manatee grass to crustaceans, fish eat the crustaceans and then are eaten by people. A similar food-chain scenario was hypothesized for migratory birds (Massol-Deyá et al. 2005).

5.2.3.1. ATSDR Evaluation

The data in Massol-Deyá et al. (2005) might well provide ecologically important information, but they are not directly relevant to evaluating human health—manatee grass is not typically a Viequense food source. ATSDR has recommended additional produce sampling.

The López Morales (2005) study was unique in that its purpose was specifically to sample the edible portion of a commonly consumed agricultural product grown in Vieques, *smooth cayenne* pineapples. As part of the evaluation of Vieques, ATSDR evaluated the level of chromium—the only metal detected—in the pineapple fruit samples. Using a standard intake rate for fruit consumption,[23] ATDSR calculated the estimated exposure dose at below levels of concern for adverse health effects.

López Morales (2005) cited two additional studies that found "no contamination in the civilian zones of Vieques": 1) College of Agriculture & Environmental Science: Soil, Plant and Water Laboratory

[23] About 7 ounces of fruit a day (mean total fruit intake; USEPA 1997)

(September 6, 2001), and 2) A & L Southern Agricultural Laboratories, Inc. (August 31, 2001). Both studies analyzed for heavy metals in guinea grass, sugar apple, wild tamarind, mango, green banana fruit, pigeon peas, genip fruit, grapefruit, and buffet grass. These studies sampled species Viequenses regularly eat. ATSDR is attempting to obtain copies of these studies, but to date has not been successful.

5.2.4. Studies from 2008

In January 2008, leaves from cilantro, spinach, beans, peppers, and papaya plants were collected from a Viequense organic farm and analyzed for cadmium, chromium, copper and lead. The researchers believed the organic farm's soil would be representative of naturally occurring soil plus any local, airborne contamination. The researchers found that concentrations of lead and cadmium in the Viequense vegetation were significantly higher than those detected in the Mayagűez reference plants (Díaz de Osborn et al. 2008). Mayagűez is a town on the western end of Puerto Rico, approximately 120 miles from Vieques

5.2.4.1. ATSDR Evaluation

In reviewing the Diaz de Osborn et al. (2008) report, ATSDR was initially concerned that the data appeared to indicate potential harm to humans consuming this produce. Due, however, to the report's lack of any data quality assurance information, ATSDR questioned whether those data accurately represented typical heavy metal concentrations in locally grown produce. ATSDR consulted with the U.S. Department of Agriculture (USDA) about the study (R. Chaney, U.S. Department of Agriculture, Agricultural Research Station, Beltsville, MD, personal communication, 2008 Oct 28–30). USDA noted that the reported levels of copper would be phytotoxic to the plants. USDA commented that the reported measurements were consistent with plants grown in soils that had been changed to increase metal uptake in the plants (Sterrett 1996). As a result, how ATSDR should interpret these data is unclear. ATSDR has recommended additional sampling of locally grown produce to resolve uncertainties in the available data. Still, until additional data are available and this exposure pathway is more thoroughly evaluated, the USDA suggests following several simple methods for reducing metal uptake into garden produce from soil. More information is available at USDA's National Agriculture Library Web site: http://www.nal.usda.gov/. Specialized gardening information is available online at: http://riley.nal.usda.gov/nal_display/index.php?info_center=8&tax_level=2&tax_subject=7&topic_id=1063.

The conclusions and recommendations from ATSDR's evaluation of local produce and livestock data follow in section 5.3 of this chapter and in Chapter 9 of this report.

5.3. Conclusions and Recommendations

5.3.1. Conclusions

1. The overall data are insufficient to quantify adequately human exposures or draw any valid health conclusions about whether consuming locally grown produce and livestock would result in harmful health effects.

2. Limited sampling data are available for pigeon peas, a staple food among Viequenses. Interpretation of these data is uncertain because of the lack of adequate QA/QC information for the analytical findings.

    - A preliminary data evaluation completed for this report has concluded that the level of cadmium reported in a few samples of locally grown pigeon peas would not contribute excess dietary cadmium to preschool children who eat less than 5 of the largest (6 ounces) servings per week of locally grown pigeon peas. Adults who eat the largest serving sizes (12 ounces) should limit intake to 11 servings per week.

    - Typical serving sizes for preschool children (1.5 ounces) do not contribute excess cadmium below 20 meals per week and adults who eat a typical serving (3 ounces) may eat up to 44 meals per week without exceeding recommended cadmium intake levels.

    - Exceeding recommended levels of cadmium in the diet would not typically result in immediate health harm. Excessive intake of cadmium over decades could contribute to harmful levels of cadmium accumulation in the kidneys, possibly resulting in kidney disease. Typically, only a very small fraction (5%) of cadmium in food is absorbed in the body, especially in individuals with healthy diets containing adequate amounts of essential minerals such as zinc, iron and calcium (Reeves and Chaney 2008).

3. Whether the limited sampling results are representative of cadmium concentrations in other locally grown pigeon peas is unclear; but the significant uncertainty in the evaluation stresses the need to conduct further sampling.

4. Preliminary evaluation results and the totality of the available data suggest a potential for uptake of metals from soil into food crops—thus further investigation is warranted. To evaluate better this exposure pathway, ATSDR has recommended a collaborative effort to conduct additional sampling of locally grown foods.

5.3.2. Recommendations

ATSDR supports additional sampling and collaborative data collection to evaluate more thoroughly this human exposure pathway. The following recommendations are intended to promote collection of high quality data of maximum utility, and to minimize data uncertainties:

1. Sampling data should represent edible portions of a cross-section of local produce from local farms, home gardens, and local markets. Sample produce that tends to accumulate heavy metals more easily (e.g., leafy vegetables such as lettuce and spinach) rather than leaves of grain or fruit crops.

2. Survey residents to identify the prevalence and type of locally grown and commonly consumed garden produce. Sampling plan design should include produce types identified from this survey.

3. Collect representative surface soil samples at the same location and time that garden and farm produce samples are taken. Soil samples should be of appropriate depth to represent the root zone.
4. Collect samples of meat and milk products from Vieques forage-consuming livestock.
5. To avoid false high or low values, sample collection and analysis should conform to high standards of data quality, including detailed quality assurance/quality control information, standard reference materials for analysis, and background correction. Design the sampling plan to collect a sufficient number of samples to ensure high statistical confidence.
6. Collect samples from an appropriate background or control location for comparison with food samples produced on Vieques.
7. To facilitate exposure assessment, report data as consumed (wet weight).
8. Plan and conduct sampling protocols in collaboration with local scientists. One way to avoid misunderstandings about the data is for local scientists and an independent expert jointly collect and split several samples and provide analytical reports with QA/QC supporting information. A QA/QC standard could be split at the time the samples are collected.
9. Request technical assistance from the U.S. Food and Drug Administration (FDA) or the U.S. Department of Agriculture (USDA) in sample collection and analytical protocols. The USDA Agriculture Research Service has offered to provide, if requested, technical assistance in sampling plan design, collection, and analysis with proper QA/QC protocols.

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6. Air Pathway

Chapter 6 Summary

This chapter reviews how potential airborne exposures to contaminants from military operations at the former Vieques Naval Training Facility might have affected Viequense residential areas. Although our review draws primarily from sources used in the 2003 ATSDR Air PHA, we also summarize air monitoring data and air dispersion studies developed or collected after publication of the 2003 Air PHA. These later data assessed effects of ongoing or proposed open detonation or open burning and included site-specific meteorological data collected after 2003.

We further evaluate the modeling process used in the 2003 Air PHA, the assumptions and data used in that modeling process, and compare the results with monitored data collected during recent open burning events. While this review finds the Air PHA modeling process consistent with established practices, it does identify two minor errors in estimating detonation source concentrations. These errors, however, do not affect the results or conclusions of the Air PHA.

Collectively, the available sampled and modeled data are adequate for the determination of any potential public health hazard arising from exposure to airborne contamination. By overestimating numerous aspects of the contaminant emissions and by assessing exposures for worst-case conditions, the 2003 ATSDR air dispersion model adequately addressed uncertainties inherent in the air dispersion modeling process.

The model results indicate that in the residential areas of Vieques, airborne contaminants from historic military exercises on the Vieques Naval Training Range would have been essentially nondetectable and unlikely to have resulted in harmful effects. These results are supported by post 2003 air monitoring studies conducted in support of the ongoing site remediation.

6.1. Introduction to Air Pathway

In 1980, not long after ATSDR's inception, Viequenses began to ask the agency whether the island's air was safe to breathe. The residents were and are concerned about contaminants released to the air during the Navy's military training exercises. These exercises included the Navy's past use of explosive ordnance (early 1970s to April 1999), as well as exercises using inert ordnance (May 2000 to May 2003).[24] Among other concerns, Viequenses questioned whether toxic dusts from the explosive-ordnance range could have blown into their neighborhoods.

During the time the Navy still conducted explosive-ordnance exercises on Vieques, three air-sampling studies occurred (1972, 1978, and 1979). Direct references for these studies are not available, but other documents reported and summarized the results (TAMS 1979; Cruz Pérez 2000). Appendix C of the Air PHA (ATSDR 2003) includes a review of the studies' data, the availability of that data, and each dataset's limitations. The Puerto Rico Environmental Quality Board conducted two of these studies, and the Navy conducted the other. None of the studies' measurements detected air pollution at levels of health concern. Those conclusions are limited by the small number of air sampling locations and the small number of measured analytes. And because those historic sampling studies did not employ data quality control procedures that are accepted today, the studies could not conclusively determine by current standards whether airborne contaminants were present in Viequense residential areas.

Thus ATSDR could not base health conclusions on these studies alone. Modeling, however, could provide another dataset that might clarify earlier findings.

When ATSDR first began evaluating the air pathway, two dispersion-modeling studies were available that produced distinctly different conclusions about potential exposures to particulate matter on Vieques. One was prepared by Navy contractors (IT 2000) and a second by Dr. Cruz-Pérez, a local professional engineer (Cruz Pérez 2000). As part of the 2003 PHA process, ATSDR hired three independent air modeling experts to review the studies. Appendix D of the Air PHA includes a summary and review of each of the modeling studies. After receiving feedback from the external reviewers, ATSDR decided to conduct an additional, independent modeling study using recommendations from the peer reviewers. Note that given the limited extent of air sampling that occurred at Vieques while the Navy used explosive ordnance, modeling was necessary. Appendix D in the Air PHA contains model documentation, including defining assumptions and results.

6.2. Assessment of Available Data

6.2.1. Assessment of Air Exposures in the Public Health Assessment

To estimate effects of explosive ordnance on air quality, ATSDR used a modeling analysis that evaluated 86 different contaminants known to be released to the air when ordnance explodes (49 organic compounds, 29 metals, 5 explosive compounds, plus chaff, depleted uranium, and particulate matter

[24] The Air Public Health Assessment includes a more complete summary of the Former Vieques Naval Training Facility operational history.

such as PM10). The model results found that as dust and smoke traveled from the explosive-ordnance range toward areas where people lived, chemicals released to the air by explosions dispersed to extremely low levels. For most contaminants, the predicted air quality effects at residential areas were so low that even if highly sensitive air sampling devices were in place they likely could not measure such low levels of the contaminants.

For example, particulate-matter contaminants emitted during explosive ordnance exercises were predicted to account for less than 1 percent of the particulate-matter[25] concentrations measured in Viequense residential areas.

This comparison suggests that LIA emissions had a small effect on residential air quality. Using this modeling analysis and the previously referenced air sampling data, ATSDR concluded that of the 86 contaminants evaluated that might have been part of emissions from the former Vieques Naval Training Range, by the time they reached the residential areas of Vieques none exceeded any health comparison values. In other words, even the total effect of the chemicals combined did not result in residential air pollution.

From May 2000 through May 2003, the Navy conducted military training exercises with inert (nonexplosive) ordnance. During 2000–2001, the Puerto Rico Environmental Quality Board conducted ambient air monitoring at two stations in Viequense residential areas. On days when such inert ordnance fell on the explosive-ordnance range, the Puerto Rico Environmental Quality Board collected more than 50 particulate-matter samples in the residential areas of Vieques. These data and supporting information are reported in the U.S.EPA Air Quality System (AQS)—formerly the Aerometric Information Retrieval System (AIRS)—and summarized in the Air PHA (Appendix C). In every sample, the levels of particulate matter were much lower than health-effects levels. In fact, no clear relationship was ever established between the quantity of inert ordnance dropped in the LIA and the levels of air pollution measured in the island's residential areas. These observations on estimated contaminant air concentrations led ATSDR to conclude that on days when inert ordnance fell into the LIA, levels of air pollution did not pose a health hazard to the island's residents.

In addition to the modeling study and the analysis of historic air monitoring data, ATSDR conducted on-site air monitoring during the June 2001 Navy air-to-ground, inert ordnance exercises. The results of this sampling effort are documented (ERG 2001), and the Air PHA describes their limitations. Due to station location/siting problems (as discussed in the Air PHA), the sampling data do not meet applicable quality control standards. The measured contaminant concentrations are nonetheless consistent with the public health conclusions.

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[25] The term "particulate matter" refers to solid particles and liquid droplets in the air. PM10 and PM2.5 refer to particulate matter having aerodynamic diameters less than or equal to 10 and 2.5 microns, respectively. Also note that while current emphasis on the health effects of particulate matter focus on PM2.5, past health-based standards used PM10. The 2003 Air PHA used PM10 to make direct comparisons with earlier measurements and model results.

The following Air PHA conclusions are based largely on ATSDR's modeling effort and on data from air monitoring stations at Isabel Segunda and Esperanza established and maintained by the Puerto Rico Environmental Quality Board:

- The Navy's ordnance exercises at the LIA did not pose a health hazard in the residential areas of Vieques.
- Wind-blown dust from the explosive-ordnance range did not and does not pose a health hazard to residents.

The Air PHA also contains a thorough review of the then-available modeling studies, the ATSDR modeling study, and other reported air monitoring datasets.

6.2.2. Review of the Air Modeling Process Used in the Air PHA

Eastern Research Group (ERG) and Trinity Consultants conducted the ATSDR air modeling study to evaluate potential air exposures from historic operations at the former Vieques Naval Training Range. The Air PHA and a follow-up report (Wilhemi et al. 2006) describe the specific procedures, assumptions, and results of the modeling effort. Trinity Consultants conducted the "Calpuff" dispersion modeling and submitted the results to ERG (Trinity Consultants 2002).

Direct measurement of airborne emissions produced by military ordnance explosions is not possible.[26] Quantitative modeling, however, is a useful approach for assessing potential emissions produced by explosive ordnance events. To evaluate potential exposures to airborne contamination, the Air PHA used the following modeling procedure:

1. Make health-protective estimates of airborne emission concentrations from individual ordnance items using the Combined Obscuration Model for Battlefield Induced Contaminants (Army Research Laboratory 2000);
2. Use a U.S.EPA-accepted air dispersion model (Calpuff) to estimate event-specific, health-protective, 24-hour and annual contaminant concentrations at points of maximum off-site exposure;
3. Calculate maximum daily and annual contaminant concentrations at off-site exposure points using documented ordnance usage data to scale up the event-specific, dispersed-contaminant concentrations; and
4. Evaluate the potential public health effects of exposure to those contaminants by comparing the estimated maximum 24-hour and annual contaminant concentrations with appropriate health comparison values.

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[26] The blasts would destroy the monitoring equipment; indirect downwind sampling is possible, however.

This review finds that the overall rationale for that approach is sound, and each of the assumptions underlying the selection of model parameters is well documented in the Air PHA and in the literature (text and Appendix D; Wilhemi et al. 2006). The modeling procedure was developed from comments and recommendations by external, independent reviewers who assessed the existing studies.

A number of factors or model assumptions within the 2003 study collectively led to an intentional overestimation of potential exposures, thus helping to ensure the conclusions are health-protective:

- Overestimate particulate emission rates from explosions by assuming all particulates are composed of the PM10 fraction (larger particles not susceptible to significant air dispersion are included as PM10).
- Overestimate emission rates of explosives (e.g., TNT, RDX, HMX, aluminum powder) by assuming 10% of explosives are not consumed in the explosion and are available for dispersion. By contrast, available data show that less than 1% of explosives remain after detonation.
- Because of variations in explosive composition of different ordnance types, maximum composition percentages of TNT, RDX, and aluminum powder were assumed to comprise collectively more than 125 percent of total explosive use.
- The emission estimates also assumed that all ordnance dropped, fired, or launched into the LIA exploded, and that all emissions emanated from a single-source location. Thus bombs exploding in multiple locations would spread the emissions over a relatively large area, leading to greater dispersion and lower concentration at any single downwind site.
- Potential exposure evaluations are all based on worst-case meteorological conditions for both 24-hour and annual exposures for a person living directly on the site boundary (i.e., the location of highest off-site concentration estimates). Residential areas are at least 3 miles farther west which, for off-site residents, would result in commensurately lower exposure doses.

Three EXCEL spreadsheets developed by ERG (METALS.xls, ORGANICS.xls, and EXPLOSIVES.xls) contain the modeling study's specific results. These spreadsheets were transmitted to ATSDR via e-mail (John Wilhelmi, ERG, to Mark Evans, ATSDR, personal communication, 2009 Dec 3). A review of the spreadsheets has revealed two minor errors or discrepancies.

First, metals concentrations within the particulate plume are calculated by adding metals in the explosive compounds, metals in the ordnance casing, and metals in the soil ejected into the air by the explosion. Concentrations of explosives (e.g., TNT, RDX, and HMX) present in Live Impact Area soils are not similarly accounted for in assessing plume concentrations of those materials. Still, because the concentrations of explosives compounds of LIA soils are so low, the relative contribution from soil ejecta is insignificant.

As an example, the concentration of TNT in LIA soil averages 2.9 parts per million (ppm). Maximum annual emissions of TNT as soil ejecta (based on the TNT soil concentration of 2.9 ppm) would be approximately 1.6 pounds per year (or 0.00027 pounds per hour; based on 5,840 hours per year operations). In comparison, the ATSDR air dispersion model assumes that airborne emissions from undetonated TNT in bombs (assuming 10% of TNT does not ignite) is 10.76 pounds *per hour*. If only 5% of TNT remains after the explosion, this hourly TNT emission rate becomes 5.38 pounds *per hour*. Considering that available studies show less than 1% of TNT does not ignite, the amount of TNT in the air is overestimated and, relative to the overestimate from TNT ignition, the contribution from TNT in soil ejecta is very small.

The second discrepancy detected in the ERG spreadsheets concerns calculation of maximum 24-hour emission rates of metals in air particulates. This calculation neglected to include a conversion factor for adjusting emission rates in pounds per hour to emissions in grams per second. Considering that an emission rate of 1 pound per hour is about 8 times greater than an emission rate of 1 gram per second, the use of an input value 8 times too large results in an eightfold overestimate of the maximum 24-hour emission rate. Collectively, however, the discrepancies in the air dispersion modeling process do not significantly affect the results or conclusions expressed in the 2003 Air PHA.

The Air PHA's Appendix E contains 39 comments on the modeling process and the PHA conclusions, and ATSDR's responses to those comments. We reviewed those comments and responses to ensure that each response adequately addressed each concern. This review finds that the responses were appropriate and provided adequate support for the Air PHA assessment procedure and the resultant public health conclusions.

We note, however, one specific concern and the response thereto (Air PHA, comment/response #8, Appendix E). The stated concern was "No data is (sic) available related to PM2.5 . . ." The response indicates that in fact PM2.5 was not explicitly modeled. But it is addressed by making the most health protective assumption possible (i.e., that the estimated PM10 concentrations consisted entirely of PM2.5 particulates). Thus the annual average and maximum 24-hour concentration increases caused by explosive ordnance events (0.04 µg/m^3 for annual average; 10.2 µg/m^3 for 24 hour average) would still be (from the 2003 Air PHA):

> " . . . considerably lower than EPA's current (PM2.5) health-based standards (15 µg/m3 for annual average, and 65 µg/m^3 for 24 hour average concentrations). Therefore, the modeling data indicate that air emissions of particulate matter, whether coarse or fine, from the military training exercises were not at levels of health concern for the residential areas of Vieques."

6.2.3. Post-PHA Air Monitoring and Air Modeling Studies

After the Air PHA's release, the Navy conducted additional air monitoring and modeling related to the "Time Critical Removal Actions" for the blow-in-place (BIP) munitions detonations. That is, for the removal of dropped, launched, or fired unexploded ordnance and for a planned effort to burn vegetation from the live-ordnance training areas. These efforts were designed to allow safe access to historic live fire areas, and were documented in a series of reports:

1. Air Dispersion Modeling of the TCRA/BIP Activities on the Former Vieques Naval Training Range, Draft (US Navy Contract Task Order 0047, February 2007; prepared by CH2MHill, Herndon, VA).

2. Air Dispersion Modeling for TCRA-Prescribed Vegetation Burns on the Former Vieques Naval Training Range, Draft Final (US Navy Contract Task Order 0047, June 2008; prepared by CH2MHill, Herndon, VA).
3. BIP Air Monitoring Data Summary Report for the Former Vieques Naval Training Range: August 2005 through December 2006, Draft (US Navy Contract Task Order 0047, February 2007, prepared by CH2MHill, Herndon, VA).
4. BIP Air Monitoring Data Summary Report for the Former Vieques Naval Training Range: January 1, 2007 through March 31, 2007, Draft (US Navy Contract Task Order 0047, June 2007, prepared by CH2MHill, Herndon, VA).
5. BIP Air Monitoring Data Summary Report for the Former Vieques Naval Training Range: April 1, 2007 through June 30, 2007, Draft (US Navy Contract Task Order 0047, January 2008, prepared by CH2MHill, Herndon, VA).
6. BIP Air Monitoring Data Summary Report for the Former Vieques Naval Training Range: January 1, 2008 through June 30, 2008, Draft (US Navy Contract Task Order 0047, February 2009, prepared by CH2MHill, Herndon, VA).

The air monitoring data summaries describe real-time, on-site (downwind) sampling events conducted before, during, and after 51 in-place ordnance detonation events at the LIA. The information in these reports shows that the monitoring analyses were conducted using accepted methods, and that the results were within acceptable limits for sampling and analytical quality assurance.

Analytes measured were PM10, metals, and explosives at hourly or 8-hour intervals. Measurements were summarized as 8-hour or 24-hour averages. No explosives or metals in any of the air samples have been reported in concentrations above regulatory or applicable health based standards. One detonation event might have ignited surrounding vegetation; it resulted in a 24-hour, PM 10 value of 153 µg/m3—just above the NAAQS standard of 150 µg/m3. This measurement, however, was taken at an on-site location immediately downwind of the detonation site. None of the 51 detonation events produced elevated PM 10 measurements at stations closer to areas of potential off-site exposure. The exposure levels for metals are more than 10 times below the health guideline. Thus interaction effects between chemicals are not likely, and additive or synergistic effects between chemicals are not likely to enhance the mixture's toxicity. In sum, harmful effects from the mixture of chemicals in air are not likely (ATSDR 2004).

An air dispersion model conducted in support of the BIP detonations (CH2MHill 2007a) supports the measured monitoring results. This modeling study used a different air dispersion model (Open Burn/Open Detonation Dispersion Model; Bjorkland et al. 1998) and site-specific meteorological data unavailable when the Air PHA was conducted. The results of this air dispersion model also support the monitoring results and the conclusions of the ATSDR modeling study. Estimated airborne contaminant concentrations from BIP events at areas of potential off-site exposure "are below both regulatory standards and reasonable analytical detection limits for all compounds."(CH2MHill 2007a).

The air dispersion modeling of the BIP detonations (CH2MHill 2007a) used meteorological data collected from the Camp Garcia airfield on Vieques. These site-specific windspeed and direction data for the year 2005 were not available when the ATSDR PHA was conducted. Instead, the ATSDR air dispersion model used then-available meteorological data from the Roosevelt Roads Naval Station and the San Juan Airport station.

Figure 6-1 shows wind rose diagrams for Camp Garcia, the San Juan LM Airport, and the Roosevelt Roads stations (from CH2MHill 2007a). The Camp Garcia site is in a shallow topographic bowl on the south central portion of Vieques. The 2005 wind rose reflects this location with the predominant wind directions blowing from the northeast, while the San Juan LM Airport and Roosevelt Roads predominant wind directions are similar, but more southeasterly and easterly. Average annual wind speeds for the Roosevelt Roads and San Juan LM Airport stations are about two to four times greater than for the Camp Garcia station (2.88 and 4.10 vs. 1.46 m/sec, respectively). No long-term meteorological data are available for the LIA. The residential areas of Vieques are west of the LIA; the use of wind data that maximizes the easterly component of dispersion and uses a higher annual average wind speed provides a health-protective estimate of contaminant transport. That is, application of the Camp Garcia wind data would tend to disperse more contaminants a shorter distance and more toward the ocean (to the south), with lesser amounts to residential areas (to the east).

In addition to the recent evaluation of BIP detonations, the Navy has proposed prescribed burning of LIA vegetation to access safely and to remove remaining unexploded ordnance. In support of this proposal, the Navy has conducted additional air modeling to assess the potential effects of such prescribed burning (CH2MHill 2008a). Although the Air PHA did not address vegetation burning, it did address past operations of open burning/open detonation (OBOD) of excess or recovered ordnance. As the mass of ordnance involved in past OBOD events was small relative to the mass involved in then-ongoing Naval operations, the 2003 Air PHA found that air emissions from past OBOD events did not present a public health hazard to Viequenses.

The 2003 Air PHA included an assessment of the public health significance of exposure to dust from African storms based on measured or estimated PM10 concentrations and found that PM10 exposures attributed to such dust storms were not a public health hazard. At the time of publication of the Air PHA, there were no data available on the chemical-specific makeup of dust from these storms. A recent study by Gioda et.al. (2007) presented PM10 and metals concentrations from air samples for several Puerto Rican locations, including Vieques, which makes such chemical-specific data available. This study was able to correlate seasonal, measured air particulate concentrations at Vieques and other Puerto Rican locations with African dust storms. Most of the metals analyzed in these samples (cadmium, cobalt, copper, iron, nickel, lead, and vanadium) were well below their applicable health comparison values and do not represent a public health hazard.

The annual average arsenic concentration of 0.0003 $\mu g/m^3$ is just above the comparison value of 0.0002 $\mu g/m^3$, which is based on health protective exposure assumptions, a lifetime excess cancer risk of 0.000001, and the U.S.EPA unit inhalation cancer risk of 4.3e-3 (per $\mu g/m^3$). Using the Gioda et.al. (2007) data, the estimated lifetime excess cancer risk for inhalation exposure to arsenic on Vieques is

$0.0003\ \mu g/m^3 \times 4.3e\text{-}3$ per $\mu g/m^3 = 0.0000013$

The measured annual average arsenic air particulate concentration and resulting estimated lifetime excess cancer risk at Vieques is midway between other Puerto Rican values and not significantly different from the Fajardo, PR background location identified by Gioda et.al. (2007). Dust from African storms provides a measurable contribution to background particulate loadings at Vieques and other locations only during summer months and thus represents only a seasonal contribution to the predominantly local air particulate loads. Inhalation of specific metals from African dust storms, while contributing to seasonal particulate loads at Vieques and other Puerto Rican locations do not present an explicit public health hazard.

Table 6-1. Average annual concentrations of PM10 and metals: Vieques and Fajardo, PR

	PM10	As	Cd	Co	Cu	Fe	Ni	Pb	V
Vieques	23.6	0.00029	0.00002	0.0002	0.001	0.00033	0.0007	0.0009	0.0025
Fajardo	25.5	0.00023	0.00002	0.00014	0.002	0.00027	0.0008	0.0007	0.0019
CV	50	0.00020	0.01	0.1	150	2200	0.09	0.15	0.2

All data from (Gioda et al. 2007)

All data in $\mu g/m^{3*}$

6.3. Findings

Every environmental dataset, whether based on direct sampled analyses or a modeling approach, includes simplifying assumptions and inherent uncertainties. Analytically measured data assumes the sampling device adequately captures the target substance, that the sampler is at the correct time and place relative to contaminant releases and exposures, and that the chemical/substance analyses produce accurate concentration estimates. Quality control and assurance procedures ensure that field sampling and laboratory measurement processes produce reliable results. That said, however, field-sampling data remain only an estimate of real-world conditions.

Quantitatively modeled datasets, such as the air dispersion model used in the Air PHA, resolve some direct sampling limitations—the modeled datasets allow estimation of results for any time or location. But air dispersion models necessarily include other assumptions, such as relevant contaminant emission rates, appropriate meteorological data, and specific aspects of the site terrain (e.g., topography). All of these site-specific conditions or model parameters influence air movement patterns. As with field sampling methods, air dispersion models also include quality assurance procedures to improve result quality. The Calpuff model used in the ATSDR Air PHA has undergone appropriate regulatory review. The U.S.EPA Support Center for Regulatory Atmospheric Modeling has approved the model for such uses as those employed by ATSDR. See: http://www.epa.gov/scram001.

Model assumptions and input parameters used in the ATSDR study are specifically documented in the 2003 Air PHA Appendix D and further described by Wilhelmi et al. (2006). By overestimating numerous aspects of the contaminant emissions and by assessing exposures for worst-case conditions, the

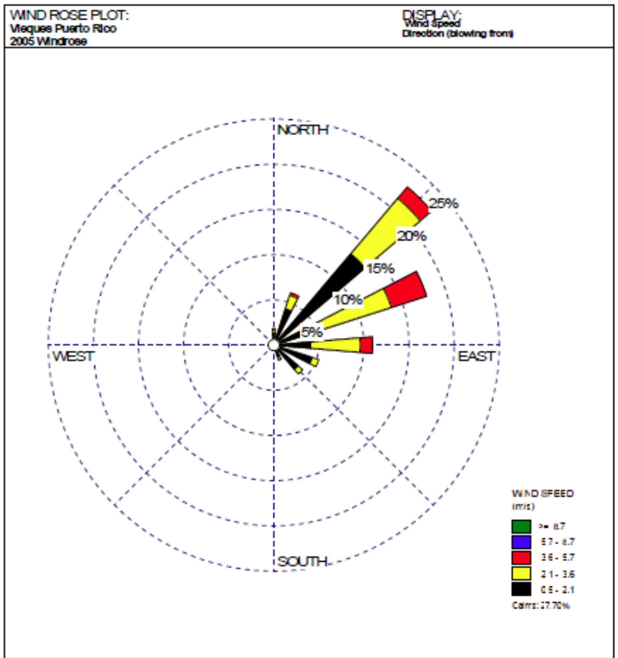

Figure 6-1a. 2005 Wind rose from Camp Garcia, Isla Vieques.

Annual average wind speed is 1.46 meters per second. From CH2MHill 2007a.

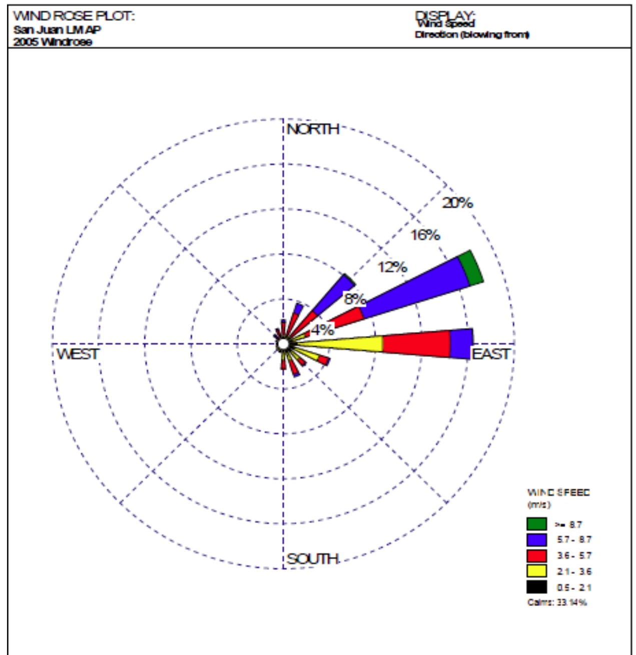

Figure 6-1b. 2005 Wind rose from San Juan LM Airport.

Annual average wind speed is 2.88 meters per second. From CH2MHill 2007a.

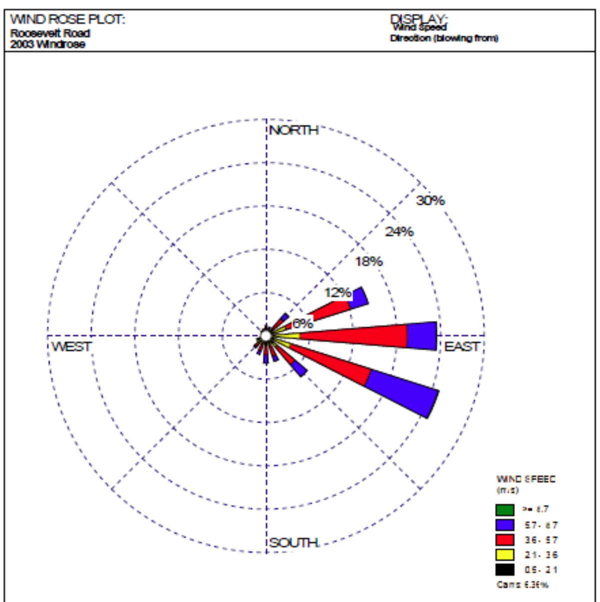

Figure 6-1c. 2005 Wind rose from Roosevelt Roads NAS.

Annual average wind speed is 4.1 meters per second. From CH2MHill 2007a.

uncertainties inherent in this air dispersion model have been adequately addressed. And despite the overestimation of potential exposures, the model results indicate that in Viequense residential areas, airborne contaminants from historic uses of the Vieques Naval Training Range would have been essentially nondetectable. The PREQB's historic and recent air sampling data and the Navy's post-PHA air sampling and air dispersion modeling support these predicted results. Collectively then, the available data are adequate for the conclusions in the Air PHA.

6.4. Conclusions and Recommendations

6.4.1. Conclusions

1. This review of potential airborne exposures within the residential areas of Vieques to contaminants from military operations at the former Vieques Naval Training Facility is based on the following sources of information that were used in the 2003 ATSDR PHA:
   - U.S. Navy records of the types and amounts of ordnance used at the training range,
   - A source term model used to estimate the amounts of material produced by ordnance detonations,
   - An air dispersion model to estimate contaminant transport from the detonation area to the residential areas,
   - Long term meteorological data from the San Juan PR airport and the Roosevelt Roads Naval Station, and
   - Ambient air monitoring in the residential areas conducted by the PREQB for the 2001-2003 time period.
2. Also summarized are air monitoring data and air dispersion studies developed or collected after publication of the 2003 Air PHA for the purpose of evaluating ongoing or proposed open detonation or open burning.
3. This review of potential airborne exposures evaluates the modeling process used in the 2003 Air PHA, the assumptions and data used in the modeling process, and compares the results of that modeling process with monitored data collected during recent open burning events.
4. While this review finds the Air PHA modeling process consistent with established modeling practices, it does identify two minor errors in estimating detonation source concentrations. One results in an overestimate of metals concentrations. The other results in a minor underestimate of explosion byproducts in entrained soil that is overcompensated by the overall estimate of explosive compound concentrations. These errors do not affect the results or conclusions of the Air PHA.
5. Collectively, the available sampled and modeled data are adequate for the determination of the potential public health hazard from exposure to airborne contamination. The uncertainties inherent in the 2003 ATSDR air dispersion model have been adequately addressed by overestimating numerous aspects of the contaminant emissions and by assessing exposures for worst-case conditions. Despite the overestimation of potential exposures, the model results indicate that airborne contaminants from historic uses of the Vieques Naval Training Range would have been essentially nondetectable in the residential areas of Vieques and unlikely to have resulted in harmful effects. These predicted results are supported by the PREQB's historic and recent air sampling data and by the Navy's post-PHA air sampling and air dispersion modeling. Collectively, the available data provide an adequate basis for the public health conclusions in the Air PHA.

6. To conduct its health protective evaluation of potential exposures to airborne contaminants from military exercises at the former Vieques Naval Training Facility, the ATSDR Public Health Assessment used appropriate modeling procedures and available monitoring data. The additional air dispersion modeling and monitoring data conducted after completion of the Air PHA further support ATSDR's public health conclusions. Because past military exercises would not likely have produced measurable concentrations of airborne contaminants in the residential areas of Vieques, no public health basis supports additional air studies or ambient air monitoring efforts related to past military exercises on Vieques.
7. Although the residents of Vieques could hear and possibly feel the explosions from military exercises on the former Vieques Naval Training Range, 8 miles is still a considerable distance. The physics of sound and seismic wave migration are very different from the physics of atmospheric dispersion of airborne particulates and gases.

6.4.2. Recommendations

No further recommendations at this time.

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7. Soil Pathway

Chapter 7 Summary

The following chapter evaluates the available data and information on Vieques soil contaminants and whether accidentally swallowing soil could make people sick. Indirect effects of soil contaminants through the terrestrial food chain are considered separately in Chapter 5, "Local Produce and Livestock Pathway." ATSDR evaluated potential direct soil exposures in two situations: people who stayed on the LIA property during 1999–2000 protests and people who live in the island's residential areas.

Sufficient data are available to conclude that people who lived on the LIA during protests were not exposed to soil contaminants at levels high enough to cause adverse health effects. In the island's residential areas, no soil data are adequate to characterize potential exposures fully. Nevertheless, consideration of soil data from other island locations and consideration of how contaminants might be transported through the air to residential areas suggests that in the island's residential areas, exposure to military activity-related soil contaminants is not high enough to result in adverse health effects. Since ATSDR's 2003 Soil PHA, more soil data have become available through investigations of known, localized areas of contamination on military lands. These were not areas accessed or occupied by the protesters, so they do not affect the conclusions drawn for those exposures. They are also not from the residential portion of the island; therefore, they do not improve the residential evaluation.

The recent data, along with the known presence of unexploded ordnance at the LIA, support the need for continuing to restrict access to the LIA and to other potentially contaminated military areas and the need to continue environmental assessment and remediation activities. To address remaining uncertainties about residential soil contamination issues, ATSDR recommends surface soil sampling in the island's residential areas.

7.1. Introduction to Soil Pathway

Several studies have examined soil contaminant levels in the Live Impact Area and elsewhere on Vieques. ATSDR evaluated the available data to determine potential effects for two situations: people who lived in areas of the LIA during 1999–2000, and people who lived (in the past and currently) on residential portions of the island. The chapter includes the following subjects:

- Ways in which people may be exposed to soil contaminants and ATSDR's focus in this chapter on direct exposures;
- Documentation of available soil data, including a discussion of the strengths and limitations of the data for assessing exposures in the LIA or the residential portion of the island and a fresh analysis of the exposures of interest focusing on uncertainties in the available data; and
- Discussion of how the above analysis might be affected by recently collected soil data in areas of concern or areas not affected by aerial bombing exercises, and a discussion of other considerations raised by interested parties related to soil exposures.

7.1.1. Soil Exposure Pathways

Environmental contaminants directly and indirectly affect the health of the planet and the people on it. ATSDR focuses on identifying exposures that might directly affect human health. For soil, we look at whether the small amount people might accidentally swallow or touch could contain enough of a particular chemical to cause health effects. Contaminated soil might also affect plants growing in it, which people might eat. And people might eat the animals that eat the plants growing in that contaminated soil. ATSDR considers such *exposure pathways* by looking at contaminant levels in the plants or animals that people actually use or eat. Characteristics of the contaminants, the soil, and the plants all affect the potential for plant uptake of contamination and may be important for food, medicinal, or ceremonial use of the plants or the animals feeding on them. For further information on exposure from plants or animals possibly affected by soil contaminants, please see Chapter 5 of this report, "Local Produce and Livestock Pathway."

ATSDR identified several ways soil contaminants might directly affect Viequenses. We considered past (i.e., both during military exercises and after), present (i.e., the past few years, after cessation of military exercises), and future potential soil exposure pathways. Table 7.1 below lists the identified direct-soil exposure pathways.

For evaluating soil exposures from accidentally swallowing or touching soil, surface soil data are preferred. Generally, in day-to-day activities people are assumed to contact only the top few inches of soil. Household dust is also considered a soil pathway constituent, given that soil may contribute contaminants to dust when it is brought indoors on shoes or hands. Windblown soil may contribute contaminants to surface soil, but its health effects are generally considered part of the air pathway. This section lists considerations on the air pathway's contribution to soil exposures, presumed to be the mechanism by which residential soil would have been initially contaminated by aerial bombing exercises several miles away in the LIA.

Table 7-1. Direct soil exposure pathways to people on Vieques

Time Frame: Past	***Point of Exposure***	***Exposed People***	***Status***
Accidentally swallowing or touching airborne dust blowing from past military activities	Residential Area of Island	Residents of Vieques	No historical data; no way to confirm model predictions
Accidentally swallowing or touching surface soil or household dust contaminated by past military activities	Residential Area of Island	Residents of Vieques	No historical data; no way to confirm assumptions, except perhaps for inorganics
Accidentally swallowing or touching surface soil while residing on Live Impact Area (during 1999 and 2000)	Live Impact Area of Navy Property	Protesters Occupying Beach Camps	Surface soil results available for the period and location of interest. Evaluated in Previous Assessment
Accidentally swallowing or touching surface soil or subsurface soil while conducting construction or excavation activities	Current and former Navy Properties	Navy Personnel or Contractors	Not evaluated at this time; focus on residents

Time Frame: Present	***Point of Exposure***	***Exposed People***	***Status***
Accidentally swallowing windblown dust from Live Impact Area	Residential Area of Island	Residents of Vieques	Current Live Impact Area soil data show contaminants too low to harm health; therefore same conclusion for windblown dust
Accidentally swallowing or touching previously contaminated surface soil or household dust	Residential Area of Island	Residents of Vieques	No data available; could collect to confirm conclusions based on other locations
Accidentally swallowing or touching surface soil in restricted access navy activity areas	Current and former Navy Properties	Navy Personnel or Contractors; Trespassers	Current data available at specific locations; few contaminants above safe levels used for screening; difficult to generalize
Accidentally swallowing or touching surface soil or subsurface soil while conducting remedial activities	Navy Property	Navy Personnel or Contractors	Not evaluated at this time; focus on residents
Time Frame: Future (Potential)	***Point of Exposure***	***Exposed People***	***Status***
More frequent exposure of civilians to surface soil in navy activity areas or former navy land	Current and former Navy Properties	Residents of Vieques	Specific areas need sampling / assessment before opening to public

7.1.2. Assessment of Available Data

Several investigations have analyzed Vieques soil samples:

- In 1972, the U.S. Geological Survey collected and described metals concentrations of samples of the soil's "C" horizon—in general, the parent rock beneath the surface soil and subsoil layers (Learned et al. 1973). This sampling was a reconnaissance geochemical survey for metals only and included 420 samples across the entire island. In a later report the data were re-reported (Marsh 1992).
- In 1978, soil samples collected from four locations within the Live Impact Area (LIA) and two locations in the Eastern Maneuver Area (EMA) were analyzed for explosives and explosion combustion products (Hoffsommer and Glover 1978; Lai 1978). The exact sampling locations and depths were not given in the reports describing this sampling.
- In 1998, to describe existing conditions before a proposed airport expansion project, five soil samples (4–12 inches below ground surface) from an area of the Naval Ammunition Support

Detachment (NASD) buffer zone were collected and analyzed for a range of potential contaminants (PMC 1998).

- In 1999, about 33 surface soil samples (0–6 inches below ground surface) were collected along the western border of the EMA and analyzed for explosive compounds (CH2MHill and Baker 1999).
- In 1999 and 2000, soil and sediment samples from 55 locations were collected from the LIA and other locations and analyzed for metals and other inorganic compounds (Garcia et al. 2000). The report describing this sampling event states that samples were collected from direct bomb-impact locations, stormwater runoff areas, adjoining conservation zones, and civilian areas, but exact locations of sampling and exact sampling depth and procedures were not given. Only the highest and second highest contaminant concentrations detected for 25 sample locations within the LIA were reported.
- In 2000, 37 surface soil samples (0–6 inches below ground surface) were collected within the LIA and adjoining conservation zones, including specific areas in the LIA occupied by protesters in 1999 and 2000 (CH2MHill 2000). These samples were analyzed for metals and explosives. Samples from the LIA were targeted to bomb craters or collection areas for stormwater runoff deemed likely to contain the highest level of explosive contaminants. Samples from protester camps were collected from locations thought to be representative of the general area.
- In 2001, to describe background conditions at the NASD, 24 surface soil samples (0–6 inches below ground surface) were collected and analyzed for inorganic compounds (CH2MHill 2002).
- Since 2003, several investigations of sites in the EMA, the Surface Impact Area (SIA), and the NASD have included surface soil sampling of between 4 and 50 samples per site (CH2MHill 2007a-c; 2008a-e). These investigations focused on known, localized areas of concern affected by Navy activities other than aerial explosive-ordnance exercises.
- In 2007, 40 surface soil samples (0–6 inches below ground surface) were collected from areas of East Vieques not obviously affected by Navy activities. The samples were analyzed for inorganic compounds to describe background conditions on eastern Vieques (CH2MHill 2007d).

7.1.3. Strengths and Limitations of Available Data for Assessing Soil Pathway

Some of the above-listed data are not appropriate for assessment of residents' exposure to contaminants in Vieques soil. Thus to assess potential soil exposures, ATSDR focused on two pathways: exposures to protesters who occupied parts of the LIA in 1999 and 2000, and exposures to bomb-related contaminants of people in the island's residential area. The following section describes the strengths and limitations of these applicable, available data.

7.1.3.1. Protesters Living in the Live Impact Area during 1999–2000

Although limited in number, the CH2MHill 2000 data are otherwise ideal for assessing exposures to protesters during 1999–2000: they match the locations and time people may have been exposed. Less specific information is known about the locations, analysis, and results reported in Garcia et al. (2000), but the samples were taken at the same general area and at the appropriate time. In both sets of data, samples from the LIA were selected from areas thought to be the most contaminated (i.e., bomb craters and stormwater runoff collection areas). The samples then were intended to describe conservatively the contaminant levels within the LIA. But the small number of samples compared with the large land area of the LIA leaves a great deal of uncertainty as to whether actual “worst case” samples were collected. This is a common limitation of environmental sampling. A further limitation of both datasets is that they only apply to periods near the protester occupation. Finally, evaluating these datasets for health hazards of chemical constituents gives little information about other serious hazards of LIA occupation, such as physical hazards posed by unexploded ordnance.

7.1.3.2. Exposures in the Residential Area of the Island

Because of current Navy property access restrictions, most exposures today would occur only in the island’s residential areas. But the only data from the residential areas are the 1972 geological survey data, which just describe the soil’s “C” horizon[27] and just analyze for metals content. These data were distributed across the residential and other areas of the island. They may not provide accurate or complete information about the surface soil people accidentally swallow or touch in their day-to-day activities. Although other data contain more complete contaminant information for soils at the surface, they were collected from uninhabited parts of the island. One limitation of these data in describing exposures is that they may not accurately represent residential exposures. Nevertheless, despite the limited nature of the available data on residential soil contaminant levels, ATSDR accessed a combination of information related to soil contaminant levels elsewhere on the island. ATSDR used this information 1) to model predictions of how contaminants could be transported through air to residential areas, and 2) to reach scientifically based conclusions about the likelihood of military exercises contaminating residential soil at levels that could cause health effects. More information on the uncertainties posed by using limited data to evaluate soil exposures is provided below in 7.2, the Analysis section.

7.2. Analysis

Among other Vieques health concerns ATSDR received were those related to contaminant exposure from military exercises involving explosive-ordnance in the LIA. Because of current Navy property access restrictions, most exposures would take place today only in the island’s residential areas. During 1999 and 2000, however, some protesters did occupy areas of the LIA. The following sections discuss the data available for assessing direct soil exposures of protesters living in the LIA during that period, and of Viequenses generally at other times in the past or present. In addition, surface soil sampling data obtained since ATSDR’s previous evaluation in 2003 are discussed as they relate to assessing potential soil pathway exposures.

[27] In general, the parent rock beneath the surface soil and subsoil layers.

7.2.1. Exposures of Protesters in the Live Impact Area During 1999–2000

In 2000, surface soil samples were collected from the specific LIA locations where protesters lived in 1999 and 2000, as well as other LIA locations (CH2MHill 2000). Samples included low-lying areas that stormwater runoff would likely affect. Around the same time, an independent organization also collected soil samples at the LIA and in areas where people lived during 1999–2000 (Garcia et al. 2000). For this sampling, the exact location, depth of sampling, and full results were not reported. Because the Garcia et al. report stated that the intent of the study was to characterize exposure, in its previous evaluation ATSDR considered the results as surface soil samples. This resulted in conservative exposure estimates because Garcia et al. only reported the highest and next-to-highest values detected. ATSDR's inclusion of these reported values in estimating average exposures biased the estimate to the high side.

