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Public Health Assessment for

PETITIONED PUBLIC HEALTH ASSESSMENT
ISLA DE VIEQUES BOMBING RANGE
VIEQUES, PUERTO RICO
NOVEMBER 22, 2002

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Agency for Toxic Substances and Disease Registry

Comment Period Ends:

FEBRUARY 24, 2003

PUBLIC HEALTH ASSESSMENT

Air Pathway Evaluation

ISLA DE VIEQUES BOMBING RANGE

VIEQUES, PUERTO RICO

Prepared by:

Federal Facilities Assessment Branch
Division of Health Assessment and Consultation
Agency for Toxic Substances and Disease Registry

THE ATSDR PUBLIC HEALTH ASSESSMENT: A NOTE OF EXPLANATION

This Public Health Assessment-Public Comment Release was prepared by ATSDR pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) section 104 (i)(6) (42 U.S.C. 9604 (i)(6)), and in accordance with our implementing regulations (42 C.F.R. Part 90). In preparing this document, ATSDR has collected relevant health data, environmental data, and community health concerns from the Environmental Protection Agency (EPA), state and local health and environmental agencies, the community, and potentially responsible parties, where appropriate. This document represents the agency's best efforts, based on currently available information, to fulfill the statutory criteria set out in CERCLA section 104 (i)(6) within a limited time frame. To the extent possible, it presents an assessment of potential risks to human health. Actions authorized by CERCLA section 104 (i)(11), or otherwise authorized by CERCLA, may be undertaken to prevent or mitigate human exposure or risks to human health. In addition, ATSDR will utilize this document to determine if follow-up health actions are appropriate at this time.

This document has previously been provided to EPA and the affected state in an initial release, as required by CERCLA section 104 (i)(6)(H) for their information and review. Where necessary, it has been revised in response to comments or additional relevant information provided by them to ATSDR. This revised document has now been released for a 30-day public comment period. Subsequent to the public comment period, ATSDR will address all public comments and revise or append the document as appropriate. The public health assessment will then be reissued. This will conclude the public health assessment process for this site, unless additional information is obtained by ATSDR which, in the agency's opinion, indicates a need to revise or append the conclusions previously issued.

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LIST OF ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
AFWTF	Atlantic Fleet Weapons Training Facility
CRDV	Committee for the Rescue and Development of Vieques
DU	depleted uranium
EIS	Environmental Impact Statement
EMA	Eastern Maneuver Area
EPA	US Environmental Protection Agency
HMX	cyclotetramethylenetetranitramine
LIA	Live Impact Area
NAAQS	National Ambient Air Quality Standard
NASA	National Aeronautics and Space Administration
NASD	Naval Ammunition Support Detachment (also referred to as West Vieques)
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Association
NRC	Nuclear Regulatory Commission
OB/OD	open burning/open detonation
PHA	public health assessment
PM10	particulate matter having aerodynamic diameters less than or equal to 10 microns
PRDOH	Puerto Rico Department of Health
PREQB	Puerto Rico Environmental Quality Board
RDX	cyclotrimethylenetrinitramine
TNT	2,4,6-trinitrotoluene
TRI	Toxic Release Inventory
TSP	total suspended particulates
$\mu g/m^3$	micrograms per cubic meter
USGS	US Geological Survey

FOREWORD

The Agency for Toxic Substances and Disease Registry, ATSDR, was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation, and Liability Act, also known as the *Superfund* law. This law set up a fund to identify and clean up our country's hazardous waste sites. The Environmental Protection Agency, EPA, and the individual states regulate the investigation and clean up of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment program allows the scientists flexibility in the format or structure of their response to the public health issues at hazardous waste sites. For example, a public health assessment could be one document or it could be a compilation of several health consultations the structure may vary from site to site. Nevertheless, the public health assessment process is not considered complete until the public health issues at the site are addressed.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by EPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists evaluate whether or not these contacts may result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high risk groups within the community (such as the elderly, chronically ill, and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicologic and epidemiologic studies and the data collected in disease registries, to determine the health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available. When this is so, the report will suggest what further public health actions are needed.

Conclusions: The report presents conclusions about the public health threat, if any, posed by a site. When health threats have been determined for high risk groups (such as children, elderly, chronically ill, and people engaging in high risk practices), they will be summarized in the conclusion section of the report. Ways to stop or reduce exposure will then be recommended in the public health action plan.

ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA, other responsible parties, or the research or education divisions of ATSDR. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also authorize health education or pilot studies of health effects, fullscale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals and community groups. To ensure that the report responds to the community's health concerns, an early version is also distributed to the public for their comments. All the comments received from the public are responded to in the final version of the report.

Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us.

Letters should be addressed as follows:

Attention: Chief, Program Evaluation, Records, and Information Services Branch, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road (E60), Atlanta, GA 30333.

I. SUMMARY

Isla de Vieques (Vieques) is an island in the Commonwealth of Puerto Rico and is located roughly 7 miles east of the main island of Puerto Rico. The United States Navy (Navy) currently owns about half of the land on Vieques and conducts military training exercises on the east side of the island. These exercises include various types of bombing and shelling, which take place at the Live Impact Area (LIA). The residential areas of Vieques are located more than 7.9 miles west of the center of the LIA.

In 1999, a resident of Vieques asked ATSDR to determine whether the Navy's operations on Vieques cause residents to be exposed to levels of environmental contaminants that could present a public health hazard. For the last 3 years, ATSDR has studied this issue extensively and is publishing its findings in a series of public health assessments (PHAs). This PHA addresses the public health implications of exposure to air contaminants potentially released from Navy property.

To characterize air quality at Vieques, ATSDR identified and obtained a wide range of relevant data. Specifically, ATSDR initiated an air sampling study during a recent military training exercise and reviewed relevant studies prepared by the following parties: the Puerto Rico Environmental Quality Board (PREQB), several academic and independent researchers from universities and private organizations in Puerto Rico, the U.S. Environmental Protection Agency (EPA), and the Navy and its contractors.

ATSDR's findings are summarized below. Later sections of this report describe how ATSDR reached these conclusions.

- *Do Navy activities at Vieques release contaminants to the air?* Yes. The Navy's military training exercises at Vieques release contaminants to the air, including dusts, chemical by-products of explosions, and metals. Even when exercises are not occurring, winds blow the surface soil and their constituent elements, including metals, from the LIA into the air. However, just because air emissions are occurring does not mean that adverse health effects will result among the island's residents. Rather, the key questions for this PHA are what amounts of contaminants are released, where these contaminants go, and whether people come into contact with levels of contamination that could present a public health hazard. The following conclusions present ATSDR's findings on these questions.

- *On days when military training exercises* ***do not*** *occur, does wind-blown dust from the LIA pose a health hazard?* **Wind-blown dust from the LIA is not a health hazard on days without bombing exercises.**

- *Do contaminants released when the Navy uses "practice bombs" pose a health hazard?* **ATSDR concludes that the Navy's military training exercises with practice bombs do not pose a health hazard.**

ATSDR recognizes that the amount of emissions from military training exercises depends on many factors, including the numbers of bombs dropped, the types of bombs dropped, and meteorological conditions, all of which vary from one exercise to the next. As a result, it is possible that future military training exercises on Vieques, if of a different nature than those that have taken place this year or if conducted during substantially different meteorological conditions, might cause levels of air pollution to be different from what PREQB has recently measured. As a prudent public health measure, therefore, ATSDR recommends that PREQB continue its air sampling efforts in the residential areas of Vieques to characterize potential exposures.

- *Did contaminants released when the Navy used "live bombs" pose a health hazard?* No, based on the results of ATSDR's modeling analysis. Military training exercises using "live bombs" (or explosive ordnance) released many contaminants into the air, including particulate matter, chemical by-products of explosions, metals, and explosives. Because the few air samples that were collected on Vieques when the Navy used live bombs are poorly documented, no reliable measurements of past levels of air contamination are available.

ATSDR's modeling considered nearly 100 different contaminants believed to be released to the air during live bombing exercises and simulated how these contaminants move through the air. The modeling analysis predicted that chemicals emitted from bombing exercises disperse to extremely low levels over the 7.9 miles that separate the emissions source (the LIA) and the receptor (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. In the case of particulate matter, for example, emissions from live bombing exercises were predicted to account for less than 1% of the concentrations of particulate matter that were recently measured in the residential areas of Vieques. This comparison suggests that emissions sources located in the residential area of Vieques—and not emissions from the past live bombing exercises—accounted for nearly all of the particulate matter that residents breathed in the past.

In summary, whether considering acute or chronic exposure scenarios, ATSDR's modeling estimates indicate that **emissions from live bombing activities did not cause ambient air concentrations of explosion byproducts, including metals released from soil, to reach levels known to be associated with adverse health effects. ATSDR concludes, therefore, that chemicals released to the air during the past live bombing exercises did not pose a health hazard.**

ATSDR acknowledges that this finding is based entirely on a modeling analysis, which has inherent uncertainties and limitations. However, as Section V.C describes, ATSDR has reason to believe that the modeling analysis has not understated exposures and public health implications. Of particular note, the approaches ATSDR used to estimate emissions of contaminants are based on, and consistent with, EPA modeling guidance and several assumptions ATSDR made likely overstate the actual emissions. These observations, combined with the fact that estimated ambient air concentrations for most contaminants considered were several orders of magnitude lower than concentrations of health concern, lead ATSDR to believe that the modeling analysis presents a reasonable account of exposures that occurred on Vieques and does not understate the exposures that residents might have experienced.

- *Do chemicals released to the air during open burning or open detonation operations pose a public health hazard?* Over the years, the Navy has conducted open burning and open detonation on Vieques to treat two types of waste: unused munitions (munitions that were never used in a military training exercise) and unexploded ordnance (munitions that were used in an exercise, but did not detonate). Based on waste management statistics obtained from both the Navy and EPA, ATSDR estimated levels of air pollution that open burning and open detonation operations would likely cause in the residential areas of Vieques. These estimated exposure concentrations were lower than levels known to be associated with adverse health effects. Therefore, **chemicals released to the air during open burning and open detonation operations on Vieques do not pose a public health hazard.**

- *Did the Navy's past use of depleted uranium pose a health hazard?* No. To address concerns about past usage of depleted uranium on the LIA, ATSDR examined several hypothetical exposure scenarios to estimate the amount of depleted uranium that residents of Vieques might contact. **Even the maximum estimated exposure to depleted**

uranium that a Vieques resident might realistically experience is considerably lower than levels known to cause adverse health effects. The very low levels of radiation released by depleted uranium at the LIA do not present health hazards. ATSDR's conclusion is consistent with findings published by the U.S. Nuclear Regulatory Commission, which collected 114 environmental samples at Vieques and found no evidence of widespread depleted uranium on the island.

- *Does the Navy's use of chaff pose a health hazard?* No. During military training exercises, the Navy has released chaff, which is aluminum coated glass fibers. Chaff is released thousands of feet in the air in order to simulate actual battlefield scenarios. Because chaff is released at such high altitudes, and never directly over the island of Vieques, only a very small fraction of the fibers used are believed to deposit in areas where people live. To date, no air samples at Vieques have shown levels of particulate matter a levels that could present a public health hazard from chaff in the air. Moreover, ATSDR investigated realistic exposure scenarios and the predicted concentrations of chaff components (e.g., aluminum) were below levels of health concern. **Therefore, the Navy's past and current use of chaff at Vieques have not led to exposures that could present a public health hazard.** Because the Navy may use chaff in the future, ATSDR recommends that additional air sampling be conducted at Vieques to evaluate further the potential air quality impacts of chaff.

II. INTRODUCTION

In May 1999, a resident of Isla de Vieques (Vieques), Puerto Rico, requested that the Agency for Toxic Substances and Disease Registry (ATSDR) determine whether contaminants released from the United States Navy's (Navy's) bombing range pose a public health hazard. This request was submitted as a petition to the agency. ATSDR accepted this petition and has since been investigating public health concerns related to operations at the Navy's bombing range.

ATSDR is responding to this petition in a series of public health assessments (PHAs) that examine what contaminants enter the environment, how these contaminants move through the environment, and what levels of contamination residents might contact. ATSDR then uses this information to determine whether residents are exposed to levels of contamination that might cause health problems.

To be most responsive to the petitioner and the people of Vieques, ATSDR is publishing a series of PHAs that address very specific questions. This PHA focuses on the public health implications of exposure to air contaminants. More specifically, this document responds to four key questions that the petitioner and residents of Vieques have asked ATSDR. ATSDR's

Key Questions for this PHA

Section V.A:	On days when bombing does not occur, does wind-blown dust from the LIA pose a health hazard?
Section V.B:	Do contaminants released when the Navy uses "practice bombs" pose a health hazard?
Section V.C:	Did contaminants released when the Navy used "live bombs" pose a health hazard?
Section V.D:	Do open burning and open detonation operations or the Navy's use of other chemicals (e.g., depleted uranium, chaff) pose a health hazard?

responses to these questions are found throughout Section V of this PHA.

Though this document focuses on air quality issues, ATSDR has committed to evaluate other ways that contaminants from the bombing range might affect public health. ATSDR has already addressed, or plans to address, these other public health issues as follows:

- In October, 2001, ATSDR released its final PHA addressing contamination in drinking water supplies and groundwater (ATSDR 2001a). This report indicated that the public drinking water supply on Vieques poses no apparent public health hazard. Copies of this report, which evaluate health issues in much greater detail, are available from ATSDR and from records repositories on Vieques and on the main island of Puerto Rico. The repositories are located at Biblioteca Publica on Vieques, the Vieques Conservation and Historical Trust, and at the University of Puerto Rico School of Public Health.

- ATSDR has evaluated the public health implications of exposures to soils on Vieques. In a PHA released for public comment in October 2001, ATSDR addressed exposures both for the residential population and for individuals who lived on the LIA between April 1999 and May 2000 (ATSDR 2001b). That document concludes that there is no evidence that any residents of Vieques are being exposed, or were exposed, to harmful levels of contamination in soils. ATSDR is currently addressing public comments on this document and plans to release the final PHA for soils in the summer of 2002.

- In July 2001, ATSDR, the Ponce School of Medicine, and the Centers for Disease Control and Prevention sponsored an expert panel review to address whether an association existed between place of residence (Vieques or Ponce Playa) and morphological cardiovascular changes among fishermen. The panel concluded that the available studies do not indicate cardiac health problems among fishermen from Vieques or Ponce Playa. The report summarizing the expert panel review (ATSDR 2001c) was released in October 2001. Copies are available by contacting ATSDR (1-888-42-ATSDR).

- ATSDR is currently evaluating whether Navy training activities have resulted in contamination of local marine fish and shellfish. ATSDR expects to release a PHA on contamination in these food items for public comment in the summer of 2002. That PHA will review the results of the fish tissue sampling project carried out by ATSDR.

III. BACKGROUND

ATSDR's initial approach to evaluating air quality issues at Vieques involved gathering background information on several important topics, such as specific health concerns, site history, local demographics, and meteorology. The following discussion reviews the information collected on these and other topics, which are important background material for ATSDR's technical analyses, as documented in the "Evaluation of Air Quality Issues" section (Section V).

The remainder of this section primarily presents facts and observations about Vieques, without any analysis or interpretation. Later sections of this PHA document ATSDR's interpretation of the background information presented below.

A. Site Description and Land Use

Vieques is the largest offshore island that is part of the Commonwealth of Puerto Rico. Vieques is 20 miles long, 4.5 miles at its widest point, and about 33,000 acres (or 51 square miles) in area. Figure 1 shows the location of Vieques and surrounding islands. As the figure shows, the nearest island to Vieques is the main island of Puerto Rico, which is approximately 7 miles west of Vieques; the island of Culebra is roughly 9 miles north of Vieques; and St. Thomas, St. John, St. Croix, and other islands within the U.S. Virgin Islands are all at least 20 miles from Vieques, generally to the northeast and southeast. Therefore, Vieques is several miles removed from sources of air pollution on any other island in the Caribbean Sea.

The detailed map in Figure 2 conveys critical background information on land use in Vieques. The figure depicts the island in three separate sections, each of which is described in greater detail below:

- *Former NASD Lands (or West Vieques).* Figure 2 labels the western portion of Vieques as "former NASD lands," which is also commonly referred to as West Vieques. Prior to May, 2001, these 8,200 acres were Navy property and were known as the Naval Ammunition Support Detachment (NASD). Most of this land is undeveloped, and Navy operations there were limited. The Navy land uses at NASD included ammunition storage, a rock quarry, communication facilities, and Navy support buildings (IT Corporation 2000). In May, 2001, the Navy transferred most of the former NASD lands to various parties, including the island of Vieques, the Puerto Rico Conservation Trust, and the U.S. Department of the Interior. The Navy retained about 100 acres of the former NASD lands to continue operating communication facilities (Navy 2001).

- *Residential Lands.* Figure 2 labels the central portion of Vieques as "residential lands." This part of Vieques spans approximately 7,000 acres and, prior to May, 2001, bordered Navy property both on the west and the east. It now borders Navy property only on the east. This section of the island houses the entire residential population of Vieques, mostly in the towns of Esperanza and Isabel Segunda. Section III.B describes the demographics of this population in greater detail. Many different land uses are found in this central portion of the island, including residential, agricultural, commercial, and industrial. The industrial land uses, however, are extremely limited, as Section III.E indicates.

- *Current Navy Property.* The Navy currently owns the lands that make up roughly the eastern half of Vieques. As Figure 2 shows, these lands are further divided into two sections. First, the Eastern Maneuver Area (EMA) spans approximately 11,000 acres located immediately east of the residential lands. The Navy uses the EMA periodically for various combat activities, such as conducting shore landing exercises and firing at small arms ranges[1] (CH2MHILL and Baker 1999; IT Corporation 2000). The EMA also

[1] "Small arms ranges" are designated areas where military personnel fire small arms (e.g., guns) at stationary and moving targets. Bombs are not dropped on the small arms ranges.

includes Camp Garcia, where Marine Corps and Navy personnel are temporarily stationed at Vieques. Typically, no more than 100 Navy personnel reside at Camp Garcia, but this number increases during training exercises. Sources of air pollution within the EMA are few, and include the small arms firing ranges, wind-blown dust, mobile source emissions, (e.g. vehicles) and releases that occur from sustaining the population in Camp Garcia (e.g., emissions from generators and small boilers, vehicle refueling and maintenance, and other small scale operations).

East of EMA is the second section of land owned by the Navy, which is called the Atlantic Fleet Weapons Training Facility (AFWTF). AFWTF spans approximately 3,500 acres (TAMS 1979). As Figure 2 shows, AFWTF is further divided into three smaller sections of land:

- The western portion of AFWTF was formerly known as the Surface Impact Area. This land is heavily vegetated and almost completely undeveloped, except for dirt roads that pass through the area, a few observation posts and towers, and a larger observation post (OP-1) located on Cerro Matias, near the easternmost portion of this land. Prior to 1978, parts of the Surface Impact Area were used as impact zones for artillery fire.

- The middle portion of AFWTF is the Live Impact Area (LIA), more commonly referred to as the bombing range. This land spans roughly 900 acres. During military exercises, both aerial bombardment and naval surface fire often take place. The overwhelming majority of ordnance impacts the LIA, but some bombs and surface fire projectiles have landed in the waters near the LIA. The land at the LIA is sparsely vegetated, and does not contain any structures except for "targets" that the Navy periodically places. The targets are few in number, and include objects such as tanks, small airplanes, and trailers. Section III.D includes much more detailed information about the Navy's bombing practices on Vieques.

- The eastern tip of AFWTF is the Punta Este Conservation Zone, which has been set aside to preserve sensitive habitats (e.g., turtle nesting areas). No Navy operations take place on this small piece of land.

Not shown in Figures 1 or 2 are terrain features of Vieques, which are important to consider when evaluating how contaminants move through the air. The highest point on the western half of Vieques is Monte Pirata (987 feet above sea level), and the highest point on the eastern half is Cerro Matias (450 feet above sea level), where OP-1 is located. Other than these peaks, the terrain at Vieques includes low rounded hills and an east-west ridge that runs through the residential lands. The average elevation of Vieques is approximately 250 feet above sea level (Cherry and Ramos 1995; Torres-Gonzalez 1989).

B. Demographics

ATSDR examines demographic data, or information on the local population, to determine the number of people who are potentially exposed to environmental contaminants, as well as the presence of any sensitive populations, such as women of childbearing age, children, and the elderly.

Table 1 summarizes demographic data for Vieques, according to the 1990 and 2000 US Census. As the census data show, the population of Vieques increased from 8,602 to 9,106 residents between 1990 and 2000. These figures include both those who live in the residential lands and those who live on Navy property. Table 1 also specifies the number of residents who fall into three potentially sensitive populations: women of childbearing age, children, and the elderly. ATSDR has received anecdotal accounts suggesting that the population of Vieques is not highly mobile and that many people are lifelong residents of the island, but the site reports that ATSDR has obtained to date do not quantify population mobility trends. ATSDR considered all of the previous demographic figures and observations when evaluating potential exposures among the Vieques residents.

As noted previously, most of the residents at Vieques live in the two largest towns on the island, Isabel Segunda and Esperanza. Although these towns are located relatively close to the Navy property line, they are several miles removed from the LIA. Specifically, the nearest point on residential lands to the geographic center of the LIA is approximately 7.9 miles (or 12.7 kilometers). Therefore, air contaminants from the LIA will disperse over a distance of at least 7.9 miles before they reach the residential populations of Vieques. This is a key issue when evaluating air pollution, as Section V describes further.

C. Climate and Prevailing Winds

The climate and prevailing wind patterns of a given location affect how contaminants move through the air. Annual climatological summaries for Vieques, provided by the National Climatic Data Center (NCDC), indicate that the annual average temperature at Vieques ranged from 77.9 to 80.0 degrees Fahrenheit over a recent 10-year period, with only modest fluctuations in monthly average temperature (NCDC 1985–1994). Annual precipitation totals were more variable, ranging from 42.91 inches in 1991 to 57.07 inches in 1993 (NCDC 1985–1994).

Regarding prevailing wind patterns, a large body of literature reports that trade winds in the Caribbean, which consistently blow from east to west, dominate the meteorology in Puerto Rico. This trend is consistent with wind speed and wind direction data collected at the US Naval Station Roosevelt Roads—the meteorological station closest to Vieques that submits hourly observations of wind speed and wind direction to NCDC. ATSDR obtained more than 10 years of hourly meteorological data for this station. Figure 3 summarizes the hourly wind speed and direction data, in a format known as a wind rose. Wind roses display the statistical distribution of wind speeds and directions in a single plot. The data in Figure 3 demonstrate that the prevailing wind direction at Roosevelt Roads, and presumably in Vieques, is indeed from east to west. In fact, the hourly data provided by NCDC indicate that winds blow from east to west[2] about 75% of the time. This trend is consistent with the influence of trade winds.

Referring to Figures 1 and 2, an easterly wind direction (i.e., winds blowing from east to west) blows contaminants generated at the LIA toward the residential area of Vieques. This observation, however, does not indicate what levels of air contamination will occur. Only sampling data or modeling analyses can provide insights into this issue, as Section V discusses.

D. Navy Operational History

The Navy first began acquiring land on Vieques in 1941 and continues operations today on the eastern half of the island. Between 1941 and the present, a wide range of military training exercises have taken place on Vieques, with the type and intensity of exercises varying from year to year. As a result, the amounts of contaminants released to the air also have changed with time.

The following paragraphs note key time frames that ATSDR has defined for purposes of evaluating the extent to which the military training exercises have released contaminants into the air. ATSDR's evaluation of air quality issues (see Section V) is based on these time frames.

[2] For this calculation, ATSDR considered all wind directions between northeast (45°) and southeast (135°) as "from east to west."

Terminology Used in this PHA to Characterize Military Training Exercises

Over the last 2 years, ATSDR has noticed that the Navy, local residents, the media, and other parties use many different terms when referring to military training exercises on Vieques. To avoid any confusion with terminology, this text box defines the terms ATSDR uses throughout this PHA to describe the Navy's military training exercises on Vieques.

Air-to-ground exercises: In this PHA, air-to-ground exercises refer to all military training exercises that involve releasing or firing of ordnance from fixed wing aircraft to targets on the ground. Over the years, many different types of ordnance have been fired in these exercises, including bombs, flares, and rockets. According to detailed statistics on ordnance usage, the total weight of explosives fired during air-to-ground exercises is far greater than the amounts fired from both ship-to-shore and land-based exercises combined.

Ship-to-shore exercises: ATSDR uses the term ship-to-shore exercises to refer to all firing of ordnance from marine vessels to targets on the island. A variety of ordnance and activities fall into this category, including artillery firing exercises. In recent years, the amount of ordnance (by weight) used for ship-to-shore exercises far exceeded that used for land-based exercises.

Land-based exercises: This PHA refers to all ordnance fired from the ground during military training exercises as land-based exercises. Ordnance fired on small arms ranges and during amphibious landings are included in this category. During the time frame when most detailed ordnance usage statistics are available, land-based exercises account for the lowest quantity of ordnance that the Navy and other parties have used on Vieques.

Live bombing exercises: For purposes of this PHA, "live bombs" refer to all general purpose bombs that have not had their explosive content replaced with inert materials. The Navy commonly refers to these bombs and other items as explosive ordnance. The live bombs used at Vieques contain a variety of explosives, including 2,4,6-trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), cyclotetramethylenetetranitramine (HMX), ammonium picrate (Explosive D), methyl-2,4,6-trinitrophenylnitramine (tetryl), and others.

Practice bombing exercises: In this document, "practice bombs" refers to those bombs whose main explosive content has been replaced with an inert material, such as sand or concrete. The Navy commonly refers to these bombs as non-explosive ordnance. ATSDR notes, however, that practice bombs might still contain a small quantity of explosives for purposes of spotting, but this quantity is considerably lower than that contained in most live bombs.

- *1941 to the early 1970s: Limited military training activities at Vieques.* Several reports (e.g., Navy 1971; Rabin 2001; TAMS 1979) indicate that the Navy first acquired land on Vieques in 1941, and continued to acquire lands on the island for several years. Of the many reports ATSDR has reviewed, two suggest that military training exercises first began on Vieques in 1947 (Navy 1971; TAMS 1979), though exercises took place in other parts of the Caribbean before that time. Regardless of the exact date when exercises began at Vieques, ATSDR notes that exercises in the late 1940s were apparently limited to ship-to-shore and land-based exercises, which occurred "only a few weeks a year" (Navy 1971). Military training exercises on Vieques apparently became more frequent in the early 1950s, but these were still limited to ship-to-shore and land-based exercises (Navy 1971; TAMS 1979).

None of the reports ATSDR has obtained documents exactly when the first air-to-ground exercises took place on Vieques. One report suggests that the Navy first established air-to-ground bombing targets on Vieques in 1960, with actual air-to-ground exercises occurring thereafter (TAMS 1979). Though the early history of air-to-ground exercises on Vieques is not entirely clear, various accounts (e.g., TAMS 1979; Navy 1977) indicate that air-to-ground bombing activity prior to 1971 was far more intense on the island of Culebra than on the island of Vieques. The frequency and intensity of air-to-ground bombing on Vieques gradually increased in the early 1970s, as the Navy slowed and eventually stopped all military training activities on Culebra by 1975.

ATSDR distinguishes between the time with limited military training activities at Vieques (i.e., from 1941 to the early 1970s) and the time with the most extensive use of the bombing range (i.e., from the early 1970s to April 19, 1999) for purposes of evaluating exposures, as Sections IV and V explain further. Note again that ATSDR has defined these time frames specifically for this PHA and no firm dates mark the transition between this time frame and the one described below.

- *The early 1970s to April 19, 1999: Most extensive use of the bombing range, including with "live" bombs.* By several accounts, the frequency and intensity of military training exercises on Vieques increased considerably in the early 1970s, after all Navy operations at the island of Culebra ceased. Moreover, air-to-ground exercises with live bombs occurred most frequently from the early 1970s through the 1990s. This period of extensive use of the bombing range ended on April 19, 1999, when two 500-pound bombs were accidentally dropped near an observation post overlooking the LIA, killing a civilian guard.

Figures 4 and 5 summarize the extent to which the Navy and other parties[3] have conducted military training exercises on Vieques between 1983 and 1999—the time frame for which the most complete range utilization statistics are available (Navy 1999). As Figure 4 shows, range utilization statistics indicate that the Navy and other parties conducted exercises on Vieques between 159 and 228 days per year, with the total number of days not varying considerably from one year to the next.

Though these usage statistics provide some insights into the number of days when military training exercises take place, the weight of ordnance used during these exercises is a much better indicator of the amount of contaminants that might be released into the air. The graph in Figure 5 illustrates how the total tons of ordnance used at Vieques, as well as the tons of high explosives within this ordnance, have changed from year to year. The range utilization statistics (Navy 1999) suggest that, on average, 1,862 tons of ordnance were used at Vieques annually between 1983 and 1998. This annual amount of ordnance used, on average, contained 353 tons of high explosives. In later sections of this PHA, ATSDR uses these average range utilization statistics to estimate air pollution

[3] Though the Navy owns the property where military training exercises take place, various parties used this property prior to 1999. These parties included the Navy, the U.S. Marine Corps, and military forces from some foreign countries.

levels that might have occurred on Vieques during the time when live bombing took place.

In addition to researching the usage of ordnance at Vieques, ATSDR considered the extent to which the ordnance is used for different categories of training exercises, namely the proportions used for air-to-ground, ship-to-shore, and land-based activities. Of these activities, air-to-ground bombing accounts for the greatest proportion of high explosives used at Vieques: according to two different reports addressing two different time frames of exercises, 94% of the high explosives used at Vieques were reportedly used for air-to-ground bombing exercises, with ship-to-shore and land-based exercises accounting for the remaining 6% of high explosives (TAMS 1979; IT 2000). These figures indicate that ordnance fired from fixed wing aircraft account for the largest portion of air emissions that occur during military training exercises.

Later sections of this PHA consider the chemical make-up of the various ordnance used at Vieques, as well as the contaminants that might be released after these items impact the LIA.

- *April 19, 1999 to May 2000: No military training exercises take place.* After the bombing accident occurred on April 19, 1999, the Navy immediately ceased all bombing operations and reviewed the accident and the need for conducting future military training activities on Vieques. After these reviews were completed, President Clinton issued a directive in January 2000 that allowed military training exercises to resume on Vieques, but only using "non-explosive ordnance" (which this document refers to as "practice bombs") and for no more than 90 days per year. No military training exercises took place on Vieques for approximately 13 months, between April 1999 and May 2000.

- *May 2000 to present: Military training exercises resume, but only with practice bombs.* Starting in May 2000, the Navy resumed its military training exercises on Vieques. These exercises have included air-to-ground, ship-to-shore, and land-based activities, but only with practice bombs and other non-explosive ordnance. The Navy completed several military training exercises in 2001, with the main exercises spanning the following dates: February 11 to February 15; April 27 to May 1; June 12 to June 29; August 2 to August 8; and September 21 to October 13. Therefore, in 2001, potential exposures associated with military training exercises using practice bombs occurred on less than 50 days.

- *Specific uses of the LIA that have concerned residents.* In addition to concerns about the Navy's more routine uses of the LIA for various military training exercises, residents of Vieques have expressed concern about sporadic uses of specific materials, primarily depleted uranium and chaff, and other activities associated with managing the range, most notably open burning and open detonation of unused waste munitions and unexploded ordnance. ATSDR has obtained the following information on these specific materials and activities:

  - *Depleted uranium.* During a February 19, 1999, training exercise, ammunition with depleted uranium penetrators was inadvertently loaded aboard two U.S. Marine Corps aircraft that were training at Vieques (NRC 2000). The pilots fired 263 rounds of this ammunition on the LIA during the exercise. The Navy has since worked to identify and recover all detectable depleted uranium penetrators. As of September 2001, the Navy reported having recovered 116 equivalent units, leaving 147 equivalent units not recovered (Higgins 2001). ATSDR has identified no other accounts of depleted uranium usage at Vieques.

- *Chaff.* Some residents have expressed concern regarding the Navy's use of chaff during military training exercises. Chaff is fine aluminum-coated glass fibers that the military has used for many years to confuse radar signals, thus allowing aircraft to operate without being easily detected. The most significant metallic constituents of chaff are aluminum and silicon, though chaff also contains trace amounts of other metallic elements (Naval Research Laboratory 1999).

  The Navy uses chaff during military training exercises only with permission from the AFWTF Commanding Officer, and the Navy prohibits chaff from being released directly over the island of Vieques and over the warning and restricted areas that extend several miles from the Vieques shoreline. Though ATSDR has identified several sources indicating that the Navy has used chaff at Vieques, none of these sources documents the exact quantities of chaff that have been used.

- *Open burning and open detonation.* Over the years, the Navy has used open burning and open detonation to treat two types of wastes: (1) unused waste munitions and (2) unexploded ordnance collected during range clearance activities. The amounts treated differ between these two types of wastes. First, reports the Navy submitted to EPA's Biennial Reporting System indicate that the amounts of unused waste munitions treated in a given year has greatly varied, from zero pounds (in 1993, 1995, 1999) to 30.945 tons (in 1997). Second, an analysis of air emissions from various range management operations indicates that the Navy typically treats 21 tons of unexploded ordnance in open detonation pits per year (IT 2000). This figure is based on waste management statistics for 1998.

The analyses of potential or completed exposure pathways (see Section IV) and evaluations of air quality issues (see Section V) review the public health implications of the different activities described in this section.

E. Other Sources of Air Contaminants

When evaluating the air exposure pathway, ATSDR not only considers emissions from the sources of concern, but also emissions from other sources in the area. This is because residents ultimately are exposed to air contaminants from all local sources, not just those from one or two. At many sites, in fact, air emissions from sources throughout a community far exceed those from a particular site of concern.

When identifying air emissions sources at a given location, ATSDR typically first accesses EPA's Toxic Release Inventory (TRI), a publicly accessible database that documents amounts of toxic chemicals that certain industrial and military facilities release to the environment. As shown in Table 2, which documents the TRI data available for Vieques, only one industrial facility on the island used hazardous chemicals in large enough quantities to trigger TRI reporting. The TRI data for this facility suggest that its air emissions were relatively low, especially when compared to data reported by facilities on the national level. Observations made during ATSDR's site visits (see Section III.F) confirm that industrial operations on Vieques are extremely limited. There are no power plants, chemical manufacturing plants, or other heavy industrial operations on the island.

Though few large industrial sources of air pollution are found on Vieques, numerous small sources of air emissions exist in and near the residential lands. Key among these are transportation sources, including motor vehicles, a small airport, and local ship traffic. Other small-scale sources include gasoline stations, auto refinish shops, construction activities, and a landfill. ATSDR has not identified a representative emissions inventory for the island from any references, thus the exact extent of emissions from these sources in residential lands is not known. Potential impacts of local emissions sources, other than the Navy bombing range, are discussed further in Section V.

In addition to expressing concerns about emissions from the military training exercises, some residents of Vieques asked ATSDR to evaluate the public health implications of exposure to emissions from "African dust storms." These dust storms occur when strong winds blow over the Sahara desert in Africa and carry large quantities of dusts in the upper air winds to locations thousands of miles away, such as the Caribbean islands and the southeastern United States. Many researchers have documented this phenomenon, including those working for the US Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Association (NOAA) (e.g., Griffin et al. 2001; Taylor 2002).

Some researchers have estimated that these dust storms release as much as one billion tons (1,000,000,000 tons) of dust to the air each year (Moulin et al.1997). This dust is composed of minerals commonly found in the soils and contains many naturally occurring elements, such as lead, iron, mercury, and beryllium. Recent studies have indicated that the dust storms also carry bacteria, fungal spores, and possibly viruses (Griffin et al. 2001). These storms reportedly have the greatest effect on Caribbean air quality during the months of June through October.

To date, community concerns about the African dust storms have fallen into two general categories: Is exposure to the material in African dust unhealthy? What is the relative impact of emissions sources thousands of miles from Vieques (such as African dust storms) and sources on the island itself (such as emissions from the LIA, motor vehicles, and the limited local industry)? To address these concerns, ATSDR researched many articles on African dust storms published in the scientific literature and consulted with several authors of these studies. ATSDR's interpretations on this issue are documented in Section VI.

F. ATSDR Involvement at Vieques

Since receiving the petition in 1999 to evaluate public health issues at Vieques, ATSDR has worked extensively to characterize and respond to community needs. Many activities to date have provided ATSDR's health assessors critical perspective for evaluating the local air quality issues. Following is a summary of ATSDR's past involvement with this site:

- *Site visits.* Teams of ATSDR scientists, health educators, and community involvement specialists have conducted more than 10 visits to Vieques since 1999. These visits were conducted for many reasons, such as working with community members to identify health concerns, training nurses on environmental health issues, and identifying sources of air contaminants throughout the island. On two site visits, ATSDR air quality specialists conducted surveys—both on land and by air—of the Navy property. During the land surveys, the specialists extensively toured the EMA and AFWTF, including a driving and walking tour of the LIA.

