REPORT NT-12-1
MAY 2012

ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES

NAVAL NUCLEAR PROPULSION PROGRAM
DEPARTMENT OF THE NAVY
WASHINGTON, D.C. 20350

This publication was printed on Recycled Paper

Report NT-12-1
May 2012

ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES 2011

Prepared by
T. J. Mueller,
J. M. Steele, and L. E. Murphy
Naval Nuclear Propulsion Program
Department of the Navy

Approved by

K. H. DONALD
Admiral, U.S. Navy
Director, Naval Nuclear Propulsion

ABSTRACT

This report assesses the environmental effect of disposal of radioactive wastes originating from U.S. naval nuclear propulsion plants and their support facilities. The total long-lived gamma radioactivity in liquids discharged to all ports and harbors from all naval nuclear-powered ships and supporting tenders, naval bases, and shipyards was less than 0.002 curie in 2011. To put this small quantity of radioactivity into perspective, it is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single nuclear-powered submarine, or the quantity of naturally occurring radioactivity in the top inch of soil on a half-acre lot. This report confirms that procedures used by the Navy to control releases of radioactivity from U.S. naval nuclear-powered ships and their support facilities have not had an adverse effect on human health or the quality of the environment. These procedures have ensured that no member of the general public has received measurable radiation exposure as a result of operations of the Naval Nuclear Propulsion Program.

The successful radiological deactivation and closures of Ingalls Shipbuilding radiological facilities in 1982 and of the Charleston and Mare Island Naval Shipyards in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

TABLE OF CONTENTS

SUMMARY 1

RADIOACTIVE LIQUID PROCESSING AND CONTROL 3

- Policy and Procedures Minimizing Release of Radioactivity in Harbors 3
- Source of Radioactivity 3
- Radioactivity Removal from Liquid at Shore Facilities 3
- Liquid Releases in Harbors 4
- Short-Lived Radionuclides 4
- Fission Product Radionuclides 4
- Tritium 6
- Carbon-14 6
- Liquid Releases at Sea 7
- Loss of USS THRESHER and USS SCORPION 7

SOLID RADIOACTIVE WASTE DISPOSAL 9

- Deactivation of Ingalls Shipbuilding Radiological Facilities 13
- Closure of Charleston and Mare Island Naval Shipyards 13
- Mixed Radioactive and Hazardous Waste 14
- Disposal of Decommissioned, Defueled Naval Reactor Plants 14

TRANSPORTATION OF RADIOACTIVE MATERIAL 15

NAVY ENVIRONMENTAL MONITORING PROGRAM 18

ENVIRONMENTAL PATHWAYS ANALYSIS 25

AUDITS AND REVIEWS 28

CONCLUSIONS 29

REFERENCES 30

LIST OF TABLES

Table 1: Disposed Radioactive Solid Waste from U.S. Naval Nuclear-Powered Ships and Their Support Facilities for 2007 through 2011 11

Table 2: Summary of 2011 Surveys for Cobalt-60 in Bottom Sediment of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built 21

Table 3: Summary of 2011 Surveys for Cobalt-60 in Marine Life of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built 23

Table 4: Summary of 2011 Offsite and Perimeter Radiation Monitoring of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built 24

Table 5: Radionuclide Releases Used for Environmental Pathways Analysis 26

Table 6: Estimated Maximum Radiation Exposure to an Individual for Assumed Liquid Releases and Airborne Radioactivity Releases from Shipyards Engaged in Naval Nuclear Propulsion Work 27

LIST OF FIGURES

Figure 1: Simplified Diagram of Radioactive Liquid Processing System 5

Figure 2: Radioactive Solid Waste Disposal in the Naval Nuclear Propulsion Program 1961–2011 12

Figure 3: Gamma Spectra of Harbor Bottom Sediment Samples with a Germanium Detector 22

Appendix: ENVIRONMENTAL MONITORING SURVEY CHARTS 35

SUMMARY

The radioactivity in materials discussed in this report originates in the pressurized water reactors of U.S. naval nuclear-powered ships. As of the end of 2011, the U.S. Navy had 72 nuclear-powered submarines, 11 nuclear-powered aircraft carriers, and 2 moored training ships in operation. Facilities involved in construction, maintenance, overhaul, and refueling of these nuclear propulsion plants include six shipyards, two tenders, and five naval bases. This report describes disposal of radioactive liquid, transportation and disposal of solid wastes, and monitoring of the environment to determine the effect of radioactive releases, and updates reports on this subject issued by the Navy in references 1 through 6 (references are listed on page 29). This report concludes that radioactivity associated with U.S. naval nuclear-powered ships has had no discernible effect on the quality of the environment. A summary of the radiological information supporting this conclusion follows:

From the start of the Naval Nuclear Propulsion Program, the policy of the U.S. Navy has been to reduce to the minimum practicable the amounts of radioactivity released into harbors. Since 1971, the total long-lived gamma radioactivity released each year within 12 miles of shore from all U.S. naval nuclear-powered ships and their support facilities has been less than 0.002 curie; this includes all harbors, both U.S. and foreign, entered by these ships.

As a measure of the significance of these data, the total quantity of long-lived radioactivity released within 12 miles of shore in any of the last 40 years is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single nuclear-powered submarine, or the quantity of naturally occurring radioactivity in the top inch of soil on a half-acre lot. In addition, if one person were able to drink the entire amount of radioactivity discharged into any harbor in any of the last 40 years, that person would not exceed the annual radiation exposure permitted by the Nuclear Regulatory Commission for an individual nuclear worker.

Environmental monitoring is conducted by the U.S. Navy in U.S. and foreign harbors frequented by U.S. naval nuclear-powered ships. This monitoring consists of analyzing harbor sediment, water, and marine life samples for radioactivity associated with naval nuclear propulsion plants; radiation monitoring around the perimeter of support facilities; and effluent monitoring. Environmental samples from each of these harbors are also checked at least annually by a Department of Energy laboratory to ensure analytical procedures are correct and standardized.

Independent environmental monitoring has been conducted by the Environmental Protection Agency in U.S. harbors during the past several decades. The results of these extensive, detailed surveys have been consistent with Navy results. These surveys have again confirmed that U.S. naval nuclear-powered ships and support facilities have had no discernible effect on the radioactivity of the environment.

This report and other reports produced by the Naval Nuclear Propulsion Program are available online at:

http://nnsa.energy.gov/ourmission/poweringnavy/annualreports

RADIOACTIVE LIQUID PROCESSING AND CONTROL

Policy and Procedures Minimizing Release of Radioactivity in Harbors

The policy of the U.S. Navy is to reduce to the minimum practicable the amounts of radioactivity released to the environment, particularly within 12 miles of shore. This policy is consistent with applicable recommendations issued by the Federal Radiation Council (incorporated into the Environmental Protection Agency in 1970), U.S. Nuclear Regulatory Commission, National Council on Radiation Protection and Measurements, International Commission on Radiological Protection, International Atomic Energy Agency, and National Academy of Sciences—National Research Council (references 7 through 16). Keeping releases small minimizes the radioactivity available to build up in the environment or to concentrate in marine life. To implement this policy of minimizing releases, the Navy has issued standard instructions defining radioactive release limits and procedures to be used by U.S. naval nuclear-powered ships and their support facilities.

Source of Radioactivity

In the shipboard reactors, pressurized water circulating through the reactor core picks up the heat of nuclear reaction. The reactor cooling water circulates through a closed piping system to heat exchangers, which transfer the heat to water in a secondary steam system isolated from the primary cooling water. The steam is then used as the source of power for the propulsion plant, as well as for auxiliary machinery. When reactor coolant water expands as a result of being heated to operating temperature, the resulting excess coolant passes through an ion exchange resin bed for purification before being transferred to holding tanks.

The principal sources of radioactivity in liquid effluents are trace amounts of corrosion and wear products from reactor plant metal surfaces in contact with reactor cooling water. Radionuclides with half-lives of approximately one day or greater in these corrosion and wear products include tungsten-187, chromium-51, hafnium-181, iron-59, iron-55, nickel-63, niobium-95, zirconium-95, tantalum-182, manganese-54, cobalt-58, and cobalt-60. The most predominant of these is cobalt-60, with a half-life of 5.3 years. Cobalt-60 also has the most restrictive concentration limit in water (as listed by organizations that set radiological standards in references 7 and 8 for these corrosion and wear radionuclides). Therefore, cobalt-60 is the primary radionuclide of interest for naval nuclear propulsion plants.

Radioactivity Removal from Liquid at Shore Facilities

Radioactive liquids at shore facilities are collected in stainless steel tanks and pumped through a processing system to remove most of the radioactivity (exclusive of tritium) prior to collection in a clean tank for potential reuse. Even after processing to approximately 10^{-8} microcuries of gamma radioactivity per milliliter, reactor coolant is not discharged to surrounding waters. Figure 1 shows a simplified block diagram of the

liquid processing system, which consists of particulate filters, activated carbon bed filters, mixed hydrogen hydroxyl resin, and colloid removal resin beds. This type of processing system has been developed and used successfully to produce high-quality water containing very low radioactivity levels. This high-quality processed water is either returned to nuclear-powered ships or evaporated.

Liquid Releases in Harbors

The total amount of long-lived gamma radioactivity released into harbors and seas within 12 miles of shore has been less than 0.002 curie during each of the last 41 years. This total is for releases from U.S. naval nuclear-powered ships and from the supporting shipyards, tenders, and submarine bases, and at operating bases and home ports in the U.S. and overseas and all other U.S. and foreign ports that were visited by naval nuclear-powered ships.

To put this small quantity of radioactivity into perspective, 0.002 curie is less than the amount of naturally occurring radioactivity contained in the volume of saline harbor water occupied by a single nuclear-powered submarine, or the quantity of naturally occurring radioactivity in the top inch of soil on a half-acre lot.

Short-Lived Radionuclides

Reactor coolant also contains short-lived radionuclides with half-lives of seconds to hours. Their highest concentrations in reactor coolant are from nitrogen-16 (7 second half-life), nitrogen-13 (10 minute half-life), fluorine-18 (1.8 hour half-life), argon-41 (1.8 hour half-life) and manganese-56 (2.6 hour half-life). For the longest lived of these, about a day after discharge from an operating reactor, the concentration is reduced to one-thousandth of the initial concentration; and in about 2 days the concentration is reduced to one-millionth. Consequently, these short-lived radionuclides are not important for liquid release considerations.

Fission Product Radionuclides

Fission products produced from fuel in the reactor, including iodine and the fission gases krypton and xenon, are retained within the fuel elements. However, trace quantities of naturally occurring uranium impurities in reactor structural materials release small amounts of fission products to reactor coolant. The concentrations of fission products and the volumes of reactor coolant released are so low, however, that the total radioactivity attributed to long-lived fission product radionuclides comprises only a small fraction of the total long-lived gamma radioactivity releases discussed elsewhere in this report.

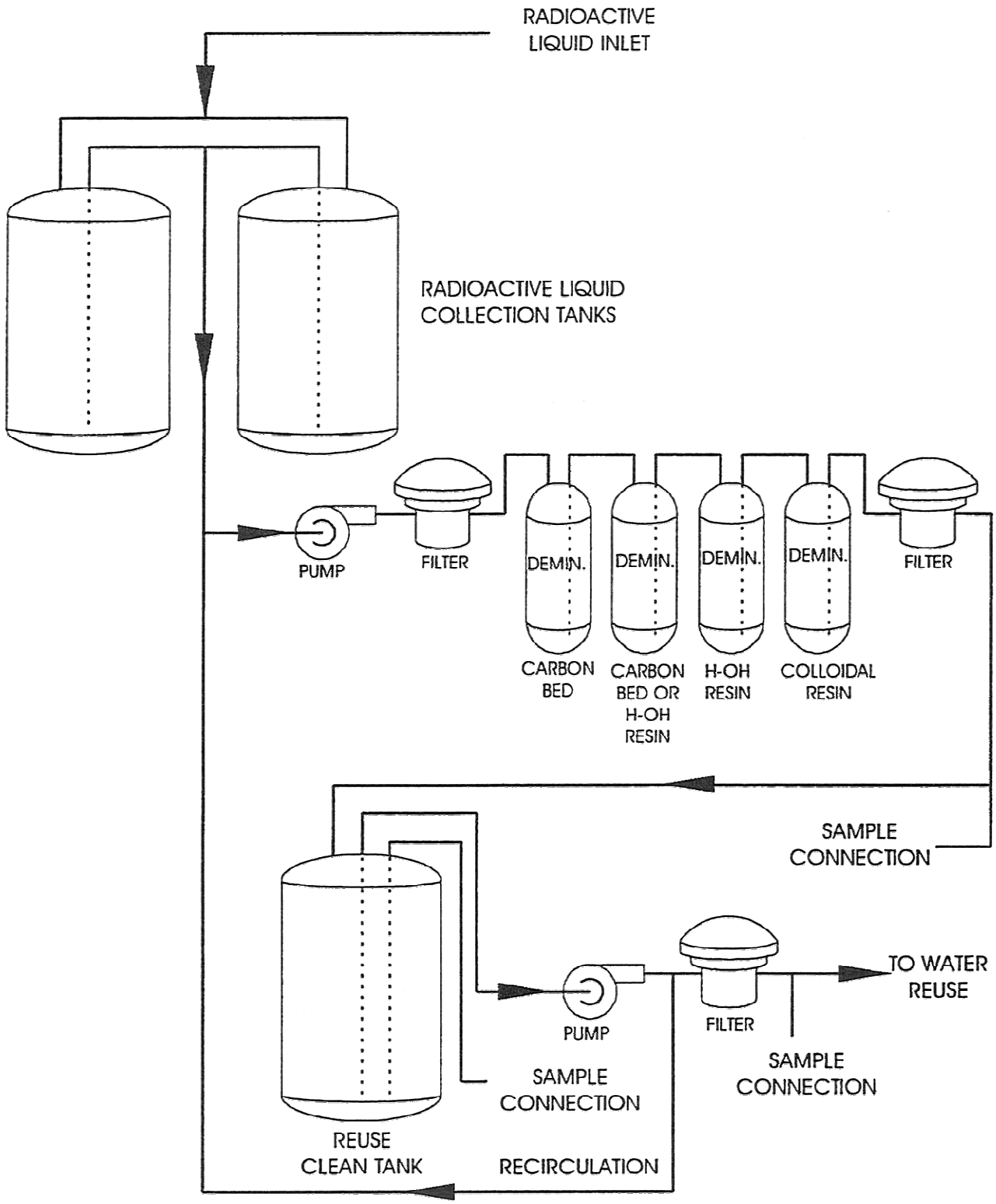


Figure 1:
Simplified Diagram of Radioactive Liquid Processing System

Tritium

Tritium is a radioactive isotope of hydrogen. Trace amounts of tritium are formed in reactor coolant systems when neutrons interact with deuterium (a non-radioactive isotope of hydrogen), which is naturally present in about 0.015 percent of seawater. Although tritium does have a half-life of 12 years, the radiation it produces is of such low energy as to be environmentally insignificant. In fact, the safety guidelines issued by the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, the U.S. Nuclear Regulatory Commission, and other standard-setting agencies permit the presence of 100 times as much tritium as cobalt-60. The tritium produced by naval nuclear reactors is in the oxide form, chemically indistinguishable from water. Unlike other radionuclides, tritium neither concentrates significantly in marine life nor collects on sediment.

Tritium occurs naturally in the environment, generated by cosmic radiation in the upper atmosphere. According to reference 18, cosmic radiation produces about 4 million curies of tritium per year. This means that there is a global inventory of about 70 million curies of tritium at any given time, about 45 million curies of which are in the oceans (reference 19). In comparison, the amount of tritium released each year from all U.S. naval nuclear-powered ships and their supporting tenders, bases, and shipyards has always been less than 200 curies—and virtually all of that was released into the ocean more than 12 miles from shore. This amount is less than the tritium released annually to the environment by a single commercial nuclear power station (reference 20). Further, the amount of tritium in water released within 12 miles of shore by U.S. naval nuclear-powered ships and their support facilities is less than one curie.