Although limited in number, the surface soil samples collected during 2000 were nearly ideal for assessing exposures to people occupying the LIA. Both in space and time the samples were representative of the soil people may have contacted while they were there. The CH2MHill 2000 data report included documentation of high standards of data quality such as quality assurance/quality control and chain of custody forms.

In its previous assessment, ATSDR estimated doses using the highest concentration measured in the locations where protesters lived; the doses were all below then-current health effects levels (ATSDR 2003). Some critics of this analysis suggested that people in the camps might have been exposed to contaminants in other parts of the LIA. In response we examined whether our conclusion would change if we used the average inorganic contaminant concentrations measured throughout the LIA as an exposure concentration (a person spending time in both the camp and in other parts of the LIA would have an average exposure over all the surface soils encountered). Although the average exposure concentrations were biased high because the averages included only the maximum and second highest soil measurement detected from the Garcia et al. study (2000), the concentrations were only slightly higher than the maximum camp value used in ATSDR's previous assessment. Following the reasoning of the previous public health assessment, exposure to these concentrations in surface soil would not be expected to result in adverse health effects (ATSDR 2003). ATSDR also looked at surface soil explosives data from other locations of the LIA collected in 2000 (CH2MHill 2000). Although those samples showed rare detections of HMX, RDX, 2-amino-DNT, and TNT, even the highest detected values were lower than screening values.[28] The average soil concentration for every chemical measured is below the respective screening value, indicating that potential mixture effects are unlikely.

Using the available data, we found no indication that protesters living on the LIA in 1999–2000 were exposed to harmful levels of surface soil contaminants. A strength of this conclusion is that the camp data were collected specifically to assess this exposure and were collected to represent the camps where protesters lived. In addition, the LIA samples were collected to assess the most contaminated areas on the LIA, so the conclusions would be based on contaminant levels that were biased high and

[28] Levels at which no adverse health effects would be expected from even continual exposure.

would be more protective. A limitation is that, as with any evaluation of this type, conclusions must be based on a small number of samples. If further sampling were to show the earlier sampling did not result in a conservative or representative description of the area of exposure, the previous conclusions might not be valid.

Another limitation of using these data to assess exposure is that they apply only to the specific scenario described. That is, is the data are restricted to protesters living in camps on the LIA in 1999–2000. In the years long before 1999-2000, contaminant levels (especially explosives) could have been much higher and could have had the potential for short- or long-term health effects (we have no way of obtaining these data today). Also, despite the fact that around the year 2000 the surface soil contaminant levels in the LIA were not high enough to expect adverse health effects, that finding alone does not mean people could safely occupy the LIA. Physical hazards remained, such as unexploded ordnance that could cause immediate injury or death to those who inadvertently disturbed it. Because these hazards remain, limiting access to the LIA and to other contaminated military areas is essential for protecting public health—at least until those areas undergo a complete environmental assessment and cleanup.

7.2.2. Exposures in the Island's Residential Areas

Lack of surface soil data is a major limitation for assessing soil exposure in the island's residential areas. The only soil data available from this section of the island were the 1972 U.S. Geological Survey data (Learned et al. 1973). Although the sample points were well distributed across residential and other areas of the island, the data described only sampling of the soil's "C" horizon (in general, the parent rock beneath the surface soil and subsoil layers). The report did state that at many points the surface soil and subsoil layers were absent (i.e., the parent rock was exposed at the surface). But the specific samples to which this applied were not stated, and the sampling depth and conditions were not available on a sample-by-sample basis. Therefore, whether the "C" horizon data truly represent the surface soil people accidentally swallow or touch in their day-to-day activities is unknown. Moreover, whether the parent rock is exposed or not, analyzing the "C" horizon provides little if any information about surface deposition of airborne contaminants (i.e., the mechanism by which contaminants from explosive-ordnance exercises are believed to reach soil).

Although the residential soil data were limited, ATSDR could use the limited data and other information to reach scientifically based conclusions about the potential for exposures to bombing-related contaminants in residential soil to result in adverse health effects. In its previous health assessment, because the residential data were limited, ATSDR used the USGS data and several other data sources from different areas of the island to evaluate the potential for residential exposure to soil to harm health (CH2MHill and Baker 1999; CH2MHill 2000; Garcia et al. 2000; Hoffsommer and Glover 1978; Lai 1978; Marsh 1992; PMC 1998). The evaluation included data from

- The LIA,
- The Eastern Maneuver Area (EMA),
- The EMA border,

- The residential area, and
- The Naval Ammunition Support Detachment (NASD).

ATSDR first compared a particular contaminant's highest level found in any sample with screening levels below which no health effects would be expected. Contaminants above the screening level were evaluated further by estimating exposure doses based on an average soil concentration. None of the contaminants in soil were at levels expected to result in harmful effects (ATSDR 2003).

The soil pathway public health evaluation conforms to ATSDR procedures for reaching public health decisions when only limited environmental data are available. In addition, the air modeling results, discussed in the previous chapter, support the hypothesis that exploded or unexploded ordnance did not contaminate residential soils to harmful levels. Models indicated that airborne contaminants would disperse to undetectable levels away from the Live Impact Area.

Although the analysis of all the information indicated that health effects from exposure to contaminants in residential soil are unlikely, a point that needs reiteration is that the previous assessment's assumptions contain uncertainty. When using discrete environmental samples to describe a large area, uncertainty is always present. This is particularly true when data collected at one location form the basis for conclusions about another, unsampled location. Additional data uncertainties include

- Averaging soil results that might include subsurface samples is not necessarily representative of the concentrations present in the surface soil that people in their normal activities accidentally swallow or touch.
- Each investigation might have a different focus and might analyze for different sets of contaminants. Also, while inorganic contaminant levels are expected to remain relatively stable over time, other contaminant levels (e.g., those of volatile compounds, certain explosives) in surface soil might, through volatilization or chemical or biological degradation, be significantly reduced over time. Therefore, even if surface soil sampling were available, the results might not represent completely all potential past exposures.
- The majority of the more recent surface soil data were collected in the LIA. Because the LIA was the focus of a citizen's petition then under consideration, ATSDR's previous assessment concentrated on describing potential residential soil effects using LIA data. Because contaminants from the LIA would be dispersed by the time they reached the residential area, using LIA data was assumed to represent "worst case" exposures possible from LIA activities. But Vieques was the site of past military activities other than those involving explosive ordnance (e.g., transportation, storage, general training). Conceivably these activities—or even nonmilitary activities—could result in different contaminant profiles in the residential portion of the island compared with the LIA.

Such data limitations aside, ATSDR still maintains that any low-level, current residential area soil exposures to explosive ordnance-related contaminants in the LIA are unlikely to cause health effects. First, recent surface soil sampling in the LIA did not show contaminant levels of health concern. Second, air modeling indicates that any windborne contaminants from the LIA would be dispersed to undetectable levels away from the LIA. Nevertheless, given the uncertainties described above, ATSDR has updated its previous conclusion (ATSDR 2003) to acknowledge these limitations and indicate that the historical data are insufficient to allow us to determine whether past exposures to explosives or other compounds in surface soil could have been high enough to increase a past risk of adverse health effects.

7.2.3. Recent Surface Soil Sampling Data on Areas of Concern

Since ATSDR's first assessment, several site investigations in the EMA, the Surface Impact Area (SIA), and the NASD have included surface soil sampling (CH2MHill 2007a-c; 2008a-e). The investigations focused on known, localized areas of concern affected by Navy activities other than explosive ordnance. This means the surface soil samples were probably not representative of residential area surface soils. ATSDR performed a preliminary evaluation of the surface soil results from these investigations, focusing on maximum detections of inorganic compounds above background and detections of organic compounds. Although several sites had contaminants higher than screening values,[29] current access restrictions due to ongoing remedial activity mean exposures to the public are unlikely. In any event, we saw no evidence that contamination associated with areas of concern was present outside the localized area. Examining the contaminants present may nonetheless provide clues to contaminants previously unrecognized but of possible concern in the residential area. For example, certain recent investigations have shown isolated detections of pesticides, semivolatile compounds, explosives, and dioxin compounds. We repeat that we have found no evidence these areas of contamination have spread beyond their isolated, local areas. Agencies responsible for characterizing the nature and extent of contamination in the future should ensure that all potential sources and contaminants are considered.

7.2.4. Recent Background Study Data

Recent soil background studies at the NASD and on East Vieques (the EMA) characterized the soils in areas not "impacted" by Navy operations—that is, not close to known, localized areas of concern and not in the runoff path from known military operations areas (CH2MHill 2001; CH2MHill 2007d). As described in the previous chapter, evaluation of the air pathway indicates that airborne contaminants would hardly be detectable after dispersing away from the bomb impact area. Examining results from background locations (not directly affected by military exercises) could be a way to confirm that soils are not currently affected by past airborne fallout of contaminants from military operations. The NASD background study, however, only included inorganics, and the East Vieques background study only included inorganics and explosives. While inorganic contaminant levels are usually relatively stable over time, levels of other contaminants (e.g., volatile compounds, certain explosives) in surface soil might, through volatilization or chemical or biological degradation, substantially reduce over time. For this reason, the background soil data were not useful for conclusions about past exposures to explosives or present and past exposures for nonanalyzed potential contaminants.

[29] Levels at which no adverse health effects would be expected from even continual exposure.

In background samples, very few contaminants were present above screening values.[30] Only total chromium slightly exceeded a screening value for hexavalent chromium. Chromium is a naturally occurring element as well as a potential contaminant. In soils it is found in several forms, including the most toxic hexavalent form (ATSDR 2000). Although the relative proportions of all the different forms of chromium were not analyzed, much of the total chromium measured probably consisted of less toxic chromium forms. In the EMA, the explosive 2-amino-DNT was detected in one sample, but it was well below the applicable screening value. The residential area of the island was much farther from the past military activities than were the background samples collected in these investigations. Dispersal would result in contaminant concentrations even lower in the residential areas than in the background sampling areas. These background data, then, further support the hypothesis that contaminants in surface soil in Vieques residential areas are not at levels known to cause health effects today. Yet detection of explosive residues in the background samples also suggested that all areas of the island, including the residential area, might have been affected by explosive compounds from past bombing activities. Although residual levels are low today, it is impossible to say what past levels were.

7.2.5. Additional Considerations

Some Puerto Rican scientists suggested to ATSDR that evaluating surface soil samples collected from 0–6 inches below land surface would underestimate potential exposure to contaminants present at high concentrations only at the very surface. To explore this concern, we considered alternate "worst case" concentration assumptions, such as assuming the contaminant was present only in the top inch rather than the entire 6 inches.

For the available data, however, we determined this was an unrealistic assumption. Most surface soil data came from the LIA, where years of widespread bomb and projectile impacts and explosions would have stirred up huge amounts of soil; any resulting contaminants were likely distributed throughout more than just the top 6 inches. Likewise, many inorganic compounds are naturally present throughout soil and would never be completely absent, regardless of depth.

Given these considerations, we decided an analysis of the available data assuming that all contaminants were present in the top inch of soil would be misleading. In future surface soil sampling events, ATSDR recommends that agencies or researchers explore this issue further by analyzing the top inch of soil separately from the typical 0–6 inches or 0–3 inches collected.

The conclusions and recommendations from ATSDR's evaluation of the soil pathway are below and in Chapter 9 of this report.

[30] Levels at which no adverse health effects would be expected from even continual exposure.

7.3. Conclusions and Recommendations

7.3.1. Conclusions

1. Those who occupied the LIA from 1999–2000 were not at increased risk of adverse health effects from exposure to surface soil contaminants. Supporting data are limited, but they are of good quality and represent the location and the period of interest. In the years before the late 1990s tests, contaminant levels in the LIA (especially explosives) might have been higher, but we have no historical data with which to evaluate this assumption.
2. This does not mean anyone can now safely visit the LIA. Remaining unexploded ordnance could cause immediate injury or death to anyone who might inadvertently disturb it. Recently collected data on specific areas of concern within military lands—not the same areas accessed and occupied by protesters—demonstrate the remaining potential for localized contamination, which, if people frequented those areas, could be of health concern.
3. Limited available data from other locations and air pathway considerations suggest that the military exercises in the LIA did not result in current contamination of residential soils with inorganic or explosive compounds at levels considered harmful. ATSDR arrives at this conclusion using a scientific evaluation of the available data. But again, data from other areas are limited in number, data for all potential contaminants of concern are not available, and no adequate surface soil data are available from the residential area itself. ATSDR nonetheless understands that community members remain concerned about residential soil exposures.
4. Modeling described in the air pathway discussion has suggested that airborne transport of contaminants during past military exercises would not have been substantial enough to have affected soils in the island's residential area. Sufficient historical data are not available to confirm this, nor will such data ever become available. Consequently, we cannot determine whether past exposures to explosives or other compounds in surface soil could have been heavy enough to increase a past risk of adverse health effects.

7.3.2. Recommendations

1. Continue to restrict access to the LIA and other potentially contaminated military areas and continue environmental assessment and remediation activities to clear the way for public access.
2. To help address community concerns regarding residential soil, work with local residents to design sampling to identify residential surface soil quality issues, whether or not those surface soil issues relate to past military activities:

   a. Focus initial sampling on areas identified as potential high-exposure areas, such as areas free of vegetation or child-use areas.

   b. To identify any possible differences in the top layer, initial sampling should analyze the top inch of soil separately from the rest of the 0–3 or 0–6 inch surface samples.

   c. Perform a full range of analyses to identify all possible contaminants.

d. Plan and conduct sample collection and analysis to ensure the results meet high data quality standards.

3. Although this sampling might provide inferences about past exposures for compounds stable over time, such as metals or other inorganic compounds, it will provide no definitive information on past surface composition and no information on past levels of compounds that react or degrade over time.
4. ATSDR also recommends collection of representative soil samples as part of its evaluation of the terrestrial food chain pathway. See Chapter 5 of this report for details.

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8. Drinking Water Pathway

Chapter 8 Summary

The following chapter evaluates the available data and information on contaminants in past and present drinking water sources on Vieques and whether consuming drinking water could make people sick. ATSDR considered three past or present drinking water sources: the current pipeline supply, public and private supply wells used in the past and still occasionally used when pipeline water is interrupted, and rainwater collection systems that may have been used in the past and may still be used.

ATSDR determined that the limited available sampling data on the pipeline water supply system and the public and private wells indicate almost all these drinking water supplies are acceptable for their current uses. One private well was found to contain nitrate-nitrite levels that could be harmful; ATSDR recommended no one drink from this well. Ongoing monitoring of the current pipeline source water is required to ensure the supply meets drinking water standards, and repeating previous sampling of storage tanks, residential taps, and wells still in use would address remaining uncertainty associated with conclusions about the pipeline water and public and private wells. A lack of adequate historical data prevents ATSDR from making any conclusion about distant past (1970s and 1980s) public supply well exposures. Also, no data are available to evaluate past or present rainwater collection systems exposures. Since ATSDR's 2001 drinking water public health assessment, more groundwater data have been collected. These data are not from current drinking water sources, so they do not provide additional exposure information. One study, however, provided results supporting ATSDR's previous conclusion that contaminants in groundwater at the LIA could not reach the public water supply wells. The other studies focused on locally contaminated areas of concern not used for drinking water; they support the continuing need for characterization and eventual cleanup of source areas resulting from past military activities on Vieques.

In addition to required testing of the pipeline source water, ATSDR recommends repeated sampling of the current public water supply (storage tanks and residential taps) and public and private wells still available for use to confirm the safety of the drinking water for consumption. Also, ATSDR recommends further evaluation of the use of rainwater collection systems and sampling if such systems are used for drinking water.

8.1. Introduction

Many Viequenses remain concerned that military activities on and near the island might have contaminated Vieques drinking water, either currently or in the past. Vieques has or has had only three past or present drinking water sources:

1. Since 1978, the Puerto Rico Aqueduct and Sewer Authority (PRASA) has provided drinking water through a pipeline from the main island. In some years, these operations were conducted by private companies contracted by PRASA. After transport from Puerto Rico, water is stored in tanks on Vieques. Most Viequenses use this water source.
2. Before 1978, public supply wells in the Esperanza well field (presumably operated by PRASA) and several private groundwater wells were sources of drinking water. Some of these wells are still used whenever water pipeline service is interrupted.
3. Reportedly, individual households use rainwater collection systems as sporadic, supplemental drinking water sources. How prevalent the systems are, or were in the past, is unclear.

ATSDR evaluated available data to describe the safety of these potential drinking water sources on Vieques. This chapter describes ATSDR's data analysis.

8.2. Assessment of Available Data

8.2.1. Pipeline Water (Current Supply)

In summer of 1999, the U.S.EPA and PRDOH collected and analyzed water samples from storage tanks for water piped from the main island and from residential water taps on Vieques (PRDOH 1999; USEPA 1999). To address quality control issues, in January 2000, U.S.EPA resampled some of the locations for explosives (USEPA 2000). In its previous assessment, ATSDR examined these data and found no contaminants above health or regulatory standards or obviously related to bombing activities, indicating that pipeline water was acceptable for consumption (ATSDR 2001). ATSDR recently obtained water quality reports of the source water dated from 2004–2009. These reports show that in 2004–2005, the action level for lead (15 μg/L) was occasionally exceeded. This was attributed to corrosion in the piping system. In 2006–2007, the number of exceedances went up sharply, with 28 in 2007 alone. For that year, the 90th percentile of lead concentrations measured (the level below which 90% of the lead concentrations measured fall) was 144 μg/L, greatly exceeding the action level. This level is a significant concern, especially to pregnant women and young children. The cause of the elevations in lead are unknown to ATSDR. But the water quality reports stated that immediate investigations were undertaken to identify the source of the lead and to address the problem. In 2008 and 2009, the number of exceedances was low (2 in 2008 and 4 in 2009); the 90th percentile of lead concentrations measured was well below the action level in both years.

To summarize, testing of the supplied water did not indicate any contaminants were related to military exercises on Vieques. Still, continued safety of the pipeline water supply relies on continued monitoring of the water supply according to federal regulations and, if necessary, on prompt action to address violations.

8.2.2. Public and Private Well Water

A 1978 sampling event reported low levels of explosives or explosives byproducts in drinking water samples taken from two public supply wells in Esperanza and Isabel Segunda (Hoffsommer and Glover 1978; Lai 1978). In its previous assessment, ATSDR questioned these reported explosive detections because of the small number of samples collected and because the sample descriptions left uncertainty as to the samples' identity and locations (ATSDR 2001). Even assuming the detections were present at that level in drinking water, the levels of explosives were too low to result in adverse health effects (ATSDR 2001). In 1995, PRDOH tested the public and private wells, as did U.S.EPA and Navy contractors in 1999 (PRDOH 1995a and 1995b; USEPA 1999; Baker 1999). ATSDR evaluated these results and found that most well water was safe to drink. One private well located on the residential portion of the island west of the EMA and LIA was found to contain high levels of nitrate-nitrite, which could pose a health hazard and were likely a result of agricultural activity or septic systems in the area. Residents were advised that this well's water was not safe for consumption. In addition to sampling data, ATSDR evaluated the island's geology and topography and concluded that activities at the Live Impact Area (LIA) were unlikely to affect groundwater in private and in former public supply wells—groundwater did not move in the direction of the wells (ATSDR 2001). Although wells used previously as public water supplies would have been subject to drinking water regulations, ATSDR did not review historical reports on the water quality from the 1970s and 1980s or before. On the basis of our experience reviewing historical records, even if the records had been maintained and could be found, too many questions would arise as to quality control measures used, adequacy of the analytical methods used, and analytes measured to make the historical records useful for assessing past exposures.

8.2.3. Rainwater Collection Systems

No information was available on rainwater collection systems. This included their prevalence, whether they had ever been used for drinking water, or whether they had ever been tested. In its previous Drinking Water PHA, ATSDR discussed but did not evaluate this potential exposure pathway. ATSDR had planned to learn about that pathway through its evaluation of the air pathway's potential to transport contaminants to the residential portion of the island and potentially contaminate rainwater collection systems. As discussed in a previous chapter, this air analysis suggested the air pathway was unlikely to transport contaminants to the residential portion of the island at levels that might result in adverse health effects (ATSDR 2003). ATSDR did recommend that Puerto Rican authorities identify representative systems and test them to ensure those systems deliver safe water. To our knowledge, such sampling has not occurred (ATSDR 2001). ATSDR also recommended sampling sediment from rainwater collection systems as an indication of potential past water quality.

8.2.4. Strengths and Limitations of Available Drinking Water Pathway Data

8.2.4.1. Pipeline Water

The available data were collected and analyzed according to standard methods and procedures. But only one round of tank sampling occurred. Only one residential tap sample representative of the water supplied to residents was collected. It is possible that the available data may not fully represent the quality of this water source over time. In fact, recent water quality reports indicate that lead levels in the supplied water have exceeded drinking water standards, sometimes significantly, in some years. Although these elevated levels are not related to bombing activities, they highlight the need to monitor continually the public water supply to ensure its quality. According to the most recent water quality reports, lead levels in source water have only rarely exceeded standards since 2007. The levels of lead do not appear to be a current concern.

8.2.4.2. Public and Private Well Water

The available, recent data were collected and analyzed according to standard methods and procedures. But, similar to the pipeline water, only one or two rounds of sampling occurred, limiting the confidence that the recent results will fully represent the wells' status over time. Regarding the historical sampling results from the 1970s, these data are insufficient for public health conclusions regarding past conditions. Only two samples were collected, and the sampling and the analysis lacked documented quality assurance. We assumed that any available water quality reports or testing from that period would be similarly limited.

8.2.4.3. Rainwater Collection Systems

No information was available on the prevalence of rainwater collection systems—including whether they were ever used for drinking water or whether they were ever tested for contaminants.

8.3. Analysis

Scientists, Viequenses, and other Puerto Ricans questioned whether the island's drinking water was safe. In response, ATSDR first evaluated the available data. The drinking water pathway's public health evaluation conformed to ATSDR procedures for using limited available environmental data to reach public health conclusions. The focus was on exposures taking place at that time. Uncertainties did arise from the limited available data, which we discuss below. We also discuss new information that may add to the previous assessment of drinking water exposures in light of groundwater sampling data obtained since ATSDR's 2001 evaluation.

8.3.1.1. Pipeline Water

In 1999–2000, only one round of sampling appears to have been done for the tanks and for the residential tap water representative of the water supplied to residents. While conditions in the tanks and the tap water are not expected to change over time, greater confidence in the safety of the storage and distribution of the municipal supply could be gained by repeating the sampling and increasing the number of samples collected at the point of use. Although Puerto Rico water authorities regularly test the source water, recent (2004–2009) water quality reports have indicated intermittent problems with elevated levels of lead in the water. That water is from Puerto Rico and would not be affected by past military activities on Vieques. But regardless of the source, lead in drinking water is a concern, especially for pregnant women and growing children. Ongoing monitoring and prompt action to address drinking water violations are essential to ensure the pipeline water's continued safety.

8.3.1.2. Public and Private Well Water

ATSDR identified two general uncertainties associated with the evaluation of the former public water supply wells and the private wells:

- Number of Data Points: The conclusions about the recent safety of the drinking water wells were based on one or two sampling events for each well (June–August 1995 and September 1999). Because well conditions usually fluctuate over time, we would have greater confidence in the safety of water from these wells were multiple time points available, encompassing at least both the rainy and dry seasons. We recognize that due to shutdown, further sampling of some of the wells (e.g., Sun Bay) is impossible, and that if people are unable to drink the water, no exposure can occur. Also, that contaminants would fluctuate between extremely low levels and levels of health concern is unlikely. Further testing would nonetheless engender greater confidence in the conclusion.
- Lack of Historical Data: The arguments given in the previous assessment support the conclusion that groundwater movement is impossible from the Live Impact Area to the aquifers used for drinking water. ATSDR's previous assessment focused only on explosive ordnance in the Live Impact Area—that was the focus of the petition then under consideration. But other military activities took place on Vieques, such as transportation, storage, and general training. These activities could have had spills or other releases that resulted in contaminants reaching the former public water supply. In addition, nonmilitary contaminant sources, such as spills, sanitary landfills, septic systems, or agricultural run-off, could also have affected the former public water supply. That explosives are or were recently present in the aquifer supplying the former municipal wells is unlikely, given that in the late 1990s nearby wells showed no detections. Yet explosives were possibly detected in the 1978 samples. But this detection was uncertain: only two samples were collected, and any mechanism by which the explosives could have entered the groundwater is unknown.

Still, to be completely rigorous, we cannot dismiss entirely the possibility that explosive residues might have been present in the past in the drinking water supply. If such possible explosives detections were representative of the typical level in the public drinking water, that level was too low to result in health effects. But too few historical data points are available to confirm this conclusion. When the public supply wells were in operation, the owner would have been subject to drinking water regulations and should have collected and maintained water quality testing results. As described previously, however, ATSDR did not attempt to gather historical information on the water quality of these wells. Assuming data and testing reports were kept from the 1970s-1980s and could be located, numerous questions would remain, such as the accuracy and precision of the analytical methods used, the quality control measures employed, whether all contaminants of potential concern were analyzed, and whether the sampling in general was adequate to describe past water quality from the wells. Thus with regard to the past condition of any well-supplied public water, sufficient data will never become available to establish fully its safety.

8.3.1.3. Rainwater Collection Systems

In its previous drinking water assessment, ATSDR did not evaluate this pathway—it remains a potential pathway of exposure. ATSDR's later air modeling suggested that air transport was, historically and currently, not likely a major contamination source for rainwater collection systems. Still, to confirm that the water is safe, sampling of representative systems would be necessary. In its previous assessment, ATSDR recommended that Puerto Rico authorities identify example systems and test them to ensure they delivered safe water. To our knowledge, this sampling has not yet occurred. If sampling were conducted today (i.e., years after active bombing ceased), it would not answer the question of whether contaminants might have entered such systems in the past. ATSDR also recommended sampling sediment from rainwater collection systems as an indication of potential past water quality. This sampling would be limited to insoluble contaminants or to contaminants that had precipitated out of solution, had settled out, and had remained unchanged over time. But as stated previously for well water systems, for rainwater collection systems, complete information about every past potential contaminant and its past level will never become available.

8.3.1.4. Recent Data

Since ATSDR's 2001 assessment, several investigations have incorporated Vieques groundwater sampling.

- In 2004, additional sampling was conducted for the wells along the western border of the Eastern Maneuver Area (EMA) (CH2MHill 2005). Groundwater analysis detected no explosives, semi-volatile organic compounds, herbicides, pesticides, PCBs, or dioxins. One inorganic (barium) and two volatile organic compounds (bromodichloromethane and chloroform) were detected above screening values.[31] Because a groundwater flow study done in conjunction with the investigation showed that groundwater did not flow from the EMA toward the western border, such exceedances were thought more likely to result from background or from recharge of municipally treated water than from past military activities. ATSDR determined that all the substances found in the investigation were at levels not expected to cause adverse health effects if people drank the water. Although limited in scope, this study provided additional evidence supporting the former assessment's conclusion: groundwater, even if contaminated by military operations, could not physically move westward toward the aquifers formerly used as a public water supply. The results of the study do not exclude the possibility for other groundwater contamination caused by military or nonmilitary activities hydrogeologically connected to the groundwater that supplies public and private wells.

[31] Levels at which no adverse health effects would be expected from even continual exposure.

- Other investigations conducted since ATSDR's initial assessment have focused on characterizing the extent of contamination at localized groundwater areas of concern identified through the remedial process (CH2MHill 2007a–c;2008a–e). Several contaminants were found at levels that would make the associated groundwater unsuitable for consumption. These studies do not address potential drinking water sources. But they do support the need for characterization and eventual cleanup of source areas resulting from past military activities on Vieques.

The conclusions and recommendations from ATSDR's evaluation of the drinking water pathway appear below and are in Chapter 9 of this report.

8.4. Conclusions and Recommendations

8.4.1. Conclusions

1. The available sampling data of Vieques storage tanks and representative drinking water taps indicate that at the time of sampling, the public drinking water supplied via pipeline from Puerto Rico was acceptable to drink. This conclusion, however, is uncertain due to the limited number of samples and lack of additional rounds of confirmatory sampling. Public water supplies are tested regularly and have to meet water quality criteria. We have reviewed recent water quality reports indicating that lead levels have been a problem in the drinking water supply, although those problems appear to have been addressed now. Ongoing monitoring of the current pipeline source water and prompt action to address problems is required to ensure the supply meets drinking water standards.
2. Limited, late 1990s sampling data from public and private wells indicated that most of the wells are acceptable for occasional consumption, such as when the pipeline source is interrupted.[32] Flow patterns preclude groundwater from the east (where most military operations occurred) affecting the public aquifers. And with the exception of one well, all groundwater contaminants were below ATSDR health screening values. But again, confidence in the conclusions is tempered by the limited number of sampling rounds, which might not have captured seasonal fluctuations in contaminant levels. Also, a lack of adequate historical data prevents ATSDR from making any conclusion about past public supply well exposures (i.e., the 1970s and 1980s).
3. Although additional sampling might change the result, ATSDR confirms its previous conclusion that nitrate-nitrite levels in one private well would pose a health hazard, especially to children. Regardless of the source of this contamination, water from this well should not be consumed unless proven safe by further, comprehensive testing.
4. No data are available to evaluate rainwater collection systems for past or present exposure potential to contaminants. Rainwater collection systems remain a potential exposure pathway.

[32] Although the "Sun Bay" public wells have been abandoned, to our knowledge the "B" public wells and the private wells can still supply drinking water.

5. Past military activities did affect groundwater, but the affected groundwater is not currently used for drinking water.

8.4.2. Recommendations

1. Continue required monitoring of the public water supply source water and take prompt action to address any exceedances of drinking water standards. Repeat the 1999–2000 storage tank and residential tap sampling, including a wider selection of representative taps. This could confirm the conclusion that the present public water supply is acceptable to drink.
2. Conduct additional sampling of the wells still available for use during pipeline service interruptions. This too could confirm the safety of drinking water from these wells.
3. Determine whether people drink water from rainwater collection systems, and if so, test the collected water to evaluate its safety. Additionally, sample the sediment from these systems; the sample results might provide limited information about the water's past quality.
4. Do not use groundwater beneath the LIA and other former military operations for drinking water; continue environmental assessment and remediation activities to identify and clean up impacted groundwater.

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9. Conclusions and Recommendations

9.1. Introduction

As part of ATSDR's evaluation of Vieques, we have evaluated multiple documents and reports. We visited Vieques, where we discussed public health concerns with local officials, with scientists, and with the Viequenses themselves. We held a meeting with other scientists in which we discussed the most current Vieques research and studies. Our conclusions and recommendations for the Vieques site and community regarding the environmental media, biomonitoring, and health outcomes follow. During the public comment period for this report, CDC/ATSDR will consult with environmental and public health agencies to determine how our recommendations may be implemented, by whom, and timelines for implementation.

9.2. Consumption of Fish from Reefs off the Vieques Coast

9.2.1. Conclusions

During ATSDR's November 2009 meeting, several scientists raised concerns about mercury levels in fish. In particular, they were concerned that the conclusions in ATSDR's 2003 Fish PHA were inconsistent with the 2004 U.S.EPA/FDA national advisory concerning mercury. Therefore, ATSDR reviewed its 2003 conclusions and recommendations about mercury in fish from reefs surrounding Vieques.

In its 2003 public health assessment regarding fish consumption, ATSDR used fish intake rates that focused on adults who ate 8 ounces of fish daily and who weighed 70 kg (or 154 pounds). Daily fish intakes rates for children were 4 ounces and children were assumed to weigh 16 kg (or 35 pounds). Estimated doses were compared with ATSDR's MRL of 0.3 µg/kg/day, which was derived from an analysis of the Seychelles Island and Faroese studies. In ATSDR's evaluation as presented in this report, ATSDR used a broad range of daily fish intakes and body weights. Using information from U.S.EPA's Exposure Factor Handbook, ATSDR assumed that daily fish intakes for adult women were as high as 14 ounces—the 99th percentile—and that women weigh as little as 46 kg (or 100 pounds). For children, ATSDR assumed that daily fish intakes were as high as 6 ounces for 1- to 2-year old children, 8 ounces for 3- to 5-year old children, 10 ounces for 6- to 14-year old children, and 20 ounces for 15- to 18-year old children. The highest intakes for children represent the 99th percentile portion size for the stated ages. In addition, ATSDR used the NAS's recommendations and U.S.EPA's Reference Dose (RfD) concerning mercury as well as human toxicity studies from the Faroe Islands. From its evaluation of mercury in Vieques fish, ATSDR reached these new conclusions:

1. ATSDR has identified mercury exposure from frequent consumption of marine seafood as a potential public health hazard. Women with a varied fish diet who typically eat more than 2 oz of fish every day have estimated mercury doses that exceed U.S.EPA's chronic RfD. As portion size increases, the estimated doses approach the lowest level known to cause harmful effects to the developing fetus. ATSDR concludes that if these women are pregnant, their developing baby has a small increased risk of neurological effects later in life. The risk of harmful effects increases as portion size increases. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.
2. Women who eat grunt or hind more frequently than other reef fish and who typically eat more than 2 oz of fish every day have estimated mercury doses two times higher than women who eat a varied fish diet. As portion size increases, the estimated doses for women who eat larger portions daily (e.g., 10 to 14 oz) approaches or exceeds the lowest level known to cause harmful effects in the developing fetus. ATSDR concludes that if these women are pregnant, their developing baby has a small increased risk of neurological effects later in life. The risk of harmful effects increases as portion size increases. Possible harmful effects identified from studies of

non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.

3. Children with a varied fish diet who typically eat more than 0.5 oz of fish every day have estimated mercury doses that exceed U.S.EPA's chronic RfD. These children have a small risk of neurological effects. But as portion size increases, the risk of harmful effects increases. Depending upon their age, children as young as 1 year who eat 3 to 4 ounces of fish every day have estimated doses that exceed doses known to cause neurological effects and have the greatest risk of harmful neurological effects. Possible harmful effects identified from studies of non-Viequense children exposed in utero involve language, attention, and memory, and to a lesser extent visual/spatial and motor functions.
4. Like women, children who eat grunt and hind more frequently than other reef fish have estimated doses two times higher than children who eat a varied fish diet. The estimated doses in these children exceed the doses associated with neurological effects.
5. Some uncertainty is associated with these findings because a person's mercury response is itself somewhat uncertain. The uncertainty could be due to sex, genetics, health and nutritional status, or how mercury is handled in the body. In the three human studies that focused on mercury exposure from eating fish and seafood, the identification of the lowest-effect levels was uncertain. Estimating the mercury dose from eating reef fish was likewise uncertain, given that the dose could vary depending on the type, frequency, and quantity of fish eaten.
6. While ATSDR supports the U.S.EPA's and the FDA's national fish advisory, portions of the advisory do not apply to the Viequenses who rely heavily on local seafood. For example, the advisory discusses fish that Viequenses do not eat, such as pollock, catfish, and tilefish. In addition, the advisory recommends that if a local advisory is not available, people should not eat more 6 ounces of local fish and should not consume any other fish during the week. We include links to the advisory for informational use and have recommended an educational program about mercury in locally consumed fish.
7. Residents need information so they can select local seafood lower in mercury over seafood higher in mercury. This will protect developing fetuses and young children from mercury in fish. For informational purposes only, the advisory and related information is available at: http://www.epa.gov/waterscience/fish/advice; http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm115662.htm, and Chapter 2, Section 2.7 of this report, Appendix 2A-3.
8. For the 104 fish samples collected from the marine areas near Vieques and from the commercial fish market, the average mercury level was 0.1 ppm and the range was nondetectable to 0.33 ppm. The mercury levels detected in Vieques reef fish are similar to levels reported by the FDA (FDA 2010). The mercury levels are in the low (0.02–0.2 ppm) to mid (0.2–0.6 ppm) mercury range identified by FDA in its recent risk and benefit assessment (FDA 2009).

9. ATSDR also conducted a statistical analysis of the 2001 fish data and concluded the following:
    a. Mercury detected in the seafood is higher in two fish families (grunt and hind) compared with other families sampled (e.g., parrotfish and snapper). The average mercury concentration in grunt and hind was higher than U.S.EPA's 0.049 ppm screening level. In testing some of the hypotheses, ATSDR used the overall average of 0.1 ppm to determine which families of reef fish were likely to exceed the overall average.
    b. Mercury levels in parrotfish were statistically lower than U.S.EPA's 0.049-ppm screening level and lower than the 0.1-ppm overall average.
    c. All snapper were lower than U.S.EPA's 0.049 ppm screening value. But an insufficient number of snapper were collected to determine whether the average snapper-mercury level was statistically different from the U.S.EPA 0.049 ppm screening level. A sufficient number of snapper were collected to determine that the average mercury level is statistically lower than the 0.1-ppm overall average.
10. Mercury is present in most seafood and is particularly high in some fish species and low in other species. While mercury was a component of the detonators of some bombs, only small amounts of mercury were introduced to the Vieques environment from this source. This conclusion is supported by the low mercury levels in LIA soils, which appear to be at naturally occurring levels. Mercury levels in fish in and around the LIA are most likely the result of the global reservoir of mercury circulating in the environment.
11. Statistical analysis showed that some fish and shellfish had higher levels of some metals and lower levels of other metals–iron, aluminum, copper, zinc, arsenic, barium, potassium and selenium were all slightly higher. These metals are materials found in bombs and metal ships, suggesting possible localized contamination. But the levels were only slightly higher and the difference was only statistically significant when compared with a few other locations.

9.2.2. Recommendations

ATSDR recommends the following for consideration by environmental and public health agencies and scientists:

1. People who frequently consume marine seafood should follow available fish advisories and fishing restrictions in Vieques. Maintain the fishing restrictions in the waters adjacent to the LIA.
2. Conduct a survey of Vieques residents to determine the types, frequency, and quantity of fish consumed.
3. Conduct additional risk assessments and statistical analyses using new information gathered from the previously recommended fish consumption survey.
4. Collect and analyze additional fish samples from Vieques should the proposed survey and statistical analysis not provide sufficient public health information. Collect sufficient fish samples to allow analysis by species and by location.

5. Develop an educational program about mercury in fish that incorporates local habits and information about Viequenses' seafood consumption. Benefits accrue to the developing fetus with maternal intake of nutrients in seafood (FDA 2009) that can outweigh the concomitant intake of small amounts of mercury. The goal of this site-specific educational program should be to educate Viequenses about the benefits of eating seafood so they can choose fish lower in mercury and still maintain their healthy dietary customs of consuming local seafood.

9.3. Biomonitoring

9.3.1. Conclusions

1. Since 1999, Vieques has hosted at least five human biomonitoring investigations. Puerto Rican scientists, physicians, or the Puerto Rico Department of Health (PRDOH) conducted all of them. The PRDOH has conducted the most extensive sampling effort, collecting biological specimens from 500 randomly selected Viequenses. The PRDOH manuscript reported that in 20% of the participants, either

   - Aluminum, lead, or mercury in blood;
   - Uranium, cadmium, or nickel in urine; or
   - Nickel or arsenic in hair

   exceeded the laboratory's reference range. The PRDOH manuscript identified cigarette use and hair dyes, as well as the consumption of seafood, as possible sources for some but not all the elevated levels. The PRDOH manuscript acknowledged that for some residents, it could not identify the source of high metal levels in urine, hair, and blood. The PRDOH manuscript did not report mercury levels in hair. Results from Dr. Ortiz Roque's investigations showed that some residents had elevated levels of mercury in hair, and that the most likely source was fish consumption; other possible sources, however, were not completely ruled out.

2. Data from these studies showed that in blood, urine, hair, or feces, some residents of Vieques had elevated levels of various metals. While some of these elevated levels might be explained by cigarette use, seafood consumption, or hair dyes, they do not account for all the elevated levels. In particular, biomonitoring results from Dr. Ortiz Roque showed that some Viequenses had elevated mercury in hair above 12 ppm, the level identified by the NAS to cause harm in 5% of fetuses exposed in utero. Dr. Ortiz Roque also showed that mercury in hair was associated with fish consumption. In contrast, the PRDOH study did not find excessive mercury levels in blood, although the study either did not measure for or did not report mercury levels in hair. Thus the prevalence of high mercury levels in Viequenses remains somewhat uncertain. Except for mercury, metal content in hair is difficult to interpret. Metals can bind directly to hair from the use of commercial hair products, making difficult any distinction between internal metal exposure via ingestion and inhalation and external exposure resulting from contact with the metal in the environment (e.g., shampoo, dyes, dirt).

3. These studies were unable to investigate each person's environment to identify the source for those who had excessive metals in hair, urine, or blood. The PRDOH study came closest to identifying possible sources (e.g., cigarette and hair dye use, seafood consumption) but acknowledged an inability to identify the source or sources for all residents with excessive metals exposure. Either through the survey instrument or through an in-home visit, it may be possible to identify other sources that increase metal exposure, such as cooking utensils, metal residues in foods (e.g., tea and vegetables), consumption of drinks with metallic packaging, antacid formulations and antiperspirant formulations.

4. ATSDR remains cautious in making decisions about using hair as an indicator of exposure to environmental contaminants and as an indicator of risk of harmful effects. A major problem in interpreting metal concentrations in hair is whether the metal content resulted from internal exposure (e.g., from ingestion or inhalation) or from external exposure (e.g., the hair coming in contact with a metal-containing product). Currently, no washing method is capable of removing exogenous metal contaminants while leaving endogenous metals undisturbed. Chemicals such as methylmercury, which originate generally from dietary sources, suffer less from this drawback, provided unusual sources of inorganic mercury do not complicate the picture, (e.g., mercury vapor in occupational or home settings).

5. These biomonitoring results do not permit any conclusions about exposure to the bombing-related contaminants.

9.3.2. Recommendations

1. Viequenses may be exposed to mercury in fish and cadmium in pigeon peas. These exposures may warrant additional environmental investigations, such as sampling locally grown produce for cadmium and gathering more information about fish consumption and possibly mercury in fish. The information could be used to decide whether to undertake human testing for mercury and cadmium in blood or urine. If other environmental exposures are identified, additional human biomonitoring investigations may be considered. More detailed information about ATSDR's recommendations concerning fish and locally grown produce can be found in Chapter 2, Section 2.3.2 and Chapter 5, Section 5.3.2, respectively.

2. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation.

3. Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis.

4. CDC/ATSDR can provide a list of qualified laboratories that can perform the tests. And if requested, CDC/ATSDR can provide information to healthcare providers about tests for metals in biologic samples.

9.4. Health Outcome Data

9.4.1. Conclusions

1. The documents ATSDR reviewed paint a complex health picture for Viequenses. The findings of these studies indicate elevations in chronic disease prevalence, cancer incidence, and cancer mortality among the population between Vieques and the rest of Puerto Rico. In addition, increased mortality in Vieques particularly from cancer may indicate lack of access to appropriate medical care. The limitations associated with these analyses, particularly the methodological concerns discussed in this report, introduce considerable uncertainty and make interpretation difficult. Some of the methodological concerns previously noted include more exhaustive cancer case finding in Vieques than the rest of Puerto Rico, differential follow-up, chronic disease prevalence estimates based on a symptom disease prevalence survey without medical record confirmation of health outcomes, and limited noncancer mortality data. Differential follow up and exhaustive case finding may result in biased estimates of cancer incidence and mortality. Uncertainty is also evident in the wide confidence intervals reported indicating imprecise estimates of cancer incidence and mortality ratios in Vieques relative to the rest of Puerto Rico (RCCPR 2009). This is not unusual when calculating estimates for small populations.

2 These findings can nonetheless serve as a guide for future investigations of Viequenses' health status.

9.4.2. Recommendations

Assess the feasibility of applying the SMART BRFSS methods for generating stable Vieques specific prevalence estimates on asthma, diabetes, hypertension, and other chronic diseases.

9.5. Local Produce and Livestock Pathway

9.5.1. Conclusions

1. The overall data are insufficient to quantify adequately human exposures or draw any valid health conclusions about whether consuming locally grown produce and livestock would result in harmful health effects.

2. Limited sampling data are available for pigeon peas, a staple food among Viequenses. Interpretation of these data is uncertain because of the lack of adequate QA/QC information for the analytical findings.

    - A preliminary data evaluation completed for this report has concluded that the level of cadmium reported in a few samples of locally grown pigeon peas would not contribute excess dietary cadmium to preschool children who eat less than 5 of the largest (6 ounces) servings per week of locally grown pigeon peas. Adults who eat the largest serving sizes (12 ounces) should limit intake to 11 servings per week.

- Preschool children who eat a typical serving size (1.5 ounces) may eat up to 20 meals per week and adults who eat a typical serving (3 ounces) may eat up to 44 meals per week without exceeding recommended cadmium intake levels.

- Exceeding recommended levels of cadmium in the diet would not typically result in immediate health harm. Excessive intake of cadmium over decades could contribute to harmful levels of cadmium accumulation in the kidneys, possibly resulting in kidney disease. Typically, only a very small fraction (5%) of cadmium in food is absorbed in the body, especially in individuals with healthy diets containing adequate amounts of essential minerals such as zinc, iron and calcium (Reeves and Chaney, 2008).

3. Whether the limited sampling results are representative of cadmium concentrations in other locally grown pigeon peas is unclear; but the significant uncertainty in the evaluation stresses the need to conduct further sampling.

4. Preliminary evaluation results and the totality of the available data suggest a potential for uptake of metals from soil into food crops—thus further investigation is warranted. To evaluate better this exposure pathway, ATSDR has recommended a collaborative effort to conduct additional sampling of locally grown foods.

9.5.2. Recommendations

ATSDR supports additional sampling and collaborative data collection to evaluate more thoroughly this human exposure pathway. The following recommendations are intended to promote collection of high quality data of maximum utility, and to minimize data uncertainties:

1. Sampling data should represent edible portions of a cross-section of local produce from local farms, home gardens, and local markets. Sample produce that tends to accumulate heavy metals more easily (e.g., leafy vegetables such as lettuce and spinach) rather than leaves of grain or fruit crops.

2. Survey residents to identify the prevalence and type of locally grown and commonly consumed garden produce. Sampling plan design should include produce types identified from this survey.

3. Collect representative surface soil samples at the same location and time that garden and farm produce samples are taken. Soil samples should be of appropriate depth to represent the root zone.

4. Collect samples of meat and milk products from Vieques forage-consuming livestock.

5. To avoid false high or low values, sample collection and analysis should conform to high standards of data quality, including detailed quality assurance/quality control information, standard reference materials for analysis, and background correction. Design the sampling plan to collect a sufficient number of samples to ensure high statistical confidence.

6. Collect samples from an appropriate background or control location for comparison with food samples produced on Vieques.
7. To facilitate exposure assessment, report data as consumed (wet weight).
8. Plan and conduct sampling protocols in collaboration with local scientists. One way to avoid misunderstandings about the data is for local scientists and an independent expert jointly collect and split several samples and provide analytical reports with QA/QC supporting information. A QA/QC standard could be split at the time the samples are collected.
9. Request technical assistance from the U.S. Food and Drug Administration (FDA) or the U.S. Department of Agriculture (USDA) in sample collection and analytical protocols. The USDA Agriculture Research Service has offered to provide, if requested, technical assistance in sampling plan design, collection, and analysis with proper QA/QC protocols.

9.6. Air Pathway

9.6.1. Conclusions

1. This review of potential airborne exposures within the residential areas of Vieques to contaminants from military operations at the former Vieques Naval Training Facility is based on the following sources of information that were used in the 2003 ATSDR PHA:

   - U.S. Navy records of the types and amounts of ordnance used at the training range,
   - A source term model used to estimate the amounts of material produced by ordnance detonations,
   - An air dispersion model to estimate contaminant transport from the detonation area to the residential areas,
   - Long term meteorological data from the San Juan PR airport and the Roosevelt Roads Naval Station, and
   - Ambient air monitoring in the residential areas conducted by the PREQB for the 2001-2003 time period.

   Also summarized are air monitoring data and air dispersion studies developed or collected after publication of the 2003 Air PHA for the purpose of evaluating ongoing or proposed open detonation or open burning.

2. This review of potential airborne exposures evaluates the modeling process used in the 2003 Air PHA, the assumptions and data used in the modeling process, and compares the results of that modeling process with monitored data collected during recent open burning events.