- *Community involvement.* Defining community concerns is an essential step in the public health assessment process. To define specific health issues of concern, ATSDR has met several times with residents of Vieques and worked closely with various local individuals and organizations (e.g., elected officials, physicians, nurses, school educators, fishermen, leaders of women's groups). During these meetings, ATSDR also inquired about the most effective ways the agency can provide public health information to the community.

- *Health education.* Another essential part of the public health assessment process is to design and implement activities that promote health and provide information about hazardous substances in the environment. ATSDR identified health education needs specific to Vieques by conducting a needs assessment in 2001. ATSDR's health education staff have since been developing and offering numerous training sessions and courses on relevant environmental health issues. For instance, ATSDR has facilitated training courses for physicians and nurses and has conducted education sessions on cancer for parents and high school students. Future health education efforts will address specific topics of concern pertaining to Vieques.

The previous list reviews ATSDR's activities while working at Vieques. In addition, ATSDR has invested considerable effort assessing this site's environmental health issues. Most of this work has been conducted at ATSDR's headquarters in Atlanta and is documented in the PHAs listed in Section II.

D. Quality Assurance and Quality Control

To prepare this PHA, ATSDR reviewed and evaluated information provided in the documents listed in the Reference section. The environmental data presented in this PHA are from reports produced by many parties, including ATSDR, EPA, and others. The limitations of these data have been identified in the associated reports, and they are restated in this document, as appropriate. After reviewing the studies conducted to date, ATSDR determined that the quality of environmental data available in the site-related documents for Vieques is adequate to make public health decisions. Appendix C presents ATSDR's specific conclusions regarding the quality of the air sampling studies that have been conducted on Vieques and indicates how the agency factored the findings from these different studies into this document's conclusions.

ATSDR also used an extensive review process for quality control purposes. The review involved numerous parties, including ATSDR scientists, lead authors of several studies cited in this report, and internationally recognized experts in the field of air quality issues and dispersion modeling. To date, all reviewers have agreed that the approaches ATSDR used to evaluate this site are scientifically sound and the available sampling data support this document's conclusions.

IV. EXPOSURE PATHWAY ANALYSIS

This section of the PHA addresses exposure pathways to air contaminants, or the various ways that residents of Vieques might come into contact with contaminants released to the air. Analyzing exposure pathways is important because:

- If people *are not exposed* to a site's environmental contamination, then the contaminants cannot pose a public health hazard and additional analyses are not necessary.

- If people *are exposed* to site-related environmental contamination, then further analysis is needed to characterize that exposure. Just because exposure occurs does not mean that people will have health effects or get sick. In fact, for many chemicals, environmental exposures are far lower than the exposures that people experience through their diets and perhaps through their occupations. Several issues must be considered to understand the public health implications of exposure: exposure concentrations, the frequency and duration of exposure, and the route of exposure by which people may be exposed. These issues must be carefully evaluated to determine if harmful health effects might result from exposure.

More detail on the air exposure pathway at Vieques follows. Section IV.A identifies the specific exposure pathways by which residents of Vieques might come into contact with air contaminants, and Section IV.B reviews the process ATSDR used to evaluate these exposure pathways.

A. Exposure Pathways for Contaminants Released to the Air

In general, there are two ways that people can come into contact with contaminants released from a source into the air. People might inhale contaminants while they are still airborne (known as direct exposure), or people might come into contact with the contaminants after they have been removed from the air by deposition or precipitation and have accumulated in other media, such as soil, groundwater, or food items (known as indirect exposure). This PHA primarily addresses the issue of direct inhalation exposure to air contaminants. ATSDR's other PHAs, which examine levels of contamination in drinking water, soil, and seafood, address the issue of potential indirect exposures to air contaminants.

ATSDR reviewed five elements of exposure pathways as a first step in evaluating the air exposure pathway. These elements, and their specific applicability to Vieques, follow:

- *Source of contamination.* A source of contamination must exist in order for exposures to occur. Many sources of air contamination are found at Vieques, most notably releases that occur during the military training exercises.

- *Environmental media and transport.* People cannot be exposed unless contaminants move from their source or origin through the environment to an exposure point. ATSDR has identified two dispersion modeling studies (Cruz Pérez 2000; IT 2001) that suggest contaminants released during the military training exercises might transport downwind in the air to the residential areas of Vieques. These contaminants will disperse greatly over the 7.9 miles that separate the LIA and residential areas. Further, during certain times (e.g., when exercises are not occurring, when rainfall removes contamination from the air, when winds blow air pollutants away from the residential areas), no contamination from the LIA reaches the residential areas. This element of the exposure pathway, therefore, is not always present. However, ATSDR considers the various pathways reviewed in this document to be completed exposure pathways during limited time periods, specifically, when the wind is blowing toward the residential areas during training exercises.

- *Point of exposure.* Exposure cannot occur unless contaminants reach a location where people have access. The two modeling studies predict that some contaminants from the LIA might cross into the residential area of Vieques in low quantities.

- *Route of exposure.* For exposure to occur, people must contact chemicals in a contaminated media, either through inhalation, ingestion, or dermal contact. Inhalation exposures clearly occur if air contaminants are present.

- *Potentially exposed population.* Ultimately, people must come into contact with chemicals at the point of exposure in order to conclude that exposure has taken place. Recognizing again that dispersion modeling studies suggest that some contaminants from the LIA reach the residential areas of Vieques, a potentially exposed population is clearly present for this site.

Of the five elements of an exposure pathway mentioned above, only the "environmental media and transport" element is not always present. Because during specific limited time periods, when training exercises are occurring and when the wind is blowing toward residential areas, ATSDR considers that the inhalation exposure pathway at the island of Vieques is a *completed exposure pathway.*

To characterize these potential exposures, ATSDR identified four inhalation exposure scenarios, which Table 3 lists. These scenarios address the main ways that residents might come into contact with contamination, and they also encompass specific concerns that community members have expressed to ATSDR since 1999 (see Section VI). The exposure scenarios considered in this PHA follow:

- Exposures to wind-blown dust on days when military training exercises do not take place.

- Exposures to contaminants released during military training exercises that involve use of only practice bombs (i.e., the types of exercises that have taken place since April 19, 1999).

- Exposures to contaminants released during the military training exercises that involved the use of live bombs (i.e., the types of exercises that took place prior to April 19, 1999, primarily those taking place between the early 1970s and April 19, 1999).

- Exposures to contaminants released during open burning and open detonation of selected wastes and to materials (depleted uranium and chaff) used sporadically on Vieques since the early 1970s.

Section IV.B presents the methodology ATSDR used to evaluate the public health implications of exposure to environmental contaminants, and Section V documents the results of ATSDR's evaluations for the four potential exposure pathways listed above.

B. Assessment Methodology

ATSDR used established methodologies to determine the public health implications of exposure to air contaminants. Specifically, ATSDR followed a three-step approach when addressing the four exposure scenarios identified in the previous section: identify concentrations of contaminants released to the air, select chemicals for further evaluation by screening the concentrations against health-based comparison values, and perform toxicologic evaluations for those contaminants selected for further evaluation. More detailed information on these individual steps follows.

The first step in addressing the exposure scenarios is tabulating ambient air concentrations for site-related contaminants. ATSDR prefers to use actual measurements for this step (i.e., air sampling results), rather than relying on engineering calculations or predictions from air quality models. This preference results from the fact that air quality models *estimate* ambient air concentrations, sometimes with great degrees of uncertainty, while sampling studies *measure* ambient air concentrations. However, air quality models are critical tools in cases when exposures occur during time frames when no samples were collected or analyzed. Section V indicates the exposure concentrations ATSDR used in this PHA.

The second step in evaluating exposure pathways is selecting chemicals for further evaluation. This is accomplished by comparing the ambient air concentrations for site-related contaminants to health-based comparison values. Comparison values are developed from the scientific literature concerning exposure and health effects. To be protective of human health, most comparison values have large safety factors built into them. In fact, some comparison values might be hundreds or thousands of times lower than exposure levels shown to produce effects in either humans or laboratory animals. As a result, ambient air concentrations lower than their corresponding comparison values are generally considered to be safe and not expected to cause harmful health effects, but the opposite is not true: ambient air concentrations greater than comparison values are not necessarily levels of air pollution that could present a possible public health hazard. Rather, chemicals with concentrations higher than comparison values require further evaluation. Chemicals without published health-based comparison values are automatically considered as requiring further evaluation. The text box on the following page presents the approach ATSDR used to select comparison values for this PHA.

The final step in the assessment methodology is evaluating the public health implications of exposure to any contaminants identified as requiring further evaluation. For these contaminants, ATSDR puts the public health implications of exposure into perspective by considering site-specific exposure conditions and interpreting toxicologic and epidemiologic studies published in the scientific literature. Thus, this step is a state-of-the-science review of what the exposure levels mean in a public health context.

Approach to Selecting Health-Based Comparison Values

For every contaminant considered in this PHA, ATSDR attempted to identify an appropriate health-based comparison value to evaluate whether ambient air concentrations of the contaminant (whether measured or modeled) warrant a detailed public health evaluation. Concentrations of contaminants lower than comparison values are believed to be "safe" or "harmless," while those greater than comparison values need to be evaluated further. ATSDR used the following hierarchy to select appropriate health-based comparison values:

- If the contaminant has comparison values published in ATSDR's "Air Comparison Values" (ATSDR 2002), the lowest of these comparison values was selected.
- If no ATSDR comparison values are available, the EPA risk-based concentration for ambient air was selected, if available. These values are published by EPA Region 3.
- If neither of the previous sources have comparison values, ATSDR researched other sources, such as EPA's National Ambient Air Quality Standards and occupational exposure limits.
- If no appropriate health-based comparison value is available, ATSDR automatically selected the contaminant for further evaluation and reviewed relevant toxicologic and epidemiologic studies to put the measured levels of contamination into a public health context.

By this approach, ATSDR identified health-based comparison values from many different sources (e.g., ATSDR's Air Comparison Values, EPA Region 3's risk-based concentrations, EPA's National Ambient Air Quality Standards). Though the comparison values from these different sources may have been derived using different assumptions, most can be interpreted in the same fashion: ambient air concentrations below the comparison values are generally considered to be safe and free from adverse health effects. In cases where chemicals have health-based comparison values published for both cancer and non-cancer effects, ATSDR chose the lower value for screening purposes, thus ensuring that the initial screening protects against both cancer and non-cancer endpoints.

ATSDR encourages readers interested in more information on health-based comparison values to refer to Appendix A. That appendix lists the different types of comparison values used in this PHA, as well as the assumptions made to derive them.

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V. EVALUATION OF AIR QUALITY ISSUES

This section of the PHA presents ATSDR's analyses of the four inhalation exposure scenarios defined in Section IV. Each scenario is addressed in a separate subsection. These subsections start by presenting the key question and ATSDR's response, followed by a review of the sampling and modeling data ATSDR considered to reach the conclusion. More detailed reviews of the environmental contamination data for this site can be found in Appendix C (sampling data) and Appendix D (modeling results). Readers interested in only a brief summary of ATSDR's technical analyses should refer to those provided in Sections I and VIII of this PHA.

A. Exposures to Wind-Blown Dust

Key Question:

On days when bombing ***does not*** *occur, does wind-blown dust from the LIA pose a health hazard?*

ATSDR's Response:

On days without bombing exercises, wind-blown dust from the LIA does not cause air concentrations of particulate matter, metals, or explosives to reach levels that could potentially present a public health hazard levels in the residential areas of Vieques. In fact, the air sampling data suggest that wind-blown dust from the LIA accounts for an extremely small portion of the levels of air pollution currently measured in the residential areas. ATSDR concludes that wind-blown dust from the LIA on days when bombing does not take place is not a health hazard.

ATSDR used the following information to reach this conclusion: 360 air samples that PREQB collected in Esperanza and Isabel Segunda, and levels of contamination measured in 43 soil samples from the LIA. The remainder of this section provides more detail on the data that support this conclusion.

Analysis:

Residents of Vieques have expressed concern to ATSDR about dusts from the LIA blowing potentially unhealthy levels of contamination into their neighborhoods, including on days when military training exercises do not take place. Concerns have been specific to dust (or particulate matter) and the possibility that this dust contains high levels of metals and explosives. ATSDR's evaluations of this issue are presented below, organized by the different classes of contaminants.

ATSDR notes that wind-blown dust is a natural phenomenon, and the amount of dusts blown into the air is determined both by soil properties and local weather conditions. An EPA model of this phenomenon, for example, suggests that the amounts of dust generated by winds depend on the wind speed, the fraction of soil covered by vegetation, the relative size of soil particles, and other factors (EPA 1985). Because these parameters do not change considerably from one year to the next, the amount of wind-blown dust is not expected to exhibit considerable annual variations.

ATSDR notes that the LIA soils clearly release dust into the air as a result of steady winds blowing over this land and much of the area not being covered with dense vegetation. This dust may contain contaminants that are in the LIA soils. Some of the dust that blows into the air settles back to the ground, some deposits in the ocean, and a small fraction may remain airborne for longer time frames. To assess whether the dust releases present public health hazards, ATSDR had to evaluate whether dusts blow into the residential areas in appreciable quantities.

ATSDR believes the best approach to evaluating this scenario is to examine the air sampling results that PREQB has collected in the neighborhoods where people live. At the time we completed this report, ATSDR had access to 266 valid air sampling results for "particulate matter" (see text box on the following page) that were collected by PREQB. The samples were collected between July 2000 and March 2002. As Appendix C.1 states, ATSDR believes PREQB's data are of a known and high quality and sufficient for use in the public health assessment process.

Following are ATSDR's specific interpretations of the available sampling data that pertain to the issue of wind-blown dust.

- Total suspended particulates *(TSP).* Wind-blown dust includes different size fractions of particulate matter (see text box on the following page). However, larger particles (e.g., TSP) are more likely to settle back to the ground surface near their source than are smaller particles (e.g., PM10, particulate matter having aerodynamic diameters less than or equal to 10 microns). In other words, TSP is less likely than PM10 to transport from the LIA to the residential areas. Nonetheless, ATSDR evaluated the levels of both TSP and PM10 that might be blown into the air.

  ATSDR identified four air sampling studies that measured ambient air concentrations of TSP on Vieques (see Appendices C.1, C.4, C.5, and C.6). Due to data quality concerns regarding three of these studies, ATSDR bases its conclusion for wind-blown dust entirely on the data recently collected by PREQB. Not only are PREQB's data well-documented and collected using rigorous methods, but they are the only extensive account of TSP levels in locations near where people live: one sampling station is in Esperanza, and the other is in Isabel Segunda (see Figure 6). PREQB started collecting 24-hour average air samples at these stations every sixth day in July 2000, and the agency continues to collect samples today. Thus, samples have been collected during all seasons

Background Information on Particulate Matter

"Particulate matter" refers to solid particles and liquid droplets (or aerosols) in the air. For nearly 20 years, EPA has monitored levels of particulate matter in the air that people breathe. Many health studies have shown that the size of airborne particles is closely related to potential health effects among exposed populations. As a result, EPA and public health agencies, including ATSDR, focus on the size of particulate matter when evaluating levels of air pollution. Particulate matter is generally classified into three categories:

Total suspended particulates (TSP) refer to a wide range of solid particles and liquid droplets found in air. TSP typically contains particles with aerodynamic diameters of 25 to 40 microns or less (EPA 1996). Many different industrial, mobile, and natural sources release TSP to the air. Until 1987, EPA's health-based National Ambient Air Quality Standards (NAAQS) regulated air concentrations of TSP. The table below lists those standards.

Particulate matter smaller than 10 microns (PM10) refers to the subset of TSP comprised of particles smaller than 10 microns in diameter. As research started to show that PM10 can penetrate into sensitive regions of the respiratory tract, EPA stopped regulating airborne levels of TSP and began (in 1987) regulating airborne levels of PM10. EPA continues to regulated PM10 concentrations today (see below). Typical sources of PM10 include wind-blown dust and dusts generated by motor vehicles driving on roadways.

Particulate matter smaller than 2.5 microns (PM2.5), or "fine particulates," refers to the subset of TSP and PM10 comprised of particles with aerodynamic diameters of 2.5 microns or less. EPA proposed regulating ambient air concentrations of PM2.5 in 1997, based on evidence linking inhalation of fine particles to adverse health effects in children and other sensitive populations. No PM2.5 sampling data are available for the island of Vieques.

EPA's relevant health-based standards. When evaluating the air sampling data collected on Vieques for PM10 and TSP, ATSDR used EPA's health-based standards for these pollutants. Refer to Appendix A for more information on these standards and what they signify.

Pollutant	Annual average concentration	24-Hour Average Concentration
PM10	50 $\mu g/m^3$	150 $\mu g/m^3$
TSP	75 $\mu g/m^3$	260 $\mu g/m^3$

Note: In 1987, EPA replaced its health-based standards for TSP with health-based standards for PM10. Though EPA no longer has a standard for TSP, ATSDR notes that the "former TSP standard" was not replaced because it was based on flawed science, but rather because exposure to PM10 was found to be more predictive of adverse health effects. Therefore, ATSDR evaluated both TSP and PM10 data.

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of the year. At the time this document was prepared, 181 valid TSP measurements were available to ATSDR for PREQB's two sampling stations on Vieques.As Appendix C.1 describes, the *average levels* of TSP measured at Esperanza and Isabel Segunda are 43.2 $\mu g/m^3$ and 34.2 $\mu g/m^3$, respectively, both of which are considerably lower than EPA's former annual health-based air quality standard for TSP (75 $\mu g/m^3$). Similarly, the *highest 24-hour average* TSP concentrations observed in Esperanza and Isabel Segunda (163 $\mu g/m^3$ and 177 $\mu g/m^3$, respectively) are considerably lower than EPA's former 24-hour average health-based air quality standard (260 $\mu g/m^3$). These comparisons indicate that wind-blown dust from the LIA between July 2000 and March 2002 did not cause levels of air pollution that could present a public health hazard. Further, because the total emissions of wind-blown dust from the LIA are not expected to vary considerably from year to year, it is reasonable to assume that wind-blown dust from the LIA has not caused levels of air pollution, that could present a public health hazard, in years when sampling did not take place. **Therefore, wind-blown dust from the LIA does not cause ambient air concentrations of TSP in Esperanza and Isabel Segunda to reach levels that could present a public health hazard.**

To analyze this issue further, ATSDR examined whether ambient air concentrations of TSP were higher on days with strong winds, as one would expect if wind-blown dust truly accounted for a large portion of TSP in the residential areas of Vieques. Based on average wind speed data observed at US Naval Station Roosevelt Roads (NCDC 2001)[4], ATSDR found the ambient air concentrations of TSP in both Esperanza and Isabel Segunda to be essentially uncorrelated with wind speed ($R^2 = 0.028$ for Esperanza, $R^2 = 0.030$ for Isabel Segunda). This observation suggests that the TSP levels measured in

[4] When this report was prepared, ATSDR had obtained meteorological data through April 30, 2001, and ambient air monitoring data through March 30, 2002. ATSDR computed daily-average wind speeds from the NCDC hourly data, but only for days having at least 16 hours of valid wind speed observations.

Esperanza and Isabel Segunda are not strongly affected by wind-blown dust from the LIA, but rather are more likely affected by local sources.

- *PM10.* The PREQB 2000–2001 air sampling data are the best indicators of potential inhalation exposures to PM10 in the residential areas of Vieques. When ATSDR completed this PHA, 179 valid ambient air concentrations of PM10 were available for the sampling stations in Esperanza and in Isabel Segunda. Figure 6 shows where these samples were collected.

  As Appendix C.1 notes, the average PM10 concentrations observed in Esperanza and Isabel Segunda (35.7 $\mu g/m^3$ and 23.5 $\mu g/m^3$, respectively) are lower than EPA's current annual average health-based standard for PM10 (50 $\mu g/m^3$). Further, the highest 24-hour average PM10 concentrations observed in Esperanza and Isabel Segunda (77 $\mu g/m^3$ and 94 $\mu g/m^3$, respectively) are lower than EPA's corresponding 24-hour average health-based standard (150 $\mu g/m^3$). ATSDR concludes from these observations that **wind-blown dust from the LIA does not cause PM10 to reach levels that could present a public health hazard in the residential areas of Vieques.**

  ATSDR also examined correlations between measured PM10 concentrations and daily average wind speed, but found that these observations also were virtually uncorrelated (R^2 = 0.037 for Esperanza, and R^2 = 0.045 for Isabel Segunda). The lack of correlation suggests that wind speed has essentially no effect on PM10 concentrations measured in the residential areas of Vieques—a trend that implies that wind-blown dust from the LIA accounts for a small portion of the PM10 that residents are breathing.

- *Metals.* Airborne particulate matter in all parts of the country contains trace levels of metals. The amounts of metals within these particles is one of the factors that may be used to determine whether people will get sick from breathing the air. To evaluate potential exposures to metals at Vieques, ATSDR first tried to access all valid air sampling results from existing studies. The only study that has collected such results is PREQB's ongoing air sampling in Vieques (see Appendix C.1). ATSDR has requested access to PREQB's sampling results (ATSDR 2001d), but has not yet received copies of the metals sampling data. Until these data are provided, ATSDR can only estimate the ambient air concentrations of metals on days when military training exercises do not occur. The rest of this section presents these estimates.

Wind-blown dust causes surface soils, and metals within or attached to these soils, to become airborne. Therefore, if wind-blown dust were the only source of particulate air pollution, a reasonable assumption would be that the concentrations of metals within the airborne dust are the same as the concentrations of metals within the surface soil from which the dust originated. ATSDR used this approach to estimate ambient air concentrations of metals on days when bombing does not occur.[5] Specifically, ATSDR estimated the air concentrations by multiplying the average concentration of PM10 (35.7 $\mu g/m^3$ in Esperanza) by the average metals concentrations in surface soils in the LIA (ATSDR 2001b).

Table 4 compares the estimated ambient air concentrations using this approach to corresponding health-based comparison values. With one exception, the estimated annual average air concentrations of all metals considered are lower than their corresponding health-based comparison values. As the exception, the estimated ambient air concentration of arsenic (0.0003 $\mu g/m^3$) is slightly higher than the lowest health-based comparison value (0.0002 $\mu g/m^3$). Examining potential exposures further, ATSDR notes

[5] ATSDR acknowledges that source of air pollution in the residential areas of Vieques (such as mobile sources) undoubtedly release metals into the air. It is possible that emissions of metals from these local sources cause actual ambient air concentrations of metals to be higher than those listed in Table 4. This possibility can only be verified by reviewing the concentrations of metals in the PM10 filters collected in Esperanza and Isabel Segunda. As Section IX of this PHA indicates, ATSDR will review PREQB's sampling results as soon as they are released.

that the estimated concentration (0.0003 $\mu g/m^3$) is within the range of ambient air levels of arsenic reported for remote areas in the United States and is lower than the ranges reported for rural and urban settings (ATSDR 2000a). Moreover, the estimated air concentration is considerably lower than the range of exposure concentrations (0.7–613 $\mu g/m^3$) that have been shown to cause harmful health effects in humans (ATSDR 2000a). Because the estimated average ambient air concentrations for nearly every metal considered is lower than their corresponding health-based comparison values, and because the levels of arsenic are not of health concern, **ATSDR concludes that the metals in wind-blown dust on Vieques do not present a public health hazard on days when military training exercises do not take place.**

Two assumptions made when evaluating exposures to metals in wind-blown dust deserve further attention. First, ATSDR used the comparison value for trivalent chromium to screen concentrations of "chromium" listed in Table 4. The available sampling data do not indicate whether the chromium detected is in the trivalent or the potentially more harmful hexavalent state. Knowing that chromium in soils tend to be in the trivalent state and that chromium air emissions from most combustion-related sources (to which explosions are similar) are believed to contain less than 1% hexavalent chromium (ATSDR 2000b), the use of the trivalent comparison value is an appropriate selection.

Second, the data in Table 4 can be compiled in different fashions. For instance, one can attempt to construct *maximum* concentrations (rather than *average* concentrations) by multiplying the highest PM10 concentration by the highest metal content observed in surface soils. ATSDR performed such calculations, which did not result in any metals concentrations significantly higher than comparison values and levels of significant exposure appropriate for acute exposure scenarios. Therefore, **metals in wind-blown dust on Vieques are not a public health hazard, both for short-term and long-term exposures.**

- *Explosives.* According to the documents ATSDR has reviewed, no agencies or researchers have attempted to measure ambient air concentrations of explosives in the residential areas of Vieques. ATSDR estimated concentrations for this group of contaminants using the same approach we used to estimate concentrations of metals. Specifically, ATSDR multiplied annual average PM10 concentrations in Esperanza by the average concentration of explosives measured in the soils of the LIA (ATSDR 2001c). This approach almost certainly overestimates the actual concentrations of explosives by assuming that 100 % of the PM10 are explosives. However, airborne particles in the residential areas clearly do not originate only from the LIA and many of the local sources of particulate matter (e.g., mobile sources) release particles that do not contain explosives. Nonetheless, ATSDR proceeded with this approach for a reasonable upper-bound estimate of actual exposures.

  Table 5 presents the estimated ambient air concentrations, which show that the levels of explosives are considerably lower than their corresponding health-based comparison values. In fact, the estimated ambient air concentrations of explosives are so low that they would not be detected by routine explosive sampling procedures. Based on this analysis, ATSDR concludes that **ambient air concentrations of explosives, as with particulate matter and metals, do not reach levels that could present a public health hazard on days when military training exercises do not occur.**

The previous analyses indicate that, on days without military training exercises, the levels of air pollution at Vieques do not present a public health hazard. In fact, the concentrations of most pollutants are orders of magnitude lower than levels believed to cause adverse health effects. This conclusion is based on a large set of sampling data, including 360 air samples collected in Esperanza and Isabel Segunda by PREQB and levels of contamination measured in the soils of the LIA. Though ATSDR believes these sampling results form an adequate basis for reaching this conclusion, the Agency is committed to reviewing the ambient air concentrations of metals that PREQB has been measuring in Esperanza and Isabel Segunda, once these data become available.

B. Exposures to Releases from Military Training Exercises Using "Practice" Bombs

Key Question:

Do contaminants released when the Navy uses "practice" bombs pose a health hazard?

ATSDR's Response:

Since April 1999, all bombing activities on Vieques have been limited to use of practice bombs, or bombs that have almost all their explosive content replaced with an inert material, like sand or concrete. Exercises involving practice bombs release contaminants into the air, primarily dusts and chemicals that were previously found in the LIA soils.

The available sampling data indicate that ambient air concentrations of particulate matter in the residential areas of Vieques are higher on days with military training exercises involving practice bombs than they are on days when no exercises occur, though most of the differences are not statistically significant. Additionally, the concentrations of particulate matter are virtually uncorrelated with the weight of practice bombs that were dropped, meaning that levels of air pollution are not consistently worse on days with the most intense exercises. These observations indicate that no clear relationship exists between military training exercises using practice bombs and ambient air concentrations of particulate matter in the residential areas of Vieques.

Regardless of the results of the statistical comparisons, PREQB's sampling data clearly indicate that ambient air concentrations of particulate matter have not reached levels that could present a public health hazard in the residential areas of Vieques on days of military training exercises involving practice bombs. This finding is based on 51 valid ambient air samples that PREQB collected on 16 days when the Navy conducted air-to-ground and ship-to-shore training exercises. Furthermore, ATSDR estimated ambient air concentrations of metals and explosives for days when the Navy dropped practice bombs on Vieques, and these estimated concentrations were all lower than levels known to cause adverse health effects. ATSDR concludes, therefore, that levels of air pollution on days with military training exercises involving only practice bombs present no health hazard to the residents of Vieques.

ATSDR recognizes that the amount of contaminants released to the air during military training exercises varies with the numbers and types of practice bombs used. As a result, even though the available data strongly suggest that the exercises using practice bombs are not a health hazard, those data may not be representative of all future exercises and meteorological conditions. As a prudent public health measure to ensure that future exercises using practice bombs are not a health hazard, ATSDR recommends that additional sampling take place during future training exercises. Section IX of this PHA presents more detailed information on this recommendation.

As Section III.D describes, the nature and extent of military training activities at Vieques changed after April 19, 1999, when a bombing accident killed a civilian guard. Since that date, a Presidential executive order has required that only practice bombs be used during these activities. Practice bombs have their entire explosive charge replaced by a non-explosive material, usually sand or concrete. Some of the practice bombs have very small quantities of explosives that are used for spotting purposes.

Figure 7 depicts the emissions that are typically associated with military training exercises using practice bombs. As the picture shows, emissions are generated when practice bombs impact the ground. The force of this impact can create a small crater, and the soil ejected from this crater typically becomes airborne. Small pieces of the practice bomb might also become airborne. After impact, however, most soil and bomb particles will fall to the ground, often within a short distance of the crater. A portion of the soils that the practice bombs eject into the air will remain airborne and travel downwind. These emissions not only include soils, but any contaminants that were previously in the soils, including metals and explosives. Though emissions clearly occur, the amounts of exposure are determined by where these contaminants go, at what levels, and for how long. The following paragraphs address these factors.

ATSDR believes an adequate set of sampling data are currently available to evaluate potential inhalation exposures during the military training exercises involving practice bombs, without the need for air quality modeling for this scenario. Specifically, as of the writing of this report, range utilization statistics indicate that the Navy has dropped practice bombs on the LIA on nearly 80 days since April 19, 1999,[6] and valid ambient air samples for particulate matter have been collected in the residential areas of Vieques on 9 of these days. In other words, valid air samples have been collected approximately one out of every five days when the Navy conducted military training exercises using practice bombs.

Though the sampling data do not capture every single practice bombing event, they provide useful perspective on the extent to which these activities contribute to exposures. Following is ATSDR's interpretation of potential inhalation exposures to airborne contaminants generated by use of practice bombs. These analyses are presented for four different groups of compounds: two forms of particulate matter (TSP and PM10), metals, and explosives.

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[6] This figure accounts for all military training exercises that have occurred in calendar years 2000 and 2001. Further, the figure indicates the number of days on which the Navy actually dropped practice bombs or fired non-explosive ordnance from ships, not the number of days the Navy had scheduled to do so. In many cases, practice bombs are dropped on only a small subset of the days within a given military training exercise. ATSDR based this number of days on range utilization statistics that the Navy routinely compiles.

- *TSP*. Table 6 summarizes PREQB's TSP sampling results collected in Esperanza and Isabel Segunda, both on days with no military training exercises and on days when exercises took place using practice bombs (see also Appendix C.1). These data indicate three important trends. First, the highest level of TSP measured on days when practice bombs were used (124 $\mu g/m^3$) is considerably lower than EPA's former health-based standard for 24-hour average concentrations (260 $\mu g/m^3$). Additionally, the average TSP concentrations in the residential areas on days with exercises involving practice bombs (53.3 $\mu g/m^3$ in Esperanza and 43.8 $\mu g/m^3$ in Isabel Segunda) are lower than EPA's former health-based standard for annual average concentrations for this pollutant (75 $\mu g/m^3$). Thus, ATSDR concludes that the **ambient air concentrations of TSP on days with military training exercises using only practice bombs do not present a likely public health hazard.**

  Second, the data trends indicate that average concentrations of TSP on days with exercises using practice bombs are higher than the average concentrations on days without this activity, but these differences are not statistically significant. The lack of statistically significant differences results largely from the fact that only a limited number of TSP samples have been collected on days when exercises involving practice bombs have taken place. Review of additional sampling results is needed to determine if this is an actual trend or an artifact of the limited sample size, and ATSDR has recommended that PREQB continue its sampling effort to help resolve such issues (see Section IX).

  Third, for days with military training exercises involving practice bombs, ATSDR compared the concentrations of TSP measured in Esperanza and Isabel Segunda to the total weight of the bombs that were dropped. ATSDR conducted this analysis to test a hypothesis: if emissions from practice bombs truly accounted for a very large fraction of particulate matter measured in the residential areas of Vieques, then concentrations of TSP would likely be positively correlated with the weight of the bombs dropped.

ATSDR found, however, that the ambient air concentrations of TSP in the residential areas of Vieques were essentially uncorrelated with the weight of practice bombs dropped (see Table 7). To a first approximation, the lack of correlations suggests that emissions from practice bombs is not the dominant factor affecting air quality on days when military training exercises take place.

Without statistically significant differences in concentrations between days with and without practice bombing, and without correlations between the concentrations and the measured TSP concentrations, ATSDR concludes that no clear relationship exists between the military training exercises conducted since April 19, 1999, and air quality in the residential areas of Vieques. More importantly, **none of the 181 TSP concentrations measured on Vieques to date, including the 25 TSP concentrations measured during military training exercises with practice bombs, have exceeded levels of health concern.**

- *PM10.* Table 6 presents a similar summary for PREQB's PM10 sampling data collected on Vieques on days when military training exercises have taken place using practice bombs (see also Appendix C.1). The conclusions from this table are also similar. First, none of the measured PM10 concentrations on days with training exercises using practice bombs exceeded EPA's 24-hour average health-based standard (150 $\mu g/m^3$) and the average concentrations did not exceed EPA's annual average health-based standard (50 $\mu g/m^3$). Therefore, ATSDR concludes that **on days when military training exercises take place with practice bombs, no exposures would occur that present apublic health hazard.**

As Table 6 shows, average concentrations of PM10 on days when practice bombs are used are higher than the average levels on days without military training exercises at both Esperanza and Isabel Segunda; the difference is not statistically significant at Esperanza, and is statistically significant at Isabel Segunda. Even though a statistically significant increase is observed at Isabel Segunda, ATSDR emphasizes that the sampling data are not sufficient for drawing conclusions on what source or sources most likely account for this difference. As evidence of this, Table 7 illustrates that PM10 concentrations in the residential areas of Vieques are essentially uncorrelated with the weight of practice bombs that were dropped. Accordingly, ATSDR believes further sampling is needed to verify that the increase in concentrations during military training exercises with practice bombs truly exists. Moreover, sampling at locations on Navy property is needed to help assess whether the increased PM10 concentrations result from emissions blowing from the LIA or perhaps from sources within the residential areas. Section IX lists the specific recommendations ATSDR has made to characterize PM10 concentrations during military training exercises more extensively.

Though additional data are needed to understand what sources contribute most to the PM10 levels measured on Vieques, ATSDR emphasizes that the available sampling records, which have been collected on days with military training exercises of varying intensity, indicate that **ambient air concentrations of PM10 on Vieques do not present a public health hazard, even on days when military training exercises using practice bombs take place.**

- *Metals.* As Figure 7 illustrates, practice bombs displace soils at the LIA when the bombs hit the ground. The soils that are ejected into the air contain metals, which include both naturally occurring metals and metals that may have accumulated soils over the years that the Navy has conducted military training exercises at Vieques. To assess potential exposures to these metals, ATSDR requested access to the air sampling data that PREQB has collected on these contaminants (ATSDR 2001d), but has not yet received those data. Without access to the measured air concentrations of metals in the residential areas, ATSDR estimated potential inhalation exposures using an understanding of how emissions are generated.

Upon impact with the ground, practice bombs tend to break into fragments and smaller pieces. Because practice bombs do not contain large explosive charges, the impact is not accompanied by a high-temperature explosion that has the potential to vaporize bomb casings. The main contaminants released by the impact, therefore, are the soils that are displaced when the practice bombs hits the ground surface. These soils will undoubtedly contain some level of metals, both naturally occurring minerals and contaminants that have resulted from the Navy's history of conducting military training exercises on Vieques. Because the practice bombs impact various locations on the LIA, the concentration of metals in the soils that become airborne is likely comparable to the average concentration of metals in soils throughout the LIA.