Because the amount of tritium occurring naturally in the environment is so large, the amount produced by U.S. naval reactors is too small to have any measurable effect on the environment. Therefore, tritium has not been combined with data on other radionuclides in this report.

Carbon-14

Carbon-14 is also formed in small quantities in reactor coolant systems as a result of neutron interactions with nitrogen and oxygen. Carbon-14 decays with a half-life of 5,730 years. Only low-energy beta radiation is emitted during decay. As a result, the radioactivity concentration guides for carbon-14 in its chemical form in air issued by the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, the U.S. Nuclear Regulatory Commission, and other standard-setting organizations are 60 times higher than for cobalt-60.

Carbon-14 occurs naturally in the environment. It is generated from cosmic radiation interactions with nitrogen and oxygen in the upper atmosphere and oxidized to form carbon dioxide. Carbon-14 is chemically indistinguishable from other isotopes of carbon. The carbon dioxide diffuses and convects throughout the atmosphere and enters the Earth's carbon cycle. Reference 21 states that the Earth's natural carbon-14

inventory is estimated to be about 250 million curies, of which approximately 95 percent resides in the oceans. The total amount of carbon-14 released annually from the operation of all U.S. naval nuclear-powered ships and their supporting tenders, bases, and shipyards has been less than 100 curies, which is far less than the natural carbon-14 production rate of 40,000 curies per year (reference 21). Since the inventory of naturally occurring carbon-14 is so large, it is extremely unlikely that releases from naval nuclear reactors could result in a measurable change in the background concentration of carbon-14.

Liquid Releases at Sea

Radioactive liquids incidental to the operation of the nuclear propulsion plants are released at sea under strict controls. These ocean releases are consistent with recommendations the Council on Environmental Quality made in 1970 to the President in reference 22, and consistent with the Marine Protection, Research, and Sanctuaries Act, reference 23. Procedures and limits for ocean releases have been consistent with recommendations made by the National Academy of Sciences—National Research Council in reference 11 and by the International Atomic Energy Agency in reference 12. Navy releases have contained much less radioactivity than the recommendations of these reports. Since 1973, the total long-lived gamma radioactivity released more than 12 miles from shore by U.S. naval nuclear-powered ships and supporting tenders has been less than or equal to 0.4 curie per year. Releases occur at different times of the year in the open sea at long distances from land in small amounts, and under rapid dispersal conditions due to wave action. This 0.4 curie is less than the naturally occurring radioactivity in a cube of seawater 100 yards on a side, or the quantity of naturally occurring radioactivity in the top ½ inch of soil on an 18-hole golf course.

Loss of USS THRESHER and USS SCORPION

Two U.S. naval nuclear-powered submarines have been lost at sea in the Atlantic Ocean. The submarine THRESHER sank on 10 April 1963, 200 miles southeast of Maine in water 8,500 feet deep. The submarine SCORPION sank on 22 May 1968, 400 miles southwest of the Azores in more than 10,000 feet of water. The reactors used in all U.S. naval submarines and surface ships are designed to minimize potential hazards to the environment even under the most severe casualty conditions, including the actual sinking of the ship. First, the reactor core is designed so that it is physically impossible for it to explode like a bomb. Second, the reactor fuel elements are made of materials that are extremely corrosion resistant, even in seawater. The reactor core could remain submerged in seawater for centuries without releases of fission products while the radioactivity decays, since the protective cladding on the fuel elements corrodes only a few millionths of an inch per year. Thus, in the event of a serious accident where the reactor is completely submerged in seawater, the fuel elements will remain intact indefinitely, and the radioactive material contained in these fuel elements should not be released. Furthermore, the maximum rate of release and dispersal of the radioactivity in the ocean, even if the protective cladding on the fuel were destroyed, would be so low as to be insignificant.

Radioactive material could be released from this type of reactor only if the fuel elements were actually to melt and, in addition, the high strength, all-welded reactor system boundary were to rupture. The reactor's many protective devices and inherent self-regulating features are designed to prevent any melting of the fuel elements. Flooding of a reactor with seawater furnishes additional cooling for the fuel elements and so provides added protection against the release of radioactive fission products.

Radiation measurements, water samples, bottom sediment samples, and debris collected from the area where THRESHER sank were analyzed for radioactivity shortly after the sinking and again in 1965 by various laboratories. Similarly, seawater and bottom sediment samples taken near SCORPION's hull were analyzed for radioactivity. In 1977, 1983, 1986, and 1998, follow-up samples of water, sediment, and marine life were collected from near the THRESHER debris. In 1979, 1986, and 1998, follow-up samples of water, sediment, and marine life were collected from near the SCORPION debris. None of these samples showed any evidence of release of radioactivity from the reactor fuel elements in either THRESHER or SCORPION.

Cobalt-60 released from both THRESHER and SCORPION coolant systems was detectable at low levels in the sediment samples in the debris areas, but not observed in samples of water or marine life. The maximum cobalt-60 concentration measured in the sediment at either site during the 1998 survey was 2.02 picocuries per gram; most samples were much less than this concentration. This is less than one-tenth the concentration of naturally occurring radioactivity in the sediment. For perspective, if a person's diet contained cobalt-60 at the maximum concentration detected in the sediment, that person would receive less than 10 percent of the radiation exposure received from natural background radioactivity.

SCORPION carried two torpedoes with nuclear weapons containing plutonium. While the monitoring campaign was for the express purpose of assessing the impacts from the nuclear reactor, sediment, water, and marine life samples collected at the SCORPION site in 1986 and 1998 were also analyzed for plutonium. Total plutonium radioactivity concentrations and the relative concentrations of plutonium isotopes were typical of background concentrations due to fallout from nuclear weapons testing. Thus, there is no evidence of leakage of plutonium from nuclear weapons that were onboard the submarine when she sank.

Summary information on the radiological surveys of the THRESHER and SCORPION sites was published in reference 24. In 1993, the Navy issued detailed unclassified reports of the radiological environmental monitoring of the THRESHER and SCORPION sites, references 25 and 26. The Navy also released a report in 2000 of the environmental monitoring conducted in 1998, reference 27. The conclusions of this report confirm the results of previous environmental monitoring expeditions and demonstrate that the THRESHER and SCORPION have had no discernible effect on the radioactivity in the environment.

SOLID RADIOACTIVE WASTE DISPOSAL

During maintenance and overhaul operations, solid low-level radioactive wastes (consisting of contaminated rags, plastic bags, paper, filters, ion exchange resin, and scrap materials) are collected from U.S. naval nuclear-powered ships and their support facilities. These low-level radioactive materials are required to be strictly controlled to prevent loss. These controls include naval accountability procedures, which require serialized tagging and marking and signatures by radiologically trained personnel.

Table 1 summarizes the total radioactivity and volumes of radioactive solid waste disposed of during the last 5 years. Table 1 includes all waste generated by U.S. naval nuclear-powered ships and the listed support facilities because all radioactive solid waste generated by U.S. naval nuclear-powered ships is transferred to the listed facilities. The quantity of solid radioactive waste in any one year from a particular facility depends on the amount and type of support work performed that year. Table 1 does not include spent fuel or other classified radioactive components shipped to Department of Energy (DOE) facilities.

Figure 2 shows that the total annual volume of solid low-level radioactive waste was substantially reduced in the 1970s, despite increasing numbers of nuclear-powered ships. This reduction was accomplished simultaneously with reduction in personnel radiation exposure, as described in reference 28. This reduction was accomplished by several techniques, including a total containment concept for radiological work, which minimizes the spread of radioactivity to non-radioactive materials; use of preplanning and mockups to minimize rework; reusing rather than disposing of tools and equipment; use of radioactive liquid processing procedures that minimize depletion of processing media; use of efficient packaging to fully use space in disposal containers; use of licensed commercial radioactive waste incineration, compaction, and radioactive metal recycling services; and separating solid waste that requires special disposal owing to its radioactive content from that which does not. The latter is achieved by worksite controls and by use of sensitive equipment to detect radioactivity only slightly greater in concentration than that found in natural materials such as soil, rocks, water, and biological matter (see reference 19), thus requiring the material to be handled as radioactive for waste disposal purposes. Material that passes the screening provided by this sensitive detection equipment can be disposed of as ordinary waste. Challenging goals are set by each shipyard to ensure continuing management attention to minimizing the generation of waste in radiological work.

The annual volume of solid low-level radioactive waste disposed of at commercial disposal sites in 2011 by the entire Naval Nuclear Propulsion Program, as shown in Table 1, could be contained in a cube measuring about 7 yards on a side. The total annual volume is less than 1 percent of the total volume of solid low-level radioactive waste buried at these sites in the States of Washington, South Carolina, and Utah each year (reference 29).

Solid radioactive waste materials are packaged in strong, tight containers, shielded as necessary, and shipped to burial sites licensed by the U.S. Nuclear Regulatory Commission or by a State under agreement with the Nuclear Regulatory Commission. Solid radioactive materials from naval nuclear-powered ships have not been disposed of at sea since 1970, when the Navy issued procedures prohibiting sea disposal of solid radioactive materials. Shipyards and other shore facilities have never been permitted to dispose of radioactive solid wastes by burial on their own sites.

The Low-Level Radioactive Waste Policy Amendments Act of 1985 establishes that the States are responsible, either individually or in multi-State compacts, for providing for the disposal of low-level radioactive waste from private and non-DOE Federal Government generators. Under this law, a waste compact may prohibit disposal of waste from outside the compact.

The Northwest Compact site in Richland, Washington, accepts waste only from the Northwest and Rocky Mountain Compacts, which include Navy facilities in Washington and Hawaii. In July 2008, the Atlantic Compact site in Barnwell, South Carolina, restricted access to out-of-compact generators. A disposal site in Clive, Utah, is licensed by the State of Utah and is accessible to generators around the country, but is only licensed to accept waste with low concentrations of radioactivity. Because almost all of the solid low-level radioactive waste routinely generated by the Naval Nuclear Propulsion Program contains only low concentrations of radioactivity, the restricted access to the Atlantic Compact disposal site has not adversely impacted Program operations.

The end of the Cold War and the resulting downsizing of the Fleet and closure of Mare Island and Charleston Naval Shipyards in the early 1990s resulted in the disposal of equipment no longer needed and of waste associated with base closure. The volume of low-level radioactive waste shipped from Mare Island and Charleston Naval Shipyards accounted for 66 percent of the total volume shipped during 1995. In 2007, the Navy YRR-14 barge that was used to support maintenance of submarines prior to 2002 was transported from Norfolk Naval Shipyard to a commercial vendor where it was dismantled and disposed of as low-level radioactive waste. This one-time dismantlement project generated 85,000 cubic feet of low-level radioactive waste, which accounted for more than 80 percent of the total radioactive waste disposed of at commercial disposal sites by the Naval Nuclear Propulsion Program in 2007.

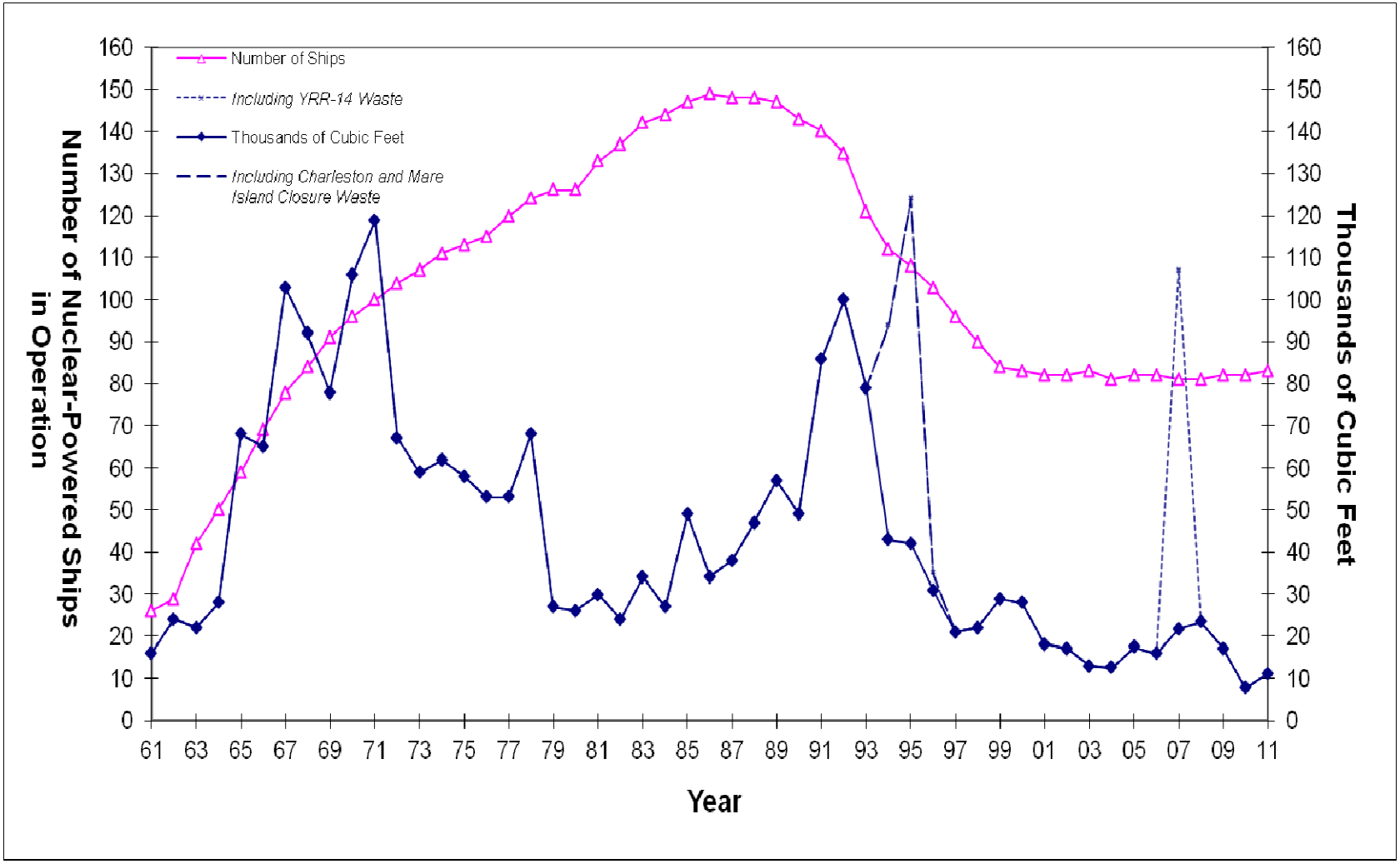
Table 1: Disposed Radioactive Solid Waste from U.S. Naval Nuclear-Powered Ships and Their Support Facilities for 2007 through 2011

FACILITY	2007		2008		2009		2010		2011	
	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES
Kittery, Maine Portsmouth Naval Shipyard	0.7	40	0.6	19	0.4	<1	0.5	22	0.4	<1
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	2.4	54	4.9	52	5.5	18	1.5	<1	1.2	41
Newport News, Virginia Huntington Ingalls Industries - Newport News Shipbuilding	3.7	<1	5.2	<1	3.1	<1	0.7	4	3.1	<1
Norfolk, Virginia Naval Shipyard and Base	88.6	79	2.9	67	0.7	26	0.9	27	0.7	26
San Diego, California Navy Bases	0.2	10	0.4	5	0.1	11	0.2	16	0.20	<1
Bremerton, Washington Puget Sound Naval Shipyard	8.0	36	5.8	10	3.6	46	2.1	43	2.0	8
Pearl Harbor, Hawaii Naval Shipyard & Intermediate Maintenance Facility	3.6	52	3.6	27	3.6	74	1.7	74	3.5	30
TOTAL	**107.2**	**271**	**23.4**	**180**	**17.0**	**175**	**7.6**	**186**	**11.1**	**106**

NOTES:

(1) This table includes all radioactive waste from tenders and nuclear-powered ships. This radioactivity is primarily cobalt-60. This radioactive waste is shipped to burial facilities licensed by the U.S. Nuclear Regulatory Commission or by a State.