3. While this review finds the Air PHA modeling process consistent with established modeling practices, it does identify two minor errors in estimating detonation source concentrations. One results in an overestimate of metals concentrations. The other results in a minor underestimate of explosion byproducts in entrained soil that is overcompensated by the overall estimate of

explosive compound concentrations. These errors do not affect the results or conclusions of the Air PHA.

4. Collectively, the available sampled and modeled data are adequate for the determination of the potential public health hazard from exposure to airborne contamination. The uncertainties inherent in the 2003 ATSDR air dispersion model have been adequately addressed by overestimating numerous aspects of the contaminant emissions and by assessing exposures for worst-case conditions. Despite the overestimation of potential exposures, the model results indicate that airborne contaminants from historic uses of the Vieques Naval Training Range would have been essentially nondetectable in the residential areas of Vieques and unlikely to have resulted in harmful effects. These predicted results are supported by the PREQB's historic and recent air sampling data and by the Navy's post-PHA air sampling and air dispersion modeling. Collectively, the available data provide an adequate basis for the public health conclusions in the Air PHA.

5. To conduct its health protective evaluation of potential exposures to airborne contaminants from military exercises at the former Vieques Naval Training Facility, the ATSDR Public Health Assessment used appropriate modeling procedures and available monitoring data. The additional air dispersion modeling and monitoring data conducted after completion of the Air PHA further support ATSDR's public health conclusions. Because past military exercises would not likely have produced measurable concentrations of airborne contaminants in the residential areas of Vieques, no public health basis supports additional air studies or ambient air monitoring efforts related to past military exercises on Vieques.

6. Although the residents of Vieques could hear and possibly feel the explosions from military exercises on the former Vieques Naval Training Range, 8 miles is still a considerable distance. The physics of sound and seismic wave migration are very different from the physics of atmospheric dispersion of airborne particulates and gases.

9.6.2. Recommendations:

No further recommendations at this time.

9.7. Soil Pathway

9.7.1. Conclusions

1. Those who occupied the LIA from 1999–2000 were not at increased risk of adverse health effects from exposure to surface soil contaminants. Supporting data are limited, but they are of good quality and represent the location and the period of interest. In the years before the late 1990s tests, contaminant levels in the LIA (especially explosives) might have been higher, but we have no historical data with which to evaluate this assumption.

2. This does not mean anyone can now safely visit the LIA. Remaining unexploded ordnance could cause immediate injury or death to anyone who might inadvertently disturb it. Recently collected data on specific areas of concern within military lands—not the same areas accessed

and occupied by protesters—demonstrate the remaining potential for localized contamination, which, if people frequented those areas, could be of health concern.

3. Limited available data from other locations and air pathway considerations suggest that the military exercises in the LIA did not result in current contamination of residential soils with inorganic or explosive compounds at levels considered harmful. ATSDR arrives at this conclusion using a scientific evaluation of the available data. But again, data from other areas are limited in number, data for all potential contaminants of concern are not available, and no adequate surface soil data are available from the residential area itself. ATSDR nonetheless understands that community members remain concerned about residential soil exposures.
4. Modeling described in the air pathway discussion has suggested that airborne transport of contaminants during past military exercises would not have been substantial enough to have affected soils in the island's residential area. Sufficient historical data are not available to confirm this, nor will such data ever become available. Consequently, we cannot determine whether past exposures to explosives or other compounds in surface soil could have been heavy enough to increase a past risk of adverse health effects.

9.7.2. Recommendations

1. Continue to restrict the LIA and other potentially contaminated military areas and continue environmental assessment and remediation activities to clear the way for public access.
2. To help address community concerns regarding residential soil, work with local residents to design sampling to identify residential surface soil quality issues, whether or not those surface soil issues relate to past military activities:
   a. Focus initial sampling on areas identified as potential high-exposure areas, such as bare areas or child-use areas.
   b. To identify any possible differences in the top layer, initial sampling should analyze the top inch of soil separately from the rest of the 0–3 or 0–6 inch surface samples.
   c. Perform a full range of analyses to identify all possible contaminants.
   d. Plan and conduct sample collection and analysis to ensure the results meet high data quality standards.
3. Although this sampling might provide inferences about past exposures for compounds stable over time, such as metals or other inorganic compounds, it will provide no definitive information on past surface composition and no information on past levels of compounds that react or degrade over time.
4. ATSDR also recommends collection of representative soil samples as part of its evaluation of the terrestrial food chain pathway. See Chapter 5 of this report for details.

9.8. Drinking Water Pathway

9.8.1. Conclusions

1. The available sampling data of Vieques storage tanks and representative drinking water taps indicate that at the time of sampling, the public drinking water supplied via pipeline from Puerto Rico was acceptable to drink. This conclusion, however, is uncertain due to the limited number of samples and lack of additional rounds of confirmatory sampling. Public water supplies are tested regularly and have to meet water quality criteria. We have reviewed recent water quality reports indicating that lead levels have been a problem in the drinking water supply, although those problems appear to have been addressed now. Ongoing monitoring of the current pipeline source water and prompt action to address problems is required to ensure the supply meets drinking water standards.
2. Limited, late 1990s sampling data from public and private wells indicated that most of the wells are acceptable for occasional consumption, such as when the pipeline source is interrupted.[33] Flow patterns preclude groundwater from the east (where most military operations occurred) affecting the public aquifer. And with the exception of one well, all groundwater contaminants were below ATSDR health screening values. But again, confidence in the conclusions is tempered by the limited number of sampling rounds, which might not have captured seasonal fluctuations in contaminant levels. Also, a lack of adequate historical data prevents ATSDR from making any conclusion about past public supply well exposures (i.e., the 1970s and 1980s).
3. Although additional sampling might change the result, ATSDR confirms its previous conclusion that nitrate-nitrite levels in one private well would pose a health hazard, especially to children. Regardless of the source of this contamination, water from this well should not be consumed unless proven safe by further, comprehensive testing.
4. No data are available to evaluate rainwater collection systems for past or present exposure potential to contaminants. Rainwater collection systems remain a potential exposure pathway.
5. Past military activities did affect groundwater under some specific military areas, but the affected groundwater is not currently used for drinking water.

9.8.2. Recommendations

1. Continue required monitoring of the public water supply source water and take prompt action to address any exceedances of drinking water standards. Repeat the 1999-2000 storage tank and residential tap sampling, including a wider selection of representative taps. This could confirm the conclusion that the present public water supply is acceptable to drink.
2. Conduct additional sampling of the wells still available for use during pipeline service interruptions. This too could confirm the safety of drinking water from these wells.

[33] Although the "Sun Bay" public wells have been abandoned, to our knowledge the "B" public wells and the private wells can still supply drinking water.

3. Determine whether people drink water from rainwater collection systems, and if so, test the collected water to evaluate its safety. Additionally, sample the sediment from these systems; the sample results might provide limited information about the water's past quality.
4. Do not use groundwater beneath the LIA and other former military operations for drinking water; continue environmental assessment and remediation activities to identify and clean up impacted groundwater.

9.9. Final Summary

ATSDR conducted a thorough review of environmental, biological, and health outcome data from the Island of Vieques. We carefully considered the data and information from Puerto Rican and other scientists who spent considerable effort and time, sometimes at their own expense, to research environmental health issues in Vieques. We are grateful for their efforts. Nevertheless, as with any site that has such a long history of environmental investigations, those data have strengths and weaknesses that become important in public health decision-making. At times, the data can raise as many questions as they can provide answers.

One such situation is mixtures. ATSDR recognizes the possibility that this report cannot address accurately the effects of mixtures and cumulative exposures on the health of Viequenses. Sometimes this is the result of a lack of data; other times it is a limitation of the science. ATSDR has published guidance for mixtures assessments (ATSDR 2004) and has some of the world's experts on these subjects among our staff. But we recognize the continuing debate among scientists on these subjects and that no scientific consensus, or "best practice," has yet emerged on how to assess these effects accurately.

Further, we are aware of the literature that examines the physical and psychological health effects stress can have on a community such as Vieques, given its six decades of military activities and lingering concern for the effects of those activities on the population's health. Studies have shown that chronic stress is a risk factor in cardiac disease and contributes to the onset of autoimmune diseases. Chronic stress also is an important factor in premature aging.

Finally, as we stated at the outset of this report, ATSDR recognizes that Viequenses are concerned about the health of everyone who lives on their island. We hope the conclusions and recommendations in this report will raise public health awareness, increase the public's well-being, and protect the health of all Viequenses.

Appendix A—Study Summaries

Category:	**Environmental Data – Radiation**
Date of Publication**:**	**November 9, 2001**
Title:	Dramatic Increase in Radiation in Vieques
Author(s):	**Frankie Jimenez**
Affiliation:	**Committee for the Rescue and Development of Vieques (CRDV)**
Publication Status:	**Press Release**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Air Pathway Evaluation)**

Study Findings

In 2001, after two rounds of bombing in Vieques, radiation sampling resulted in these findings:

Table A-1. Radiation sampling in Vieques, 2001

Date	*Sampling Location*	*Radiation Level*
June 2001	Civilian areas Yayi Beach (near bombing range)	No increase 60% increase
September-October 2001	Esperanza Beach (civilian area, south coast) Main town (Isabel II, north coast)	248% increase 225% increase

The authors attributed the radiation increase to soil dispersion contaminated by past use of depleted uranium (DU) penetrators at the Live Impact Area (LIA). The press release did not indicate how levels of radiation were measured, what types of radiation were measured, or the actual amounts of radiation detected.

The press release did, however, condemn future bombing exercises planned for November–December 2001.

How ATSDR Addressed the Study Findings

In 2002, ATSDR contacted the Committee for the Rescue and Development of Vieques (CRDV) to learn more about this sampling effort, but did not receive a response. The allegation that radiation levels increased on Vieques during military training exercises could not be confirmed. No public health decisions could be made based on a reported 248% increase in radiation levels without data. The more important indicator of exposure is the actual level of radiation, not the relative increase. No confirmation of statements made in the press release could be obtained. Nonetheless, in Section V.D of the PHA's Air Pathway Evaluation, ATSDR used established background levels to investigate the public health implications of the reported radiation increase.

To estimate the effect of a reported 248% dose increase, ATSDR used data collected by the Nuclear Regulatory Commission (NRC) to establish background radiation levels. In June 2000, the NRC recorded radiation dose rate measurements at 29 locations in Vieques residential areas using a Ludlum Model 19 microR meter. These observations were collected at a distance of 1 meter above ground surface. The 29-measurement average exposure rate was 4 microroentgens per hour (µR/hour)—approximately equal to 4 microrem per hour (µrem/hour). ATSDR assumed this dose rate represented external radiation background levels in the Vieques residential areas. If the CRDV data were based on similar dose rate observations, a 248% increase in radiation would imply that radiation levels increased from 4 µrem/hour to 14 µrem/hour, or a net increase above background of 10 µrem/hour. Assuming this increase above background occurred 24 hours per day for 90 days per year (i.e., the maximum amount of time the Navy could conduct military training exercises on Vieques), the overall increase in radiation dose for the year would be 22 mrem—a level well below ATSDR's chronic minimal risk level (MRL) for ionizing radiation. The MRL is defined as an increase in ionizing radiation dose of 100 mrem above background per year. Thus given these parameters, ATSDR does not consider a 248% increase indicates radiation exposures at levels of concern presuming an exposure rate of 4 µrem/hour.

In fact, ATSDR noted that the levels of radiation measured in the NRC study appear to be well within background levels observed throughout the United States. And a non-CRDV press release (Fellowship of Reconciliation 2001) announced that the highest level of radiation measured during the recent survey on Vieques was 18 µR/hour—approximately equal to 18 µrem/hour. These levels are comparable to survey readings collected elsewhere in the United States; they are considerably lower than background measurements from many areas at elevations of several thousand feet such as Denver, Colorado. Due to its higher elevation, Denver would be expected to have higher-than-average radiation levels.

As part of the agency's analysis of data, ATSDR again requested more information on the study. In response to ATSDR's request, the report **"**Radioactivity in Vieques" was received on August 5, 2009.

Reference

Fellowship of Reconciliation. 2001. Vieques issue brief: environmental impacts of navy training; November 2001.

Category:	**Environmental Data – Radiation**
Date of Publication:	**circa 2000**
Title:	Radioactividad en Vieques Radioactivity in Vieques [trans.]
Author(s):	**Frankie Jimenez**
Affiliation:	**Committee for the Rescue and Development of Vieques (CRDV)**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

From October 7, 1999 to February 3, 2000, radiation sampling was conducted on the Live Impact Area (LIA). The investigator conducted the sampling in response to the U.S. Navy's accidental use of depleted uranium projectiles on February 19, 1999. The investigator took gamma radiation measurements from around the targets (e.g., tanks and aircraft), from the roads leading to the targets, and from areas where former targets were buried. Yayí Beach was measured as the background location.

According to the investigator's report, samples were collected with an instrument "manufactured by the Nuclear Research Corporation." The report provided no further sampling device information nor did the report list actual amounts of radiation detected at other locations. It provided instead the percent increase above readings at Yayí Beach. Lastly, the report did not specify the averaging time for individual measurements. Thus whether the findings were based on instantaneous peak radiation levels or sustained averages is unclear.

Table A-2. Vieques LIA radiation sampling, 1999–2000

Sampling Location	***Radiation Level***
Yayí Beach (background location)	7 µR/hr
Mayor of Cataño's camp	30% increase
Several aircraft behind the "Pro Vieques" camp	50% increase in front of the planes, "normal" away from the planes
Tank just before the mountain	200% increase
Tank at the top of the mountain	100% increase
Roads leading to the targets	100% increase, "normal" immediately beyond the roads
Tanks near the Monte David camp	50% increase
Slope of the mountain near the Monte David camp	220% increase
Tanks near Salina Sur Beach	100% increase

µR/hr = microroentgens per hour

At the beginning of the article, the investigator noted that radiation levels in the LIA were "over 500% higher than normal." But 220% was the highest percent increase listed. Because certain areas indicated "above-normal" radioactivity, the investigator concluded that radioactive material was present on and around the targets as well as under the surface (e.g., roads and burial grounds). After completing some sampling, on January 19, 2000, the investigator filed a complaint with the Nuclear Regulatory Commission (NRC). That complaint might have triggered the NRC study reviewed in the PHA's Air Pathway Evaluation.

How ATSDR Addressed the Study Findings

ATSDR received this report on August 5, 2009. Because this report—like a contemporary press release entitled *Dramatic Increase in Radiation in Vieques*—lacked an actual radiation level reading, ATSDR investigated the public health implications of the reported increase in radiation using the same approach as presented in Section V.D of the PHA's Air Pathway Evaluation. A 220% increase in radiation would imply that radiation levels increased from the background of 7 µr/hour (approximately equal to 7 microrem per hour [µrem/hour]) to 22 µrem/hour, or a net increase above background of 15 µrem/hour. Assuming this increase above background occurred 24 hours per day, 365 days per year, the overall increase in radiation dose for the year was 131 mrem. ATSDR's chronic minimal risk level (MRL) for ionizing radiation is defined as an increase in ionizing radiation dose of 100 mrem above background per year. Even given that this estimated dose exceeded ATSDR's MRL, the calculation did not take into account individual occupancy. That is, for the MRL to be exceeded, a person would have to find the elevated radiation-level location and remain there 24 hours per day for an entire year. A more realistic—yet still unlikely—scenario is for a person to remain at the location 4 hours per day over the course of a year. This would result in an increased radiological dose of 20 mrem for the year.

Thus with respect to the actual method used to detect the radiation, the information supplied is of limited use: the background range was not specified. Typically, gamma radiation measurements will vary by 3 to 5 µR/h. As the author stated, the measured background was 7 µR/h, which ATSDR believes could vary up to 11 or 12 µR/h. Such a meter variation could also account for the large percentages observed. For example, if the average were 7 µR/h, an increase in 3 µR/h would represent a 50% increase.

Further, although depleted uranium (DU) is radioactive, its gamma radiation emission is low. It would not add to the ambient background radiation detectable by the type of radiation meter used in this study. In fact, the United Nations estimated that DU radiation is so weak it would be shielded by the soil in which it was buried.[34] Thus ATSDR believes the reported DU radiation was in error.

[34] World Health Organization (2001). Report of the World Health Organization. Depleted uranium mission to Kosovo. Available online at http://www.who.int/ionizing_radiation/pub_meet/en/Report_WHO_depleted_uranium_Eng.pdf [accessed 2011 June 13].

Category:	**Environmental Data – Soil, Sediment, and Water**
Date of Publication:	**July 11, 2000**
Title:	Environmental Impact of Navy Activities in Vieques
Author(s):	**N García Martínez, AM López, M Soto, T Garcia, S Rosado, B Berríos**
Affiliation:	**Servicios Científicos y Técnicos**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Soil Pathway Evaluation)**

Study Findings

From May 1999 to April 2000, personnel from Servicios Científicos y Técnicos, Inc. collected and analyzed soil, sediment, and surface water samples from 55 Vieques locations. Their purpose was to determine levels of metals and other inorganic compounds in the Vieques ecosystem. Forty-four samples were collected from the LIA: specifically, areas of direct impact, target areas, and nearby areas. Five were collected from the Punta Este Conservation Zone, and six were taken from the residential area. Eleven water samples were collected from lagoons in the LIA, from Carrucho Beach, and from the Punta Este Conservation Zone. The sample analysis included highest and second highest concentrations:

Table A-3. Water samples from LIA lagoons

Chemical	*Highest Concentration (ppm)*	*Type of Sample*	*2nd Highest Concentration (ppm)*	*Type of Sample*
Aluminum	24,500	soil	23,600	soil
Ammonia	50.1	sediment	46.8	soil
Arsenic	20.2	soil	16.4	soil
Barium	1,170	soil	1,100	soil
Cadmium	31.3	soil	27.4	soil
Chromium	40.2	sediment	31.9	soil
Cobalt	26.4	soil	21.4	soil
Copper	501	soil	313	soil
Iron	67,900	soil	51,400	sediment
Lead	138	sediment	75.4	soil
Manganese	1,111	soil	811	soil
Mercury	4.21	sediment	0.329	sediment
Nickel	68.7	soil	32.9	sediment

Chemical	***Highest Concentration (ppm)***	***Type of Sample***	***2nd Highest Concentration (ppm)***	***Type of Sample***
Nitrates plus Nitrites	50.8	sediment	30.2	soil
Phosphorous	40.4	soil	16	sediment
Selenium	1.48	sediment	1.34	sediment
Silver	0.625	soil	0.526	sediment
Sulfate	8,590	NA	8,380	NA
Tin	38.7	surface water	NA	NA
Vanadium	178	soil	164	soil
Zinc	872	soil	325	soil

NA = not available

ppm = parts per million

The authors reported that higher levels of metals and other substances were in the sediment, soil, and water samples collected from the LIA as opposed to samples collected from the eastside territory and from the civilian zone. LIA zinc and copper concentrations were higher than those USGS reported in 1973. The authors recommended additional environmental sampling in the civilian area and western portion of Vieques, as well as biomonitoring samples from Vieques residents.

How ATSDR Addressed the Study Findings

In a statistical comparison with other LIA data, these data show nine of the 20 chemicals were significantly different (higher, $p < 0.05$): ammonia, barium, cadmium, copper, lead, mercury, nickel, nitrate/nitrite, and zinc. This does not imply any data discrepancy; it simply means that using only the highest and second highest detections rather than the complete dataset would skew any results. Therefore, these data were not used in the statistical analyses to evaluate general soil characteristics. They were, however, used to form the following conclusions during the public health evaluations in the PHA's Soil Pathway Evaluation (see Section IV in the Soil Pathway Evaluation):

- During the public health assessment process, all available soil sampling data were considered, including the data presented in the Servicios Científicos y Técnicos report.
- To evaluate human exposures, ATSDR compiled roughly 600 soil/sediment samples (for a soil sampling summary, see pages 13–15 of the PHA).
- Vieques residents are not currently exposed to harmful levels of chemicals in the soil.
- Although in the past, Navy training activities elevated the levels of some metals in the soil on the former LIA, those levels remain too low to be of health concern.
- Protestors who lived on the LIA for a year (1999–2000) endured the longest exposure to LIA soil contaminants. ATSDR analyzed the soil data collected by Servicios Científicos y Técnicos—

together with Navy data—from areas where the protestors lived. ATSDR determined that the protestors were not exposed to harmful levels of chemicals in the soil.

Category:	**Environmental Data – Sediment**
Date of Publication:	**2002**
Title:	Metales pesados en sedimentos de las Lagunas Gato y Anones. Heavy Metal Studies in Sediments from Gato and Anones Lagoons [trans.]
Author(s):	**Arturo Massol-Deyá and Elba Diáz**
Affiliation:	**Casa Pueblo de Adjuntas; University of Puerto Rico, Mayaguez Campus**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

Gato and Anones lagoons are on the western side of the Live Impact Area (LIA), near the Surface Impact Area (SIA). On February 12, 2000, to characterize heavy metal contamination, a sediment sample was collected from each lagoon. The samples were taken only from the lagoon dry areas.

The samples were 50 and 30 centimeters deep and were analyzed in 10- and 5- centimeter intervals (Gato and Anones, respectively). The authors reported that with respect to depth, the metals were almost homogeneously distributed. No significant differences appeared in the concentrations of heavy metals at different depths, nor between the lagoons. The authors noted that the "results display a high degree of mixture in the sediments down to at least 50 cm (20 inches) caused primarily by the intensity of bomb impacts in the area."

The authors reported sampling results in a bar chart. An approximate interpretation of their data is presented below.

Table A-4. Sediment samples from Gato and Anones Lagoons

	mg/kg						
	Copper	***Cobalt***	***Cadmium***	***Lead***	***Nickel***	***Chromium***	***Manganese***
Gato	40–60	60–100	60–100	100–130	60–125	300–500	900–1750
Anones	40–85	75–110	75–110	90–140	75–100	200–250	600–1000

No health guideline was cited.

How ATSDR Addressed the Study Findings

ATSDR obtained this study in July 2009, and reviewed the data as part of its evaluation of Vieques.

These data were collected from the former LIA—a restricted area. Thus no one is now continuously exposed to these chemicals. The longest potential exposure occurred from April 1999 to May 2000, when protestors occupied the LIA. As reported by Massol-Deyá and Diáz (2002), the maximum concentrations of cobalt, cadmium, lead, nickel, chromium, and manganese were higher than the concentrations evaluated in the 2003 Soil Pathway Evaluation. And when matched with health-based comparison values, the cadmium and chromium concentrations were higher as well. As noted, however, access remains restricted to the former LIA (including Gato and Anones lagoons).

Category:	**Environmental Data – Plants**
Date of Publication**:**	**April 10, 2000**
Title:	Metales pesados en la vegetación dominante del área de impacto de Vieques, Puerto Rico. Heavy Metals in the Impact Area Prevailing Vegetation, Vieques, Puerto Rico [trans.]
Author(s):	Arturo Massol-Deyá and Elba Diáz
Affiliation:	**Casa Pueblo de Adjuntas and University of Puerto Rico, Mayagüez**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Soil Pathway Evaluation)**

Study Findings

In February and March 2000, researchers from Casa Pueblo and the University of Puerto Rico's Recinto Universitario de Mayagűez (RUM), sampled vegetation for heavy metals in the Live Impact Area (LIA)—specifically, Carrucho Beach, Monte David, and Gato and Icacos Lagoons. Reference populations of the same species were also collected in Bosque Seco de Guánica and RUM Alzamora Ranch. Researchers sampled the following plants:

Urochloa maxima (root and stem),

Sporobolus virginicus (root and stem),

Syringodium filiform (stem),

Ipomoea violaceae (fruit),

Faidherbia albida (stem), and

Calotropis procera (leaves).

The average concentrations are presented in Table A-5.

Table A-5. LIA vegetation sample results

Average concentrations (µg/g)									
	Lead	***Cobalt***	***Nickel***	***Manganese***	***Chromium***	***Cadmium***	***Copper***	***Magnesium***	***Zinc***
Playa Carrucho									
S. filiforme	33.32	29.60	28.66	58.23	2.78	2.78	30.48	9929.14	106.24
Sargazo	22.69	130.46	28.23	169.07	7.36	2.83	28.27	17914.70	187.54
Monte David									
U. maxima (root)	12.85	63.66	14.19	115.44	21.04	2.89	17.10	2550.16	65.78
U. maxima (stem)	10.25	48.65	5.08	135.02	5.99	1.57	4.03	1667.61	42.98
C. procera (leaves)	30.05	68.40	18.08	287.94	12.68	3.11	4.63	11401.98	112.47
A. farnesiana (stem)	8.13	10.15	5.33	18.27	2.86	ND	4.04	2095.67	15.14
Laguna Icacos									
Aquatic plant	2.69	36.31	29.31	1740.42	42.14	4.63	12.93	-	68.97
Laguna Gato									
I. violaceae (fruit)	32.61	25.75	7.64	40.31	1.17	ND	9.39	1867.95	50.86
S. virginicus (root)	17.17	68.61	78.26	882.35	182.62	1.18	10.36	5135.36	73.20
S. virginicus (stem)	30.45	34.81	ND	670.57	5.32	ND	ND	1553.96	24.40
S. pyramidatus (root)	18.77	22.91	7.14	156.23	15.77	2.25	9.02	4450.16	45.06
S. pyramidatus (stem)	12.19	2.73	1.25	31.75	3.03	ND	ND	2931.47	15.60
Bosque Seco de Guanica and Alzamora Ranch (reference populations)									
C. procera (leaves)	1.29	2.59	5.17	17.85	9.31	1.03	5.69	-	19.91
S. filiforme (stem)	5.57	4.19	14.64	251.44	27.93	2.79	15.39	-	59.31
S. virginicus (stem)	0.60	3.11	5.36	7.54	7.35	0.79	2.76	-	14.83
U. maxima (root)	ND	6.89	19.95	78.61	23.75	0.80	14.52	-	75.77

U. maxima (stem)	ND	4.69	10.50	35.19	12.24	0.60	12.93	-	59.53

ND = not detected

The authors reported that in Vieques vegetation, concentrations of heavy metals such as lead, cobalt, and manganese were significantly higher than concentrations detected in the reference locations. The authors concluded that with the levels detected, if people were to eat these plants they would be exposed to critically hazardous doses. The authors recommended remediation to reduce the transport of chemicals from the LIA to the residential areas.

How ATSDR and the Puerto Rico Department of Agriculture Addressed the Study Findings

This and other studies by the same researchers reported metals in plants and livestock. Consequently, on August 7, 2001, the Puerto Rico Department of Agriculture placed an embargo on Vieques produce and livestock. The Puerto Rico Department of Agriculture, in cooperation with the Farmers Association of Puerto Rico, then sampled grass, fruit-bearing trees, and bovine livestock for cadmium, cobalt, copper, lead, manganese, and nickel. Samples were taken from Monte Carmelo, Martineau, Monte Santo, Esperanza, Lujan, Gubeo, and western Vieques. Sample analysis resulted in the conclusion that Vieques agricultural products were in fact suitable for consumption and did not contain toxic levels of the named contaminants (Department of Agriculture 2001). Because government and Farmer's Association researchers could not duplicate Dr. Massol's results, the embargo was lifted (El Nuevo Día 2001).

As part of the previous public health assessment, ATSDR requested that an agronomist with the U.S. Department of Agriculture (USDA) independently review the Casa Pueblo and RUM studies. The agronomist determined that although the studies provided evidence of heavy metals accumulation in plants, the studies' limitations prevented an estimation of human exposure dose. The agronomist further concluded that

> Many of the species sampled in this study were not eaten, and when edible species were sampled, the edible portions were not sampled. Human exposures from locally grown foods are best estimated from the edible portions of the food source. In general, the edible portions of plants are less likely to accumulate metals from soil because of normal plant processes (i. e., physiological barriers that prevent contaminants from reaching the tops of plants) (ATSDR 2001).

Additionally, the studies lacked standard reference materials to demonstrate that the results were accurate and lacked background corrections for lead, cobalt, nickel, and cadmium to eliminate the effect of light scattering by non-element materials in the samples.
The metals analysis also did not indicate whether the metals were bioavailable. This is important because vegetation samples include both contaminants taken up by the plant and soil particles from the growing media. Thus even with a thorough washing, small soil particles will adhere to the plant

materials and can actually carry more contaminants than those taken up by the plant from the soil (ATSDR 2001). When the external soil contamination is ingested, the chemicals bound to soil are not usually in a form the body can absorb. While methods are available to determine how much of a chemical concentration is adhered as soil and how much is in the plant tissue, the researchers here did not use them.

Thus ATSDR could neither quantify human exposures nor draw any health conclusions about whether consuming plants grown in Vieques would result in harmful health effects. As part of its evaluation, ATSDR recommended additional sampling of subsistence produce.

References

ATSDR. 2001. Summary Report for the ATSDR Expert Panel Meeting on Tribal Exposures to Environmental Contaminants in Plants. Atlanta: Division of Health Assessment and Consultation; 2001 March 23.

Department of Agriculture. 2001. Letter from Luis Colón to the Undersecretary of Agriculture concerning heavy metal tests on Vieques bovine livestock. 2001 October 17.

El Nuevo Día. 2001. They declare suitable the agricultural products in Vieques. 2001 December 13.

Category:	**Environmental Data - Plants**
Date of Publication:	**January 10, 2001**
Title:	Metales tóxicos en la vegetación de la zona civil de Vieques, Puerto Rico. Toxic Metals in the Vegetation of the Civilian Zone of Vieques, Puerto Rico [trans.]
Author(s):	**Arturo Massol-Deyá and Elba Diáz**
Affiliation:	**Casa Pueblo de Adjuntas and University of Puerto Rico, Mayagüez**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Soil Pathway Evaluation)**

Study Findings

Researchers from Casa Pueblo and University of Puerto Rico's Recinto Universitario de Mayagűez (RUM) randomly collected agricultural and common vegetation from three sites within 1) a Vieques residential section, 2) an agricultural area in Monte Carmelo as well as a section of Monte Carmelo that borders Camp Garcia, and 3) an agricultural farm in Barrio Monte Santo, Gobeo sector. The ensuing paper, however, limited its discussion to the two farms sampled in the civilian area of Vieques and focused its conclusions and recommendations on plants grown for an agricultural economy.

The study reported that all metals (cadmium, cobalt, copper, lead, and manganese) were found at toxic levels. Lead and cadmium had the highest absorption rates. Sampling included leaves and stems of pumpkin, pepper, pigeon peas, pineapple, and yucca. Only guamá and mangoes showed acceptable metals levels.

The study reported the following average concentrations found in plant stems and leaves. It did not report concentrations in the edible portions of the plants sampled (See Table A-6).

The authors concluded that the highest concentrations of metals were found in plants that had shallow roots—where higher contamination levels would be expected to be found in the soil— and plants requiring higher watering rates (more access to soil contamination).

Study recommendations included

- Permanent cessation of contamination-causing activities.
- A moratorium on consumption of plants grown in Vieques and compensation for farmers.
- Preventative actions for children who are more sensitive to toxins.

How ATSDR and the Puerto Rico Department of Agriculture Addressed the Study Findings

Because this and other studies by the same researchers reported metals in plants (Massol 2000) and livestock (Massol 2001), the Puerto Rico Department of Agriculture on August 7, 2001, placed an embargo on Vieques produce and livestock. The Puerto Rico Department of Agriculture, in cooperation with the Farmers Association of Puerto Rico, sampled grass, fruit-bearing trees, and bovine livestock from Monte Carmelo, Martineau, Monte Santo, Esperanza, Lujan, Gubeo, and western Vieques for cadmium, cobalt, copper, lead, manganese, and nickel. The Department of Agriculture and the Farmer's Association concluded that the agricultural products from Vieques were suitable for consumption and did not contain toxic levels of the named contaminants (Department of Agriculture 2001). When the Department of Agriculture and the Farmer's Association could not duplicate Dr. Massol's results, the embargo was lifted (El Nuevo Día 2001).

Table A-6. Vegetation samples

	Average Concentrations (µg/g dry weight)					
	Lead	***Cobalt***	***Nickel***	***Manganese***	***Cadmium***	***Copper***
Monte Carmelo, agricultural area						
C. procera (leaves)	62.16	15.54	20.76	469.58	4.87	28.78
A. farnesiana (leaves)	11.77	7.57	5.81	338.81	1.79	22.90
A. famesiana (stem)	13.04	7.47	5.14	33.26	1.10	14.70
U. maxima (leaves)	8.97	15.24	6.50	29.80	1.57	14.79
Pumpkin (leaves)	42.23	22.52	22.96	97.69	7.94	32.57
Pepper (leaves)	22.64	21.45	9.07	68.53	3.91	21.98
Pepper (stems)	11.85	24.55	12.31	21.66	5.73	41.68
Pigeon Peas (leaves)	10.59	14.81	10.28	193.36	2.72	15.44
Pigeon Peas (stem)	4.80	16.06	4.00	40.38	1.38	8.77
Bo. Monte Santo. Gobeo Sector						
Pepper (leaves)	39.52	6.04	12.90	30.48	2.59	34.11
Pepper (stem)	44.65	8.93	5.52	11.50	2.55	27.66
Mango (leaves)	12.40	3.51	3.00	372.90	0.75	6.26
Yucca (leaves)	29.23	10.22	3.49	104.46	2.23	39.27
Guama (leaves)	7.80	3.81	2.07	155.11	0.94	13.02
Banana (leaves)	29.99	6.06	2.25	507.53	0.64	16.57
Pigeon Pea (leaves)	49.14	6.03	6.65	74.60	1.10	25.81
Pigeon Pea (stem)	63.17	14.58	11.35	37.58	3.57	22.67
Pumpkin (leaves)	17.02	9.86	13.99	110.49	3.58	33.71
U. maxima (leaves)	8.58	2.75	4.79	57.97	0.69	11.48
Pineapple (leaves)	40.46	6.78	14.48	98.85	2.78	17.64
Quenepa (leaves)	18.68	8.33	5.25	34.78	1.06	14.61

As part of the 2001 public health assessment, ATSDR requested independent review of the study by an agronomist with the U.S. Department of Agriculture (USDA). That agronomist determined that although the studies provided evidence that heavy metal accumulation in plants, the study's limitations prevented estimation of a human exposure dose. The agronomist further concluded:

> Many of the species sampled in this study are not eaten, and when edible species were sampled, the edible portions were not. Human exposures from locally grown foods are best estimated from the edible portions of the food source. In general, the edible portions of plants are less likely to accumulate

metals from soil because of normal plant processes (e.g., physiological barriers that prevent contaminants from getting to the tops of plants) (ATSDR 2001).

The study lacked the use of standard reference materials to demonstrate that the results were accurate. The study also lacked background corrections for lead, cobalt, nickel, and cadmium to eliminate the effect of light scattering by non-element materials in the samples.
The metals analysis did not indicate whether the metals were bioavailable. This is important because samples of vegetation include both contaminants taken up by the plant and soil particles from the growing media. Even with a thorough washing, small soil particles will adhere to the plant materials, and can actually carry more contaminants than those the plant takes up from the soil (ATSDR 2001). When the external soil contamination is ingested, the chemicals bound to soil are not usually in a form that the body can absorb. While methods are available to determine how much of a chemical concentration adheres as soil and how much is in the plant tissue, the researchers here did not employ such methods.

Because of these factors, ATSDR could neither quantify human exposures nor draw any health conclusions regarding whether consuming plants grown in Vieques would result in harmful health effects. As part of its evaluation, ATSDR recommended additional sampling of subsistence produce.

References

ATSDR. 2001. Summary Report for the ATSDR Expert Panel Meeting on Tribal Exposures to Environmental Contaminants in Plants. Division of Health Assessment and Consultation; Atlanta, Georgia. March 23, 2001.

Department of Agriculture. 2001. Letter from Luis Colón to the Undersecretary of Agriculture concerning heavy metal tests on Vieques bovine livestock. October 17, 2001.

El Nuevo Día. 2001. They declare suitable the agricultural products in Vieques. December 13, 2001.

Category:	**Environmental Data – Plants**
Date of Publication:	**2003**
Title:	Trace Element Composition in Forage Samples from a Military Target Range, Three Agricultural Areas, and One Natural Area in Puerto Rico
Author(s):	**Elba Diáz and Arturo Massol-Deyá**
Affiliation:	**University of Puerto Rico, Mayagűez**
Publication Status:	**Caribbean Journal of Science 2003;39(2):215–220**
Peer Review Status:	**Peer reviewed**
Cited Previously by ATSDR:	**No**

Study Findings

This paper discusses the same data that the authors published in April 10, 2000 – plant samples collected February and March 2000 and analyzed for heavy metals. The paper compares concentrations found on Vieques with concentrations detected on the main island of Puerto Rico. The 2000 sampling included plant stems and leaves, but it did not include the edible portions of the plants sampled. This peer-reviewed publication did, however, provide more information on sampling, preparation, and analytical techniques than did the April 2000 report.

In addition to the 2000 sampling data, this paper included new samples of *C. cajan* (pigeon peas) leaves and fruit taken August 18, 2001 and discussed the ratio of contamination detected in the fruit to contamination detected in the leaves.

In Table 1 of the study, leaves and stems of four plant species were compared. When these findings were compared with samples from mainland Puerto Rico, the Vieques plant samples contained more lead, cobalt, and manganese, but less chromium and copper. For nickel and cadmium, results were mixed.

TABLE 1. Elemental analysis of leaf samples collected at two locations in Puerto Rico.

	Chemical element (µg/g dry weight)[1]						
	Pb	Co	Ni	Mn	Cr	Cd	Cu
Guánica, State Forest							
Calotropis procera	1.29 (1.10)	2.59 (0.00)	5.17 (1.46)	17.85 (1.10)	9.31 (0.73)	1.03 (0.00)	5.69 (1.46)
Syringodium filiforme	5.57 (1.90)	4.19 (0.06)	14.64 (4.74)	251.44 (1.39)	27.93 (1.60)	2.79 (0.04)	15.39 (4.16)
Sporobolus virginicus	0.60 (0.32)	3.11 (2.06)	5.36 (0.59)	7.54 (0.44)	7.35 (0.71)	0.79 (0.05)	2.76 (0.40)
Panicum maximum	nd	4.69 (0.16)	10.50 (2.95)	35.19 (1.24)	12.24 (3.71)	0.60 (0.85)	12.93 (2.11)
Vieques, AFWTF							
Calotropis procera	30.05 (3.63)	68.40 (9.08)	18.08 (2.50)	287.94 (3.39)	12.68 (2.82)	3.11 (2.09)	4.63 (4.25)
Syringodium filiforme	33.32 (10.77)	29.60 (5.51)	28.66 (1.58)	58.23 (1.86)	2.78 (1.33)	2.78 (1.33)	30.48 (3.63)
Sporobolus virginicus	30.45 (5.36)	34.81 (1.80)	nd	670.57 (267.85)	5.32 (0.99)	nd	nd
Panicum maximum	10.25 (1.27)	46.65 (8.91)	5.08 (3.25)	135.02 (31.72)	5.99 (0.58)	1.57 (0.14)	4.03 (3.34)

[1]Average (standard deviation; n = 2); nd = not-detectable.

Table 2 of the study compared leaves and stems of two plant species (pigeon peas and squash). As in Table 1, the Vieques samples had more lead and cobalt, but these two samples contained more cadmium and copper and less nickel and manganese.

Both sample sets showed that the Vieques plants contained more lead and cobalt. For the other metals, results were mixed depending on plant species.

TABLE 2. Trace element composition in forage from the civilian area of Vieques and mainland Puerto Rico.

	Chemical element (µg/g dry weight)[1,2]					
	Pb	Co	Ni	Mn	Cd	Cu
Mainland, Puerto Rico[3]						
Cajanus cajan	4.93 (0.28)	4.31 (0.30)	7.44 (0.56)	137.43 (6.68)	0.90 (0.13)	11.04 (0.41)
Cucurbita moschata	4.51 (1.54)	– (–)	17.43 (0.23)	113.03 (55.73)	0.65 (0.32)	21.16 (3.71)
Vieques, Puerto Rico[4]						
Cajanus cajan	29.14* (17.61)	10.42** (5.15)	7.38 (3.05)	126.32 (54.85)	1.79** (0.78)	20.58* (5.53)
Cucurbita moschata	33.08* (19.06)	7.95 (2.44)	10.32 (4.27)	92.54 (20.92)	2.34** (1.44)	29.76* (5.25)

[1]Average (standard deviation; n = 4 to 6); Dash = not available.
[2]Significant differences $*p < 0.05$; $**p < 0.10$.
[3]Mainland, includes samples from Mayagüez and Las Marías.
[4]Vieques, includes samples from Monte Carmelo, Villa Borinquen and Monte Santo.

Table 3 of the study compares concentrations detected in pigeon pea fruit and leaf samples collected August 18, 2001. For some metals, higher concentrations were found in the fruit (zinc, nickel, cadmium and cobalt). For other metals (i.e., copper and lead), higher concentrations were found in the leaves.

TABLE 3. Chemical elements in leaves and fruits of *Cajanus cajans* collected at [1]Monte Carmelo (Vieques, Puerto Rico) [μg/g dry weight].

	Cu	Zn	Ni	Pb	Cd	Co
Leaves	10.72 (6.06)	32.12 (9.95)	2.26 (0.28)	15.12 (0.59)	2.42 (0.23)	17.46 (0.95)
Fruits	8.22 (1.69)	34.00 (1.86)	4.80 (0.75)	6.35 (2.06)	3.17 (1.36)	25.75 (3.48)
Fruits/leaves[2]	0.8	1.1	2.1	0.4	1.3	1.5

[1]Samples were collected from all available plants (aprox. 20 individuals) on August 18, 2001.
[2]Fruits/leaves = 1.0, equal metal concentration in both plant tissue samples. Fruits/leaves > 1.0, higher metal concentration in the fruits. Fruits/leaves < 1.0, lower metal concentration in fruits.

How ATSDR Addressed the Study Findings

ATSDR obtained this study in May 2009. Because pigeon peas are a species Vieques residents eat, ATSDR has undertaken a review of the new pigeon pea data as part of its analysis of Vieques data (see Chapter 5).

Category:	**Environmental Data – Plants**
Date of Publication:	**August 14, 2005**
Title:	Trace Elements Analysis in Forage Samples from a U.S. Navy Bombing Range (Vieques, Puerto Rico)
Author(s):	**Arturo Massol-Deyá, Dustin Pérez, Ernie Pérez, Manuel Berrios, and Elba Díaz**
Affiliation:	**University of Puerto Rico**
Publication Status:	**Int J Environ Res Public Health 2005;2(2):263–266**
Peer Review Status:	**Peer reviewed**
Cited Previously by ATSDR:	**No**

Study Findings

This paper discussed the same data the authors published in April 10, 2000, and 2003 – plant samples collected February and March 2000 and analyzed for heavy metals. The authors note that "distinctive profiles are observed within the studied species thus reflecting differences in their physiological properties."

In addition to the 2000 sampling data, this paper included new samples of *Syringodium filiforme* (Manatee grass) taken from the Atlantic Fleet Weapons Training Facilities (AFWTF) in 2004 and from Guánica State Forest in 2003 and 2004. Concentrations of heavy metals were higher at AFWTF. The authors advanced the hypothesis of bioaccumulation through the food chain: manatee grass to crustaceans and fish to humans. A similar food chain scenario was presented for migratory birds.

The authors evaluated temporal variations of the *S. filiforme* samples. Table 2 of their study shows heavy metal concentrations in 2004 (after bombing activities stopped) were approximately ½ the concentration levels found in 2000 (when the bombing range was active). Similar results were found in the control population—plants from Guánica State Forest located approximately 120 miles from the bombing range.

Although not specifically stated by the authors, their data pointed out that "safe concentrations" detected in one species do not imply that other plant species have the same physiological properties and are also safe for consumption.

Table 2: Elemental analysis of *Syringodium filiforme* collected at the AFWTF and Guánica State Forest

	[1]*Chemical Element (g/g dry weight)*						
	Pb	*Co*	*Ni*	*Al*	*As*	*Cd*	*Cu*
AFWTF-2001 (Active)	33.32 (10.77)	29.60 (5.51)	28.66 (1.58)	na na	na na	0.28 (0.13)	30.48 (3.63)
AFWTF-2004 (Non-active)	8.14 (3.15)	10.61 (4.21)	3.43 (2.13)	154.3 (67.7)	0.61 (0.46)	0.15 (0.15)	17.42 (1.83)
Guánica-2001	5.58 (1.90)	4.19 (0.06)	14.64 (4.75)	na na	na na	0.28 (0.01)	15.39 (4.16)
Guánica-2003/2004	2.33 (2.24)	1.82 (0.43)	3.75 (1.85)	341.2 (112.9)	1.04 (0.25)	0.28 (0.22)	12.16 (2.83)

[1]Average (standard deviation; n = 2 to 10);
na = not available.

How ATSDR Addressed the Study Findings:

Manatee grass is not a species Vieques residents eat. These data might provide ecologically important information, but they are not directly relevant to evaluating human health. ATSDR has recommended additional sampling of subsistence produce.

Category:	**Environmental Data - Plants**
Date of Publication:	**January 2008**
Title:	Evaluación de Metales Pesados en Productos Agrícolas de una Finca con Prácticas Orgánicas en el Bo. Luján Sector Destino de Vieques (Puerto Rico). Evaluation of Heavy Metals in Agricultural Products of a Farm with Organic Practices in the Bo. Lujan Sector Destination of Vieques (Puerto Rico) [trans.]
Author(s):	Elba Diaz de Osborne, Pablo Acevedo-Acevedo, and Arturo Massol-Deyá
Affiliation:	**University of Puerto Rico**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited by Previously ATSDR:	**No**

Study Findings

In January 2008, researchers visited an organic farm in Vieques and collected leaves from cilantro, spinach, beans, peppers, and papaya plants. The researchers also analyzed for cadmium, chromium, copper, and lead. The researchers selected an organic farm because they believed the soil would be representative of naturally occurring soil and local airborne contamination. The researchers found concentrations of lead and cadmium in the Vieques vegetation significantly higher than concentrations detected in the reference plants in Mayagűez, a town on the western end of Puerto Rico, approximately 120 miles from Vieques.

Table A-7. Heavy metal levels in vegetation and health guideline from 1999 study

	mg/kg, dry weight			
	Cadmium	***Chromium***	***Copper***	***Lead***
Health Guideline cited in Study*	1.0	None given	None given	None given
Vieques	0.52 – 19.50	0.98-2.69	30.18 – 112.48	3.43 – 16.43
Mayagűez	0.74 – 1.70	No samples	44.05 – 54.24	1.88 – 5.10

*Food, Safety & Health of the European Union (1999)

Using these data, the researchers demanded that

1. The Navy compensate Vieques residents for the impact on agricultural activities: contaminated soil from Navy activities was windborne to the civilian areas of Vieques where it was taken up by agricultural plants.
2. Cleanup of the Live Impact Area (LIA) should include not only unexploded bombs, but contaminated soil as well: winds still blow contaminated soil toward the civilian area.
3. Cleanup of the Live Impact Area (LIA) should include removal of unexploded bombs in the sea adjacent to Vieques.
4. The Puerto Rico Environmental Quality Board should deny the Navy's application for a waiver to conduct open burning of vegetation: plants have taken up contamination in the soil, and burning plants would release that contamination to the air where it would ultimately reach Vieques residents.

How ATSDR Addressed the Study Findings

ATSDR requested and received this study from the author in October 2008. ATSDR found the concentrations, as reported, would be harmful to humans. Thus ATSDR consulted with the U.S. Department of Agriculture (USDA) about the study (Rufus Chaney, USDA, personal communication, October 28–30, 2008). USDA noted that

- The reported levels of copper would be phytotoxic to the plants.
- The soil might have been experimentally enhanced to increase metal uptake. The measurements reported were consistent with plants grown in soils artificially enhanced to increase metal uptake in plants.

Because of the limitations of this study, ATSDR recommended additional sampling of subsistence produce (see Chapter 5, Section 5.3.2).