To evaluate potential exposures to metals, ATSDR estimated exposure concentrations following the approach used to evaluate exposures to metals in wind-blown dust. Specifically, ATSDR assumed that the ambient air concentrations of particulate matter in the residential area of Vieques are composed entirely of soils ejected from the LIA by practice bombs. By this approach, the exposure concentrations for metals are calculated by multiplying the measured ambient air concentrations of particulate matter and the average soil concentrations from the LIA. ATSDR found that the estimated ambient air concentrations of all metals considered were lower than health-based comparison values, except for arsenic.[7] Estimated ambient air concentrations for arsenic were within the

[7] Table 4 presents ATSDR's estimates of ambient air concentrations of metals for exposures to wind-blown dust. These were calculated based on an average PM10 concentration of 35.7 $\mu g/m^3$. The highest average PM10 concentration on days with military training exercises using practice bombs (40.1 $\mu g/m^3$) was only marginally higher. Therefore, the estimated ambient air concentrations of metals during the practice bombing exercises are only marginally higher (roughly 12% higher, not enough of a difference to represent a public health concern) than those shown in Table 4. This PHA does not include a separate table to document these marginally higher levels.

range of those reported for remote areas of the United States and are not of health concern. ATSDR concludes, therefore, that **military training exercises involving practice bombs do not cause ambient air concentrations of metals to reach levels that could present a public health hazard in the residential areas of Vieques.**

Some additional observations deserve further attention. First, the assumption that soil ejected from the LIA accounts for all of the particulate matter in the residential area of Vieques does not account for potential contributions from local sources (e.g., motor vehicles, construction activities, outdoor fires). It is likely, therefore, that sources other than those related to Navy training exercises contribute to actual ambient air concentrations of metals during military training exercises. ATSDR will consider this scenario when reviewing metals sampling data collected by PREQB, once they are provided. Second, while researchers may debate the exact quantity of metals emitted when a practice bombs impact the ground surface, ATSDR believes metals emissions from practice bombing events are unquestionably less than the emissions that occur when live bombs (of the same weight) impact the ground surface. Because ATSDR's air quality modeling analysis for live bombing scenarios (see Section V.C) suggests that ambient air concentrations of metals did not exceed levels of health concern when the Navy used live bombs, one can reasonably infer that ambient air concentrations of metals during practice bombing exercises also are safely below levels of health concern.

In summary, ATSDR's analyses indicate that **the amounts of soil on the LIA that become airborne during practice bombing exercises do not carry levels of metals that could present a public health hazard to the residential areas of Vieques.** This conclusion is based on PREQB's ambient air sampling data for PM10 and TSP and reasonable assumptions regarding the composition of these pollutants. PREQB has already collected additional data that likely provide additional perspective on exposures to metals. As Section IX notes, ATSDR remains committed to evaluating the public health implications of these data, once PREQB releases them to ATSDR.

- *Explosives.* During military training exercises using practice bombs, explosives may be released to the air in two ways. First, spotting charges in these bombs might release trace amounts of explosives, though amounts of explosives in these charges are far less than the high explosive charge in most live bombs. Further, range utilization statistics indicate that the total amount of explosives used in an entire day of practice bombs does not exceed the amount of explosives found in a single 1000-pound live bomb. Second, falling practice bombs may release soils to the air that were contaminated with explosives during the time when the Navy conducted military training exercises using live bombs. However, the soil sampling data ATSDR previously reviewed suggest that the LIA soils contain only trace amounts of explosives (at the part per million (ppm) level, see Table 5).

ATSDR used two approaches to evaluate whether practice bombs cause explosives to be released to the air in levels that could present a public health hazard. First, according to the analysis of wind-blown dusts (see Table 5), the estimated ambient air concentrations of explosives were more than 1,000 times lower than health-based comparison values. Given that ambient air concentrations of particulate matter on days when practice bombs were used are not considerably different from those on days when no bombs were dropped, it is highly unlikely that emissions caused by practice bombs could increase the estimated levels of explosives by a factor of 1,000.

Second, ATSDR notes that its air quality modeling analysis indicates that estimated ambient air concentrations of explosives did not reach levels that could present a public health hazard in the residential areas of Vieques, even when the Navy was using live bombs (see Section V.C). Because the amounts of explosives in practice bombs are substantially lower than the amounts in live bombs, one can reasonably infer that explosives released from practice bombs also do not cause ambient air concentrations of explosives that could present a public health hazard in the residential areas of Vieques. **Thus, ATSDR's air quality modeling results indicate that emissions of explosives during military training exercises using practice bombs do not lead to ambient air concentrations of explosives of health concern.**

The previous analyses indicate that, on days with military training exercises using practice bombs, the levels of air pollution at Vieques do not present a public health hazard. Both measured air concentrations and estimated air pollution levels are considerably lower than levels believed to cause adverse health effects. This conclusion is based largely on routine air sampling conducted by PREQB.

When evaluating potential exposures associated with the Navy's use of practice bombs, ATSDR recognizes that the nature and extent of emissions from the LIA undoubtedly vary, perhaps considerably, from one military training exercise to the next. Meteorological conditions also vary. As a result, the air sampling results currently available may not be representative of future exposures. Therefore, as a prudent public health measure, ATSDR recommends that continued air sampling take place on Vieques, both in the residential areas of the island and on Navy property, to provide additional insights into potential exposures and the sources that most significantly affect them. Section IX describes this recommendation in greater detail.

C. Exposures to Releases from Military Training Exercises Using "Live" Bombs

Key Question:

Did the contaminants released when the Navy used "live" bombs pose a health hazard?

ATSDR's Response:

ATSDR thoroughly evaluated the public health implications of contaminants released to the air during the time when the Navy used live bombs. Because no sampling programs extensively characterized air quality on Vieques during live bombing exercises, ATSDR relied entirely on a modeling study to evaluate this exposure scenario. To do so, ATSDR estimated the amount of chemicals that would be released to the air during bombing exercises, and then the agency evaluated how those chemicals would move through the air to where people might inhale them.

ATSDR's conclusions on this question depend on the type of contaminant. ATSDR estimated ambient air concentrations for more than 80 different explosives, metals, and organic by-products of explosions. For all contaminants considered, the estimated ambient air concentrations were considerably lower than levels of potential health concern. Though the modeling analysis involves some uncertainty, the estimated concentrations for most contaminants were orders of magnitude lower than relevant health-based comparison values. As a result, ATSDR is confident that airborne levels of explosives, metals, and organic by-products of explosions were not at levels that could present a public health hazard during the time when the Navy used live bombs.

For particulate matter, ATSDR evaluated two scenarios: annual average exposures and short-term (or maximum 24-hour) exposures. Over the long term, particulate matter emissions from the LIA have relatively little impact on air quality in the residential areas of Vieques. In fact, ATSDR's best estimates suggest that, when averaged over the year, emissions from the LIA account for less than 1% of the particulate matter found in the air in Esperanza and Isabel Segunda.

When evaluating acute exposure durations, on the other hand, ATSDR found that short-term increases (e.g., over the course of a day) in particulate matter do occur during military training exercises. For a given day, the amount of the increase depends on local weather conditions and the amounts and types of ordnance the Navy used. Based on detailed scientific analyses of the best available information, ATSDR found that the short-term increases in particulate matter in the residential areas are not at levels of health concern, even during the most intense exercises. These analyses are based on calculations and air quality modeling studies that have inherent uncertainties and the actual air concentrations of particulate matter might be slightly higher or lower than the levels ATSDR predicted. However, ATSDR's modeling approach is based on several assumptions that likely overstate actual exposure concentrations. Overall, ATSDR's detailed modeling analysis indicate that no exposures to particulate matter occurred that could present a public health hazard as a result of the Navy's past training exercises using live bombs.

The following discussion presents a general overview of ATSDR's analysis of the public health implications of live bombing exercises on Vieques. Refer to Appendix D.3 for a technical description of the air quality modeling analysis used to evaluate this issue.

Military training exercises involving live bombs were part of the Navy's operations at Vieques for many years. As Section III.D explains, the most intense activity at Vieques started in the early 1970s, when the Navy gradually stopped conducting exercises on Culebra, and continued through April 19, 1999, when a bombing accident killed a civilian guard. Between the early 1970s and 1999, the Navy's use of live bombs greatly varied from month to month, and even from day to day. However, relatively small variations in bombing activity occurred from one year to the next (see Figures 4 and 5).

Because they contain high explosive charges, live bombs release more contaminants to the air than practice bombs. Figure 8 identifies the types of contaminants emitted and how they are formed. When live bombs impact the surface, an explosion almost always follows. These explosions are a series of chemical reactions that consume the high explosive charge and release large amounts of energy. For instance, some live bombs used at Vieques contained 2,4,6-trinitrotoluene, or TNT. During explosions, chemical reactions rapidly break TNT down into smaller molecules. These reactions release energy previously stored in the chemical bonds of TNT. The energy released causes the bomb casings to fragment, a crater to form, and dust to be ejected into the air.

Explosions from live bombs release many different contaminants to the air, which fall into four general categories: particulate matter, chemical by-products of explosions, metals, and the explosives themselves (e.g., TNT). Analyses later in this section describe how each type of contaminant is formed, the amounts that are released, and the amounts that might have been found in the air in the residential areas of the island.

The primary focus of this analysis is to characterize potential exposures that occurred during the time when the Navy used live bombs. Because the center of the LIA is located 7.9 miles away from the nearest residential areas of Vieques, all contaminants released from live bombs dispersed greatly in the air before reaching locations where they might be inhaled. Nonetheless, as this section shows, residents of Vieques were likely exposed to trace levels of various contaminants on days when live bombing exercises took place. The fact that exposure occurred does not mean that adverse health effects resulted. After all, residents of Vieques, like residents throughout the United States, are exposed to air contaminants from many sources of air pollution on a daily basis. The key question is not simply whether exposure occurred, but rather whether exposures occurred at levels that might be harmful to human health.

To quantify exposures to chemicals released by explosions, ATSDR first examined the available air sampling data, or measurements of what residents of Vieques might have actually breathed. Unfortunately, very few air samples were collected during the time when the Navy used live bombs, and documentation of these sampling studies is either incomplete or missing (see Appendix C.4, C.5, and C.6). As a result, ATSDR had to use air quality models to evaluate exposures to chemicals released from live bombing activities. ATSDR emphasizes that air quality modeling results only *estimate* air pollution levels and the model output may be higher or lower than actual levels. This is not to say, however, that models are not useful in the public health assessment process, because rigorous modeling studies can generate convincing, scientifically defensible conclusions. The utility of a given study depends on the limitations and uncertainties of the model selected and the assumptions made when running the model Thus, ATSDR carefully reviews these factors before making any conclusions based on modeling results.

ATSDR identified two existing air quality modeling studies that estimated air quality impacts from live bombing activities at Vieques. One was conducted by a contractor to the Navy (IT 2000, 2001), and the other by a local professional engineer (Cruz Pérez 2000). ATSDR critically reviewed these studies and identified strengths and weaknesses in both of them (see Appendix D.1 and D.2). To have the best information available for this PHA, ATSDR eventually decided to conduct its own air quality modeling study of how military training exercises using live bombs might have affected air quality at Vieques (see Appendix D.3). The following discussion summarizes ATSDR's findings, organized by four groups of contaminants:

- *Particulate Matter.* When live bombs explode at the ground surface, the energy released forms craters and ejects soil particles into the air. The amount of particles released depends on many factors, such as the total weight of high explosives in the bomb, whether the bomb explodes at or below the surface, and properties of the soil where the bomb is detonated. The particles released to the air vary in size, which causes them to move in the air differently. Much of the soil ejected from craters, for example, immediately returns to the ground in large clumps and does not blow to downwind locations. Other soil particles are ejected high into the air during an explosion and settle to the ground in the immediate vicinity of the crater. Finally, a small fraction of the particles are small enough that they can remain airborne for extended periods of time and thus blow with the wind toward the residential areas of Vieques.

To evaluate the public health implications of the particulate matter that live bombs released to the air, ATSDR first reviewed available air sampling data as documented in three air sampling studies that measured levels of airborne particles during the 1970s. As Appendix C.4., C.5, and C.6 indicate, none of these studies is well documented and the quality of the sampling results is not known. With no information on data quality, ATSDR decided not to base its conclusions on the limited sampling results.

Without sufficient sampling data to reach a conclusion, ATSDR decided to use modeling analyses to put potential exposures to particulate matter into perspective. Appendix D.3 describes ATSDR's modeling approach in detail. This modeling involved two steps: first estimating the amount of particulate matter released to the air and then predicting ambient air concentrations in the residential areas of Vieques. In its analysis, ATSDR used a model that the Army Research Laboratory has developed and enhanced over the last 15 years to estimate the amount of soil particles an explosion releases to the air (Army Research Laboratory 2000). This model has many desirable features, including the ability to estimate (although roughly) the size distribution of particles released to the air. ATSDR specifically used the model to estimate emissions of PM10, the particles most likely to transport longer distances.[8] ATSDR's estimated PM10 emission rate (280

[8] Particles larger than PM10 are more likely to deposit on the ground than blow several miles down wind. As a result, ATSDR did not model TSP emissions.

tons per year) is considerably higher than that documented in a dispersion modeling analysis performed by a Navy contractor (80 tons per year).

Estimated emissions of PM10 are not a direct measure of exposure, but they can be used with air quality models to generate reasonable estimates of ambient air concentrations. ATSDR used its emissions estimates as an input to the CalPUFF air quality model to predict what levels of exposure might take place in the residential areas of Vieques, both over the short term and the long term. The following paragraphs summarize the modeling results:

- *Annual average concentrations.* ATSDR's air quality model simulations indicate that the Navy's live bombing exercises at the LIA would have caused annual average PM10 concentrations in the residential areas of Vieques to increase by 0.04 $\mu g/m^3$. Recent air samples collected when no military training exercises occurred, however, indicate that annual average PM10 concentrations in Esperanza and Isabel Segunda are 35.7 $\mu g/m^3$ and 23.5 $\mu g/m^3$, respectively. Therefore, PM10 emissions from the past live bombing exercises at Vieques probably accounted for less than 1% of the total PM10 to which residents were typically exposed. Figure 9 illustrates this further in two pie charts. In short, the models suggest live bombing exercises at Vieques had little impact on long-term average PM10 exposures in the residential areas. More importantly, reasonable estimates of annual average PM10 concentrations in both Esperanza and Isabel Segunda are lower than 50 $\mu g/m^3$, EPA's health-based standard for annual average concentrations of particulate matter.

- *Maximum 24-hour average concentrations.* Recognizing that the nature and extent of military training exercise vary from day to day, ATSDR conducted additional modeling to determine whether increased PM10 emissions over the short term caused acute exposures that could present a public health hazard. To do so, ATSDR reviewed nearly 7 years of range utilization statistics to identify the day on which the largest amount (by weight) of explosive ordnance were used during a military training exercise. This search identified a day of operation on which the Navy dropped 38.9 tons of high explosives on the LIA. ATSDR used this level of bombing activity to evaluate the maximum 24-hour average air concentrations of particulate matter that may have occurred when the Navy used live bombs.

On this date, ATSDR constructed an upper-bound exposure scenario to evaluate the highest exposures that may have occurred. Appendix D.3 lists the assumptions made in this evaluation. In short, ATSDR derived a reasonable upper-bound estimate of emissions, or the amount of PM10 released to the air. ATSDR also reviewed 5 years of meteorological data to identify worst-case atmospheric dispersion conditions. Combined, both upper-bound assumptions suggested that this intense military training exercises using live bombs caused the 24-hour average PM10 concentration in residential areas to increase by 10.2 $\mu g/m^3$. This increase in PM10 concentrations, even when added to the highest PM10 concentration measured at Vieques to date (77 $\mu g/m^3$), suggests that maximum 24-hour PM10 concentrations in the residential areas likely did not exceed 87 $\mu g/m^3$—a level lower than EPA's 24-hour health-based standard (150 $\mu g/m^3$). ATSDR acknowledges that the uncertainty associated with predicting a maximum 24-hour concentration is typically greater than the uncertainty associated with predicting annual average concentrations. However, ATSDR notes that its estimated ambient air concentration is based on a series of events that occur infrequently (e.g., the highest level of bombing activity occurring on the day with both the least favorable meteorological conditions and the highest "background" concentration of PM10). The likelihood that these events truly coincide seems remote.

In summary, ATSDR thoroughly reviewed potential exposures to PM10, drawing from the best information readily available. **ATSDR's modeling suggests that, during the time the Navy conducted military training exercises using live bombs, residents of Vieques were not exposed to levels of particulate matter that could present a public health hazard, either over the long-term and the short-term.** In fact, on the majority of days bombing exercises took place, ATSDR estimates that emissions from the explosions at the LIA account for a very small fraction of the PM10 in the air 7.9 miles downwind in the residential areas of the island. Appendix D.3 presents extensive details on ATSDR's dispersion modeling analysis on which this conclusion rests.

- *Chemical By-products of Explosions.* During an explosion, chemical reactions not only consume high explosives in bombs, but they also form a variety of explosion by-products, both organic and inorganic chemicals. The overwhelming majority of the explosion by-products are generally benign from a public health perspective. Examples include water vapor, nitrogen, solid carbon, and carbon dioxide—all of which are relatively abundant in the atmosphere. Several researchers have estimated that these by-products tend to account for a very large proportion of the overall amounts of chemicals that explosions release (e.g., Bjorklund et al. 1998; Cooper 1996; Defense Nuclear Agency 1981).

To evaluate potential exposures to chemical by-products of explosions, ATSDR conducted a modeling analysis, because air quality measurements for almost all known explosion by-products are not available. As Appendix D.3 describes in detail, ATSDR's modeling analysis is based largely on studies that measured air emissions of explosion by-products for various types of high explosives. In these studies, called "Bangbox studies," explosives are detonated in an enclosed structure, after which the air within the

concludes that any increase in ambient air concentrations of metals that resulted from live bombing exercises are of no public health significance. Appendix D.3 presents a detailed account of the data ATSDR considered to reach this conclusion.

- *Explosives.* The live bombs used at Vieques contained high explosive charges of varying quantities. Once initiated, an explosion is a series of chemical reactions that rapidly consume the high explosive charge and release large amounts of energy. Explosives within the charge are chemicals with a structure and composition that greatly facilitates the chemical reactions (i.e., oxidation reactions) that occur during an explosion.

To estimate emissions and ambient air concentrations of explosives at Vieques, ATSDR first evaluated the proportion of explosive chemicals that are not consumed during an explosion and thus are available for downwind transport. In other words, ATSDR considered how efficient explosions are in destroying their high explosive charges. This efficiency has not been measured specifically for the bombing exercises at Vieques. However, researchers have reported that open burning and open detonation of explosives are much more than 99% efficient at destroying explosive chemicals (Radian 1996; Halliburton NUS 1995).

Appendix D.3 describes how ATSDR evaluated releases and atmospheric transport of the explosives the Navy has used at Vieques. Based on an assumed 95% destruction efficiency and the maximum explosive content of ordnance used in 1998, ATSDR estimated the following exposure point concentrations:

Explosive	Highest Estimated Air Concentration	Comparison Value
RDX	0.002 μg/m^3	0.057 μg/m^3 (RBC-c)
TNT	0.003 μg/m^3	0.21 μg/m^3 (RBC-c)
All others	< 0.0003 μg/m^3	NA

Notes: RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine (CAS #121-82-4)
The highest estimated air concentrations are the highest annual average concentrations estimated for locations in the residential areas of the island.
The comparison values used in this table are both Risk-Based Concentrations for carcinogenic effects developed by EPA Region 3. See Appendix A for more information on these comparison values.

These data show that the estimated ambient air concentrations for the explosives used in highest quantities are considerably lower than health-based comparison values, or levels that would require more detailed evaluations. Comparison of estimated annual average concentrations to the comparison values is appropriate, given that the comparison values are derived for long-term average exposure scenarios. In the table, "all other" explosives refer to various high explosive materials that comprise relatively small portions of high explosive charges. These include lead azide, HMX, and other impurities. The highest estimated ambient air concentrations for these compounds appear to be lower than highly sensitive sampling methods would be able to detect.

ATSDR recognizes that the ambient air concentrations listed above are estimates and some uncertainty was involved in deriving them. Arguably the most critical assumption was assigning a destruction efficiency of 95% to the live bombing activities. ATSDR notes, however, that estimated ambient air concentrations of explosives would still be lower than health-based comparison values when considering a very wide range of destruction efficiencies. For instance, even if the destruction efficiencies were 10% (an unrealistically low value), the estimated ambient air concentrations would still be lower than health-based comparison values. Thus, all reasonable estimates of destruction efficiencies would lead to the same conclusion: **Explosives in live bombs are chemicals**

that are largely destroyed during explosions. Reasonable modeling studies show that live bombing exercises did not release explosive chemicals at levels of health concern.

The previous analyses suggest that levels of air pollution at levels that could present a public health hazard did not occur on Vieques during the time when the Navy used live bombs. This conclusion is based entirely on ATSDR's air quality modeling study, which estimated ambient air concentrations that would result from live bombing exercises. Key assumptions, limitations, and uncertainties associated with the model are document throughout the previous paragraphs and, in far greater detail, in Appendix D.3. Though live bombing exercises release many contaminants, these contaminants disperse greatly in the air over the 7.9 miles that separates the center of the LIA from the nearest residential areas of the island. Contaminants disperse to even lower levels before they reach the more populated areas of Isabel Segunda and Esperanza, both located at further downwind distances.

Reasonable emissions estimates show that annual average concentrations of all contaminants considered were lower than corresponding health-based comparison values, often by very large margins. Increases of air pollution over the short term (i.e., on days with live bombing exercises) also were not at levels of health concern, even when considering releases from the most intense military training exercises.

Throughout this section, ATSDR has noted that air quality modeling studies can predict or estimate levels of air pollution, and modeling results should not be viewed as actual measurements of environmental contamination. Recognizing the limitations of environmental models, ATSDR usually recommends actions to reduce uncertainties in its public health evaluations based primarily on modeling results. However, past levels of air pollution obviously cannot be measured today. The best opportunity to reduce uncertainty in this analysis, therefore, is to collect air samples on days with live bombing exercises, if such exercises ever resume on

Vieques—a recommendation that ATSDR makes in Section IX of this PHA. ATSDR has no knowledge of whether or not such exercises will take place.

D. Exposures to Releases Associated with Other Activities

Key Question:

Does open burning and open detonation or the Navy's past or ongoing use of other chemicals (e.g., depleted uranium, chaff) pose a health hazard?

ATSDR's Response:

The following paragraphs present ATSDR's analyses of open burning and open detonation activities and the Navy's use of chemicals and materials other than those released by bombs. These latter analyses focus specifically on depleted uranium and chaff. The best available information suggests that open burning and open detonation activities and the usage of depleted uranium and chaff have not caused adverse health effects among residents of Vieques. In fact, estimated exposures to these materials are at levels considerably lower than levels believed to be harmful to human health.

Because the Navy continues to use chaff at Vieques, an opportunity exists to characterize potential exposures to chaff further. Accordingly, ATSDR recommends that PREQB continue to collect particulate air samples on Vieques and analyze these samples for aluminum, a main component of chaff.

- *Open burning and open detonation (OB/OD).* As Section III.D indicates, the Navy has conducted OB/OD operations on Vieques to treat both unused waste munitions (i.e., munitions that were never dropped on the LIA) and unexploded ordnance collected during range clearance activities (i.e., munitions that were dropped on the LIA but did not detonate). The data available on the extent of the OB/OD operations are limited. Based on queries of EPA's Biennial Reporting System and data documented in the Navy's dispersion modeling analysis (IT Corporation 2001), ATSDR found waste management statistics for the OB/OD operations for the years 1993, 1995, 1998, and 1999. Data from these years indicate that the highest annual amount of wastes treated in OB/OD operations was 30.945 tons.

ATSDR's evaluation of the OB/OD operations examined whether treating 30.945 tons of waste (whether waste munitions or unexploded ordnance) is expected to cause levels of air pollution to reach levels that could present a public health hazard, both over the short term and the long term. To evaluate short-term or acute exposures, ATSDR considered the possibility that the Navy uses OB/OD to treat 30.945 tons of waste munitions on a single day. Recognizing that emissions from OB/OD treatment of waste munitions are likely not considerably different from emissions from munitions detonated in military training exercises, ATSDR used its conclusion for live bombing exercises to evaluate how OB/OD treatment may have affected air quality. Specifically, because a single day of live bombing exercises involving 38.93 tons of high explosives did not appear to cause ambient air concentrations to reach levels that could present a pubic health hazard (see Section V.C), it is reasonable to assume that OB/OD treatments involving 30.945 tons of waste munitions annually also do not cause exposures that could present a public health hazard in the residential areas of Vieques. ATSDR believes this assumption is justified because the composition of waste material treated in OB/OD operations is similar to the composition of material in live bombs.

Regarding long-term or chronic exposures, ATSDR considered whether treating 30.945 tons of waste munitions over the course of a calendar year would contribute to levels of contamination that could present a public health hazard. To assess the impacts of these operations, ATSDR reflected on its findings for military training exercises involving live bombs, for which range utilization statistics indicate that the Navy detonated, on average, 353 tons of high explosives per year. In other words, the amount of high explosives treated in OB/OD operations at Vieques accounts for less than 10% of the amount of high explosives that were detonated during exercises involving live bombs. Based on these relative quantities, the OB/OD operations likely would account for only small increases (less than 10%) in the estimated ambient air concentrations shown in Tables 8 and 9 and Figure 9.[9] Such increases would not cause any of the estimated ambient air concentrations to exceed their corresponding health-based comparison values.

Overall, these analyses indicate that **OB/OD operations at Vieques, whether conducted to treat waste munitions or unexploded ordnance collected during range clearance activities, do not cause levels of air pollution that could present a public health hazard in the residential area of Vieques.**

- *Depleted uranium.* Over the last 2 years, ATSDR has received several inquiries about the public health implications of the use of depleted uranium (DU) penetrators on the LIA during a February 1999 military training exercise. Specifically, residents have expressed concern that ongoing exercises at Vieques might cause soils potentially contaminated with DU to become airborne and blow downwind to the residential areas of the island. The following paragraphs address these concerns, first by summarizing past DU usage at Vieques and then by evaluating potential exposures. Based on ATSDR's analyses, as

[9] As Appendix D.3 indicates, when estimating ambient air concentrations resulting from live bombing exercises, ATSDR assumed that every bomb used in an exercise detonated on the LIA. In reality, a small fraction of the bombs dropped do not detonate when dropped and remain on the LIA until range clearance operations collect these unexploded ordnance for waste treatment. As a result, ATSDR's dispersion modeling analysis for live bombing exercises actually accounts both for emissions during these exercises and emissions that result from treatment of unexploded ordnance.

well as analyses conducted by the U.S. Nuclear Regulatory Commission (NRC), **the amount of DU previously used at Vieques does not pose a public health hazard.**

Background information on DU. Uranium occurs in various chemical forms in nature. Naturally occurring uranium is actually a mixture of three different types (or isotopes) of uranium. All uranium isotopes are radioactive, meaning they are unstable and gradually decay through a series of transformations to form stable elements. Naturally occurring uranium is found at trace levels in rocks and soils throughout the world, including the rocks and soils on Vieques.

Many industries process uranium to create materials for various products and purposes. A by-product from some of these industrial processes is depleted uranium (DU). Like naturally occurring uranium, DU is a mixture of isotopes. However, it is mostly depleted of certain radioactive uranium isotopes. As a result, DU is considerably less radioactive than the uranium typically found in nature. DU has been used to make a variety of products, including some aircraft, certain types of sailboats, and protective shielding for industrial applications.

Because DU is a very dense material, the military uses DU in some types of ammunition, known as penetrators, which can travel through certain materials that other types of ammunition cannot. When fired upon tanks, rocks, or other hard objects, DU penetrators typically are crushed into fragments and dust and some of the DU may vaporize and ignite and eventually enter the air as aerosols (UNEP 1999). Because DU is dense, almost twice as dense as lead, it does not travel far in air and often deposits near its release point.

When fired upon dirt and sandy surfaces, however, DU penetrators generally are not destroyed. Rather, they remain largely intact and penetrate as far as 1 meter beneath the soil surface (UNEP 1999). The DU in these penetrators will remain in the soil for extended periods of time. Eventually, the DU in the soils will either transport to other locations by various natural environmental processes, be removed from the soils by some type of man-made intervention (e.g., a clean-up activity or a military training exercise), or remain in place and gradually decay to form more stable elements.

Usage of DU at Vieques. As Section III.D indicates, 263 DU penetrators were fired on the LIA during a military training exercise on February 19, 1999. These penetrators each contained 148 grams (about 0.33 pounds) of DU (Navy 1994). Overall, therefore, roughly 86 pounds of DU landed on the LIA. On March 5, 1999, the Naval Radiation Safety Committee notified the NRC of this unauthorized use of DU. Shortly thereafter, the Navy began an effort to remove all DU penetrators that could be identified in the LIA soils.

To date, the Navy has removed the equivalent of 116 DU penetrators from the LIA soils, leaving the equivalent of 147 DU penetrators not accounted for. Accordingly, 38 pounds of DU have been removed from the LIA, and 48 pounds of equivalent penetrators have not been recovered. The fate of the unrecovered penetrators is uncertain: they might have fragmented and become airborne shortly after their use, they might have been buried in soils and become airborne during later military training exercises, or they might still be buried in the LIA soils at depths beyond the range of equipment used to detect the penetrators. ATSDR scientists who toured the field where the DU penetrators were recovered noted that the area is covered with soils without large rocks or boulders—a surface that DU ammunition is known to penetrate without significant fragmenting.

Evaluation of potential non-radiological hazards. Studies of uranium toxicity have generally focused on two issues: whether uranium exposures present chemical hazards (to the kidney) and whether exposures presents radiological hazards. ATSDR considered both types of hazards when evaluating the public health implications of DU usage at Vieques. Findings specific to potential chemical hazards are presented first, followed by those specific to potential radiological hazards.

To evaluate the chemical hazards associated with potential exposures to DU, one must first know where the DU transports in the environment, and at what levels. In June 2000, the NRC evaluated this issue by collecting 114 environmental samples for analysis of uranium content. These samples were collected from soils, sediments, surface water, and vegetation in the LIA, on other Navy property, and on the residential areas of Vieques. All environmental samples were analyzed in a laboratory, using methods known to generate high quality observations of uranium concentrations. Representatives from the Puerto Rico Department of Health witnessed, and assisted with, the NRC involvement at Vieques. Based on its sampling results, NRC concluded that ". . . there was no spread of DU contamination to areas outside of the LIA and that contamination from the DU inside the LIA was limited to the soil immediately surrounding the DU penetrators" (NRC 2000).

ATSDR notes that NRC's findings are consistent with conclusions reached by the United Nations Environment Programme (UNEP) regarding the potential use of a similar quantity of DU penetrators in Kosovo in 1999 (UNEP 1999). Specifically, UNEP assembled a panel of international experts to examine the public health implications of the localized use of 22 pounds of DU—a scenario quite similar to the usage of DU at Vieques, where 48 pounds of DU have not been recovered. The UNEP analyses, which were based on modeling evaluations and not on sampling data, concluded that firing of 22 pounds of DU would cause no chemical toxic effects among people who did not visit the specific areas where DU penetrators were fired. UNEP evaluated whether people who inhale dusts when walking around a target area (after the DU penetrators had been fired) could breathe amounts of DU that might present a public health hazard. The UNEP conclusion was that the amounts of uranium inhaled in such circumstances, even by an individual who spent an entire year in the affected area, would not exceed levels known to cause chemical toxicity (UNEP 1999).

In addition to the NRC and UNEP analyses, ATSDR conducted its own evaluation of the specific community concern (i.e., whether ongoing military training exercises are causing harmful air releases of the unrecovered DU). To conduct this evaluation accurately, one would need to know how much DU is released to the air, but such information is not available. As a defensible estimation, ATSDR assumed that the entire mass of unrecovered DU at Vieques has been released to the air by the various military training exercises that have taken place since February 1999. In other words, ATSDR assumed that the entire 48 pounds of unrecovered DU has been released between the time the DU was fired and today. Based on this and other assumptions,[10] ATSDR estimated the DU emission rate to be no more than 0.017 pounds per hour. ATSDR emphasizes that this is an upper-bound estimate of the actual emission rate over the long term, because some of the unrecovered DU may still remain buried at depth.

Combining this estimated emission rate with the findings of ATSDR's air quality modeling analysis (see Appendix D.3), ATSDR estimates that the long-term average ambient air concentration of uranium in the residential areas of Vieques attributed specifically to the DU usage at the LIA is likely not greater than 0.000008 $\mu g/m^3$. This ambient air concentration is nearly 40,000 times lower than ATSDR's chronic inhalation minimal risk level (0.3 $\mu g/m^3$). In other words, the estimated amounts of uranium that

[10] For an upper-bound estimate, ATSDR assumed that military training exercises using practice bombs caused all of the unrecovered DU to be emitted to the air. To calculate an emission rate, ATSDR assumed that these exercises took place 16 hours per day on 90 days per year for 2 years of duration.

people of Vieques might breathe do not present a public health hazard, with a very large margin of safety.[11]

To put this estimated concentration into perspective, ATSDR calculated that a resident of Vieques might inhale a total of 56 nanograms (ng) of uranium per year from the past DU usage at the LIA—a finding based on the conservative assumption that all unrecovered DU from the LIA soils have been released by military training activities since February 1999. This estimated intake was calculated by multiplying the estimated air concentration by the average inhalation rate of an adult. As the table below shows, the estimated intake is considerably lower than the amounts of uranium that some people encounter in their daily lives:

Scenario	Estimated Uranium Intake
Estimated amount of uranium inhaled from releases of unrecovered DU from the LIA at Vieques	56 ng/year
Estimated amount of uranium inhaled from smoking two packages of cigarettes per week for a year	1,125 ng/year (a)
Estimated amount of naturally occurring uranium ingested in normal dietary intake	328,500 ng/year (b)

Notes: (a) Source of information: UNEP 1999.
(b) Source of information: ATSDR 1999a. Intake of naturally occurring uranium selected is the lowest estimate of average daily intake in Chapter 5.5 of the toxicological profile. Naturally occurring uranium is found at trace levels in a variety of food products throughout the United States and the world.

As the information above shows, the amounts of uranium that might be released from unrecovered DU penetrators and transported to the residential areas of Vieques are very

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[11] The exposure scenario considered above—releases of uranium over a 2-year time frame—was used to address the specific community concerns that ATSDR received. In addition to this scenario, ATSDR evaluated other scenarios, such as the entire unrecovered amounts being released on a single day or during a 2-week military training exercise. Those evaluations also found estimated ambient air concentrations of uranium considerably lower than their appropriate health-based comparison values (i.e., acute-duration and intermediate-duration comparison values). The assumptions made in these evaluations are very conservative, since some DU penetrators will likely remain buried and not be entirely released over durations considered in this evaluation.

low in comparison to the amounts of naturally occurring uranium that residents may encounter normally in their daily lives. Moreover, the estimated ambient air concentrations of uranium associated with past usage of DU penetrators are well below levels believed to cause adverse health effects in humans. Therefore, the DU penetrators that were fired at Vieques do not pose a health hazard in terms of their chemical toxicity.

Potential exposure to radiation as a result of DU usage. Because uranium is radioactive, ATSDR evaluates potential exposures to radiation at most sites where uranium contamination has been documented. ATSDR notes, however, that both naturally occurring uranium and DU are weakly radioactive, and people exposed to large amounts of these types of uranium typically experience chemical toxicity effects before they experience effects of radiation (ATSDR 1999a). To be thorough, ATSDR evaluated potential exposures to radiation as a result of the DU usage on Vieques.

Knowledge of the radiation that uranium emits is critical in evaluating the potential for adverse health effects to occur. When undergoing radioactive decay, all three isotopes of uranium that comprise DU release alpha particles (or alpha radiation) (ATSDR 1999a), and subsequent steps in the uranium decay series release other types of radiation. Alpha radiation has relatively low penetrating power and typically does not travel long distances in the environment. In fact, alpha particles typically travel less than 10 centimeters in air before they reach their resting point (ATSDR 1999b). Because the uranium isotopes in DU primarily emit alpha particles, decaying uranium at the LIA is expected to affect radiation levels only in very localized areas.

Analyses by NRC and UNEP confirm that DU penetrators tend to affect radiation levels only in their immediate proximity, with virtually no impacts observed even short distances away. For instance, based on its extensive sampling project witnessed by the Puerto Rico Department of Health, NRC concludes that ". . . members of the public [on

Vieques] could only have received a measurable dose from the DU penetrator event if they directly accessed a DU penetrator for extended periods of time" (NRC 2000). Similarly, UNEP concluded that radiation hazards among the population in Kosovo may exist for very limited scenarios, such as placing a DU penetrator in one's pocket and carrying it continuously for several weeks (UNEP 1999). Clearly, both exposure scenarios are not realistic for the population at Vieques and ATSDR concludes that no residents of the island are exposed to levels of radiation that could present a public health hazard as a result of past usage of DU penetrators during military training exercises.