Figure 2:
Radioactive Solid Waste Disposal in the Naval Nuclear Propulsion Program 1961–2011



Deactivation of Ingalls Shipbuilding Radiological Facilities

From 1958 to 1980, Ingalls Shipbuilding was engaged in the construction and overhaul of U.S. naval nuclear-powered ships in Pascagoula, Mississippi. The shipyard radiological facilities that supported this work were deactivated between 1980 and 1982 by removing and disposing all radioactive material associated with naval nuclear propulsion plants. Reusable items, such as tools and equipment that were radioactively contaminated, were transferred to other organizations in the Naval Nuclear Propulsion Program. The remaining radioactive material was disposed of as solid waste.

Extensive radiological decommissioning surveys were performed to verify the removal of this radioactive material. Direct radiological surveys were performed on over 274,000 square feet of building and facility surfaces. Over 11,000 samples of these surfaces (as well as soil, ground cover, and concrete) were taken from all areas where radioactive work was previously performed. These samples were analyzed using sensitive laboratory equipment. In addition, both the State of Mississippi and the Environmental Protection Agency (EPA) performed overcheck surveys of the deactivated facilities. After these surveys were completed, the Ingalls facilities were released for unrestricted use. Personnel who subsequently occupy these facilities will not receive measurable radiation exposure above natural background levels that exist in areas not affected by naval nuclear propulsion plant work. Reference 30 is the report of the survey of the Ingalls facilities by the EPA.

Closure of Charleston and Mare Island Naval Shipyards

Mare Island Naval Shipyard was engaged in the construction, overhaul, and refueling of U.S. naval nuclear-powered ships from 1956 to 1995. Charleston Naval Shipyard was engaged in overhaul and refueling of naval nuclear-powered ships from 1962 to 1994. The 1993 round of the Base Closure and Realignment Act process directed closure of these shipyards. The radiological facilities at both Charleston and Mare Island have been deactivated in a manner similar to the process followed for the deactivation of radiological facilities at Ingalls Shipbuilding. The shipyards were closed in April 1996.

As at Ingalls, extensive radiological decommissioning surveys were performed to verify the removal of radioactive material. At each shipyard, direct radiological surveys were performed on over 5 million square feet of building and facility surfaces, and over 40,000 samples of soil, ground cover, and concrete were analyzed using sensitive laboratory equipment. No cobalt-60 was detected, other than trace concentrations in a few localized areas. Simple, proven cleanup methods were used to remediate these areas. Both the radiological deactivation work and the survey work were performed by shipyard workers. The total amount of Program radioactivity remediated at each shipyard was about the same as that contained in a typical household smoke detector (2 to 3 microcuries).

The Navy's radiological verification surveys were completed in March 1996. Both the EPA and the States reviewed the Navy's survey data, conducted overcheck surveys, and agreed with the Navy's results. Personnel who occupy these facilities will not receive measurable radiation exposure above natural background levels.

The successful radiological deactivation and closures of the Ingalls radiological facilities in 1982 and of Charleston and Mare Island in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

Mixed Radioactive and Hazardous Waste

Waste that is both radioactive and chemically hazardous is regulated under both the Atomic Energy Act and the Resource Conservation and Recovery Act (RCRA) as "mixed waste." Within the Naval Nuclear Propulsion Program, concerted efforts are taken to avoid commingling radioactive and chemically hazardous substances so as to minimize the potential for generation of mixed waste. These efforts include avoiding the use of acetone solvents, lead-based paints, lead shielding in disposal containers, and chemical paint removers. As a result of Program efforts to avoid the use of chemically hazardous substances in radiological work, Program activities typically generate each year less than 20 cubic meters of mixed waste that requires offsite treatment following completion of onsite processing. As of the end of 2011, about 3 cubic meters of Program mixed waste are stored, pending shipment to DOE and commercial mixed waste treatment facilities.

Disposal of Decommissioned, Defueled Naval Reactor Plants

During the 1980s, the U.S. naval nuclear-powered submarines constructed in the 1950s and 1960s began to reach the end of their service life. In 1982, the Navy, with DOE as a cooperating agency, published a Draft Environmental Impact Statement (EIS) on the disposal of decommissioned, defueled naval submarine reactor plants. The Draft EIS was widely distributed to individuals, environmental organizations, State and local officials, and other Federal agencies. All substantive comments were analyzed and addressed in the Final EIS, which was issued in 1984 (reference 24). Although the Navy had evaluated the option of disposing of the defueled ships by sinking at sea, the preferred option identified in the Final EIS was to dispose of the defueled reactor plants at a Federal disposal facility already used for low-level radioactive waste disposal. In December 1984, the Secretary of the Navy issued a Record of Decision to proceed with land disposal. In 1996, the Navy issued a Final EIS (reference 31), which evaluated the disposal of defueled reactor plants from cruisers and newer submarine classes. The Navy and the DOE issued a Record of Decision to dispose of these defueled reactor plants by land disposal in the same manner.

A nuclear-powered ship is constructed with the nuclear power plant inside a single section of the ship, called the reactor compartment. Before the reactor compartment is disposed of, the nuclear fuel is removed and handled in the same manner as nuclear fuel

removed during refueling of nuclear-powered ships. The defueled reactor compartments are removed from decommissioned nuclear-powered ships in drydocks at the Puget Sound Naval Shipyard in Bremerton, Washington. After removal from a ship, the reactor compartment is sealed and loaded onto a barge for transport to the Port of Benton on the Columbia River near the Department of Energy Hanford Site. At the Port of Benton, the reactor compartment is transferred to a land transporter, which carries the reactor compartment to the disposal trench on the Hanford Site. Further information on this process is contained in the Final EIS (reference 31). The first defueled reactor compartment was shipped to Hanford in 1986. The Naval Nuclear Propulsion Program shipped one defueled reactor compartment in 2011. The total number shipped is 123.

TRANSPORTATION OF RADIOACTIVE MATERIAL

Shipments of radioactive materials in the Naval Nuclear Propulsion Program must be made in accordance with applicable regulations of the U.S. Department of Transportation (DOT), the Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC). The purpose of these regulations is to ensure that shipments of radioactive material are adequately controlled to protect the environment and the health and safety of the general public. These regulations apply to all radioactive material shipments and provide requirements for container design, certification, and identification pertaining to the specific quantity, type, and form of radioactivity being shipped.

In addition to the above, requirements for certain naval shipping container designs incorporate shielding and integrity specifications. These requirements provide for container design analysis, training and qualification of workers who construct containers, and quality control inspections during fabrication to ensure the containers will meet design requirements.

In addition to imposing requirements of Federal transportation regulations, the Naval Nuclear Propulsion Program has issued standard instructions to further control shipments of radioactivity. These standard instructions result in a quality assurance program that includes inspections and assessments by independent organizations and senior management. Organizations making shipments are required to prepare procedures that direct the use of compliance checklists and management review to ensure compliance with applicable DOT, Navy, and disposal site requirements. Only specially trained, designated people, knowledgeable in shipping regulations, are permitted to authorize shipments of radioactive material.

Protective transportation services, such as signature security service or sealed shipping vehicles, are required for radioactive material shipments to ensure point-to-point control and traceability of each shipment from shipper to receiver. A readily accessible log of all shipments in transit is maintained to enable prompt identification and provide the basis for advice on the nature of the shipment. Receivers must make return receipts in writing to ensure that radioactive material has not been lost in shipment. Inspection of containers of radioactive material and accompanying documents is required promptly after receipt. Receivers must report even minor

discrepancies from detailed shipping regulations to the shipper, so that correction can be made in future shipments. This is done to ensure compliance with shipping regulations.

Radioactive materials shipped in the Naval Nuclear Propulsion Program include anticontamination clothing for laundry, small sealed sources used for calibrating radiation monitoring instruments, tools and equipment used for radioactive work, low-level radioactive waste, radioactive components, and new and spent naval fuel. Each year, Program activities make less than 1,000 shipments, which are a small part of the nearly 3 million shipments of radioactive materials made annually in the United States (reference 32).

In the Naval Nuclear Propulsion Program, most radioactive shipments contain only low-level radioactivity and are classified under DOT regulations as low specific activity, surface contaminated objects, or excepted package shipments. The predominant radionuclide associated with most of these shipments is cobalt-60 in the form of insoluble metallic oxide corrosion products attached to surfaces of materials inside shipping containers.

Most of these radioactive material shipments are made by truck. Air shipments are used only when necessary and are not made on passenger planes. All shipments are in accordance with DOT regulations.

About two-thirds of the low-level shipments are anticontamination clothing, equipment, tools, and routine waste. On average, one shipment of low-level radioactive waste is made every month from each Naval Nuclear Propulsion Program facility. The anticontamination clothing is special outer clothing that becomes potentially contaminated with low levels of radioactivity while worn in controlled work areas. This clothing is occasionally shipped to NRC or agreement State-licensed contractors for cleaning and reuse. About one-fifth of the low-level shipments are environmental and chemistry samples en route to analytical laboratories. Less than one-tenth of the low-level radioactivity shipments are minute quantities in sealed instrument calibration check sources. These sources contain insignificant quantities of radioactivity, comparable to the radioactivity in typical household smoke detectors.

The remaining few shipments are new and spent naval fuel and radioactive components associated with reactors, and are shipped by DOE. Such shipments are infrequent because naval nuclear-powered ships currently require at most one refueling during their service life. Measures are carried out to help safeguard these shipments and ensure they reach their destination without incident. Each spent naval fuel shipment is escorted by U.S. Government representatives, and each shipping container is specifically designed to survive extreme accident conditions, to withstand fire and water immersion, and to prevent release of the material to the environment. The cargo in the nuclear fuel and radioactive component shipments is non-explosive and nonflammable; in addition, the radioactive material in these components is insoluble and therefore would not likely be dispersed even if there were an accident.

Since 1957, all spent fuel removed from naval reactors has been shipped to the DOE's Idaho National Laboratory (INL) for examination. Until 1992, naval spent fuel was reprocessed by the DOE after examination. In 1992, the DOE ceased reprocessing operations. Since then, post-examination naval spent fuel has been temporarily stored at INL pending the availability of a permanent repository or centralized interim storage site. Continued shipment of naval spent fuel to INL for examination and temporary storage was fully evaluated in a comprehensive DOE spent fuel management EIS, published in April 1995 (reference 34). (The Navy participated as a cooperating agency). Under the Record of Decision for this EIS and a court-ordered agreement between the Navy, DOE, and the State of Idaho, naval spent fuel will continue to be shipped to INL through 2035 for examination, and it will be temporarily stored there until it can be shipped to a permanent geologic repository for burial or a centralized interim storage site outside Idaho for storage as soon as either facility is available.

Estimates of annual radiation exposure to transportation crews and the general public from shipments of radioactive materials in the Naval Nuclear Propulsion Program have been made in a manner consistent with that employed by the NRC in reference 32. Based on comparisons of the types and numbers of radioactive shipments made, the total annual radiation exposure to all transportation crews for all shipments is estimated to be approximately 3 rem. If one person were to receive all this exposure, that person would not exceed the annual radiation exposure permitted for an individual worker by the NRC. The total estimated radiation exposure accumulated by the public along transportation routes is 10 rem. The maximum exposure to any individual member of the public would be far less than that received from natural radiation.

For naval spent fuel shipments, more detailed exposure estimates are described in the DOE spent fuel management EIS cited above (reference 34) and in the Department of the Navy spent fuel container system Environmental Impact Statement published in November 1996 (reference 35). The analyses described in these EISs demonstrate that for the 818 container shipments of spent fuel made through the end of 2011, the total collective population dose is about 3 rem.

Shipments of radioactive materials associated with naval nuclear propulsion plants have not resulted in any measurable release of radioactivity to the environment. There have never been any significant accidents involving release of radioactive material during shipment since the Naval Nuclear Propulsion Program began.

The Naval Nuclear Propulsion Program requires that the carriers for all radioactive material shipments have accident plans identifying the actions to be taken in case the transportation vehicle is involved in an accident. These plans provide for notification of civil authorities and the originating facility. Also provided is a 24-hour telephone number for emergency guidance and assistance. The U.S. Navy would communicate with and cooperate fully with State radiological officials in the event of unusual occurrences involving shipments of radioactive materials.

NAVY ENVIRONMENTAL MONITORING PROGRAM

To provide additional assurance that procedures used by the U.S. Navy to control radioactivity are adequate to protect the environment, the Navy conducts environmental monitoring in harbors frequented by its nuclear-powered ships. Environmental monitoring surveys for radioactivity are periodically performed in harbors where U.S. naval nuclear-powered ships are built or overhauled and where these ships have homeports or operating bases. Samples from each harbor monitored are also checked at least annually by a DOE laboratory to ensure analytical procedures are correct and standardized. The DOE laboratory findings have been consistent with those of the shipyards.

The Navy environmental monitoring program consists of analyzing samples of harbor sediment, water, and marine life, supplemented by shoreline surveys, dosimeters, and effluent monitoring. Sampling harbor sediment and water each quarter is emphasized because they would be the most likely affected by releases of radioactivity.

As discussed earlier, cobalt-60 is the predominant radionuclide of environmental interest resulting from naval nuclear reactor operations. Therefore, Navy monitoring procedures require collecting in each harbor approximately 10 to 100 sediment samples once each quarter for analysis to detect cobalt-60 and other gamma-emitting radionuclides. Locations and numbers of sediment samples for a particular harbor depend on the size of the harbor and the number and separation of locations where nuclear-powered ships berth. Sampling points are selected to form a pattern around ship berthing locations and at points in areas away from them. The sampling locations selected are based on the individual characteristics of each harbor.

Sediment samples are collected using a dredge that samples a surface area of 36 square inches and has been modified to collect only the top layer of sediment (about an inch). The top layer was selected because it should be more mobile and more accessible to marine life than deeper layers. The samples are drained of excess water and put directly into a Marinelli container for analysis. Each sediment sample is analyzed for gamma radioactivity in the container in which it is collected, using a solid-state germanium detector with a multichannel analyzer. The gamma data are analyzed specifically for the presence of cobalt-60. Results of the sediment samples from harbors monitored by the Navy in the U.S. and its possessions are summarized in Table 2.

Table 2 shows that in 2011 all harbor samples did not have detectable levels of cobalt-60. As reported in the past, low levels of cobalt-60, less than 3 picocuries per gram, have been detected around a few operating base and shipyard piers where nuclear-powered ship maintenance and overhauls were conducted in the early 1960s. These low levels are well below the naturally occurring radioactivity levels in the harbors, and result from operations conducted from that same time period. As discussed previously, from 1971 to 2011 the total long-lived gamma radioactivity released each year within 12 miles of shore from all U.S. naval nuclear-powered ships and their support facilities has been less than 0.002 curie. This low release amount is

too small to be detectable in the harbors. A measure of the significance of these low levels is that if all of a person's food (reference 36) were to contain 3 picocuries of cobalt-60 per gram, that person would receive less than 10 percent of the dose from natural background radiation (see reference 19). The 3 picocuries per gram cobalt-60 concentration also is less than the concentration established by the International Atomic Energy Agency (reference 37) for determining whether dredged sediments can be regarded as non-radioactive or de minimis under the Convention on Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, 1972), reference 38. Cobalt-60 is not detectable in general harbor bottom areas away from these piers.

Low levels of cesium-137 were detected in some sediment samples. The cesium-137 detected is not related to naval nuclear reactor operations, because the high integrity naval fuel retains fission products. The cesium-137 concentrations measured in the sediment are due to worldwide dispersion from weapons testing or fallout from the Chernobyl and Fukushima Daiichi reactor accidents.