Category:	**Environmental Data – Pineapples and Soil**
Date of Publication:	**2005**
Title:	Determination of Arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co) and Lead (Pb) in "Smooth Cayenne" Pineapple Fruit, Leaves Tissue and Soil Using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)
Author(s):	**José L. López Morales**
Affiliation:	**University of Puerto Rico, Mayagüez Campus**
Publication Status:	**Masters in Chemistry Thesis**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

In 2004, researchers from the University of Puerto Rico's Agricultural Extension Service in Vieques and the Land Authority of the Commonwealth of Puerto Rico collected study specimens. They collected a total of 72 samples of smooth cayenne pineapple fruit, leaf tissues, and soil from two pineapple plantations (one located in Barrio Luján in the civilian zone in Vieques and a control located in Barceloneta on the mainland of Puerto Rico). Inductively coupled plasma with optical emission spectrometry, together with U.S.EPA Method 200.7, were used to determine the total concentration of arsenic, cadmium, chromium, cobalt, and lead in the samples.

Table A-8. Heavy metals in pineapple and soil

Maximum Pineapple Fruit Concentration (mg/kg)					
	Arsenic	***Cadmium***	***Chromium***	***Cobalt***	***Lead***
Vieques	below LOD or ND	ND	2.3*	ND	ND
Barceloneta	below LOD or ND	ND	6.4	ND	ND
Maximum Soil Concentration (mg/kg)					
Vieques	169.7	3.9	6.7	9*	32.2
Barceloneta	268.4 or 331.4†	6.3	64.2 or 77.4†	12.7	76.5

LOD = limit of detection

mg/kg = milligrams per kilogram

ND = not detected

*Exact number not reported—value estimated from a bar graph.

†Both numbers are reported as the maximum detection.

The author concluded that samples from neither plantation showed contamination in the pineapple fruit or leaves. In all the fruit samples, arsenic, cadmium, cobalt, and lead were either below levels of detection or not detected. No contamination was observed in the pineapples from Vieques when compared with those from the Barceloneta plantation. Higher levels of metals were found in the soil at the Barceloneta plantation, which the author attributed to the soil's natural composition. The author concluded that these results were in agreement with those of ATSDR and that all values were within accepted regulatory levels.

How ATSDR Addressed the Study Findings:

As part of its analysis of Vieques data, ATSDR evaluated the level of chromium—the only metal detected—in the pineapple fruit samples (see Chapter 5, Section 5.2.3). Using a standard intake rate for fruit consumption,[35] the estimated exposure dose ATDSR calculated was below levels of health concern.

[35] About 7 ounces of fruit a day (mean total fruit intake; USEPA 1997)

Category:	**Environmental Data – Livestock**
Date of Publication:	**2001**
Title:	Herbivorous: Additional Evidence of Heavy Metal Mobilization through the Food Web
Author(s):	**Arturo Massol-Deyá**
Affiliation:	**Casa Pueblo de Adjuntas and University of Puerto Rico**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Soil Pathway Evaluation)**

Study Findings

On August 18, 2001, researchers from Casa Pueblo de Adjuntas collected hair samples from goats grazing in Vieques' Mount Santos and Santa María areas. As a reference, samples were also collected from goats that pasture in the main island of Puerto Rico.

The publication reported that hair from goats grazing in Vieques contained higher levels of metals than did similar samples from goats on the main island. No mercury was detected in any goat hair (detection limit was 0.03 µg/g).

Table A-9. Metals detected in goat hair

Metals Detected in Goat Hair (µg/g)					
	Lead	***Cadmium***	***Cobalt***	***Nickel***	***Aluminum***
Main Island - Adjuntas, average	0.12	0.02	0.07	0.14	27.8
Vieques – Monte Santo, average	0.35	0.04	0.11	0.21	17.0
Vieques – Santa María, average	2.87	0.09	0.24	0.18	89.0
Monte Santo/Adjuntas	2.9	2.1	1.5	1.5	0.6
Santa María/Adjuntas	23.9	4.5	3.4	1.2	3.2
Maximum Ratio*	49.2	7.0	5.5	2.3	5.0

The authors concluded that their study confirmed the "spread of dangerous levels of contaminants through the Viequense's food web." Yet the study provided no comparison values.

Additional information about this study is found in *Science and Ecology: Vieques in Environmental Crisis*, pages 52–53, by the same authors. They noted that goats and cattle that grazed on guinea grass and that other plants consumed by humans had higher concentrations of lead and cadmium.

How ATSDR and the Puerto Rico Department of Agriculture Addressed the Study Findings

The Soil Pathway Evaluation (see pages 57–58 in the PHA) addressed this issue as a community concern. Because this and other studies by the same researchers reported elevated levels of metals in plants and livestock, on August 7, 2001, the Puerto Rico Department of Agriculture placed an embargo on Vieques produce and livestock. The Puerto Rico Department of Agriculture, in cooperation with the Farmers Association of Puerto Rico, sampled grass, fruit-bearing trees, and bovine livestock from Monte Carmelo, Martineau, Monte Santo, Esperanza, Lujan, Gubeo, and western Vieques for cadmium, cobalt, copper, lead, manganese, and nickel. the Department of Agriculture and the Farmer's Association concluded that the agricultural products from Vieques were suitable for consumption and did not contain toxic levels of these contaminants (Department of Agriculture 2001). Because the Department of Agriculture and the Farmer's Association could not duplicate Massol's results, the embargo was lifted. (El Nuevo Día 2001)

References

Department of Agriculture. 2001. Letter from Luis Colón to the Undersecretary of Agriculture concerning heavy metal tests on Vieques bovine livestock. 2001 October 17.

El Nuevo Día. 2001. They declare suitable the agricultural products in Vieques. 2001 December 13.

Category:	**Environmental Data – Sea Life**
Date of Publication:	**December 6, 1999**
Title:	Draft Findings in Vieques, Puerto Rico (AKA Heavy Metals in Reefs Where Bombs Are)
Author(s):	**James Porter**
Affiliation:	**University of Georgia, Consultant to King and Spalding**
Publication Status:	**Letter to law firm, King and Spalding**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Fish and Shellfish Evaluation)**

Study Findings

On November 26–30, 1999, Dr. Porter conducted a field survey to examine the health of the coral reefs to the south of the Live Impact Area (LIA).

The study reported on four objectives:

1. Collect samples of chemicals leaking from the bombs. The letter reported that analysis should have been available in late December, 1999.
2. Determine the origin of craters in the area. Magnetometer readings suggested that metal objects (i.e., bombs) were imbedded in the crater walls. The study concluded that detonations caused the craters.
3. Determine whether bombing occurred after 1993. Dr. Porter used draft cards data and serial numbers to identify dates. But no data or conclusions regarding when bombing occurred were presented in the letter.
4. Determine the extent of chemical contamination. Analyses were not available at the time of the letter, but visual observations were reported:

   a. Coral in contact with one of the leaking bombs was diseased and highly discolored.

   b. 100–150 barrels and one compressed gas cylinder were located near a sunken barge.

   c. 900–1000 barrels were located near a second barge that was broken in two. (The second barge was later identified as the former USS Killen, sunk during target practice.)

Dr. Porter's letter recommended

1. Identifying additional undersea areas with barrels—local fishers reported two additional areas.
2. Sampling barrels and gas cylinders to determine contents, management, and removal options.

3. Sampling coral in the area to determine the coral's age and hence the date when the barrels were sunk. [In a University of Georgia (UGA) press release dated December 13, 1999, Dr. Porter estimated the barges had sunk about 10 to 12 years previously.]

In a December 13, 1999, UGA press release, Dr. Porter reported seeing the sunken vessel and hundreds of 55-gallon drums. Available at: http://www.uga.edu/news/newsbureau/releases/1999releases/porter_rico.html.

Note: Dr. Porter published his results in 2004. Dr. Porter then concluded that "concentrations of explosive chemicals found in fish and lobster collected in the vicinity of the USS Killen are below the EPA's Risk-Based Concentrations for commercially edible seafood."

How ATSDR Addressed the Study Findings

Dr. Porter's 1999 press release regarding leaking barrels prompted ATSDR's exposure investigation team to sample fish in Vieques coastal waters. In 2001, ATSDR and U.S.EPA collected 104 fish and 42 shellfish from six locations in and around Vieques, including the area that Dr. Porter sampled near the former USS Killen. To determine other sampling locations and species of fish to collect, ATSDR relied on research by Universidad Metropolitana, discussions with the person who had petitioned ATSDR for an assessment of public health conditions on Vieques, residents of Vieques, and information provided in the Vieques Special Commission Report. ATSDR collected grouper, snapper, parrotfish, grunt, goatfish, land crabs, queen conch, and spiny lobster. In addition, to address a specific community concern, ATSDR collected one honeycomb cowfish from a local fish market.

In 2003, ATSDR concluded the following in its Fish and Shellfish Evaluation:

- Explosive compounds were not detected in any of the edible fish and shellfish sampled from Vieques.
- Metals were detected in the fish and shellfish.
- ATSDR evaluated several consumption scenarios, including eating fish every day. ATSDR found that it is safe to eat a variety of fish and shellfish from Vieques on a daily basis, including snapper (the most desirable and commonly consumed species). ATSDR concluded in 2003 that fish and shellfish caught at any of the locations are safe to eat, including fish and shellfish from areas in and around the former LIA and USS Killen.

ATSDR is reevaluating mercury in fish and shellfish. The results from our evaluation of Vieques are in this report's Chapter 2.

Category:	**Environmental Data – Crabs**
Date of Publication:	**January 12, 2000**
Title:	Biomagnification of Carcinogenic Metals in Crab Tissue, Vieques, Puerto Rico
Author(s):	**Arturo Massol-Deyá and Elba Diáz**
Affiliation:	**Casa Pueblo de Adjuntas and University of Puerto Rico, Mayagüez**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Fish and Shellfish Evaluation)**

Study Findings

In November 1999, researchers from Casa Pueblo de Adjuntas, in cooperation with the Biology Department of Recinto Mayagűez at the University of Puerto Rico, sampled male fiddler crabs from Icacos Lagoon in the Live Impact Area (LIA). As a control, the researchers took samples from Puerto Mosquito, just east of Esperanza. Icacos Lagoon is adjacent to Anones Lagoon; the researchers sampled soil in Anones Lagoon on February 12, 2000. The purpose of the research was to assess the potential transport of metals from soil in the LIA to other ecosystems.

At each location, researchers collected close to 35 fiddler crabs. They analyzed the extremities (i.e., levers and legs) separately from the body (i.e., shell and internal contents) for cadmium, chromium, cobalt, copper, lead, manganese, nickel, and zinc.

The researchers then compared the levels of the heavy metals detected in fiddler crabs in Icacos Lagoon with the levels in the soils. They reported that with regard to cadmium, biomagnification was occurring; cadmium concentrations in the fiddler crabs were 10–20 times higher than in the soils.

The researchers further reported that the average cadmium concentration (8.05 µg/g) of crab bodies (i.e., shell and internal contents) exceeded the World Health Organization's (WHO) weekly maximum allowable concentration (0.007 µg/g) (approximately 60 µg/person/day for a 60 kg person) and the U.S. Food and Drug Administration's (USFDA) daily critical concentration for persons older than 2 years (6 µg/g).

Table A-10. Metals detected in fiddler crabs

Metals detected in fiddler crabs (µg/g dry weight)								
Location-Sample	***Copper***	***Manganese***	***Zinc***	***Lead***	***Chromium***	***Cadmium***	***Nickel***	***Cobalt***
Puerto Mosquito – extremities	49.94	86.56	62.99	n/d	25.48	1.74	17.15	12.17
Icacos Lagoon - extremities	51.18	37.17	61.91	n/d	23.07	4.77	7.02	9.82
Puerto Mosquito - bodies	381.75	199.96	120.80	n/d	40.27	2.24	21.81	10.32
Icacos Lagoon - bodies	499.91	97.75	75.59	n/d	40.70	8.05	18.95	35.69

nt detected/d = no

How ATSDR Addressed the Study Findings

Dr. Massol's study established that fiddler crabs contained evidence of heavy metals. The study raised the question of what metal concentrations would be found in the crabs humans eat.

But the study could not answer that question. It involved fiddler crabs, which humans do not eat. And the study did not separate the crab meat and shell—his analysis was of the shell and body contents combined.

Dr. Massol's report of high fiddler crab contamination did prompt ATSDR to sample land crabs, which humans do eat. In 2001, during the Fish and Shellfish Evaluation, ATSDR and U.S.EPA collected land crabs from three locations on Vieques, including the former LIA (see Sections IV and V and Appendix D of the PHA). No explosives compounds were detected in the edible portions of land crabs from any of the locations. Although metals were detected in land crabs, the levels were too low to be of health concern for people eating them.

ATSDR also reviewed the U.S. Fish and Wildlife Service's (USFWS) 2001 ecological study in the Fish and Shellfish Evaluation of land crabs and fiddler crabs from west Vieques (see pages 12–13 of the 2003 PHA). The USFWS research established that fiddler crabs and land crabs contained some heavy metals and pesticides. Because the USFWS samples were analyzed as whole body, the data from the report were useful to evaluate ecological contamination, but could not be easily converted to evaluate human health.

In 2006, an ATSDR health consultation assisted the USFWS to determine whether selected refuge areas could be opened to harvest land crab. In 2005, NOAA sampled 74 land crabs from 14 locations, analyzing them for explosive compounds, PCBs, organochlorine pesticides, and trace elements:

- The levels found in the land crabs were much lower than levels the scientific literature reported as causing harmful health effects.
- Explosive compounds were not detected in any crab sample.
- No association was found between sampling location and land crab contaminant levels.

Category:	**Environmental Data – Sea Grass**
Date of Publication:	**June 2000**
Title:	Evaluación Preliminar de las Condiciones Químicas y Físicas de las Hierbas Marinas *Thalassia testudium* y *Syringodium filiforme* en Vieques. Research on the Physical and Chemical Conditions of Sea Grasses *Thalassia testudium* and *Syringodium filiforme* in Vieques [trans.]
Author(s):	**Fernando L. Herrera, Brenda Alicea Lopez, Blanca Diaz Perez, Siomara Cardona Vilella, Neritza Guerra Villanueva, and Maria C. Ortiz Rivera**
Affiliation:	**Metropolitan University, School of Environmental Affairs; Universidad de Puerto Rico, Arecibo**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

The survey's purpose was to perform a demographic and morphological assessment of *Thalassia testudium* and identify and determine the heavy metal content in *Thalassia* and *Syringodium* tissues. In sea grasses around Vieques, Dr. Herrera found "high concentrations" of aluminum, arsenic, iron, nickel, zinc, cadmium, cobalt, and lead. He also noted a close relation between past military activities and the pollution found in Vieques marine plants.

How ATSDR Addressed the Study Findings

Dr. Herrera's report of heavy metals in sea grass—a substance humans do not eat—prompted ATSDR to sample conch, which humans do eat and which are sea-grass habitués. In 2001, ATSDR and U.S.EPA collected 20 conchs from four sea grass beds around Vieques—north of the LIA, near the USS Killen, south of Esperanza, and west of the Monte Pirata Conservation Zone. These locations were chosen to represent productive fishing areas around the island. The conch meat was analyzed for explosive compounds and heavy metals:

- No explosive compounds were detected in conch from any of the locations.
- Metals were detected in conch, but those levels were too low to be of health concern for people who eat conch.

Category:	**Environmental Data – Fish**
Date of Publication:	**June 2000**
Title:	Estudio Toxicológico de Metales Pesados en Poblaciones de Peces en la Isla de Vieques. Toxicological Study of Heavy Metals in Fish Populations at Vieques Island [trans.]
Author(s):	**Doris Caro PhD, Mei-Ling Nazario, and Noel Díaz**
Affiliation:	**Metropolitan University**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Fish and Shellfish Evaluation)**

Study Findings

Between December 1999 and April 2000, researchers from Metropolitan University collected fish from fish markets on the northern and southern coasts of Vieques and from the Parguera fish market in Lajas on the western side of the Puerto Rico mainland.

To determine fish consumption rates and which species to sample, researchers used a questionnaire to ask Vieques residents about their dietary habits. Fifty-one residents responded.

The researchers concluded that "based on the data obtained . . . we were not able to verify our hypothesis of potential bioaccumulation in the fish . . . there is no clear relationship between fish weight and size and their metal content."

In the 78 fish samples analyzed, no cadmium was detected, and no lead was detected in the fish fillets. But the authors did report "high concentrations" of arsenic, mercury, selenium, and zinc.

Table A-11. Heavy metals in market fish

Heavy Metals in Market Fish—Fish Fillet Samples (ppm)						
	Lead	***Cadmium***	***Arsenic***	***Mercury***	***Selenium***	***Zinc***
Vieques, north	n/d	n/d	0.325-1.676	0.019-0.048	0.123-1.290	1.2-9.1
Esperanza	n/d	n/d	0.290-0.658	0.022-0.048	0.168-0.713	3.3-8.2
Parguera, Main Island	n/d	n/d	0.000-2.236	0.000-0.008	0.103-0.502	0.7-5.9

n/d, none detected

Cadmium detection limit, 0.005 ppm

Lead detection limit, 0.050 ppm

How ATSDR Addressed the Study Findings

In the 2003 Fish and Shellfish Evaluation (see pages 11–12 of the PHA), ATSDR evaluated whether the concentrations reported by the authors would result in harmful health effects for people consuming fish. ATSDR determined at the time that it was safe to eat fish from the sampled fish markets on a daily basis (i.e., all of the concentrations reported by Universidad Metropolitana were too low to be of health concern). The study did, however, provide valuable information on dietary habits: specifically, how often Vieques Islanders ate fish and what species they ate. ATSDR used that dietary information throughout the PHA.

In Chapter 2 of this report, ATSDR uses information from Dr. Caro's survey and its own fish data to evaluate local fish consumption. The conclusions and recommendations from this evaluation are presented in Chapters 2 and 9.

Category:	**Environmental Data – Sea Life**
Date of Publication:	**March 8, 2004**
Title:	Radiological, Chemical, and Environmental Health Assessment of the Marine Resources of the Isla de Vieques Bombing Range, Bahia Salina del Sur, Puerto Rico
Author(s):	**James Barton and James Porter, PhD**
Affiliation:	**Underwater Ordnance Recovery, Inc. and University of Georgia, respectively**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

This report describes research undertaken to determine the radiological, explosive, and chemical safety of the marine coastal waters in the vicinity of the USS Killen submerged wreck site. The report provided the following findings and conclusions:

Radiological

- Normal ambient radiological readings were found around the USS Killen and around the 55 gallon drums.
- The readings indicate no health threat.
- The wreck of the USS Killen and 55 gallon drums should be left undisturbed to provide marine habitat.

Explosives

- Measurable readings of explosive residues were detected in some biota from the vicinity of the some bombs, with concentrations decreasing with increasing distance from the source.
- The readings from the decaying ordnance are localized, and pose a minimal toxicological threat to humans.
- The fish and lobster collected in the vicinity of the USS Killen are safe to eat. The concentrations of explosive chemicals are below the U.S.EPA's risk-based concentrations for commercially edible seafood.
- As increased human access and environmental leaching patterns increase the risk of detonation, spread, and bioaccumulation in the immediate vicinity of UXO and related debris, all such items located from the high water mark on shore to the bottom of Bahia Salina del Sur should be removed.

Metals

- Arsenic concentrations in fish (0.76 and 1.05 ppm) are above the U.S.EPA Risk-Based Concentration Guide (0.26 ppm).
- The authors noted that concentration of total arsenic in lobster collected from Site 1 (11.0 ppm) is within the normal range for Atlantic spiny lobster (10–20 ppm). The report text states that the arsenic levels are above the U.S.EPA Risk-Based Concentration Guideline (0.13 ppm) and may warrant a limited consumption advisory.
- Concentrations of barium, cadmium, chromium, and selenium in fish and lobster were below the U.S.EPA Risk Based Concentration Guidelines and within the ranges reported in the 2001 ATSDR fish sampling event.
- Uranium and lead were not tested for fish collected from Sites 1 and 2.

Table A-12. Sampling results of marine coastal waters

Matrix	Site 1(-fore)		Site 1(-aft)		Site 2		Site 3		Hatillo, P.R. (control)	
	As	Se	As	Se	As	Se	As	Se	As	Se
Water	2.51 µg/L	30.8 µg/L	1.15-1.38 µg/L	19.0 - 27.4 µg/L	0.93-1.02 µg/L	17.1-25.0 µg/L	1.30-1.42 µg/L	21.8-25.5 µg/L	---	13.75 µg/L
Sediment	5.24 mg/kg	<2.70 mg/kg	1.75 mg/kg	<2.70 mg/kg	3.17-5.99 mg/kg	<2.70 mg/kg	1.28-1.90 mg/kg	<2.70 mg/kg	4.22 mg/kg	<2.70 mg/kg
Drums	---	---	---	---	2.55-42.2 mg/kg	<2.70 mg/kg	---	---	---	---
Fish	0.76 mg/kg	<0.90 mg/kg	---	---	1.05 mg/kg	1.06 mg/kg	---	---	---	<0.9 mg/kg *
Coral	<0.20 mg/kg	< 2.3 mg/kg	<0.20 mg/kg	< 2.3 mg/kg	<0.20-0.91 mg/kg	<2.3 mg/kg	0.41 mg/kg	<2.3 mg/kg	<1.13 mg/kg	<2.3 mg/kg
Lobster	38.4 mg/kg	11.0 mg/kg	---	---	---	---	---	---	---	---

** Control is fish from local Kroger, Athens, GA*

Table 4.4. Summary of As and Se concentration detected in samples analyzed. The EPA Drinking Water Maximum Contaminant Level (MCL) value for As is 50 µg/L, and for Se is 50 µg/L. The EPA Risk-Based Concentration (RBC) for As in fish is 0.26 mg/kg and 20 mg/kg for Se.

How ATSDR Addressed the Study Findings

Although the data were not published until 2004, in 1999 the University of Georgia issued a press release reporting that Dr. Porter discovered leaking barrels off the LIA coast. This report prompted ATSDR's 2001 exposure investigation during which it sampled fish, crabs, lobster, and conch around Vieques. In 2001, ATSDR and U.S.EPA collected 104 fish and 42 shellfish from six locations on Vieques, including the area that Dr. Porter sampled near the former USS Killen. In 2003, ATSDR's Fish and Shellfish Evaluation evaluated data from the agency's 2001 sampling event and concluded the following:

- Explosive compounds were not detected in any of the edible fish and shellfish sampled from Vieques.
- Metals were detected in the fish and shellfish.
- ATSDR evaluated several consumption scenarios, including eating fish every day. ATSDR found that it was safe to eat a variety of fish and shellfish from Vieques on a daily basis, including snapper (the most desirable and commonly consumed species).
- Fish and shellfish caught at any of the locations were safe to eat, including from areas around the former LIA and the USS Killen.

As part of its analysis of Vieques data, ATSDR evaluated the level of mercury in fish collected from the reefs surrounding Vieques and from a fish market on the island. The results from our evaluation of Vieques can be found in Chapter 2.

Arsenic levels in fish and shellfish are often reported as total arsenic. It is important, though, to distinguish between inorganic arsenic, which is harmful to humans, and arsensobetaine, which is an arsenic-containing compound that is not harmful to humans. Arsenobetaine is not harmful because it is not metabolized by humans and is easily and quickly excreted within 2 to 3 days of ingestion. Most of the arsenic (usually less than 1%) in fish and shellfish, such as lobster, is the non-toxic arsensobetaine (Sloth 2005, Fabris 2006, Green 2006). One particular study reported the percent inorganic levels in the spiny lobster (*Panulirus* species) was 0.01 to 0.2 percent (Peshut 2008). *Panulirus* is the genus of lobster found near Vieques and other parts of the Caribbean.

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Fabris G, Turoczy NJ, Stagnitti F. 2006. Trace metal concentrations in edible tissue of snapper, flathead, lobster, and abalone from coastal waters of Victoria, Australia. Ecotoxicology and Environmental Safety 63;286-292.

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Greene R, and Crecelius E. 2006. Total and inorganic arsenic in mid-Atlantic marine fish and shellfish and implications for fish advisories. Integrated Environmental Assessment and Management 2(4);344-354.

Category:	**Environmental Data – Sea Life**
Date of Publication:	**February 21, 2009**
Title:	Carcinogens Found in Marine Life in Island of Vieques in Puerto Rico
Author(s):	**James Porter, PhD**
Affiliation:	**University of Georgia**
Publication Status:	**Press Release**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

This press release announced that Dr. Porter would present the findings of his 1999 sampling event at the Second International Dialogue on Underwater Munitions on February 25–27, 2009 in Honolulu, Hawaii.

Dr. Porter's 2004 report recommended leaving the unexploded bombs in place. According to the new press release, he now recommended ordnance removal using an ordnance recovery system designed by Underwater Ordnance Recovery, Inc., and using the technical expertise of machinists at the University of Georgia instrument shop.

The press release noted that carcinogenic material was detected up to 2 meters from the bombs and quoted Dr. Porter as saying a future step will be "to determine the link from unexploded munitions to marine life to the dinner plate."

How ATSDR Addressed the Study Findings

The Centers for Disease Control and Prevention (CDC) participated in the panel presentation at the Second International Dialogue on Underwater Munitions. ATSDR considered Dr. Porter's new information as part the agency's analysis of Vieques data.

Category:	**Environmental Data - Air**
Date of Publication:	**May 1999**
Title:	Contaminación Producida por Explosivos y Residuos de Explosivos en Vieques, Puerto Rico. Contamination Produced by Explosives and Explosive Residues in Vieques [trans.]
Author(s):	**Rafael Cruz Pérez, PE**
Affiliation:	**College of Engineers**
Publication Status:	**Dimension magazine**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2003 Public Health Assessment: Air Pathway Evaluation)**

Study Findings

Dr. Cruz-Pérez modeled air quality effects resulting high explosives used at Vieques.

Dr. Cruz-Pérez concluded that

- Detonation of a single artillery shell (i.e., a 105 mm mortar projectile) could emit 400 kilograms of soil and explosive residue into the air.
- Ambient air concentrations of pollutants from military training exercises are inversely proportional to the downwind distance raised to the 1.5 power.
- A single explosion of an artillery shell would cause ambient air concentrations of particulate matter in the residential areas of Vieques to increase by 33 $\mu g/m^3$ over the course of 15.9 minutes.
- Including contributions from background, an unspecified level of military training exercises would lead to particulate matter concentrations of 197 $\mu g/m^3$ in the residential areas of Vieques.

How ATSDR Addressed the Study Findings

When ATSDR first began its evaluation of the air pathway, two dispersion modeling studies were available—one prepared by Navy contractors and the other by Dr. Cruz-Pérez, whose air modeling of particulate matter disagreed with the Navy's modeling. This prompted ATSDR to hire three modeling experts to review both studies critically. After examining the reviewers' findings, ATSDR decided to conduct an independent modeling study that did not suffer from some of the previous studies' shortcomings. Note that given the limited air sampling that occurred at Vieques during the time when the Navy used live bombs, modeling was necessary.

The Air Pathway Evaluation conclusions were based largely on ATSDR's modeling effort. The Air Pathway Evaluation also included ATSDR's evaluation of Dr. Cruz-Pérez's air modeling analysis (see pages D-11 through D-15 of the PHA).

Dr. Cruz-Pérez's article provided no hard evidence (e.g., references, equations, input parameters) to defend the estimated air emission rate of 400 kilograms of soil per single artillery shell. In Appendix D of the PHA, to estimate emissions, ATSDR used a published model and documented all input parameters and assumptions.

Dr. Cruz- Pérez based the estimated ambient air concentrations on an assumed decay rate with downwind distance. All three expert reviewers questioned Dr. Cruz-Pérez's estimated decay rate, with one expert reviewer citing peer-reviewed publications suggesting that pollutants from instantaneous plumes—like those associated with bombing activity—would decay much more quickly than Dr. Cruz-Pérez's calculations suggested. Expert reviewers identified at least one error in Dr. Cruz-Pérez's calculations, and ATSDR noted that the approach did not take into account parameters known to affect atmospheric dispersion (e.g., initial cloud height, atmospheric stability, wind speed, wind direction, mixing height). To estimate ambient air concentrations at Vieques, ATSDR used a U.S.EPA-recommended model (CALPUFF) with options for modeling "puff" (i.e., instantaneous) sources, such as the bombing events at Vieques. ATSDR's modeling predicted the air quality effects of more than 75 pollutants—not just a single pollutant. And in its PHA, ATSDR fully documented all model assumptions, input parameters, and run-time options.

By contrast, Dr. Cruz-Pérez estimated particulate matter ambient air concentrations on days when military training exercises occurred. Expert reviewers noted, however, that these estimates do not document the averaging time for the concentrations (e.g., 24-hour, annual average) nor do they specify the particle size (e.g., PM10, PM2.5, TSP), both of which are important health evaluation considerations. ATSDR's modeling analysis accounted for these shortcomings by specifying the particle sizes considered and by evaluating both acute and chronic exposure durations. The PHA documents all ambient air concentrations ATSDR estimated during the modeling effort.

Category:	**Environmental Data - Water and Soil**
Date of Publication:	**May 11–16, 1978**
Title:	Vieques Litigation Support: Explosives Analyses of Water and Soil Samples Taken on Vieques Island, Puerto Rico
Author(s):	**JC Hoffsommer and DJ Glover**
Affiliation:	**Navy, Naval Surface Weapons Center, Explosives Chemistry Branch, MD**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2001 Public Health Assessment: Drinking Water Supplies and Groundwater Pathway Evaluation and 2003 Public Health Assessment: Soil Pathway Evaluation)**

Study Findings

From May 11 to May 16, 1978, the Naval Surface Weapons Center (NSWC) obtained and analyzed water and soil samples from inside and outside the Vieques Island live impact area (LIA). The samples were collected 1 week after a military exercise in which live ordnance was used at the LIA. Samples were analyzed for TNT, RDX, and Tetryl. The study also analyzed for the biotransformation products of TNT: 4-amino-2, 6-dinitrotoluene, and 2-amino-4, 6-dinitrotoluene. NSWC detected no biotransformation products.

NSWC did find that concentrations of TNT and RDX were below the toxicological hazard levels suggested by the U.S. Army Medical Bioengineering Research and Development Laboratory in 1977. No guideline was given for Tetryl.

NSWC took 26 water samples: 15 within the LIA (one drinking water) and 9 in Navy-controlled areas west of LIA (one drinking water) including the Naval Ammunition Facility (NAF) and Camp Garcia, drinking water in Isabel Segunda, and drinking water in Esperanza.

Table A-13. NSWC water sample results

Station	*Station Description*	*TNT, ppm**	*RDX, ppm*	*Tetryl, ppm*
	Health Guideline cited in study	<0.01	<0.03	NA
	Drinking Water Samples			
5	Pump house water, NAF magazine Area	Absent	0.00006	Absent
6	Drinking Water, Esperanza	Absent	0.00004	Absent
7	Drinking Water, Isabel Segunda	Absent	0.00004	0.0005
OP-1	Drinking water Cerro Matias (within LIA)			
	Surface Water Samples			
1	Magazine water run-off NAF Area (maximum detected off LIA)	<0.00004	0.001	<0.0009
19	Crater A run-off water (maximum TNT detected within LIA)	0.00003	0.00045	Absent
20	Lagoon water (maximum RDX detected within LIA)	Absent	0.0059	Absent

*ppm = parts per million

NSWC collected six soil samples on land under Navy control; no samples were taken in residential areas. Like the water samples, these samples were analyzed for TNT, RDX, Tetryl, and biotransformation products of TNT. In addition, the soil samples were analyzed for acetone extractables. No Tetryl or biotransformation products were detected.

Table A-14. NSWC soil sample results

Station	*Station Description*	*TNT, ppm**	*RDX, ppm*	*% Acetone Extractables*
	Health Guideline cited in study	<0.01	<0.03	NA
8	Soil near Bahia de la Chiva, Maneuver Area, Camp Garcia (maximum detected TNT)	0.0060	0.0030	0.04
24	Soil from Crater b, Demolition Range #6	0.0071	0.0054	0.14
20	Lagoon soil (maximum % acetone extractables detected)	Absent	0.024	0.31

*ppm = parts per million

How ATSDR Addressed the Study Findings

ATSDR evaluated the data from this report as part of the Drinking Water Supplies and Groundwater Pathway Evaluation (see page 32 and Appendix E of the drinking water PHA) and the Soil Pathway Evaluation (see Section IV of the PHA).

The concentrations of explosive compounds reported in both drinking water and lagoon water were well below levels considered harmful to human health. Past exposure to these compounds did not pose a public health hazard.

The drinking water samples (4) and the chemicals analyzed in this study were both limited. To arrive at its drinking water health call, ATSDR used additional data. In the drinking water PHA, Appendix B lists sampling events and Appendix C lists chemicals for which analyses were performed.

Other sampling events detected no RDX or tetryl in the drinking water supplies. The study noted, "a completely positive identification was not possible due to the extremely low concentrations found." It further noted, "if these explosives are present, the concentrations do not exceed the values reported here." The Navy laboratory that analyzed the samples had developed sensitive techniques to test for explosives in seawater and particularly to detect explosive compounds. These methods were more sensitive than the current U.S.EPA laboratory methods now considered the standard for environmental work. The reported soil levels were below comparison values and did not indicate a health hazard.

The number of soil samples (6) was limited. Thus for its soil health call, ATSDR used additional data. For example, in 1999 and 2000, the Navy (at ATSDR's request) and Servicios Científicos y Técnicos collected soil samples from areas where the protestors lived. Protestors who lived on the LIA for a year (1999–2000) endured the longest exposure to contaminants in the LIA soil. ATSDR reviewed the data and determined that the protestors were not exposed to harmful levels of soil-embedded chemicals.

Category:	**Health Outcome Data – Heart Disease**
Date of Publication:	**January 2001**
Title:	Vibroacoustic Disease Induced by Long-Term Exposure to Sonic Booms
Author(s):	**R Torres, G Tirado, A Roman, R Ramirez, H Colon, A Araujo, F Pais, W Maciniak, J Nobrega, A Bordalo e Sa, JMC Lopo Tuna, M Alves-Pereira, NAA Castelo Branco**
Affiliation:	**Virtual Research Group and Center for Human Performances**
Publication Status:	**Draft manuscript**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Yes (2001 Vieques Heart Study Expert Panel Review)**

Study Findings

In January 2001, a pilot study comparing the echocardiograms of commercial fishers in Vieques and in Ponce Playa, Puerto Rico reported large proportion of Vieques fishers with substantial valvular abnormalities and pericardial thickening—conditions not seen in Ponce Playa. The possible abnormalities noted in the Vieques fishers were attributed to "vibro-acoustic disease" (VAD), which Portuguese investigators had described in the medical literature. VAD was said to occur as the result of noise and vibrations caused by naval exercises on Vieques Island. By Presidential directive, the Department of Health and Human Services undertook an investigation of the issues raised by the study. The Department, in turn, referred this request to ATSDR, then currently investigating environmental public health issues in Vieques. The Cardiovascular Diseases Branch of Centers for Disease Control (CDC) provided considerable assistance in this investigation.

Concurrent with this request, the Ponce School of Medicine (PSM), led by President and Dean Dr. Manuel Martínez Maldonado, began a more definitive study of possible cardiac abnormalities among Vieques residents. This study sought to overcome methodological problems in the earlier pilot study. On March 29–30, 2001, scientists from ATSDR and CDC met with the PSM investigators and agreed that their review and interpretation of the findings should include an independent opinion of recognized practitioners and scientists.

How ATSDR Addressed the Study Findings

In July 2001, ATSDR, PSM, and CDC co-sponsored an expert panel to review PSM's follow-up study. The panel's principal conclusion was that neither the PSM nor the Mayo Clinic readings contained information indicating a cardiac health problem in the commercial fishers from either location. The initial report of gross valvular pathology from the pilot study was not replicated. All reviewers agreed that contrary to pilot study reports, no clinically relevant difference in pericardial thickness surfaced between Vieques and Ponce Playa subjects. Moreover, neither the PSM nor the Mayo Clinic measurements showed any subject's pericardial thickness to be larger than 2 mm—a metric the published literature considered the upper limit of normal.

The PSM study does not support findings of cardiac pathology among Vieques fishers. Because of the inability of trans-thoracic echocardiography to measure reliably the small differences found, those reported are likely due to measurement error—intrinsic to the technique, not to scientists who use it. This in all likelihood accounts for the different results obtained when Mayo Clinic readings of pericardial thickness were used in place of PSM readings.

Category:	**Human Biomonitoring – Hair and Stool**
Date of Publication:	**circa 2000**
Title:	Investigación Científica de los Metales Tóxicos habidos en el Terreno Biológico de niños y adultos viequenses y sus efectos sobre los Minerales Nutrientes. Scientific Investigation of Toxic Metals Present in the Biological Terrain of Vieques Children and Adults and Their Effects on Nutrient Minerals [trans.]
Author(s):	**Carmen Colón de Jorge, Edgardo Santiago, John Brooks, Francisco Lopez Perez, Jaime Rivera, Rafael Valle**
Affiliation:	**College of Physicians and University of Puerto**
Publication Status:	**draft manuscript (unpublished)**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**Not cited, but basis for the 2001 Hair Analysis Panel Discussion**

Study Findings

In 1999 and 2000, Dr. Colón de Jorge collected hair and stool samples from Vieques residents. The doctor stated that 45–50% of these nonrandomly selected people were poisoned with mercury. Using results from stool samples, the doctor found that 3 out of the 6 children tested in Vieques had metal concentrations in stools above the reference range provided by the clinical laboratory (i.e., Doctor's Data). The doctor also reported that 5 out of 6 children tested had antimony and arsenic in stool samples that exceeded the lab's reference range. And these were children who, unlike adults, might not be exposed to metals in paint, cigarette paper, tobacco, old pots, makeup, and hair dye.

Dr. Colón de Jorge reported that 30 hair samples were collected from Vieques residents with self-reported health conditions. The doctor also concluded that 1) 50% of the people tested were contaminated with antimony compared with 29% from a control population, 2) 50% of the people tested were contaminated with arsenic compared with 29% from a control population, and 3) 50% of the people tested had a selenium imbalance. Dr. Colón de Jorge pointed out that antimony levels were high because it was used in ballistics on the island, thus making the case that naval bombardment activity was the reason antimony levels were high in children.

Dr. Colón de Jorge also used the following statements to summarize the results of seven control patients:

- None of the seven patients showed total toxic levels of metals. Two cases had antimony above the reference range established by the laboratory compared with 29% of those investigated outside Vieques. Selenium was normal for exogenous contamination.

- Two cases had arsenic above the reference range compared with 29% of the cases outside Vieques. Selenium was normal for exogenous contamination.
- Because their selenium levels were normal and within the reference range, the seven control patients did not have endogenous heavy metals contamination.
- Dr. Colón de Jorge collected hair samples at random from seven persons in Rio Piedras, on the main island of Puerto Rico. None of the results showed toxic levels of heavy metals. By contrast, tests of 21 of 30 persons (i.e., 63%) from Vieques with known health conditions (and thus not randomly selected) detected various metals at toxic levels.
- Dr. Colón de Jorge's report contains several appendices with additional information, mostly focused on how to evaluate and interpret elemental results in hair. One of the appendices contained a Doctor's Data report entitled *Comprehensive Interpretations for Hair Elements from Al to Zn* (Quiq 1998).

How ATSDR Addressed the Study Findings

To determine the relationship between hair data and the potential for adverse health effects, ATSDR sought the assistance of external experts. In June 2001, ATSDR convened an expert panel to discuss the state of the science relating to analyzing hair for environmental exposure (ATSDR 2001). The panel comprised persons from state and federal government agencies, academia, and private practice whose expertise, interests, and experience covered a wide range of relevant technical disciplines.

The panelists agreed that

> . . . for most substances, insufficient data currently exist that would allow the prediction of a health effect from the concentration of the substance in hair. The presence of a substance in hair may indicate exposure (both internal and external), but does not necessarily indicate the source of exposure.

The panel noted that—provided external contamination can be ruled out—a relationship between contaminant concentrations in hair and any kind of measurable outcome have only been established for methylmercury and, to a limited extent, for arsenic.

The panel recognized that laboratory methods are available to measure the levels of some environmental contaminants in hair, but commented that procedures needed to be standardized to help ensure more accurate and reliable results. They also identified several factors that limited the interpretation of even the most accurate, reliable, and reproducible laboratory results.

The community concern about hair analysis was briefly addressed in the 2001 Soil PHA (see page 58).

References

Agency for Toxic Substances and Disease Registry. 2001. Summary Report, Hair Analysis Panel Discussion: Exploring the State of the Science. June 12–13, 2001. Atlanta: Division of Health Assessment and Consultation and Division of Health Education and Promotion; 2001 December. Available from: http://www.atsdr.cdc.gov/hac/hair_analysis/ [accessed 2010 Jan 13].

Category: **Human Biomonitoring – Hair**

Date of Publication: **January 29, 2002**

Title: Heavy Metal Exposure and Disease in the Proximity of a Military Base

Author(s): **Carmen Ortiz Roque**

Affiliation: **Private practice, GINECO, San Juan, PR**

Publication Status: **draft manuscript (unpublished)**

Peer Review Status: **None**

Cited Previously by ATSDR: **No**

Study Findings

From January 2000 to July 2001, Dr. Carmen Ortiz Roque collected hair samples from 203 Viequenses. Table A-15 shows hair data for various metals.

Table A-15. Results of metal analysis of hair samples collected from Viequenses from January 2000 to July 2001.

Metal in ppm	*% Elevated*	*Average (95% CI)*	*Females*	*Males*	*Children <10 years old*
Mercury, N= 205	33% > 1 ppm	2.07 (0 – 8.9)	2.87	1.08	1.89
Aluminum, N=145	56% > 17 ppm	25.74 (10.52-25.75)	26.45	24.18	34.94
Cadmium, N=205	26% > 0.47 ppm	0.65 (0-5.0)	0.75	0.55	Not available
Lead, N=205	2.9% > 25 ppm	8.07 (0-19.0)	4.28	12.47	Not available
Arsenic, N=205	0 > 1 ppm	0.18 (0 – 3.0)	0.141	0.233	Not available

Dr. Ortiz Roque stated that elevated levels of mercury (33%), aluminum (56%), cadmium (26%), and lead (6%) were found in the participants. Hair arsenic levels were not elevated.

Dr. Ortiz Roque further stated that 22% of women and 60% of children sampled in Vieques had mercury levels above what the United States considers the 90th percentile.

A subset of 22 Vieques matched pairs of mothers and their children 5 years or younger was analyzed further. Dr. Ortiz Roque reported a significant correlation between mercury hair levels in mothers and their children (Pearson's correlation 0.93, p = 0.0001). Average aluminum hair concentration for Viequenses was 25.74 ppm, and this concentration exceeded the upper limit of a standard human population. Dr. Ortiz Roque pointed out that aluminum levels in children's hair are normally higher than in adults.

The doctor concluded that the data showed Viequenses had internal exposure to heavy metal, and that the data were supported by the high percentage of women and children with hair mercury levels above the 90^{th} percentile compared with the continental United States. While none of the women in the NHANES 1999 survey had mercury hair levels above 12 ppm, 3 of 45 Viequenses women had hair levels above 12 ppm (i.e., 15.41, 25.26, and 101.3 ppm).

Dr. Ortiz Roque concluded that the correlation between mother and offspring hair showed that mercury exposure occurred *in utero,* that Viequenses exposure to mercury was too high to be considered safe, and that mercury was used in the detonators.

How ATSDR Addressed the Study Findings

As mentioned previously, ATSDR convened a panel of experts who agreed that

> . . . for most substances, insufficient data currently exist that would allow the prediction of a health effect from the concentration of the substance in hair. The presence of a substance in hair may indicate exposure (both internal and external), but does not necessarily indicate the source of exposure.

Nevertheless, Dr. Ortiz Roque documented several mothers with elevated mercury levels in hair and her findings are described in Chapter 3. Viequenses who remain concerned about exposure to mercury, cadmium other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing.

Category:	**Human Biomonitoring – Hair**
Date of Publication:	**2004**
Title:	Mercury Contamination in Reproductive Age Women in a Caribbean island: Vieques
Author(s):	**Carmen Ortiz Roque, Yadiris López-Rivera**
Affiliation:	**Private Practice, GINECO, San Juan, Puerto Rico**
Publication Status:	**J Epidemiol Community Health 2004;58:756–57**
Peer Review Status:	**Yes**
Cited Previously by ATSDR:	**No**

Study Findings

Dr. Ortiz Roque published the mercury data from the 2001 hair study of Vieques residents. That study investigated hair mercury levels in women 16 to 49 years old who lived on the island of Vieques. The doctor compared those levels with women from San Juan and Ceiba, Puerto Rico. Women were excluded whose hair had been chemically treated within 3 months of the test. A 1.5-cm proximal hair sample was collected and analyzed by one of two licensed laboratories.

Dr. Ortiz Roque reported statistics on 41 Viequenses women together with information about seafood consumption, and compared these data with mainland Puerto Rico and the United States. Table A-15 summarizes the data. Dr. Ortiz Roque used margin of exposure (MOE) to define unsafe exposure levels.

Table A-16. Mercury hair results in women published by Dr. Ortiz Roque in 2004

	#	*Age*	*Mercury in ppm*			*Margin of Exposure*	*Seafood Consumption*			*% Women> RfD*
			Median	*Mean*	*90th Percentile*		*Total*	*Local*	*Local fish*	
Vieques	41	31.8	0.66	4.4	8.96	1.3	4.9	2.9	1.9	26.8
PR	45	29.9	0.38	0.4	1	12	2.8	1.1	0.7	6.6
US	702	NA	0.2		1.4	8.6	NA	NA	NA	7

Dr. Ortiz Roque's MOE approach originated in a 2001 MMWR article and with the National Research Council. The NRC recommended a 5% effect level derived from the 95% lower confidence limit of a benchmark dose (BMDL). The basis for the 5% effect level is abnormal scores on cognitive function tests in children exposed *in utero* to methylmercury. The NRC recommended that the U.S.EPA derive their Reference Dose using a BMDL of 58 ppb methylmercury in cord blood, which was identified as the 5% effect level from a Faroe Islands study using statistical models. The 58-ppb cord blood translates to 12 ppm in hair (Ortiz Roque 2004; NRC 2000).

Results showed that the 90th percentile mercury hair concentration in Vieques women was 8.96 ppm compared with 1 ppm in women from Puerto Rico and 1.4 ppm in women from the United States. Dr.

Ortiz Roque concluded that Viequenses women of reproductive age were exposed to mercury concentrations unsafe to their developing fetuses.

How ATSDR Addressed the Study Findings

Dr. Ortiz Roque documented several mothers with elevated mercury levels in hair. Her findings are described in Chapter 3.

Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing.

References

[NRC] National Research Council. 2000. Toxicological Effects of Methymercury. Washington (DC): National Academy of Sciences, National Research Council. Pubs: National Academy Press.

Ortiz Roque C, López-Rivera Y. 2004. Mercury contamination in reproductive age women in a Caribbean island: Vieques. J. Epidemiol Comm Health 58:756–57.

Category:	**Human Biomonitoring – Hair, Nails and Urine**
Date of Publication:	**2004 and 2006-2008**
Title:	Arsenic Detected in Urine, Nails, and Hair Study (Exact title not available)
Author(s):	**Carlos Rodríguez Sierra**
Affiliation:	**University of Puerto Rico, Department of Environmental Health**
Publication Status:	**El Vocero (newspaper article)**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

Dr. Carlos Rodríguez Sierra apparently conducted two urine arsenic studies in Vieques. The first was before 2004 and the results were presented at several public health conferences, including the 2004 8th International Symposium on Metal Ions in Biology and Medicine. The second arsenic study was from 2006 to 2008 and was reported in *El Vocero* in March 2009. Neither study has been published in a peer-reviewed journal. ATSDR has requested that Dr. Rodríguez Sierra share a manuscript or summary statistics but have not received a response. Dr. Rodriquez Sierra is with the Department of Environmental Health, Site Medical Sciences, University of Puerto Rico.

The following information comes from a March 2009 newspaper article in *El Vocero* describing arsenic exposure in Vieques residents from eating fish. The article stated that inorganic arsenic was found in a representative sample of Viequenses with high fish consumption.

Dr. Rodríguez Sierra identified two groups in Vieques: one consisted of 30 persons who consumed substantial quantities of fish. Another consisted of 22 persons who consumed very little fish. As a biomarker of short-term exposure, the researchers measured the levels of inorganic arsenic in urine. As a biomarker of long-term exposure, they measured arsenic in nails and in hair.

The article stated that the researchers measured arsenic in urine and found that, on average, levels in urine, hair and nails were generally low. Nevertheless, some people, and particularly some men, who ate fish frequently had higher concentrations of *inorganic* arsenic in their nails—an indicator of long-term exposure.

How ATSDR Addressed the Study Findings

Because the data were not available, ATSDR considered the results qualitatively in Chapter 3. Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing.