ATSDR is aware that a recent press release from the Committee for the Rescue and Development of Vieques (CRDV) reports that levels of radiation on Vieques increased during certain military training exercises—an increase the authors seem to attribute to the past use of DU penetrators at the LIA (CRDV 2001). Specifically, this press release suggests that levels of radiation at certain parts of Vieques increased by as much as 248% during military training exercises that occurred between July and October, 2001. However, the press release does not indicate how levels of radiation were measured, what types of radiation were measured, and the actual amounts of radiation detected, all of which are critical considerations when evaluating data on radiation. ATSDR has contacted CRDV to learn more about this sampling effort (ATSDR 2001e), but did not receive a response in time to address specific information in this release of the PHA. ATSDR will evaluate CRDV's data in greater detail in future releases of this PHA if data are received in a timely fashion.

Although ATSDR cannot confirm that radiation levels increased on Vieques during recent military training exercises, ATSDR must emphasize that 248% increases in levels of radiation do not necessarily indicate that public health hazards are occurring. The more important indicator of exposure is the actual level of radiation, not the relative increase. However, ATSDR evaluated the public health implications of the reported increases in radiation nonetheless.

In June 2000, NRC made dose rate measurements of radiation at 29 locations of the residential areas of Vieques using a Ludlum Model 19 microR meter (NRC 2000). These observations were collected at a distance of 1 meter above the ground surface and the average exposure rate of the 29 measurements was 4 microroentgens per hour (μR/hour), which is approximately equal to 4 microrem per hour (μrem/hour). ATSDR will assume for the following analysis that this dose rate represents background levels of external radiation in the residential areas of Vieques.

If the CRDV data are 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. Even if ATSDR assumes this increase above background occurs 24 hours per day for 90 days per year (i.e., the maximum amount of time the Navy is currently allowed to 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 MRL for ionizing radiation. This MRL is an increase in ionizing radiation dose of 100 mrem above background per year. Based on this analysis, ATSDR does not believe that CRDV's press release necessarily indicates radiation exposures at levels of concern. However, to be certain of this finding, ATSDR would like to review the original data compiled by CRDV before issuing the final release of this PHA.

For perspective on the reported increases in radiation at Vieques, ATSDR notes that many activities that people undertake lead to increased exposures to radiation. Such increases are generally not viewed as unhealthy, but simply occur as people come closer to sources of radiation, such as the sun or certain medical equipment. For example, individuals who take round-trip flights across country typically receive increased radiation doses of 10 mrem during their air travel, by virtue of being closer to sources of cosmic radiation; and individuals who receive chest x-rays typically receive increased radiation doses of 14 mrem per procedure (ATSDR 1999b). Such increases due to single events are comparable to the increase in radiation that ATSDR calculated from the CRDV data collected on Vieques (see the previous paragraph). This comparison shows that periodic increases in exposures to radiation are not an adequate basis for judging whether adverse health effects might occur.

Finally, ATSDR notes that the levels of radiation measured in the study cited by CRDV appear to be well within background levels observed throughout the United States. Specifically, a press release other than CRDV's announced that the highest level of radiation measured during the recent survey on Vieques was 18 μR/hour (Fellowship of Reconciliation 2001), which is approximately equal to 18 μrem/hour. Not only are these levels comparable to survey readings collected elsewhere in the United States, but they are actually considerably lower than background measurements from many areas at elevations of several thousand feet, such as Denver, Colorado (ATSDR 1999b). Although this information suggests that the levels of radiation measured at Vieques do not appear to be notably elevated, ATSDR hopes to review data provided by CRDV for a more complete analysis of the matter.

Conclusion. Overall, ATSDR concludes that any exposures to uranium as a result of past usage of DU penetrators at Vieques are trivial in comparison to the daily exposures to naturally occurring uranium that residents experience through their diets and other activities. Further, ATSDR's conservative modeling analysis predicts that **any exposures to uranium are considerably lower than levels believed to cause either chemical or radiological health effects in humans—a finding that is consistent with studies published by NRC and UNEP.** Though the best information currently available indicates that levels of radiation on Vieques are not at levels of concern, ATSDR will review this finding further upon receipt of data collected by CRDV.

- *Chaff.* Both community members and various media reports have voiced concern about the public health implications of the Navy's use of chaff at Vieques. As Section III.D indicates, chaff is a material that the military uses to confuse radar signals, which allows aircraft to operate without being easily detected. Chaff is aluminum-coated glass fibers. Therefore, the main metallic elements in chaff are aluminum and silicon—two of the most abundant elements naturally occurring in the Earth's crust. Chaff fibers typically are 25 microns (μm) thick and between 1 and 2 centimeters long (Naval Research Laboratory 1999). In other words, chaff fibers are visible to the human eye and have the appearance of short, very fine, hair-like fibers.

  ATSDR searched various records on the Navy's usage of chaff both at Vieques and across the country. Nationwide statistics indicate that the Navy's annual average usage of chaff between 1991 and 1997 at all domestic installations was 133 tons of chaff per year (GAO 1998). This includes amounts of chaff that were released from aircraft (69 tons per year, on average) and from ships (64 tons per year, on average). Chaff usage statistics specific to Vieques are not documented in any of the reports that ATSDR was provided and reviewed. Thus, ATSDR can only conclude that the chaff usage at Vieques cannot be greater than 133 tons per year and is considerably lower than this amount, since several Navy installations other than Vieques also use chaff.

  At Vieques, the Navy uses chaff to conduct realistic military training exercises, in which hiding aircraft from radar sources is desired. During these exercises, chaff is intentionally released into the air in the offshore training area near the LIA. As Section III.D noted, the Navy prohibits chaff from being released directly over the island of Vieques and over the warning and restricted areas that extend several miles from the Vieques shoreline. Since the chaff is released at elevations where airplanes fly (i.e., several thousand feet above the ground), the fibers drift in the wind and remain airborne over long distances. In fact, a recent study has suggested that chaff fibers can transport aloft for hundreds of miles before depositing on the ground (GAO 1998). This observation is consistent with data from weather radar signals, which have detected chaff particles floating in the air at locations several hundred miles from where they were released. In short, when released high in the air, chaff fibers can drift over extremely large areas and are greatly dispersed before ever reaching the Earth's surface.

ATSDR notes that no researchers have quantified the fate of chaff used at Vieques (e.g., what amounts deposit on the island, and what amounts deposit in the ocean waters around the island). A general understanding of where chaff transports can be derived from some basic observations of the local geography. Specifically, the Earth's surface in the vicinity of Vieques (see Figure 1) is primarily covered with water. This observation, combined with knowledge that chaff released aloft can transport for hundreds of miles, suggests that much of the chaff used at Vieques probably deposits in waters surrounding the island, and a very small portion of the chaff that is released settles in the residential areas.

To address health concerns related to chaff, ATSDR conducted two evaluations of potential exposure scenarios. ATSDR's first evaluation interpreted the existing air sampling data for particulate matter to assess potential impacts of chaff fibers on air quality. Given the shape and composition of chaff, one would expect that its greatest impacts on air quality, if any, would be observed in the measured concentrations of particulate matter (and possibly aluminum and silicon). Though ATSDR would prefer to base toxicological evaluations of chaff on published data documenting responses to actual exposures, no extensive data exist on exactly how chaff affects people who come into contact it. In the absence of such data, ATSDR evaluates the public health implications of the Navy's usage of chaff by characterizing exposures to the overall material (as PM10) as well as to chaff's principal components (aluminum and silicon).

As Sections V.A and V.B explain, 360 air samples have been collected on Vieques and analyzed for particulate matter and not a single measurement has been at levels of potential health concern. The available sampling data, therefore, show no evidence of chaff significantly affecting concentrations of particulate matter on Vieques. ATSDR acknowledges, however, that only 51 of the 360 valid air sampling results were collected during military training exercises and ATSDR has no data on the corresponding amounts of chaff used during these exercises, if any.

ATSDR's second evaluation considered chaff usage statistics and reasonable assumptions about how chaff moves through the air to estimate potential ambient air concentrations of the material. In this evaluation, ATSDR assumed a variety of daily chaff usage rates and general transport behavior, namely the area and depth over which chaff might evenly disperse. Moreover, ATSDR assumed that all airborne chaff fibers break up into particles small enough to be considered PM10—or particle sizes small enough to be considered respirable. This assumption almost certainly leads to an overestimate of potential exposures, because chaff fibers probably do not break into hundreds of pieces when settling in the atmosphere. (Chaff fibers, which are typically between 1 and 2 centimeters long, would have to break into hundreds of pieces in order to be measured as PM10.)

Nonetheless, even under these assumptions that likely overstate potential exposures, ATSDR estimated that PM10 concentrations at Vieques would not increase by more than 4 $\mu g/m^3$ by virtue of chaff usage.[12] This figure should be viewed as an upper bound of the

[12] In this particular evaluation, ATSDR assumed that the Navy uses 1 ton of chaff per day of military training exercises. ATSDR notes that this daily usage rate, if it were to occur on the maximum number of days that the Navy is authorized to conduct exercises on Vieques (i.e., 90 days), would account for nearly 90% of the Navy's

actual air quality impacts of chaff: the increase in PM10 levels, if any, is probably much lower because chaff fibers almost certainly do not uniformly degrade into respirable particles. Regardless, an increase in PM10 of 4 $\mu g/m^3$ over the background levels observed at Vieques, even if such an increase occurred, would not lead to a public health hazard, either in terms of particulate matter or in terms of the metallic components of the fibers.

The outcome of ATSDR's evaluations is consistent with the general scientific understanding of chaff and how people might be exposed to it. For instance, a panel of independent experts from various universities and research institutes concluded that chaff fibers are too large to be inhaled into the lungs and are therefore not of health concern for inhalation exposure (Naval Research Laboratory 1999). The large particles would instead be collected in the mouth or nasal tract, and presumably may be ingested (or swallowed).

ATSDR notes that the amount of aluminum that might be swallowed by chaff depositing in the mouth or nose is trivial in comparison to the quantities of aluminum that people consume in food products and medicines. Specifically, given that chaff is 40% aluminum by weight, ATSDR's previous analyses suggest that ambient air concentrations of aluminum resulting from chaff usage are likely no higher than 2 $\mu g/m^3$ in the residential areas of Vieques (or half of the calculated increase in particulate concentrations, using conservative assumptions). This concentration should be viewed strictly as the highest estimated aluminum levels that might result from chaff usage.

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annual chaff usage *across the nation*. In short, the assumed usage rate is an overestimate of the actual chaff usage. Next, ATSDR assumed that the chaff disperses evenly over an area of 150 square miles—an area approximately three times as large as Vieques. ATSDR also assumed that the chaff disperses evenly in the lowest 2,000 feet of the atmosphere. These assumptions likely overstates exposures, since radar images and engineering analyses have demonstrated that chaff released from planes can remain aloft for extended periods of time and transport over much larger distances (GAO 1998).

ATSDR evaluated this potential exposure by considering people who breathe air containing large particles with 2 $\mu g/m^3$ of aluminum. Assuming all of these large particles deposit in the mouth and are swallowed, and assuming an average inhalation rate of 20 m^3/day, an individual in this scenario will ingest 15 milligrams of aluminum from this source in a given year. This annual ingestion intake is the same amount of aluminum that people ingest from a single tablet of buffered aspirin or antacid (ATSDR 1999c). Thus, the usage of chaff does not cause people to ingest amounts of aluminum that could present a public health hazard.

The previous review of sampling data and reasonable exposure scenarios all suggest 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. This conclusion is based on sampling data of limited duration and realistic calculations of potential exposures. Because the Navy likely will continue to use chaff in the offshore training area near Vieques, an opportunity exists to conduct additional sampling to help determine what impacts chaff usage has, if any, on the air that the residents breathe. As a result, ATSDR recommends that PREQB continue to collect and analyze air samples from Esperanza and Isabel Segunda. ATSDR specifically recommends that PREQB analyze its particulate samples for concentrations of aluminum, one of the major components of chaff (see Section IX).

VI. COMMUNITY HEALTH CONCERNS

An integral part of the public health assessment process is addressing community concerns related to environmental health. Throughout this process, ATSDR has been working with, and will continue to work with, the Vieques community to define specific health issues of concern. On multiple trips to the island, ATSDR has met with numerous individuals and organizations, including local officials, physicians, nurses, pharmacists, leaders of women's groups, teachers, students, fishermen, businessmen, and families. Meeting with community members was critical to identifying and understanding residents' health concerns.

This PHA has addressed four key questions that community members have repeatedly asked about inhalation exposures to contaminants from the Navy's bombing range at Vieques. ATSDR's other PHAs have addressed, or will address, community concerns regarding levels of contamination in other environmental media, including water, soils, and food items. These documents address the main concerns that ATSDR has received since first working on the island of Vieques.

In addition to the four key questions pertaining to air contaminants released from the LIA (see Section V), ATSDR has identified other community concerns that are relevant to the air exposure pathway. These additional concerns are summarized below in three questions, along with ATSDR's responses.

A. Is Water from Rainfall Collection Systems Safe to Drink?

ATSDR Response: The majority of residents on Vieques receive drinking water from the public water supply, which draws from surface water (Rio Blanco) on the main island of Puerto Rico. However, ATSDR has received accounts that some residents obtain drinking water using rainfall collection systems. The exact number of residents with such systems is not known. The following paragraphs address the public health implications of obtain drinking water from these rainfall collection systems.

Rainwater can be a safe and reliable source of drinking water and is used widely for this purpose throughout the Caribbean. However, the method of collecting and treating rainwater determines how safe the water is. Because rooftops are open to the air, a wide range of materials might settle on them. These materials include leaves, mold spores, dead insects, bird droppings, and particulate matter from local sources of air pollution. Some of these materials can contain significant bacterial contamination. Though dusts from the LIA might blow in the air for several miles and then settle on the rooftops in the residential areas of Vieques, analyses in Section V suggest that local sources of air pollution (e.g., motor vehicles) probably account for a majority of particulate matter in these areas.

The following discussion first outlines recommended sanitation practices for obtaining drinking water from rainfall collection systems and then presents ATSDR's specific comments on use of these systems on Vieques.

General Sanitation Practices

When rainwater falls on rooftops, it can wash the various materials that have settled onto the rooftops into the device used to collect the rainwater, usually a cistern or a storage tank. If residents consume the untreated water that first flows from the rooftops, they might be exposed to a wide range of disease-causing bacteria. As evidence of harmful exposures, scientists have suspected that an outbreak of salmonella in the West Indies resulted from residents drinking water from a rooftop collection system that was heavily contaminated with bird feces (Koplan et al. 1978). Many other accounts of diseases caused by water-borne pathogens have been attributed to use of poorly maintained rainfall collection systems. Therefore, consumption of untreated water from rooftop collection systems is not advised.

Various health and environmental agencies have published guidelines for ensuring that rainfall collection systems provide for a safe drinking water supply. Many of these guidelines involve minimal monetary investments to implement. The following suggestions are provided in several references on good sanitation practices for obtaining drinking water (e.g., Salvato 1982, Texas Water Development Board 1997, United Nations Environment Programme 1997):

- The water that initially flows from the rooftop likely contains the greatest amount of chemical and biological contamination, especially if the time between rainfalls is great. This water should be diverted from the water storage tank and should never be consumed. According to a United Nations document, ". . . water captured during the first 10 minutes of rainfall during an event of average intensity is unfit for drinking purposes" (United Nations Environment Programme 1997). Consumption of this water can be avoided by using diversion valves that cause the initial flow of water to bypass the storage tank.

- Some measures should be taken to periodically clean the various surfaces that might come into contact with the rainwater, including the rooftops and cisterns.

- The rainwater that is eventually collected should be filtered before entering the storage tank to remove gross impurities (e.g., leaves, insects). Separating and removing sediments in storage tanks is also recommended, as insoluble contaminants may pass through filters and then settle in the storage tanks. Finally, many agencies advise chemical treatment of collected water, such as chlorination.

By following these and other sanitation practices, residents of Vieques can ensure that drinking water provided by rainfall collection systems is relatively free of contamination, including contaminants from local sources (e.g., birds, insects, motor vehicles), as well as the much smaller quantities of contaminants that might transport from the LIA.

Information Specific to Vieques

Focusing specifically on Vieques, ATSDR has learned that some community members obtain drinking water from rooftop collection systems (Cherry and Ramos 1995), though detailed information on the extent to which this takes place is not available. It is ATSDR's understanding that most residents converted their collection systems into closed tanks that now store water provided by the public water supply, and not by local rainwater. However, some residents may still use rainwater from rainfall collection systems in addition to water from the public water supply. The main community concern about the rainfall collection systems is that dusts from the LIA might settle on rooftops and eventually contaminate the rainwater that is collected.

No sampling studies have been conducted to characterize the quality of water in rainfall collection systems on Vieques. Therefore, no firm conclusions can be drawn based on site-specific sampling data. ATSDR's response to this question addresses the general advantages and disadvantages of using rainfall as a source of drinking water. **If good sanitation practices are followed, rainfall collection systems on Vieques are expected to provide clean water that does not pose health hazards.**

ATSDR has collected many documents that list recommended sanitation practices for rainfall collection systems. Some of these documents address issues specific to water supplies in the Caribbean. For the residents' benefit, ATSDR has placed copies of two key documents in the records repositories for the Vieques site, which are located at Biblioteca Publica on Vieques, the Vieques Conservation and Historical Trust, and at the University of Puerto Rico School of Public Health.

B. Is Exposure to the Material in African Dust Unhealthy?

ATSDR's Response: The purpose of this PHA is to evaluate the public health implications of exposures to air contamination associated with the Navy's military training activities on Vieques. When evaluating this issue, however, some Vieques residents also expressed concern that "African dust storms" might influence air quality on the island. To be responsive to these concerns, ATSDR researched the potential impacts of these dust storms and reached the conclusions summarized below.

Public Health Implications of African Dust Storms

As Section III.E explains, many researchers have studied African dust storms, or events in which strong winds blow large amounts of dust from arid northern Africa soils into the air. Some dust clouds have been observed thousands of miles from Africa, including over areas in the Caribbean and the southeastern United States. ATSDR emphasizes that the presence of dust particles in the air does not imply that unhealthy exposures occur. The public health implications of the African dust storms depend on other factors, such as the amount of dust in the air, the duration of the storms, and the relative amounts of chemical and biological contaminants in these dusts.

Regarding the amount of dust in the air, authors of key studies on African dust storms have doubted that the levels of dust alone would exceed EPA's health-based standards for particulate matter (Prospero 1999a). However, they have hypothesized that the amount of African dust in the air, when added to particulate matter from local sources of air pollution, might lead to unhealthy levels of air pollution. This hypothesis has never been verified for Vieques. In fact, none of the particulate sampling studies conducted on Vieques (see Appendix C) have ever shown potentially unhealthy levels of particulate matter, as gauged by EPA's health-based National Ambient Air Quality Standards. Moreover, the historical record of particulate sampling along the eastern shore of the main island of Puerto Rico reveals a similar trend (see Appendix

C). These consistent trends among the sampling studies suggest that **levels of particulate matter on Vieques have not reached levels that could present a public health hazard, even during African dust storms.** This finding should be verified by ongoing review of sampling data collected on the island.

Unfortunately, less information is available on the chemical and biological makeup of dust particles during these African dust storm events. ATSDR has identified studies indicating that the dust particles contain various minerals, and even traces of bacteria and viruses (Griffin et al. 2001). These studies have speculated about potential public health impacts, but no link between adverse health effects and the components of African dust has been established. ATSDR believes its recommendation for sampling of airborne metals (see Section IX) will address the data gap on the mineral content of African dust, and ATSDR supports further research into the type and amounts of biological material (e.g., bacteria, viruses) that may be transported with African dust.

Relative Amounts of Particulate Matter from African Dust Storms and from the LIA

Some community members have asked ATSDR to explain how it is possible that two different sources of air pollution located thousands of miles apart (i.e., the LIA and Africa) can have similar impacts on air quality at Vieques. The key to understanding this issue is that the LIA and African dust storms release dramatically different quantities of particulate matter.

Though emissions from both sources cannot be measured directly, emissions estimates suggest that African dust storms release far more particulate matter to the air than the Navy's military training exercises. Specifically, the Navy has estimated that its operations at Vieques release 70 tons of PM10 to the air per year (IT 2000). On the other hand, researchers have estimated that African dust storms release between 100,000,000 and 1,000,000,000 tons of particulate matter to the air per year (Shinn et al. 2000). Assuming the emissions estimates quoted above are reasonably accurate, the data suggest that African dust storms may release more than 1,000,000 times as much particulate matter as does the LIA.

Therefore, even though the source of African dust is several thousand miles away from Vieques, the fact that African dust storms release dramatically higher levels of particulate matter explains why they can have noticeable impacts on air quality in the Caribbean, even when local sources of air pollution (e.g., the Navy's military training exercises) might have little air quality impacts at distances as short as 7.9 miles from the source.

C. Can ATSDR Provide General Information on Asthma and Air Pollution?

ATSDR's Response: Asthma is a common, and potentially deadly, chronic (or long-term) lung disease. A person with asthma might suffer from "asthma attacks." These attacks can vary in frequency and severity. Some people with asthma have attacks often, while others have them rarely. Less severe asthma attacks result in difficultly breathing, tightness in the chest, coughing, and wheezing. More severe asthma attacks can be life-threatening if a person stops breathing. As a result, it is very important for a person with asthma to get help from a doctor to manage the disease. This is especially important for children with asthma, who have been found to be a sensitive sub-population for acute responses to outdoor air pollution (Clark et al. 1999).

No one has determined exactly what causes some people to have asthma and other people to not have the disease. However, scientists have identified many "asthma triggers" that are known to cause people with asthma to have asthma attacks. Different people are affected by different asthma triggers, and a doctor can help determine which asthma triggers appear to be a problem for a given person. The following list identifies some (but not all) of the known or suspected asthma triggers:

- Indoor air contaminants: mold, tobacco smoke, household chemicals, dust, and allergens from pets and insects.

- Outdoor air contaminants: particulate matter, pollen, and ozone.

- Other factors: sinus infections, certain medications, and food additives.

Though outdoor air pollution can trigger asthma attacks, the extent to which outdoor air pollution causes people to have asthma in the first place is unclear. As evidence of this, asthma occurs in areas with relatively low levels of air pollution. Further research is needed to understand to what extent outdoor air pollution affects whether or not a given person has asthma.

ATSDR notes that its review of outdoor air pollution on Vieques was based in part on EPA's health-based National Ambient Air Quality Standards. EPA developed these standards to protect public health, including the health of potentially sensitive populations, like asthmatics. Therefore, ATSDR's analyses found that **levels of particulate matter on Vieques do not present a public health hazard, even for people who have asthma.** However, ATSDR acknowledges that some asthmatics with extreme sensitivities might have attacks triggered by low levels of pollution. Recognizing that asthma is potentially serious and needs to be treated correctly, ATSDR urges all individuals with asthma—on Vieques and elsewhere in Puerto Rico and the United States—to work with a doctor to set up an asthma management plan. Following such a plan can help keep asthma under control.

Other Community Concerns:

ATSDR is committed to addressing additional community concerns relevant to environmental health issues, as these concerns arise. Vieques residents can direct their health concerns to ATSDR either in writing or via the telephone. Please submit written questions and inquiries to:

Program Evaluation, Records and Information Services Branch
ATSDR, Division of Health Assessment and Consultation
Attn: Isla de Vieques, Puerto Rico
1600 Clifton Road, NE (E-32)
Atlanta, GA 30333

Community members can also call ATSDR either by contacting our regional representatives in New York, New York, at (212) 637-4307 or by calling our toll-free telephone number, 1-888-42-ATSDR (or 1-888-422-8737).

VII. ATSDR CHILD HEALTH INITIATIVE

Because children often are at greater risk than adults for being exposed to toxic chemicals, and because more than 10% of the residential population at Vieques is children (age 6 and under), ATSDR's exposure and public health evaluations for this site specifically considered children's health issues. In general, children are more likely than adults to suffer from adverse health effects due to environmental exposure for several reasons, such as:

- Children's developing bodies can be particularly sensitive to toxic exposure during certain critical growth stages, especially when children are exposed to chemicals known to cause developmental effects (e.g., lead).

- Children weigh less than adults. As a result, when children and adults ingest or inhale the same amount of chemicals, children receive a greater dose (on a pound of contaminant per pound of body weight basis) than adults. For many chemicals, this higher dose causes a greater likelihood for developing adverse health effects.

- Because children play outdoors more than adults, they are often more likely to come into contact with contaminated soils and to inhale greater amounts of airborne pollutants.

For these reasons, ATSDR specifically considered children's health issues in two critical steps of the public health assessment process. First, when comparing levels of air pollution to health-based comparison values (e.g., see Table 4), ATSDR identified comparison values that are protective of children's exposures and of health conditions more common in children (e.g., asthma), to the extent they are available. For instance, ATSDR used EPA's air quality standards for particulate matter and lead when evaluating the air sampling data on Vieques. These standards were developed to protect the health of sensitive populations, including children.

Second, when evaluating scenarios with ambient air concentrations that exceeded or were near to health-based comparison values, ATSDR's toxicological evaluations considered the most current information on health hazards associated with exposures, usually as documented in the "Children's Susceptibility" section of ATSDR's *Toxicological Profiles*.

With this approach, ATSDR ensured that its review of environmental health issues would consider any specific children's health issues at Vieques. Although ATSDR found that children on Vieques are exposed to environmental contamination from many different sources, the levels of inhalation exposures are far too low to cause adverse health effects. **In other words, ATSDR's evaluations found no evidence that chemicals released from the Navy's military training exercises pose any unique health hazards for children.** Nonetheless, as a prudent public health measure, ATSDR recommends that air sampling continue to take place at Vieques to ensure that exposures that might present a public health hazard do not occur among the population, including children. Section IX of this report provides more details on this recommendation.

VIII. CONCLUSIONS

This PHA evaluates potential inhalation exposures to air contaminants released from the Navy property on Vieques. ATSDR has been examining, and continues to examine, potential exposures to contamination from other environmental media (e.g., drinking water, soil, and food products). After completing its evaluations, ATSDR will assess the public health implications of the cumulative or overall exposures from the other potential pathways the agency has considered.

For the air exposure pathway, ATSDR concludes the following:

- As of the writing of this report, more than 250 valid air samples have been collected on Vieques on days when bombing exercises do not take place. All samples have shown that levels of particulate matter are much lower than health-based air quality standards. Thus, wind-blown dust from the LIA is not a health hazard on days without military training exercises.

- Military training exercises using *practice bombs* release various contaminants to the air, but the available sampling data indicate that ambient air concentrations of particulate matter, metals, and explosives do not reach levels that present a public health hazard. Additional sampling data are needed to characterize potential exposures during these exercises more thoroughly.

- The past military training exercises involving *live bombs* released many contaminants to the air, but most dispersed to extremely low concentrations over the 7.9 miles that separate the center of the LIA from the nearest residential areas of Vieques. ATSDR's best estimates of ambient air concentrations suggest that past exposures during the live bombing exercises were at levels below those associated with adverse health effects. This conclusion is based entirely on modeling results and therefore involves some uncertainty, though ATSDR believes its approach to evaluating the live bombing exercises provides a reasonable account of past exposures.

- Though open burning and open detonation operations to treat unused munitions and unexploded ordnance have undoubtedly released contaminants to the air, these operations account for a small fraction (<10%) of the high explosives that were previously detonated during military training exercises using live bombs. ATSDR's modeling analysis indicate that emissions from the open burning and open detonation operations do not cause levels of pollution that could present a public health hazard in the residential areas of Vieques.

- Residents of Vieques are not exposed to levels of environmental contamination that could present a public health hazard, whether chemical or radiological, as a result of the Navy's limited past use of depleted uranium penetrators during military training exercises. Further, no adverse health effects are expected to result from the Navy's usage of chaff, because this material disperses considerably between the time it is released (several thousand feet above sea level) and the time it settles to the ground. Ambient air sampling during future military training exercises can provide additional insights into potential exposures associated with chaff.

- Overall, ATSDR found that the residents of Vieques have been exposed to contaminants released during the Navy's military training exercises, but these exposures are far lower than levels known to be associated with adverse health effects. As a result, ATSDR finds that the air exposure pathway at Vieques presents **no apparent public health hazard**.

Aware of the level of community health concerns at Vieques, ATSDR is committed to reviewing additional air sampling data and health outcome data as they become available. The Public Health Action Plan (Section IX) outlines future actions that various agencies will take to evaluate environmental health issues at Vieques.

IX. PUBLIC HEALTH ACTION PLAN

The Public Health Action Plan for Vieques describes specific actions that have been taken, are scheduled to take place, or should be taken by numerous parties, including ATSDR, EPA, PREQB, PRDOH, and the Navy. The purpose of this Public Health Action Plan is to ensure that this PHA not only identifies potential public health hazards, but also produces a plan of action to mitigate and prevent harmful human health effects that may be resulting from exposure to hazardous substances in the environment. The following list identifies the public health actions that have been completed, that are ongoing, and that ATSDR recommends take place:

Actions Completed:

- Ambient air sampling has been conducted by various parties, including ATSDR, PREQB, and the Navy.

- In August 1999, ATSDR conducted its initial site visit to Vieques to meet with the petitioner, to tour the island and the bombing range, and to gather available environmental data. ATSDR accepted the resident's petition and initiated the PHA process.

- In September 2000, ATSDR met with various agencies, including PRDOH, PREQB, EPA, and the Navy to gather data and to discuss the scope and nature of ATSDR's health assessment activities. ATSDR also toured various sites on Vieques with the petitioner.

- In June and October 2000, ATSDR discussed public health concerns with local health care providers and provided training about how to medically assess environmental exposures. During these visits, ATSDR also met with numerous residents to discuss health concerns.

- In February 2001, ATSDR released the public comment version of the Public Health Assessment for the Drinking Water Supplies and Groundwater Pathway Evaluation. In March 2001, ATSDR held a public availability session to meet individually with community members to discuss the findings of this document. In October 2001, ATSDR released the final version of this PHA.

- In July 2001, ATSDR, the Ponce School of Medicine, and the Centers for Disease Control and Prevention sponsored an expert review panel to address whether an association existed between place of residence (Vieques or Ponce Playa) and morphological cardiovascular changes among fishermen. In October 2001, ATSDR released a report summarizing this expert panel review.

- In September 2001, ATSDR conducted additional community involvement activities to inform participants of the scope of ATSDR investigations and to seek additional community input. Continuing education on public health training was offered to nurses on Vieques and environmental health instruction was provided to parents and high school students.

- In October 2001, ATSDR released the public comment version of the Public Health Assessment for the Soil Pathway Evaluation.

Actions Ongoing:

- ATSDR is currently assessing potential exposures to environmental contamination in locally caught fish and shellfish. ATSDR plans to issue a PHA on this topic in the summer of 2002.

- ATSDR is continuing to meet with various community members and organizations to receive concerns and exchange information. This effort will continue throughout the public health assessment process.

- ATSDR is continuing to meet with local health care providers to discuss health concerns for the community and to provide educational materials for addressing the community's health needs.

- PRDOH is updating its cancer registries for all of Puerto Rico, and specifically for Vieques, by gathering and documenting information on the incidence of cancer. ATSDR does not know when these updates will be completed.

Recommendations for Further Action:

- To provide more information on long-term exposures to air contaminants, ATSDR recommends that PREQB continue its routine air sampling of particulate matter and metals in Esperanza and Isabel Segunda.

- To provide more information on short-term exposures to air contaminants during military training exercises involving practice bombs, ATSDR recommends that PREQB continue to collect air samples for particulate matter and metals daily during these exercises. ATSDR recommends that the Navy coordinate similar sampling on its property, such that researchers can identify the sources of air pollution that contribute most significantly to the measured levels of contamination. ATSDR recommends that such a sampling study take place during a typical exercise involving practice bombs.

- Several recent press releases have suggested that the Navy might conduct military training exercises using live bombs in the future. ATSDR has no knowledge whether or not live bombing will ever resume at Vieques. If it does, ATSDR recommends that PREQB collect daily samples in Esperanza and Isabel Segunda of particulate matter, metals, volatile organic compounds, and semi-volatile organic compounds. Moreover, ATSDR recommends that the Navy coordinate similar sampling on its property such that researchers can identify sources that most likely contribute to air concentrations of contaminants that are detected.

- ATSDR recommends that any residents using rainfall collection systems for a drinking water supply read the documents that ATSDR has placed in the records repositories regarding good sanitation practices for harvesting rain water. These good sanitation practices will help ensure that water obtained from these systems is safe to drink and relatively free of contamination from all local sources.

- ATSDR plans to review cancer registry information and data gathered by PRDOH. This review will consider the data documented in ATSDR's PHAs and will evaluate the general health status of the communities on Vieques. ATSDR's review will follow the official release of PRDOH's review of the cancer registries, but it is not known when this will occur.

- ATSDR will periodically review air sampling data that PREQB and other parties collect at Vieques, as these data become available. In particular, ATSDR will review ambient air monitoring data that PREQB has collected on metals, once those become available.

- After completing the pathway-specific PHAs, ATSDR will prepare a brief summary of environmental health issues for Vieques.

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TABLES

Table 1
1990 and 2000 US Census Data for Vieques

Parameter	1990 Census Data		2000 Census Data	
	Number of Residents	Percent of Total Residents	Number of Residents	Percent of Total Residents
Total residents	8,602	100%	9,106	100%
Men	4,234	49%	4,512	50%
Women	4,368	51%	4,594	50%
Women of childbearing age	1,766	21%	1,701	19%
Children	1,106	13%	1,001	11%
Elderly	993	12%	1,263	14%

Sources of data: US Bureau of the Census 1990, 2000.

Notes: According to the 1990 census data, 2,056 families lived on Vieques. In 2000, this number increased to 2,366.

Both the 1990 and 2000 census data include residents living on Navy lands and in the residential area.

Definitions: Women between the ages of 15 and 44 are considered of childbearing age.

Children are residents who are 6 years old or younger.

The elderly includes all residents of age 65 and older.

Table 2
Toxic Release Inventory (TRI) Data for Vieques

Year	Name of Facility (as Listed in TRI)	Chemical Released	Air Releases (pounds per year)
1987	GE Co. Caribe	1,1,1-Trichloroethane	9,314
1988	GE Co. Caribe	1,1,1-Trichloroethane	8,400
1989	*No data reported for the island of Vieques*		
1990	GE Co. Caribe	1,1,1-Trichloroethane	10,900
1991	Caribe GE Distribution Transformers Inc.	1,1,1-Trichloroethane	10,500
1992	Caribe GE Distribution Transformers Inc.	Copper	0
1993	Caribe GE Distribution Transformers Inc.	Copper	0
1994	Caribe GE Distribution Transformers Inc.	Copper	0
1995	Caribe GE Distribution Transformers Inc.	Copper	5
1996	GE Power Protection of PR	Copper	15
1997	GE Power Protection of PR	Copper	30
1998	GE Power Protection of PR	Copper	30
1999	GE Power Protection of PR	Copper	30

Source of data: EPA 1997, 2001.

Notes:
The table lists only the air releases that facilities in Vieques reported to TRI.
For reporting years 1987 through 1995, the "name of facility" is taken from one source of data (EPA 1997); for reporting years 1996 through 1999, it is from another (EPA 2001). Release data for more current years are not yet publicly available.
TRI data are self-reported; the accuracy of the release data for individual facilities is not known.
The TRI regulations require facilities in certain industries to disclose releases of specific hazardous chemicals and selected waste management activities. However, the regulations do not require that all facilities report, and do not address all contaminants, which is presumably why the table does not account for other emissions sources on Vieques. Therefore, the data in this table should not be viewed as a comprehensive emissions inventory for Vieques.
Releases of zero pounds suggest that the facility manufactured, processed, or otherwise used the chemical in large enough quantities to trigger TRI reporting, but none (or less than 0.5 pounds per year) were estimated as being released to the air.

Table 3
Summary of Air Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Potential Source of Contamination	Environmental Media	Point of Exposure	Route of Exposure	Exposed Population		
Potential Exposure Pathways							
Inhalation of contaminants in wind-blown dust when bombing does not occur (see Section V.A)	Wind-blown dust from the LIA	Air: transport from the LIA downwind to residential locations	Ambient air	Inhalation	Residents of Vieques	Entire history of Navy operations	Extensive sampling collected by PREQB has shown that levels of wind-blown dust on days without military training exercises are not of public health concern.

Table 3 (Continued)
Summary of Air Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Potential Source of Contamination	Environmental Media	Point of Exposure	Route of Exposure	Exposed Population		
Inhalation of contaminants released on days when the Navy conducts military training exercises using *only* practice bombs (see Section V.B)	Military training exercises at the LIA using practice bombs	Air: transport from the LIA downwind to residential locations	Ambient air	Inhalation	Residents of Vieques	Exposures have only occurred on the days since April 1999 when military training exercises occur. This is limited to no more than 90 days per year.	PREQB has collected numerous air samples on days when the Navy conducted training exercises using practice bombs. These samples indicate that levels of particulate matter have not reached levels that could present a public health hazard on days when practice bombs are used. The air sampling results, combined with soil sampling data, also indicate that exposures to metals and explosives are not of health concern on days when practice bombs are used.