In addition to Navy analysis of environmental samples, at least nine sediment samples from each harbor monitored have been sent each year to a DOE laboratory, as a check of Navy results. This DOE laboratory provides a further check on the quality of environmental sample analyses by participating in the quality control programs sponsored by Environmental Resource Associates.

The check samples were analyzed for gamma radionuclides in a manner similar to Navy procedures but with greater sensitivity. Figure 3 depicts the gamma spectra for two such samples. Both spectra show the presence of abundant, naturally occurring radionuclides, which contribute to measured radioactivity even if cobalt-60 were not present. The upper spectrum is for a sample to which cobalt-60 has been added to achieve a concentration of approximately 3 picocuries per gram and shows easily recognizable energy peaks due to the presence of this small concentration of cobalt-60. The lower spectrum is typical of most of the sediment samples, and does not contain detectable cobalt-60.

At least five water samples are taken in each harbor once each quarter in areas where nuclear-powered ships berth, as well as from upstream and downstream locations. These samples are analyzed for the presence of gamma-emitting radionuclides, including cobalt-60. A solid-state germanium detector with a multichannel analyzer is used to measure gamma radioactivity and detect the presence of cobalt-60. Procedures for analysis will detect cobalt-60 if its concentration exceeds the EPA drinking water limits (reference 15). No cobalt-60 has been detected in any of the water samples taken from any of the harbors monitored.

An EPA evaluation in reference 39 shows that the cobalt-60 from naval nuclear propulsion plants is in the form of metallic corrosion product particles, which do not appear to be concentrated in the food chain. Nevertheless, samples of marine life (such as mollusks, crustaceans, and marine plants) have been collected from all harbors

monitored. Marine life samples are also analyzed using a germanium detector with a multichannel analyzer. The results of the marine life sample analysis (summarized in Table 3) show that no buildup of cobalt-60 associated with U.S. naval nuclear-powered ships has been detected in these samples of marine life.

In all monitored harbors, shoreline areas uncovered at low tide are surveyed twice per year for radiation levels, using sensitive scintillation detectors to determine if any radioactivity from bottom sediment washed ashore. All results were the same as background radiation levels in these regions, approximately 0.01 millirem per hour. Thus, there is no evidence in these ports that these areas are being affected by the operation of nuclear-powered ships.

Ambient radiation levels are continuously measured using sensitive thermoluminescent dosimeters posted at locations outside the boundaries of areas where radiological work is performed. These dosimeters are also posted at locations remote from support facilities to measure background radiation levels from natural radioactivity. The results of dosimeters posted at support facilities between radiologically controlled areas and the general public and dosimeters posted at remote background locations up to several miles away are compared in Table 4. The range of dosimeter readings is also given: natural background radiation levels vary from location to location primarily due to the concentration of radionuclides in the soil (reference 19). Table 4 shows that Naval Nuclear Propulsion Program activities had no distinguishable effect on normal background radiation levels at the site perimeter.

Naval nuclear reactors and their support facilities are designed to ensure that there are no significant discharges of radioactivity in airborne exhausts. Radiological controls are exercised in support facilities to preclude exposure of working personnel to airborne radioactivity exceeding one-tenth of the limits specified in reference 7. These controls, discussed in reference 28, include containment for radioactive materials to provide a barrier to prevent significant radioactivity from becoming airborne. Further, all air exhausted from these facilities is passed through high-efficiency particulate air (HEPA) filters and monitored during discharge. Comparison of sensitive airborne radioactivity measurements in shipyards demonstrated that air exhausted from these facilities actually contained a smaller amount of particulate radioactivity than it did when it was drawn from the environment. In 2011, some air samples taken away from shipyards for measuring background radioactivity had elevated concentrations of cesium-137 and cesium-134, which were attributed to the Fukushima Daiichi reactor accidents.

Table 2: Summary of 2011 Surveys for Cobalt-60 in Bottom Sediment of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built

Facility	Number of Samples	Number of Samples with Detectable Cobalt-60	Range of Detected Cobalt-60 Results (pCi/gm)(1)	Range of Cobalt-60 MDC(2) Values for Samples with No Detectable Cobalt-60 (pCi/gm)
Kittery, Maine Portsmouth Naval Shipyard	120	0	ND(3)	<0.02 – <0.09
Groton, New London, Connecticut Electric Boat Division and Naval Submarine Base	300	0	ND	<0.01 – <0.08
Newport News, Virginia Huntington Ingalls Industries - Newport News Shipbuilding	132	0	ND	<0.02 – <0.03
Norfolk, Virginia Naval Shipyard and Base	280	0	ND	<0.02 – <0.05
Charleston, South Carolina Naval Nuclear Power Training Unit	36	0	ND	<0.01 – <0.01
Kings Bay, Georgia	100	0	ND	<0.02 – <0.05
San Diego, California Navy Bases	252	0	ND	<0.01 – <0.08
Puget Sound, Washington Naval Shipyard and Bases	392	0	ND	<0.01 – <0.05
Pearl Harbor, Hawaii Naval Shipyard & Intermediate Maintenance Facility	208	0	ND	<0.01 – <0.05
Apra Harbor, Guam	132	0	ND	<0.01 – <0.03
Port Canaveral, Florida	80	0	ND	<0.01 – <0.04

NOTES:

(1) pCi/gm = picocurie per gram. 1 pCi = 1×10^{-12} curie (Ci).

(2) The less-than symbol [<] indicates that no cobalt-60 was detected in the sample. The number given is the minimum detectable concentration (MDC); i.e., the concentration at which cobalt-60 could be detected if it were present. The MDC varies from sample to sample and location to location due to differences in the amount of naturally occurring radioactivity in each sample, differences in the weight of the sample, detection equipment differences, and statistical fluctuations.

(3) ND = Not Detected. Sample analysis detected no photopeak.

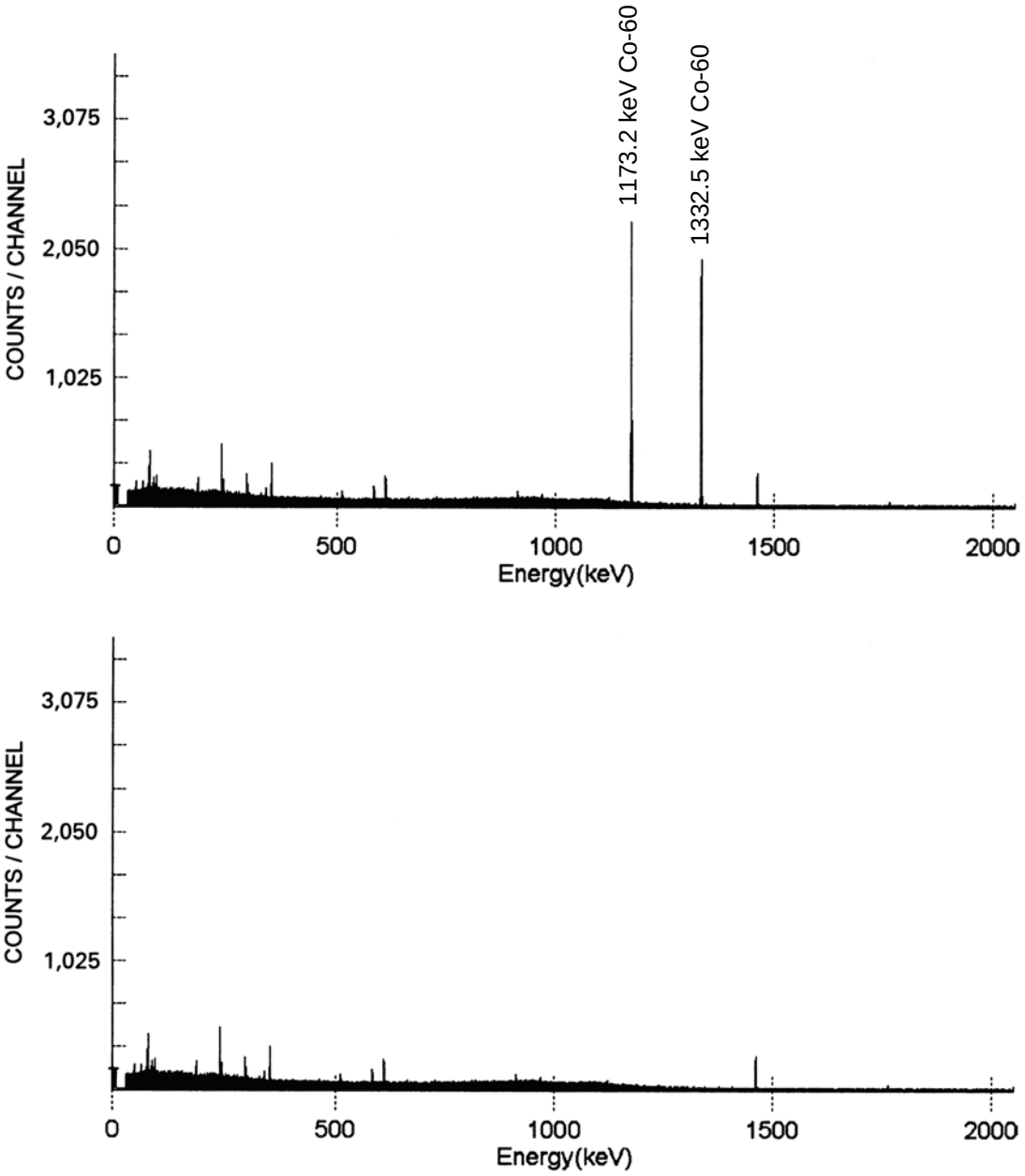


Figure 3:
Gamma Spectra of Harbor Bottom Sediment Samples with 3 pCi/gm cobalt-60 added (top) and without cobalt-60 (bottom) performed with a Germanium Detector.
The unlabeled energy peaks are from naturally occurring radioactivity.

Table 3: Summary of 2011 Surveys for Cobalt-60 in Marine Life of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built

Facility	Mollusks	Crustaceans	Marine Plants
	Cobalt-60 Analytical Results (pCi/gm)	Cobalt-60 Analytical Results (pCi/gm)	Cobalt-60 Analytical Results (pCi/gm)
Kittery, Maine Portsmouth Naval Shipyard	<0.03	<0.05	<0.08
Groton, New London, Connecticut Electric Boat Division and Naval Submarine Base	<0.05	<0.05	<0.07
Newport News, Virginia Huntington Ingalls Industries - Newport News Shipbuilding	<0.2	<0.02	<0.02
Norfolk, Virginia Naval Shipyard and Base	<0.04	<0.04	<0.04
Charleston, South Carolina Naval Nuclear Power Training Unit	<0.01	<0.01	Not Applicable
Kings Bay, Georgia	<0.03	Not Applicable	<0.04
San Diego, California Navy Bases	<0.03	<0.03	<0.08
Puget Sound, Washington Naval Shipyard and Bases	<0.04	<0.02	<0.04
Pearl Harbor, Hawaii Naval Shipyard & Intermediate Maintenance Facility	Not Applicable	<0.04	<0.04
Apra Harbor, Guam	<0.02	<0.02	<0.02
Port Canaveral, Florida	<0.03	<0.04	<0.03

NOTES:

(1) The less-than symbol [<] indicates that no cobalt-60 was detected in the sample. The number given is the minimum detectable concentration (MDC); i.e., the concentration at which cobalt-60 could be detected if it were present. The MDC varies from sample to sample and location to location due to differences in the amount of naturally occurring radioactivity in each sample, differences in the weight of the sample, detection equipment differences, and statistical fluctuations.

(2) pCi/gm = picocurie per gram. 1 pCi = 1×10^{-12} curie (Ci).

(3) Not Applicable: Marine life samples of the specified type were not available for collection.

Table 4: Summary of 2011 Offsite and Perimeter Radiation Monitoring of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built

FACILITY	Average Off-site Dosimeter (mrem/qtr)	Range of Off-site Dosimeter (mrem/qtr)	Average Perimeter Dosimeter (mrem/qtr)	Range of Perimeter Dosimeter (mrem/qtr)
Kittery, Maine Portsmouth Naval Shipyard	15	12 - 21	18	11 - 29
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	17	14 - 20	17	9 - 24
Newport News, Virginia Huntington Ingalls Industries - Newport News Shipbuilding	16	11 - 24	14	9 - 22
Norfolk, Virginia Naval Shipyard and Tenders	16	7 - 25	15	7 - 26
Charleston, South Carolina Naval Nuclear Power Training Unit	12	6 - 19	12	8 - 16
Kings Bay, Georgia	12	9 - 15	13	9 - 19
San Diego, California Navy Bases	21	14 - 27	17	10 - 31
Puget Sound, Washington Naval Shipyard and Bases	11	8 - 15	11	7 - 16
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	9	7 - 12	8	6 - 11
Apra Harbor, Guam	11	9 - 13	9	8 - 12
Port Canaveral, Florida	9	8 - 12	9	7 - 12

NOTES:
(1) mrem/qtr = millirem per quarter year. 1 mrem = 1×10^{-3} rem.

ENVIRONMENTAL PATHWAYS ANALYSIS

Results of monitoring of environmental samples described above show that environmental radioactivity levels have not changed appreciably; therefore, radiation exposure to the public from operations of U.S. naval nuclear-powered ships and their support facilities is too low to measure. Nevertheless, an analysis has been performed to provide a quantitative estimate of the radiation to which any member of the general public might be exposed as a result of radioactivity in liquid and airborne effluents.

For analysis of airborne effluents, the EPA COMPLY computer program is used, as required by EPA regulations in reference 40. Site-specific input parameters include radionuclide releases, distance to members of the public, wind speed and direction, and food production. The releases of airborne effluents used in the analysis are summarized in Table 5. Cobalt-60 values include actual measurements of cobalt-60 emissions from the exhaust of Navy facilities, in addition to estimates of other potential sources of cobalt-60. Estimated values for other airborne radionuclides are based upon detailed study of land-based naval nuclear propulsion prototype plants, nuclear-powered ships, and their support facilities.

Results of the airborne effluent analysis are summarized in Table 6. Table 6 compares the estimated maximum exposure to a member of the public from Program effluents with guidelines of the NRC in reference 14. These numerical guidelines on calculated radiation exposures implement the concept that radioactivity in effluents from light water nuclear electric power reactors should be limited to amounts and quantities as low as reasonably achievable. Although these guidelines are not applicable to nuclear-powered ships and their support facilities, they provide a context in which to judge the significance of radiation exposures from Program effluents. The estimated maximum radiation exposure to a member of the general public from releases of airborne radioactivity is much less than the standard of 10 millirem per year established by the EPA in reference 40.

Table 5: Radionuclide Releases Used for Environmental Pathways Analysis

Radionuclide	Annual Airborne Release (Curies)
Cobalt-60*	<0.0004
Tritium*	<1.5
Carbon-14*	<20
Krypton-83m	0.011
Krypton-85m	0.027
Krypton-85	0.000023
Krypton-87	0.035
Krypton-88	0.055
Xenon-131m	0.0015
Xenon-133m	0.012
Xenon-133	0.30
Xenon-135	0.33
Argon-41	3.3
Iodine-131	0.0000050
Iodine-132	0.0000054
Iodine-133	0.000014
Iodine-135	0.0000097

* Site-specific values are used for these radionuclides. The tabulated values bound the site-specific values used in the analysis.

For liquid effluents, the results of the environmental monitoring samples demonstrate, without the need for any detailed theoretical model calculations, that there is no significant radiation exposure to members of the public. For example, the samples of marine life obtained from the immediate vicinity of shipyard piers and drydocks did not have any detectable cobalt-60, even with sensitive analysis. Even if cobalt-60 were assumed to be present at concentrations just below the limits of detection shown in Table 5 and a person were to eat 40 pounds per year of mollusks and crustaceans caught directly from these areas, the person would receive much less than one millirem per year. Similarly, even though the Navy minimizes releases of radioactive liquids and there has never been any detectable cobalt-60 in harbor water, the water consumption pathway cannot result in any dose to the public since seawater is not used for drinking water consumption in the vicinity of these facilities. Thus, exposures to members of the public from the Naval Nuclear Propulsion Program liquid effluents are far less than the guidelines of the NRC, which are listed in Table 6.