Category:	Human Biomonitoring – Blood
Date of Publication:	**November 2006**
Title:	Executive Summary of the Prevalence of Heavy Metals in Vieques
Author(s):	**Juan Alsono Echanove and Luis Manuel Santiago**
Affiliation:	**Commonwealth of Puerto Rico, Department of Health**
Publication Status:	**draft manuscript**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

Beginning in 2004, the Puerto Rico Department of Health (PRDOH) conducted a two-phase, 5-year, 500 person, epidemiological study of heavy metals in residents' blood, urine, and hair. The results were presented in a draft manuscript in 2006. In the first phase, the PRDOH study conducted interviews and laboratory analysis on 1) arsenic in hair and urine, 2) nickel in hair and urine, 3) cadmium in hair and urine, 4) mercury in blood, 5) lead in blood, 6) aluminum in blood, and 7) uranium in urine. The second phase of the investigation involved collecting and analyzing blood samples from Phase I participants whose tests showed metals at toxic levels. Phase II was carried out from December 2005 to March 2006.

The PRDOH manuscript reported the main findings of this study as

- Detectable levels of at least one heavy metal were found in over 90% of the population.
- The levels of aluminum in blood, arsenic in urine, and nickel in hair were over the laboratory threshold in more than 20% of the study participants. Arsenic results in urine were for total arsenic, not inorganic arsenic.
- Geometric means for uranium in urine, mercury in blood, lead in blood, aluminum in blood, nickel in hair, and cadmium in urine were significantly higher than geometric means from the 1999 NHANES survey.
- None of the geometric means identified by the laboratory was over the laboratory's toxicity threshold.
- For arsenic, cadmium, and nickel, the use of cigarettes, consumption of seafood, and use of hair dye were identified as risk factors for levels above the laboratory threshold.
- Fifteen persons (3%) were identified with levels above the toxicity threshold for aluminum in blood (10), lead in blood (2), mercury in blood (1), and cadmium in urine (2).
- In the follow-up study on 10 of the 15 persons, only one person with levels above the toxicity threshold was identified.

The PRDOH manuscript suggested establishment of a voluntary health registry of Vieques residents. A health registry would 1) allow for systematic documentation of factors related to potential risks, 2) identify people with early signs and symptoms that may be associated with illness, and 3) facilitate early care and health service access needs.

The PRDOH manuscript pointed out that blood lead levels were unknown for the 1,000 Vieques children 6 years of age and younger. This high-risk group is more vulnerable to lead exposure than are adults. The PRDOH manuscript stated that an epidemiologist would be appointed to work towards establishing this program, which will follow CDC guidelines for case management. Whether at this time this program has been implemented is unknown.

How ATSDR Addressed the Study Findings

The PRDOH biomonitoring study provided much insight into metal exposure for Vieques residents. Some results from the PRDOH study suggested elevated levels of various metals, thus raising concerns about excessive exposure on the island. The PRDOH study is described in detail in Chapter 3. Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing.

Category:	**Human Biomonitoring – Hair**
Date of Publication:	**None**
Title:	Title not determined
Author(s):	**Dr. John Wargo**
Affiliation:	**Yale University, Connecticut**
Publication Status:	**draft manuscript (not available)**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

Yale University's Dr. John Wargo considered analyzing data and preparing a paper about heavy metals in Viequenses hair. However, he has informed ATSDR that he no longer plans to do this analysis because of quality assurance/quality control issues with the hair data and because of problems with using hair to measure most metals.

How ATSDR Addressed the Study Findings

No study findings will be available.

Category:	**Health Outcome Data**
Date of Publication:	**November 7, 2006**
Title:	Cancer Incidence and Mortality in Vieques 1990–2001
Author(s):	**Nayda R. Figueroa, MD, MPH, Erick Suárez, PhD, Taina De La Torre, MS, and Mariela Torres, MS**
Affiliation:	**Commonwealth of Puerto Rico, Department of Health**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

From 1973 to 1989, the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program in part funded the Puerto Rico cancer registry (PRCR). After 1989, the contract between the PRCR and SEER was not renewed, and until 1997, PRCR operated on local funding. In 1997, the PRCR applied for and received funding from the Centers for Disease Control and Prevention (CDC) through a cooperative agreement via the National Program of Cancer Registries. In calendar year 1998, beginning with cancer cases diagnoses, the PRCR provided data to the CDC .

In this report, cancer incidence and mortality in Vieques during 1990–2001 for the most common anatomical sites (i.e., breast, colorectal, cervical, oral cavity and pharynx, lung and bronchus, and prostate) and a few other cancers potentially associated with environmental exposures (i.e., liver and intrahepatic bile duct, kidney and renal pelvis, bladder, lymphoma and leukemia) were assessed for two periods (1990–1995 and 1996–2001). Cancers were also assessed by sex where applicable. To present 5-year cancer incidence and mortality rates is standard practice, as noted in publications such as SEER's *Cancer Statistics Review*, the North American Association for Central Cancer Registries' *Cancer in North America*, and joint publications such as the *United States Cancer Statistics*.

After age adjustments, the analysis identified increased cancer *incidence* in Vieques for some specific anatomical sites as well as in all cancers combined. Significant increases were only identified in the 1990–1995 time period. Statistically significant, age adjusted standardized incidence ratios (SIRs) with corresponding 95% confidence intervals (95% CIs) were

- All cancers for both sexes combined (SIR=1.19; 95%CI 1.02, 1.39);
- Lung and bronchus for both sexes combined (SIR=2.25; 95%CI 1.35, 3.52);
- Lung and bronchus for men (SIR=2.24; 95%CI 1.19, 3.83); and
- Prostate (SIR=1.47; 95%CI 1.03, 2.03).

After age adjustments, the analysis identified an increased cancer *mortality* in Vieques for some specific anatomical sites as well as for all cancers combined. Statistically significant, age adjusted standardized mortality ratios (SMRs) with corresponding 95% confidence intervals (95% CIs) were

- All cancers for both sexes combined, 1990–1995 (SMR=1.26; 95%CI 1.01, 1.57);
- All cancers for women, 1990–1995 (SMR=1.43; 95%CI 1.01, 1.96);
- All cancers for both sexes combined, 1996–2001 (SMR=1.25; 95%CI 1.01, 1.52);
- Breast cancer, 1990–1995 (SMR=0.26; 95%CI 0.03, 0.92); and
- Oral cavity and pharynx for men, 1990–1995 (SMR=3.96; 95%CI 1.08, 10.00).

As mentioned briefly in the document and as confirmed by Dr. Figueroa (personal communication, July, 2009), some follow up was necessary to identify cases in Vieques that were not processed uniformly with the rest of PR. One example relates to documentation of age for cases in the registry. For this assessment, on the island of Vieques all cases indicating residence had their ages confirmed. But this practice was not followed on the PR main island. If a case did not have a known age, it was omitted from any rate calculations. Given the small number of Vieques cases, the age was confirmed to ensure that all potential cases could be included.

How ATSDR Addressed the Study Findings

Health outcome data was not included in previous ATSDR reports about Vieques. This study's results are now discussed in Chapter 4.

Category:	**Health Outcome Data**
Date of Publication:	**March 2000**
Title:	Exploratory study of health and other conditions in Vieques
Author(s):	**Yadiris Lopez, and Crisarlin Carrosquillo**
Affiliation:	**Scientific and Technical Services and the University of Puerto Rico Graduate School of Planning**
Publication Status:	**Self-published**
Peer Review Status:	**Unknown**
Cited Previously by ATSDR:	**No**

Study Findings

This document describes a cross sectional study of residents in four Vieques neighborhoods—Lujan, Puerto Rico Reconstruction Administration settlement (PRRA), Esperanza, and Santa Maria. Reportedly, fieldwork for this study occurred between April and November 2000.[36] The authors attempted to include all residents in each neighborhood and allowed the head of a household—typically the matriarch—to provide proxy responses for all household members. Beyond the demographic, employment, and dietary habit information collected, the survey also gathered self-reported disease prevalence data.

Cancer, heart disease, hypertension, diabetes, and asthma were self-reported at a higher prevalence than referent data from the main island of Puerto Rico. Specifically, the reported case rates were 1.18–2.69 times the reported case rates from a 1994 Puerto Rico study. All data were self-reported or reported via proxy. No attempt was made to access medical records to validate the collected information.

The four neighborhoods were collectively described as representative of the Vieques population. Lujan had 132 reported residents with a reported age range of 5–25 years, PRRA had 306 reported residents with a reported age range of 59–70 years, Esperanza had 388 reported residents, and Santa Maria had 217 reported residents.

How ATSDR Addressed the Study Findings

Health outcome data was not included in previous ATSDR reports about Vieques. This study's results are now discussed in Chapter 4.

[36] This time frame as reported appears inconsistent with the March 2000 publication date.

Category:	**Health Outcome Data**
Date of Publication:	**November 25, 2009**
Title:	Incidence and Mortality of Cancer in Vieques 1990–2004
Author(s):	**Nayda R. Figueroa, MD, MPH, Erick Suárez, PhD, Taina De La Torre, MS, Mariela Torres, MS, and Javier Perez, MPH,CTR**
Affiliation:	**Commonwealth of Puerto Rico, Department of Health**
Publication Status:	**Self-published**
Peer Review Status:	**None**
Cited Previously by ATSDR:	**No**

Study Findings

From 1973 to 1989, the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program in part funded the Puerto Rico cancer registry (PRCR). After 1989, the contract between the PRCR and SEER was not renewed, and until 1997, PRCR operated on local funding. In 1997, the PRCR applied for and received funding from the Centers for Disease Control and Prevention (CDC) through a cooperative agreement via the National Program of Cancer Registries. In calendar year 1998, beginning with cancer cases diagnoses, the PRCR provided data to the CDC .

In this report, cancer incidence and mortality in Vieques during 1990–2004 for the most common anatomical sites (i.e., breast, colorectal, cervical, oral cavity and pharynx, lung and bronchus, and prostate) and a few other cancers potentially associated with environmental exposures (i.e., liver and intrahepatic bile duct, kidney and renal pelvis, bladder, lymphoma and leukemia) were assessed for three periods (1990–1994, 1995-1999, and 2000–2004). Cancers were also assessed by sex where applicable. To present five-year cancer incidence and mortality rates is standard practice, as noted in publications such as SEER's *Cancer Statistics Review*, the North American Association for Central Cancer Registries' *Cancer in North America*, and joint publications such as the *United States Cancer Statistics*.

After age adjustments, the analysis identified increased cancer *incidence* in Vieques for some specific anatomical sites as well as in all cancers combined. Significant increases were identified in 1990–1994 and 1995-1999. Statistically significant, age adjusted standardized incidence ratios (SIRs) with corresponding 95% confidence intervals (95% CIs) were identified for:

1990–1994

- Lung and bronchus for both sexes combined (SIR=2.34; 95%CI 1.36, 3.75 and ;
- Lung and bronchus for men (SIR=2.43; 95%CI 1.25, 4.24);

1995–1999

- All cancers for both sexes combined (SIR=1.26; 95% CI 1.08, 1.47)
- All cancers for men (SIR=1.31; 95% CI 1.07, 1.60)
- Prostate (SIR=1.53; 95%CI 1.09, 2.09).

After age adjustments, the analysis identified an increased cancer *mortality* in Vieques for some specific anatomical sites as well as for all cancers combined. Statistically significant, age adjusted standardized mortality ratios (SMRs) with corresponding 95% confidence intervals (95% CIs) were identified for:

1990 – 1994 - Colorectal cancer for women (SMR=2.75; 95% CI 1.11, 5.67)

1995 – 1999 – All cancers for both sexes combined (SMR=1.35; 95% CI 1.08, 1.67)

2000 – 2004

- All cancers for men (SMR=1.40; 95% CI 1.07, 1.80)
- Prostate cancer (SMR=2.62; 95% CI 1.66. 3.93)

As mentioned briefly in the document and as confirmed by Dr. Figueroa (personal communication, July, 2009), some follow up was necessary to identify cases in Vieques that were not processed uniformly with the rest of PR. One example relates to documentation of age for cases in the registry. For this assessment, on the island of Vieques all cases indicating residence had their ages confirmed. But this practice was not followed on the PR main island. If a case did not have a known age, it was omitted from any rate calculations. Given the small number of Vieques cases, the age was confirmed to ensure that all potential cases could be included.

How ATSDR Addressed the Study Findings

Health outcome data was not included in previous ATSDR reports about Vieques. This study's results are now discussed in Chapter 4.

Category:	**Environmental Data – Coral Reef Ecosystem**
Date of Publication:	**June 2002**
Title:	Ex-USS Killen Site Investigation and Biological Characterization, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico
Author(s):	**Ken Deslarzes, Robert Nowajchik, and David Evans**
Affiliation:	**Geo-Marine, Inc**
Publication Status:	**Self-published**
Peer Review Status:	**No**
Cited Previously by ATSDR:	**Yes**

Study Findings

In November 2001, marine scientists mapped the remains of the former USS Killen (in two pieces in Bahia Salina del Sur), and assessed the submerged aquatic vegetation, fish population, and coral population around the sunken vessel. Given the amount of superstructure missing from the Killen, the hypothesis was that the drums were used as ballast to redistribute the weight of the target ship. They also found that several of the drums had been sealed empty to provide buoyancy to certain of the ship's compartments. The submerged aquatic vegetation around the two areas was comparable to the control site and did not exhibit signs of environmental distress. The vessel supported fish and coral populations similar to the control site, and was not found to be negatively affecting the ecosystem. The study concluded that the sunken vessel was acting as a productive artificial reef habitat.

How ATSDR Addressed the Study Findings

ATSDR used the results of this study in the 2003 Fish and Shellfish Evaluation to address the Viequenses' concerns about the former USS Killen and the drums associated with it. As part the agency's evaluation of Vieques, a summary of the study was added to the section discussing the effects former military activities on Vieques have had on the surrounding marine environment (See Chapter 2, Section 2.1.4).

Category:	**Environmental Data – Coral Reefs**
Date of Publication:	**July 2008**
Title:	A Tale of Germs, Storms, and Bombs: Geomorphology and Coral Assemblage Structure at Vieques (Puerto Rico) Compared to St. Croix (U.S. Virgin Islands)
Author(s):	**Bernhard Riegl, Ryan P. Moyer, Brian K. Walker, Kevin Kohler, David Gilliam, and Richard E. Dodge**
Affiliation:	**National Coral Reef Institute**
Publication Status:	**Journal of Coastal Research 24(4):1008–1021**
Peer Review Status:	**Yes**
Cited Previously by ATSDR:	**No**

Study Findings

This study compared the variability of coral assemblages of reef zones between Vieques and St. Croix to evaluate the differences and the influence of natural and manufactured factors. The researchers established 18 sites at Vieques (12 inside the former LIA and 6 in the former EMA) and 6 at St. Croix for evaluation of coral assemblage structure. No differences in living benthic coral reef cover or composition of coral assemblages between inside and outside the LIA were found at Vieques. Also, coral assemblages at Vieques and St. Croix were similar in composition and biotic coverage. The researchers considered the lack of differentiation within the coral communities of Vieques and between Vieques and St. Croix the most pronounced outcome of the study. Because the reefs at St. Croix were not in better condition than reefs at Vieques, the authors suggest that natural disturbances (disease and storms) had a greater impact on coral communities than former military bombing activities.

How ATSDR Addressed the Study Findings

Because Viequenses are concerned about the effects that bombing activities have had on the marine environment, ATSDR reviewed this new study as part the agency's evaluation of Vieques. A summary of the study was added to the section discussing ecological impacts to the coral reefs around Vieques (see Chapter 2, Section 2.1.4).

Category:	**Environmental Data – Fish and Shellfish**
Date of Publication:	**November 2001**
Title:	Field Data Summary, Vieques Fish Assessment, Vieques, Puerto Rico
Author(s):	**Daniel Cook, Steven Clapp, and Alan Humphrey**
Affiliation:	**Lockheed Martin/REAC and U.S. Environmental Protection Agency/Environmental Response Team**
Publication Status:	**Self-published**
Peer Review Status:	**No**
Cited Previously by ATSDR:	**Yes**

Study Findings

The U.S. Environmental Protection Agency's Environmental Response Team (EPA/ERT) collected and analyzed 104 fish and 38 shellfish (representing 20 different edible species) from the coastal waters and near shore land on Vieques in July 2001. Fiddler crabs from the LIA were also collected. EPA/ERT caught fish and shellfish from five preferred fishing locations (north of the LIA, south of the LIA, south of Esperanza, north of Isabel Segunda, and west Vieques) as well as from a local fish market in Isabel Segunda. Several heavy metals were detected in the fish and shellfish. No explosive compounds were detected in the fish and shellfish, with the exception of low levels of cyclotetramethylene tetranitramine (HMX) and a chemical *similar* to cyclotrimethylene trinitramine (RDX)[37] in fiddler crabs and a chemical *similar* to RDX in one trunkfish from the fish market. Because the fiddler crabs had not been rinsed prior to analysis, the detection may have been the result of soil contamination. Explosive compounds were not detected in any of the other 142 edible fish or shellfish samples. EPA/ERT statistically determined that the chemical concentrations in fish and shellfish collected from south of the LIA were similar to those collected from west Vieques. The divers qualitatively noted that the reefs were in good condition and the fish appeared healthy. They documented the presence of unexploded ordnance to the north and south of the LIA.

How ATSDR Addressed the Study Findings

EPA/ERT conducted the study to assist ATSDR with their evaluation of whether commonly consumed fish and shellfish from Vieques contain levels of heavy metals and explosives compounds that would adversely affect public health. The results of the study were thoroughly evaluated and discussed in the 2003 Fish and Shellfish Evaluation. As part the agency's evaluation of Vieques, a brief summary of the general reef conditions found during the study was added to the section discussing ecological impacts to the coral reefs around Vieques (See Chapter 2, Section 2.1.4).

[37] A conclusive identification could not be confirmed by the laboratory that conducted the analyses.

Category:	**Environmental Data – Sea Life and Sediment**
Date of Publication:	**May 2010**
Title:	An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico Part II: Field Studies of Habitats, Nutrients, Contaminants, Fish, and Benthic Communities
Author(s):	**Bauer, L.J. and M.S. Kendal (eds.)**
Affiliation:	**National Oceanic and Atmospheric Administration (NOAA)**
Publication Status:	**Government Publication, NOAA**
Peer Review Status:	**Yes**
Cited Previously by ATSDR:	**No**

Study Findings

The purpose of this study was to provide a spatially comprehensive characterization of the marine ecosystem surrounding Vieques. It builds on NOAA's previous efforts by investigating fish fauna, benthic communities, nutrient levels, and chemical contaminants in the marine environment around Vieques. The data were grouped and analyzed according to former land use. The key findings are summarized below:

- A stratified random design was used to select 75 sites for benthic and fish community surveys around Vieques. The researchers found that Vieques was similar in terms of benthic cover, total fish abundance, and biomass to other nearby locations (southwest Puerto Rico, St. Croix, and St. John). Differences in fish and benthic communities could not be conclusively linked to former land use patterns.

- A stratified random design was used to select 78 sites for sediment (lagoon and offshore) and 35 sites for coral tissue sampling. The sediment and coral tissue samples were analyzed for 150 chemical contaminants including metals, pesticides, and explosives. Overall, contaminant concentrations were below established sediment quality guidelines, sediments from lagoons typically had higher concentrations than offshore sites, and sediments had higher concentrations of trace and major elements than corals. Sediment samples analyzed for 14 explosive compounds yielded no confirmed detections. DDT (at four sites) and chromium (at one site) were detected in sediment samples above established sediment quality guidelines. However, no sites had contaminant concentrations that were likely to affect sediment-dwelling biota. Sediment concentrations of polycyclic aromatic hydrocarbons were significantly higher in the land-use zone that included the former Naval Ammunition Support Detachment. The concentration of cadmium was significantly higher in the former LIA.

- Water samples from 40 stratified random designed sampling stations were analyzed for nitrate nitrite, silicate, orthophosphate, ammonium, urea, total nitrogen, and total phosphorus. No

> evidence of anthropogenic over-enrichment of nutrients was discovered. Nutrient concentrations were generally low and similar in magnitude to those measured elsewhere in Puerto Rico. Nitrogen and phosphorus concentrations were below published threshold values considered threatening for macroalgal overgrowth on coral reef ecosystems.

The authors concluded that there was little evidence of any difference in marine resources, nutrients, or contaminants around Vieques compared to other coral reef ecosystems in Puerto Rico and the U.S. Virgin Islands. The reef ecosystem appears to be shaped primarily by regional-scale processed rather than local factors. The results of the study supported neither of the following hypotheses: 1) naval activities negatively affected the marine environments around Vieques and 2) the lack of development on two-thirds of the island was a positive influence by preventing human activities documented elsewhere to be harmful to marine environments.

How ATSDR Addressed the Study Findings

Because Viequenses are concerned about the effects that bombing activities have had on the marine environment, ATSDR reviewed this new study as part the agency's evaluation of Vieques. The results of the heavy metal sampling in sediment and coral are discussed in Chapter 1, Section 1.3.3. A summary of the study was also added to the section discussing ecological impacts to the coral reefs around Vieques (see Chapter 2, Section 2.1.4). ATSDR notes that the scope of the study was to characterize the entire marine ecosystem around Vieques; it was not intentionally directed toward characterizing the impact from bombing activities.

Appendix B—Summaries of Previous ATSDR Documents

This appendix contains summaries of ATSDR's previous documents evaluating environmental data related to Vieques. The appendix also includes summaries of two panel reviews funded by ATSDR – one concerning heart echocardiograms and the other concerning elemental hair analysis.

The question of peer reviews for public health assessments is often raised. Public health assessments are generally not peer reviewed; Congress specifically directed that "all studies and results of research conducted under this section (other than health assessments) shall be reported or adopted only after appropriate peer review." See 42 U.S.C. §9604(i)(13) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA).

Although public health assessments are generally not peer reviewed, they are released for public comment. In addition, some public health assessments are in fact peer-reviewed. For those relevant Vieques public health assessments that were peer reviewed, this appendix notes the public comment date and the peer reviewers' names.

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Category:	**Environmental Data – Drinking Water Supplies and Groundwater**
Publication Date:	**February 20, 2001: Public Health Assessment released for public comment; October 16, 2001: Final Public Health Assessment**
Title:	Isla de Vieques Bombing Range Public Health Assessment: Drinking Water Supplies and Groundwater
Author:	**ATSDR**
Publication Status:	**Published after public comment and peer review**
Peer Review Status:	**The document was technically reviewed by**

- Dr. Fernando Diaz-Barriga, Universidad Autonoma de San Luis Potosi, Mexico
- Robert E. Faye, P.E., Robert E. Faye and Associates, Inc.
- Hernan Horta Cruz, MS, Puerto Rico Department of Health (PRDOH),
- Mike Glogower, U.S. Environmental Protection Agency (EPA) Region II,
- Sigfredo Torres-Gonzales, U.S. Geological Survey (USGS)

A Vieques resident petitioned ATSDR to investigate whether contaminated groundwater might move from beneath the Live Impact Area (LIA) to the populated areas of Vieques. ATSDR studied the hydrogeology of the island and evaluated chemical levels in drinking water and in groundwater samples collected from Vieques wells and tanks. ATSDR thereafter concluded that

The water from the current public water supply system is safe to drink

Most Vieques residents receive their drinking water through an underwater pipeline from the Puerto Rico mainland. In 1999 and 2000, the U.S. Environmental Protection Agency, the Puerto Rico Department of Health, and the U.S. Navy tested the public water supply system drinking water for volatile organic compounds, inorganic compounds, and explosive compounds. After an evaluation of the test results, ATSDR concluded that Navy activities did not affect the public drinking water supply and that the water was safe to drink.

The water from most groundwater wells on the island is safe to drink

In the past, residents drew from groundwater wells in the Esperanza and Resolucion valleys. Smaller private wells in the residential areas also supplied drinking water. Many such wells currently provide supplementary drinking water whenever the mainland public water supply system is interrupted.

From 1995 to 2000, the U.S. Environmental Protection Agency, the Puerto Rico Department of Health, the U.S. Geological Survey, and the U.S. Navy sampled groundwater wells on the island for volatile organic compounds, inorganic compounds, pesticides, herbicides, polychlorinated biphenyls, and explosive compounds. Explosive compounds and their residues were not found in any of the wells. ATSDR evaluation included whether, for people drinking water from the wells, detected chemicals were at harmful levels.

ATSDR concluded that during public water supply interruptions, water from all but one of the wells was safe to drink. But ATSDR also found that the groundwater wells had naturally high sodium content—thus residents on sodium-restricted diets were advised to consider limiting their intake of water from the island's groundwater wells. One private well (Well 3-7) also showed high levels of nitrates/nitrites. Thus the water from Well 3-7 was not safe to drink, especially for children and pregnant women. The Puerto Rico Department of Health issued an appropriate advisory, and the department's staff personally informed residents that water from Well 3-7 was not safe. Given Vieques hydrogeology, ATSDR did not believe that contamination was a consequence of bombing range activities; rather, it was in all likelihood the result of area agricultural activities or septic systems.

Vieques Island's geology and topography prevent groundwater movement from the Live Impact Area into the area where groundwater wells are located

ATSDR evaluated the hydrogeology of the island to determine whether hazardous substances from the Live Impact Area could groundwater-migrate to the drinking water wells area. ATSDR determined that the wells were within isolated aquifers and therefore not geologically connected to the groundwater on the island's eastern end. In addition, between the Live Impact Area and the wells' location, the island's bedrock and westward topography sloped upward. Thus rather than migrating toward the wells, groundwater at the Live Impact Area moved slowly downhill toward the lagoons and, eventually, toward the ocean.

If good sanitation practices are followed, water from rainfall collection systems is safe to drink

Because no sampling studies characterized the quality of water in rainfall collection systems on Vieques, no site-specific sampling data were available on which to base firm conclusions. Nevertheless, if accepted sanitation practices were followed, ATSDR expected rainfall collection systems on Vieques would provide clean water that posed no health hazards.

In the past, Vieques water was safe to drink

In 1978, the Navy reported very low levels of explosive compounds in drinking water samples from Vieques. The laboratory that analyzed the water samples stated some uncertainty in the results. ATSDR reviewed those data, as well as the sampling and analytical procedures, to evaluate whether those reported detections posed a potential health hazard. To be protective of public health, ATSDR analyzed the results assuming that the explosive compounds were present. ATSDR concluded that the concentrations reported were well below harmful levels. The water did not pose a health hazard to anyone drinking it in the past. And recent analyses of drinking water samples using updated sampling and analysis methodologies did not detect any explosive-related contamination.

Category:	Environmental Data – Soil
Publication Date:	**October 23, 2001 – Public Health Assessment released for public comment** **February 7, 2003 – Final Public Health Assessment**
Title:	Isla de Vieques Bombing Range Public Health Assessment: Soil Pathway
Author:	**ATSDR**
Publication Status:	**Published after public comment and peer review**
Peer Review Status:	**The document was technically reviewed by** • David Smith, USGS • Sigfredo Torres-Gonzalez, USGS • Rufus Chaney, Ph.D., U.S. Department of Agriculture (USDA)

Community members expressed concern that contaminants generated by bombing and other Navy training activities might have been windborne from the Live Impact Area and deposited on soils of Vieques residential areas. To address this concern, ATSDR evaluated roughly 600 soil samples collected by the U.S. Geologic Survey, the Puerto Rico Department of Natural Resources, the U.S. Navy, and Servicios Científicos y Téchnicos, Inc. ATSDR analyzed the samples for metals, other inorganic compounds, and explosive compounds, and concluded that

Residents of Vieques are not exposed to harmful levels of chemicals in the soil.

ATSDR compared the levels of chemicals found in Vieques soils to levels public health professionals consider safe. ATSDR also conducted detailed analyses to determine the amount of chemicals to which people were expected to be exposed over a lifetime. The analyses showed that for either adults or children living on Vieques, incidental ingestion of soil or contact with soil would not result in harmful health effects.

The protestors who lived on the Live Impact Area for a year were not exposed to harmful levels of chemicals in the soil.

From April 1999 to May 2000, to protest the U.S. Navy's presence on Vieques, adults and children camped in the Live Impact Area. The Navy and Servicios Científicos y Téchnicos, Inc., collected soil samples from the areas where the protestors encamped. ATSDR analyzed the data and determined that for anyone incidentally ingesting or touching the soil, all of the chemicals were at levels below those that might cause harmful health effects.

In comparison with soil elsewhere in the region, some of the metals detected in Vieques soil were moderately elevated.

ATSDR compared Vieques soil quality with sediment on the Puerto Rico mainland and with soil in the United States. ATSDR found that the maximum level of some of the metals detected in Vieques soil was moderately elevated when compared with soil in Puerto Rico and in the United States. ATSDR also analyzed the chemical characteristics of soil on Vieques to determine whether metals were at unnaturally high levels. To do this, ATSDR grouped soil samples throughout the island according to their underlying rock (the geologic units), and compared the general chemical characteristics of those soils. ATSDR found that the Vieques soils were strongly influenced by the type of rock from which they were formed—in other words, soils developed on different underlying rock had different levels of metals. The levels of metals detected on Vieques were consistent with those normally found in soils underlain by the type of rock found on Vieques (e.g., volcanic rocks) and were not at levels of health concern.

The concentrations of metals in the soils of the Live Impact Area appeared moderately elevated but not at harmful levels.

According to ATSDR's analysis, Live Impact Area soils appeared to have been influenced by Navy training activities and contained elevated metals levels. ATSDR determined, however, that the metals concentrations in the soil were not at harmful levels.

ATSDR's spatial analysis showed that metals were apparently not moving from the Live Impact Area into Vieques residential areas.

ATSDR examined the soil data for spatial trends that might show movement of metals from the Live Impact Area to the residential areas of Vieques (i.e., a pattern of high to medium to low concentrations from east to west). To do this, ATSDR created spatial maps showing the locations of metal concentrations detected on Vieques. None of the spatial maps showed any patterns beginning with high concentrations in the Live Impact Area and decreasing concentrations tapering off to the western parts of the island. Thus the soil data collected from across the island indicated that contaminants from the Live Impact Area were not air-transported in substantial quantities and deposited in the island's residential areas.

Category:	**Environmental Data – Fish and Shellfish**
Publication Date:	**November 14, 2002 – Public Health Assessment released for public comment** **June 27, 2003 – Final Public Health Assessment**
Title:	Isla de Vieques Bombing Range Public Health Assessment: Fish and Shellfish
Author:	**ATSDR**
Publication Status:	**Published after public comment and peer review**
Peer Review Status:	**The document was technically reviewed by**

- Felix Lopez, U.S. Fish and Wildlife Service (FWS)
- Carlos Ramos, U.S.EPA Region II
- Jerry Stober, U.S.EPA Region IV

Previous studies reported elevated levels of metals in fish and shellfish that are eaten by the residents of Vieques. To address this concern, ATSDR worked with the U.S. Environmental Protection Agency's Environmental Response Team to collect and analyze fish and shellfish from the coastal waters and near-shore land on Vieques to determine whether fish and shellfish muscle tissues contain levels of metals and explosive compounds that would be harmful to human health.

From July 16th to 20th, 2001, fish and shellfish were collected from six locations on Vieques. ATSDR decided to collect grouper, snapper, parrotfish, grunt, goatfish, blue land crab, spiny lobster, and queen conch because they were identified by several sources as types of seafood that are commonly caught and eaten. These fish and shellfish were collected from reefs and near shore areas at the following six locations: (1) north of the Live Impact Area, (2) south of the Live Impact Area, near a sunken Navy vessel, (3) south of Esperanza, (4) north of Isabel Segunda, (5) a fish market in Isabel Segunda, and (6) west of the Laguna Kiani Conservation Zone on the west end of Vieques. Fillet and muscle tissues were analyzed for metals and explosive compounds. All sampling and analysis procedures were conducted in accordance with established U.S. Environmental Protection Agency protocols.

During the sampling event, the divers noted that all sample locations supported diverse, healthy populations of marine organisms and that all reefs were in good condition. They also noted that, with very few exceptions, the organisms collected appeared to be healthy.

ATSDR reached the following conclusions:

- Explosive compounds were not detected in any of the edible fish and shellfish from Vieques.
- Metals were detected in the fish and shellfish from Vieques; however, the levels were too low to cause harmful health effects for people eating the seafood.
- It is safe to eat fish and shellfish from Vieques every day.

According to a local consumption study, almost half of the residents of Vieques eat seafood one or two times a week. However, some people responded that they eat seafood five or more times a week. To be protective of all residents, ATSDR estimated exposure by determining the amount of metals people would most likely be exposed to over their lifetime if they ate fish or shellfish every day for 70 years. ATSDR then compared the levels to those that are considered to be safe by public health professionals. ATSDR found that it is safe to eat a variety of fish and shellfish from Vieques on a daily basis.

Because of ATSDR's current evaluation of Vieques, some of these conclusions have changed. Please see Chapter 9 for new conclusions and recommendations concerning fish and shellfish.

Category:	**Environmental Data – Air**
Publication Date:	**November 22, 2002 – Public Health Assessment released for public comment** **August 26, 2003 – Final Public Health Assessment**
Title:	Isla de Vieques Bombing Range Public Health Assessment: Air
Author:	**ATSDR**
Publication Status:	**Published after public comment and peer review**
Peer Review Status:	**See footnote #38**

Several Vieques residents asked ATSDR if the air on the island was safe to breathe. The residents were most concerned about contaminants released into the air during the Navy's military training exercises. These concerns included the Navy's past live bombing exercises as well as the more recent practice bombing exercises. The residents also had questions about whether contaminated dusts from the bombing range might blow into their neighborhoods.

ATSDR concluded that

Given the results of ATSDR's modeling analysis, the Navy's "live bombing" exercises did not pose a health hazard to residents.

Three air-sampling studies were conducted during the time when the Navy used live bombs on Vieques. The Puerto Rico Environmental Quality Board conducted two of these studies, and the Navy conducted the other. None of the measurements in these studies found air pollution to be at levels of health concern. However, because original documentation of these studies has not been located, ATSDR could not rest its health conclusions on these studies alone.

ATSDR estimated air quality impacts from live bombs using a modeling analysis. This analysis considered nearly 100 different contaminants that are known to be released to the air when ordnance explodes. The modeling analysis found that chemicals released to the air in smoke by the bombs dispersed to extremely low levels as the smoke traveled from the bombing range toward where people live. For most contaminants, the predicted air quality impacts where residents live were so low that even highly sensitive air sampling devices would likely not be able to measure them. In the case of particulate matter, for example, emissions from live bombing exercises were predicted to account for less than 1 percent of the concentration of particulate matter currently measured in the residential areas of Vieques. This comparison suggests that emissions from the bombing range have extremely small impacts on the air quality in the residential areas of Vieques. Based on this modeling analysis, ATSDR concluded that emissions from live bombing exercises did not cause air pollution to reach levels known to be associated with health effects.

The Navy's practice bombing exercises did not pose a health hazard to residents.

From May 2000 through May 2003, the Navy's military training exercises were conducted with so-called practice bombs. On days when practice bombs fell on the bombing range, the Puerto Rico Environmental Quality Board collected more than 50 particulate matter samples. In every sample the particulate matter levels were lower than health concern levels. In fact, in the residential part of the island no clear relationship appeared between the number of practice bombs dropped and the levels of air pollution measured. Using these observations and estimating air concentrations of other contaminants, ATSDR found that on days when practice bombing occurred, levels of air pollution did not present a health hazard to the island's residents.

Wind-blown dust from the bombing range does not pose a health hazard to residents.

The air quality effects of windborne dust are typically evaluated by measuring the levels of particulate matter in the air. The term "particulate matter" refers to solid particles and liquid droplets in the air that we breathe. For the last 3 years, the Puerto Rico Environmental Quality Board has measured levels of particulate matter at two locations in Vieques residential areas. By the time the ATSDR air evaluation was complete, nearly 450 air samples had been collected. In every measurement, the amounts of particulate matter were well below health concern levels.[38]

[38] The public health assessment in which this air sampling was discussed was presented at the Air and Waste Management Association's 96th Annual Conference and Exhibition in San Diego, June 22–26, 2003.

Category:	**Environmental Data – Land Crab**
Publication Date:	**February 22, 2006 – Final Health Consultation**
Title:	Isla de Vieques Bombing Range Health Consultation: Land Crabs
Author:	**ATSDR**
Publication Status:	**Self-Published**
Peer Review Status:	**None**

The National Oceanic and Atmospheric Administration (NOAA) asked ATSDR to determine whether eating land crabs from various Vieques locations was safe. In June 2005, NOAA collected land crabs (*Cardisoma guanhumi*) from 14 locations (13 on Vieques and one on the Puerto Rico mainland). The crabs were analyzed for explosive compounds, polychlorinated biphenyls (PCBs), organochlorine pesticides, and trace elements. After reviewing the analyses, ATSDR concluded that

Land crabs are safe to eat

The levels of PCBs, organochlorine pesticides, and trace elements found in land crabs were much lower than levels reported to cause harmful health effects. The levels were also below the U.S. Food and Drug Administration (USFDA) regulatory limit for shellfish consumption. Only a few land crab samples contained PCBs and pesticides, indicating these chemicals were not widespread. ATSDR did not expect harmful health effects to occur in people who ate Vieques land crabs.

Children should not eat the land crab's internal organs

Because of the amount of copper in land crab internal organs, children who ate those internal organs could experience stomach issues. As for the land crab's muscle meat, children can safely eat that every day. Prudent public health practice would dictate, however, that children reduce their exposure to copper by not eating land crab internal organs.

Explosive compounds were not detected in any crab sample, and no association was found between land crab sampling location and contaminant levels

In some of the areas sampled, land crabs contained higher average concentrations for certain chemicals than did land crabs in other areas. As for other chemicals, no remarkable differences were found between the locations. ATSDR found that people could safely eat every day one meal of land crab from any of the sampled locations.

Category:	**Human Biomonitoring - Hair**
Publication Date:	**June 2001**
Title:	Hair Analysis Panel Discussion: Exploring the State of the Science – June 2001
Author(s):	

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- Dan Pascal, Ph.D., Centers for Disease Control and Prevention
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Publication Status:	**Published by ATSDR**
Peer Review Status:	**Not applicable. Document is a panel discussion summary.**

Executive Summary

In Atlanta, Georgia, on June 12 and 13, 2001, the Agency for Toxic Substances and Disease Registry (ATSDR) convened a seven-member panel to review and discuss the then-state of the science related to hair analysis; specifically, its use in assessing environmental exposures. ATSDR invited a cross-section of scientific experts in the fields of hair analysis, toxicology, and medicine to participate in 1½ days of discussion on a variety of topics, including analytical methods, factors affecting the interpretation of analytical results, toxicologic considerations, and data gaps/research needs.

Background

ATSDR convened this panel in response to 1) a then-growing number of inquiries from community members looking for assistance in interpreting hair analysis results, and 2) agency interest in learning more about the utility of hair analysis when evaluating exposures and health effects at hazardous waste sites. The agency anticipated using the input received from this effort to develop guidance for agency health assessors on the use and interpretation of hair analysis data.

The general questions that ATSDR sought to answer included

- For what substances are reliable hair analysis methods available?
- When is it appropriate/inappropriate to consider hair analysis in assessing human exposures to environmental contamination?
- What if any data gaps limit the interpretation and use of hair analysis in the assessment of environmental contaminants?

This summary report presents the findings of the panel discussions. Principal discussion points are highlighted.

Discussions Overview

Panelists engaged in a series of discussions to address ATSDR's questions, pointing to several limitations with the then-state of knowledge on the usefulness of hair analysis in environmental exposure assessments. Discussions focused primarily on metals and trace elements in scalp hair. Panelists considered the distinct differences between using hair analysis to identify exposures (e.g., Is the substance reaching people? Does a competed pathway exist?) and using it to predict, diagnose, or treat disease (e.g., What do hair concentrations tell us about the likelihood of harmful health effects?). Panelists noted that the latter question pointed up the largest data gaps that then existed.

Although not required to reach consensus, the panelists did agree on the following summary statement related to the overall usefulness of hair analysis in evaluating environmental exposures:

> For most substances, insufficient data were available that would allow the prediction of a health effect from the concentration of the substance in hair. The presence of a substance in hair may indicate exposure (both internal and external), but does not necessarily indicate the source of exposure.

For what substances are reliable hair analysis methods available?

The group agreed that then-available laboratory methods could measure the levels of some environmental contaminants in hair. But to help ensure more accurate and reliable results, procedures needed to be standardized. That would include ensuring samples were collected by a trained person and would include but not be limited to establishing consistent sampling protocols, washing protocols, and quality control/quality assurance procedures. The panel further agreed that testing should be targeted to the specific element of interest.

When is it appropriate/inappropriate to consider hair analysis in assessing human exposures to environmental contamination?

In general, panelists agreed that before determining whether hair analysis was an appropriate assessment tool, assessors should consider

1. *The exposure type and period.* To understand the likelihood that a particular substance will be in the hair at the time of testing and to identify other exposure sources (e.g., hair treatments), take exposure histories.
2. Because the growth rate of hair is on average 12 centimeters per year, the panel concluded that hair analysis is not generally useful for evaluating very recent exposures or those longer ago than 1 year. Segmental analysis of hair (i.e., looking at concentration trends along the length of the hair) may have a role in documenting exposures over time (e.g., identification of a high-dose acute exposure). But this would require consideration on a subject-, substance-, and situation-specific basis.
3. *The type of substance and its behavior in the body.* Determine the biological plausibility that a particular substance will be present in hair and whether it is a marker of external contamination.
4. The group agreed that little is known about the transfer kinetics of substances into hair.
5. *The clinical relevance of a negative or positive finding.* Determine the dose-response relationship, if any, between chemical concentrations in hair and target organ effects/illness. Without an understanding of a dose-response relationship, useful interpretations would not be possible.

The panelists agreed that a relationship between contaminant concentrations in hair and any kind of measurable outcome has only been established for two substances: methyl mercury (e.g., the relation between maternal hair levels and observed developmental neurological abnormalities in offspring) and, to a limited extent, arsenic (e.g., segmental analysis for forensic analysis)—provided external contamination can be ruled out. Unique forensic settings for other substances could, however, provide similar relationships.

The group also indicated the need to evaluate, on a substance- and exposure-specific basis, the extent to which hair analysis might be more advantageous than other biological sampling, such as blood or urine analysis.

What if any data gaps limit the interpretation and use of hair analysis in the assessment of environmental contaminants?

The group identified several factors that limited the interpretation of even the most accurate, reliable, and reproducible laboratory results. These include

- *The lack of reference (or background) ranges in which to frame the interpretation of results.* In the absence of environmental exposures, assessors need a greater understanding of what is expected to be in hair to determine whether detected levels are elevated as a result of environmental releases, including possible geographical or regional differences in background levels.
- *Difficulties in distinguishing endogenous (internal) from exogenous (external) contamination in hair.* Making this distinction is important in evaluating internal doses of the substance of

interest. The group voiced different views on the effectiveness—before analysis—of washing hair to eliminate external contamination. Some felt that the then-current literature suggested no reliable washing method capable of separating external contamination from internal deposition of elements. One suggestion was that where possible, identifying metabolites (or other unique markers of internal exposure) for substances of interest was most helpful in distinguishing internal from external contamination.

- *A lack of understanding of how and to what extent environmental contaminants are incorporated into the hair.* At the time of the conference, little scientific information was available on the uptake or incorporation of environmental contaminants into hair. For metals or for environmentally relevant organic compounds, neither kinetic models nor metabolite data were known or fully understood.
- *The lack of correlation between levels in hair and blood and other target tissues, as well as the lack of epidemiologic data linking substance-specific hair levels with adverse health effects.* Before hair analysis results could be used as a diagnostic tool or to predict health endpoints, these correlations must be understood. The panel noted that hair analysis was not likely to play a role in evaluations of some of the more common health concerns associated with hazardous waste sites (e.g., cancer, birth defects).
- *Little information was available that was pertinent to the study of environmentally relevant organic compounds in hair.*
- The panel recommended taking advantage of what was known about hair analysis in testing for drugs of abuse.

The panelists encouraged standardization of sampling protocols and identified possible research areas. Yet hair analysis could only become a valid tool for any particular substance if research

- Could establish better reference ranges,
- Gained a better understanding of hair biology and pharmacokinetics,
- Further explored possible dose-response relationships,
- Established whether and when hair might serve as a better measure or predictor of disease than other biological samples (e.g., blood or urine), and
- Learned more about organic compounds in hair.

Category: **Human Biomonitoring – Heart Study**

Publication Date: **July 2001**

Title: Expert Review of the Vieques Heart Study

Author(s):

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- Elizabeth Ofili, MD, MPH, Morehouse School of Medicine
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- Jesús Vargas-Barrón, MD, Instituto Nacional de Cardiología "Ignacio Chávez"

Publication Status: **Published by ATSDR**

Peer Review Status: **Not applicable. Document is a record of peer review comments on the Ponce School of Medicine Heart Study**

In January 2001, a pilot study comparing the echocardiograms of residents in Vieques and in Ponce Playa, Puerto Rico reported substantial valvular abnormalities and pericardial thickening in a large proportion of the Vieques residents—findings not seen among Ponce Playa residents. The possible abnormalities noted in the Vieques residents were attributed to "vibro-acoustic disease" (VAD), previously described in the medical literature by Portuguese investigators. VAD was said to occur as the result of noise and vibrations caused by naval exercises on the Island of Vieques. By Presidential directive, the Department of Health and Human Services investigated the issues raised by the study. The Department, in turn, referred this request to the Agency for Toxic Substances and Disease Registry (ATSDR), which was already investigating environmental public health issues in Vieques.

Concurrent with this request, the Ponce School of Medicine (PSM) led by President and Dean Dr. Manuel Martínez Maldonado had begun a more focused study of possible cardiac abnormalities among Vieques commercial fishers. This study sought to overcome methodological problems (e.g., sampling frame, lack of blinding) found in the earlier pilot study. On March 29–30, 2001, scientists from ATSDR and CDC met with the PSM investigators and agreed to invite the assistance of recognized practitioners and scientists in reviewing and interpreting the findings. The chosen reviewers were experts with international reputations in echocardiography and environmental or cardiovascular epidemiology. Because of its extensive experience, the echocardiography "core" laboratory at Mayo Clinic, directed by Dr. Jae K. Oh, was selected to review the echocardiograms.

Eight accomplished physician-scientists accepted invitations to participate. They were principally from academic institutions: four panelists were from U.S. universities, two from Mexico, and two from Spain. Half of the panelists were specialists in cardiology and echocardiography; others were epidemiologists. Additional meeting participants included personnel or consultants of PSM and ATSDR, Dr. Jae Oh of Mayo Clinic, and Dr. John Rullán, Secretary of Health of Puerto Rico. The meeting took place July 12–13, 2001, in the Condado Plaza Hotel in San Juan. Dr. Martínez Maldonado and Dr. David Fleming, then Deputy Administrator of ATSDR, co-chaired. Participants reviewed the methods, results, and public health significance of the Vieques Heart Study, considering both PSM and Mayo Clinic data.

Dr. Martínez Maldonado and Dr. Carlos Ríos presented the Vieques Heart Study. The study objective was to determine any association between place of residence (Vieques or Ponce Playa) and morphological cardiovascular changes among commercial fishers.

Investigators sampled randomly from the lists of licensed commercial fishers from Vieques and from Ponce Playa and obtained 53 and 42 subjects from the two areas, respectively. Investigators measured height, weight, blood pressure, and other physical parameters, collected questionnaire data on demographics and possible confounders, and recorded subjects' echocardiographic images. The echocardiograms were read "blindly" (i.e., without knowledge of the site of residence of the particular subject) for pericardial thickness by a group of several experienced PSM cardiologists, with caliper placement done by consensus and by using magnified images.

By PSM's measurements, the average pericardial thickness was slightly greater among Vieques fishers than among those from Ponce Playa (1.20 mm vs. 1.05 mm), and this difference was statistically significant ($P = 0.03$). The values for pericardial thickness measured by Mayo were within the same range as those measured by PSM, but did not achieve statistical significance when Vieques and Ponce fishers were compared (0.78 mm vs. 0.82 mm, respectively).

Panel Conclusions

The panel's principal conclusion was that neither the Ponce Playa nor the Mayo readings contained information indicating a cardiac health problem in the fishers. The initial report of gross valvular pathology from the pilot study was not replicated. All reviewers agreed that no clinically relevant difference between Vieques and Ponce Playa subjects in pericardial thickness appeared, contrary to that reported in the pilot study. Moreover, neither the PSM nor the Mayo measurements showed any subject's pericardial thickness to be larger than 2 mm—a value the published literature considered in the upper limit of normal.