Table 3 (Continued)
Summary of Air Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Potential Source of Contamination	Environmental Media	Point of Exposure	Route of Exposure	Exposed Population		
Inhalation of contaminants released on days when the Navy conducted military training exercises using live bombs (see Section V.C)	Military training exercises at the LIA using live bombs	Air: transport from the LIA downwind to residential locations	Ambient air	Inhalation	Residents of Vieques	Dates of bombing exercises between 1941 and April 19, 1999	Modeling analyses of reasonable exposure scenarios indicate that the military training exercises involving live bombs did not result in exposures at levels of health concern for all categories of contaminants considered, including particulate matter, chemical by-products of explosions, metals, and explosives.
Inhalation of contaminants released during open burning and open detonation (see Section V.D)	Open burning and open detonation of waste munitions and unexploded ordnance	Air: transport from the LIA downwind to residential locations	Ambient air	Inhalation	Residents of Vieques	On isolated days from at least the early 1970s through the present	Modeling analyses of reasonable exposure scenarios indicate that the limited open burning and open detonation activities have not resulted in exposures at levels of health concern for all categories of contaminants considered, including particulate matter, chemical by-products of explosions, metals, and explosives.

Table 3 (Continued)
Summary of Air Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Potential Source of Contamination	Environmental Media	Point of Exposure	Route of Exposure	Exposed Population		
Inhalation of contaminants used sporadically during military training exercises (see Section V.D)	Past firing of depleted uranium penetrators and ongoing use of chaff.	Air: transport from the LIA (for depleted uranium) and in upper air winds patterns (chaff) downwind to residential locations	Ambient air	Inhalation	Residents of Vieques	Depleted uranium: limited to the date when the rounds of concern were used, and dates thereafter; chaff: on dates when the Navy uses the material during military training exercises.	Modeling analyses of reasonable exposure scenarios indicate that the amounts of depleted uranium that were fired at Vieques and the amounts of chaff that have been released to the air do not result in exposures (either chemical or radiological) at levels of health concern in the residential areas of Vieques.

Note: Indirect exposures to air contaminants in other media (groundwater, soil, biota) are being addressed in other PHAs.

Table 4
Estimates of *Annual Average* Ambient Air Concentrations of Metals on Vieques When Military Training Exercises Do Not Take Place

Refer to footnotes at the end of the table before interpreting any of the data presented below.				
Element	Average Concentration of Element in LIA Surface Soils (ppm, by weight)	Estimated Annual Average Air Concentration of Element in PM10 (μg/m^3)	Health-based Comparison Value (μg/m^3)	Type of Comparison Value
Aluminum	16,200	0.58	3.7	RBC-n
Antimony	1.14	0.00004	1.5	RBC-n
Arsenic	7.87	0.0003	0.0002	CREG
Barium	105	0.004	0.51	RBC-n
Beryllium	0.241	0.000009	0.0004	CREG
Boron	15.7	0.0006	210	RBC-n
Cadmium	1.71	0.00006	0.0006	CREG
Chromium	37.8	0.0013	5500	RBC-n
Cobalt	14.6	0.0005	0.1	EMEG-c
Copper	39.1	0.0014	150	RBC-n
Iron	33,500	1.2	1,100	RBC-n
Lead	8.49	0.0003	1.5	NAAQS
Manganese	723	0.026	0.04	EMEG-c
Mercury	0.0216	0.0000008	0.2	EMEG-c
Nickel	15.9	0.0006	0.2	EMEG-c
Scandium	12.5	0.0005	NA	NA
Selenium	1.23	0.00004	180	RBC-n
Strontium	156	0.0056	2200	RBC-n

Table 4 (Continued)
Estimates of *Annual Average* Ambient Air Concentrations of Metals on Vieques When Military Training Exercises Do Not Take Place

Refer to footnotes at the end of the table before interpreting any of the data presented below.				
Element	Average Concentration of Element in LIA Surface Soils (ppm, by weight)	Estimated Annual Average Air Concentration of Element in PM10 (μg/m³)	Health-based Comparison Value (μg/m³)	Type of Comparison Value
Tin	4.87	0.0002	2200	RBC-n
Titanium	1,650	0.059	310	RBC-n
Vanadium	106	0.0038	0.2	MRL
Yttrium	20.8	0.0007	NA	NA
Zinc	47.5	0.0017	1100	RBC-n
Zirconium	59	0.0021	NA	NA

Notes: The "average concentration of element in LIA surface soils" is taken from ATSDR's previous analysis of soils contamination (ATSDR 2001b).
The "estimated annual average air concentration of element in PM10" is the product of the values in the first two columns.
The "estimated annual average air concentration of element in PM10" was calculated by multiplying the annual average air concentration of PM10 in Esperanza (35.7 μg/m3, see Appendix C.1) and the average concentration of the element in LIA soils. This product was divided by 1,000,000 to convert the estimated concentration into units of μg/m3.
The "type of comparison value" indicates the reference for the comparison value selected (see Appendix A). Abbreviations used in this field are:
CREG: ATSDR cancer risk evaluation guide
EMEG-c: ATSDR environmental media evaluation guide for chronic exposure
MRL: ATSDR Minimal Risk Level
NAAQS: EPA National Ambient Air Quality Standard
RBC-n: EPA Region 3 risk-based concentration for noncancer effects
NA: Scandium, yttrium, and zirconium do not have relevant health-based comparison values.
The comparison value for "chromium" is for trivalent chromium, not hexavalent chromium. See Section V.A for an interpretation of this selection.

Table 5
Estimates of *Annual Average* Ambient Air Concentrations of Explosives on Vieques When Military Training Exercises Do Not Take Place

Refer to footnotes at the end of the table before interpreting any of the data presented below.

Chemical	Average PM10 Concentration at Esperanza (μg/m³)	Average Concentration of Chemical in the LIA Soils (ppm, by weight)	Estimated Annual Average Air Concentration of Chemical in PM10 (μg/m³)	Health-based Comparison Value (μg/m³)	Type of Comparison Value
2-Amino-4,6-dinitrotoluene	35.7	0.62	0.00002	0.22	RBC-n
HMX	35.7	0.39	0.00001	180	RBC-n
Nitroglycerin	35.7	8.1	0.0003	0.45	RBC-c
RDX	35.7	0.41	0.00002	0.057	RBC-c
TNT	35.7	2.85	0.0001	0.21	RBC-c

Notes: The "average PM10 concentration at Esperanza" is based on the PREQB 2000–2001 sampling results (see Appendix C.1).
The "average concentration of chemical in the LIA soils (ppm, by weight)" is the average concentration of explosives in soil samples collected at the LIA reported in the PHA on soil contamination (ATSDR 2001b).
The "estimated annual average air concentration of chemical in PM10" is the product of the values in the first two columns.
The "health-based comparison value" is a toxicity screening value (see Section IV.B and Appendix A for more details).
The "type of comparison value" indicates the reference for the comparison value selected (see Appendix A). Abbreviations used in this field are:
RBC-c: EPA Region 3 risk-based concentration for cancer effects
RBC-n: EPA Region 3 risk-based concentration for noncancer effects

Table 6
Ambient Air Concentrations of Particulate Matter in the Residential Areas of Vieques

Parameter	Summary of PREQB's Sampling Results					
	Data Collected in Esperanza			Data Collected in Isabel Segunda		
	Average Concentration (μg/m³)	Concentration Range (μg/m³)	Number of Samples	Average Concentration (μg/m³)	Concentration Range (μg/m³)	Number of Samples
Summary statistics for total suspended particulates (TSP)						
Sampling results for days without military training exercises	41.3	17–163	77	33.0	14–177	79
Sampling results for days with exercises using only practice bombs	53.3	25–124	15	43.8	18–105	10
Summary statistics for particulate matter smaller than 10 microns (PM10)						
Sampling results for days without military training exercises	35.0	14–64	75	21.6	10–60	78
Sampling results for days with exercises using only practice bombs	40.1	22–77	13	34.7	11–94	13

Notes: Data Source: See Appendix C.1.

Dates with "exercises using only practice bombs" were determined from Navy range utilization statistics. Dates on which air-to-ground or ship-to-shore firing of "non-explosive ordnance" were considered as being exercises using only practice bombs.

ATSDR ran t-tests to determine if statistically significant differences existed between the average concentrations listed above. These tests revealed that the differences in TSP levels at Esperanza and Isabel Segunda and the differences in PM10 levels at Esperanza were not statistically significant (p-level > 0.05). At Isabel Segunda, the average PM10 concentration during training exercises using practice bombs was greater than the average concentration when no practice bombs were used ($p = 0.0005$).

Table 7
Correlation Between Weight of Bombs Dropped and Air Sampling Results

Date	Total Weight of Non-Explosive Ordnance Used (tons)	24-Hour Average Ambient Air Concentrations Measured by PREQB ($\mu g/m^3$)			
		TSP Concentrations in Esperanza	TSP Concentrations in Isabel Segunda	PM10 Concentrations in Esperanza	PM10 Concentrations in Isabel Segunda
8/4/00	0.67	51	No sample	50	No sample
8/16/00	7.03	78	30	No sample	23
10/15/00	2.39	32	24	22	11
5/1/01	1.13	25	24	22	12
6/18/01	12.75	57	No sample	55	39
8/2/01	5.85	45	31	39	No sample
8/3/01	4.80	36	No sample	30	No sample
8/4/01	2.77	56	No sample	47	33
8/6/01	34.01	25	18	22	14
8/7/01	19.06	87	69	77	60
8/8/01	6.17	124	105	No sample	94
9/28/01	12.89	40	43	32	28
10/4/01	1.14	50	51	50	47
10/10/01	0.06	No sample	No sample	No sample	26

Table 7 (Continued)
Correlation Between Weight of Bombs Dropped and Air Sampling Results

Date	Total Weight of Non-Explosive Ordnance Used (tons)	24-Hour Average Ambient Air Concentrations Measured by PREQB ($\mu g/m^3$)			
		TSP Concentrations in Esperanza	TSP Concentrations in Isabel Segunda	PM10 Concentrations in Esperanza	PM10 Concentrations in Isabel Segunda
10/11/01	0.28	39	43	33	30
10/12/01	8.42	54	No sample	39	34

Notes: Data on weight of practice bombs dropped are taken from the Navy's range utilization statistics (Navy 2002); air sampling data were provided by PREQB (see Appendix C.1). Total weight of non-explosive ordnance used equals the sum of the amounts used for air-to-ground and ship-to-shore exercises.

"No sample" indicates that PREQB did not report a valid sampling result for the pollutant, date, and location indicated.

The weight of practice bombs dropped on the LIA was essentially uncorrelated with the TSP concentrations at Esperanza ($R^2 = 0.000$), the TSP concentrations at Isabel Segunda ($R^2 = 0.011$), the PM10 concentrations at Esperanza ($R^2 = 0.002$), and the PM10 concentrations at Isabel Segunda ($R^2 = 0.000$).

Data are presented for only those days when practice bombs were dropped and valid air sampling results were available. Practice bombs were dropped on additional dates not shown in the table, but no valid sampling results were collected on those days.

Table 8
Estimated Annual Average Concentrations of Chemical By-products of Explosions in the Residential Areas of Vieques that Resulted from Live Bombing Exercises

Chemical	Estimated Annual Average Ambient Air Concentration ($\mu g/m^3$)	Health-Based Comparison Value ($\mu g/m^3$)	Type of Comparison Value
1,3,5-Trinitrobenzene	0.0000001	110	RBC-n
1,3-Butadiene	0.0000005	0.004	CREG
1,4-Dichlorobenzene	0.00000002	100	EMEG-c
2,4-Dinitrotoluene	0.0000003	7.3	RBC-n
2,6-Dinitrotoluene	0.00000003	3.7	RBC-n
2-Methylphenol	0.00000005	180	RBC-n
4-Methylphenol	0.00000004	18	RBC-n
4-Nitrophenol	0.0000002	29	RBC-n
Acetophenone	0.000001	0.021	RBC-n
Ammonia	0.00002	100	RfC
Benzene	0.00007	0.1	CREG
Benzo(a)pyrene	0.0000003	0.002	RBC-c
Benzyl alcohol	0.00000001	1,100	RBC-n
Biphenyl	0.000000004	180	RBC-n
Bis(2-ethylhexyl)phthalate	0.0000002	0.45	RBC-c
Butylbenzylphthalate	0.00000007	730	RBC-n
Carbon dioxide	0.1	9,000,000	REL
Carbon monoxide	0.0005	10,000	NAAQS
Carbon tetrachloride	0.0000005	0.07	CREG
Dibenz(ah)anthracene	0.0000001	0.00086	RBC-c

Notes: All estimated annual average ambient air concentrations are based on outputs from ATSDR's air quality modeling analysis (see Appendix D.3). The concentrations listed are the highest estimated levels in the residential areas of Vieques.

Refer to Appendix D.3 for estimated ambient air concentrations for the 11 chemicals considered in the modeling analysis that do not have health-based comparison values. Estimated concentrations of these chemicals are all considerably lower than air sampling methods can reliably detect.

Refer to Appendix A for explanations of the abbreviations used to describe the comparison values.

Table 8 (Continued)
Estimated Annual Average Concentrations of Chemical By-products of Explosions in the Residential Areas of Vieques

Chemical	Estimated Annual Average Ambient Air Concentration (µg/m³)	Health-Based Comparison Value (µg/m³)	Type of Comparison Value
Dibenzofurans	0.0000001	150	RBC-n
Diethylphthalate	0.00000003	2,900	RBC-n
Dimethylphthalate	0.00000006	37,000	RBC-n
Di-n-butylphthalate	0.000006	370	RBC-n
Di-n-octylphthalate	0.0000001	73	RBC-n
Diphenylamine	0.000000006	91	RBC-n
Naphthalene	0.00001	10	EMEG-c
Nitric oxide	0.001	370	RBC-n
Nitrogen dioxide	0.0002	100	NAAQS
N-Nitrosodiethylamine	0.000000008	0.00002	CREG
N-Nitrosodiphenylamine	0.0000004	1.3	RBC-n
Phenol	0.000002	2,200	RBC-n
Sulfur dioxide	0.00002	80	NAAQS
Vinyl chloride	0.00000009	0.1	CREG

Notes: All estimated annual average ambient air concentrations are based on outputs from ATSDR's air quality modeling analysis (see Appendix D.3). The concentrations listed are the highest estimated levels in the residential areas of Vieques.

Refer to Appendix D.3 for estimated ambient air concentrations for the 11 chemicals considered in the modeling analysis that do not have health-based comparison values. Estimated concentrations of these chemicals are all considerably lower than levels that air sampling methods can reliably detect.

Refer to Appendix A for explanations of the abbreviations used to describe the comparison values.

Table 9
Estimated Annual Average Concentrations of Metals in the Residential Areas of Vieques that Resulted from Live Bombing Exercises

Chemical	Estimated Annual Average Ambient Air Concentration (µg/m³)	Health-Based Comparison Value (µg/m³)	Type of Comparison Value
Aluminum	0.02	3.7	RBC-n
Antimony	0.000003	1.5	RBC-n
Arsenic	0.0000004	0.0002	CREG
Barium	0.00006	0.51	RBC-n
Beryllium	0.00000001	0.0004	CREG
Boron	0.0000008	210	RBC-n
Cadmium	0.00009	0.0006	CREG
Chromium (total)	0.00002	5,500	RBC-n
Chromium (hexavalent)	0.0000004	0.00008	CREG
Cobalt	0.0000006	0.03	EMEG-i
Copper	0.003	150	RBC-n
Iron	0.03	2,200	RBC-n
Lead	0.0001	1.5	NAAQS
Manganese	0.0007	0.04	EMEG-i
Mercury	0.00000001	0.2	EMEG-i
Molybdenum	0.0000004	18	RBC-n
Nickel	0.000006	0.2	EMEG-i
Selenium	0.00000005	18	RBC-n
Strontium	0.000007	2,200	RBC-n
Tin	0.0000002	2,200	RBC-n

Notes: All estimated annual average ambient air concentrations are based on outputs from ATSDR's air quality modeling analysis (see Appendix D.3). The concentrations listed are the highest estimated levels in the residential areas of Vieques.

Refer to Appendix D.3 for estimated ambient air concentrations for the metals considered in the modeling analysis that do not have health-based comparison values (e.g., calcium). Estimated levels of these chemicals are all considerably lower than air sampling methods can reliably detect.

Refer to Appendix A for explanations of the abbreviations used to describe the comparison values.

Table 9 (Continued)
Estimated Annual Average Concentrations of Metals in the Residential Areas of Vieques that Resulted from Live Bombing Exercises

Chemical	Estimated Annual Average Ambient Air Concentration (µg/m^3)	Health-Based Comparison Value (µg/m^3)	Type of Comparison Value
Titanium	0.0001	31	RBC-n
Vanadium	0.000005	0.2	EMEG-a
Zinc	0.002	1,100	RBC-n

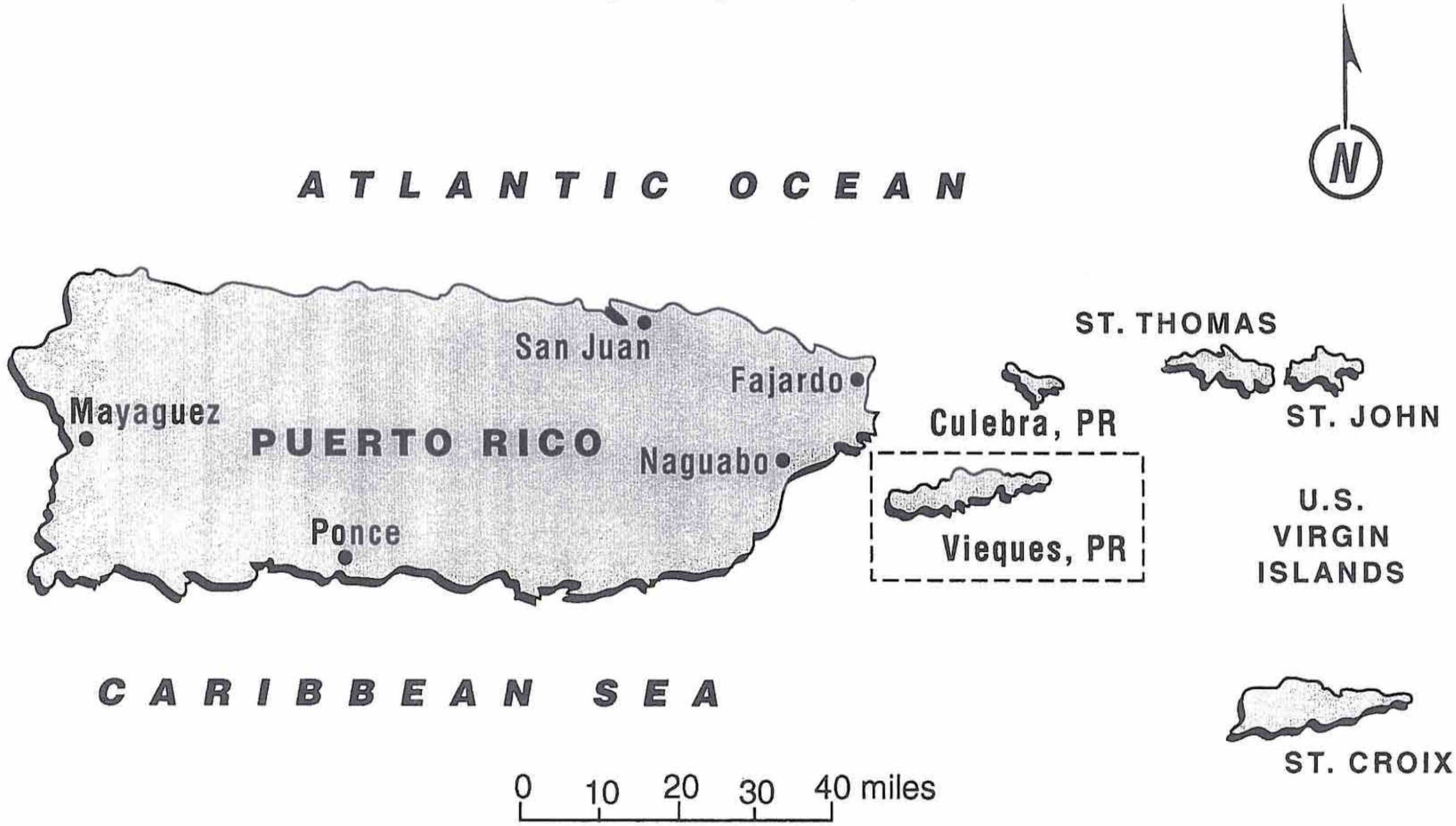
Notes: All estimated annual average ambient air concentrations are based on outputs from ATSDR's air quality modeling analysis (see Appendix D.3). The concentrations listed are the highest estimated levels in the residential areas of Vieques.

Refer to Appendix D.3 for estimated ambient air concentrations for the metals considered in the modeling analysis that do not have health-based comparison values (e.g., calcium). Estimated levels of these chemicals are all considerably lower than air sampling methods can reliably detect.

Refer to Appendix A for explanations of the abbreviations used to describe the comparison values.

FIGURES

Figure 1
Map of Vieques Vicinity



Reference: Torres-Gonzalez, 1989

Figure 2
Map of Vieques

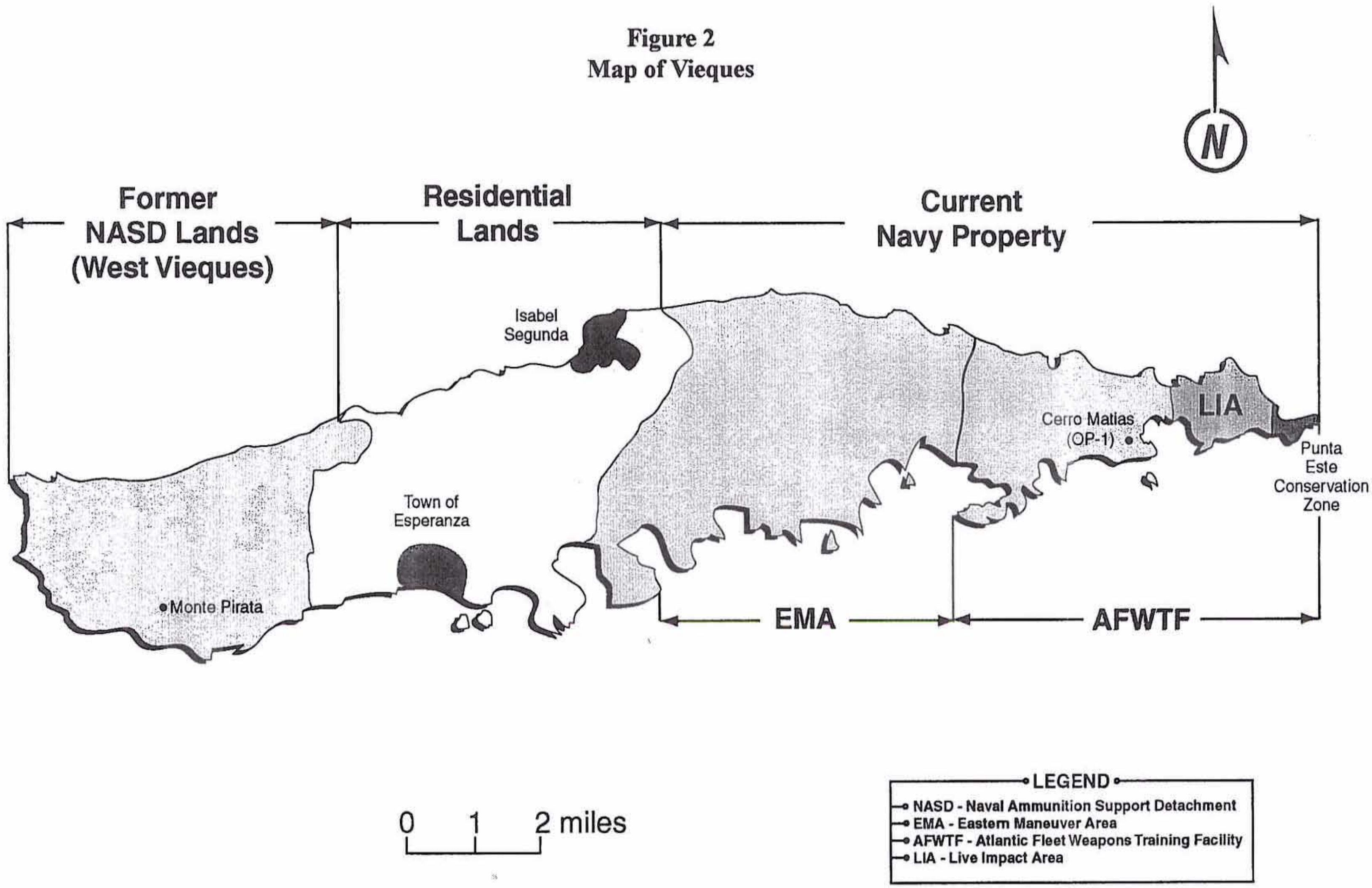
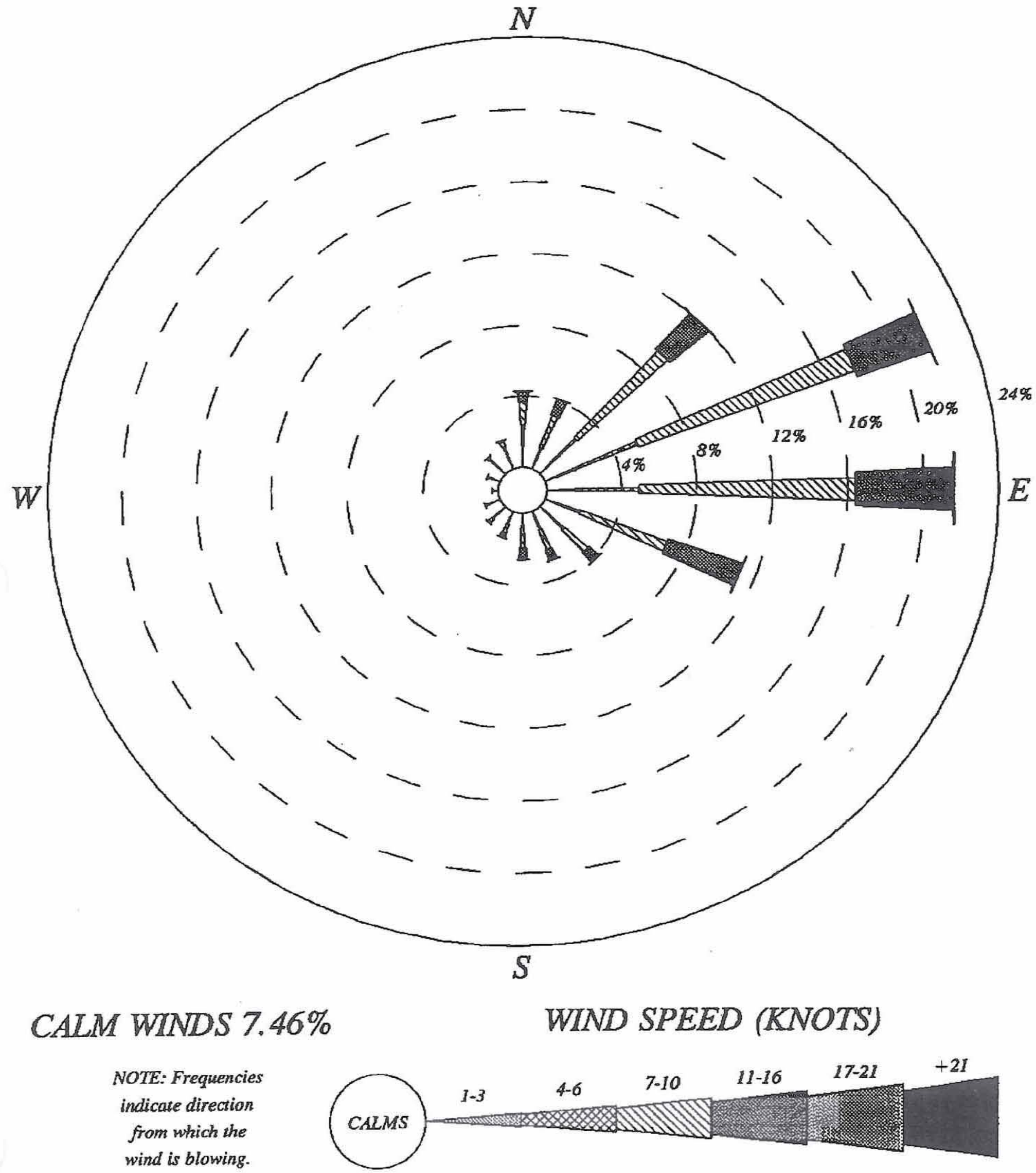
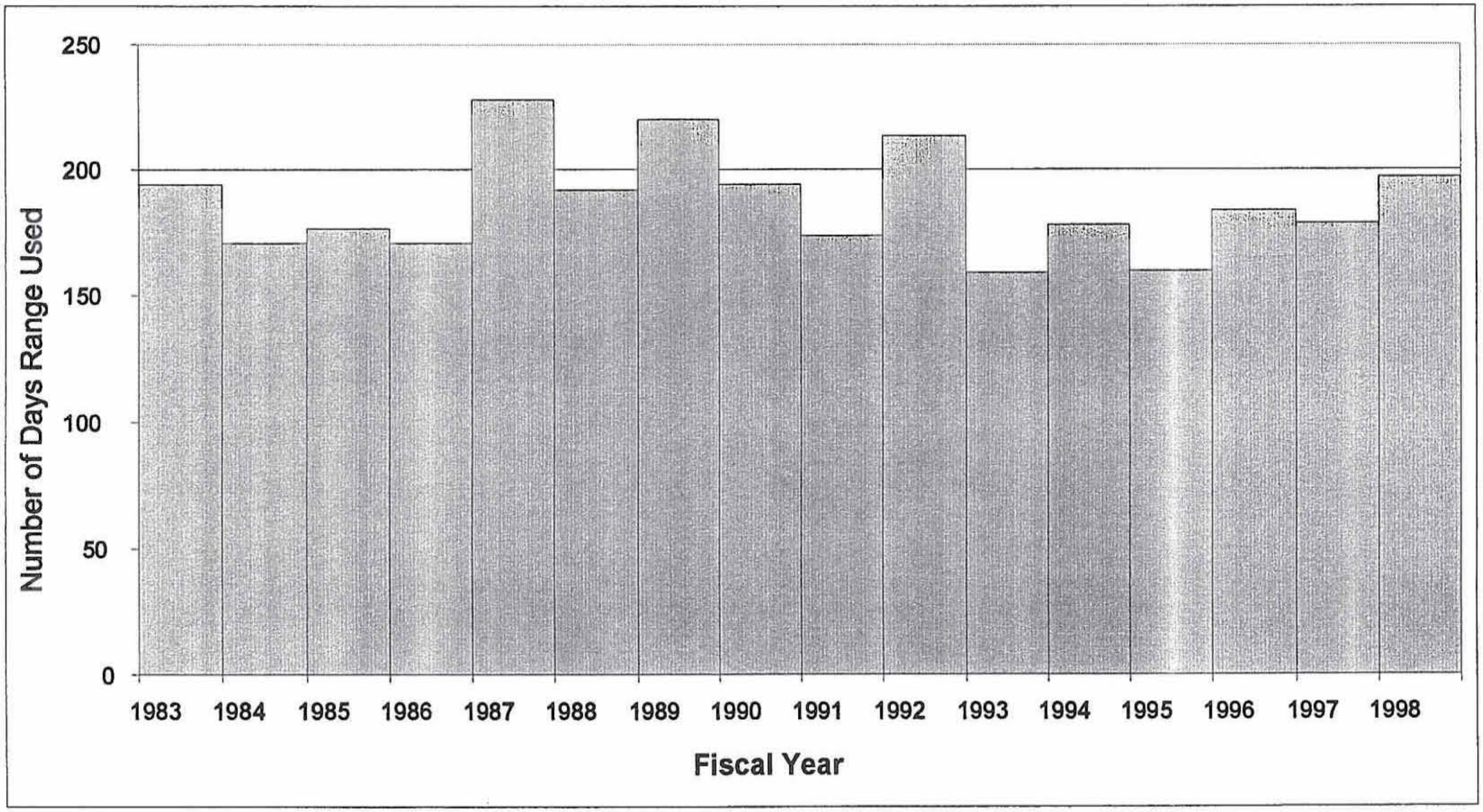


Figure 3
Wind Rose From US Naval Station Roosevelt Roads: 1990-2000



Date source: NCDC 2001.

Figure 4
Number of Days the Bombing Range (LIA) on Vieques Was Used, by Fiscal Year

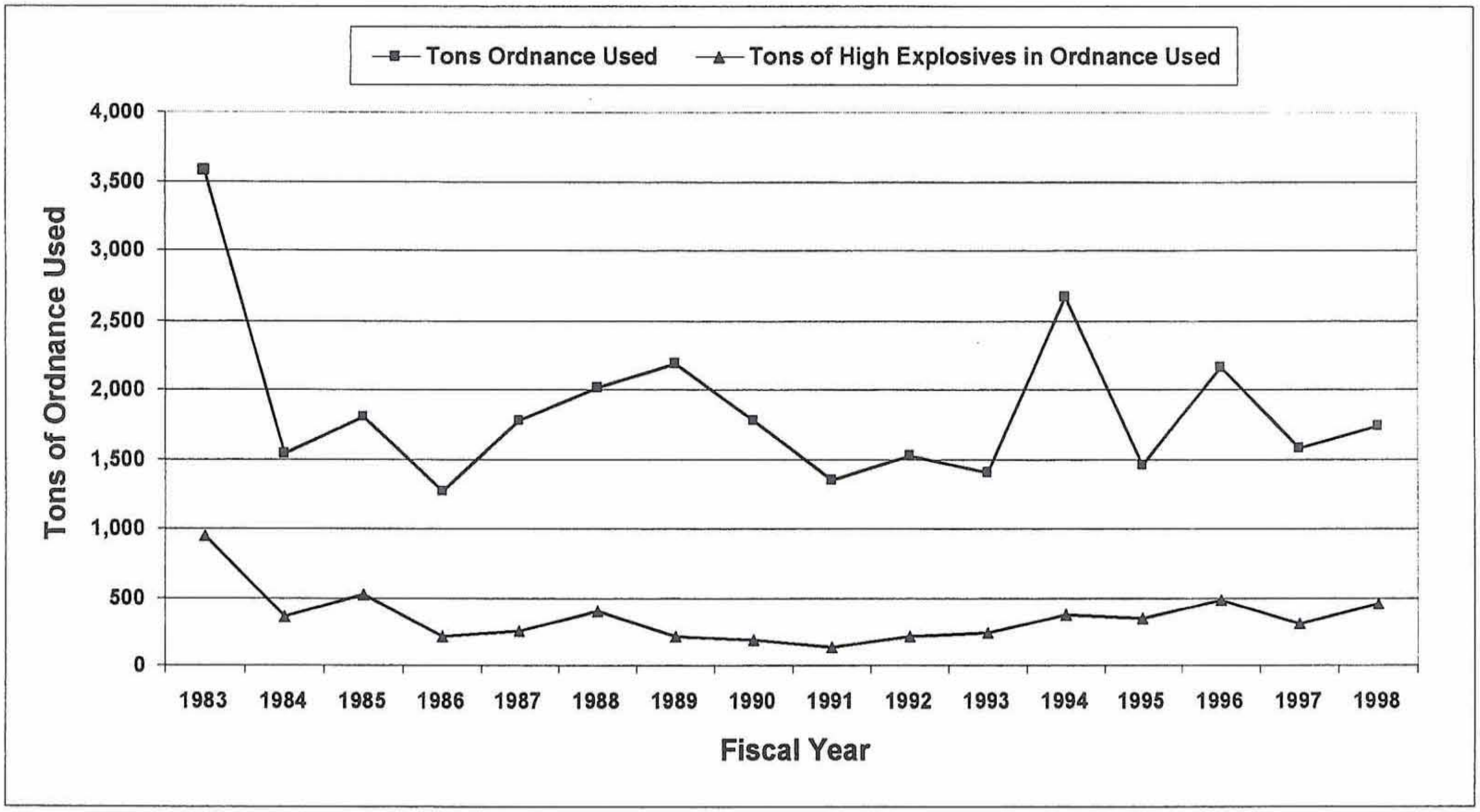


Notes: Data Source: Navy 1999

"Number of days range used" includes the total number of days the Navy and other parties used the range for all military exercises, including air-to-ground, ship-to-ground, and land-based activities.