Table 6: Estimated Maximum Radiation Exposure to an Individual for Assumed Liquid Releases and Airborne Radioactivity Releases from Shipyards Engaged in Naval Nuclear Propulsion Work

SOURCE	Maximum Exposure to an Individual	
	NRC Guideline (millirem/year)	Estimated Value (millirem/year)
From Radionuclides in Liquid Releases	3 whole body, or 10 any organ	< 1
From Gaseous Radionuclides in Airborne Releases	5 whole body, or 15 skin	< 1
From Other Radionuclides in Airborne Releases	15 any organ	< 1

SOURCE	Maximum Exposure to an Individual	
	EPA Regulation (effective whole body, millirem/year)	Estimated Value (effective whole body, millirem/year)
From Radioiodine in Airborne Releases	3	< 0.03
From Other Radionuclides in Airborne Releases	10	< 1

AUDITS AND REVIEWS

The requirements and procedures for control of radioactivity are an important part of the training programs for everyone involved with radioactivity in the Naval Nuclear Propulsion Program. Such training is part of the initial qualification of shipyard workers and of naval personnel assigned to ships and bases, and is required to be repeated regularly. Emphasis on this training is part of the concept that radiological control personnel alone cannot always cause radiological work to be well performed; production and operations personnel and all levels of management must be involved in the control of radioactivity.

Checks and balances of several kinds are also set up to help ensure control of radioactivity. Written procedures exist that require verbatim compliance. Radiological control personnel monitor various steps in radioactive waste processing. In each shipyard, an independent organization, separate from the radiological control organization, audits all aspects of radioactive waste processing. Audits are performed by representatives from Naval Reactors Headquarters who are assigned full-time at each shipyard. Radiological control personnel from Headquarters also conduct periodic inspections of each shipyard. In addition, shipyards have made detailed assessments of the environmental effects of shipyard operations and have published reports on the results of these assessments. Similarly, there are multiple levels of audits and inspections for the other Navy shore facilities, tenders, and nuclear-powered ships, as well as for other radiologically controlled functions (such as transportation). Even the smallest audit findings are followed up to ensure proper recovery and permanent corrective actions are taken and to help minimize the potential for future deficiencies.

The policy of the Navy is to closely cooperate and effectively communicate with State radiological officials whenever there are occurrences that might cause concern because of radiological effects outside the ships or shore facilities. The Navy has reviewed radioactive waste disposal, radiological environmental monitoring, transportation, and other radiological matters with State radiological officials in the States where U.S. naval nuclear-powered ships are based, overhauled, or built. Although there were no occurrences in 2011 that resulted in radiological effects to the public outside these facilities, States were notified when inquiries showed public interest in the possibility that such events had occurred. The Navy has encouraged States to conduct independent radiological environmental monitoring. The States' findings have been consistent with the Navy's as documented in reports such as references 41 and 42.

Since the early 1960s, a laboratory of the Environmental Protection Agency and its predecessor agency the Public Health Service has conducted detailed environmental surveys of selected U.S. harbors. The most recent EPA reports, providing results of the radiological surveys performed at the New London and Hampton Roads facilities, were issued in August and October 2005, respectively. References 30 and 43-51 document the most recent EPA surveys in the harbors at Pascagoula, Mississippi; Charleston, South Carolina; Pearl Harbor, Hawaii; San Diego, Alameda, San Francisco, and Vallejo, California; New London and Groton, Connecticut; Newport News, Portsmouth, and Norfolk, Virginia; Kings Bay, Georgia; Kittery, Maine / Portsmouth, New Hampshire; and Bremerton and Bangor, Washington. EPA findings have been consistent with those of the Navy, and have concluded that operation of naval nuclear-powered ships has had no adverse impact on public safety or health.

CONCLUSIONS

1. The total long-lived gamma radioactivity in liquids released into all ports and harbors from the Naval Nuclear Propulsion Program was less than 0.002 curie in 2011. For perspective, 0.002 curie is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single nuclear-powered submarine, or the quantity of naturally occurring radioactivity in the top inch of soil on a half-acre lot.

2. No increase of radioactivity above normal background levels has been detected in harbor water during Navy and EPA monitoring of harbors where U.S. naval nuclear-powered ships are based, overhauled, or constructed.

3. Liquid releases from U.S. naval nuclear-powered ships and their support facilities have not caused a measurable increase in the general background radioactivity of the environment.

4. Low-level cobalt-60 radioactivity in harbor bottom sediment was detected around a few operating base and shipyard piers in some previous years from low-level liquid releases in the 1960s. However, these concentrations of cobalt-60 were less than those of naturally occurring radionuclides around these piers. Cobalt-60 was not detectable in general harbor bottom areas away from these piers.

5. Estimates of radiation exposures to members of the public from the Naval Nuclear Propulsion Program are far less than EPA environmental standards, NRC guidelines, or the exposure from natural background radioactivity.

6. Procedures used by the Navy to control releases of radioactivity from U.S. naval nuclear-powered ships and their support facilities have been effective in protecting the environment and the health and safety of the general public. Independent radiological environmental monitoring performed by the EPA and the States have confirmed the adequacy of these procedures. These procedures have ensured that no member of the general public has received measurable radiation exposure as a result of current operations of the Naval Nuclear Propulsion Program, thus the Naval Nuclear Propulsion Program has not had an adverse effect on human health or the quality of the environment.

7. The successful radiological deactivation and closures of Ingalls Shipbuilding radiological facilities in 1982 and of Charleston and Mare Island Naval Shipyards in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

REFERENCES

1. U.S. Navy Reports, "Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," M. E. Miles et al., for calendar years 1965 through 1969 published in Radiation Health Data and Reports; May 1966, December 1967, April 1969, September 1969, and August 1970.

2. U.S. Navy Reports, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," M. E. Miles et al., for calendar years 1970 through 1978 published with the following numbers and dates: NT-71-1, May 1971; NT-72-1, September 1972; NT-73-1, September 1973; NT-74-1, October 1974; NT-75-1, May 1975; NT-76-1, August 1976; NT-77-1, June 1977; NT-78-1, February 1978; NT-79-1, January 1979.

3. U.S. Navy Reports, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," P. D. Rice et al., for calendar years 1979 through 1981 published with the following numbers and dates: NT-80-1, March 1980; NT-81-1, February 1981; NT-82-1, February 1982.

4. U.S. Navy Reports, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," C. H. Schmitt et al., for calendar years 1982 and 1983 published with the following numbers and dates: NT-83-1, February 1983; NT-84-1, February 1984.

5. U.S. Navy Reports, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," J. J. Mangeno et al., for calendar years 1984 through 2000 published with the following numbers and dates: NT-85-1, February 1985; NT-86-1, February 1986; NT-87-1, February 1987; NT-88-1, February 1988; NT-89-1, February 1989; NT-90-1, February 1990; NT-91-1, February 1991; NT-92-1, February 1992; NT-93-1, February 1993; NT-94-1, March 1994; NT-95-1, March 1995; NT-96-1, March 1996; NT-97-1, March 1997; NT-98-1, February 1998; NT-99-1, March 1999; NT-00-1, March 2000; NT-01-1, April 2001.

6. U.S. Navy Reports, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities," T. J. Mueller et al., for calendar years 2001 through 2010 published with the following numbers and dates: NT-02-1, March 2002; NT-03-1, March 2003; NT-04-1, March 2004; NT-05-1, February 2005; NT-06-1, March 2006; NT-07-1, March 2007; NT-08-1, March 2008; NT-09-1, March 2009; NT-10-1, March 2010; NT-11-1, May 2011.

7. Code of Federal Regulations, Title 10 (Nuclear Regulatory Commission), Part 20, "Standards for Protection Against Radiation."

8. U.S. Environmental Protection Agency, "Federal Guidance Report No. 13 – Cancer Risk Coefficients for Environmental Exposure to Radionuclides," September 1999.

9. International Commission on Radiological Protection, Publication 26, “Recommendations of the International Commission of Radiological Protection,” January 1977.

10. Federal Radiation Council, “Radiation Protection Guidance for Federal Agencies,” approved by President Eisenhower on May 13, 1960.

11. National Academy of Sciences—National Research Council, Publication 658, “Radioactive Waste Disposal from Nuclear-Powered Ships,” 1959.

12. International Atomic Energy Agency, “Safety Guide No. WS-G-2.3, Regulatory Control of Radioactive Discharges to the Environment,” 2000.

13. National Council on Radiation Protection and Measurements, Report No. 116, “Recommendations on Limits for Exposure to Ionizing Radiation,” 1993.

14. Code of Federal Regulations, Title 10 (Nuclear Regulatory Commission), Part 50, “Domestic Licensing of Production and Utilization Facilities, Appendix I, Numerical Guides For Design Objectives And Limiting Conditions For Operation To Meet The Criterion “As Low As Reasonably Achievable” for Radioactive Material In Light-Water-Cooled Nuclear Power Reactor Effluents.”

15. Code of Federal Regulations, Title 40 (Environmental Protection Agency), Part 141, “National Primary Drinking Water Regulations.”

16. International Commission on Radiological Protection, Publication 30, “Limits for Intakes of Radionuclides by Workers,” July 1978.

17. National Academy of Sciences National Research Council, “Radioactivity in the Marine Environment,” 1971.

18. National Council on Radiation Protection and Measurements, Report No. 62, “Tritium in the Environment,” March 1979.

19. National Council on Radiation Protection and Measurements, Report No. 94, “Exposure of the Population in the United States and Canada from Natural Background Radiation,” December 1987.

20. U.S. Navy Report, “Radioactive Effluents Released From Civilian Nuclear Power Plants, 2005-2009,” M. E. Walker, NT-10-6, August 2010.

21. National Council on Radiation Protection and Measurements, Report No. 81, “Carbon 14 in the Environment,” May 1985.

22. Council on Environmental Quality Report to the President, “Ocean Dumping: A National Policy,” October 1970.

23. Marine Protection, Research, and Sanctuaries Act of 1972, United States Public Law 92 532.

24. U.S. Navy, “Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants,” May 1984.

25. Knolls Atomic Power Laboratory, “Deep Sea Radiological Environmental Monitoring Conducted at the Site of the Nuclear-Powered Submarine SCORPION Sinking,” by R. B. Sheldon and J. D. Michne, KAPL-4749, October 1993.

26. Knolls Atomic Power Laboratory, “Deep Sea Radiological Environmental Monitoring Conducted at the Site of the Nuclear-Powered Submarine THRESHER Sinking,” by R. B. Sheldon and J. D. Michne, KAPL-4748, October 1993.

27. Knolls Atomic Power Laboratory, “Deep Sea Radiological Environmental Monitoring Performed During September 1998 at the Sites of the Sunken Submarines USS THRESHER and USS SCORPION,” by D. R. Marx, KAPL-4842, July 2000.

28. U.S. Navy Report, “Occupational Radiation Exposure from U.S. Naval Nuclear Propulsion Plants and Their Support Facilities,” T. J. Mueller, et al., NT-11-2, May 2011.

29. U.S. Department of Energy, Manifest Information Management System, Volume and Activity Summary, 2012, at http://mims.apps.em.doe.gov/.

30. U.S. Environmental Protection Agency Report, “Radiological Survey of Ingalls Shipbuilding Division, Pascagoula, Mississippi, and Environs,” Report 520/5 83 022, September 1983.

31. U.S. Navy, “Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Cruiser, OHIO-Class, and LOS ANGELES-Class Naval Reactor Plants,” April 1996.

32. American Nuclear Society Report, “The Safety of Transporting Radioactive Materials,” Position Statement 18, June 2002.

33. U.S. Nuclear Regulatory Commission, “Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes,” NUREG 0170, December 1977.

34. U.S. Department of Energy Report, “Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Program’s Final Environmental Impact Statement,” DOE/EIS-0203-F, April 1995.

35. Department of the Navy, Final Environmental Impact Statement for a Container System for the Management of Naval Spent Nuclear Fuel, November 1996.

36. International Commission on Radiological Protection, Report No. 23, “Report of the Task Group on Reference Man,” October 1974.

37. International Atomic Energy Agency Report, “Determining the Suitability of Materials for Disposal at Sea Under the London Convention 1972: A Radiological Assessment Procedure.” International Atomic Energy Agency Report, IAEA-TECDOC-1375, October 2003.

38. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, 1972), at http://www.imo.org/OurWork/Environment/SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx.

39. U.S. Environmental Protection Agency Report, “Radiological Surveys of Pearl Harbor, Hawaii, and Environs,” by D. F. Cahill, H. D. Harvey, Jr., et al., issued in Radiation Data and Reports, June 1972.

40. Code of Federal Regulations, Title 40 (Environmental Protection Agency), Part 61, Subpart I, “National Emission Standards for Radionuclide Emissions From Facilities Licensed by the Nuclear Regulatory Commission and Federal Facilities Not Covered by Subpart H.”

41. Georgia Department of Natural Resources, Environmental Protection Division, “Environmental Radiation Surveillance Report 2000 – 2002,” at http://www.gaepd.org/Documents/radrpt2002.html.

42. Washington Department of Health, “Washington State Department of Health and Puget Sound Naval Shipyard and Intermediate Maintenance Facility Joint Environmental Sampling, July, 2009 through June, 2010.”

43. U.S. Environmental Protection Agency Report, “Radiological Survey at the Naval Nuclear Power Training Unit—Charleston,” by T. W. Fowler and S. W. Poppell, Jr., Report EPA-402-R-03-004, August 2003.

44. U.S. Environmental Protection Agency Report, “Radiological Survey of the Pearl Harbor Naval Complex,” by K. R. Pohl, Report EPA-402-R-01-014, November 2001.

45. U.S. Environmental Protection Agency Report, “Radiological Survey of San Diego Bay,” by R. Goodman, Report EPA-402-R-98-011, January 1999.

46. U.S. Environmental Protection Agency Report, “Radiological Survey of the Mare Island Naval Shipyard, Alameda Naval Air Station, and Hunters Point Shipyard,” by M. O. Semler and R. L. Blanchard, Report 520/5 88-018, June 1989.

47. U.S. Environmental Protection Agency Report, “Radiological Survey at the New London Harbor Facilities,” Report EPA-402-R-05-002, August 2005.

48. U.S. Environmental Protection Agency Report, “Radiological Survey Hampton Roads Harbor Facilities,” Report EPA-402-R-05-004, October 2005.

49. U.S. Environmental Protection Agency Report, “Radiological Survey at the King’s Bay Naval Submarine Base,” Report EPA-402-R-04-004, October 2004.

50. U.S. Environmental Protection Agency Report, “Radiological Survey of Portsmouth Naval Shipyard,” by J. M. Smith and V. D. Lloyd, Report EPA-402-R-01-013, November 2001.

51. U.S. Environmental Protection Agency Report, “Radiological Surveys at the Puget Sound Naval Shipyard and Naval Submarine Base–Bangor,” by T. W. Fowler and C. Cox, Report EPA-402-R-98-003, July 1998.

APPENDIX:

ENVIRONMENTAL MONITORING SURVEY CHARTS

Environmental monitoring survey charts for harbors monitored for radioactivity associated with U.S. naval nuclear-powered ships in the U.S. and possessions are listed below and included in this appendix. The sampling locations for harbor water and harbor sediment are shown. In addition, shoreline survey areas and the locations of posted dosimetry devices are shown on the figures.