The PSM study got generally high marks from the panelists regarding study design and statistical analysis. The sampling frame (lists of registered fishers) was regarded as appropriate, and reviewers generally felt that the response rate was adequate. The fact that reasonably clear-cut hypotheses had been developed beforehand largely obviated concerns about the problem of multiple comparisons. In general, panelists felt that the statistical tests used were appropriately chosen and employed. Panelists noted that echocardiographic readings were performed with appropriate blinding—including masking of dates—at both PSM and Mayo.

Summary Conclusion

The PSM study did not support a finding of cardiac pathology among Vieques commercial fishers. Because of the inability of trans-thoracic echocardiography to measure reliably the small differences found, the differences reported were likely due to measurement error (intrinsic to the technique, not the scientists who used it). This fact almost certainly accounts for the different results obtained when Mayo readings of pericardial thickness replaced PSM readings.

The Vieques Heart Study represented a valuable contribution to scientific knowledge regarding the use of echocardiography. The panelists recommended the study's publication in the peer-reviewed scientific literature.

Appendix C—Peer Review Comments and ATSDR Responses

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Introductory note: We submitted the same six questions to all six peer reviewers. Some of those questions included requests for comments to specific sub questions. We reproduce here each of the questions and sub questions we asked, each reviewer's comments to the questions and sub questions, and our responses to their comments. Also, throughout our responses we refer to An Evaluation of Environmental, Biological, and Health Data from the Island of Vieques, Puerto Rico as simply "the Report."

Reviewer 1

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

[Comment] The document as a whole is well written and relatively easy to follow. However, it suffers from a significant lack of consistent focus. While the ostensible question addressed by the document is whether the historical bombing exercises at Vieques have impacted public health, the document only sporadically focuses on those environmental health impacts that are specifically linked to the bombing and related military activities and often shifts focus to general environmental exposure and health considerations. Given the stated purpose of the review, one would expect that (at least for the environmental exposure/risk assessment portion of the review) there would be a logical structure that first defines the activities with a potential to impact public health, then identified the environmental contaminants that could be anticipated to result from those activities, then identified the environmental/biological media in which those contaminants are likely to be found, then presented the sampling results for those media and contaminants, and then compared those results to appropriate background data to make a determination of whether the exposures and potential exposures related to the sampling data were likely to be associated with the bombing and related activities. This logical progression should have been driven by one or two focused and explicit hypotheses to be tested. These hypotheses would take a form similar to, "The bombing and related military activities in Vieques have resulted in exposures to specific environmental contaminants above non-bombing-related background levels," and "Elevated levels of the specific bombing-related contaminants pose a significantly elevated health risk to the exposed population." While such an approach is implied in the review, it is only intermittently followed.

The review does refer to specific contaminants that were identified as resulting from the bombing activities - TNT, RDX, aluminum powder and "86 contaminants" including 15 metals that were identified in the BangBox test series. However, the relationship between the prevalence of these contaminants in the explosives and their likelihood of occurrence in environmental/biological media is not presented. This lack of prioritization not only makes hypothesis formulation and testing unclear, but also results in large uncertainty in distinguishing bombing-related contamination from background.

In contrast, the review seems to present information about environmental contamination that often appears to have no clear potential relationship with the bombing-related activities either with respect to the contaminants discussed or the spatial relationship between the impacted areas and the location of the samples. While this disconnect is not always the case in the review, it is the case sufficiently often that the reader loses the sense of a clear focus and context for the information presented. This is most notably the case in the sections on the Fish Pathway and Biomonitoring, although similar considerations also apply to the document's treatment of other pathways. For example, in the Biomonitoring and Fish sampling portions of the document, there is a large focus on mercury. Given the extent of that focus, one could conclude that mercury contamination in fish and seafood is highly anticipated to result from the bombing-related activities and is a major focus of the environmental health impact associated with those activities. However, I have not found any place in the document where the relationship between those activities and mercury contamination in the environment in general, or in marine species in particular, is established. A more focused and useful formulation and discussion of the potential impact of the bombing-related activities on mercury/methylmercury impact on the Vieques population could proceed along the following lines:

- Is mercury/methylmercury contamination expected to be a major outcome of bombing-related activities?
- If so, where would the impact be expected?
- Are the fish that are likely to be affected by bombing-related mercury, the fish that are consumed by Vieques residents?
- What are the consumption patterns of Vieques residents relative to the likely impacted fish?
- What is the background dietary exposure to methylmercury in Vieques (i.e., from non-impacted fish) and how does it compare to the exposure from the likely impacted fish?

Given the ubiquity of at least low-level methylmercury contamination of fish worldwide, it should be anticipated that mercury would be found to some extent in all fish caught and/or consumed in Vieques. Furthermore, without a clear understanding of the background methylmercury exposure and the Vieques-specific fish consumption patterns, there is no clear way to distinguish the potential impact of bombing-related mercury exposure from the background in Vieques.

ATSDR generated few focused data specific to the assessment of bombing-related impacts in Vieques, but instead had to rely on existing data, much of which were not generated specifically for the purpose of this assessment and/or were not collected or analyzed in a systematic fashion designed for the appropriate hypothesis testing. This results in the classic situation where ATSDR largely ends up looking for its “keys” (i.e., relevant data) next to the lamppost because that’s where the light is. The quality of the overall assessment needs to be viewed in light of these limitations. Nonetheless, the use of the existing data without a clearer focus on the goal of the assessment and without a clear discrimination of the data relative to its quality and its relevance to the that goal has resulted in a document that is not clearly focused and often confusing in important parts.

> **ATSDR Response:** All reviewers commented on contaminants that could be linked to military exercises on Vieques. We therefore provided additional clarification within the summary report and provided references from one section to other sections. For example, when we discussed substances measured in fish, we included references to explosive ordnance constituents and soil measurements. We also provided some perspective about those media constituent levels we expected to be higher than others. The Report (Executive Summary and Chapters 1; 2; 3; 6; and 9) has been revised to reflect greater clarity between substances found in the Viequense environment and those associated with activities related to military exercises involving live ordnance.

ATSDR recognizes that the Report discusses both pathway-specific exposures to military exercise-related contaminants and to more general public health exposures. In that regard, ATSDR evaluated its previous work in response to continuing concerns about Viequenses' general health. The above-referenced revisions do identify possible links found between substances in the environment and military exercises. While most of our data on contaminants in soil, water, air, and seafood are relatively recent, the releases that might or might not have contributed to them are historical.

To establish conclusive links or specific pathways between the two is impossible, except in the rare case where contaminants are uniquely associated with a site, such as RDX and TNT and bombing activities. This situation is not unique to Vieques—it is an inherent problem at any site where environmental contaminants have many potential sources, including some associated with past activities at that site.

Regarding mercury, scientists visited ATSDR in November 2009. They requested that ATSDR take another look at mercury levels in fish in light of the National Academy of Sciences' statements on mercury's harmful effects. We have added information to Chapter 2 to make this point more clearly.

Finally, ATSDR does not typically collect environmental samples. We rely on available data from other sources.

Has ATSDR adequately addressed the pathways of human exposure to bombing range-specific contaminants?

[Comment] ATSDR has identified and addressed the appropriate pathways of exposure. However, as discussed above, with obvious exceptions (e.g., TNT, RDX) it has not clearly identified those environmental contaminants that are bombing range-specific, nor has it identified the extent of exposures to contaminants in the environment that are potentially associated with bombing range activities. The exceptions to this are the air and soil contact pathways where ATSDR has made a strong case that significant exposure to bombing-related contaminants is unlikely.

ATSDR Response: We provided additional clarification within the Report and provided references from one section to other sections. We included references to explosive ordnance constituents when we discussed substances measured in fish. The Report (Executive Summary and Chapters 1; 2; 3; 6; and 9) has been revised to reflect greater clarity between substances found in the environment and those associated with military exercises involving live ordnance.

Please include specific comments on:

Consumption of seafood from reefs near Vieques

[Comment] While the very limited data on contaminants unequivocally associated with the bombing-related activities (e.g., TNT, RDX, Al) suggests that there is little or no significant accumulation of these chemicals in Vieques fish and little or no potential for accumulation, the great bulk of the assessment of consumption of bombing-related contaminants in fish is focused on mercury (Hg). As discussed above, there is no clear rationale provided for this focus. The nature and extent of the relationship between the bombing-related activities and mercury is not discussed and it is not even clear whether an accumulation of methylmercury (MeHg) in fish would be expected as a result of the bombing-related activities. I suspect that the focus on mercury in fish results more from the availability of data related to more general concerns about MeHg exposures than from a specific connection to the bombing-related activities.

> **ATSDR Response**: Because scientists who visited ATSDR in November 2009 raised mercury in fish as a health concern, ATSDR reviewed its findings for mercury in fish. The scientists were concerned that ATSDR did not consider the National Academy of Sciences' (NAS) evaluation of mercury in fish and the NAS's Reference Dose recommendations to the U.S.EPA. Moreover, residents are still concerned that the fish they eat are contaminated with mercury. We have added information to Chapter 2 to make this point more clearly.
>
> Iron, aluminum, copper, manganese, zinc, and lead are the metals that are most likely to be elevated in LIA soils from bombing activity, though other metals were also found in the bombs. It should be noted that all of these metals are also naturally present in the soils and rocks of Vieques (ATSDR 2003a, Learned 1973, USGS 1997 and 2001).
>
> We also associated aluminum, iron, copper, and explosive compounds in some LIA-vicinity seafood with LIA-related military exercises. But these associations did not include mercury or other substances. Nonetheless the Report (Executive Summary and Chapters 1, 2, 3, 6, and 9) has been revised to clarify any relationship between substances found in the Viequense environment and those associated with military exercises involving live ordnance.

[Comment continued] There were few data available on the fish actually consumed by Vieques residents. The primary source of species-specific consumption data appears to be the data collected by Dr. Caro in 2000. However, those data were based on a sample size of only 51 consumers. This sample size is unlikely to be representative of the population as a whole. No information is presented about the demographic representativeness of that sample, of the geographic location of the sample relative to the locations of concern, or of the fishing habits of the subjects relative to the population of Vieques in general. Furthermore, as presented, the data provide no information about the relative consumption frequency by species or of the variability in frequency among consumers. The document states that ATSDR "used multiple information sources to identify the preferred types of fish and shellfish for collection" including the data of Dr. Caro. However, the other sources are not specified and the manner in which the data in total were used is not specified. These data gaps make it very difficult to create a reasonable model of fish consumption in Vieques and, in turn, to assess the exposure to contaminants in fish in general in Vieques, and especially in fish potentially impacted by bombing-related activities.

ATSDR Response: ATSDR agrees with the comments about Dr. Caro's 2000 survey. This is why we supplemented Dr. Caro's data with information gathered from 1) discussions with the residents of Vieques, 2) information provided in the Vieques Special Commission Report (Government of Puerto Rico 1999 as cited in Navy 2000b), 3) visits to local fish markets, and 4) PRDOH's 2006 report. These discussions confirmed Dr. Caro's findings. Dr. Caro's data suggested 34% of Viequenses ate fish more than 3–4 times a week. PRDOH's more extensive and random 2004 survey supported these findings (PRDOH 2006). We added this fact to Chapter 2.

Yet to refine our exposure estimates from eating reef fish, we do need additional information. We know that a significant proportion of Viequenses eat fish regularly. Still, more information about Viequense dietary habits would be useful, such as the frequency of consumption by sex and age for

- Reef fish, ocean-going fish, and canned fish,
- Various fish species,
- Portion size, and
- Reef location.

This additional information would allow more refined dose estimates and subsequent risk evaluations. In any event, we have made changes in Chapter 2 to highlight the lack of information about frequency of fish consumption by species and that having this information would allow more refined estimates of dose and subsequent risk evaluations.

Use of biomonitoring tools to assess exposure to metals and other hazardous chemicals in blood, urine, or hair that are related to historical bombing exercises

[Comment] Biomonitoring of exposure is potentially a very powerful tool. However, the occurrence of contaminants in biological media integrates exposures from all sources. Thus, the interpretation of biomonitoring data relative to the exposure and public health implications for a specific population from a specific source is highly reliant on both the understanding of the sources of exposure and the background of the exposure from other sources in that population. The biomonitoring studies considered in the review have significant limitations for the assessment of the public health impact of the bombing-related activities. The sample sizes in the studies other than the PRDOH study were quite small (n = 30, 52), the relationship of the subjects to potential sources of the specific exposures in question were not presented, and there was no appropriate referent population from Vieques that could be used to distinguish background sources of exposure from bombing-related sources of exposure. Information about background levels of exposure were either from Puerto Rico, US-NHANES or from laboratory reference ranges. The relationship between the background exposures in the Puerto Rico and NHANEs data and those in Vieques were not discussed and the nature of the laboratory reference ranges was likewise not discussed. Furthermore, based on the ATSDR assessment of the

PRDOH study, the data were not finalized and were of uncertain reliability. Elevations of biomonitoring levels relative to the mean or median levels in a dataset are to be expected due to normal statistical variation. To interpret those elevations in an exposure context requires either a statistically valid reference population and/or a separate measure of exposure (e.g., air, soil, water, food) that is comparable in time and space to the biomonitoring data and that can be used to elucidate the exposure context of those elevated biomonitoring levels.

Much of the biomonitoring data was for mercury relative to methylmercury exposure from fish consumption. However, I was unable to discern information from those data that allowed levels of mercury in those data to be related to potential bombing-related exposure (or lack of exposures). In any fish-consuming population, one would expect to find measurable concentrations of mercury in hair and blood and it would not be surprising to find a fraction of the population with levels that exceeded the levels corresponding to the USEPA RfD. This would be the case for populations consuming store-bought fish caught in remote locations and for populations consuming locally caught fish. Elevated levels of mercury in such datasets cannot be attributed to specific sources of contamination without additional data: mercury levels in a comparable population without exposure to locally impacted fish; the specific types of fish consumed; the locations those fish were caught; and the sources of contamination in those sources.

ATSDR Response: We agree that the Vieques human biomonitoring studies are limited. We also agree that using biomonitoring data can be problematic, especially when attempting to determine whether residents have been exposed to contaminants in explosive ordnance. For clarification, we have made changes in Chapter 3.

We dedicated a large portion of the Report to describing mercury exposures. Many of the Report details were absent from the original PHAs. We were concerned that such disproportionate discussion of mercury might lead reviewers to conclude that we found an association between mercury and military exercises on Vieques. On the contrary, our assessment focused only on that chemical exposure scenario posing the greatest human health risk. Chemical results for soil, air, water, and biota did not reveal extensive contamination. And biomonitoring studies are unlikely to reveal whether residents were or are exposed to contaminants from explosive ordnance. We clarified these conclusions by revising Chapters 1, 2, and 3. In summary, chemical results for soil, air, water, and biota did not reveal extensive site-related contamination. Soils from the LIA, however, were shown to contain metals above typically occurring background levels and some of these metals are associated with bombing activities (e.g., iron, copper zinc, and lead). None of the levels detected in soil are harmful to humans. Although biomonitoring is unlikely to establish any link between human biomonitoring data and military contaminants on Vieques, some biomonitoring might identify unusual exposures. We agree that for some exposures, no reliable, accepted biomonitoring detection/measurement methods are available. We further agree that all biomonitoring has some limitations.

Consumption of food (produce, meat, dairy, eggs) grown on the island

[Comment] Because endogenous mercury in hair and blood almost exclusively reflects methylmercury exposure and because methylmercury exposure comes almost exclusively from fish/seafood consumption, mercury biomonitoring data (other than urine data) can be related to fish consumption even if the additional data needed to relate that fish consumption to a specific source of mercury are not available. For other contaminants, where there is a unique or nearly unique source of exposure, positive biomonitoring results for those contaminants can provide clear evidence of exposure to those sources. However, for the biomonitoring of contaminants with multiple sources of exposure, including all of the metals reported for biomonitoring results from Vieques residents, biomonitoring data without additional exposure context provide little or no useful information about specific sources of exposure. Furthermore, to relate reliably biomonitoring levels to exposure from single source or from a combination of discrete sources, there has to be a known and established relationship between the concentration of the contaminant in the given biological medium (e.g., hair) and the exposure to that contaminant. Not all media have a valid concentration-exposure relationship for a given contaminant. Specifically, cadmium (Cd), arsenic (As), nickel (Ni), antimony (Sb) and lead (Pb) in hair are, to the best of my knowledge, not established or directly interpretable biomarkers of exposure.

For these reasons I do not believe that the biomonitoring data presented by ATSDR can be interpreted relative to exposure to produce grown on the island, much less to exposure to contaminants from the bombing-related activities through consumption of food grown on the island.

> **ATSDR Response**: ATSDR agrees with the reviewer's comment about the irrelevancy of the mercury exposure source when evaluating the association between mercury and seafood consumption. In summary, chemical results for soil, air, water, and biota did not reveal extensive site-related contamination. Soils from the LIA, however, were shown to contain metals above typically occurring background levels and some of these metals are associated with bombing activities (e.g., iron, copper zinc, and lead). None of the levels detected in soil are harmful to humans.

[Comment continued] With respect to the direct sampling of locally grown food, ATSDR correctly points out the limitations in much of the available data. These include sampling of inedible portions of food plants and sampling of non-food plants, lack of appropriate analytical standards, and lack of consideration of bioavailability. Considerable discussion is focused on the cadmium levels in pigeon peas. While I agree with ATSDR's analysis of the potential health impact of consumption of the sampled peas, that discussion is presented without a context for the results. It is unclear how, if at all, the sampled peas reflect exposure to pigeon peas island-wide, or the extent to which pigeon peas figure in the diet of the Vieques population in general. For the peas in particular and for the sampled produce in general, there is no basis for connecting data on contaminant levels in those samples to the bombing-related activity.

> **ATSDR Response**: Text in Chapter 5, Section 5.2.2 has been modified to address the reviewer's comments. At this time, no data (i.e., consumption survey or further info on intake of pigeon peas relative to total legumes) are available on consumption patterns. Thus for this preliminary analysis we used conservative assumptions that modeled high-end

intake rates. Further refinement of these exposure estimates could make them more realistic and more representative of the Viequense population.

ATSDR agrees with the lack of evidence to support any assertion of a viable transport pathway of metals contamination from the Live Impact Area to distant areas where food is grown. Any detected metals are more likely to reflect other sources, such as soil background concentration or some other local source. This is an important distinction; yet the community did cite food intake as a health concern. Thus as a public health measure we used available data to conduct a conservative, preliminary evaluation of this pathway.

Exposure to air, soil, and water on Vieques

[Comment] My conclusions presented above for interpretation of biomonitoring data relative to locally grown food apply equally to exposures from air, soil, and water on Vieques.

With respect to direct assessment of the air pathway, this is the strongest section and the one most clearly relevant to assessment of the potential impact of the bombing-related activities. In lieu of real time air monitoring data, the modeling approaches evaluated by ATSDR are the best approach to assessing this pathway. The conclusions from these analyses are robust and clearly support a conclusion that the bombing-related activities did not result in a significant exposure to residential areas.

With respect to the assessment of bombing-related contaminants in soil, although the sampling of on-site soil was necessarily limited, the conclusions of little historical health risk to the on-site protestors appear reasonable. This conclusion is based on the observations that the samples were taken at relevant and representative areas, that the bombing-related activities appear to have been widespread in that part of the island, and that essentially none of the soil sampling results indicated significant risk with long or short-term exposure. With respect to the impact of the bombing-related activities on the more remote, residential areas, ATSDR is correct in pointing out that potential transport of contaminants from the bombing areas to the residential areas would only have occurred by the same pathways that would have resulted in residential inhalation exposure to those contaminants. Thus, the modeled lack of significant airborne contamination from the bombing sites at the residential areas likewise, indicates lack of deposition of those contaminants to residential soil.

With respect to the assessment of drinking water, the provision of drinking water through the pipeline system remote from the bombing locations ensures that there is no exposure through drinking water for the great majority of the Vieques population. The lack of clear data on the extent of private well water and rain collection basin use and the associated lack of data for the quality of those sources creates some uncertainty about exposure from drinking water. Nonetheless, the hydrogeologic findings regarding the direction of groundwater flow appear to preclude contamination of the relevant aquifers. However, there are no data presented to substantiate that claim and these would be helpful (e.g., groundwater flow contours).

ATSDR Response: Thank you for your comments. We have added a topographical map showing groundwater flow contours as Figure 1.3 in the Report.

Does the Vieques summary report adequately present and describe the limitations and uncertainty of assessing human exposure to bombing range-specific contaminants?

[Comment] For the most part, ATSDR appears to be aware of the limitations of the available data for assessing human exposure to the bombing-related contaminants. The consideration of the air exposure, although somewhat short on detail, appears to be both site-specific, and appropriate in scope. The drinking water data are largely straightforward and are presented with the appropriate limitations largely arising from uncertainties about the extent of private well use. For the other exposures, despite awareness of the limitations associated with those data, data of limited or doubtful relevance are presented and considered in the overall assessment. I believe that more stringent criteria for inclusion of data in the review would have been appropriate for those exposures. In addition, particularly, in the sections on fish consumption and biomonitoring, ATSDR seems to repeatedly lose sight of the distinction between exposure to contaminants in general and exposure to contaminants specifically arising from the bombing-related activities. Specific instances of these points are presented in my text-specific comments.

> **ATSDR Response**: As for the specific example of mercury, visiting scientists in November 2009 requested that ATSDR review again its findings on mercury levels in fish, especially in light of the National Academy of Sciences' statements on mercury's harmful effects. As stated, the disproportionate focus on mercury might mislead reviewers into concluding that we found an association between mercury and the military exercises on Vieques. We could not show an association. On the contrary, in our assessment we focused heavily on the chemical exposure scenario that posed the greatest risk. Chemical results for soil, air, water, and biota did not reveal any such extensive mercury contamination.
>
> Describing all the environmental and health data available for Vieques is important—even when some of the data could not be verified or validated. The hair data results were presented for numerous metals. Some scientists believed the data were valid and drew conclusions from them. We described the limitations of these data in detail, pointing out the inability to distinguish between external contact and internal ingestion for most metals, except mercury. To this extent, ATSDR has attempted to report fairly the available data and to provide insight into their usability in making health decisions. In our conclusions and recommendations the data that could not be verified or validated were either not used (e.g., metals in hair, except mercury) or were used qualitatively (e.g., arsenic in urine reported in a Webinar).
>
> All reviewers commented on Report discussions about possible links between contamination and the military exercises on Vieques. We thus provided additional clarification within the Report and provided references from one section to other sections. For example, when we discussed substances measured in fish, we included references to the explosive ordnance constituents and soil measurements. We also provided some perspective about various media constituents we expected to be higher than others. The

Report (Executive Summary and Chapters 1, 2, 3, 6 and 9) has been revised to clarify further those substances found in the environment and those associated with military exercises.

In that regard, ATSDR recognizes the Report discusses both pathway-specific exposures to explosive-ordnance contaminants and more general public health exposures. This resulted from the request ATSDR received to review its previous work in light of Viequenses' general health concerns. The revisions referenced above provide information on possible links between substances found in the environment and military exercises on Vieques. Yet to prove links or specific pathways between current detections and historical releases of contaminants from multiple potential sources is impossible. This is not a Vieques-specific problem—it is inherent at many sites where historical activities possibly resulted in environmental contamination.

Are independent studies utilized appropriately in the determination of potential health hazards?

[Comment] As indicated above, many of the independent studies were not conducted specifically to address the issue of the impact of the bombing-related activities. Some of the other studies that attempted to focus more directly on those activities were poorly designed or too limited in scope to be useful. ATSDR did not set a particularly high standard for discriminating among those studies in terms of incorporating data into its overall assessment. To some extent this is understandable given the necessity of addressing the communities concern and the limited pool of data with which to work. However, the net effect is one of a very mixed and loosely woven patch quilt of data sources. I address more specific comments below.

ATSDR response: We agree that the data are of varying quality, and we described their limitations. That said, only in very few instances did poor data underlie potential exposure assessments. Mercury in some fish—the public exposure scenario that posed the greatest health risk— was based on very high quality data. But even those data were limited.

In response to the concerns about independent studies, it is important to describe all the environmental and health data that are available for Vieques. And this is true even when some of the data might be questionable. For instance, hair data results were presented for numerous metals. Some scientists believed these data were valid and drew conclusions on them. But ATSDR described the limitations of these data in detail. We pointed out the inability to distinguish between external contact and internal ingestion for most metals, except mercury. To this extent, ATSDR has attempted to report fairly the available data and to provide insight into their usability in making health decisions. In our conclusions and recommendations, these questionable data were either not used (e.g., metals in hair, except mercury) or were used qualitatively (e.g., arsenic in urine reported in a Webinar).

On the basis of ATSDR's re-evaluation of historical bombing activities in the Vieques summary report, has ATSDR reached the appropriate conclusions and recommendations?

[Comment]

Fish pathway. I believe that the conclusions about mercury (Hg) levels by species and the health risk (relative to the methylmercury RfD) of consuming those fish at given rates of consumption are appropriate. Nonetheless, the connection between those conclusions and the impact of the bombing-related activities remains a salient gap. I therefore agree with ATSDR's conclusion that, "ATSDR cannot be certain of the extent that military activities did or did not contribute to the mercury levels found in fish." However, given this conclusion, the discussion of methylmercury (MeHg) exposure from fish consumption in Vieques is likely to be misleading as a connection to the bombing-related activities is implied by that discussion.

> **ATSDR Response**: We agree that the mercury discussions are extensive. We further agree that some readers might assume that mercury is related to explosive ordnance used during military exercises on Vieques. We clarified this possible misconception by revising Chapters 1, 2, and 3.

[Comment continued]

Biomonitoring. ATSDR did not actually reach conclusions regarding the biomonitoring or its relationship to the bombing-related activities. Other than to express caution about the use of biomonitoring using hair due to potential exogenous contamination (and not, however, because of the lack of a clear relationship between endogenous hair concentration and internal exposure as discussed above), ATSDR merely reiterated the conclusions of the individual investigators and did not attempt and overall synthesis. I believe that the appropriate conclusion is that the biomonitoring results do not permit any conclusions about exposure to the bombing-related contaminants.

> **ATSDR Response**: We agree. Biomonitoring studies do not reveal whether residents were or are exposed to contaminants from live ordnance used during military exercises. We clarified this point by revising Chapter 3.

[Comment continued]

Health Outcome Data. Here too, ATSDR did not state clear conclusions about the relationship between the health outcomes data and the bombing-related activities. I agree, however, with the ATSDR's conclusions about the methodological limitations of the Vieques disease incidence data.

> **ATSDR Response**: Thank you for your comment. ATSDR did not state clear conclusions about any potential relationship due to the various methodological limitations in the limited, historical work.

[Comment continued]

Local Produce and Livestock Pathway. I agree with ATSDR's overall conclusion for this area that, " Currently available plant and livestock data are not adequate to evaluate thoroughly the extent of exposure to heavy metals in people who eat locally grown Vieques produce." I also agree with the conclusion that (as discussed above) the conclusions for the air pathway would appear to preclude significant off-site contamination of produce either by direct deposition onto plants, or deposition to soil followed by uptake by plants.

> **ATSDR Response**: Thank you for your comment.

[Comment continued]

Air Pathway. I agree with ATSDR's conclusion that "…airborne contaminants from historic uses of the Vieques Naval Training Range would have been essentially nondetectable in the residential areas of Vieques and unlikely to have resulted in harmful effects."

> **ATSDR Response**: Thank you for your comment.

[Comment continued]

Soil Pathway. I agree with ATSDR's conclusion that, "Those who occupied the LIA from 1999–2000 were not at increased risk of adverse health effects from exposure to surface soil contaminants." I also agree with the conclusion that, "Limited available data from other locations and air pathway considerations suggest that the military exercises in the LIA did not result in current contamination of residential soils with inorganic or explosive compounds at levels considered harmful," and the related conclusion that, "Modeling described in the air pathway discussion has suggested that airborne transport of contaminants during past military exercises would not have been heavy enough to have affected soils in the island's residential area." It is not clear to me that the additional qualifiers that appear in the Chapter 9 conclusions are necessary.

> **ATSDR Response**: Thank you for your comment. Because we wanted to identify clearly all possible uncertainties regarding our evaluation, we kept the qualifiers.

[Comment continued]

Drinking Water Pathway. I agree with ATSDR's conclusion that consumption of the pipeline source of drinking water precludes exposure to drinking water contaminants from the bombing-related activities. I am somewhat confused, however, by the apparent contradiction between ATSDR's conclusion on the one hand about the direction of groundwater flow precluding groundwater contamination westward of the bombing sites, and its conclusion on the other hand that an insufficient number of wells have been sampled to draw firm conclusions about the potential impact of bombing-related activities on drinking water wells.

> **ATSDR Response:** We added clarifying text to Chapter 8, Section 8.3.1.2. Our evaluation indicates that bombing activities on Vieques would not affect the former drinking wells. Still, limited sampling in the 1970s showed two detections of explosives; thus we could not exclude the possibility of an unknown, past mechanism. But even conceding that the contaminants might have been extant in the past, they have not been detected in recent years.

Select the appropriate category below:

List recommended changes (or reasons for not recommending)

- Recommend ( )
- Recommend with Required Changes (X)
- Not Recommended ( )

Additional Questions:

Are there any comments on ATSDR's peer review process?

No comment from the reviewer.

Are there any other comments?

Text-Specific Comments

Pg. 15, last par. - The FDA's risk benefit analysis has only been circulated in draft form and has been broadly criticized by the USEPA. While there is clearly a risk benefit trade off with respect to fish consumption and mercury (Hg), there is no clear basis for quantifying the nature of that trade-off at this time.

ATSDR Response. We agree. Thank you for the comment

[Comment continued]

Pg. 17, par. 2 - "…the authors concluded that the results show that mercury concentrations are higher in fish from markets in Vieques compared with the control population from Parquera." There is no statistical analysis presented to support this assertion. Furthermore, the comparison between Vieques and Esperanza does not indicate a likely significant difference. Without more information and contextual description, no conclusion can be drawn from these data.

ATSDR Response: This conclusion is based on averages calculated much differently than proposed by the U.S.EPA or FDA. Some of Dr. Caro's conclusions were based on two samples, analyzed at separate times, and treating a nondetected value differently from that suggested by U.S.EPA. Of the few species that had sufficient samples for comparison (hind, parrot, and grunt), only grunt had statistically higher levels of mercury in Vieques. The highest mercury level found by Dr. Caro of 0.052 ppm was found in Parguerra and this was 37% higher than the highest level found in Vieques. Complete data tables from Dr. Caro's appendix 10 have been added to Chapter 2 (see Table 2-2).

[Comment continued]

Table 2-2 - This table requires sample numbers (n's) to be valid.

ATSDR Response: We have added the sample numbers to Table 2-2.

[Comment continued]

Pg. 18, par. 1 - What is the source of the fish referred to here as "market fish?"

> **ATSDR Response**: In Chapter 2, Section 2.2.1, we clarified that the market fish in this statement refers to Vieques fish markets.

[Comment continued]

Pg. 22, par. 1 - The goal here is to characterize consumption, not the species *per se*. Therefore, discussion about combining species should have been driven by consideration of which species were most commonly consumed.

> **ATSDR Response**: Insufficient data are available to evaluate contaminant levels by species; we had to combine fish by families. In most cases, this resulted in data by genus rather than by species. Grouping fish by families did allow an evaluation of mercury levels in grunt, hind, and snapper.

[Comment continued]

Last paragraph - If, as stated "*…the data were not adequate for comparison by species,*" then why does the preceding discussion compare grunt/hind with other fish.?

> **ATSDR Response**: We have analyzed the data further and found that some species could be compared. Previously we grouped species in each family (e.g., hind, grunt, snapper) together to compare concentrations at locations. We have since determined that some species (e.g., rock hind and red hind) can be individually compared. These comparisons are described in Chapter 2, Section2.5.

[Comment continued] Pg. 26, #5 - There is no basis for this assertion. There is no LOAEL or NOAEL for MeHg

> **ATSDR Response**: We have modified the sentence.

[Comment continued]

Last paragraph - The NAS report did <u>not</u> support a lowest observed effect level (LOAEL) for MeHg. Pg. 27, par. 1 - The notion that the NAS report identified a LOAEL or (as stated here, a "lowest level known to cause harmful effects," is incorrect. The value endorsed by the NAS report and ultimately adopted by the USEPA is based on benchmark dose modeling. It is an estimate of an effect level (i.e., doubling of the population in the lowest 5% of performance) not a lowest or no-effect level. Pg. 28, par. 3 - See language in the previous comment regarding the nature of the basis for the USEPA MeHg RfD.

> **ATSDR Response**: We have modified the language in Chapter2, Section 2.2.5 to be consistent with terminology used by the NAS and USEPA.

[Comment continued]

Pg. 29, second bullet – *"… whether eating those fish and shellfish could make people sick…"* This is not the appropriate outcome or terminology – particularly with respect to MeHg. Rather, the issue is increased risk of an adverse effect.

> **ATSDR Response**: We have changed the wording in Chapter 2, Section 2.3.1.

[Comment continued]

Pg. 34, limitations - It appears that the choice of fish samples was not based on any direct data about actual consumption by species. This should be added as a significant limitation of the sampling strategy.

> **ATSDR Response:** We used the direct data collected by Dr. Caro and supplemented these data with information gathered from discussions with the residents of Vieques, information provided in the Vieques Special Commission Report (Government of Puerto Rico 1999 as cited in Navy 2000b), and visits to local fish markets.
>
> ATSDR agrees that additional information is needed to refine exposure estimates from eating reef fish. We know that a significant proportion of Viequenses eat fish regularly. However, more information about Viequenses dietary habits would be very useful. It would be useful to know the frequency of consumption by gender and age for:
>
> - Reef fish, ocean-going fish, and canned fish,
> - Various fish species,
> - Portion size, and
> - Reef location.
>
> This additional information would allow a more refined risk estimate. In any event, we have made changes to Chapter 2.

[Comment continued]

Pg. 49, par. 2 - All biological media are not equally appropriate for all analytes because of a lack of a demonstrable exposure-concentration relationship. In general, hair is considered a standard biological medium for Hg only. I am not aware of any established method for biomonitoring of Sb in hair. In NHANES, CDC quantified Sb in urine.

> **ATSDR Response**: ATSDR agrees. While antimony levels in hair can be measured, interpreting the results is difficult. Distinctions are impossible between oral intake of antimony (internal exposure) and hair contact with antimony-containing products (external exposure).

[Comment continued]

Par. 2 - *"… Dr. Ortiz Roque's identification of three residents with hair mercury levels above 12 ppm is an important finding."* Other than possibly from a clinical standpoint, why is this an important finding?

Without information on sources of exposure (e.g., canned tuna), no inference for environmental exposure can be drawn.

> **ATSDR Response**: We agree. The findings are important from a clinical perspective but do not indicate an association to military activities on Vieques. Regarding the finding that some women and children with mercury hair levels above a level that might cause harmful effects to a developing fetus or a young child indicates excessive mercury exposure for at least some residents. While the assumption is that this excessive exposure comes from eating fish, only follow up can confirm this. The mercury exposure might have resulted from a high frequency of eating a certain fish (e.g., canned tuna, certain reef fish, or certain ocean-going fish). The Chapter 2 dose estimates indicate that exposure to mercury can be excessive in some people who frequently eat fish that contain moderate to high levels of mercury.

[Comment continued]

Pg. 51, Table 3-2 - The summary information on the studies of mercury in blood is 3-5 years out of date.

> **ATSDR Response**: The studies referred to in Table 3-2 for mercury are the Faroe Islands study, the Seychelles study, and the New Zealand study. These are the principal studies the National Academy of Sciences, the U.S.EPA, and ATSDR use to develop health guidelines. The studies have resulted in numerous peer-reviewed journal articles that we consulted when evaluating the toxicologic significance of the methylmercury exposure. ATSDR is not aware of more recent peer-reviewed studies.

[Comment continued]

Pg. 52, par. 5 and ff. - "…when… a person is found to have an elevated metal or chemical in a biological matrix a follow-up investigation should be considered."

Why? From an individual chemical standpoint, an elevated biomonitoring result warrants follow-up only if there is a potential for adverse effects. From a population-based standpoint, a single elevated level provides little or no useful inferential data.

> **ATSDR Response**: ATSDR agrees that a single elevated level in one person provides very limited information when it comes to making broad statements about inferring exposure to bomb-related chemicals and elements. We have changed the text accordingly. Prudent public health practice, however, requires follow-up investigations when persons have metals in biological matrices at levels of health concern. A prime example is elevated blood lead levels.

[Comment continued]

Pg. 57 - I suggest adding the following to the end of the paragraph: "and whether the results will be informative about health risk. It is not, for example, clear that elevated levels of Al or Zn provide useful information about health risk."

ATSDR Response: We agree and have changed the text.

[Comment continued]

Pg. 69, par. 3 - In this context, “expected” has not been defined. If it is based on NHANES data, it is not clear that it is appropriate to assess the distribution of these biomarkers in a Puerto Rico, or Vieques (as opposed to U.S.) population based on NHANES data.

ATSDR Response: We reported the findings as stated in a 2006 draft manuscript prepared by PRDOH as part of a biomonitoring study in Vieques.. We cannot say what is meant by the use of “expected.” Given the study context, the PRDOH study could have meant comparison to statistics generated by NHANES. We agree with the comment that the U.S. NHANES may not be wholly applicable to a Puerto Rican or Viequense population. In Chapter 3 we discuss the need to include a control or reference population from the Commonwealth of Puerto Rico.

[Comment continued]

Pg. 73 - Table 3A-3 appears to be mislabeled based on its identification on pg. 67 where it is described as the Phase 2 results (i.e., follow-up on elevated levels in Phase 1), whereas the table, itself, is labeled as referring to the Phase 1 results.

ATSDR Response: We have corrected the numbering of Table 3A-2 (Phase 1 results) and Table 3A-3 (Phase 2 results) in Chapter 3, Appendix 3-A.

[Comment continued]

Pg. 76, par. 4 - It is not clear that it is appropriate to combine data from head, pubic and maxillary hair.

ATSDR Response: ATSDR agrees. We have added a caution to Chapter 3, Sections 3.7.2.1 and 3.7.8.1.

[Comment continued]

Pg. 77, table - The table does not have a number assigned to it. Also, the data presented for males and females separately are not labeled. Are these *average* levels by sex?

ATSDR Response: The table is labeled Table 3A-5. We have modified the heading to state clearly that the values reported are averages for various groups.

[Comment continued]

Pg. 79, par. 1 - Data on matched pair correlations are not presented. In addition, the children’s ages are not given. The conclusion about mother-child correlation and in-utero exposure are not substantiated.

ATSDR Response: Dr. Ortiz Roque’s manuscript does not provide data on matched paired correlations. As stated in the text, Dr. Ortiz Roque reported that in one subset of 22 matched pairs, the age of children was less than 5 years. As stated in the text, Dr. Ortiz

Roque reported that the Pearson's correlation was 0.93 and the p value was 0.0001. No Report changes are warranted.

[Comment continued]

Pg. 84, par. 2 - Where did the 52 subjects reside? What were the criteria for their recruitment? What was the dichotomous criterion for dividing the subjects into high and low fish consumption categories?

ATSDR Response: We have modified the text to indicate that the 52 subjects were Viequenses. Because this information came from a Webinar, we cannot currently answer the other questions. This information is likely to be available when

Dr. Rodríguez Sierra publishes his data.

[Comment continued]

Pg. 85, table - Given the previous, brief description of the 2009 Rodríguez Sierra study, I would have expected to see the data stratified by high and low fish consumption rates.

ATSDR Response: Because this information came from a Webinar, we cannot currently answer the question. This information is likely to be available when

Dr. Rodríguez Sierra publishes his data.

[Comment continued]

Pg. 97, par. 3 - The levels of 85 and 58 µg/L are somewhat misleading. Although 58 µg/L is the lower 95% CL on the dose corresponding to a 5% decrease in performance, the value of 5.8 µg/L to a significant extent reflects the population variability in the intake dose (µg/kg/day) required to reach 58 µg/L. Therefore, the factor of 10 reduction from 58 µg/L is not simply an arbitrary default.

ATSDR Response: The paragraph cited does not discuss 5.8 µg/L or the use of an uncertainty factor of 10 to derive 5.8 µg/L from 58 µg/L. The paragraph comes from a CDC Web site and is provided for informational purposes. No report changes are warranted.

[Comment continued]

Pg. 102, par. 2 - It is not clear how "cancer registries typically represent the best population-based dataset for any chronic health condition."

ATSDR Response: Our intent was to communicate that the infrastructure for reporting cancer and the legal requirements for doing so are more rigorous than for most noninfectious chronic diseases and typically produce good data. We have clarified the text.

[Comment continued]

Pg. 103, par. 1 - The sentence starting, "One initiative…" is not a complete sentence.

> **ATSDR Response**: We revised the sentence in the fourth paragraph of Chapter 4, Section 4.1 as listed below.
>
> The Selected Metropolitan/Micropolitan Area Risk Trends (SMART) project was initiated to develop prevalence estimates at the local level.

[Comment continued]

Pg. 108, #2 and ff. Given the latency for most cancers, how do temporal aspects of cancer incidence relate to military activities on Vieques?

> **ATSDR Response** The U.S. Navy has occupied some part of Vieques since 1941. Considering the latency of most cancers, evaluating cancer incidence and mortality from 1990–2004 is a reasonable timeframe.

[Comment continued]

Pg. 109, #4 - It is important to discuss the socio-economic status (SES) of Vieques relative to Puerto Rico.

> **ATSDR Response**: ATSDR added a discussion of SES in Chapter 1.

[Comment continued]

Pg. 115, first bullet - Where are the locations of the reference populations given here? It would be useful to have a map at this point.

> **ATSDR Response**: We agree a map would be helpful. Unfortunately, Figure 2 of Massol-Deya 2000 contains only the study areas. Other than the name, no details of the reference area and sampling locations are available.

[Comment continued]

Pg. 116, first complete bullet - Do the “toxic” levels of “all metals” referred to here refer to plant toxicities or human toxicities? Also, why are “absorption rates” for Pb and Cd referenced here instead of concentrations?

> **ATSDR Response**: We have modified the text in Chapter 5, Section 5.2.1 of the Report to address these comments.

[Comment continued]

Last bullet. Are the goats in Puerto Rico that are being compared to those in Vieques the same species of goat? Are they the same age? What were the levels in Vieques and Puerto Rico goats? Was the difference statistically significant?

> **ATSDR Response**: This information was not included in the publication (Massol-Deya 2002) that presented the hair sampling data. Among other things, the lack of this information precluded ATSDR from using these data to evaluate human exposure from consuming local-livestock meat and milk products.

[Comment continued]

Pg. 121, Table 5-1 - If the childhood exposure duration (ED) is assumed to be 6 yr, the adult ED should be 70 - 6 = 64 yr rather than the 70 yr value used here for adults if a 70 yr lifetime is assumed. Also, why do the ingestion rate (IR) assumptions differ for the MRL calculation (0.10, 0.05 kg/day) versus the NOAEL/LOAEL calculations (0.05, 0.01 mg/kg/day)?

> **ATSDR Response**: Table 5-1 has been modified to show that exposure duration had no effect on the estimated daily dose. The ingestion rates used for comparison to the MRL of 0.10 and 0.05 kg/day reflect 95th percentile intake rates for adults and children, respectively. The rates for the NOAEL and LOAEL comparisons reflect 95th and 50th percentile intakes for children only.

[Comment continued]

Pg. 124, par. 2 - How many pineapple samples were taken? Was it only 1? If so, how can this observation be used to support modeling?

> **ATSDR Response**: Lopez Morales (2005) does not overtly state the sample number, but apparently a total of 72 samples were taken: 36 from the study site and 36 from a reference plantation.

[Comment continued]

Pg. 126, par. 2. I do not see that these very limited data support any larger assessment of exposure or risk.

> **ATSDR Response**: Thank you for your comment. ATSDR agrees that limitations in the current sampling data make it difficult to evaluate the extent of public health impact from exposure to metals in locally grown produce. Given the uncertainties in the data, ATSDR believes prudent public health practice requires further investigation of this potential exposure pathway. To address this data deficiency, ATSDR has recommended further sampling.

[Comment continued]

Pg. 164, par. 1. The sentence starting, "Examining results from background locations not directly affected by military operations…" does not make logical sense. If the samples are, in fact, background samples, this implies that they are assumed not to be impacted by specific activities.

> **ATSDR Response:** In Chapter 7, Section 7.2.4, we inserted parentheses around the phrase to indicate that background locations are by definition not affected by military operations.

[Comment continued]

Pg. 165, par. 2 - This is a reasonable assumption for the sites of the actual explosions. However, when considering off-site transport, surficial material becomes more important.

ATSDR Response: Most of the surface soil samples used in this evaluation were collected directly from the LIA. We recommend that any future sampling conducted outside the LIA consider surficial (top 3 inches) contamination.

[Comment continued]

Pg. 190, 1b - Hair is not an appropriate medium for biological monitoring for most contaminants. Blood is generally more appropriate. But for blood too, the determination of the applicability of its use for biological monitoring is contaminant-specific.

ATSDR Response: We agree that with the exception of mercury, hair is of limited use for environmental exposure monitoring. Numerous statements in the Report convey this message. We also agree that if other metals are considered as part of a biomonitoring study, developing a scientifically rigorous and valid protocol is important. This includes determining whether the results will inform about health risk.

[Comment continued]

Pg. 192, #2 - The review has not provided any basis to conclude what this single observation of Cd levels in the pigeon peas implies for exposure. This observation should not be presented and discussed without proper context.

ATSDR Response: Text in Chapter 5, Section 5.2.2 of the Report has been modified to address these comments.

[Comment continued]

Pg. 193, #5 - Add “and false low values” after, “To avoid false high values”

ATSDR Response: Text in Chapter 5, Section 5.3 of the Report has been modified.

Reviewer 2

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

[Comment] The ASTDR document: A Fresh Look at Environmental, Biological, and Health Data from the Island of Vieques, attempts to explain in readily accessible language, the potential for human health effects as a result of decades of use of portions of the island as a U.S. Navy training and testing area. The document has been developed using data collected by related agencies specifically for the purposes of this risk assessment as well as data collected by external sources. The risk assessment discussion has been organized based on individual pathways as a means to both structure the information and explain the potential risks in a systemized manner.

In evaluating this document, I've approached the information as a scientist versed in bioavailability of contaminants in soil systems as well as someone familiar with Vieques. Before graduate school, I worked in Vieques for two winters during the mid-1980s. At this time the Navy still had an active presence on the island. I remember being able to both feel and hear some of the munitions testing during my time on the Island. I read about protests by Viequenses that were a factor in the decision to end the testing operations. I have also been back since the Navy ceased operations and the former Navy bases became wildlife areas managed by U.S. Fish and Wildlife.

Understandably, the residents of Vieques are concerned about potential negative health effects as a result of the decades long use of the island as a training and testing area for the Navy. Certain factors, including high cancer rates and increased incidences of select medical conditions would suggest to concerned residents that there is likely a link between the testing operations and these observed health effects. The risk assessment document attempts to ascertain any potential relationship between the testing and these observed effects by going through each exposure pathway and discussing all available evidence linking any human health effects to the testing results for each pathway.

This effort is handicapped by a number of factors. The testing began several decades before any research efforts to document health effects were started. It is likely that the records of testing re: chemical composition, quantity and final fate of the ordinance used, is not complete. Some of the data used for the current effort was compiled by external scientists, without the appropriate quality assurance, quality control, information on methods, and control populations that are general considered essential for the data to be considered appropriate for use. Finally, the necessary studies to provide quantitative guidance on contaminant concentrations in different human tissues, soils, fish that are likely associated with health effects are not available for all of the contaminants considered in this document.

In general, this review is very sympathetic to the concerns of the residents of Vieques. Data is included in this analysis that is likely inappropriate for use in a more rigorous exercise. Examples of this include web casts and unpublished data on health of residents. The desire to address concerns of residents has also resulted in credence and attention being given to certain pathways that are not realistically supported by the data as being a significant threat.

ATSDR Response: Thank you for your summary comments.

Has ATSDR adequately addressed the pathways of human exposure to bombing range-specific contaminants?