The fiscal year is not the same as the calendar year. Currently, fiscal years start on October 1 and end on September 30 (e.g., fiscal year 1999 began on October 1, 1998, and ended on September 30, 1999).

Figure 5
Total Weight of Ordnance Used, by Year



Notes: Date Source: Navy 1999

"Tons Ordinance Used" includes the total weight of ordnance that the Navy and other parties used for all military training exercises, including air-to-ground, ship-to ground, and land-based activities: "tons of High Explosives in Ordnance Used" indicates the total weight of high explosives within the tons ordnance used.

The fiscal year is not the same as the calendar year. Currently, fiscal years start on October 1 and end on September 30 (e.g., fiscal year 1999 began on October 1, 1998, and ended on September 30, 1999).

Figure 6
Air Sampling Locations on Vieques

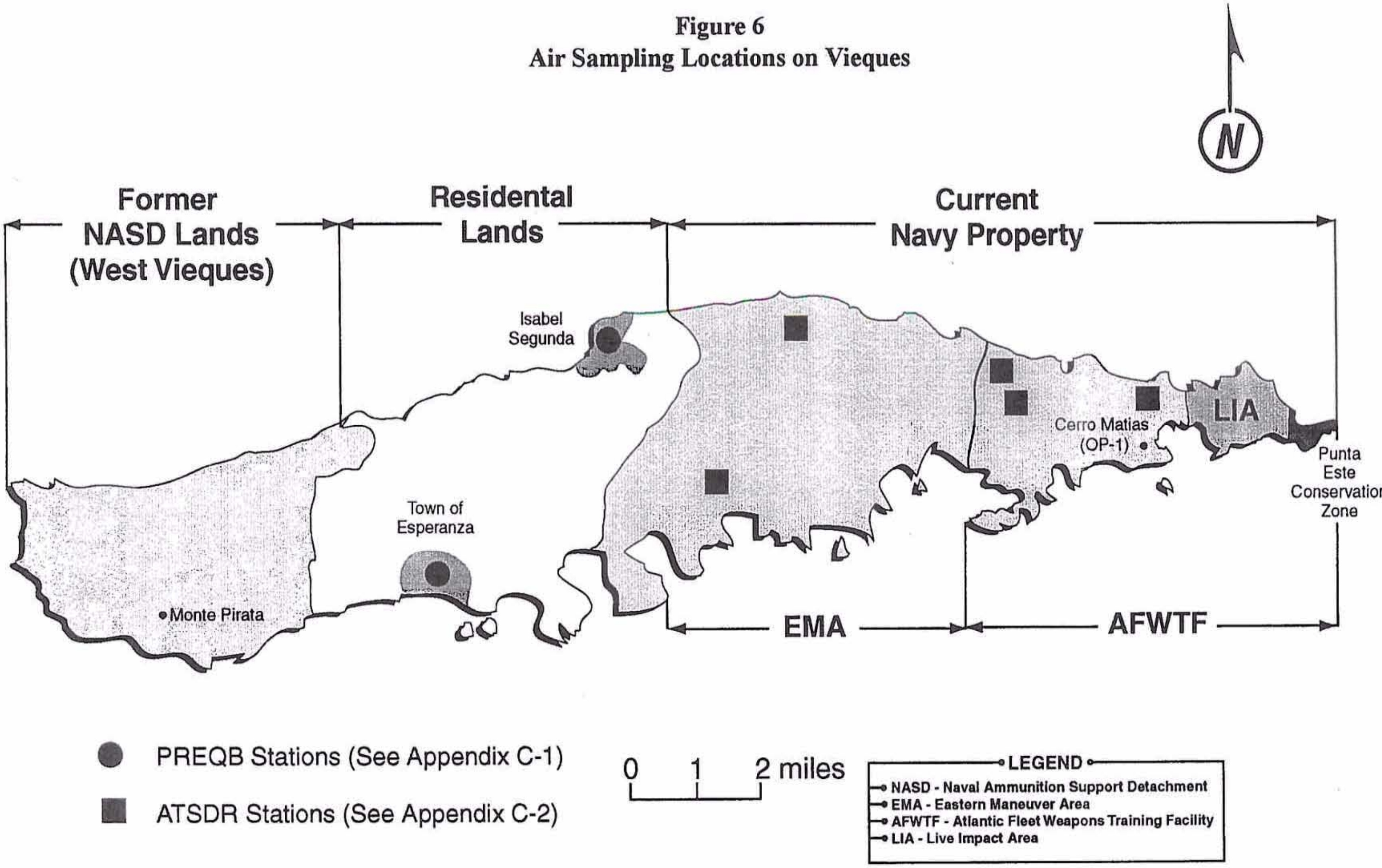
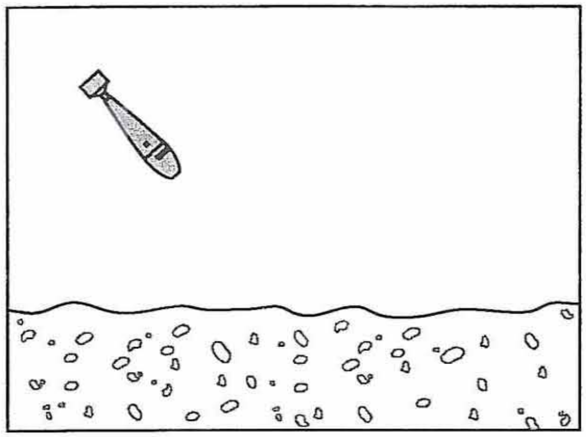
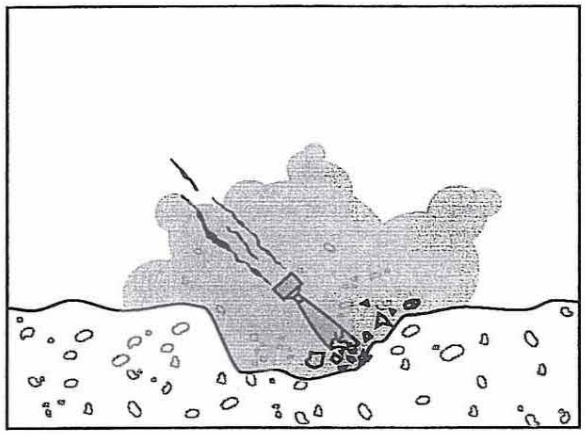


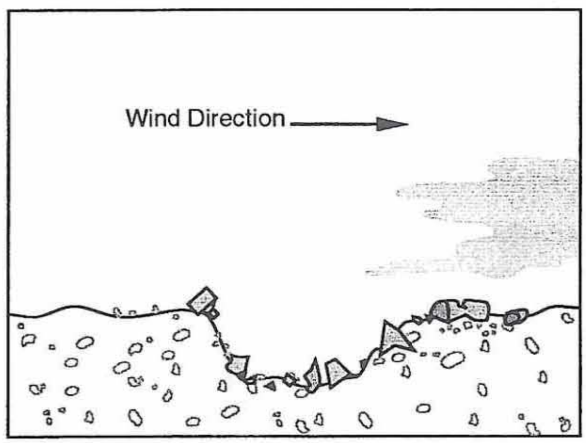
Figure 7
Emissions from Exercises Involving "Practice" Bombs



Before Impact: The practice bomb nears the ground surface.



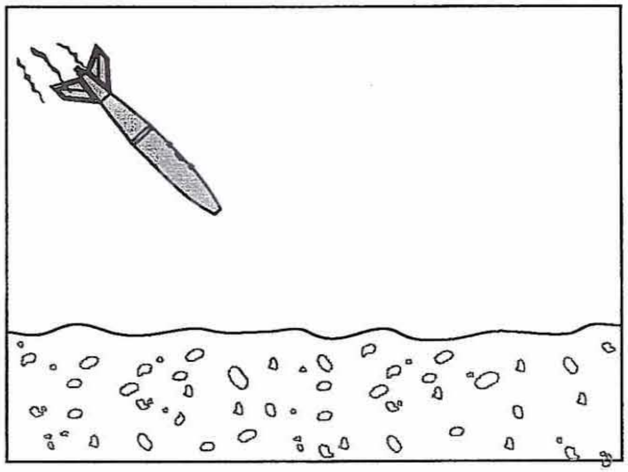
During Impact: The force of the impact with the ground creates a small crater and some soils become airborne. The practice bomb casings often break into smaller pieces, and these pieces typically remain on the ground. Some bombs will "skip" along the surface, causing more soil to enter the air.



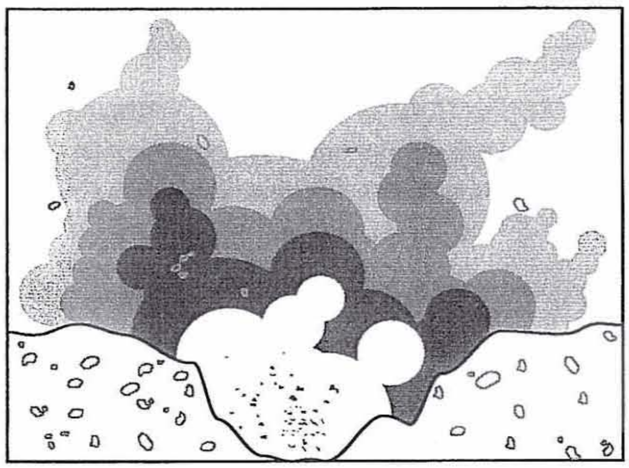
After Impact: Fragments of the practice bomb are usually visible. Much of the soil that became airborne during impact falls down to the ground. A small portion of the soil remains airborne and blows downwind. These airborne particles may contain contaminants that were previously in the soil.

□Note: This figure is meant to provide general information on the type of emissions that are released during military training exercises involving practice bombs. The actual amount of emissions released from practice bombs depends on many factors not shown here, such as the size of the bomb, the height from which it was dropped, and the type of soils on which the bomb lands.

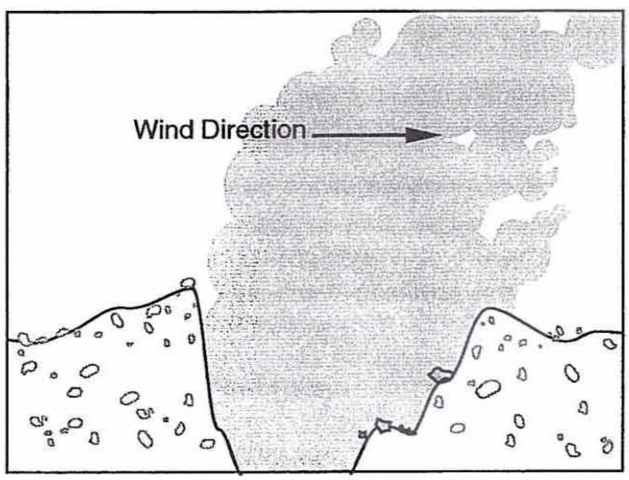
Figure 8
Emissions from Exercises Involving "Live" Bombs



Before Impact: The live bomb nears the ground surface.



During Impact: The explosion is initiated either by a fuze device or by the force of impact. Once detonated, the explosion proceeds as a rapid series of chemical reactions, which release large amounts of energy. This energy is great enough to fragment the bomb casing, vaporize some of the bomb materials, and generate a large crater. The energy released is a function of the amount of explosive chemicals originally in the bomb.

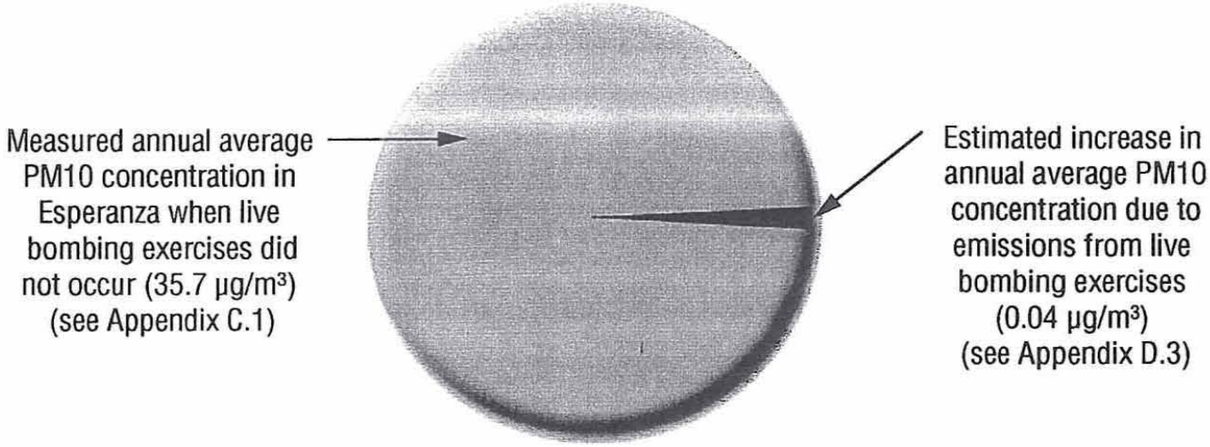


After Impact: The energy released from live bombs cause emissions to blow up to several hundred feet into the air. These emissions include three categories of contaminants. First, a small amount of the explosives in the original bomb might be present in the emissions. Second, the explosions produce chemical byproducts, many of which are naturally found in the air. Third, the force of the explosions causes releases of particulate matter, both from the soil and from the bomb casings. This particulate matter contains metals. All of these contaminants then blow downwind.

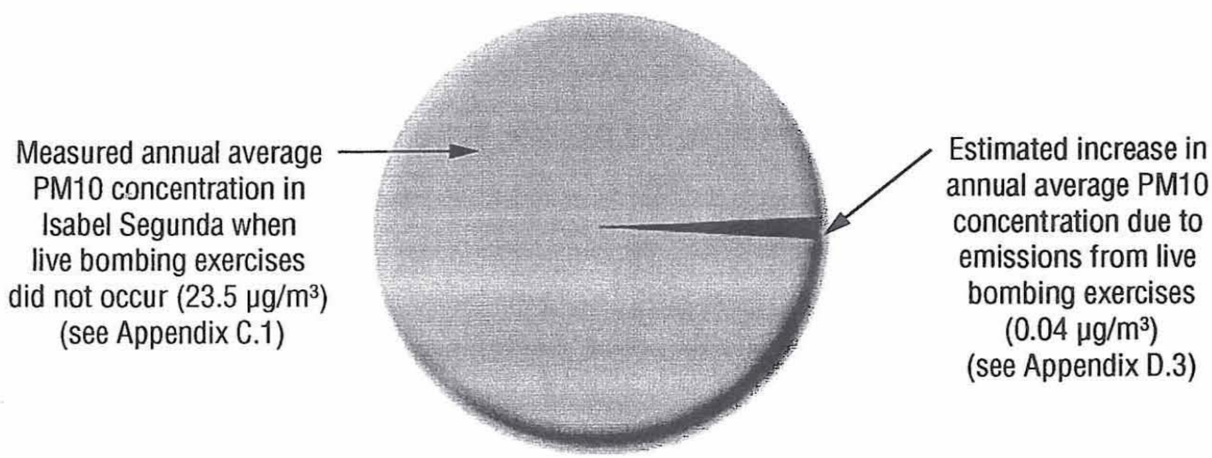
□Note: This figure is meant to provide general information on the type of emissions that are released during military training exercises involving live bombs. The actual amount of emissions released from live bombs depends on many factors not shown here, such as the size of the bomb, the height from which it was dropped, and the type of soils on which the bomb lands.

Figure 9
Effect of Live Bombing Exercises on Annual Average PM10 Concentrations on Vieques

Esperanza



Isabel Segunda



Appendix A

Comparison Values

Appendix A
Comparison Values

Following are definitions of the various health-based comparison values that ATSDR used in this PHA to put the measured and modeled levels of environmental contamination into perspective:

CREG: Cancer Risk Evaluation Guide, a highly conservative value that would be expected to cause no more than one excess cancer in a million persons exposed over time.

EMEG: Environmental Media Evaluation Guide, a media-specific comparison value that is used to select contaminants of concern. Levels below the EMEG are not expected to cause adverse noncarcinogenic health effects. These have been developed for acute exposure scenarios (EMEG-a), intermediate exposure scenarios (EMEG-i), and chronic exposure scenarios (EMEG-c).

NAAQS: National Ambient Air Quality Standard, an ambient air concentration that EPA has established to characterize air quality. The standards are health-based and were designed to be protective of many sensitive populations, such as people with asthma and children. The standards have been developed only for a small subset of pollutants, and the averaging time and statistical interpretations of the standards vary among the regulated pollutants.

RBC: Risk-based Concentration, a contaminant concentration that is not expected to cause adverse health effects over long-term exposure. These have been developed for both cancer outcomes (RBC-C) and noncancer outcomes (RBC-N).

REL: Recommended Exposure Level, an air concentration that the National Institute for Occupational Safety and Health (NIOSH) recommends should not be exceeded. RELs are designed primarily for occupational settings and exposures. The RELs used in this PHA are all based on 8-hour time weighted average exposures.

RfC: Reference Concentration, an ambient air concentration developed by EPA that people, including sensitive subpopulations, likely can be exposed to continuously over a lifetime without developing adverse noncancer health effects. RfCs typically have uncertainty factors built into them to account for any perceived limitations in the data on which they are based.

Appendix B

ATSDR's Glossary of Terms

ATSDR Glossary of Environmental Health Terms

Acute Exposure: Contact with a chemical that happens once or only for a limited period of time. ATSDR defines acute exposures as those that might last up to 14 days.

Adverse Health Effect: A change in body function or the structures of cells that can lead to disease or health problems.

ATSDR: The Agency for Toxic Substances and Disease Registry. ATSDR is a federal health agency in Atlanta, Georgia that deals with hazardous substance and waste site issues. ATSDR gives people information about harmful chemicals in their environment and tells people how to protect themselves from coming into contact with chemicals.

Background Level: An average or expected amount of a chemical in a specific environment. Or, amounts of chemicals that occur naturally in a specific-environment.

Biota: Used in public health, things that humans would eat – including animals, fish and plants.

Chronic Exposure: A contact with a substance or chemical that happens over a long period of time. ATSDR considers exposures of more than one year to be *chronic*.

Completed Exposure Pathway: See **Exposure Pathway**.

Comparison Value: **(CVs)** Concentrations or the amount of substances in air, water, food, and soil that are unlikely, upon exposure, to cause adverse health effects. Comparison values are used by health assessors to select which substances and environmental media (air, water, food and soil) need additional evaluation while health concerns or effects are investigated.

Concern: A belief or worry that chemicals in the environment might cause harm to people.

Concentration: How much or the amount of a substance present in a certain amount of soil, water, air, or food.

Contaminant: See **Environmental Contaminant**.

Dose: The amount of a substance to which a person may be exposed, usually on a daily basis. Dose is often explained as "amount of substance(s) per body weight per day".

Dose / Response: The relationship between the amount of exposure (dose) and the change in body function or health that result.

Duration: The amount of time (days, months, years) that a person is exposed to a chemical.

Environmental Contaminant: A substance (chemical) that gets into a system (person, animal, or the environment) in amounts higher than that found in **Background Level**, or what would be expected.

Environmental Media: Usually refers to the air, water, and soil in which chemcials of interest are found. Sometimes refers to the plants and animals that are eaten by humans. **Environmental Media** is the second part of an **Exposure Pathway**.

Exposure: Coming into contact with a chemical substance.(For the three ways people can come in contact with substances, see **Route of Exposure**.)

Exposure Pathway: A description of the way that a chemical moves from its source (where it began) to where and how people can come into contact with (or get exposed to) the chemical.

ATSDR defines an exposure pathway as having 5 parts:

VIII. Source of Contamination,
IX. Environmental Media and Transport Mechanism,
X. Point of Exposure,
XI. Route of Exposure, and
XII. Receptor Population.

When all 5 parts of an exposure pathway are present, it is called a **Completed Exposure Pathway**. Each of these 5 terms is defined in this Glossary.

Frequency: How often a person is exposed to a chemical over time; for example, every day, once a week, twice a month.

Health Effect: ATSDR deals only with **Adverse Health Effects** (see definition in this Glossary).

Indeterminate Public Health Hazard: The category is used in Public Health Assessment documents for sites where important information is lacking (missing or has not yet been gathered) about site-related chemical exposures.

Inhalation: Breathing. It is a way a chemical can enter your body (See **Route of Exposure**).

No Apparent Public Health Hazard: The category is used in ATSDR's Public Health Assessment documents for sites where exposure to site-related chemicals may have occurred in the past or is still occurring but the exposures are not at levels expected to cause adverse health effects.

No Public Health Hazard: The category is used in ATSDR's Public Health Assessment documents for sites where there is evidence of an absence of exposure to site-related chemicals.

PHA: Public Health Assessment. A report or document that looks at chemicals at a hazardous waste site and tells if people could be harmed from coming into contact with those chemicals. The PHA also tells if possible further public health actions are needed.

Plume: A line or column of air or water containing chemicals moving from the source to areas further away. A plume can be a column or clouds of smoke from a chimney or contaminated underground water sources or contaminated surface water (such as lakes, ponds and streams).

Point of Exposure: The place where someone can come into contact with a contaminated environmental medium (air, water, food or soil). For examples: the area of a playground that has contaminated dirt, a contaminated spring used for drinking water, the location where fruits or vegetables are grown in contaminated soil, or the backyard area where someone might breathe contaminated air.

Public Health Hazard: The category is used in PHAs for sites that have certain physical features or evidence of chronic, site-related chemical exposure that could result in adverse health effects.

Public Health Hazard Criteria: PHA categories given to a site which tell whether people could be harmed by conditions present at the site. Each are defined in the Glossary. The categories are:
I. Urgent Public Health Hazard
II. Public Health Hazard
III. Indeterminate Public Health Hazard
IV. No Apparent Public Health Hazard
V. No Public Health Hazard

Route of Exposure: The way a chemical can get into a person's body. There are three exposure routes:
- breathing (also called inhalation),
- eating or drinking (also called ingestion), and
- or getting something on the skin (also called dermal contact).

Source (of Contamination): The place where a chemical comes from, such as a landfill, pond, creek, incinerator, tank, or drum. Contaminant source is the first part of an **Exposure Pathway**.

Urgent Public Health Hazard: This category is used in ATSDR's Public Health Assessment documents for sites that have certain physical features or evidence of short-term (less than 1 year), site-related chemical exposure that could result in adverse health effects and require quick intervention to stop people from being exposed.

Appendix C

Review of Air Sampling Studies

Appendix C
Review of Air Sampling Studies

Air sampling results are measurements of the levels of air contamination that people might actually breathe. These are critical elements to this PHA, because they are direct measures of exposure point concentrations and do not involve the inherent uncertainties of modeling studies. ATSDR invested considerable effort in obtaining all ambient air monitoring data that might be relevant to air quality issues in Vieques.

This appendix presents ATSDR's review of all air sampling studies identified for this site. The reviews that follow present key information on the studies, such as number and locations of sampling stations, sampling frequencies, number of samples collected, pollutants measured, and comparisons of measured concentrations to health-based comparison values. Section V of this PHA indicates how ATSDR interpreted the air sampling data when reaching its conclusions for this site.

C.1 Review of PREQB's 2000–2001 Ambient Air Monitoring Data

Starting in July, 2000, and continuing to the present, PREQB has been collecting ambient air samples every sixth day at two locations on Vieques, and daily sampling has occurred during some of the Navy's military training exercises. According to EPA's Aerometric Information Retrieval System (AIRS), one sampling location is listed as "Ed. Defensa Civil Isabel II" (in Isabel Segunda) and the other sampling location is listed as "Esc. Juanita Rivera Albert La Esperanza" (in Esperanza). These locations are shown in Figure 6.

Both sampling locations are equipped with two hi-vol gravimetric sampling devices, one to collect 24-hour average PM10 samples, the other to collect 24-hour average TSP samples. PREQB is using an EPA Reference Method to measure the concentrations of PM10. These methods have been shown to generate highly accurate and precise data when operated according to the specifications outlined in the EPA Reference Method and the manufacturer's user manual. All data that PREQB has collected at these stations are reviewed for quality before being submitted to EPA's AIRS database. ATSDR has learned from verbal communications with PREQB that the air samples have also been analyzed for concentrations of metals. ATSDR has requested access to PREQB's sampling results for metals (ATSDR 2001d), but has not yet received copies of the data.

For several reasons, ATSDR believes the data collected by PREQB are of a known and high quality. First, the PM10 measurements were made using EPA-approved reference method sampling devices, and the TSP measurements were made using widely-used methods. Second, PREQB's monitoring network throughout the Commonwealth follows a quality assurance plan and EPA's reference method, which includes requirements for periodic flow and calibration checks. Finally, all data collected by PREQB must be reviewed for quality before being submitted to AIRS. ATSDR has visited both of PREQB's monitoring stations on Vieques and did not identify any circumstances that would cause the devices to measure concentrations much lower than actual ambient conditions (e.g., the devices were not under the drip lines of trees).

At the time this report was written, sampling results from PREQB's monitors are available from July 2000 to March 2002. This time frame includes several military training exercises that involved use of practice bombs. Overall, 51 valid samples were collected during these exercises. Table C-1 summarizes the sampling results for both PM10 and TSP concentrations. The table indicates that the average and maximum ambient air concentrations of PM10 are lower than EPA's current health-based National Ambient Air Quality Standard (NAAQS) and the average and maximum ambient air concentrations of TSP are lower than EPA's former NAAQS for this pollutant.

C.2 Review of ATSDR's 2001 Vieques Air Monitoring Program

In late May, 2001, the Navy officially announced plans to conduct military training exercises on Vieques starting on June 18, 2001. Given the residents' health concerns about exposures to air contaminants during bombing exercises and the fact that no metals sampling had ever been conducted during such exercises, ATSDR coordinated an air sampling project that lasted throughout much of the scheduled exercises. Due to the limited time available to plan for this project and the fact that no previous sampling had occurred for the contaminants being considered (i.e., metals and explosives), the sampling program was designed to be an initial survey of air quality impacts that might result from the use of practice bombs.

The "Vieques Air Monitoring Program" involved contributions from ATSDR, the Navy, and contractors to both parties (ERG 2001). In general, contractors to the Navy were responsible for collecting samples, and contractors to ATSDR were responsible for analyzing them in the laboratory. All sampling took place during the military training exercises the Navy conducted in June, 2001. This program was conducted to characterize air concentrations of three classes of contaminants: PM10 (through both continuous and integrated measures), metals, and explosives and selected decomposition products. Key findings from the four different types of sampling that took place follow:

- *Continuous PM10 sampling.* Continuous PM10 sampling devices were operated at two locations during the VAMP. One device malfunctioned during the program, and the other reported an average PM10 concentration of 26.0 $\mu g/m^3$ over roughly 1 week of operation. The continuous measurements were made with a field surveying tool.

- *Hi-Vol PM10 sampling.* 24-hour average integrated PM10 samples were collected using

General Metal Works Model 1200 PM10 Samplers at six locations on and near Vieques (see Figure 6). The measured PM10 concentrations from the 49 samples ranged from 13.9 to 176.9 $\mu g/m^3$, with the highest concentration occurring at a sampling location upwind (on a boat) from the Navy's bombing range. These measurements were found to be of questionable quality for several reasons. Though sampling was intended to follow specifications in EPA's reference method, site conditions prevented the field sampling team from adhering to some critical aspects of the method, particularly with regard to siting and sample duration. The deviations from the reference method, combined with poor precision of collocated samples and extremely poor agreement with the collocated continuous PM10 measurements, strongly suggest that the Hi-Vol PM10 sampling data from this program were of questionable quality. Placement of the sampling devices on dirt surfaces may have contributed to a positive bias in the measurements.

- *Metals data.* Every filter collected using the Hi-Vol PM10 sampling devices was analyzed for 18 metals. Most metals were detected in every sample. The metals detected at highest levels were magnesium, sodium, and aluminum. The quality of the measured metals concentrations depends both on the quality of the laboratory analysis and the quality of the field sampling. Multiple data quality indicators compiled by the analytical laboratory suggest that the filter analyses were both highly accurate and precise. As stated above, the Hi-Vol PM10 devices were not operated according to the EPA reference method. Because inaccuracy or imprecision in the Hi-Vol PM10 measurements also affects the accuracy and precision of the metals measurements, the metals sampling data from this program were also of questionable quality.

- *Explosives and decomposition product data.* Field sampling personnel collected four samples for explosives using sorbent cartridges. They returned the cartridges for analysis, but discarded, instead of returning to the laboratory, the sampling filters that collect particulate-bound contaminants. As a result, all measurements of explosives represent estimates of vapor-phase explosives only and do not characterize amounts of airborne particulate-bound explosives. Several data quality indicators suggested that the laboratory analyses of explosives samples were of a known and high quality. Of the 13 analytes considered, eight were not detected in any sample. Four analytes were detected at trace levels less than twice those found in blank samples; detections at these levels therefore cannot be considered significant. One analyte, nitrobenzene, was detected at trace levels (0.0019–0.0024 ppb) in three of the four samples. Additional sampling is needed to verify the presence of nitrobenzene and to characterize the total ambient air concentrations of particulate-phase and gas-phase explosive compounds.

Overall, the Vieques Air Monitoring Program had several unforeseen difficulties, which resulted in the organizers of the program concluding that all measurements are of questionable quality. Accordingly, ATSDR believes the utility of the sampling results is limited, and they should be viewed only as very rough indicators of air quality during a military training exercise using practice bombs. Given the data quality concerns, ATSDR did not consider these sampling results when evaluating air quality issues at Vieques. Nonetheless, ATSDR still recognizes the need for having high quality air sampling results during military training exercises involving practice bombs and has made a recommendation in this PHA (see Section IX) to ensure that this data gap is filled.

C.3 Review of Other Air Sampling Results Downloaded from EPA's AIRS Database

In the interest of being thorough, ATSDR not only downloaded ambient air monitoring data collected in Vieques from EPA's AIRS database, but also downloaded data collected from sampling stations near the east coast of the main island of Puerto Rico. ATSDR briefly reviewed these data to identify evidence of any potential regional air quality problems (i.e., elevated levels of air pollution that might exist throughout the area).

This query on AIRS identified two particulate sampling stations on the eastern shore of Puerto Rico, one in Fajardo and the other in Ceiba. Between the two stations, 1,780 particulate sampling observations were recorded, including concentrations of TSP, PM10, and PM2.5. However, none of the 24-hour average sampling results for these stations, or the corresponding annual averages that ATSDR computed, exceeded EPA's current or former health-based air quality standards. Moreover, ATSDR found no evidence suggesting that concentrations of particulate matter at these locations might be traced to a single source.

ATSDR realizes that the sampling results from Fajardo and Ceiba are of limited utility in this PHA, because the sampling locations in these cities are approximately 20 miles away from the residential areas of Vieques. The only conclusion that ATSDR draws from these results is that particulate emissions from the Navy bombing range do not appear to present health hazards at locations on the main island of Puerto Rico. This finding, however, provides no insights into levels of air pollution in the residential areas of Vieques.

C.4 1972 PREQB Air Sampling Study

Over the last 2 years, ATSDR has identified two documents indicating that PREQB conducted air sampling on Vieques in 1972 (Cruz Pérez 2000; TAMS 1979), but original documentation for this sampling effort apparently cannot be located. The two secondary references of this sampling project are reasonably consistent, implying that the information presented in these documents is correct. The following bulleted items summarize the information presented in the individual secondary references, after which ATSDR presents its interpretation of the sampling project.

- *Information documented in "Cruz Pérez 2000."* This reference is an article that is published in a magazine published by the College of Engineers and Surveyors of Puerto

Rico. According to the article, the 1972 PREQB sampling project included placement of sampling devices at two locations, one in Isabel Segunda and the other in Esperanza. Sampling results presented in the article follow:

Pollutant	Range of Concentrations Measured
Hydrocarbons (aldehydes)	2.74–40.00 μg/m^3
Nitrogen dioxide	Not detected–35.8 μg/m^3
Ozone	Not detected–29.0 μg/m^3
Particulate matter	13.9–98.98 μg/m^3
Sulfur dioxide	Not detected in any sample

The article does not provide critical information ATSDR typically reviews when interpreting sampling results, such as the time (in what months) samples were collected, how many samples were collected, the averaging time of the samples, the exact locations of sampling stations, and the methods used to collect and analyze samples. Moreover, the article does not mention whether sampling took place during military training exercises. The article cited the following report as the original reference for the sampling data: "Vieques 1972, Survey of Natural Resources, EQB, 1972–1973." ATSDR has contacted several agencies in attempts to obtain this report, but none has been able to locate a copy.

- *Information documented in "TAMS 1979."* This reference is an environmental impact statement that a Navy contractor prepared in 1979, and it also documents a PREQB air sampling project taking place on Vieques in 1972. The report provides much more detailed information on the sampling project, such as noting the exact locations of the two sampling stations: one at Duteil School in Isabel Segunda and the other at Puerto Rico Aqueduct and Sewer Authority Pump Station No. 1 in Esperanza. The report also presents a specific time frame for this sampling project: August 3 to August 22, 1972. Further, the report presents a data summary identical with the one listed above, and provides the additional insight that the concentrations listed are 24-hour average observations. Unfortunately, this report also fails to document critical information ATSDR typically reviews when evaluating data, such as the frequency of sampling, the number of samples collected, the methods used to collect samples, and whether samples were collected during military training exercises. This report cites the following document as the primary reference of the 1972 sampling results: "Ecology and Environment, Inc., 1978." A more detailed citation is not provided.

- *ATSDR's interpretation of these accounts.* Given the similarity between the two accounts of the PREQB 1972 air sampling project, ATSDR assumes that this sampling did take place during August 1972 at the two locations specified in the TAMS report and that the concentrations listed above are the actual measurement results. ATSDR further assumes that the concentrations of "particulate matter" are actually concentrations of TSP. This assumption is based on the fact that EPA did not start regulating PM10 as a criteria pollutant until 1987 and the overwhelming majority of particulate sampling during the 1970s was for TSP, not PM10. Neither report specifies whether this sampling took place during military training exercises. Overall, ATSDR finds that the sampling results listed above are of unknown quality, because detailed information on the sampling methods and quality assurance is not available.

ATSDR encourages any individual with access to the original documentation and data from the PREQB 1972 sampling project to provide copies to the agency for review. Though the two accounts of the 1972 sampling project are similar, ATSDR always prefers to base important public health conclusions on primary, rather than secondary, references of environmental sampling studies.

C.5 1978 Air Sampling Study

ATSDR has identified two references suggesting that another air sampling project took place on Vieques in 1978, starting on May 16 and continuing through July (Cruz Pérez 2000; EPA 1999). However, original documentation of this sampling project has not been located. In this project, 11 valid samples were taken, all of which were reportedly "particulate matter" samples collected with a hi-vol device. The sampling is said to have taken place at two locations near water tanks while the Navy intermittently fired 105 mm cannons over a time frame of 8 hours (EPA 1999). It is not clear, however, if this level of ordnance usage occurred on a single day of the program or on every day of the program. According to an interview between EPA and the manager of the sampling project, a PREQB laboratory weighed the particulate filters collected by the hi-vol devices (EPA 1999).

No detailed results from this 1978 sampling are presented in either reference ATSDR obtained, other than suggesting that the measured particulate concentrations fell within the range (13.9–98.98 $\mu g/m^3$) observed during the 1972 sampling (Cruz Pérez 2000). Overall, the account of the 1978 sampling at Vieques is incomplete. Most notably, detailed information on sampling locations, sampling frequency, measured concentrations, and quality assurance are not provided. The article cites the following document, which cannot be retrieved, as a reference of the 1978 sampling data: "Muestreo Especial de Vieques: 3 de Julio del 1978, Memorial Interno, Ing. Edgardo Soto, Junta de Calidad Ambiental."

In summary, ATSDR assumes the project occurred during an 8-hour intermittent exercise involving shelling with 102 mm ordnance and measured particulate matter concentrations were within the range 14–99 $\mu g/m^3$. ATSDR again assumes that these concentrations are TSP and not PM10, given the year in which this sampling project occurred. Because no quality assurance data are available, ATSDR finds that the 1978 sampling results are of unknown quality.

C.6 Navy Air Sampling During the 1970s

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). The EIS appears to be the primary reference for this sampling program, as the document does not cite other reports when presenting the program's results. According to the EIS, the sampling program started in July 1978 and ended 60 days later, in August 1978. Of these 60 days, 20 days of continuous sampling took place during military training exercises, and the remaining 40 days of sampling occurred when the bombing range was idle. This program involved three sampling locations, all within either the EMA or ATWTF. No information is provided on the sampling methods used or on data quality.

According to the EIS, the geometric mean TSP concentrations at the three sampling locations were 39.5 $\mu g/m^3$, 40.2 $\mu g/m^3$, and 35.4 $\mu g/m^3$ (TAMS 1979). Moreover, the sampling program found that geometric mean TSP concentrations on days without bombing exercises were higher than the program-average geometric mean concentrations. The EIS infers from this trend that ". . . the effects of ordnance detonation have a negligible effect on 24-hour values of particulate levels" (TAMS 1979).

ATSDR has considered these sampling results in this PHA. However, ATSDR finds that the measured concentrations from this sampling effort are of an unknown quality, because no documentation can be found describing the sampling methods used or the quality assurance measures taken.

C.7 Reports that EPA Conducted Air Sampling on Vieques During the 1970s

ATSDR has identified two accounts of an EPA air sampling project that reportedly took place on Vieques in the 1970s (ViequesLibre 2001, ViequesWar 2001). According to one of these accounts, ". . .the US Environmental Protection Agency sampled Vieques' air and soil. After studying the samples, the EPA determined that the air has unhealthy levels of particulate matter and the ground has iron levels above normal" (ViequesLibre 2001). The account from the other source is nearly identical (ViequesWar 2001). However, neither account cites an EPA document where these findings are published or provides critical information ATSDR would need to interpret this sampling project, such as the number and locations of sampling stations, the sampling methods, and the measured air concentrations.

Given the implications of the quote cited above, ATSDR made several attempts to locate the primary sources of information on EPA's sampling. First, ATSDR downloaded all ambient air monitoring results for Vieques from EPA's Aerometric Information Retrieval System (AIRS)—an online clearinghouse of air sampling data. However, AIRS had no sampling records for Vieques from the 1970s. The absence of data from AIRS does not necessarily mean that samples were never collected, but EPA typically submits its sampling results for criteria pollutants to this system. Second, ATSDR contacted senior officials from EPA Region 2 and EPA's Caribbean Environmental Protection Division. Individuals from both offices had no knowledge of the agency ever conducting air sampling projects on Vieques. Third, ATSDR conducted a thorough review of the project files on the Vieques site at EPA Region 2, and found no information about past air sampling projects.

Therefore, based on the best information available, ATSDR has reason to believe that EPA never sampled air on Vieques in the 1970s. Because valid sampling data form the best basis for evaluating the public health implications of exposure to air pollution, ATSDR encourages any individuals with detailed information on past sampling projects to submit them to the agency for review.

Table C-1
Summary of PREQB's 2000–2001 Sampling Results

Parameter	Sampling Results, by Location	
	Esperanza	Isabel Segunda
Summary Statistics for PM10 Sampling		
Number of samples	88	91
Average concentration	35.7 µg/m³	23.5 µg/m³
Range of concentrations	14–77 µg/m³	10–94 µg/m³
Summary Statistics for TSP Sampling		
Number of samples	92	89
Average concentration	43.2 µg/m³	34.2 µg/m³
Range of concentrations	17–163 µg/m³	14–177 µg/m³

Notes: Data downloaded from EPA's AIRS database.
EPA's current health-based air quality standards for PM10 are: 150 µg/m³ for 24-hour average concentrations, and 50 µg/m³ for annual average concentrations. The maximum and average PM10 concentrations measured at both stations on Vieques are lower than their corresponding standards.
EPA's former health-based air quality standards for TSP were: 260 µg/m³ for 24-hour average concentrations, and 75 µg/m³ for annual average concentrations. The maximum and average TSP concentrations measured at both stations on Vieques are lower than their corresponding standards.

Appendix D

Review of Air Quality Modeling Studies

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Review of Air Quality Modeling Studies

ATSDR views environmental sampling data as critical inputs to the public health assessment process. As evidence of this, ATSDR strongly recommends the use of validated sampling data as the basis for public health decisions. In some circumstances, however, sampling data are not sufficient to characterize all site-specific exposures. For instance, few air samples were collected on Vieques between the early 1970s and 1999—the years when the Navy's military training exercises using live bombs were most extensive—and the few samples that were collected are of questionable quality. In such cases, models are arguably the best tools available to evaluate the nature and extent of contamination. ATSDR emphasizes that models are only capable of *estimating* exposure concentrations, based on a scientific understanding of how chemicals move in the environment. All models, however, have assumptions and uncertainties and may not accurately represent actual environmental conditions. Therefore, ATSDR carefully reviews all modeling applications to determine whether they provide meaningful estimates of environmental contamination and whether they can be used in the public health assessment process.

When evaluating the four key questions in this PHA (see Section V), ATSDR determined that the available sampling data were sufficient to address two of the key questions, without the need for modeling. On the other hand, insufficient sampling data were available to characterize air quality during live bombing exercises and to evaluate releases from the Navy's periodic use of certain materials (e.g., depleted uranium, chaff). ATSDR decided to use modeling analyses to put these two exposure scenarios into perspective.

The remainder of this appendix presents ATSDR's review of the modeling studies available for the island of Vieques. This includes modeling studies conducted by contractors to the Navy (Appendix D.1), by an engineer from Vieques (Appendix D.2), and by contractors to ATSDR (Appendix D.3). Sections V.C and V.D describe how ATSDR used these modeling analyses to reach public health conclusions.

D.1 Review of the Navy's Modeling Study of Live Bombing Activities (IT 2000, 2001)

In February 2000, contractors to the Navy completed an air dispersion modeling study of selected air emissions sources on the island of Vieques (IT 2000). The modeling study had two objectives: to determine whether certain environmental regulations apply to the Navy's operations on Vieques and to estimate ambient air concentrations of contaminants released to the air during military training exercises and open detonation of unexploded ordnance. In May 2001, the Navy released a revision to this air dispersion modeling study to correct a computational error (IT 2001). Once corrected, the estimated emission rates (and likewise the estimated ambient air concentrations) increased slightly, by less than 5% for most contaminants. Copies of both versions of this dispersion modeling report are in the Vieques site's records repositories, which are located at Biblioteca Publica on Vieques, the Vieques Conservation and Historical Trust, and the University of Puerto Rico School of Public Health.

D.1.A Overview of the Navy Contractor's Modeling Approach

The following paragraphs review three key features of the Navy contractor's modeling analysis: how emission rates were estimated, how atmospheric fate and transport was simulated, and how results were presented and interpreted. Refer to Section D.1.B for ATSDR's evaluation of the scientific rigor of the Navy contractor's modeling analysis.

- *Approach to estimating emissions.* The Navy contractor estimated emissions from a variety of air pollution sources on the Navy property at Vieques. The majority of emissions for most of the contaminants originated from sources on the LIA. These included emissions from air-to-ground exercises, ship-to-shore exercises, land-based exercises, and open detonation of unexploded ordnance. Other sources considered included emissions from generators and small arms firing ranges. However, for almost every contaminant, emissions from these sources accounted for a very small portion of the total emissions calculated. Accordingly, ATSDR focused its review of this dispersion modeling study on the approach used to estimate emissions from activities associated with bombing exercises.

  The Navy contractor estimated emissions for a single calendar year, 1998—a year the authors asserted was representative of prior years' activities at Vieques. Further, emissions were estimated only on an annual basis. Estimating emissions over shorter time frames, such as highest daily emissions, was not conducted. The following paragraphs describe how emissions were estimated for different categories of contaminants. ATSDR's comments on these approaches are presented in Section D.1.B.

  Emissions of particulate matter. Particulate matter emissions were estimated using a model that the Army Research Laboratory developed to predict how much dust, smoke, and debris is released to the air during realistic battlefield situations (Army Research Laboratory 2000). In general, this model characterizes the size of craters formed by explosions and then quantifies the amount of particulate matter that may be released to the air as a result. According to this model, the emission rate of particulate matter following an explosion is a function of several parameters, including the net explosive weight (NEW) of the ordnance fired and soil properties.

  When calculating emission rates using this model, the Navy contractor assumed that only those bombs that contain at least 10 pounds of high explosives will generate craters that release particulate matter to the air upon detonation. During 1998, the base year for the modeling analysis, only four types of ordnance—all air-to-ground bombs—met this

10-pound criterion. Because all land-based and ship-to-shore ordnance used in 1998 contained less than 10 pounds of NEW, this approach effectively asserted that none of the ship-to-shore or land-based activities caused emissions of particulate matter.

To estimate particulate matter emissions, the Navy contractor first estimated the volume of craters generated by bombs. The mass of soil apparently ejected from craters was estimated by multiplying the crater volumes listed above by an assumed soil density (1.5 g/cm^3). To estimate how much of the soil released is emitted as PM10, the Navy contractor multiplied the mass of soil ejected by a scaling factor documented by the Army Research Laboratory as the proportion of crater ejecta that is believed to be released as "small particles," or particles with radii less than 10 microns (Army Research Laboratory 2000). This scaling factor was 0.01007, meaning that roughly 1% of the crater ejecta is assumed to be released as PM10 emissions, and the remaining crater ejecta will be larger particles that settle to the ground in the vicinity of the impact location.

Following the aforementioned approach, the Navy contractor estimated that total PM10 emissions from the air-to-ground bombing exercises and open detonation activities were 76 tons per year. The combined PM10 emissions from all other sources evaluated (e.g., wind-blown dust, dust from driving on dirt roads, generator exhaust) was less than 5 tons per year. Thus, by the Navy contractor's approach, emissions from the bombing exercises account for an overwhelming majority of the estimated PM10 emissions. ATSDR has many comments on the approach described in the previous paragraphs, as Appendix D.1.B describes further.

Emissions of explosion by-products. The Navy contractor used emission factors to estimate releases of inorganic and organic explosion by-products. The emission factors were derived from a series of source tests, known as "Bangbox" studies, that measured the amounts of selected inorganic and organic chemicals released during the open detonation of various types of ordnance. The Bangbox is a flexible structure in which ordnance is detonated. Because the Bangbox is completely enclosed, pollutants released during the detonation do not escape the structure and can be measured by air sampling equipment. The Bangbox has thus allowed scientists to estimate emission factors for various types of ordnance, many of which are similar to those the Navy uses at Vieques. The emission factors used estimate the amounts of chemicals released to the air per weight of NEW detonated.

The Navy contractor reviewed many Bangbox emission factors to select appropriate factors to apply to the military training activities at Vieques. Emission factors were identified for several types of contaminants, including criteria pollutants, metals, volatile organic compounds, and semi-volatile organic compounds. The Navy contractor selected two different sets of Bangbox emission factors to estimate air releases from the following sources:

- *Emission factors for air-to-ground exercises.* For the year being evaluated (1998), range utilization statistics indicated that usage of MK82, MK83, and MK84 bombs accounted for more than 99% of the explosives used during all air-to-ground exercises. The explosive charges in these bombs are composed of either 2,4,6-trinitrotoluene (TNT) with aluminum powder or a mixture of TNT, RDX, and aluminum powder. When estimating air emissions from air-to-ground exercises, the Navy contractor considered only those Bangbox studies that tested these specific types of explosives. For every contaminant, the Navy contractor selected the highest emission factor from the relevant Bangbox results.

- *Emission factors for ship-to-shore exercises and land-based exercises.* In any given year, the Navy uses ordnance with varying compositions for its ship-to-ground and land-based exercises. Rather than attempting to model each composition individually, the Navy contractor instead used an approach designed to provide an upper-bound estimate of actual emissions. For every chemical considered, the Navy contractor selected the highest emission factor from all of the Bangbox tests identified. These tests included emissions from various propellants and high explosives.

Once the Navy contractor selected emission factors for the two types of activities, air emissions were estimated by multiplying the chemical-specific emission factors by the corresponding weight of explosives (expressed as NEW) used.

Emissions of metals. To estimate the amounts of metals released during military training exercises, the Navy contractor used emission factors published in an open detonation burn plan conducted for another Navy installation (Radian 1996). ATSDR notes that these emission factors combine together the amounts of metals detected during Bangbox experiments and the entire mass of four metals—aluminum, copper, manganese, and zinc—commonly found in bomb casings. Therefore, the emission factors assume that the entire metallic content of the casings is vaporized during an explosion.

As with the emission factors for the by-products of explosions, two different sets of emission factors for metals were selected. First, emission factors for air-to-ground exercises were selected from the Bangbox studies involving TNT, RDX, and aluminum powder explosives. Second, emission factors for all other exercises were determined from the highest factors reported for all Bangbox studies identified.

- *Approach to modeling atmospheric transport.* The Navy contractor used the INPUFF dispersion model to estimate ambient air concentrations of the pollutants released during the military training exercises. This model was originally designed to simulate atmospheric transport for instantaneous or "puff-like" releases, like the emissions that occur from individual bombing events. The modeling scale for INPUFF ranges from downwind distances of several meters to tens of kilometers (EPA 1986)—a scale that is therefore sufficient for modeling transport from the LIA to the residential areas of Vieques. The INPUFF model does not explicitly account for terrain or chemical reactions that might take place in the atmosphere (EPA 1986).

The INPUFF simulations calculated ambient air concentrations of contaminants at downwind locations from a limited set of input parameters. To run INPUFF, the Navy contractor used meteorological conditions observed at the US Naval Air Station Roosevelt Roads, located on the eastern shore of the main island of Puerto Rico, less than 10 miles from the western shore of Vieques. The Navy contractor also selected values for the locations and size of dust clouds generated by explosions during the military training exercises. Section D.1.B presents ATSDR's comments on the selected input values.

- *Presentation and interpretation of results*. The dispersion modeling report summarizes estimated ambient air concentrations in two sections of the report. First, two figures show how concentrations of two contaminants (manganese and RDX) vary with location in the residential areas of Vieques. Second, a table documents the estimated annual average concentrations of all pollutants considered in the modeling analysis, except for particulate matter. ATSDR does not present the Navy contractor's specific findings in this PHA, because ATSDR's conclusions regarding live bombing exercises are based entirely on the agency's own dispersion modeling outputs (see Appendix D.3). Nonetheless, ATSDR notes that the Navy contractors analyses predict that the highest ambient air concentrations of pollutants occur in the northeast portion of the residential area of Vieques, which is also the residential area located closest to the LIA. The Navy contractor's modeling study did not estimate ambient air concentrations over shorter averaging periods (e.g., maximum 24-hour air concentrations).

D.1.B ATSDR's Review of the Navy Contractor's Modeling Analysis

Because limited environmental sampling data are available to characterize how the Navy's live bombing activities affected air quality at Vieques, ATSDR thoroughly evaluated all modeling studies of these activities to determine if the modeling results can be used to reach scientifically defensible public health conclusions. ATSDR's specific comments on the Navy contractors' dispersion modeling analysis follow, organized by topic.

- *Scope of modeling study.* As Section D.1.A indicates, the Navy contractor's modeling study examined only annual average air quality impacts. When evaluating environmental contamination, however, ATSDR examines the public health implications of both long-term and short-term exposures. For the air exposure pathway, this typically involves characterizing both annual average and highest 24-hour average ambient air concentrations. Therefore, the Navy contractor's study is not sufficient for evaluating acute exposure scenarios. As Appendix D.3 indicates, ATSDR designed its modeling study to estimate both annual average and maximum 24-hour average ambient air concentrations.

By design, the Navy contractor's modeling study was based entirely on range utilization statistics for 1998, and the amount of ordnance used in 1998 was assumed to be representative of amounts used in previous years (IT 2000). This is a critical assumption, because the model predictions for 1998 will not be representative of other years if the range utilization statistics for 1998 were unusually high or low. To evaluate whether 1998 is an adequate base year for the modeling application, ATSDR thoroughly evaluated range utilization statistics available for the years 1983 to 1998—the time frame for which the most complete statistics are available. An overview of ATSDR's review of those statistics follows:

- In fiscal year 1998, the Navy used the bombing range on 197 days (see Figure 4). Between fiscal years 1983 and 1998, the Navy used the bombing range, on average, 187 days per year.
- In fiscal year 1998, the Navy used 458 tons of high explosives on the bombing range (see Figure 5). Between fiscal years 1983 and 1998, the average annual usage of high explosives was 353 tons per year.

Based on these observations and on the fact that emissions from the bombing exercises depend directly on the number of exercises and amounts of high explosives used, ATSDR finds that 1998 indeed appears to be an adequate base year for the modeling analysis. Because range usage in 1998 was greater than the long-term average, using 1998 as a base years might lead to a slight overestimate of emission rates.

- *Comments on approach used to estimate emissions of particulate matter.* As Section D.1.A explains, the Navy contractor used a model developed by the Army Research Laboratory to estimate particulate matter emissions from bombing exercises at Vieques. The model—the Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC)—was developed to predict how much smoke and dust certain battlefield activities may emit. Accurate predictions of these emissions are necessary because high levels of smoke and dust can interfere with critical electro-optical systems that the military needs to operate in battlefield environments.

  For several reasons, ATSDR believes COMBIC is an adequate basis for estimating emissions of particulate matter from bombing exercises. First, ATSDR doubts that COMBIC grossly underestimates emissions of dusts and particles, because significant underestimates may cause modelers to reach incorrect conclusions that have potentially serious consequences to military personnel in battlefield environments (e.g., predicting that critical electro-optical equipment will function, when they might not). Further, according to the model documentation, several key input parameters have been established empirically from field studies involving high explosive ordnance, much like the ordnance the Navy uses at Vieques. Moreover, the model predictions have proven consistent with observations documented in other publications.

Though ATSDR believes COMBIC is a reliable model for estimating particulate emissions from bombing exercises, assumptions made when applying the model may lead to biases in emissions estimates. ATSDR identified the following potential shortcomings in the Navy contractor's application of COMBIC at Vieques:

- As Appendix D.3 describes further, COMBIC can be used to estimate emissions of different size fractions of particulate matter. The Navy contractor appropriately focused on identifying releases of "small particles," which COMBIC defines as being "less than 10 microns in radius," or presumably particles less than 20 microns in aerodynamic diameter (Army Research Laboratory 2000). COMBIC includes algorithms for quantifying emissions of these small particles in three distinct parts of dust clouds formed in explosions: the fireball, the stem of the fireball, and the "skirt" (i.e., particles released near ground level at the base of the stem). The Navy contractor calculated small particle emissions for the fireball and the stem of the dust cloud, but not for the skirt. According to the COMBIC documentation, the amount of small particles in the skirt is 1.875 times greater than the combined mass of small particles in the fireball and stem of the dust cloud. Therefore, by not considering particles in the skirt of explosions, the Navy contractor's emission rates for PM10 are underestimated by nearly a factor of two.

- When estimating emissions, the Navy contractor assumed that particulate matter releases from ordnance containing less than 10 pounds of explosives are negligible. According to the 1998 range utilization statistics, the weight of ordnance used that contained less than 10 pounds of explosives was 441 tons—all of which the Navy contractor assumed generates no particulate matter emissions. ATSDR notes that the COMBIC model indicates that particulate matter emissions for high explosives scale with the net explosive weight (in TNT equivalents) raised to the 1.111 power (Army Research Laboratory 1999); the model does not imply that any lower bound threshold determines whether particulate matter emissions occur. Simply stated, ordnance containing less than 10 pounds of explosives will generate particulate matter emissions, though clearly in less quantities than ordnance containing hundreds of pounds of high explosives. In ATSDR's modeling analysis (see Appendix D.3), all ordnance containing high explosives was considered when estimating particulate matter emissions.

- When computing mass emission rates from crater volumes, the Navy contractor assumed a default soil density of 1.5 kg/m^3. ATSDR recently reviewed the results of numerous soil sampling studies at Vieques (ATSDR 2001b) and identified two reports that document soil density measurements from Vieques. One sampling effort documents the soil density in three samples collected at the LIA, with an average density of 1.76 kg/m^3 (CH2MHILL 2000). Another report indicates that the average density in the top foot of soils on Vieques ranges from 1.25 kg/m^3 to 1.5 kg/m^3 (Lugo-López, Bonnet, García 1953). Based on these observations, ATSDR believes the Navy contractor's assumed default density of 1.5 kg/m^3 is a reasonable value in the absence of more extensive site-specific data.

- *Comments on approach used to estimate emissions of explosion by-products.* The Navy contractor used emission factors derived from Bangbox studies to estimate emissions of chemical by-products of bombing activities. These emission factors have been widely used to assess environmental impacts from open burning and open detonation activities. For instance, the Open Burn/Open Detonation Model (OBODM), available from EPA's clearinghouse of dispersion models on the agency's technology transfer network, also estimates air emissions from the Bangbox emission factors. ATSDR acknowledges that the representativeness of static detonation tests to live bombing exercises has not been established. However, source testing (or emissions measurements) during live bombing exercises is an extremely complicated endeavor, given the potential safety hazards associated with placing field surveying equipment in the proximity of bombing targets. In the absence of such source testing results, ATSDR believes the Bangbox emission factors are reasonable indicators of chemical releases from explosions.

  ATSDR further believes the Navy contractor's approach used to select emission factors from the available Bangbox studies was appropriate. For instance, to characterize emissions from air-to-ground exercises, the Navy contractor first identified the subset of Bangbox studies that tested explosives with similar compositions to those used at Vieques, and then selected the highest emission factor for every chemical from the various tests. As a result, the emission factors used are the highest measured releases of chemical by-products from the available Bangbox studies. Moreover, when applying the emission factors to the net explosive weight of explosives in ordnance, the Navy contractor included quantities of aluminum dust in the explosive charge toward the net explosive weight. This approach likely leads to overestimates of organic by-products of explosions, because the aluminum dust is not an explosive chemical that releases energy (and forms organic by-products) during explosions.

  Though the Navy contractor's approach includes assumptions that appear to overstate emissions of explosion by-products, it remains unclear exactly how representative the Bangbox studies are to live bombing exercises. Appendix D.3 discusses this issue further. Ultimately, ATSDR used the same set of emission factors, with one exception, to estimate releases of chemical by-products of explosions. As the exception, the emission factor for 2-nitrophenylamine was apparently transcribed incorrectly in the Navy contractor's modeling analyses. This error caused the Navy contractor to underestimate this chemical's emissions by a small margin (7%).

- *Comments on approach used to estimate emissions of metals.* The Navy contractor used two sources of information to estimate emissions of metals from bombing exercises. First, emission factors from the Bangbox studies were considered. These emission factors represent the amount of metals detected within the Bangbox following explosion of various types of ordnance. The metals detected in the Bangbox tests presumably originated from casings or impurities in the explosives themselves. Second, the Navy contractor considered compositions data from casings and assumed that the entire metallic portion of the casings vaporizes upon explosions. The casings composition data, however, only account for quantities of aluminum, copper, manganese, and zinc. Combined, these metals comprise roughly 3% of the total casing material. ATSDR's specific comments on the approach used to estimate emissions of metals follows:

  - The Navy contractor's approach does not account for the fact that particulate emissions from craters formed during bombing exercises will include metals that were originally in the soils. Omitting this potential source causes the Navy contractor's modeling analysis to underestimate emissions and ambient air concentrations of metals. ATSDR's previous public health evaluations for Vieques have shown that soils throughout the LIA contain metals (ATSDR 2001b), which can become airborne when craters are formed. As Appendix D.3 indicates, ATSDR's modeling analyses accounts for emissions of metals in crater ejecta.

  - The Navy contractor's emission factor for aluminum assumes that 0.0435 pounds of aluminum are released for every pound of high explosives that is used. This emission factor accounts for aluminum that might be in the casings but does not account for the fact that many types of ordnance used at Vieques contain aluminum dust in the explosive charge. As a result, the Navy contractor may have considerably underestimated emissions of aluminum. ATSDR's modeling analysis considers the entire weight of aluminum in bombs used at Vieques, including amounts in the casing and in the explosive charge.

  - The Navy contractor used emission factors that account for roughly 3% of the metals within bomb casings. Moreover, these emission factors for casings considered only potential releases of aluminum, copper, manganese, and zinc. ATSDR has identified more detailed composition data on bomb casings which identify additional metals that might be released, though in relatively low quantities. Appendix D.3 lists these other metals and their estimated emissions.

- *Comments on the approach used to model atmospheric transport.* The Navy contractor used the INPUFF dispersion model to predict the fate and transport of chemicals released from the LIA. ATSDR thoroughly reviewed the modeling approach and findings and presents selected comments on this analysis here:

- *Model selection.* Since it was designed to model dispersion from sources of instantaneous releases, like an explosion's dust cloud, INPUFF appears to be an adequate model selection for this application. INPUFF does not explicitly account for complex terrain in its simulations. However, because the estimated release heights for all air-to-ground bombing exercises (217 to 324 meters) were higher than the highest local terrain feature (Cerro Matias, 137 meters), use of a simple terrain dispersion model is justified for this type of source.

- *Meteorological data.* The Navy contractor processed meteorological data collected at US Naval Air Station Roosevelt Roads for use in the INPUFF modeling analysis. As Appendix D.3 explains further, ATSDR believes this data set is the most representative available information for conducting dispersion modeling at Vieques.

- *Other model inputs.* Several other model inputs were specified in the Navy contractor's simulations, including the dimensions and height of the explosion clouds and the locations and elevations of the different receptors. The values selected for the cloud dimensions appear to be consistent with those published in various reports on high explosives, as Appendix D.3 describes. Ambient air concentrations were estimated at receptor locations in the residential areas of Vieques on a very fine grid with 10 meter by 10 meter spacing. This resolution is more than adequate to characterize exposures, especially considering that the source being modeled is several miles from the receptor grid.

- *Comments on the presentation and interpretation of results.* The Navy contractor estimated annual average ambient air concentrations of all pollutants considered but the summary report does not interpret the significance of the estimates nor does it present estimates of air quality impacts over shorter averaging periods. ATSDR designed its modeling analysis (see Appendix D.3) to provide perspective on the public health implications of exposure, including both acute and chronic exposure scenarios.

D.2 Review of Rafael Cruz Pérez's Modeling Study of Live Bombing Activities (Cruz Pérez 2000)

In 2000, Dimension Magazine, a publication of the College of Engineers and Surveyors of Puerto Rico, released an article written by Rafael Cruz Pérez, PE, about environmental contamination at Vieques (Cruz Pérez 2000). ATSDR has identified additional releases of this article from earlier years, but bases its review of the article on the most recent version. The article summarizes levels of environmental contamination, both measured and modeled, in multiple media, including soil, surface water, groundwater, and air. This review focuses specifically on an air modeling analysis documented in the article of high explosives used at Vieques. Refer to Appendix C.4 and C.5 for ATSDR's review of this article's summary of ambient air sampling on Vieques.

D.2.A Overview of Rafael Cruz Pérez's Modeling Approach

The following paragraphs review three key features of Rafael Cruz Pérez's modeling analysis: how emission rates were estimated, how atmospheric fate and transport was simulated, and how results were presented and interpreted. Refer to Section D.2.B for ATSDR's evaluation of the scientific rigor of this modeling analysis.

- *Approach to estimating emissions.* The modeling analysis conducted by Rafael Cruz Pérez evaluated potential air quality impacts associated with bombing activities involving one type of ordnance: 105 mm high explosive mortar projectiles. According to Navy ordnance statistics, these projectiles weigh 33 pounds and contain 5.1 pounds of high explosives. When evaluating air quality impacts, the modeling analysis considered emissions of only particulate matter and did not consider emissions of other pollutants that bombing activities release.

  To estimate air emissions, Rafael Cruz Pérez reported that firing a single 105 mm high explosive mortar will displace 400 kg of soil. Of this amount, 80% (or 320 kg) was assumed to fall to the ground immediately in the vicinity of the impact location. The remaining 80 kg of particles that remain airborne were assumed to be available for downwind transport. Rafael Cruz Pérez further estimated that 94% of these remaining airborne particles will fall to the ground within several hundred feet of the impact location. With this assumption, 4.8 kg of the soil particles released are considered available for longer range transport. Information on the assumed particle sizes is not provided. The publication by Rafael Cruz Pérez cites no references for any of the aforementioned assumptions and emissions estimates.

- *Approach to modeling atmospheric fate and transport.* The article by Rafael Cruz Pérez indicates that estimates of ambient air concentrations at downwind locations were calculated using a dispersion equation, but the equation is not provided. According to other text in the article, the equation assumes that ambient air concentrations of particulate matter are inversely proportional to the downwind distance raised to the 1.5 power. Rafael Cruz Pérez cites a 1976 publication by the Naval Surface Weapons Center as the source of this concentration decay term. ATSDR located this citation, which was released as "preliminary draft" by the Naval Surface Weapons Center in 1978 (Young 1978). The 1978 document, in turn, cites a 1968 publication of the U.S. Atomic Energy Association as the original source of information on the assumed concentration decay being inversely proportional to downwind distance raised to the 1.5 power (Slade 1968). Refer to Section D.2.B for ATSDR's comments on this dispersion algorithm.

- *Presentation and interpretation of results.* Rafael Cruz Pérez presents estimates of ambient air concentrations in the article for various averaging times, depending on the distance from the LIA. First, Rafael Cruz Pérez reports estimated ambient air concentrations for the scenario of the Navy firing a single 105 mm high explosive mortar. As an example of the results, the article indicates that estimated ambient air concentrations of particulate matter at distances between 3,000 and 4,722 meters from the LIA will be 173 $\mu g/m^3$, and this concentration is assumed to occur over a duration 10.5 minutes. Further, at distances between 6,000 and 18,900 meters from the LIA, which includes the residential areas of Vieques, the estimated concentration of particulate matter is 33 $\mu g/m^3$, which is assumed to last for 15.9 minutes. These concentrations represent Rafael Cruz Pérez's estimates of the incremental air quality impact of firing a single mortar and do not include contributions from other sources.

  To predict actual exposure point concentrations, Rafael Cruz Pérez presented several additional data points. First, the article indicates that an exercise involving the use of several 105 mm high explosive mortars can increase ambient air concentrations of particulate matter in the residential areas of Vieques by 98.38 $\mu g/m^3$, but the article does not present the equations used to estimate this concentration nor does it indicate the averaging time for this reported increase. Next, the article indicates that actual exposure point concentrations would be higher than 197 $\mu g/m^3$—a level apparently calculated by adding the 98.38 $\mu g/m^3$ increase in concentration to an assumed background concentration of 99 $\mu g/m^3$. No averaging period is given for the estimated concentration of 197 $\mu g/m^3$ or the assumed background concentration. The article concludes by asserting that the estimated concentrations are higher than EPA's primary and secondary air quality standards, which are cited as 75 $\mu g/m^3$ (annual average) and 60 $\mu g/m^3$ (highest 24-hour average), respectively. Section D.2.B, below, presents ATSDR's review of Rafael Cruz Pérez's modeling analysis.

D.2.B ATSDR's Review of Rafael Cruz Pérez's Modeling Analysis

As with the Navy contractor's modeling analysis, ATSDR thoroughly reviewed Rafael Cruz Pérez's publication on environmental contamination at Vieques. ATSDR's specific comments on this modeling analysis is presented below, organized by the same three topics presented in Section D.2.A:

- *Comments on approach used to estimate emissions of particulate matter.* ATSDR cannot critically evaluate the approach used to estimate emissions, because the article by Rafael Cruz Pérez does not provide any references for the main assumptions used in the emissions calculations. Nonetheless, several notable observations can be made from the estimated emission rates. First, ATSDR notes that the Rafael Cruz Pérez study predicts that firing of ordnance containing less than 10 pounds of high explosives can displace considerable amounts of soil. As Section D.1.A indicates, the Navy contractor's modeling analysis assumed that all such ordnance would not generate any particulate matter emissions. ATSDR's modeling analysis (see Appendix D.3), like Rafael Cruz Pérez's study, assumes that all high explosive ordnance generates particulate matter emissions.

Next, ATSDR notes that Rafael Cruz Pérez's study and the Navy contractor's study are quite similar in terms of estimating the proportion of displaced soil that is available for longer range downwind transport. Specifically, Rafael Cruz Pérez assumed that 1.2% of the soil displaced by an explosion will travel in the plume for long distances, though information on the particle sizes is not provided. The Navy contractor, on the other hand, assumed that 1.007% of the soil displaced will be emitted as PM10 and will remain airborne for long distances. Section D.3.B presents ATSDR's approach to estimating emissions of airborne particles, as well as more detailed information on the particle sizes.

Finally, to get a sense for how the two modeling studies compare, ATSDR used the Navy's total annual usage of high explosives to extrapolate Rafael Cruz Pérez's emissions estimates to an annual value. To do this calculation, ATSDR noted that Rafael Cruz Pérez's study predicts that 4.8 kg of particulate matter (available for long-range transport) are generated for every 5.1 pounds of high explosives used; further, the Navy's usage of high explosives in 1998 was 771,734 pounds (IT 2000). Assuming, to a first approximation, that particulate matter emissions vary linearly with the amount of high explosives in the ordnance, Rafael Cruz Pérez's emissions estimates imply that the annual releases of particulate matter may be as high as 800 tons per year. This emission rate is 10 times higher than the particulate matter emission rate used in the Navy contractor's modeling analysis. Therefore, the approaches used by the Navy contractor and Rafael Cruz Pérez lead to considerably different emissions estimates. Section D.3.B presents ATSDR's best estimate of particulate matter emissions from military training exercises at Vieques. ATSDR's estimate is higher than the Navy's, and lower than Rafael Cruz Pérez's.

- *Comments on the approach used to model atmospheric fate and transport.* ATSDR cannot critically evaluate the approach Rafael Cruz Pérez used to model atmospheric fate and transport, because the article does not provide sufficient information (e.g., equations) for ATSDR to reproduce the estimated ambient air concentrations. ATSDR can comment on the general approach, however, which assumed that ambient air concentrations of contaminants decrease by the downwind distance raised to the 1.5 power. This assumed rate of concentration decay is a reasonable first approximation for estimating ambient air concentrations for *continuous* plumes, but releases from high explosive mortars generate *instantaneous* plumes. Instantaneous plumes have concentrations that decay more rapidly with downwind distance by virtue of dispersion along the downwind direction, which need not be accounted for with continuous plumes. An expert reviewer of this modeling analysis suspected that concentrations from an instantaneous plume would probably decay with downwind distance raised to an exponent between 2 and 2.5 (Hanna 2001). In other words, concentrations within an instantaneous plume would likely decay much faster than predicted in Rafael Cruz Pérez's article. Consequently, the approach used to estimate dispersion overstates actual concentrations.

The appropriate value of the concentration decay term notwithstanding, ATSDR emphasizes that Rafael Cruz Pérez's approach to estimating ambient air concentrations likely provides only a very rough approximation of actual air quality. Many years of research have established that atmospheric dispersion is not only a function of downwind distance, but is also a function of atmospheric stability. Further, the approach used by Rafael Cruz Pérez does not account for varying wind speeds, wind directions, mixing heights, and other meteorological phenomena that affect how contaminants move through the atmosphere. As Section D.3.C describes, ATSDR used a model that accounts for how site-specific meteorological conditions at Vieques affect atmospheric fate and transport.

- *Comments on the presentation and interpretation of results.* The article by Rafael Cruz Pérez presents various ambient air concentrations as results of its modeling analysis. The final analyses in the article presents an estimated concentration (98.38 $\mu g/m^3$), which is apparently an estimated 24-hour average concentration resulting from the firing of numerous 105 mm high explosive mortars. The article does not describe how this result was calculated and how many mortars were assumed to be fired to generate this level of contamination. To evaluate the significance of this estimate, Rafael Cruz Pérez estimated an exposure point concentration in the residential areas of Vieques by adding the estimated ambient air concentration resulting from the mortar fire (98.38 $\mu g/m^3$) to an assumed background concentration (99 $\mu g/m^3$). The article then compares the resulting exposure concentration (197 $\mu g/m^3$) to EPA's former primary and secondary standards for TSP.

ATSDR has several comments on the article's interpretation of the estimated ambient air concentrations. First, ATSDR notes that not enough information is provided to evaluate how Rafael Cruz Pérez estimated the increase in particulate matter concentrations resulting from the mortar firing (i.e., 98.38 $\mu g/m^3$), which is apparently based on a 24-hour averaging period. Nonetheless, the interpretations of this estimated concentration appear to be flawed. Specifically, ATSDR notes that the assumed background concentration used in the article is the highest ambient air concentration of TSP (99 $\mu g/m^3$) measured in two different studies (see Appendix C.4 and C.5). The background concentration selected is more than twice as high as the average TSP levels that PREQB recently measured at Vieques using rigorous sampling methods. Therefore, the estimated background concentration appears to be more representative of a maximum concentration than of an average concentration.

More importantly, ATSDR does not believe comparing an estimated 24-hour average concentration to an annual average health-based standard is appropriate. A more appropriate interpretation would compare the estimated 24-hour average concentration (197 $\mu g/m^3$) to the former 24-hour average health-based standard for TSP (260 $\mu g/m^3$), assuming the estimated concentrations are indeed total suspended particulates. ATSDR's modeling analysis, documented throughout Appendix D.3, estimates both annual average and maximum 24-hour average concentrations of particulate matter, and compares these estimates to the appropriate health-based standards.