[Comment]

The document divides the potential for harm to have resulted from Navy activities into the following categories:

Consumption of fish

Terrestrial food chain pathway

Air pathway

Soil pathway

Drinking water pathway

The pathway approach is appropriate. In addition, all relevant pathways have been considered.

ATSDR Response: Thank you for your comments.

Please include specific comments on:

Consumption of seafood from reefs near Vieques

Use of biomonitoring tools to assess exposure to metals and other hazardous chemicals in blood, urine, or hair that are related to historical bombing exercises

[Comments combined by reviewer]

The primary conclusions of the report are that the pathways that have the potential to be of concern are the consumption of fish and the terrestrial food chain pathway. Mercury is the primary contaminant of concern for the consumption of fish and Cd is the primary concern for the terrestrial food chain pathway. The authors cite data from a number of studies that show elevated Hg concentrations in certain fish species caught in the vicinity of testing impacted reefs in Vieques. They also cite less credible studies that indicate elevated Hg concentrations in hair for, depending on the study, a significant number of Viequenses in comparison to control populations (Dr. Colón de Jorge and Dr. Rodríguez Sierra). The elevated Hg in humans is related to the observed high Hg content in fish. The authors of the current report conclude that reducing fish consumption and avoiding certain species of fish are sensible options to reduce any risk associated with elevated Hg in seafood. These conclusions are reasonable based on the Hg concentrations in certain of the fish species sampled as well as the availability of other fish species that have been shown to have low levels of Hg in edible tissue. The authors of this report present the findings of Dr. Colón de Jorge and Dr. Rodríguez Sierra while also pointing out the flaws or unknowns for both studies. It does not make sense to spend additional resources to test human Hg body burdens when a clear option for reducing Hg in diets while maintaining fish as a staple source of protein has been described. The one factor that is not considered in this discussion is the potential for the observed excess Hg in fish to be related to Naval activities. There is no discussion in the document on the quantities of Hg that were likely used in Naval activities or whether elevated Hg concentrations have been detected in reefs impacted by Naval activities. So while the conclusions and recommendations of the ASTDR report re fish consumption are reasonable, a clear link has not been made between the observed elevated concentrations in certain fish species and Navy activities on the island.

> **ATSDR Response:** The Report focused heavily on mercury in fish because it poses the greatest risk of those scenarios assessed. Chemical results for soil, air, water, and biota do not reveal extensive contamination and do not identify an association between mercury and the bombing activities. We clarified this point by revising the Executive Summary and Chapters 1, 2, 3, 6, and 9.

Consumption of food (produce, meat, dairy, eggs) grown on the island

Exposure to air, soil, and water on Vieques

[Comments combined by reviewer] The other main concern outlined in the report is the potential for high Cd consumption from eating pigeon peas. This recommendation is based on a single study that included samples of about 20 pigeon pea plants from a single area on the island. This recommendation is also based on the assumption that a high quantity of pigeon peas will be part of a daily diet and that these peas will be grown on the island. For this reviewer, this conclusion and recommendation is not supported by the available data. There are a number of reasons for this.

The report concludes that there is no basis for concerns re direct ingestion of soils (the soil pathway) or from airborne contaminants. Both the available data and modeling efforts show no evidence of or potential for significant hazards associated with either the soil pathway or the air pathway for residents in the middle portion of the island. This is the inhabited portion and has always been exempt from military testing. For pigeon peas to have excess Cd as a result of the Naval testing, there would also need to be associated soil contamination. As modeling and data show no hazard from the soil pathway or the airborne pathway, it is also highly unlikely that soils would have become sufficiently contaminated with Cd as a result of the Naval activities to result in consistently elevated plant Cd concentrations in the edible portions of plant tissue.

As was stated earlier with Hg, there is no evidence provided of high Cd use or Cd concentrations in any of the munitions used in the testing. Cadmium was historically used as a pigment. It is not clear that any more than trace amounts of this metal were involved in any of the Naval activities. Soils can be naturally elevated in Cd- for examples soils in Salinas, California, derived from Monterrey shale have Cd concentrations ranging from 0.05-10.1 mg kg^{-1} (Burau et al., 1973). Sediment samples collected from the LIA show Cd concentrations ranging from 60-110 mg kg^{-1}. This was in an area where metal concentrations were elevated through the sampling depth as a result of direct impact of explosives.

While these sediment Cd concentrations are clearly very high, they are directly in the impacted area. It is highly unlikely that agricultural soils will show any detectible increase in soil Cd as a result of the Navy activities.

There are other factors that make the high Cd concentrations in this single study an insufficient basis for concern. Plant uptake of Cd will likely vary based on specific soil and plant factors. The study used as a basis for concern was from a single site. It is highly likely that Cd concentrations for peas grown in different areas of the island would vary significantly. A mean value, from a range of sites, showing highly elevated Cd, would be much more significant.

Bioavailability of Cd will also vary based on the nutritional status of the individuals. A study showed significantly higher adsorption of Cd in cases where Ca and Fe were below required levels (Reeves and Chaney, 2001). Sufficient Zn in diets was also observed to protect against excess Cd adsorption. The most studied cases of adverse health effects as a result of excess diet Cd were in Japan where milled rice was the staple grain. This occurred after WW II when diets were poor in Japan. Pigeon peas are likely a far superior source of essential elements than milled rice. In addition, diets in Vieques are likely superior to those where Cd in food resulted in adverse health effects.

Finally, it is highly unlikely that enough pigeon peas are grown in Vieques to feed a significant portion of the population for any amount of time. Although historically sugar cane was an important crop economically, agriculture in Vieques is limited. Families will have a few citrus trees, some banana and other sundry plants, however, there are very few large- scale farms in Vieques. During my time there, there was one attempt to grow tomatoes for export that failed. There isn't sufficient rainfall to consistently grow crops commercially without irrigation.

The above comments can be applied to the entire food chain transfer model (excluding seafood). Looking at the soil pathway section, there is no data presented in this chapter. However, based on the airborne discussion and the conclusions in the soil chapter, it seems pertinent to revisit the conclusions reached on metal uptake from home grown vegetables. That chapter did not include data on metal concentrations in soils where plants were grown. The chapter on soil pathways suggest that the potential for elevated soil metals as a result of Navy activities in the populated portion of the island, the portion that might be used for agricultural activities, is minimal. Airborne spread of metals would be the primary pathway for metal contamination of these soils. Metals would persist in the soil over time, unlike the organic contaminants that were also measured. The absence of any increase in soil metals suggests that the elevated Cd content in the pigeon peas is not likely related to soil contamination as a result of previous Naval activities. There are many factors that can lead to elevated plant metal concentrations, including a high soil electrical conductivity level, low soil Zn concentrations, and there may be a relation with low soil phosphorus. Many of these soil factors can be controlled with proper management. Appropriate soil testing and agricultural practices are suggested as a means to address concerns.

> **ATSDR Response:** Thank you for your comments. Relevant text in Chapter 5, Section 5.2.2 has been modified.

Does the Vieques summary report adequately present and describe the limitations and uncertainty of assessing human exposure to bombing range-specific contaminants?

[Comment] Yes

Are independent studies utilized appropriately in the determination of potential health hazards?

[Comment] In the interest of including as much information as possible with a particular goal of including any information generated by researchers from Puerto Rico, information is included in this report that would not be considered of sufficient scientific integrity to be included in most studies. There are a range of reasons for doing this, and the inclusion of these studies has not resulted in unreasonable recommendations. The recommendations from the report are likely to be more broadly accepted because this data has been included.

ATSDR Response: Thank you for your comment

On the basis of ATSDR's re-evaluation of historical bombing activities in the Vieques summary report, has ATSDR reached the appropriate conclusions and recommendations?

[Comment] See discussion on plant Cd concentrations above, however general response is yes.

ATSDR Response: None required.

Select the appropriate category below:

List recommended changes or reasons for not recommending

- Recommend (X)
- Recommend with Required Changes ( )
- Not Recommended ( )

Additional Questions:

Are there any comments on ATSDR's peer review process?

[Comment] No

Are there any other comments?

[Comment] In general, the report is potentially too lenient in its use of any and all appropriate data. The report expresses concerns with minimal basis. The information presented suggests that the history of naval activities on Vieques has not resulted in any measurable human health impacts. With that said, it is likely that if full and unrestricted access was granted to the former naval areas including home construction, the conclusions of this risk assessment would need to be revisited. The area is likely to require extensive remediation before unrestricted access can be permitted. In addition, the limited data presented in this report on contamination both in the waters around Vieques and for portions of the impacted areas suggest that a full ecosystem risk assessment would reach very different conclusions than this limited human health risk assessment.

ATSDR Response: Thank you for your comment. We changed the text (in the Executive Summary, Chapters 1, 2, and 3 to improve the discussion of contaminants in bombs and their possible contribution to various pathways. Iron, aluminum, copper, manganese, zinc, and lead are the metals most likely to be elevated in LIA soils from bombing activity, though other metals were also found in the bombs. It should be noted that all of these metals are also naturally present in the soils and rocks of Vieques (ATSDR 2003a, Learned 1973, USGS 1997 and 2001).

Although associations with these samples and military activities are not strong, the samples were not designed for a thorough ecological assessment. Thus they should only serve as indicators of further study.

Also, in Chapters 7 and 9 we clarified that ATSDR recommends environmental assessment and remediation activities continue at the LIA and at other potentially contaminated sites on Vieques. Restricted access to those areas should continue until the areas are cleared for unrestricted access.

Reviewer 3

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

[Comment] Yes, the re-evaluation has been appropriate. The exposure pathways have been adequately considered, local studies that were made available were included and analyzed and proposals have been made for further work. My answer is qualified by only two things. First, there seems to be a degree of ignorance on local conditions, which are reflected in the report: the recommendation for Viequenses to follow the U.S.EPA/FDA's national fish advisory and its three recommendations for selecting and eating fish and shellfish, and the lack of knowledge concerning the public water supply of Vieques. My second qualification has to do with the multiplicity of samplings and data gathering activities that are recommended to fill current data gaps. Considered individually, I generally agree with them. However, taken as a whole, they constitute a huge and expensive undertaking likely to take many years. It is suggested that priorities be established and the most important gaps be filled first in order to establish within a reasonable period of time whether the health of Viequenses is at risk or not.

Details of this are given below.

> **ATSDR Response**: Thank you for your comments. We have modified the text in Chapter 2 to better reflect local fish consumption habits. We also modified Chapter 8 to address concerns about the public water supply. ATSDR considers education about choosing fish with lower mercury levels to be the highest priority public health recommendation and plans to work with our partners and the community to prioritize other recommendations.

Has ATSDR adequately addressed the pathways of human exposure to bombing range-specific contaminants?

[No Comment]

Please include specific comments on:

Consumption of seafood from reefs near Vieques

[Comment]

1. I agree with recommendations #1-3. However, ATSDR should reconsider recommendation #4 (Viequenses follow the U.S.EPA/FDA's national fish advisory and its three recommendations for selecting and eating fish and shellfish). These recommendations are hardly applicable at Vieques.

Consider that Viequenses eat fish provided by local fishers, which consist mainly of those shown in Table 2-1. The EPA/FDA's recommendations are for them to eat canned light tuna, or three other species (salmon, pollock and catfish) that are non-existent in the area. This is not going to happen, and instead the recommendation should be to eat local species that are low in mercury, and a table should be provided.

Viequenses are asked to check local advisories about fish safety. To my knowledge no such advisories are made in Puerto Rico. This same recommendation makes reference to "local lakes, rivers…" of which there are none in Vieques. Using these references gives the impression that ATSDR is not aware of the local situation.

Viequenses are told not to eat shark, swordfish, king mackerel, or tilefish, species that are not listed in Table 2-1.

> **ATSDR Response**: We agree that portions of the EPA/FDA national fish advisory do not apply to Viequenses. We have modified this recommendation in Chapter 2,Section 2.3.2.
>
> Using all the data from Dr. Caro's survey, we expanded the list of fish that Viequenses eat (see Table 2-1 in Chapter 2, Section 2.2.1). Table 2-1 now shows the 22 fish species and two shellfish (i.e., conch and lobster) that the 51 respondents reported to Dr. Caro that they eat. Note that residents reported eating shark, tuna, and marlin—species that can have very high mercury levels. In addition, residents reported eating salmon, a low-mercury containing species. That Viequenses eat canned tuna seems a reasonable assumption. Therefore, some portions of the EPA/FDA national advisory apply while other portions clearly do not.
>
> During the November 2009 scientific meetings, a scientist also criticized the agency for 1) not citing the EPA/FDA national fish advisory and 2) contradicting the national advisory in ATSDR's previous, 2003 Fish PHA findings. That Viequenses know which reef fish have higher mercury levels is important, as is knowing which reef fish have lower mercury levels. ATSDR now recommends that the agency develop a health education program specific to Vieques. This health education program should empower Vieques residents to choose to eat fish that are lower in mercury.

[Comment]

2. Dr. Caro's study:

   Table 2-2 appears to be incomplete (it only shows three fish species). Caro characterizes this three fish as "…an example, the average contents of the metal may be mentioned in the following fish…." She adds that: "Additional data in Annex 10 illustrate these results." However, this and many other annexes were not included in the copy of the Caro report that was sent by ATSDR.

> **ATSDR Response**: We added the additional information from Annex 10 to Table 2-2 in Chapter 2, Section 2.2.1.

[Comment]

I agree that not knowing whether the results are dry weight or wet weight prevents comparison with other datasets and estimation of human doses from eating fish, but assuming dry weight would provide a conservative estimate and allow for qualified comparisons and estimation of doses. If wet weight is used the actual tissue concentrations could be higher.

> **ATSDR Response**: We provided additional analysis of Caro's data. See Chapter 2, Section 2.2.1

[Comment]

The correct spelling for Parquera is Parguera. The Caro report appears to make the same mistake.

> **ATSDR Response**: The spelling of this town is corrected.

[Comment]

It is said the ATSDR is currently renewing its efforts to determine whether the data was dry weight or wet weight. Please note that Dr. Caro passed away in 2002.

> **ATSDR Response**: We tried to contact the laboratory. We revised the sentences in the Chapter 2, Section 2.2.1 to reflect our efforts accurately.

[Comment]

3. Fish and Seafood Data from ATSDR

   It is indicated that ATSDR used standard body weights for adults and children. If this refers to a mainland standard, it should be noted that generally Puertoricans are smaller in size and weight, which could under estimate calculations on tissue concentration.

> **ATSDR Response**: In ATSDR's 2003 Fish PHA, we used standard body weights of 70 kg for adults and 16 kg children. The point that Puerto Ricans typically weigh less also was raised by scientists in our November 2009 discussions. Therefore, in the current Report, we used a range of body weight from 4.5 to 100 kg (9.9 to 220 pounds) to represent the body weight of various age groups (see Chapter 2, Section 2.6, Table 2A-1 in Appendix 2A-2). We also included a range of daily fish ingestion rates to cover daily intakes up to the 99th percentile. Therefore, the estimated doses of mercury in this report include a much wider range of doses than the 2003 Fish PHA.

[Comment]

4. There is a poster presentation titled "Health Risk Assessment of Arsenic from Fish in Coastal Waters of Vieques, PR" by Acevedo et al, which measured arsenic concentrations in eight edible fish in Vieques in 2001. Concentrations ranged from 0.3 to 3.53 mg/Kg wet. The study considered different exposure scenarios for inorganic As and found that concentrations exceeded EPA's reference dose of 0.0003 mg/Kg/d in six or more fish species for systemic

effects in adults and children. The probability of excess lifetime cancer for exposure to As by adults was estimated to exceed the acceptable cancer risk of 10^{-6}. I do not believe that this study has been published but the poster may be obtained from Dr. Carlos Rodríguez Sierra at the School of Public Health of the Medical Sciences Campus of the University of Puerto Rico.

ATSDR Response: ATSDR has attempted to locate this information but has not been successful. Average total arsenic in fish samples collected by ATSDR in 2001 ranged from 1.85 ppm (or mg/kg) to 2.84 ppm (wet weight), with one trunkfish sample showing 8.3 ppm total arsenic. The median total arsenic concentration in fish was 2.8 ppm. Conch and land crabs had similar levels (0.3 ppm and 3.9 ppm, respectively). These levels are typical for total arsenic concentrations in seafood, and in particular for fish (WHO 2001, Rodríguez Sierra 2002, ATSDR 2007) and are similar to the levels reported by the reviewer in the poster (0.3-3.53 ppm).

Numerous studies have shown that the predominant form of arsenic in fish is arsenobetaine, an organic arsenic (ATSDR 2007). Arsenobetaine is not harmful to humans because humans rapidly excrete this chemical unchanged within 24 to 48 hours of ingestion. The remaining small amount of inorganic arsenic in fish is not harmful (WHO 2001).

Spiny lobster from Vieques reef were shown to have total arsenic levels ranging from 27 ppm to 48 ppm with an average of 33 ppm. Like fish, most of the arsenic in spiny lobster (genus *Panulirus*) is arsenobetaine and only about 0.05% is inorganic arsenic (Peshut et al. 2007). No changes were made in the report.

Use of biomonitoring tools to assess exposure to metals and other hazardous chemicals in blood, urine, or hair that are related to historical bombing exercises

[Comment]

1. The chapter provides a good review of six Vieques human biomonitoring studies. I was surprised to learn that ATSDR's previous public health assessments did not review biomonitoring data from Vieques.

   ATSDR Response: Thank you for your comment. The biomonitoring studies were not readily available when the public health assessments for Vieques were being written or, in the case of the PRDOH study, had not yet been conducted. When ATSDR began its evaluation of Vieques in 2009, we knew that PRDOH had conducted a study, but were not aware that a draft manuscript was available. ATSDR was provided a draft copy of the PRDOH study in late 2009

[Comment]

2. The Puerto Rico Department of Health (PRDOH) appears to have conducted the most comprehensive biomonitoring study, in which it collected hair, urine or blood samples from 500 randomly selected Viequenses. However, no public report was ever released and it was not until August 2009 that ATSDR obtained a draft, unpublished manuscript. Quite frankly, the way this is

written makes one wonder why it took three years for ATSDR to obtain a copy, and how it was obtained.

ATSDR Response: When ATSDR began its evaluation of Vieques in 2009, we learned that PRDOH had conducted a study, but were not aware that a draft report was available. Shortly before the November 2009 meeting with invited scientists, ATSDR received a draft copy of the PRDOH study.

[Comment]

3. The discussion in Chapter 3.3 of the strengths and limitations of previous human biomonitoring studies for Vieques is comprehensive and balanced. It is recognized that NHANES biomonitoring data applies to the entire U.S. population and that due to regional, cultural, and ethnic differences they can only cautiously apply to Puerto Rico. I completely agree that when looking for a Vieques comparison group, a control population from another town in Puerto Rico should be more appropriate.

ATSDR Response: Thank you for your comment.

[Comment]

4. The conclusions from Dr. Colón de Jorge's investigations indicate that children could not be exposed to metals in paint as adults might be. As EPA states in http://www.epa.gov/lead/pubs/leadinfo.htm#hazard (accessed 19July10):

"Lead-based paint may also be a hazard when found on surfaces that children can chew or that get a lot of wear-and-tear. These areas include

Windows and window sills.

Doors and door frames.

Stairs, railings, and banisters.

Porches and fences."

My own experience with lead paint studies indicates that Puerto Ricans tend to paint their houses using layer upon layer of paint, and that the inner layers (which are the older) are the ones that have lead paint. Children will chew all the layers, thus exposing them to the lead paint.

ATSDR Response: We agree that children can be exposed to lead from lead-based paint and have added a comment to Chapter 3, Section 3.7.9.1.

[Comment]

5. "Dr. Colón de Jorge pointed out that antimony levels were high because antimony was used in explosive ordnance on Vieques, thus making the case that military exercises was the reason antimony levels were high." This conclusion appears to have no supporting data or analysis and the review by ATSDR of the report should so state.

   ATSDR Response: Dr. Colón de Jorge states that antimony levels in bombs were high and this is the reason that some children have high antimony levels. We have modified the text in Chapter 3, Sections 3.2 and 3.7.9.1 to include Dr. Colón de Jorge justification. We also have pointed out that Dr. Colón de Jorge did not describe how residents might have been exposed to antimony.

[Comment]

6. The discussion of the investigations by Dr. Carlos Rodríguez (this is the same person as the one referenced in comment 4 of the section on consumption of seafood from reefs near Vieques above) is based on a presentation made in a webinar. Although it is stated that Dr. Rodríguez intends at some point to publish his data, he has apparently not done so, which raises an overall concern that I have about the lack of peer review of many of the local studies that are presented in the ATSDR report.

   ATSDR Response: ATSDR agrees that using peer-reviewed data is preferable. But data collected and analyzed using valid quality assurance/quality control procedures is also acceptable. In an effort to consider all available Vieques data, ATSDR chose to include the non peer-reviewed data in the Report. In the Report appendix, ATSDR summarizes all the available data and designates whether the data are peer-reviewed. In e-mail conversations with Dr. Rodríguez Sierra, he stated that his biomonitoring data were submitted for publication and are currently in the journal's peer-review process. Those data will be available to ATSDR after publication

Consumption of food (produce, meat, dairy, eggs) grown on the island

[Comment]

1. This chapter includes an analysis of several studies dealing with contaminants detected in locally raised garden produce and livestock. All the studies present serious limitations. For example, one included plant stems and leaves but did not include the edible portions of the plants sampled. It appears that the locally grown pigeon peas could have a high cadmium level, but, again, there are insufficient data.

   ATSDR Response: ATSDR concurs. Thank you for your comment.

[Comment]

2. Reference is made to USDA's suggestion of several simple methods for reducing metal uptake when soils are contaminated. It is stated that most home gardeners use many of the suggested practices. However, the referenced website goes to a very general page on plants and crops. A more specific reference should be provided, insuring that the suggested practices are applicable to Vieques.

    ATSDR Response: No specific reference was available. We defaulted to USDA recommendations, which are generally applicable and relevant to gardening and agriculture.

Exposure to air, soil, and water on Vieques

[Comment]

1. *Air Pathway* The chapter makes no mention of the possibility of Saharan dust contributing contaminants to the air or soil in Vieques. For example, see Garrison et al (Rev. Biol. Trop. 54 (Suppl. 3): 9-21. Epub 2007 Jan. 15.) who sampled in the Virgin Islands where trace metal concentrations in the Saharan dust were found to be similar to crustal composition. Although I think that metals concentrations in Saharan dust are not going to be high enough to make a significant contribution to metals found in Vieques, the issue should be addressed.

    ATSDR Response: *African Dust Storms*: The 2003 Air PHA evaluated the public health implications of exposure to airborne particulates from African Dust Storms (pages 59–61) and found that PM10 (and PM2.5) from such storms on Vieques were not at levels of health concern. However, no contaminant specific data on dust from African Dust Storms were available at the time of the Air PHA (which recommended further evaluation if such contaminant specific data became available). Contaminant specific dust data are presented in a recent study by Gioda et.al. (2007) and a discussion of this information has been added to Chapter 6, Section 6.2.3.

[Comment]

2. The discussion of post-Air PHA sampling results and modeling studies as well as recent BIP detonations is comprehensive and leads to the stated conclusion that in the residential areas of Vieques, airborne contaminants from past military operations at the Vieques Naval Training Range would have been essentially nondetectable and unlikely to have resulted in harmful effects.

    ATSDR Response: Thank you for your comment.

[Comment]

1. *Soil Pathway* This chapter evaluated potential direct soil exposures in two situations: people who stayed on the LIA property during 1999-2000 protests and people who live in the island's residential areas. It concluded that people who lived on the LIA during protests were not exposed to soil contaminants at levels high enough to cause adverse health effects. This

conclusion is well supported by the available data as discussed in the report. Concerning the island's residential areas, no soil data are deemed adequate to characterize potential exposures fully. Although current or reasonable recent data supports the conclusion that the existing contaminant levels at residential areas are not likely to cause adverse effects, there is a lack of historical data that would support a wider conclusion to the effect that it never has. The report calls for additional sampling to resolve existing uncertainties, which would be appropriate, but the wider question is now impossible to resolve.

ATSDR Response: Thank you for your comment.

[Comment]

Drinking Water Pathway

1. The Puerto Rico Aqueduct and Sewers Authority (PRASA), a public corporation in existence since 1945, is charged with providing drinking water and wastewater treatment for the Commonwealth of Puerto Rico. It is the only entity in the United States with a statewide mandate, and as such is one of the largest water and wastewater utilities in the United States. In 2005 PRASA ran 130 different water systems throughout Puerto Rico, which processed 500 million gallons of water a day. It also operated 29 sewage disposal plants and 1,600 pump stations. Vieques is part of its service area. While it is correct that in recent years (for about eight years until 2004) PRASA had part of its operations partially conducted by private corporations such as the mentioned Compañía de Aguas or at another time by ONDEO de PR, it has always been regulated by the Safe Drinking Water Act as a public water system. This regulatory function has been delegated by EPA to the Puerto Rico Department of Health (DOH). PRASA is required to annually produce and distribute to its users Consumer Confidence Reports where the quality of its water is reported and explained in non-technical language. Such reports for the years 2004-2009 can be obtained at http://www.acueductospr.com/AMBIENTE/ccr_reports.htm

(the system that feeds the Vieques pipeline appears under 5386-Humacao Urbano and then as Río Blanco in the pdf file) and reports for earlier years should easily be available at PRASA or the DOH. This data should be enough to settle the question concerning the quality of the pipeline water. For example, the data for 2009 shows that the lead action level of 15 ppb was exceeded four times.

ATSDR Response: We have modified text in Chapter 8, Section 8.1 to correct any inaccuracy regarding the current operators of the public water supply. We did not include detailed descriptions of the water supply system; it could detract from our evaluation of possible exposures from all water supplies, past and present.

The water quality reports from 2004–2009 referenced in the comment indicate that the pipeline supply has occasionally exceeded drinking water standards for microbial contaminants, turbidity, and lead. Elevated lead levels, detected particularly in 2006 and 2007, were not related to military exercises on Vieques. But regardless of source, lead in drinking water is an important public health issue. ATSDR has reworded text and added discussion to address these points in Chapter 8 and Chapter 9, Sections 9.8.1, and 9.8.2 of the Report.

[Comment]

2. The ATSDR report also addresses wells that had been and are now occasionally used for drinking water. These wells are very likely to belong to PRASA, who should have historical data on the quality of their water. Also concerning the wells, the presence or absence of a sanitary landfill in Vieques that might be impacting groundwater and the use of septic tanks for sewage disposal should be discussed.

    ATSDR Response: We added discussion about historical data to the Report in Chapter 8, Sections 8.2.2, 8.2.4.2, and 8.3.1.2. We did not attempt to gather additional historical information on the water quality of these wells. Even if available, questions about sampling, analytical, and quality control procedures from the 1970s and 1980s render unlikely the possibility that such reports would give us sufficient information to alter our current conclusions. Similarly, a lack of adequate historical data precludes any conclusion about more remote (1970s and 1980s) public supply well exposures.

    Thus, in Chapter 8, Section 8.3.1.2 we reworded text and added a statement about possible nonmilitary sources of contaminants, including sanitary landfills and septic systems. While sanitary landfills and septic systems could affect groundwater resources, whether they have was not a focus of our evaluation. Instead, ATSDR based its conclusions on actual sampling of supply wells, private wells, and taps.

[Comment]

Although it would be good to have data on the rainwater systems, their overall use and effect is likely to be very small.

> **ATSDR Response**: Thank you for the comment.

[Comment]

ATSDR should consider rewriting this whole chapter to better reflect the role of PRASA in supplying the drinking water at Vieques.

> **ATSDR Response**: We have modified text in Chapter 8, Section 8.1 to correct any inaccuracy regarding the current operators of the public water supply. We did not include detailed descriptions of the water supply system. We were concerned that it might detract from our evaluation of possible exposures from all water supplies, past and present.

Does the Vieques summary report adequately present and describe the limitations and uncertainty of assessing human exposure to bombing range-specific contaminants?

[Comment]

I believe that the report is not as clear as it should be, particularly from the point of view of a lay person. The limitations and uncertainty are adequately presented, for a person that carefully reads the report in its entirety. Just reading the summary report does not present the same picture.

> **ATSDR Response**: In the Report, we provided additional information regarding environmental data available for assessing any exposures associated with the military exercises on Vieques. We identified that those chemicals found in environmental samples were also found in explosive ordnance. Changes were made to the Report's Executive Summary and Chapters 1, 2, 3, 6, and 9.

Are independent studies utilized appropriately in the determination of potential health hazards?

[Comment]

Yes, but they are being given the same weight as other peer-reviewed studies.

> **ATSDR Response**: The principal consideration for independent studies is the importance of describing all the environmental and health data available for Vieques—even when some of the data were not peer reviewed. We considered hair data results for numerous metals. Some scientists believed these data were valid and drew conclusions from them. ATSDR described the limitations of these data in detail, pointing out the inability to distinguish between external contact and internal ingestion for most metals, except mercury. To this extent, ATSDR attempted to report fairly the available data and to provide insight into their value for health decisions. In our conclusions and recommendations, these data of questionable quality either were not used (e.g., metals in hair, except mercury) or were used qualitatively (e.g., arsenic in urine reported in a Webinar).

On the basis of ATSDR's re-evaluation of historical bombing activities in the Vieques summary report, has ATSDR reached the appropriate conclusions and recommendations?

[Comments]

Yes as to their quality, but I have the following comments regarding the presentation:

1. It is confusing that there are conclusions and recommendations at the end of each chapter and in Chapter 9, and they are different. For example, at the end of Chapter 5 there is a nine-row paragraph with recommendations, while in Chapter 9 these recommendations are expanded to ten items over one full page. Also, as another example of confusion, Chapter 5 is called Terrestrial Food-Chain Pathway in the text of the report while in Chapter 9 it is referred to as Local Produce and Livestock Pathway. A similar thing happens with Chapter 2.

   > **ATSDR Response**: To address this comment, we changed "Terrestrial Food-Chain Pathway" to "Local Produce and Livestock Pathway" in the Executive Summary and Chapter 5" The conclusions and recommendations in Chapter 2 are now consistent with Chapter 9.

[Comment]

2. Consider the first recommendation in Chapter 9 about Chapter 4 Health Outcome Data:

   Assess the feasibility of applying the SMART BRFSS methods for generating stable Vieques specific prevalence estimates on asthma, diabetes, hypertension, and other chronic diseases.

In Chapter 4 the complete Recommendations paragraph reads:

> At this time, ATSDR recommends performing additional analyses to quantify cancer and noncancer morbidity and mortality, assessment of primary and specialty health care needs, and alternative approaches for delivery of health services.

So, in Chapter 9 specific methods come up without any explanation as to what they are, why they are better or even needed at all.

> **ATSDR Response**: Assessing the feasibility of SMART to overcome the limitations of developing prevalence estimates in a small population should be included as a recommendation or next steps in chapter 9. We have made the recommendations in Chapter 4 consistent with the recommendations listed in Chapter 9. The language local level versus small population is interchangeable.

Comment]

In Chapter 9 some of the previous chapters have Summary and Conclusions while others only have Conclusions. There should be consistency on this to avoid further confusion.

> **ATSDR Response**: Revisions have been made so that the heading reads conclusions.

Select the appropriate category below:

List recommended changes or reasons for not recommending)

- Recommend ( )
- Recommend with Required Changes (X)
- Not Recommended ( )

[Comment]

Rewrite the Drinking Water Pathway chapter to better reflect the role of PRASA in supplying the drinking water at Vieques.

> **ATSDR Response**: We have modified text in Chapter 8, Section 8.1 to correct any inaccuracy regarding the current operators of the public water supply. We did not include detailed descriptions of the water supply system. We were concerned it would detract from our evaluation of possible exposures from all water supplies, past and present.

Additional Questions:

Are there any comments on ATSDR's peer review process?

[Comment]

None, except for Question 6 above.

Are there any other comments?

[Comment]

None.

Reviewer 4

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

[Comment] This reviewer recognizes and applauds the strong efforts done by the people and community leaders of Vieques and of PR to access the health status of its community. In addition, congratulates all the researchers that have contributed to the generation of scientific knowledge in this area. Overall, the re-evaluation done by ATSDR seems appropriate. This report supports the need for additional studies and public health interventions in Vieques, PR, as although some results are still not conclusive, evidence supports potential environmental exposures in this population, as well as health disparities as compared to the mainland of PR and the United States. Most studies have been included in the discussion, although additional efforts should be made to contact researchers whose results have not been published. This reviewer has highlighted several issues that merit consideration before this manuscript is published (see below).

ATSDR Response: We appreciate all the comments.

Has ATSDR adequately addressed the pathways of human exposure to bombing range-specific contaminants?

Please include specific comments on

Consumption of seafood from reefs near Vieques

[Comment] Chapter 2. The ATSDR concludes that children who consumed fish from the reefs near Vieques and those born to mothers who also had this consumption were at increased risk for several health conditions. Nonetheless, the report highlights that this conclusion about the risk of harmful effects to the fetus and to children is somewhat uncertain because a person's mercury response may vary by sex, genetics, health and nutritional status. It is the belief of this reviewer that, despite some limitations, the observed association between fish consumption in Vieques and health hazards in these population sub-groups is very relevant and should not be minimized. ATSDR should add to its recommendations in this area the need for an assessment of the health and nutritional status of children in Vieques and how these factors can influence the impact that fish consumption could have on the health of children in Vieques. Some information regarding nutritional status of adults and children in Vieques could be collected from the BRFSS and the Youth Risk Behavior Survey (YRBS) of PR.

ATSDR Response: Thank you for your comments.

Children and pregnant women are advised by the U.S. Food and Drug Administration (FDA) to avoid eating those fish with the potential for the highest level of mercury contamination (e.g., shark, swordfish, king mackerel or tilefish); to eat up to 12 ounces (two average meals) per week of a variety of fish and shellfish that are lower in mercury (e.g., canned light tuna, salmon, pollock, catfish); and check local advisories about the safety of fish caught in local lakes, rivers and coastal areas. Since fish are highly consumed in Vieques, we believe that fish consumption among this population should be addressed.

[Comment]

Table 2-2 (page 17): Efforts should be made to contact Dr. Caro and determine if the data came from dry or wet weight fish.

> **ATSDR Response:** Dr. Caro is deceased. The laboratory that conducted the fish analysis for her report has not responded to phone calls or e-mails. We have provided additional analysis to Dr. Caro's data in Chapter 2, Section 2.2.1.

[Comment]

Chapter 2. Given that the authors highlight lack of knowledge regarding the estimation of combined doses of exposure (from single and multiple pathways) regarding possible mixture effects for residents eating seafood, ATSDR should add to the recommendations of this chapter (and of the overall report) that risk from possible mixtures effects for residents eating seafood should be further studied.

> **ATSDR Response:** At this time, evaluation of possible mixtures effects from chemicals in fish is not possible because of limitations in the science. This topic is discussed in Chapter 2, Section 2.2.6.

[Comment]

Chapter 2.3.2. The list of recommendations on Chapter 2.3.2 could be more specific and describe in more detail some of the recommendations previously mentioned in chapter 2. In addition, the authors should add to the recommendations of this chapter "Collecting additional fish samples (within each family and by reef location) from Vieques."

> **ATSDR Response:** We provided additional information in Chapter 2 specifying the need to collect additional fish samples to allow analysis by species and location.

Use of biomonitoring tools to assess exposure to metals and other hazardous chemicals in blood, urine, or hair that are related to historical bombing exercises

[Comment] Chapter 3 (page 50). The authors highlight that the levels of inorganic arsenic in Viequenses urine were higher than those reported in the U.S. general population according to the NHANES survey. To facilitate the discussion in this section, I suggest adding a table with the values of metals observed in the general population of the US according to NHANES.

> **ATSDR Response:** In Tables 3A-3 and Table 3B-1, ATSDR has included data from NHANES showing the average concentration of metals in urine and blood.

[Comment]

Chapter 3.2 (page 50, fourth paragraph). To complement this first sentence, the authors should include a brief summary of the conclusions of the studies by Dr. Colón de Jorge and Dr. Ortiz-Roque.

> **ATSDR Response:** The conclusions from Dr. Colón de Jorge's and Dr. Ortiz Roque's studies are presented in the second, third, fifth, and sixth paragraphs in Chapter 3, Section.3.2. No changes were made in the Report.

[Comment] Chapter 3. Section 3.5.1 Conclusions: Section does not acknowledge that metals were also detected in feces. In addition, sentence 6 of this paragraph starts by saying *"Another study weakness…"* Given that this is the only weakness discussed, the sentence should start by saying "A study weakness…."

> **ATSDR Response:** ATSDR has included feces in the list of biological matrices where metals were detected and rephrased the discussion about study weakness.

[Comment] Section 3.5.2 (page 56). In the conclusions of this chapter, the authors recommend that additional biomonitoring studies should measure mercury levels in blood and hair of Viequenses; these studies should also consider other metals and substances in the assessment. The authors should stress in this paragraph why additional studies are needed, as presented evidence already suggests high mercury levels (and other metals) in hair and blood of Viequenses-suggesting a health hazard in this population.

> **ATSDR Response:** ATSDR has added additional information to the Report conclusions in Chapter 3. While Dr. Ortiz Roque found several women with elevated levels of mercury in hair, the PRDOH study did not show high mercury levels in the blood of 500 Viequenses. Some uncertainty therefore remains regarding whether high mercury exposure is prevalent on the island.

[Comment] Section 3.7.1. Summary of Human Biomonitoring, (page 61, third sentence): "These studies are briefly mentioned in the main text (not only in this appendix) for Chapter 3 and are described in more depth…" The word "depth" should be added to the sentence.

> **ATSDR Response:** ATSDR has reworded this sentence.

[Comment] Section 3.7.2.2. PRDOH Discussion Phase 1 (bottom of page 65-top of page 66)- Given that the authors mention that "At the total population level, the average concentration of some metals was above expected norms as established by Quest Laboratories but not above toxic levels as also established by Quest Laboratories. The PRDOH manuscript stated that this suggests the need for further investigation concerning the various risk factors, with particular emphasis on how smoking contributes to metal body burden." Thus, it is the recommendation of this reviewer that future studies should do a complete assessment of tobacco consumption of persons in Vieques. Although data presented in some of the analyzed reports does not suggest a higher prevalence of smoking in Vieques than in the rest of PR, this data should be analyzed in depth and included in this report. Given that it is of great relevance for various topics within this assessment, it should be included or recommended for inclusion in future studies in this population?

ATSDR Response: ATSDR agrees that future studies should include detailed information about tobacco use for study participants. Since PRDOH's 2006 study is confidential, ATSDR is unable to obtain the raw data. We are consequently unable to provide more detailed information about tobacco use in Vieques.

[Comment] Section 3.7.2.2 (page 66, line 5)- Regarding the following statement "PRDOH concludes that eating fish within 3 days of a test or smoking could partly explain some but not all of the elevated metal body burdens in participants.", the authors should add to the text a discussion of what other potential explanations does the PRDOH provide for this result.

ATSDR Response: ATSDR agrees and has added text to Chapter 3, Sections 3.7.2.2 and 3.7.4.

[Comment continued] The authors highlight in this appendix that PRDOH data show that "In over 90% of the population, detectable levels were found of at least one heavy metal. In more than 20% of the study participants, the levels of aluminum in blood, arsenic in urine, and nickel in hair were over the laboratory reference threshold. Geometric means for uranium in urine, mercury in blood, lead in blood, aluminum in blood, nickel in hair, and cadmium in urine were significantly higher than the geometric means from the 1999 NHANES survey." Nonetheless, the conclusions of chapter 3 recommend additional research in this area. A statement highlighting the reasons for these additional studies is warranted in the main conclusions/recommendations of this chapter.

ATSDR Response: ATSDR has added clarifying text in the Executive Summary for its recommendations about future biological sampling and in particular the need for an appropriate comparison group.

[Comment] Section 3.7.5 (page 70). According to the referenced manuscript, the correct sample size of the study was 500 participants (not n=499).

ATSDR Response: The draft PRDOH report uses both numbers as the sample size: 499 and 500. Which is the correct sample size is unclear. We will use 500.

[Comment] Section 3.7.7.1 (page 76). Results of Dr. Roque regarding the high levels of mercury in the hair of Viequense women as compared to those of women in the mainland of PR and the US should be highlighted as evidence in the main text. Particularly, given that evidence exists that mercury in hair of pregnant mothers is an indicator of disease risk in the fetus.

ATSDR Response: Dr. Ortiz Roque's findings are highlighted in the main text of Chapter 3 in statements such as these:

Chapter 3, Section 3.2. Dr. Ortiz Roque identified several residents with hair-mercury levels above 12 ppm—the level the National Research Council identified as causing a 5% increase in neurological effects in children who were exposed in utero (NRC 2000).

Chapter 3, Section 3.7.8.3. Dr. Ortiz Roque's identification of three residents with hair mercury levels above 12 ppm is an important finding.

[Comment] Section 3.7.8.3. Dr. Ortiz Roque's identification of three residents with hair mercury levels above 12 ppm is an important finding.

> **ATSDR Response:** ATSDR agrees that Dr. Ortiz Roque's findings are important. We have made this point several times in Chapter 3. In particular, biomonitoring results from Dr. Ortiz Roque showed that some Viequenses had elevated mercury in hair above the level identified by the National Academy of Sciences to cause harm in 5% of fetuses exposed *in utero*.

[Comment] Section 3.7.6.2. The manuscript mentions that the PRDOH will develop a protocol for the management of persons with suspected acute poisoning of heavy metals using CDC guidelines. What is the status of this protocol? Has it been already developed and implemented? The authors could contact the PRDOH and include this information as part of the manuscript.

> **ATSDR Response:** ATSDR has been unable to determine whether PRDOH has developed and implemented a blood lead survey of Viequense children.

[Comment] Section 3.7.6.3 (page 73). Table 3A-3 would be enriched by the inclusion of levels of heavy metals found in the U.S. population according to NHANES.

> **ATSDR Response:** As suggested, ATSDR has included data from NHANES in Tables 3A-3 and 3B-1.

[Comment] Section 3.7.8.2 (page 78, line 8). When discussing Dr. Ortiz-Roque's study, the authors say that the non-random participant selection might account for some confounding factor elevating the rates. Nonetheless, it should be highlighted that this procedure could also have reduced them.

> **ATSDR Response:** ATSDR agrees that a nonrandom survey could be a confounding factor that increases or decrease rates. We have made the suggested change in the text.

[Comment] Section 3.8.3 (page 94). Add reference for the following statement: "Several population studies of persons residing in areas with higher cadmium soil concentrations or with cadmium pollution have reported mean blood and urine cadmium levels as much as 10 times higher than control groups or representative U.S. data."

> **ATSDR Response:** The paragraph with this statement has been deleted from the report; and, the reader is referred to the 4th Report, which contains toxicological information about metals.

[Comment] Section 3.8.3 (page 95, first line)- Please include references regarding the impact that cadmium levels in blood or urine could have on human health.

> **ATSDR Response:** The paragraph with this statement has been deleted from the report; and, the reader is referred to the 4th Report, which contains toxicological information about metals.

[Comment] Chapter 4 Summary (page 101). The authors emphasize that "As a result of the small population, all studies suffer to some degree from a lack of statistical power and methodological limitations that make interpretation difficult. Despite these limitations, the studies are valuable for describing the health status of Viequenses. And in Vieques relative to the rest of Puerto Rico, the studies indicate elevations in the prevalence of chronic disease, cancer incidence and mortality, and infant mortality." This reviewer disagrees with the statement that interpretation of these studies is difficult. I suggest rephrasing this statement.

> **ATSDR Response:** Quantifying differences in rates of morbidity and mortality is statistically challenging in small populations. The limitations previously described also introduce additional uncertainty. Despite these limitations, the studies are valuable for describing the health status of Viequenses. Relative to the rest of the population in Puerto Rico, these studies indicate elevations in the prevalence of chronic disease, cancer incidence and mortality, and infant mortality in Vieques.

Consumption of food (produce, meat, dairy, eggs) grown on the island

[Comment] Chapter 5. We agree with the authors in that evidence shows that "Levels of cadmium in pigeon peas could be potentially harmful for preschool children who eat more than four 6-ounce portions of pigeon peas each week for several years; possibly resulting to health problems later in life."

> **ATSDR Response:** Thank you for your comment. Relevant text in Section 5.2.2 has been revised based on comments received.

Exposure to air, soil, and water on Vieques

[Comment] Section 6.2.1 (page 133, third paragraph). Regarding the Air PHA conclusions, the authors mention that the *"The Navy's ordnance exercises at the LIA did not pose a health hazard in the residential areas of Vieques."* This statement should be clarified and highlight that it is referring specifically to the hazard of residential areas specifically by air pollution (other hazards may still be possible through other pathways).

> **ATSDR Response:** The statement referenced summarizes the conclusions of our previous Air Public Health Assessment. The current report clarifies this issue (see Chapter 6).

[Comment] Section 6.2.1 (page 134, first bullet). The authors highlight that levels of contaminants in air were low, and not at levels that would be associated to disease risk. Regarding the Air PHA conclusions, the authors mention that the ***"****Wind-blown dust from the explosive-ordnance range did not and does not pose a health hazard to residents."* Comment should be more specific, as contaminants were measured in the air, and air quality was not associated to disease risk. This is of particular relevance given that cumulative exposure has not been evaluated.

> **ATSDR Response:** As there was no significant transport of airborne contaminants from the LIA to the residential areas of Vieques, there was no significant deposition to soils or subsequent leaching of contaminants from soil to groundwater. Consequently, the exposure

pathways for soil and groundwater contaminants (from military operations) are incomplete and there is no basis for assessing cumulative exposures for these pathways. The Report does discuss the issue of cumulative exposures (as chemical mixtures in fish consumption) in Chapter 2, Section 2.2.6 and in Chapter 9, Section 9.9.

[Comment] Section 6.2.3 (page 140). Regarding the following statement in the text: "In addition to the recent evaluation of BIP detonations, the Navy has proposed prescribed burning of LIA vegetation to access safely and remove remaining unexploded ordnance. In support of this proposal, the Navy has conducted additional air modeling to assess the potential effects of such prescribed burning (CH2MHill 2008a). Although the Air PHA did not address vegetation burning, it did address past operations of open burning/open detonation (OBOD) of excess or recovered ordnance. As the mass of ordnance involved in past OBOD events was small relative to the mass involved in then-ongoing Naval operations, the 2003 Air PHA found that air emissions from past OBOD events did not present a public health hazard to the residents of Vieques. A permit to allow LIA vegetation burning is pending before the U.S.EPA and the Puerto Rico Environmental Quality Board. If so requested by these agencies or by any concerned citizen, ATSDR will further evaluate this issue." Have any requests been done? Do we need to wait for a request to do this or is ATSDR recommending that it should be done anyway?

Besides the data presented on Chapter 8 (Drinking Water Pathway), have any effort be made to determine the effect of airborne contaminants to water sources?

ATSDR Response: Although ATSDR has not received a specific request to evaluate the pending air quality permit, Chapter 6 does include a summary of the air modeling and monitoring studies that support the permit application. Those studies indicate that vegetation burning in the LIA will not result in harmful inhalation exposures in the residential areas of Vieques and are in agreement with the results of the Air PHA. There is no public health basis for further evaluation of this issue. We have revised the Report by deleting the sentence indicating that ATSDR will further review this issue if so requested.

[Comment] Chapter 7 Summary (page 150). We agree with the authors in the "…need for continuing to restrict access to the LIA and to other potentially contaminated military areas until environmental assessment and remediation clear the way for unrestricted public access. To address remaining uncertainties about residential soil contamination issues, ATSDR recommends surface soil sampling in the island's residential areas." Particularly as some of the data evaluated is old (from the 1970's) and may not represent the reality of the soil today. Nonetheless, this summary paragraph of chapter 7 should include the recommendation of soil cleanup (as it does in the chapter-section 7.2.1).

ATSDR Response: Thank you for this comment. We reworded the relevant section of the Report, Chapter 7 Summary and in Chapter 9, Section 9.7.2, to clarify that we do recommend continuation of environmental assessment and remediation activities.

[Comment] Chapter 7 Section 7.2.1 (page 158). The authors mention that a limitation of the study by Garcia (2000) (study that collected soil samples at the LIA and in areas where people lived during 1999-2000) was that it was missing information on 1) the exact location, depth of sampling, and a 2) complete presentation of study results. Did the authors do an effort to contact Garcia and colleagues to clarify this missing information? This information is important in this assessment, as the authors are suggesting that Garcia's findings may be biased high (getting this information will clarify if this assumption is in fact correct).