Finally, to assess whether the predicted air quality impacts are reasonable, ATSDR extrapolated the predicted concentrations to a larger-scale bombing event: firing a single 2,000-pound bomb containing 1,000 pounds of high explosives. To extrapolate to this scenario, ATSDR notes that Rafael Cruz Pérez analysis predicts that firing a single round of ordnance containing 5.1 pounds of high explosives would cause short-term average air concentrations in the residential areas of Vieques to increase by at least 33 $\mu g/m^3$. To a first approximation, firing a single bomb that contained 200 times as much high explosives would cause approximately a 200-fold higher air quality impact, or a short-term concentration of 6,600 $\mu g/m^3$. Although extensive sampling data are not available to determine whether or not such predicted concentrations are reasonable, these increases in concentrations, if correct, would likely be associated with significantly impaired visibility throughout the residential areas of Vieques. ATSDR has heard no accounts of such air quality impacts and has not witnessed such effects on visibility during open detonation events involving much more ordnance than a single bomb. These observations, combined with the previous comments, suggest that Rafael Cruz Pérez's modeling analysis may overstate air quality impacts from military training exercises on Vieques.

D.3 ATSDR's Modeling Study of Navy Exercises Using Live Bombs (ERT 2001)

Much of ATSDR's efforts evaluating this site have focused on air quality between the 1970s and 1999—the years when the Navy conducted military training exercises on Vieques using live bombs. Though three parties conducted air sampling projects during this time frame, all of which did not find ambient air concentrations of pollutants at levels above EPA's air quality standards, the quality of the sampling data are not known because original documentation on the sampling projects is limited or not available. As a result, ATSDR used modeling studies to evaluate potential exposures to contaminants released from live bombing activities.

Before estimating emissions and modeling fate and transport, ATSDR first obtained and thoroughly reviewed the two air quality modeling studies that were readily available for Vieques. In so doing, ATSDR not only could build upon the strengths of the work already completed but also could identify and improve upon potential shortcomings noted in Appendix D.1 and D.2. Key features of ATSDR's dispersion modeling analysis are reviewed in the following sections.

D.3.A Goal of ATSDR's Modeling Study

ATSDR designed its modeling study to generate reasonable estimates of how air-to-ground, ship-to-shore, and land-based military activities at Vieques affect air quality in the residential areas of the island. Because this PHA is evaluating potential inhalation exposures, the emphasis in ATSDR's modeling was to make reasonable estimates of ambient air concentrations; characterizing deposition of air particles was not considered in this study, since ATSDR's other PHAs have already addressed (or will soon address) levels of contamination present in other environmental media, including drinking water supplies, soils, and biota. Recognizing that military training exercises at Vieques are not continuous and vary in intensity from one exercise to the next, ATSDR estimated both annual average and maximum 24-hour average exposure point concentrations. These concentrations were then used to evaluate chronic exposure scenarios and acute exposure scenarios, respectively.

The rest of this appendix describes the approaches ATSDR used to estimate emissions from the various military training exercises (Section D.3.B) and to model the atmospheric fate and transport of these emissions (Section D.3.C). Section D.3.D then presents key findings from the modeling analyses. ATSDR's public health interpretations of the modeling results are documented in Sections V.C and V.D.

D.3.B Emissions Estimates

This section describes how ATSDR estimated emission rates from the Navy's military training exercises, including both maximum 24-hour emissions and annual average emissions. Consistent with the goal of the modeling study, ATSDR estimated the combined emissions from the use of high explosives ordnance during air-to-ground, ship-to-shore, and land-based exercises. ATSDR notes that the Navy periodically collects unexploded ordnance from the LIA and destroys the explosive charges in open detonation events. ATSDR's approach to estimating emissions assumed that all ordnance fired on the LIA explodes upon impact. With this approach, performing separate calculations for open detonation events is unnecessary, because ATSDR has already accounted for the potential explosion by-products in its calculations for the bombing exercises.

ATSDR estimated emissions using the range utilization statistics for 1998—the same base year that the Navy contractor used in its modeling analysis (see Appendix D.1.A). ATSDR selected this base year for several reasons, but primarily because 1998 has the most detailed range utilization statistics of all years of data that ATSDR has reviewed. Further, the Navy's use of the range in 1998 is representative of that of previous years. More specifically, ATSDR found that the number of days the Navy used the range in 1998 and the amount of high explosives that were fired on the range in 1998 exceed the long-term average for these parameters over a 16-year period (see Appendix D.1.A). Finally, by using the same base year as the Navy contractor, ATSDR can compare emissions estimates between the studies on the same basis. The remainder of this section describes how ATSDR estimated emissions for different classes of pollutants released during military training exercises:

- *Emissions estimates for particulate matter.* ATSDR is unaware of any studies that have directly measured the amount of particulate matter that an explosion during a military training exercise releases to the air. As Appendix D.1 noted, measuring emissions from explosions is inherently difficult, because measurement devices cannot easily be placed in close proximity to the site of an explosion. Nonetheless, researchers have long observed explosions and have been able to estimate the amounts of particles ejected by evaluating crater sizes, deposition, and other relevant phenomena. ATSDR's particulate emission estimates were made using the COMBIC model, which Appendix D.1 describes. ATSDR emphasizes that this model has been developed to perform realistic simulations of battlefield scenarios, for which accurate predictions are needed to determine whether critical equipment can function in combat situations. Though the intended application of the model provides confidence that the estimated emission rates will be reasonable, it does not guarantee that the predictions will match actual conditions.

  ATSDR's use of the COMBIC model differs from the evaluation performed by the Navy contractor (see Appendix D.1) in three important regards. First, ATSDR considered emissions to the "skirt" of the explosion cloud, which the Navy contractor did not—a factor that results in approximately a 2-fold difference in the emission rates, all other inputs considered equal. Second, ATSDR assumed that all ordnance used during military training exercises, and not just those with more than 10 pounds of high explosives, generate particulate emissions. Third, although bombs at Vieques are fuzed to detonate on impact, ATSDR assumed that the bombs penetrate the surface, which leads to higher emissions estimates than a surface detonation. Table D-1 lists several key inputs used to, and assumptions made when, estimating emissions of particulate matter. Based on these inputs, including a detailed distribution of high explosive ordnance types (as documented in IT 2000), ATSDR estimated that the military training exercises release 277 tons of particulate matter into the air per year. A much greater amount of soil is displaced during the explosions and falls back to the ground in the immediate vicinity of the craters. ATSDR assumed that the 277 tons of emissions are in the form of PM10, even though the COMBIC model documentation indicates that these particles range in sizes from 0–20 microns. More detailed information on particle size distributions is not available.

  To estimate maximum daily particulate emissions, ATSDR reviewed nearly 6 years of daily range utilization statistics to characterize the most intense bombing activity over a 24-hour time frame. Only 6 years were considered because only annual range utilization statistics are available for other years. The daily bombing activity selected to calculate the highest 24-hour average emission rate occurred in October 1995, when 94.5 tons of ordnance containing 39 tons of high explosives were used on a single day. Based on this level of activity and the assumption that the distribution of ordnance types used was the same as the annual average, ATSDR estimated the daily worst-case emission rate to be 28 tons of PM10 released on this one day identified as being representative of the most intense military training exercises. The emission rate for this one day should not be viewed as being representative of typical conditions. In fact, the range utilization statistics indicate that less than 10 tons of ordnance were fired per day of military training exercises scheduled.

ATSDR acknowledges that these estimated emission rates have inherent uncertainties, and the actual emission rates may be higher or lower than the levels calculated. The estimated emission rates used in these analyses are believed to be based on the best information currently available. Though predicting the amount of emissions from a single explosion is extremely difficult, due to the variability in blast behavior and soil properties from one event to the next, the COMBIC model is designed to given reasonable predictions for a series of events, such as those that occur over a year or a day of intense activity.

- *Emissions estimates for explosion by-products.* ATSDR estimated emission rates for chemical by-products of explosions using BangBox emission factors, which Appendix D.1 describes. ATSDR's approach is nearly identical to that used by the Navy contractor in its modeling analysis. The BangBox emission factors are also documented in OBODM (Bjorklund et al. 1998), which is the only atmospheric dispersion model on EPA's Support Center for Regulatory Air Models designed specifically to characterize emissions of explosion by-products. These emission factors are believed to be the best information currently available, and arguably the most widely used basis, for estimating air emissions from detonations of high explosives.

  When selecting emission factors, ATSDR first identified all of the BangBox studies that considered high explosives of similar composition to those the Navy used at Vieques, namely those that contain some combination of TNT, RDX, and aluminum powder. From this set of studies, the highest emission factor was selected for this modeling analysis for every chemical measured. Table D-2 lists the chemicals by-products of explosions that ATSDR considered, along with their emission factors, emission rates, and estimated annual average air concentrations. Section D.3.D comments on the uncertainties associated with the data presented in Table D-2.

- *Emissions estimates for metals.* ATSDR identified four different ways that metals may be emitted to the air during military training exercises: bomb casings may vaporize, trace metals in the explosive mixture may be released, larger amounts of aluminum in the high explosive charge may be released, and soils that contain metals may be ejected into the air. ATSDR notes that the Navy contractor's modeling analysis did not consider at least two of these factors contributing to air emissions. Approaches ATSDR used to represent these different factors follow:

- *Metals released from bomb casings.* ATSDR reviewed data provided by the Navy on the composition of metals in the bomb casings. This data indicated that the following metals were present in some types of bomb casings at the concentrations specified: aluminum (5.6%), boron (0.0002%), chromium (0.02%), copper (2.35%), iron (93.11%), manganese (1.82%), molybdenum (0.001%), nickel (0.01%), titanium (0.01%), and zinc (0.45%). The estimated weight of the casings was calculated as the difference between the total amount of ordnance used in 1998 (1,295 tons) and the total amount of high explosives within the ordnance (386 tons). Metals emissions were calculated by multiplying the composition by the total weight of the casings. ATSDR conservatively assumed that the entire casings are vaporized in every explosion. This assumption clearly overstates emissions, because fragments of casings have remained on the ground after most military training exercises, including those that used live bombs.

- *Trace amounts of metals in the high explosive mixture.* The BangBox studies reviewed for this public health assessment include emission factors for 14 metals: aluminum, antimony, barium, cadmium, calcium, chromium (trivalent and hexavalent), copper, lead, mercury, nickel, potassium, sodium, titanium, and zinc. These metals were presumably present in the casings or the high explosive mixture tested in the BangBox studies. Even if their origin was the casings, which were addressed separately in the emissions calculations, ATSDR considered the BangBox emission factors to estimate releases. The emission factors for these metals can be obtained from the OBODM model (Bjorklund et al. 1998).

- *Aluminum in the high explosive charge.* According to the Navy's bomb composition statistics, the high explosive charges for the ordnance most commonly used at Vieques contained varying amounts of organic compounds (typically a mixture of TNT and RDX) and aluminum powder. The highest composition of aluminum powder in the bombs most commonly used was 21%. ATSDR assumed that this amount of aluminum powder was present in all rounds of ordnance fired and that all of the powder was emitted as PM10.

- *Metals in soils.* The soils at the LIA contain naturally-occurring metals as well as metals contamination. To estimate the amount of metals released in crater ejecta, ATSDR multiplied the particulate emission rates by the average metals concentrations in the LIA soils (see Table 4).

Table D-3 lists the annual emission rates that ATSDR calculated for metals, organized by the four different factors that contribute to these emissions. The table also lists the estimated annual average air concentrations. Section D.3.D comments on the uncertainty associated with the metals emissions estimates.

- *Emissions estimates for explosives.* Range utilization statistics indicate the total weight of high explosive charges in the ordnance used at the LIA (e.g., 386 tons in 1998). Further, ordnance composition data compiled by the Navy characterize the typical chemical composition of these high explosive charges. In recent years, these have been composed primarily of TNT and RDX; aluminum powder is also found in considerable quantities in these charges, but emissions of aluminum were calculated with those for the other metals. To estimate air emissions of the organic high explosives (TNT and RDX), ATSDR multiplied the weight of the high explosive charge by the maximum composition of the individual constituents.

  Approximately 93% of the high explosive material used during the base year was from three different types of air-to-ground ordnance, which contain TNT and RDX at concentrations up to 80% and 45.1%, by weight. ATSDR used these maximum levels to estimate the total quantity of these chemicals in the charges, even though both chemicals clearly cannot be present at these concentrations in the same mixture. The remaining 7% of high explosive material has widely varying compositions. Rather than calculating the quantities of each component in the charges, ATSDR instead calculated a single emission rate for "all other" high explosive chemicals.

  After calculating the amounts of chemicals present in the charges, ATSDR then estimated the proportion of the high explosives that are consumed during the detonation. Although destruction efficiencies for high explosives have not been measured for live bombing exercises, ATSDR notes that the BangBox emission factors suggest that open burning and open detonation activities are typically more than 99% efficient at destroying organic high explosive chemicals. High destruction efficiencies are assumed to apply to the military training exercises at Vieques, primarily because rapid destruction of the charge is needed for ordnance to be effective. The fact that only trace amounts of high explosive chemicals remain in the LIA soils (ATSDR 2001b) is consistent with the assumed high destruction efficiency. To calculate emissions for the dispersion modeling analysis, ATSDR assumed that 10% of the organic chemicals in high explosive charges are emitted. In other words, ATSDR assumed that the explosions have a 90% destruction efficiency for the organic chemicals in the charges.

  ATSDR's emissions estimates for high explosives, along with the estimated ambient air concentrations that result from the modeling analysis, are summarized below:

Chemical	Estimated Emissions	Estimated Air Concentration
TNT	31 tons/year	0.0058 $\mu g/m^3$
RDX	19 tons/year	0.0035 $\mu g/m^3$
All others	2.8 tons/year	0.00052 $\mu g/m^3$

D.3.C Atmospheric Fate and Transport

ATSDR used the CALPUFF dispersion model to evaluate the atmospheric fate and transport of air emissions. This model was selected because it has been designed to assess many types of sources, including non-continuous (or "puff") sources, and can also assess deposition, which other "puff" models (like INPUFF) cannot do. The modeling was performed using CALPUFF Version 5.5, Level 010730_1. The following paragraphs describe key inputs selected for this application; a complete listing of these inputs is available in the final modeling report (Trinity Consultants 2002):

- *Source parameters.* All emissions were assumed to originate from the geographic center of the LIA (coordinates: 257.748 km East, 2,006.944 km North, Zone 20). This choice is considered acceptable because ordnance is likely to impact many different locations at the LIA. The emissions clouds generated during explosions were modeled as elevated volume sources. Three different sets of source parameters were used, corresponding to cloud heights predicted for air-to-ground exercises using 500-lb, 1,000-lb, and 2,000-lb bombs (IT 2000). These three bombs account for more than 90% of the high explosive ordnance used during the base year. The emissions were represented as puff releases with a diurnal emissions profile: emissions were set to zero between 11:00 PM and 7:00 AM every day. This diurnal profile reflects the times of day when the Navy used live bombs prior to 1999 (IT 2000). The center of the cloud heights varied from 285 to 424 meters, and the initial lateral dimensions from 44 to 66 meters. These values were used in the Navy contractor's dispersion modeling analysis, and are based on observations of explosion characteristics made by the former Defense Nuclear Agency. Unit emission rates were used in the model.

- *Meteorological data.* CALPUFF can use three dimensional meteorological fields when extensive meteorological data are available, particularly for multiple sites. Since the data needed to generate these meteorological fields are not available for Vieques, CALPUFF was run using meteorological data like that compiled for running EPA's Industrial Source Complex (ISC) models. The meteorological data were based on surface measurements taken at the U.S. Naval Station at Roosevelt Roads, Puerto Rico, upper air measurements from San Juan, Puerto Rico, and precipitation data from Fajardo, Puerto Rico. Data were processed for the years 1985, 1985, 1989, 1990, and 1991, such that ATSDR's results could be compared directly to those of the Navy contractor. Missing surface data observations were relatively few (less than 100 hours missing per year), and were filled according to EPA guidance. Missing data periods of greater than 5 hours were left as missing in the model ready files.

- *Receptor locations.* The model was run with a computational grid that spanned 100 km by 100 km. The receptor domain was limited to the residential areas of Vieqeus. In this area, ambient air concentrations were predicted for a receptor grid with 100 meter spacing. Receptors were also placed at 100 meter spacing along the boundary that separates the residential area on Vieques from Navy property. Terrain elevations were input to the model by interpolating from Digital Elevation Model data obtained from the U.S. Geological Survey.

- *Run options.* Gaseous and particulate emissions were modeled separately, given their different deposition properties. Particulates were modeled assuming that they were all present as PM10. CALPUFF's default deposition parameters were selected for all events. Liquid (0.00066 1/s) and frozen (0.00022 1/s) wet scavenging coefficients were selected for the particulate emissions; these were taken from the most recent User's Guide for the Industrial Source Complex models. Runtime options typical of regulatory applications were selected for all other parameters. Complex terrain was not considered in these evaluations because the estimated initial cloud heights were greater than the elevations of the local terrain features.

- *Outputs.* Normalized concentrations were calculated for several scenarios. For every year of meteorological data considered, and for each of the three different cloud types modeled, annual average and maximum 24-hour average normalized concentrations were calculated for particles (with deposition algorithms "on"), and annual average and maximum 24-hour average normalized concentrations were calculated for gaseous contaminants (with deposition algorithms "off"). The modeling results, and associated uncertainties, are summarized in the following section.

D.3.D Results

Modeling results were reported as normalized concentrations, based on unit emission rates (Trinity Consultants 2002). For all three initial cloud dimensions considered, the highest normalized concentrations occurred for receptors along the property line that separates the residential areas of the island from Navy property. These receptor locations are at least 1 mile upwind from the most heavily populated areas on Vieques.

At the location with highest predicted air quality impacts, the annual average normalized concentrations varied with initial cloud height and the year of meteorological data considered.

Table D-4 summarizes the main model outputs for the various scenarios considered. The modeling results showed that concentrations did not change dramatically with initial cloud height, as annual average ambient air concentrations varied by less than a factor of two between the 500-pound and 2,000-pound bombing events, whose initial cloud heights differ by 160 meters.

The approach used to calculated air concentrations from the normalized concentrations depends on the averaging time and contaminant of concern. The normalized concentrations for particles (i.e., considering deposition) were used to estimate air concentrations for both metals and particulate matter, while those for vapors (i.e., not considering deposition) were used to estimate air concentrations for chemical by-products of explosions and high explosive chemicals. The highest daily emission rate was multiplied by the 24-hour maximum normalized concentrations when assessing worst case air quality impacts over the short term. This approach assumes that the most intense bombing activity occurred on the day that had the least favorable meteorological conditions—an unlikely scenario, but one that helps ensure that the modeling analysis does not underestimated 24-hour average concentrations. To calculate annual average air concentrations, the annual average emission rates were multiplied by the corresponding annual average normalized concentrations.

As acknowledged throughout this section, air dispersion modeling analyses have inherent uncertainties and limitations, and the concentrations predicted in this analysis may be higher or lower than the actual impacts that occurred on Vieques during military training exercises with live bombs. Specific comments on uncertainties associated with individual contaminants follow:

- *Metals.* The approach used to estimate emissions for metals is believed to be an upper bound estimate of actual emissions. That is, the amount of metals released to the air is likely not higher than the amount of metals in the casings, in the high explosive charge, and in the soils ejected into the air. Although predicting crater ejecta arguably involves the greatest uncertainty, assumptions that the entire bomb casings vaporize and that all of the aluminum powder in high explosive charges is emitted are conservative. As a result, ATSDR has confidence that the metals emissions data and estimated air concentrations are reasonable and do not understate the actual amounts that military training exercises contributed to air quality.

- *Organic by-products of explosives.* The BangBox emissions studies are widely used to characterize emissions from detonations involving high explosives. The extent to which results from these highly-controlled studies represent conditions during military training exercises is not known. However, ATSDR notes that the predicted ambient air concentration for every by-product considered was more than three orders of magnitude lower than health-based comparison values. Given this substantial difference between predicted concentrations and the concentrations that would require further evaluation, ATSDR again has confidence that the model predictions are a sound basis for making public health conclusions, even if the BangBox emissions studies do not perfectly replicate conditions in the field.

- *Explosives.* The modeling analysis assumed that every high explosive charge contains 80% TNT and 41.5% RDX, which are the highest cited concentrations from bomb composition data. These assumed compositions clearly overstate the total amount of high explosives released to the air. The percentage of organic high explosives that are destroyed in bombs used during military training exercises is not known. As a first approximation, based loosely on destruction efficiencies reported for open detonation events, ATSDR assumed that 90% of the organic high explosives are destroyed when ordnance is fired on the LIA. ATSDR acknowledges that the estimated air concentrations are highly dependent on this assumed destruction efficiency. However, even if ATSDR assumed that only 10% of the explosives were destroyed (an unrealistically low number), the estimated ambient air concentrations of TNT and RDX would still be below health-based comparison values. As a result, ATSDR has confidence that the conclusions made for high explosives are appropriate.

- *Particulate matter.* The uncertainty involved in estimating particulate matter emissions is arguably the greatest, and is also most difficult to interpret. The fact that the predicted increase in annual average PM10 concentrations (0.04 $\mu g/m^3$) is at least two orders of magnitude lower than levels of health concern is reassuring. Moreover, the fact that the air sampling studies from the 1970s, though of questionable quality, did not report particulate concentrations greater than EPA's air quality standards also provides some level of comfort that the estimated concentrations do not grossly underestimate actual air concentrations.

Table D-1
Review of Selected Inputs to COMBIC and CalPUFF Models

Parameter	Input/Assumption Selected	Comments
Approach used to estimate particulate emissions	COMBIC model	This model was developed by the Army to estimate airborne dust levels during battlefield scenarios. Accurate prediction of emissions is necessary to ensure that critical equipment will operate during combat situations.
Annual amount of high explosives in the ordnance used	386 tons, based on calendar year 1998 range utilization statistics	This annual usage rate of high explosive chemicals is higher than the average (353 tons) for 1983 to 1998, the longest period of record for which detailed utilization statistics are available. Selection of the 1998 base year will therefore not understate the annual air quality impacts, when averaged over the long term. Note that this amount of high explosives is based on firing 1,295 total tons of ordnance. The total tonnage is greater, because it includes contributions from casings, fuzes, and fillers.
Maximum daily amount of high explosives in the ordnance used	39 tons, based on a review of daily range utilization statistics from 1993 to 1998)	This usage was determined from reviewing nearly 6 complete years of daily range utilization statistics. The amount of high explosives assumed to be fired on the day with most intense activities equals roughly 10% of the annual usage. This value appears to be reasonable, especially when noting that military training exercises occurred on approximately 200 days per year prior to 1999.
Percent of bombs that detonate upon impact	100%	Not all bombs detonate upon impact. Site documents imply that over 90% of the bombs fired on the LIA do detonate. Assuming that all bombs detonate will lead to an overestimate of emissions.
Soil type	Dry cohesive soils	This soil type is most consistent with the soils on the LIA. Of the six soil types considered by COMBIC, "dry sandy soils" leads to the highest proportion of small particles in the emissions cloud.

Table D-1 (Continued)
Review of Selected Inputs to COMBIC and CalPUFF Models

Parameter	Input/Assumption Selected	Comments
Depth of burst	1 foot	Bombs fired on the LIA are fuzed to detonate upon impact. To be conservative, ATSDR assumed that the center of a bomb penetrates up to 1 foot of soil before the bomb explodes. This assumption leads to predicted emission rates approximately 40% higher as compared to the emissions from surface detonations.
Particle size distribution in emissions	100% PM10	The COMBIC model reports that "small particle" emissions have diameters less than 20 microns. Therefore, the emission rates that ATSDR calculated include both PM10 and larger particles. For a conservative evaluation of air quality impacts, however, ATSDR assumed that all of the "small particle" emissions have diameters less than 10 microns. This assumption leads to lower deposition estimates, and therefore higher estimates of ambient air concentrations. Moreover, by assuming that all of the emissions are in particle size ranges that are more likely to be inhaled, this approach also overstates the toxicity of the particles. Thus, assuming the particles are all PM10 is a conservative approach to assessing the emissions.
Approach to estimate emissions for chemical by-products of explosions	BangBox emission factors	BangBox emission factors have been widely used in estimating air quality impacts resulting from the detonation of high explosives. The only air emissions and dispersion model available from EPA's Support Center for Regulatory Air Models that is specifically designed to evaluate these detonations estimates emissions using the BangBox emission factors.

Table D-1 (Continued)
Review of Selected Inputs to COMBIC and CalPUFF Models

Parameter	Input/Assumption Selected	Comments
Approach to estimate emissions of metals	Multiple considerations	Section D.3.B lists the different assumptions made when estimating air emissions of metals. Assuming that the bomb casings and aluminum powder completely vaporize likely leads to an overstated emission rate. Adding the BangBox emission factors to the estimated releases from casings may be "double-counting," and therefore overstating, emissions.
Approach to estimate emissions of high explosives	Assumed explosions are 90% efficient in consuming organic chemicals in the high explosive charge	The chemical bonds in the organic chemicals in an explosive charge (e.g., TNT and RDX) contain the energy released during a detonation. These chemicals react quickly during an explosion, releasing large amounts of energy as they break up into smaller molecules. A considerable fraction of these organic chemicals must react in order for a bomb to be effective. ATSDR assumed that the bombs at Vieques consume 90% of the organic chemicals in the high explosive charges. This percentage is relatively low (and therefore leads to overstated emission rates for these chemicals), when compared to the destruction efficiencies (>99%) typically reported for open detonation activities.

Table D-1 (Continued)
Review of Selected Inputs to COMBIC and CalPUFF Models

Parameter	Input/Assumption Selected	Comments
Modeling deposition of particulate matter	Used regulatory default procedures in modeling analysis	The COMBIC model predicts that the "small particle" emissions (i.e., those considered in this modeling analysis) have a settling velocity of 0.3 cm/s. Therefore, over the course of an hour, or the time it generally takes wind to blow from the LIA to the residential areas of Vieques, particles would be expected to settle approximately 10 meters, on average. This would result in essentially the entire "skirt" of the emissions cloud, or the near ground-level emissions, to settle to the surface well before plumes reach the residential areas of Vieques. To be conservative, ATSDR assumed that these emissions transport downwind in the "puff" generated during an explosion, which has the greater potential for long-range transport.

Table D-2
Emission Factors, Emission Rates, and Estimated Annual Average Concentrations for Chemical By-Products of Explosions

Chemical	Emission Factor (grams emitted per grams of NEW used)	Emission Rate (pounds per year)	Estimated Annual Average Air Concentration in Residential Areas ($\mu g/m^3$)
Carbon dioxide	1.33e+00	9.58e+05	9.54e-02
Carbon monoxide	7.17e-03	5.17e+03	5.14e-04
Nitrogen dioxide	2.60e-03	1.87e+03	1.87e-04
Nitric oxide	1.46e-02	1.05e+04	1.05e-03
Sulfur dioxide	2.23e-04	1.61e+02	1.60e-05
2,4-Dinitrotoluene	3.51e-06	2.53e+00	2.52e-07
2,6-Dinitrotoluene	4.39e-07	3.16e-01	3.15e-08
N-2,4,6-Tetranitroaniline	2.20e-08	1.59e-02	2.98e-09
1,2-Methylnaphthalene	3.00e-05	2.16e+01	2.15e-06
1,1,3-Trimethyl-3-Phenylindane	5.70e-07	4.11e-01	4.09e-08
1,3,5-Trinitrobenzene	1.97e-06	1.42e+00	1.41e-07
1,3-Butadiene	4.09e-06	2.95e+00	4.73e-07
1,4-Dichlorobenzene	3.15e-07	2.27e-01	2.26e-08
1-Nitropyrene	1.06e-06	7.64e-01	7.61e-08
2,5-Diphenyloxazole	7.23e-05	5.21e+01	5.19e-06
2-Methylnaphthalene	1.77e-06	1.28e+00	1.27e-07
2-Methylphenol (o-cresol)	6.84e-07	4.93e-01	5.19e-08
2-Nitrodiphenylamine	6.01e-07	4.33e-01	4.31e-08
2-Nitronaphthalene	6.43e-07	4.63e-01	4.61e-08
4-Methylphenol (p-cresol)	5.68e-07	4.09e-01	4.08e-08

Table D-2 (Continued)
Emission Factors, Emission Rates, and Estimated Annual Average Concentrations for Chemical By-Products of Explosions

Chemical	Emission Factor (grams emitted per grams of NEW used)	Emission Rate (pounds per year)	Estimated Annual Average Air Concentration in Residential Areas (µg/m³)
4-Nitrophenol	2.59e-06	1.87e+00	1.86e-07
Acetophenone	1.50e-05	1.08e+01	1.08e-06
Dimethylphenethylamine	0.00e+00	0.00e+00	5.20e-09
Acetylene	1.82e-05	1.31e+01	1.31e-06
Ammonia	2.92e-04	2.10e+02	2.10e-05
Benzene	9.62e-04	6.93e+02	6.90e-05
Benzo(a)pyrene	4.77e-06	3.44e+00	3.42e-07
Benzyl alcohol	1.41e-07	1.02e-01	1.01e-08
Biphenyl	5.20e-08	3.75e-02	3.73e-09
Bis(2ethylhexyl)phthalate	2.93e-06	2.11e+00	2.10e-07
Butylbenzylphthalate	1.03e-06	7.42e-01	7.49e-08
Carbon tetrachloride	6.30e-06	4.54e+00	4.52e-07
Dibenz(a,h)anthracene	1.73e-06	1.25e+00	1.24e-07
Dibenzofurans	1.32e-06	9.51e-01	9.47e-08
Diethyl phthalate	3.04e-07	2.19e-01	2.70e-08
Dimethyl phthalate	8.64e-07	6.22e-01	6.20e-08
Di-n-butyl phthalate	8.32e-05	5.99e+01	5.97e-06
Di-n-octyl phthalate	1.87e-06	1.35e+00	1.34e-07
Diphenylamine	7.73e-08	5.57e-02	5.55e-09
Methane	5.88e-03	4.24e+03	4.27e-04
Naphthalene	1.50e-04	1.08e+02	1.08e-05
Nnitrosodiethylamine	1.18e-07	8.50e-02	8.47e-09
Nnitrosodiphenylamine	5.86e-06	4.22e+00	4.20e-07

Table D-2 (Continued)
Emission Factors, Emission Rates, and Estimated Annual Average Concentrations for Chemical By-Products of Explosions

Chemical	Emission Factor (grams emitted per grams of NEW used)	Emission Rate (pounds per year)	Estimated Annual Average Air Concentration in Residential Areas ($\mu g/m^3$)
Non-benzene aromatics	3.16e-03	2.28e+03	2.27e-04
Olefins (VOCs)	1.35e-03	9.73e+02	9.89e-05
Paraffins (VOCs)	1.81e-04	1.30e+02	1.30e-05
Phenol	2.52e-05	1.82e+01	1.81e-06
Total PAHs	1.74e-05	1.25e+01	1.25e-06
Vinyl chloride	1.23e-06	8.86e-01	8.83e-08

Notes: Emission factors and emission rates listed are for air-to-ground activities only. ATSDR used different sets of emission factors for ship-to-shore and land-based activities, but these activities consistently accounted for approximately 5% of the total concentrations and are not summarized in this table.
The ambient air concentration listed is for the location in the residential area of Vieques found to have the highest air quality impacts from the military training exercises. The concentrations reflect contributions from all three types of military training exercises.

Table D-3
Estimated Emission Rates and Annual Average Concentrations for Metals

Metal (or Element)	Estimated Contribution (kg/year) to Emissions from Different Factors				Estimated Annual Average Ambient Air Concentration in Residential Areas (µg/m³)
	Casings	BangBox Data	Aluminum Powder	Crater Ejecta (Soil)	
Aluminum	1.14e+04	7.54e+03	9.39e+04	4.08e+03	2.04e-02
Antimony	0.00e+00	1.84e+01	0.00e+00	2.87e-01	3.27e-06
Arsenic	0.00e+00	5.20e-01	0.00e+00	1.98e+00	4.37e-07
Barium	0.00e+00	3.28e+02	0.00e+00	2.65e+01	6.19e-05
Beryllium	0.00e+00	0.00e+00	0.00e+00	6.08e-02	1.06e-08
Boron	4.07e-01	0.00e+00	0.00e+00	3.96e+00	7.62e-07
Cadmium	0.00e+00	5.27e+02	0.00e+00	4.31e-01	9.22e-05
Calcium	0.00e+00	1.66e+03	0.00e+00	2.87e+04	5.31e-03
Chromium	4.07e+01	4.14e+01	0.00e+00	9.53e+00	1.60e-05
Chromium VI	0.00e+00	2.07e+00	0.00e+00	0.00e+00	3.62e-07
Cobalt	0.00e+00	0.00e+00	0.00e+00	3.68e+00	6.43e-07

Table D-3 (Continued)
Estimated Emission Rates and Annual Average Concentrations for Metals

Metal (or Element)	Estimated Contribution (kg/year) to Emissions from Different Factors				Estimated Annual Average Ambient Air Concentration in Residential Areas (µg/m³)
	Casings	BangBox Data	Aluminum Powder	Crater Ejecta (Soil)	
Copper	4.79e+03	1.29e+04	0.00e+00	9.86e+00	3.10e-03
Iron	1.90e+05	0.00e+00	0.00e+00	8.44e+03	3.46e-02
Lead	0.00e+00	6.28e+02	0.00e+00	2.14e+00	1.10e-04
Manganese	3.71e+03	0.00e+00	0.00e+00	1.82e+02	6.79e-04
Mercury	0.00e+00	5.75e-02	0.00e+00	5.44e-03	1.10e-08
Molybdenum	2.04e+00	0.00e+00	0.00e+00	0.00e+00	3.56e-07
Nickel	2.04e+01	1.14e+01	0.00e+00	4.01e+00	6.25e-06
Potassium	0.00e+00	5.86e+02	0.00e+00	0.00e+00	1.02e-04
Scandium	0.00e+00	0.00e+00	0.00e+00	3.15e+00	5.50e-07
Selenium	0.00e+00	0.00e+00	0.00e+00	3.10e-01	5.42e-08
Sodium	0.00e+00	1.50e+02	0.00e+00	0.00e+00	2.63e-05
Strontium	0.00e+00	0.00e+00	0.00e+00	3.93e+01	6.87e-06
Tin	0.00e+00	0.00e+00	0.00e+00	1.23e+00	2.14e-07

Table D-3 (Continued)
Estimated Emission Rates and Annual Average Concentrations for Metals

Metal (or Element)	Estimated Contribution (kg/year) to Emissions from Different Factors				Estimated Annual Average Ambient Air Concentration in Residential Areas (µg/m^3)
	Casings	BangBox Data	Aluminum Powder	Crater Ejecta (Soil)	
Titanium	2.04e+01	1.07e+02	0.00e+00	4.16e+02	9.49e-05
Vanadium	0.00e+00	0.00e+00	0.00e+00	2.67e+01	4.67e-06
Yttrium	0.00e+00	0.00e+00	0.00e+00	5.24e+00	9.16e-07
Zinc	9.16e+02	8.21e+03	0.00e+00	1.20e+01	1.60e-03
Zirconium	0.00e+00	0.00e+00	0.00e+00	1.49e+01	2.60e-06

Note: Section D.3.B discusses the assumptions made to estimate the emission rates for metals. Several assumptions are highly conservative (e.g., the casings from all high explosives completely vaporize upon impact) and most likely cause these emissions estimates to overstate actual emissions levels.

Table D-4
Normalized Concentrations Predicted by CALPUFF

Emissions Scenario	Particle or Vapor	Averaging Period	Normalized Concentration (µg/m³)/(lb/hr)
500-lb air-to-ground bombing event	Particle	Annual average	0.000464
		24-hour maximum	0.00317
	Vapor	Annual average	0.000543
		24-hour maximum	0.00366
1,000-lb air-to-ground bombing event	Particle	Annual average	0.000338
		24-hour maximum	0.00273
	Vapor	Annual average	0.000393
		24-hour maximum	0.00319
2,000-lb air-to-ground bombing event	Particle	Annual average	0.000258
		24-hour maximum	0.00230
	Vapor	Annual average	0.000299
		24-hour maximum	0.00269

Note: The annual average normalized concentrations are averages of the annual average concentrations output for the five different years of meteorological data; the 24-hour average normalized concentrations are the highest daily-average level predicted for the five years of meteorological data.