> **ATSDR Response:** ATSDR has attempted to contact Dr. Garcia on two different occasions by e-mail but has not yet received a response. The authors reported only the highest and next-to-highest detections, so that would by definition high-bias the concentrations.

[Comment] Section 7.2.1 (page 159). Even though the authors conclude that there is no indication that protesters living in the LIA in 1999-2000 were exposed to harmful levels of surface soil contaminants, they mention that a limitation is that conclusions were based on a small number of samples (making the conclusion not valid if future/representative analyses showed something different). This is not consistent with their sentence in the Summary section of this chapter (page 149) that says that *"Sufficient data are available to conclude that people who lived on the LIA during the protests were not exposed to soil contaminants at levels high enough to cause adverse health effects."* Although at this point evidence does not support risk for this group, the limitation of small sample size should be included in the summary statement.

> **ATSDR Response**: The limitation mentioned in Chapter 7, Section 7.2.1 is a common limitation for any environmental characterization. Despite this limitation, the soil data collected for protesters living in the LIA were sufficient to characterize potential exposures during that time. Samples collected from the protester camp were designed to represent actual exposures to those living there. Samples collected from the LIA were collected from areas likely to have higher concentrations of contaminants. These samples, although limited in number, are reasonable to use as protective descriptors of exposures that might have occurred to protesters.

[Comment] *Section 7.2.4 (page 164, last 2 sentences). The authors mention that* "Yet detection of explosive residues in the background samples also suggested that all areas of the island, including the residential area, might have been affected by explosive compounds from past bombing activities. Although residual levels are low today, it is impossible to say what past levels were." The authors should highlight that although this cannot be corroborated at this point, these exposures may have had an impact in the past, this should be highlighted in the conclusions, as right now they are suggesting that residential exposure was likely minimal.

> **ATSDR Response:** No changes were made in the report. Although verification is impossible regarding past levels of explosives in residential areas, the modeling work described in Chapter 6 and the levels of residues in background areas on the land adjacent to the LIA do suggest that any past residential exposures were small.

[Comment] Chapter 8. As recommended by ATSDR, it is the opinion of this reviewer that additional studies of the pipelines, wells and rainwater collection systems are needed to confirm the safety of the drinking water consumption of Vieques. For groundwater, we agree with the authors in that current results do not exclude the possibility for other groundwater contamination caused by military and nonmilitary activities hydrogeologically connected to the groundwater that supplies water wells. Thus, supporting the need for additional research in this area.

> **ATSDR Response:** Thank you for the comment.

[Comment] Section 8.2.2 (page 172, line 4). The authors mention that "Even assuming the detections were present at the level in drinking water, the levels of explosives were too low to result in adverse effects (ATSDR, 2001)." What about cumulative exposure? Its possibility and potential harm should be acknowledged in the text.

> **ATSDR Response:** No significant transport of airborne contaminants occurred from the LIA to the residential areas of Vieques. No significant deposition occurred in soils. Consequently, the exposure pathways for air and soil were incomplete; thus assessment of cumulative exposures for these pathways was without basis. For drinking water, the health guideline values used to compare with the possibly detected levels of explosives in this section were chronic guidelines. They would have assumed regular exposure of more than 1 year. But the historical data were extremely limited. Using such data to draw definitive public health conclusions about past exposures, or about past cumulative exposures, is impossible. The Report does discuss the issue of cumulative exposures (as chemical mixtures in fish consumption) in Chapter 2, Section 2.2.6 and in Chapter 9, Section 9.9.

[Comment] Section 8.4. Given that several contaminants were found at levels that would make groundwater unsuitable for consumption, the need for further studies and cleanup of this sources should be highlighted in the summary and recommendations sections of this chapter, as it has been done within the chapter.

> **ATSDR Response:** We added recommendations that environmental assessment and cleanup of groundwater affected by military operations continue to Chapter 8, Section 8.4.2 and Chapter 9, Section 9.8.2 of the Report.

Does the Vieques summary report adequately present and describe the limitations and uncertainty of assessing human exposure to bombing range-specific contaminants?

[Comment] Overall, strengths and limitations of studies seem appropriately discussed in the report. Besides the recommendations already provided in this regard, additional specific recommendations are provided below.

Chapter 3 (page 81). Given the relationship between metal toxicities and various diseases and health conditions, the report should also include recommendations for additional studies of the effect of metal toxicities to: cardiac conditions, cardiovascular, emotional disturbances, violence, poor absorption and cancer.

> **ATSDR Response:** Until more information is available that shows contamination of the environment with specific metals or explosive compounds and exposure of Viequenses,

additional recommendations are not warranted to study the effects of metals on various health conditions.

[Comment] Chapter 4, Section 4.1. The correct term is the "Puerto Rico Central Cancer Registry (PRCCR)," not the Comprehensive Cancer Registry (PCCPR)

ATSDR Response: We have corrected Chapter 4, Section 4.1 to reflect the Puerto Rico Central Cancer Registry.

[Comment] Chapter 4. When describing the PR Cancer Registry, the following statement/reference should be added to the text:

"In the year 2003, a CDC audit concluded that 95.3% of all cancer cases diagnosed or treated in hospital facilities in PR were appropriately reported to the PRCCR; a result comparable to the US median (95%)."

REFERENCE: ORC MacroSM. *National Program of Cancer Registries, Technical Assistance and Audit Puerto Rico Central Cancer Registry 2000, Case Completeness and Data Quality Audit. Centers for Disease Control and Prevention.* Department of Health and Human Services; 2003. pp. 1–32.

ATSDR Response: The statement was added to the Report text as the closing statement in the paragraph below:

The data reported by the RCCPR have several strengths. Cancer registries typically represent the best population-based dataset for any chronic health condition. Most cancer cases are captured by registries due to legal reporting requirements, redundancies in the reporting system (i.e. reporting by labs, clinics, hospitals, and specific oncologists), and the clinical course of most cancers that requires substantial follow up and repeated visits. The analysis of cancer registry data should then represent the most accurate assessment of cancer incidence in Vieques. CDC has continuously funded the cancer registry through a cooperative agreement since 1998 and the cancer registry has steadily improved its data accuracy. Finally, "in the year 2003, a CDC review concluded that 95.3% of all cancer cases diagnosed or treated in hospital facilities in PR were appropriately reported to the PRCCR; a result comparable to the US median (95%)."

[Comment] Section 4.1 (page 103). Although not mentioned, another limitation of the BRFSS is that it is based on self-reported information. Nonetheless, given that the National Health and Nutrition Examination Survey (NHANES) of the US does not collect data for PR, the BRFSS is the best available data of population-based morbidity and health behaviors in PR. In order to generate consistent population-based data of the health status of people living in PR, efforts should be made to include PR (and Vieques) in the US NHANES survey. ATSDR could help in these efforts.

> **ATSDR Response:** NHANES is not intended to provide national prevalence estimates. BRFSS would thus continue as a better population-based data option for the health status of PR residents.

[Comment] Section 4.2.1 (page 105). The report highlights that all cancer cases in Vieques were age-confirmed, an activity that could not be done with all cancer cases in PR, where if a case did not have a known age, it was not included in any rate calculation. The authors suggest that this could have inflated standardized incidence ratios. Is there indication on the PRCCR reports of the percent of cases excluded from analyses from the PR mainland due to this reasons? This could give an idea if the potential for bias is small or high. If the reports do not specify, this information can be obtained by contacting the PRCCR and Dr. Nayda Figueroa. Despite this limitation, mortality rates would not be affected by this, and in fact they show higher mortality from certain cancer types in Vieques as compared to PR. This should be given higher relevance in the report. In addition, results from this analysis could be better described in tables/graphs in order to give the reader a sense of the excess risk observed in Vieques as compared to PR.

> **ATSDR Response:** We contacted Dr. Figueroa to obtain information on the percentage of cases in PR that were excluded from analyses because of the lack of age confirmatory data. We have not heard back from Dr. Figueroa, and therefore have nothing to add to this response at this time. We are continuing to follow up.
>
> The magnitude of the combined effect of excluding cases from Puerto Rico and actively seeking out cases in Vieques and not in Puerto Rico would make the SIR higher than if the limitations mentioned were not present. The magnitude of this bias is unclear—it may or may not change the overall conclusions. We agree that mortality for certain cancer types is higher in Vieques than in Puerto Rico. Although mortality is an important measure of health status, we believe that disease incidence is a better measure than is mortality for assessing whether military activities affected Viequenses' health.

[Comment] Section 4.2.2 (Page 105). The authors say that the demographics in 2 of the 4 communities studied by Lopez and Carrosquillo (2002) in the study appear unusual. On what basis the authors conclude this and why is this a limitation of the study? The demographics of Vieques are in fact different from those of PR, a reference from the Census that supports this statement should be included.

> **ATSDR Response:** A review of the 1990 and 2000 census data showed that the selected sample population was older than the population in Vieques. Also, only persons ages 5–25 were selected from Lujan, and only older persons ages 59 –70 were selected from Puerto Rico Reconstruction Administration PRRA. The percentage of people in the sample population who were 60 years of age or older appears to be higher than the percentage of people in that same age category based on data from the 1990–2000 census report. This is not a limitation, but an inconsistency that we observed.

[Comment] Table 4.1 could be strengthened by including in the table the percent of persons that were affected with each of the health conditions (Lopez and Carrosquillo 2002).

ATSDR Response: The percent of persons affected was added to Table 4.1 as suggested.

[Comment] Section 4.2.4 (page 107). A better description of the results obtained in the study by Roque (2002) could be included in this section. On this page, the following statement should be highlighted as a strength: *"Typically, mortality data are population-based, with near universal coverage, and are less prone to bias."*

ATSDR Response: Our statements about the strengths of mortality data were intended to apply for both the cancer registry and for Dr. Ortiz Roque. We modified the paragraph to make this point clearer. Mortality data reported by RCCPR and Ortiz Roque may also provide meaningful insight into the health status of Viequenses and have several strengths. Typically, mortality data are population-based, with near universal coverage, and are less prone to bias. Analyses of mortality patterns in a population can be useful for hypothesis generation. But using these data to quantify potential relationships in exposure-disease relationships has limitations. Many potential confounding variables are not susceptible to assessment (e.g., access to care, lifestyle factors, and dietary habits).

[Comment] Section 4.2.2 (page 108). Was an effort made to contact the study researchers of the Lopez Carosquillo study and get information of the confidence intervals for the risk ratio estimates to identify differences? Despite the lack of confidence intervals, the magnitude of the excess risk observed in this study should be considered a strength that supports the greater disease burden in Vieques as compared to PR.

ATSDR Response: We did not attempt to contact researchers to obtain confidence intervals for this review. We relied on the reports as written and commented on strengths and weaknesses of the methods used to produce results.

[Comment] Section 4.2.4 (page 108, line 15)-The authors say that "Finally, whether the Puerto Rico disease prevalence data was used as a reference from the PRCMS or some other source is unclear—the PRCMS was based on systematic self-reporting mechanisms (e.g. , the Behavioral Risk Factor Surveillance System)." This statement is not clear to this reviewer. The PRCMS data is based on the Continuous survey of PR (See page 15 of the Lopez and Carosqullo study, 2002).

ATSDR Response: This statement was deleted. At the time of our initial draft of this report, we did not have a copy of the 1994 Annual Survey.

[Comment] Section 4.3 Findings (page 108). Please add to this section information on the PRCCR report of 2009, as it does not seem to have been addressed.

ATSDR Response: The findings reported in 5-year intervals (1990–1994, 1995–1999, 2000–2004) are from the 2009 report. We added tables to make this more apparent.

[Comment] Section 4.3 (page 109). Authors suggest that the fact that 36% of participants from the Lopez and Carrosquillo (2002) study were unemployed may have implications for lack of insurance coverage and access to appropriate medical care, thus affecting morbidity and mortality data. Even though this may be in part true, the authors should acknowledge that approximately 90% of the population of PR are insured, and close to 40% of the population of PR are covered by *Reforma* (the public, government funded health insurance program). Thus, most unemployed people will in fact have access to health care through *Reforma*. Nonetheless, physical barriers (such as lack of proximity to health care providers) does exist for residents of Vieques.

> **ATSDR Response:** Of the participants in the Lopez and Carrosquillo (2002) study, 36% were unemployed. Although these participants may have access to health care through the government funded health program, their implications may be due to the lack of access to specialty care, thus affecting morbidity and mortality data.

[Comment] Section 4.4.2 (page 110). Contrary to what is expressed by the authors "The limitations associated with these analyses, particularly the methodological concerns discussed in this report, introduce considerable uncertainty and make interpretation difficult. These findings can nonetheless serve as a guide for future investigations of Viequenses health status." This reviewer believes that the data provided suggests evidence of a higher burden of chronic disease in the population of Vieques as compared to PR. The recommendations for the section of "Health Outcomes" seem vague. What are the specific recommendations in this area? There is enough evidence to support higher cancer incidence and particularly mortality among people residing in Vieques as compared to PR. What are the specific recommendations regarding future studies in this area? Also, additional future studies of chronic disease prevalence in Vieques as compared to PR should be added to the list of recommendations in this section.

> **ATSDR Response:** We agree that the health outcome data suggest a higher burden of disease in the population of Vieques as compared with Puerto Rico. But we also believe that the limitations in the available data reduce the strength of these conclusions. The limitations include the completeness of the Registry for much of the period of analysis and the self-reported data from the symptom prevalence survey. We believe that the next steps should focus on studies that better define exposure and that better characterize the occurrence of cancer and noncancer morbidity and mortality. ATSDR plans to consult with the community in Vieques, scientists in Puerto Rico, public health officials, and other external stakeholders to determine recommended, specific studies.

[Comment] Chapter 6. Page 131 (second paragraph). Could the air-sampling studies performed in the 1970's by the Navy be biased given that they were not corroborated or validated by an independent group? Is there any way to validate this data?

> **ATSDR Response:** The 2003 Air PHA included a comprehensive review of historic data, including a determination of their utility as a basis for public health determinations. The Air PHA determined an adequately *post facto* data quality assessment was impossible. We consequently developed an air modeling study to assess historic exposures. The results of the air modeling study are consistent with all of the air monitoring studies and collectively provide an adequate basis for the public health conclusions.

Are independent studies utilized appropriately in the determination of potential health hazards?

[Comment] Overall, independent studies have been used appropriately in the determination of health hazards. Most studies have been included in the discussion, although additional efforts should be made to contact researchers whose results have not been published. In addition, as it has been already mentioned in this evaluation, additional efforts should be made to get specific unavailable information from some of these studies, as it is very relevant for a complete assessment. Also, as previously stated, results from the section of Health Outcomes seem strong, and should be acknowledged as so in that Chapter. Additional recommendations are described below.

Even though on section 2.5.1 (page 34) the authors say that "By collecting only larger species, the average concentrations might have been biased high, which might have resulted in a mercury overestimate" , they later says (page 35) that the "School of environmental matters collected 52 fish of varying sizes.." These statements seem inconsistent, please clarify.

> **ATSDR Response:** Chapter 2 discusses two fish sampling plans, one from ATSDR and the other from Dr. Caro. ATSDR attempted to capture larger fish because larger fish tend to have higher contaminant concentrations. ATSDR's sample of various fish species might therefore show high-biased mercury levels. We intended this bias so that ATSDR would be sure to sample fish with higher contaminant levels. Dr. Caro reported that she could not find an association between mercury content and fish size. She attributed this lack of association to the predominance of smaller fish in her study. We provided additional information about Dr. Caro and ATSDR's fish data in Chapter 2, Sections 2.2.1 and 2.2.2.

[Comment] Section 2.5.6 (page 38). Authors mention that "Table C1 in Appendix C of U.S.EPA (2001a) includes a complete summary of all comparisons between locations, parametric and nonparametric, for all species." For the convenience of the readers, please consider including this table as an appendix to this manuscript.

> **ATSDR Response:** As requested, Table C1 from U.S.EPA's analytical report of ATSDR's 2001 fish sample has been added to the Report, Chapter 2, Section 2.5.6.

[Comment] Chapter 4. PRCCR data and the Lopez Carrosquillo study could be further discussed in this chapter (see previous comments). In addition, other references cited in this paper by Lopez and Carrosquillo (2002) seem relevant to the assessment in discussion, and should be considered for inclusion in this report.

> **ATSDR Response** The references mentioned in the Lopez and Carrosquillo paper did not provide any additional information on morbidity and mortality other than what we obtained previously from other reports.

Chapter 4. The 2009 report of the PRCCR, which evaluated cancer incidence and mortality from 1990–2004, is not summarized in the Appendix of this manuscript. Please include.

ATSDR Response: We added a summary of the 2009 PRCCR report to Appendix A.

[Comment] The study by Dr. Carlos Rodríguez Sierra regarding arsenic levels in people of Vieques (page 272) is very relevant for biomonitoring. Further efforts should be made by the authors to contact Dr. Rodríguez Sierra and get a copy of his results for further discussion in this report.

ATSDR Response: On September 23, 2010, Dr. Rodríguez Sierra responded to our request for additional information about his arsenic studies with this statement:

"Regarding the results of arsenic in Vieques, we just submitted this work as a research manuscript to a journal to be evaluated for publication (waiting time is 6-10 weeks)."

If the study is accepted for publication, it should be available in 2011. Dr. Rodríguez Sierra has repeatedly declined to share his data with ATSDR—that he wishes to publish the data first is understandable. Until his data are available, ATSDR will use the results he presented in his Webinar for qualitative purposes only.

On the basis of ATSDR's –re-evaluation of historical bombing activities in the Vieques summary report, has ATSDR reached the appropriate conclusions and recommendations?

[Comment] *Despite some limitations characteristic of research studies, previous research suggests a high burden of environmental health risks and of chronic conditions in the Viequense population. This reviewer overall agrees with recommendations/conclusions made in Chapter 9 of this manuscript. Nonetheless, specific suggestions are described below.*

Fish pathway:

Given that this manuscript shows potential health risks associated with the consumption of large amounts of fish in Vieques, this reviewer agrees with the proposed recommendations of additional conclusive studies in this area. These future studies should consider fishes of different sizes, different classes of fish within the same family species and from different reef locations.

ATSDR Response: We added the concept of looking at fish species and locations to the recommendation for an additional fish study. See Chapters 2 and 9.

[Comment]

Biomonitoring:

Increased blood levels of mercury in blood and hair of Viequenses has already been documented. Given that some limitations have been discussed in the text regarding this data, the authors should clarify in the recommendations of this chapter (Chapter 9) why they are suggesting additional studies.

ATSDR Response: We have recommended that a survey of Vieques residents be conducted to determine the types, frequency, and quantity of fish consumed. The results of this survey could be used to conduct additional risk assessments and statistical analyses to validate our concerns about mercury in Vieques reef fish. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation

We have recommended that if individual Viequenses remain concerned about exposure to mercury, cadmium, other metals, or metalloids, they should consult their healthcare provider to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis.

[Comment]

Health Outcome Data

Increased burden of chronic diseases, cancer incidence and cancer mortality are documented in Vieques as compared to PR. The authors suggest that the confidence intervals are too wide. To what study are they making reference when doing this comment?

ATSDR Response: We are referring to the last line of paragraph 2 on page 56 of the 2009 Cancer Incidence and Mortality report, which refers to low precision in the confidence intervals. We added language to clarify our reference to cancer incidence and mortality in Chapter 9, Section 9.4.1. The revised response refers to cancer incidence and mortality**.** Uncertainty is also evident in the wide confidence intervals reported indicating imprecise estimates of cancer incidence and mortality ratios in Vieques relative to the rest of Puerto Rico (RCCPR 2009).

[Comment]

Section 9.4.2 (page 191, 4th recommendation). Why do they suggest point 4?? The data already provide evidence of increased disease risk in this population. Please provide more specific recommendations of the reasons for future studies in this area, and the suggested qualities/focus that these studies should have.

ATSDR Response: Although the data suggest increased prevalence of chronic diseases, we believe the findings contain considerable uncertainty. The conclusions for the prevalence of noncancer chronic diseases are based solely on one report. We believe that the next steps should focus on studies that better define exposure and that better characterize the occurrence of cancer and noncancer morbidity and mortality.

[Comment]

Local Produce and local Livestock Pathway

Given that evidence suggests potential contamination of foods (i.e. pigeon peas), potential for uptake of metals from soil into local food crops, and lack of definite data on contamination of edible portions of produce and livestock, this reviewer agrees with the recommendation of further sampling and research in this area. The splitting of samples between labs for further validation of results is an important suggestion.

ATSDR Response: Thank you for your comment.

[Comment]

Air Pathway:

Is there any way to confirm the U.S. Navy records of the types and amounts of ordnance used at the training range? Fluctuations in this records could impact the models developed to access population exposure

ATSDR Response: The 2003 Air PHA included a comprehensive review of the Navy's ordnance usage data and metals and explosive by-products emissions estimates that ATSDR derived from them. While there is no way to provide an ordnance usage estimate independent of naval records it should be noted that the Navy does not keep such records for environmental assessment purposes. The Navy maintains ordnance usage data for the purpose of monitoring training activities and ultimately because they must replace expended ordnance. Consequently, there is little rationale for the Navy to underestimate ordnance usage.

[Comment]

The report concludes no potential exposure to residential areas and thus, no further research in this area. Given that this reviewer is not an expert in Air pathways, the feedback of another reviewer in this area is recommended.

ATSDR Response: Comment noted.

[Comment]

Soil Pathway:

The results presented in this chapter suggest that contaminant levels at the LIA may have in the past been high, and are potentially high in the present, and thus may represent a harm for human exposure. Thus, this reviewer agrees with the need of future studies in this area. Validation of samples between laboratories should be done during these efforts.

ATSDR Response: Thank you for your comment.

[Comment]

Drinking Water Pathway:

I agree with the recommendation of additional research to further sample drinking water in Vieques to determine the safety of its consumption.

> **ATSDR Response:** Thank you for your comment.

[Comment]

Section 9.9- Final Summary

The authors suggest the need for a well-conceived and well-conducted biomonitoring study. They should further elaborate on the proposed characteristics for this study, including that it should have the capacity to study mixtures and cumulative exposures and their impact on human health in Vieques.

> **ATSDR Response:** In this type of document, elaboration is not appropriate regarding the study design of any future biomonitoring study in Vieques. A more appropriate approach is first to gather buy-in from scientists and health professionals who would be interested in such a study. After identifying such a group or groups, much discussion would be needed to determine the metals and other compounds that could be monitored and that could provide insight into whether residents are being exposed to contaminants from past military exercises. Adding mixtures to such a study would require a great deal more thought and insight. Many reviewers commented that one failing of the previous studies and work on Vieques was the inability to relate contaminants to bombs and munitions. Thus identifying which metals are military exercise-related is important, as is whether a pathway of exposure can be identified that warrants a biomonitoring study. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation. The Report does discuss the issue of cumulative exposures (as chemical mixtures in fish consumption) in Chapter 2, Section 2.2.6 and in Chapter 9, Section 9.9. No change was made in the Report.

Select the appropriate category below:

List recommended changes or reasons for not recommending)

- Recommend ( )
- Recommend with Required Changes (X)
- Not Recommended ( )

Additional Questions:

Are there any comments on ATSDR's peer review process?

[Comment] This report acknowledges the commitment of ATSDR in its continuing involvement in Vieques and in continuing to work with local community and health and environmental officials to implement the recommendations of this report. This reviewer thinks that this commitment is essential, not only in expertise, but also in other recourses, such as financial matters (as a future, well-rounded study will be costly).

ATSDR Response: Thank you for your comment.

Are there any other comments?

[Comment] The following terms (and others) should be abbreviated on their first use in the text, then the abbreviation should be used consistently throughout the document.

Live impact area (LIA)

Puerto Rico Department of Health (PRDOH)

National Research Council (NRC)

Nuclear regulatory commission (NCR)

Eastern Maneuver Area (EMA)

National Health and Nutrition Examination Survey (NHANES)

ATSDR Response: Thank you for your comment. Changes have been made as appropriate.

[Comment] Section 2.2.1 (page 16). The correct term is Parguera (not Parquera), an area located at the west of Puerto Rico's mainland.

ATSDR Response: We have corrected the spelling.

[Comment] Section 3.3 (page 52). A description of the NHANES survey is done on page 52, although the study is mentioned previously in the text. Its description should come earlier.

ATSDR Response: The use of NHANES has been corrected.

[Comment] Section 3.4.1 (page 55). When the authors suggest that before hair analysis could become a valid diagnostic tool for any particular substance, research needed to *"*to"*…4) learn more about organic compounds in hair."* Please specify what kind of knowledge is suggested in this area.

ATSDR Response: This type of discussion is beyond the scope of this report.

[Comment] Section 3.4.2 (page 55). Add reference for the report of the 2005 German Federal Environment Agency report.

ATSDR Response: The reference is included in the reference section to Chapter 3 and in the text (see GFEA 2005 in Section 3.4.2). No change in the report is needed.

[Comment] *The results of this manuscript should be discussed with researchers, community leaders, the Department of Health of Puerto Rico and other people interested in the health of Vieques for further evaluation and recommendations. Multidisciplinary and collaborative efforts should be developed to further study and improve the health of this community.*

ATSDR Response: Thank you for your comment. ATSDR plans to work with our partners to discuss the implementation of the Report's recommendations.

Reviewer 5

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

> **ATSDR Note**: Peer Reviewer 5 did not answer the six questions that were sent, but rather provided comments in the format below. ATSDR has provided responses to the comments after each comment where appropriate.

[Comment]

Critique of Air Pathway Analysis:

1. Failure to Collect and Manage Air Pollution Data: ATSDR concluded that air pollution data was mismanaged and therefore provides unreliable information regarding the magnitude and distribution of air contaminants during high activity periods on the Live Impact Area.

The Navy's 1979 Environmental Impact Statement (EIS) for continued use of the bombing range documents results from a 2-month air sampling program (TAMS 1979 provided no information on the sampling methods used or on data quality. No documentation can be found describing the sampling methods used or the quality assurance measures taken.

> **ATSDR Response**: Quality of data used in the assessment: The Air PHA included a comprehensive review of all of the available air monitoring data, modeling studies, and meteorological data. While historic data and data reports do not include all of the data quality assessments that are required in current practice, this does not preclude the use of such historic data. Such data, however, should be interpreted with caution. The Air PHA used the historic data in conjunction with recent monitoring data and modeling studies. Although in isolation each of these information sources includes aspects of uncertainty, collectively they provide a comprehensive assessment of the potential airborne exposures in the residential areas of Vieques.

[Comment]

Exposures to Releases from Military Training Exercises Using "Live" Bombs

Averaging Periods: A problem is identified with respect to air pollution modeling. Pollution levels were averaged over two periods, one year and 24 hours. This may be relevant for chronic respiratory disease prevalence, however it neglects the potential for short term bursts of pollution to exacerbate existing respiratory problems such as asthma, allergies and chronic bronchitis. Averaging pollution over 24 hours could make temporal bursts caused by periodic explosions disappear, while these episodes may be quite relevant to estimating respiratory distress among the sensitive. This is especially problematic for young children who have immature and narrower airways than adults.

> **ATSDR Response**: The reviewer is correct in noting that there was no assessment of PM10 concentrations for time periods fewer than 24 hours, and that military operations could have resulted in higher PM10 concentrations for time periods of fewer than 24 hours. The

U.S.EPA and the California Air Review Board have established recommended procedures for converting between various air loading averaging periods (USEPA 1992; CA ARB 1994). The recommended conversion to estimate a 1-hour averaging period from a 24-hour period is to multiply the 24-hr value by 2.5 (Figure H.1/ Appendix H, CA ARB, 1994).

Using the upper-bound assumptions for contaminant emissions, daily ordnance use, and meteorological transport conditions, the ATSDR Air PHA estimated that "live bombs caused the 24-hour average PM10 concentrations in residential areas to increase by 10.2 $\mu g/m^3$ " (page 40, Air PHA). Using the above conversion procedure, the maximum 1-hour increase in PM10 would be 25.5 $\mu g/m^3$ (10.2 $\mu g/m^3$ x 2.5). Adding the calculated maximum 1-hour increase of 25.5 $\mu g/m^3$ to the maximum 24 hour measured PM10 concentration (94 $\mu g/m^3$; Isabel Segunda, page C-9, Air PHA) results in a maximum short-term air PM10 concentration of 119.5 $\mu g/m^3$. This value is below the 24-hour PM10 standard of 150 $\mu g/m^3$ and unlikely to result in respiratory distress or other adverse health effects. As shorter averaging periods do not change the health determination, no changes to document have been made as a result of this comment.

[Comment]

2. Particle Size: Low diameter particles (less than 2.5 microns in size) were not measured. These fine and ultrafine particles may stay suspended for longer periods of time, move longer distances and may become more deeply embedded in the lungs.

   ATSDR Response: Chapter 6, Section 6.2.2 (of the summary document explicitly addressed the issue of PM2.5. No further revisions are necessary.

3. Wind Blown Dust: It was concluded that wind-blown dust from the LIA on days when bombing did not take place is not a health hazard.

   ATSDR Response: Thank you for your comment.

4. Total Suspended Particulates (TSP) are primarily a measure of larger diameter airborne particles that would likely settle out in close proximity to the location of their generation. Particles of smaller diameter—PM 2.5 microns in diameter and smaller—are far more likely to remain in the atmosphere for longer periods of time and travel longer distances before deposition. These finer particles were not measured by ATSDR, the Navy or EPA. These particles may also act as nuclei for other hazardous VOC's.

   ATSDR Response: Chapter 6, Section 6.2.2 of the summary document explicitly addressed the issue of PM2.5. No further revisions are necessary.

[Comment]

5. *Chaff:* Chaff fibers typically are 25 microns (µm) thick and between 1 and 2 centimeters long. Chaff fibers are visible to the human eye and have the appearance of short, very fine, hair-like fibers.

a. ATSDR estimates that 266,000 pounds/year of chaff may have been deliberately dropped over or near Vieques.

b. Ground level concentrations were never monitored by the Navy or other government authorities.

 ATSDR Response – Chaff: Regarding the issue of chaff emissions and exposures, the Air PHA explicitly addressed the issue of chaff emissions and potential exposures. Using health protective assumptions regarding emissions, exposure, and uptake, the Air PHA concluded that "…the usage of chaff at Vieques does not pose a public health hazard, whether the chaff particles are inhaled or deposited in the mouth and swallowed." The Report summarizes this finding regarding chaff and other air contaminants in Chapter 6, Section 6.2.1. No further revisions or assessment are necessary.

[Comment]

Critique of Drinking Water Analysis

[Comment]

1. Chemicals released to the environment of the island of Vieques by the U.S. Navy may have resulted in human exposure and associated health threats that may be dose dependent. A 35 year period between 1943 and 1978 is the most likely time when the island's population was exposed via drinking water to possible hazardous compounds released to the environment by the Navy. Yet this is also a period when government testing of environmental quality on the island was minimal.

 ATSDR Response: The current conclusion that a lack of historical data prevents a definitive conclusion about distant-past exposures to drinking water from wells is consistent with this comment; therefore, no changes have been made. We believe, however, it is important to indicate what limited past information and data do tell us about the relative likelihood of past exposures through the drinking water pathway. As discussed in Chapter 1, Section 1.2, ordnance training on Vieques was not scaled up until the 1970s, particularly after 1975, when training on the island of Culebra was discontinued. Therefore, it is not unreasonable to presume that contamination of public supply wells or cisterns was very unlikely before the mid-1970s.

2. [Comment] The poor history and quality of water testing makes it difficult to precisely reconstruct a history of exposure. Water supplies were not routinely tested for chemicals that were released to the environment by the Navy.

ATSDR Response: The problem of limited historical environmental monitoring data is not specific to Vieques. It is common at many sites that operated in the past. ATSDR evaluates public health effects from potential past exposures in such situations by reviewing available contaminant fate and transport data and, using professional judgment, making assumptions about past exposure and identifying areas of uncertainty.

3. [Comment] The most probable routes of exposure to chemicals released to the Vieques environment by the Navy include: 1) contamination of drinking water wells from airborne chemicals that drifted and settled in the watersheds surrounding municipal wells; 2) contamination of cisterns from airborne chemicals that drifted and settled into the tanks; 3) contamination from Naval use of pesticides and herbicides; 4) contamination from airborne and surface fuel releases; 5) waste disposal practices.

   ATSDR Response: Thank you for this comment. ATSDR's drinking water PHA and Chapter 8 of this report discuss contamination of drinking water wells and cisterns (rainwater collection systems). Potential sources of contamination, including use of pesticides or herbicides, releases of fuels, and waste disposal practices, are evaluated by evaluating levels of associated contaminants in air, soil, or drinking water, as was done in past ATSDR PHAs and this report.

4. [Comment] Most reported studies are not peer reviewed, remain unpublished and are often based upon sampling designs and exceptionally small sample sizes (ranging between 1-12 samples). Degradation products were not tested or reported.

   ATSDR Response: ATSDR summarized the findings, strengths, and limitations of the reviewed studies in Appendix A of the Report. ATSDR was requested to review all available studies and data related to potential exposures at Vieques. While many of the studies were limited, they added to the body of knowledge about Vieques environmental exposures.

5. [Comment] Since the ATSDR drinking water study was completed prior to the air study the conclusions of this report are not conclusive. The most plausible pathway for drinking water contamination resulting from Navy activity on the islands is from airborne chemicals having settled in drinking water systems.

   ATSDR Response: As described in Chapter 6 and detailed in ATSDR's Air Pathway Public Health Assessment (2003), evaluation of the air pathway suggested that no substantial levels of atmospheric contamination had reached the residential area of Vieques. ATSDR was unable to evaluate directly the potential for exposures from cistern water as no cistern water data are available.

6. [Comment] These studies do not provide a reasonable estimate of the drinking water contamination that may have occurred prior to the completion of the municipal water supply line from the main island of Puerto Rico in 1978.

   ATSDR Response: As concluded in Chapter 8, Section 8.4.1 and Chapter 9, Section 9.8.1, ATSDR recognizes that the 1978 data are insufficient to make public health conclusions about exposures long past. But as detailed in Chapters 6 and 8, consideration of groundwater flow patterns, air modeling studies, actual bombing patterns, and recent sampling results suggest that past exposures from drinking water were not high.

7. [Comment] The EPA studies cited did not test for pesticides and herbicides. Also an analysis of military use of pesticides and herbicides not been conducted or presented.

   ATSDR Response: The Report does not consider pesticides and herbicides. As discussed in ATSDR's Drinking Water Pathway PHA (2001), 1995 sampling had shown no detections of a wide range of pesticides and herbicides, indicating that drinking water supplies had not been contaminated at any location by pesticides or herbicides. Pesticides and herbicides were not analyzed in many of the soil sampling events. Soil sampling at the NASD and recent EMA sampling related to remediation activities have found a few detections of DDT and its breakdown products. In all but one specific location, these detections were far below health-based comparison values; one location had detections higher than comparison values. ATSDR's recommendation to restrict the LIA and other potentially contaminated military areas and continue environmental assessment and remediation activities will protect the public from any harmful exposures to pesticides and herbicides remaining from military activities.

8. [Comment] It was reported the presence of RDX (0.04 ppb) and Tetryl (0.05) in the drinking water supplies of Isabel Segunda (0.5 ppb) and RDX (0.04 ppb) in the drinking water of Esperanza in May of 1978, referencing a Naval Surface Weapons Center report (Hoffsommer and Glover 1978; Lai 1978).

   ATSDR Response: ATSDR discussed these findings in Chapter 8, Sections 8.2.2 and 8.3.1.2 of the Report.

9. [Comment] The studies interpreted by ATSDR do not demonstrate the absence of health threats associated with naval activities. Instead, they demonstrate the absence of proper testing of the community's drinking water supplies at a time in its history when it was most vulnerable.

   ATSDR Response: As concluded in Chapter 8, Section 8.4.1 and Chapter 9, Section 9.8.1, ATSDR recognizes that the 1978 data are insufficient to make public health conclusions about distant past exposures.

Critique of Soil Analysis:

1. [Comment] Failure to Collect and Manage Soil Contamination Data: The Navy consistently failed to collect data on soil contamination associated with training and operations. The absence of these data prevented the understanding when and where possible soil contamination might have posed a public health threat. This could occur from particles exploding into the atmosphere, drifting along the island into the breathing zone of inhabitants, settling on soils, infiltrating water supplies, being absorbed by plants, some of which might have been consumed by animals, in turn consumed by humans. By failing to monitor pollution air pollution, patterns

of deposition to soil and other sediments, this in turn prevented an understanding of possible food chain dynamics.

ATSDR Response: We agree that the issue of food-chain dynamics has not been thoroughly investigated on Vieques. Long-range transport of certain contaminants (e.g., aerial deposition of mercury) has been observed elsewhere under the right conditions (i.e., continuous emissions of large quantities from a single large source or multiple smaller sources, combined with appropriate meteorological conditions). Nevertheless, actual sampling data and air dispersion modeling on Vieques do not indicate that environmental transport of contamination originating from the bombing areas would be expected to affect areas distant from the range. It appears that any environmental effect from past range use activities is localized.

2. [Comment] Grazing Animals and their Products: The Navy, EPA and ATSDR did not do research on grazing activities by cattle, goats, sheep, pigs and chickens. Their importance to the diet of Viequenses is also poorly understood, but could potentially be an important additional pathway of contaminant exposure. The community members expressed concern over the possibility that livestock are accumulating heavy metals by grazing on contaminated plants.

   ATSDR Response: Thank you for your comment. At the time of the original public health assessment discussing the soil evaluation pathway, little information or data were available pertaining to the potential for heavy metal accumulation in local livestock. The Puerto Rico Department of Agriculture, in cooperation with the Farmers Association of Puerto Rico, sampled grass, fruit-bearing trees, and bovine livestock from Monte Carmelo, Martineau, Monte Santo, Esperanza, Lujan, Gubeo, and western Vieques for cadmium, cobalt, copper, lead, manganese, and nickel. They concluded that the agricultural products from Vieques did not contain toxic levels of these contaminants and were suitable for consumption (El Nuevo Día 2001).

   Since that time, additional plant data have been collected. But due to data limitations, uncertainty remains regarding the degree of potential exposures from consuming local produce. The Report contains a thorough discussion of currently available sampling data from locally produce and livestock. Although the results of sampling by the Puerto Rico Department of Agriculture is reassuring, ATSDR recommends additional sampling of locally grown produce to allow a more complete evaluation of this exposure pathway.

3. [Comment] Air, Soil and Water: The most plausible hypothesis regarding transport and fate of chemicals is that chemicals released to the atmosphere were eventually deposited on soils and plants and then washed into underlying aquifers by rains.

   ATSDR Response: To assess whether the dust releases present public health hazards, ATSDR evaluated whether dusts blow into the residential areas in appreciable quantities. The findings of the Air Pathway Evaluation, described in Chapter 6, suggest that substantial levels of atmospheric contamination had not reached the residential area of Vieques.

4. [Comment] Plant Contamination: ATSDR could not quantify exposures to contaminants from these reports nor draw any health conclusions about whether consuming plants grown in Vieques would result in harmful health effects.

   ATSDR Response: Most of the relevant studies sampled plant species typically not eaten by humans or sampled the parts not eaten. As a result, the data were not useful for interpreting the degree of exposure or representative of locally grown produce on the island. To address this data gap, ATSDR recommends further sampling.

Reviewer 6

Overall, has ATSDR's re-evaluation of public health issues associated with historical bombing exercises at Vieques been appropriate?

[Comment] According to my best knowledge, the ATSDR re-evaluation of public health issues associated with historical bombing exercises at Vieques is appropriate. This opinion is based on the evidence presented, including ATSDR own data and the data generated by Puerto Rican scientists and researchers. As ATSDR recognizes, there is a huge degree of uncertainty in this type of analysis and the recommendations made are directed to reduce that uncertainty. Vieques was used as a military target and ammunition-explosive storage for more than 60 years and, as expected, these military activities are a major source of contamination, which constitutes a human health concern. Past and present conditions of Vieques reflect the difficulties of approaching this type of human health assessment based on environmental data that was not necessarily developed to answer the type of questions associated with public health issues. In addition, Vieques social and environmental conditions are very complex. Thus, some degree of uncertainty will always remain. Nevertheless, military activities were always considered the major environmental and social stressor of Vieques' residents. Some connections between military activities and human health concerns in Vieques have been established by local scientists and researchers and this report very well examines the scientific strengths and weaknesses of those connections. This report also incorporates new environmental, biomonitoring and health outcome data and revisits the previous ATSDR reports. Therefore, new recommendations and findings are integrated into this report.

> **ATSDR Response**: Thank you for your comments.

Has ATSDR adequately addressed the pathways of human exposure to bombing range-specific contaminants?

Please include specific comments on:

Consumption of seafood from reefs near Vieques

[Comment] This subject was addressed adequately. ATSDR recognized the limitations of the data in measuring mercury levels in fish and shellfish. It also indicates that some children born to women who frequently ate fish from water surrounding Vieques were at increased risk of adverse health effect and some children who frequently ate the same fish were also at risk of harmful effects. Based on the information available, ATSDR could not make any connection with the military activities and the mercury level found in fish. Then, the best recommendation is to make a risk assessment around the LIA to determine the effect that military activities have had on the marine ecosystem.

> **ATSDR Response:** Thank you for your comments. The National Oceanic and Atmospheric Administration's (NOAA) National Centers for Coastal Ocean Science (NCCOS), in consultation with NOAA's Office of Response and Restoration (OR&R) and other local and regional experts, conducted a characterization of coral reef ecosystems, contaminants, and nutrient distribution patterns around Vieques (NOAA 2010).

Use of biomonitoring tools to assess exposure to metals and other hazardous chemicals in blood, urine, or hair that are related to historical bombing exercises

[Comment] This subject was addressed adequately in some extent. ATDSDR reviewed the PRDOH, and some local researcher studies, and found elevated levels of various metals in residents' blood, urine and hair. ATSDR emphasized that the weakness of all these studies was the inability to investigate each person's environment, thus making it impossible to identify the source for high metal concentration. The PRDOH identified cigarette use, hair dyes and seafood consumption as possible sources for high metal concentration. Dr. Ortiz Roque showed that some residents had elevated levels of mercury in hair and that the most likely source was fish consumption. The best recommendation to address this issue is to make a survey of Viequenses to determine the type and quantity of fish consumed as well as a biomonitoring study to measure mercury and other metals in blood and hair. ATSDR should use the preliminary data developed by PRDOH and Dr. Ortiz to enforce a more specific study, which include an association between residents' habits, their environmental conditions and metal concentration in different parts of their body.

> **ATSDR Response**: Thank you for your comment. We have recommended that a survey of Vieques residents be conducted to determine the types, frequency, and quantity of fish consumed. The results of this survey could be used to conduct additional risk assessments and statistical analyses to validate our concerns about mercury in Vieques reef fish. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. If a biomonitoring investigation is conducted, it should include a comparison group from mainland Puerto Rico. If requested, CDC/ATSDR subject matter experts will provide technical assistance and support to PRDOH in planning and conducting such an investigation. Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing. A qualified laboratory should do the testing and analysis. Consumption of food (produce, meat, dairy, eggs) grown on the island

[Comment] This subject was addressed adequately. The main ATSDR conclusion about this subject is that the overall data is insufficient to adequately determine human exposure or to draw any valid health conclusion. ATSDR evaluated Dr. Díaz and Dr. Massols (2003) research, which found cadmium levels in pigeon peas potentially harmful for preschool children. ATSDR cannot be certain of the extent to which military activities contribute to the cadmium level found in pigeon peas. Recommendations suggested by ATSDR encouraged additional sampling and collaborative data collection for plants, livestock and soil. Based on the data collected by Dr. Díaz and Dr. Massol, ATSDR should enforce more specific studies about this subject and its association with military activities.

> **ATSDR Response**: Thank you for your comment. In fulfilling its role as a nonregulatory science advisory agency, ATSDR cannot direct other entities to conduct further studies, nor collect samples of local produce. However, we hope that recommendations for a

collaborative sampling effort will help resolve uncertainties and limitations in data on locally grown produce.

Exposure to air, soil, and water on Vieques

[Comment] This subject was addressed adequately to some extent. The main objective of this section was to determine whether airborne contaminant could potentially expose Viequenses in residential areas to harmful levels of metals and particulates that might result in adverse health effects. ATSDR used all the climate and meteorological information available as well as the ordinance detonation and the residential area air quality data. ATSDR reviewed and adapted a new version of a dispersion model and applied it to Vieques. Using this model ATSDR concluded that in residential areas of Vieques airborne from past military operations would have been essentially nondetectable and unlikely to have resulted in harmful effect. This conclusion is very critical in the sense that most of Vieques population receive the winds coming from the east (where the LIA was located) and they were not located far away from this military activities. This model should incorporate measurement of 2.5pm that is proved to be harmful for humans. This model should also include measurement of particulate matter coming from the Sahara desert, which is very well documented that affects human health throughout the Caribbean region. A conclusion sustaining that there is no air pollution reaching soil or water is somewhat uncertain. The rest of the data, conclusion and recommendations are very well documented.

ATSDR Response: Chapter 6, Section 6.2.2 of the summary document explicitly addressed the issue of PM2.5. No further revisions are necessary. The 2003 Air PHA evaluated the public health implications of exposure to airborne particulates from African Dust Storms (pages 59–61) and found that PM10 (and PM2.5) from such storms on Vieques were not at levels of health concern. But no contaminant-specific data on dust from African Dust Storms were available at the time of the Air PHA (which recommended further evaluation if such contaminant specific data became available). Contaminant-specific dust data are presented in a recent study by Gioda et.al. (2007) and a discussion of this information has been added to 6.2.3.

Does the Vieques summary report adequately present and describe the limitations and uncertainty of assessing human exposure to bombing range-specific contaminants?

[Comment] Yes, the summary report, in general, adequately describes the limitations and uncertainties of assessing human exposure to military activities. As the report recognized, the data used has strengths and weaknesses and cannot address the effect of mixture and cumulative exposure on the health of Viequenses.

ATSDR Response: Thank you for your comment—no revision required.

Are independent studies utilized appropriately in the determination of potential health hazards?

[Comment] Yes, independent studies contained in this report are properly used to determine the potential health hazard caused to the population of Vieques by past military activities. Most of these studies bring out new information and data to support new evidence and conclusions.

> **ATSDR Response**: Thank you for your comment.

On the basis of ATSDR's reevaluation of historical bombing activities in the Vieques summary report, has ATSDR reached the appropriate conclusions and recommendations?

[Comment] Based on the data and information available ATSDR, in general, reached appropriate conclusions and recommendations. As stated in the report, more studies could be done in order to complete the whole picture of a really complex environmental and human health problem. At this moment, the information collected represents a lot of fragmented pieces of an environmental health puzzle**.** Therefore, an integrated and holistic approach could be developed for future studies.

> **ATSDR Response**: ATSDR agrees and has made recommendations in the Report to 1) conduct a scientific survey of Viequenses to assess their seafood consumption and other food consumption, and 2) reanalyze the existing data using information obtained from the survey. Although ATSDR is not recommending a comprehensive, systematic biomonitoring effort at this time, public health officials could consider a limited and focused human biomonitoring investigation following the release of this report. ATSDR also recommends that Viequenses who remain concerned about exposure to mercury, cadmium, other metals, or metalloids should consult their healthcare provider to discuss the need for and cost of testing.

Select the appropriate category below:

List recommended changes or reasons for not recommending)

- Recommend ( )
- Recommend with Required Changes (X)
- Not Recommended ( )

Additional Questions:

Are there any comments on ATSDR's peer review process?

[Comment] The peer review process is very well documented and guided.

> **ATSDR Response**: Thank you for your comment.

Are there any other comments?

[Comment] Sometimes science is not sufficient to find answers to some environmental problems. Particularly, when dealing with the human health dimension of these problems. What is critical is to find the best possible response to the particular environmental health problem. In the case of Vieques, I think that a necessary approach is to develop a comprehensive epidemiological study of its population. This study should consider all human health conditions and diseases. It should also consider peoples' habits, cultural activities and personal and social environmental conditions. This study should be complemented with several studies recommended in the different sections of this report. But, instead of approaching the problem from an environmental perspective, it will be better to approach the analysis from a human health dimension. I completely agree that a future comprehensive study should investigate the combined and cumulative effects of exposure to military activities in Vieques.

> **ATSDR Response**: ATSDR is mandated to focus on the environmental associations with adverse health effects. Also, it is not methodologically feasible to consider "all human health conditions and diseases." Understanding these two facets, the agency's approach is typically to identify environmental exposures of concern and then evaluate biologically plausible health effects possibly associated with these exposures.