Figure No.	Location
	California
1	U.S. Naval Air Station North Island, San Diego
2	U.S. Naval Submarine Base, San Diego
3	U.S. Naval Station, San Diego
	Connecticut
4	Electric Boat Corporation, Groton
5	U.S. Naval Submarine Support Facility, New London Harbor
	Florida
6	Port Canaveral
	Georgia
7	U.S. Naval Submarine Base, Kings Bay
	Guam
8	Apra Harbor
	Hawaii
9	Pearl Harbor Area
10	Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility — Shipyard Area, Pearl Harbor
11	Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility — Submarine Base Area, Pearl Harbor
	Maine
12	Portsmouth Naval Shipyard
	South Carolina
13	Naval Nuclear Power Training Unit, Charleston
	Virginia
14	Huntington Ingalls Industries - Newport News Shipbuilding
15	Norfolk Naval Shipyard, Portsmouth
16	U.S. Naval Station, Norfolk
17	Norfolk Portsmouth Virginia Area
	Washington
18	Puget Sound Naval Shipyard
19	Bangor / Hood Canal
20	U.S. Naval Station, Everett

FIGURE 1
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL AIR STATION NORTH ISLAND
SAN DIEGO, CA

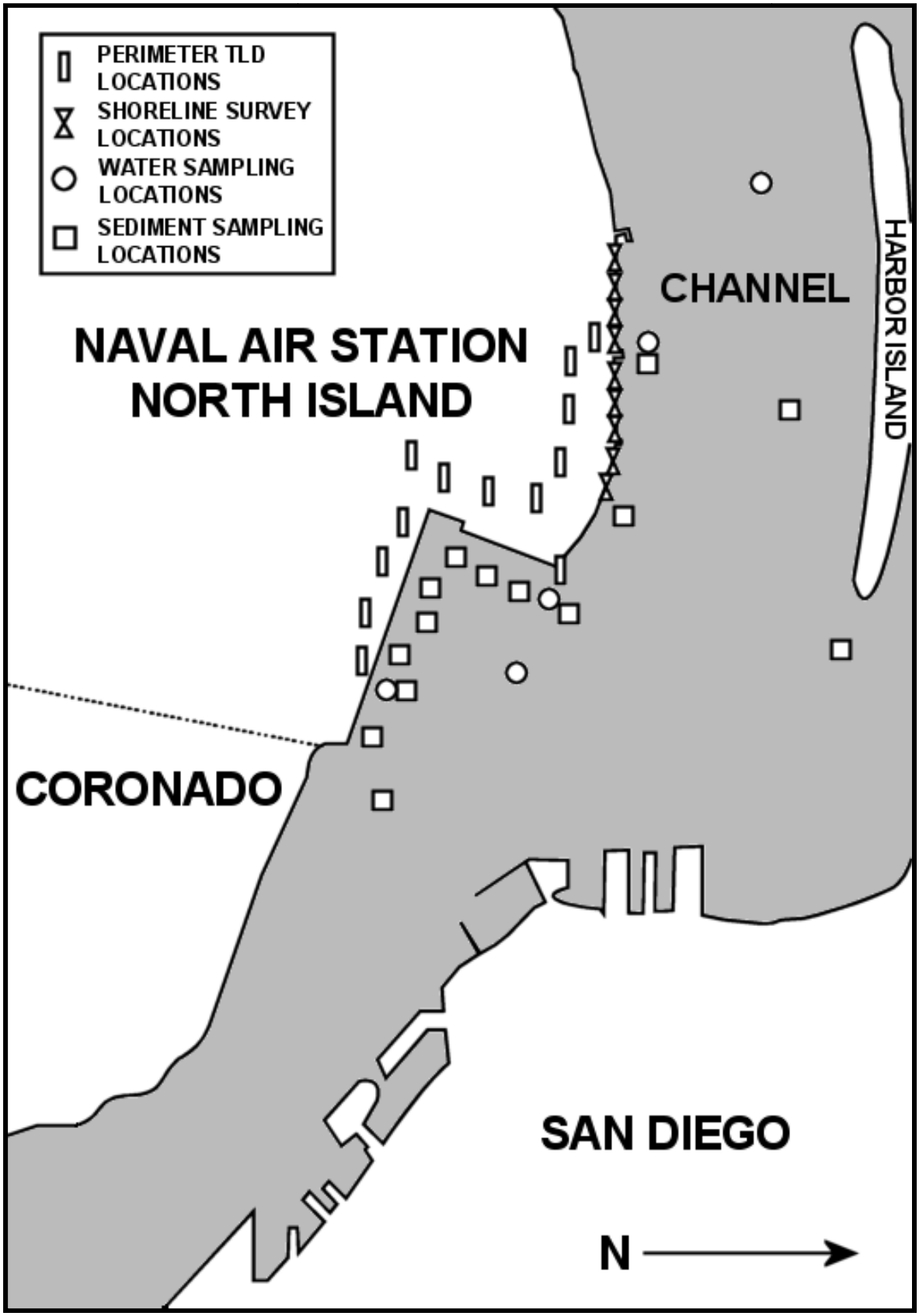


FIGURE 2
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE
SAN DIEGO, CA

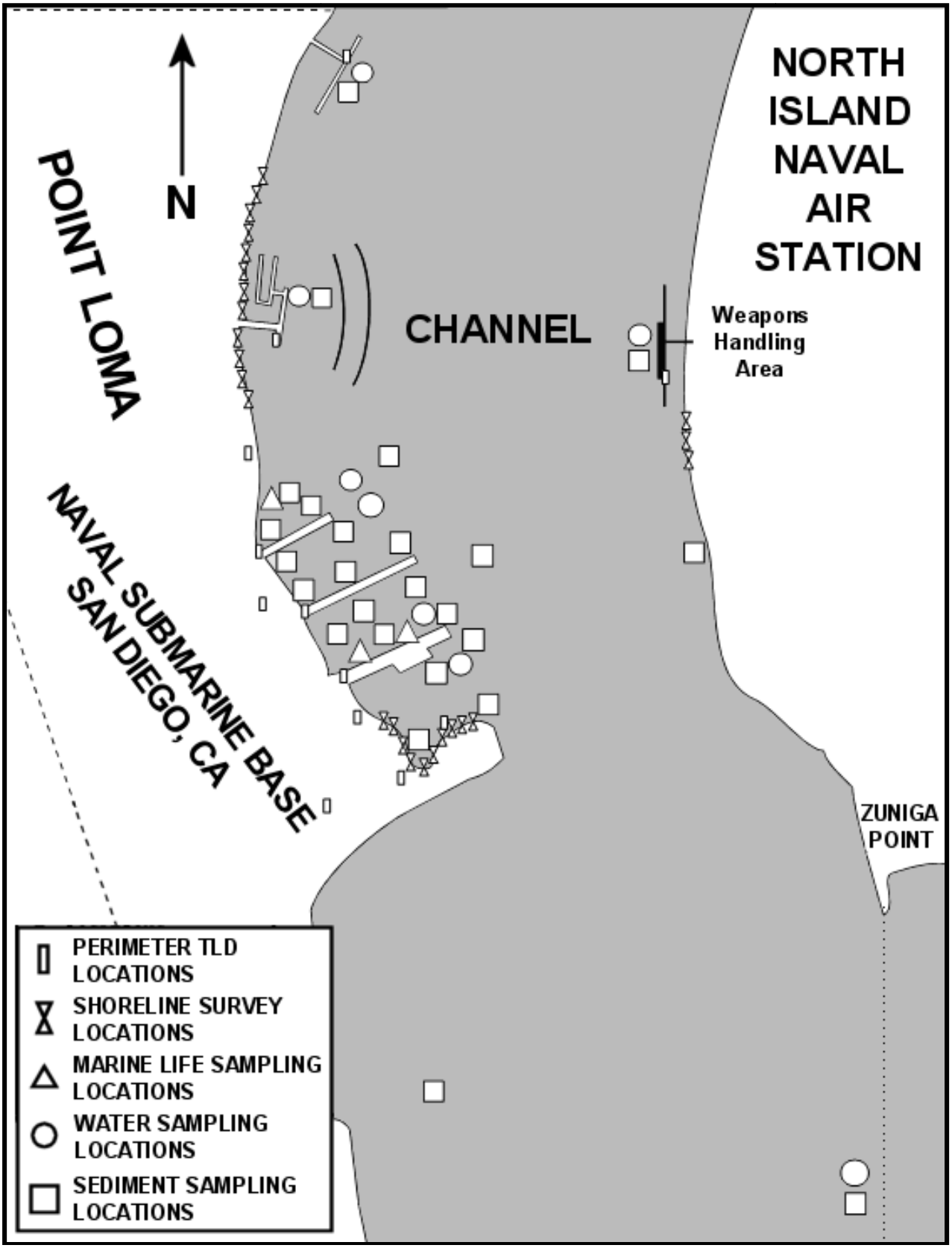


FIGURE 3
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION
SAN DIEGO, CA

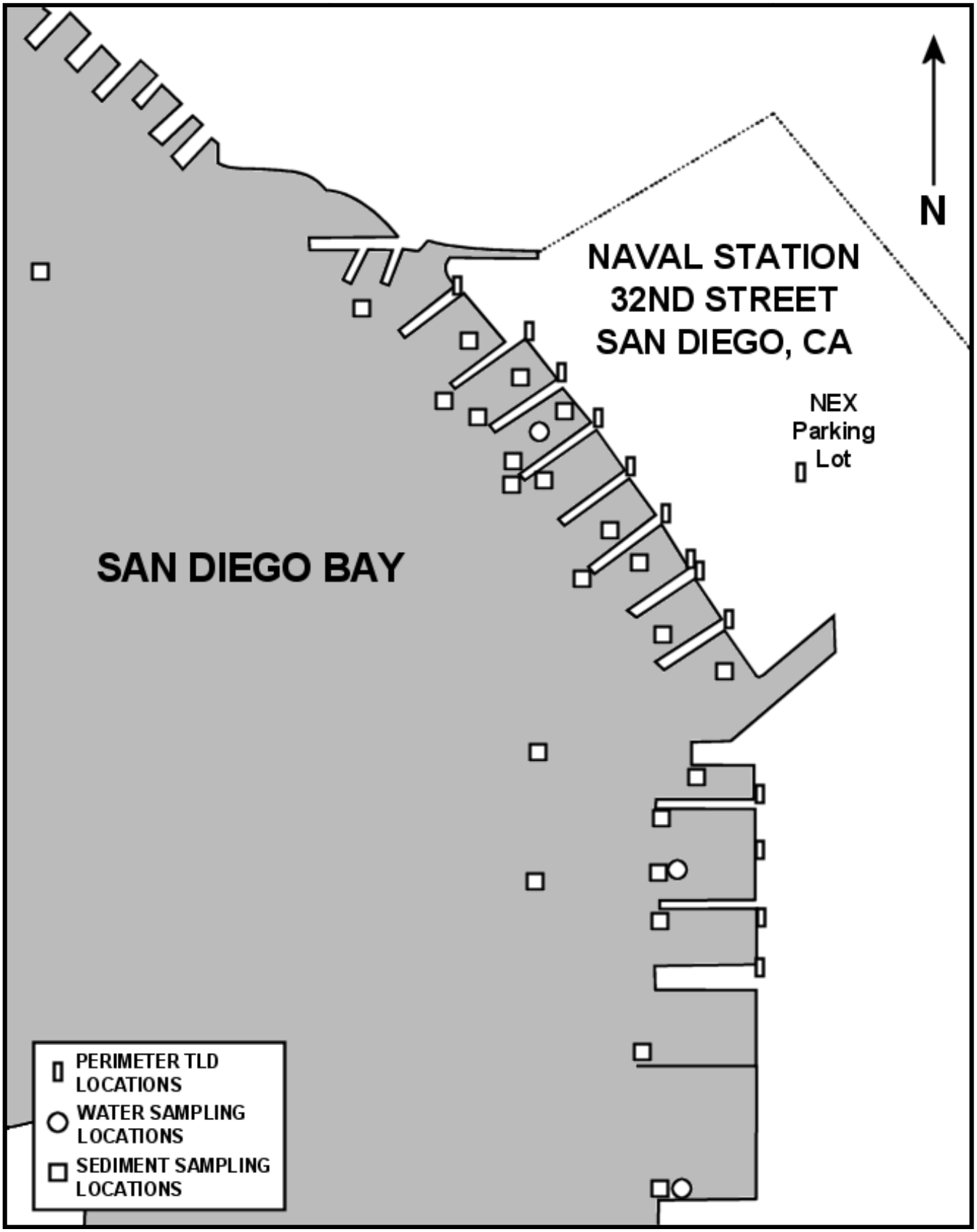


FIGURE 4
ENVIRONMENTAL MONITORING LOCATIONS AT
ELECTRIC BOAT CORPORATION
GROTON, CT

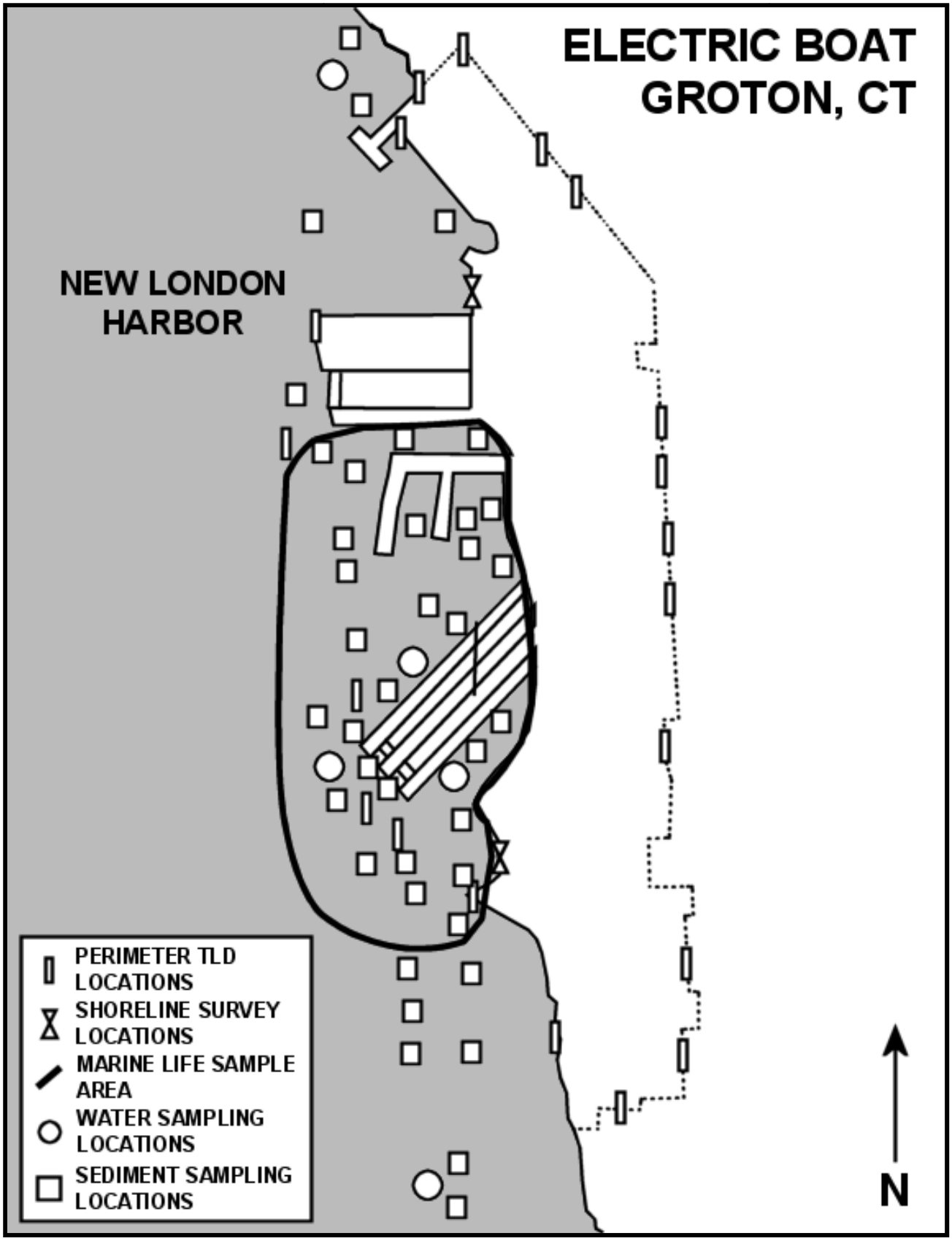


FIGURE 5
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE
NEW LONDON, CT

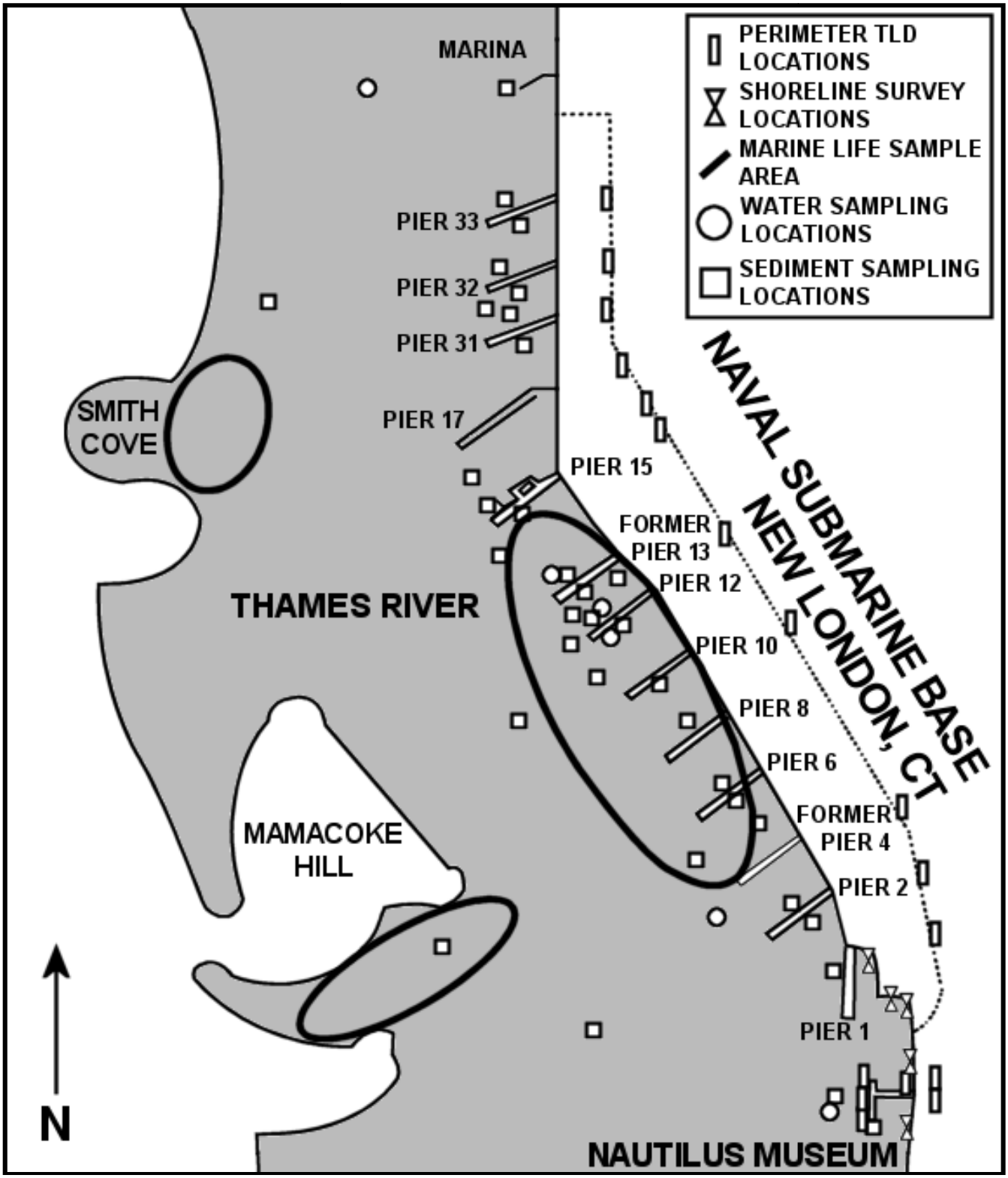


FIGURE 6
ENVIRONMENTAL MONITORING LOCATIONS AT
PORT CANAVERAL, FL

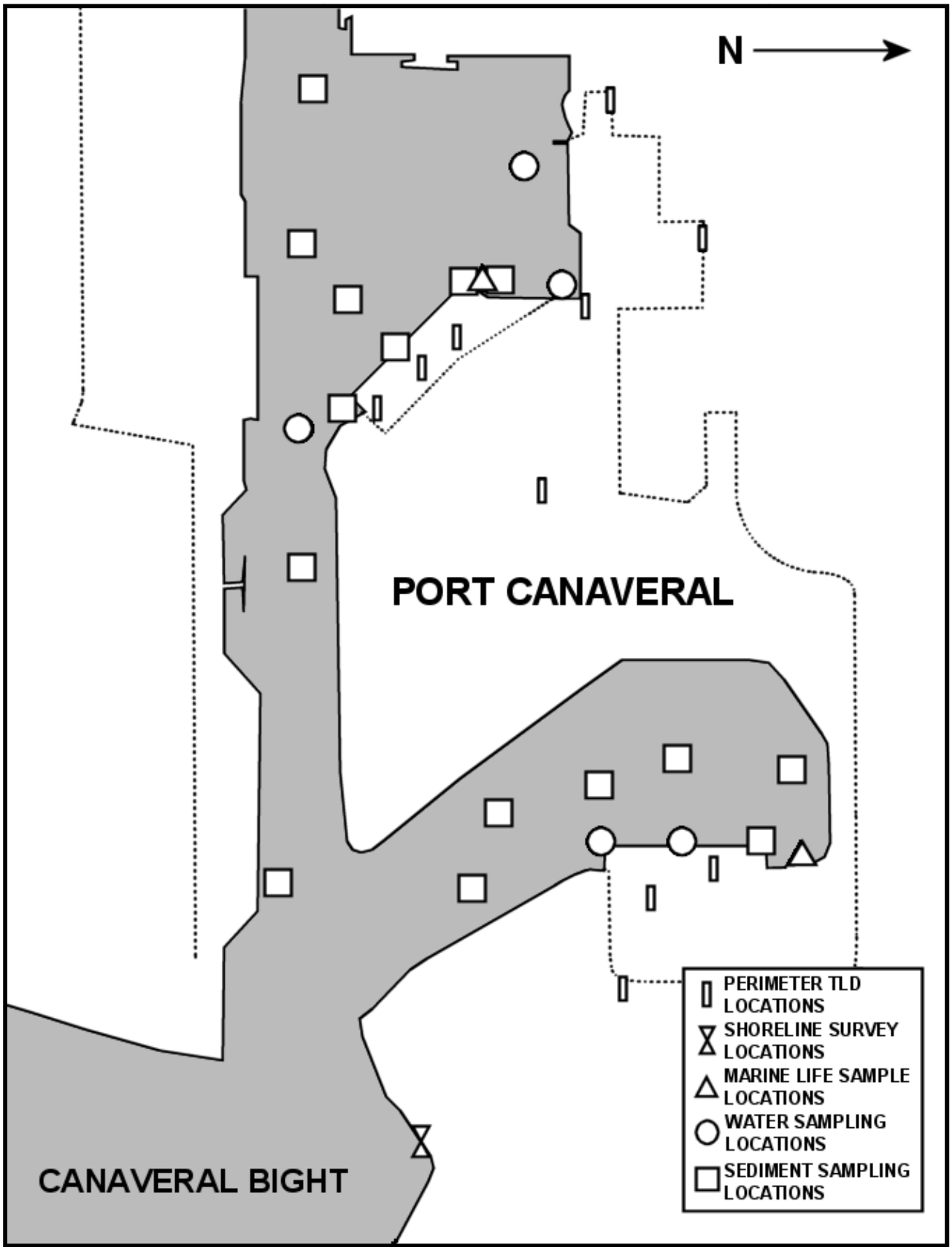


FIGURE 7
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE
KINGS BAY, GA

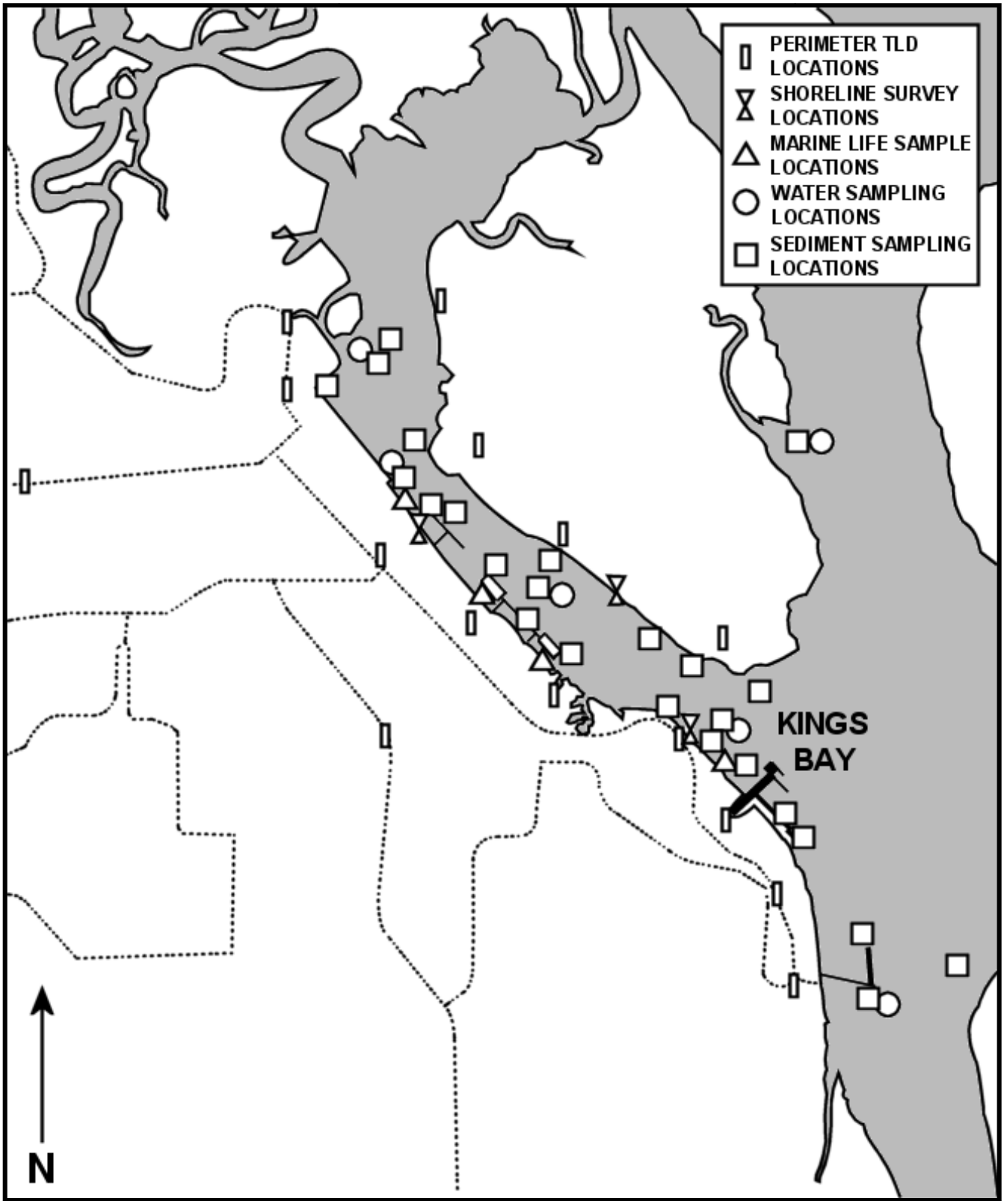


FIGURE 8
ENVIRONMENTAL MONITORING LOCATIONS AT
APRA HARBOR, GUAM

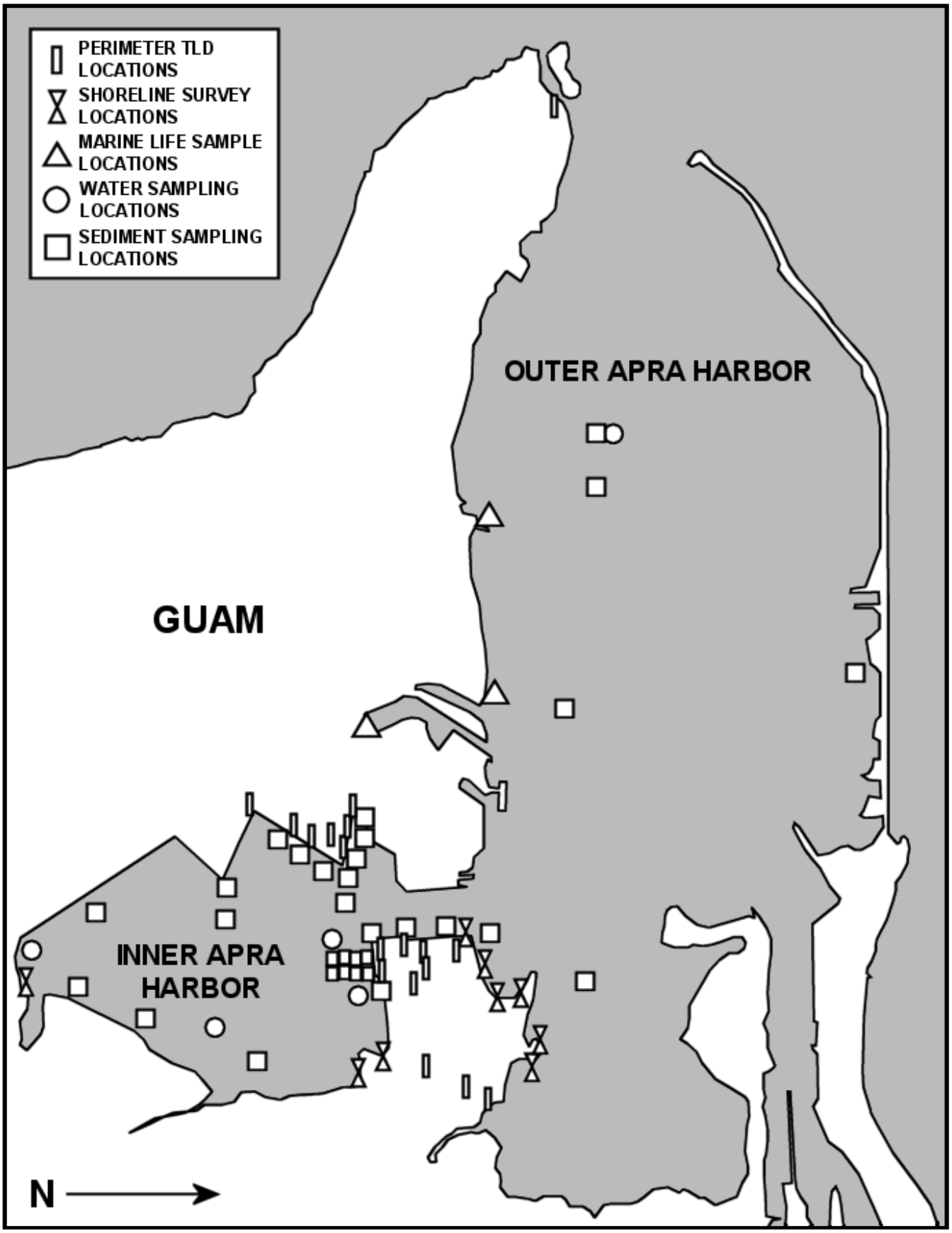


FIGURE 9
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR, HI

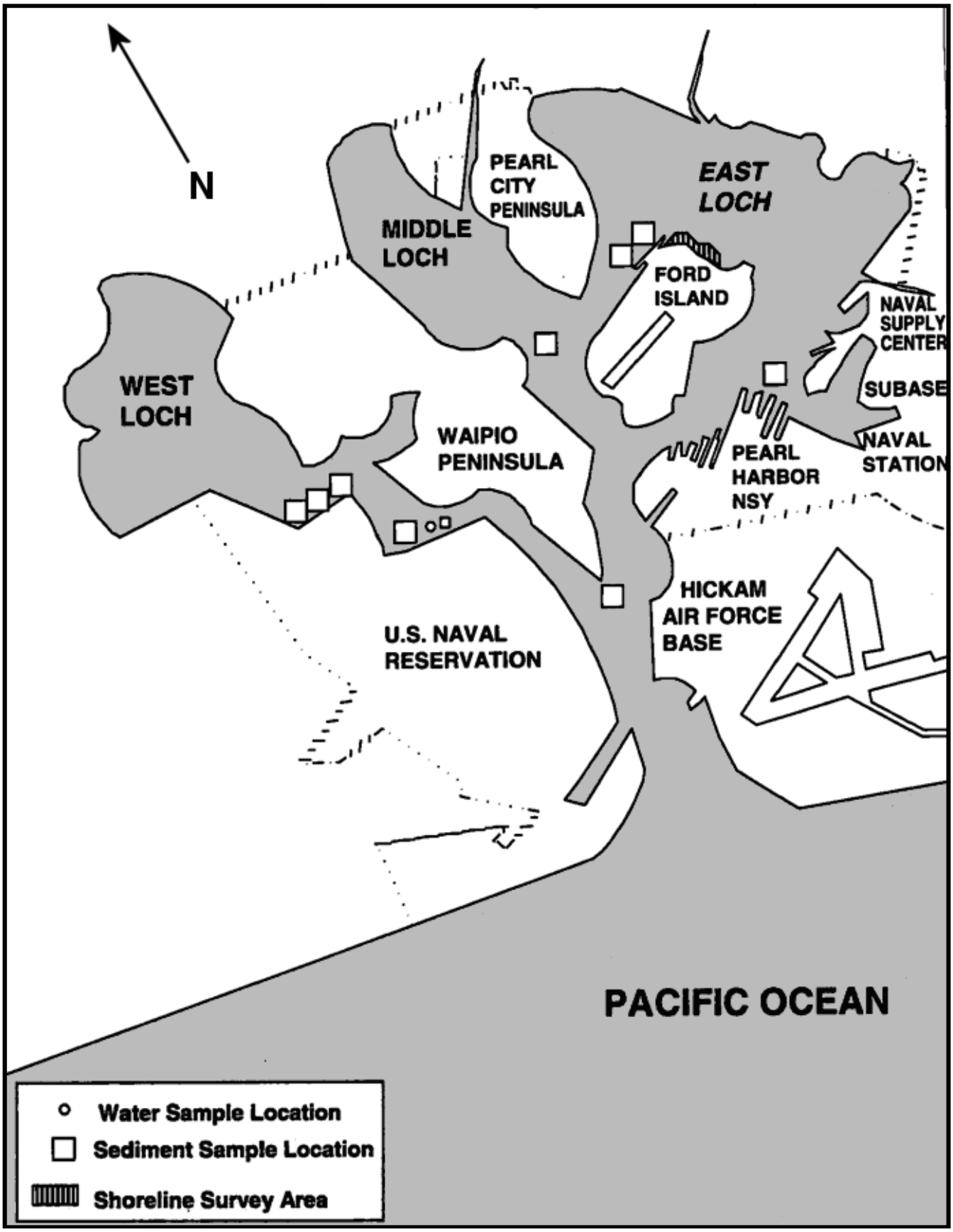


FIGURE 10
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR NAVAL SHIPYARD AND INTERMEDIATE
MAINTENANCE FACILITY – SHIPYARD AREA

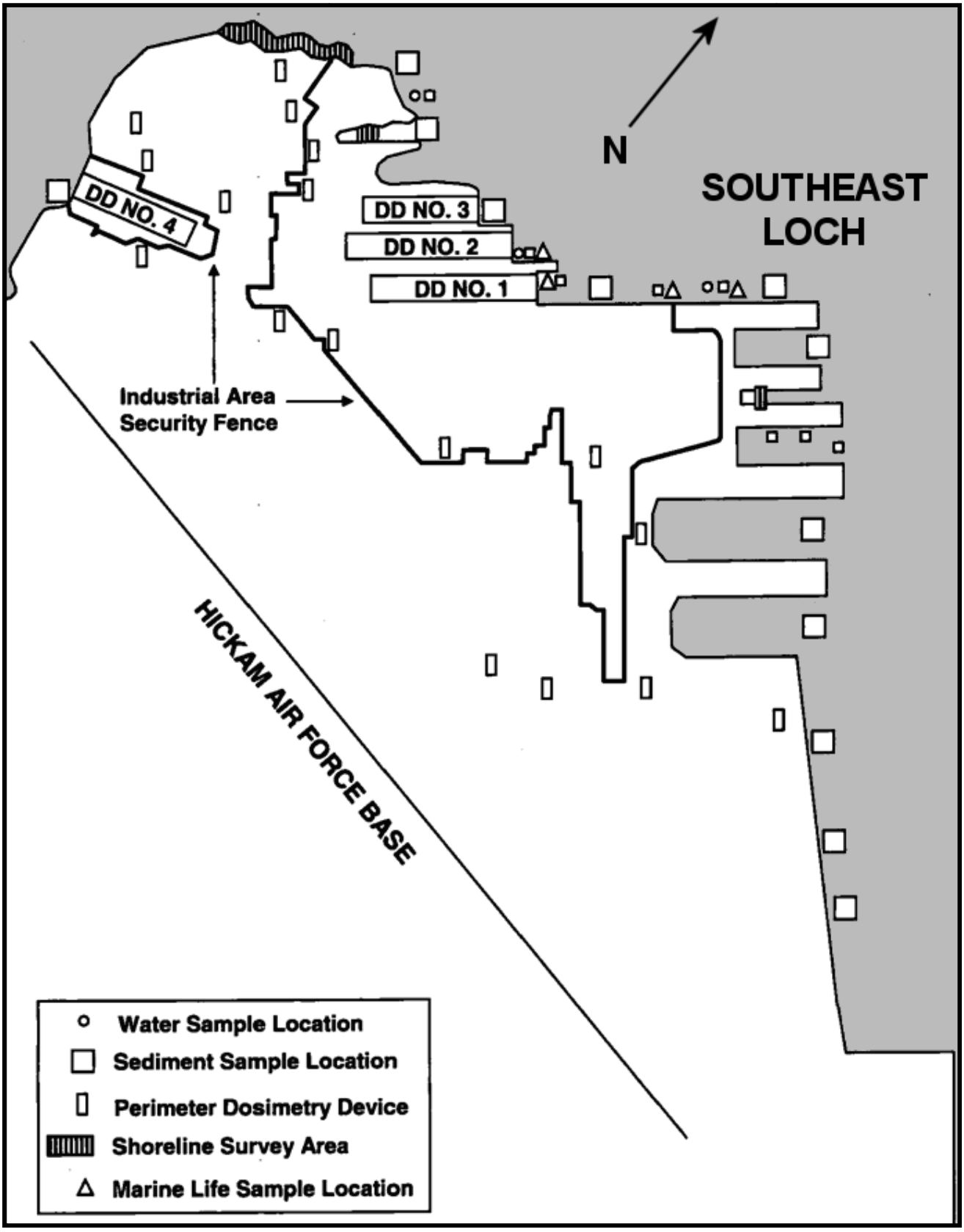


FIGURE 11
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR NAVAL SHIPYARD AND INTERMEDIATE MAINTENANCE FACILITY
SUBMARINE BASE AREA

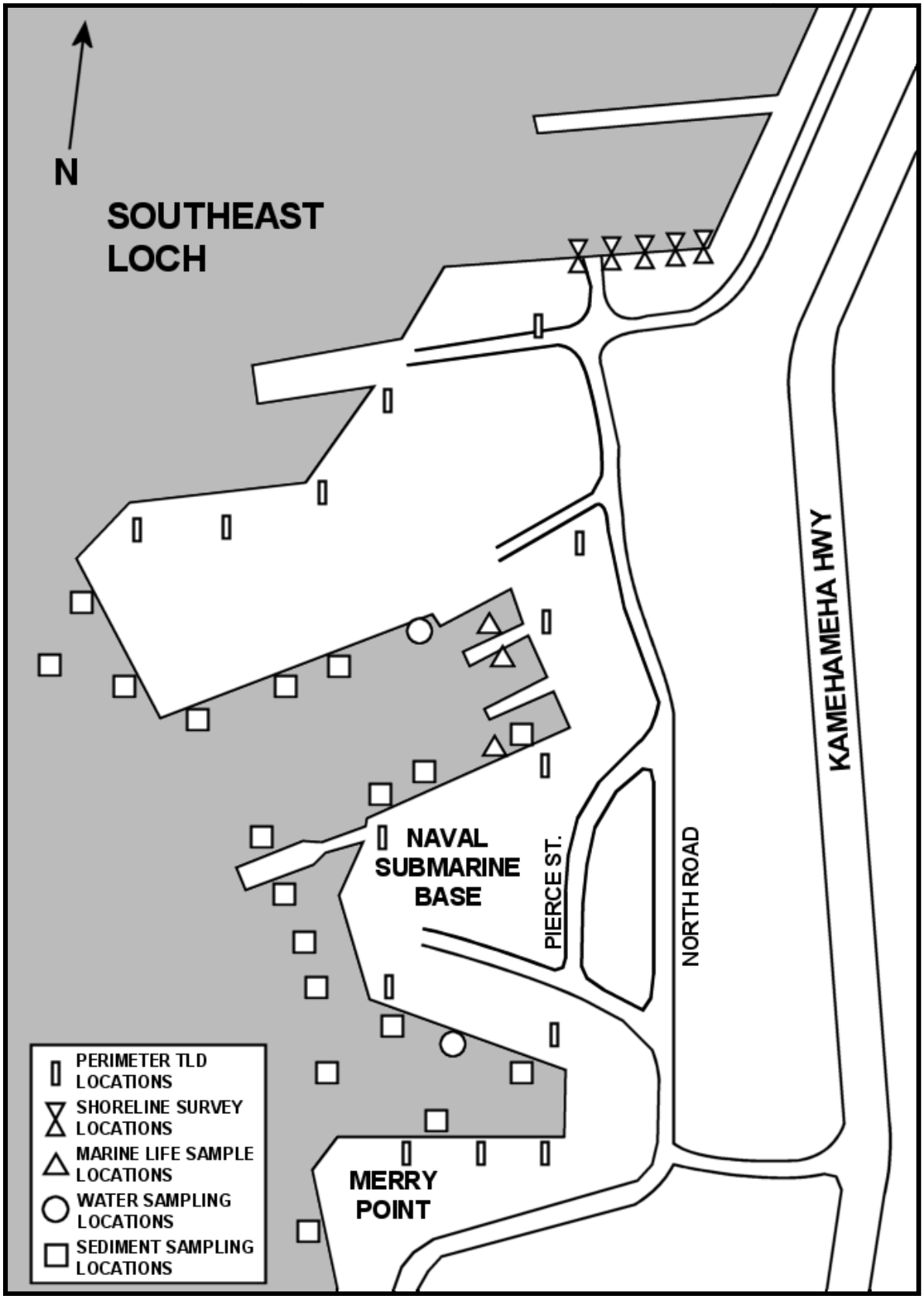


FIGURE 12
ENVIRONMENTAL MONITORING LOCATIONS AT
PORTSMOUTH NAVAL SHIPYARD
KITTERY, ME

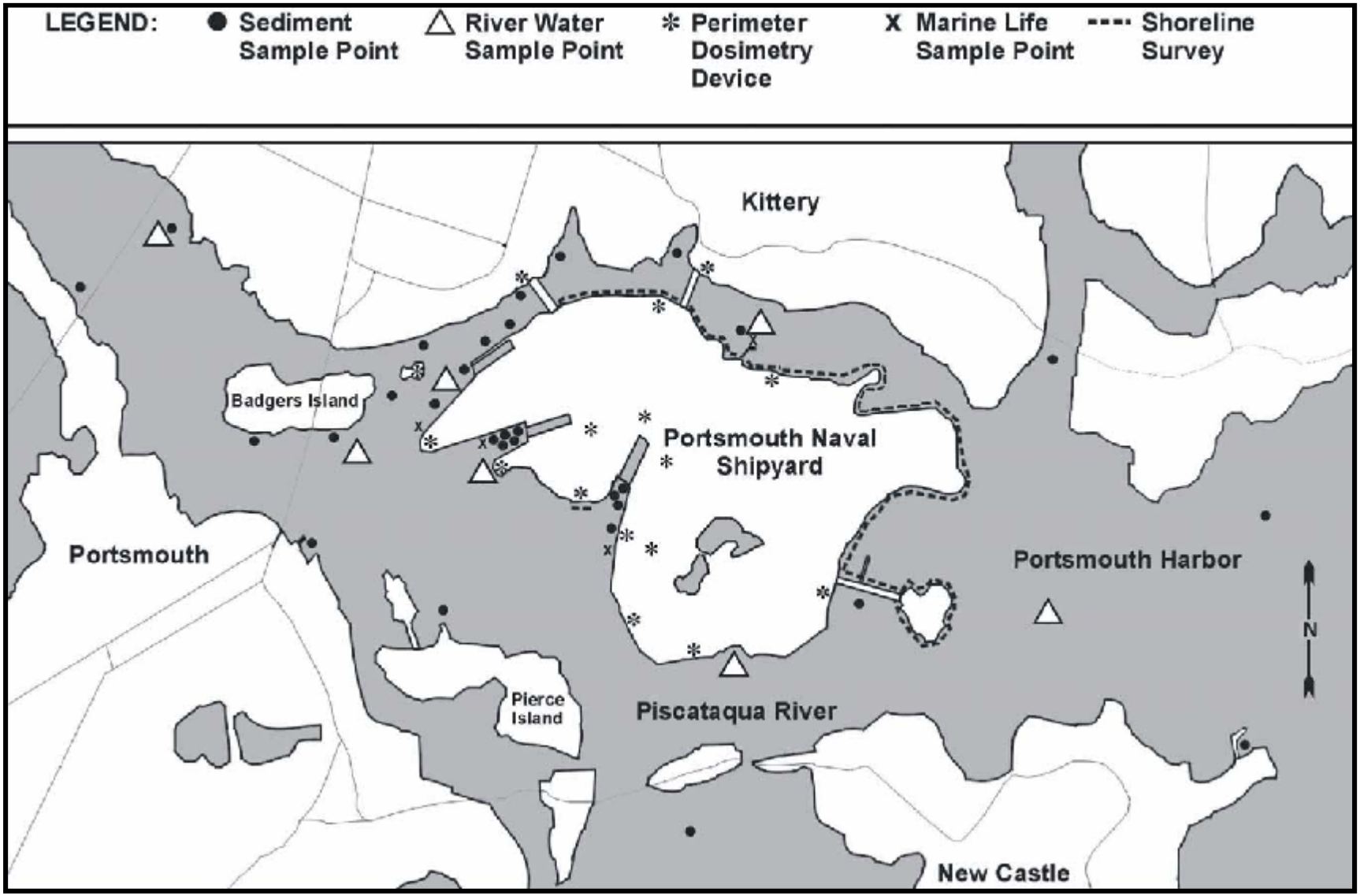


FIGURE 13
ENVIRONMENTAL MONITORING LOCATIONS AT
NAVAL NUCLEAR POWER TRAINING UNIT
CHARLESTON, SC

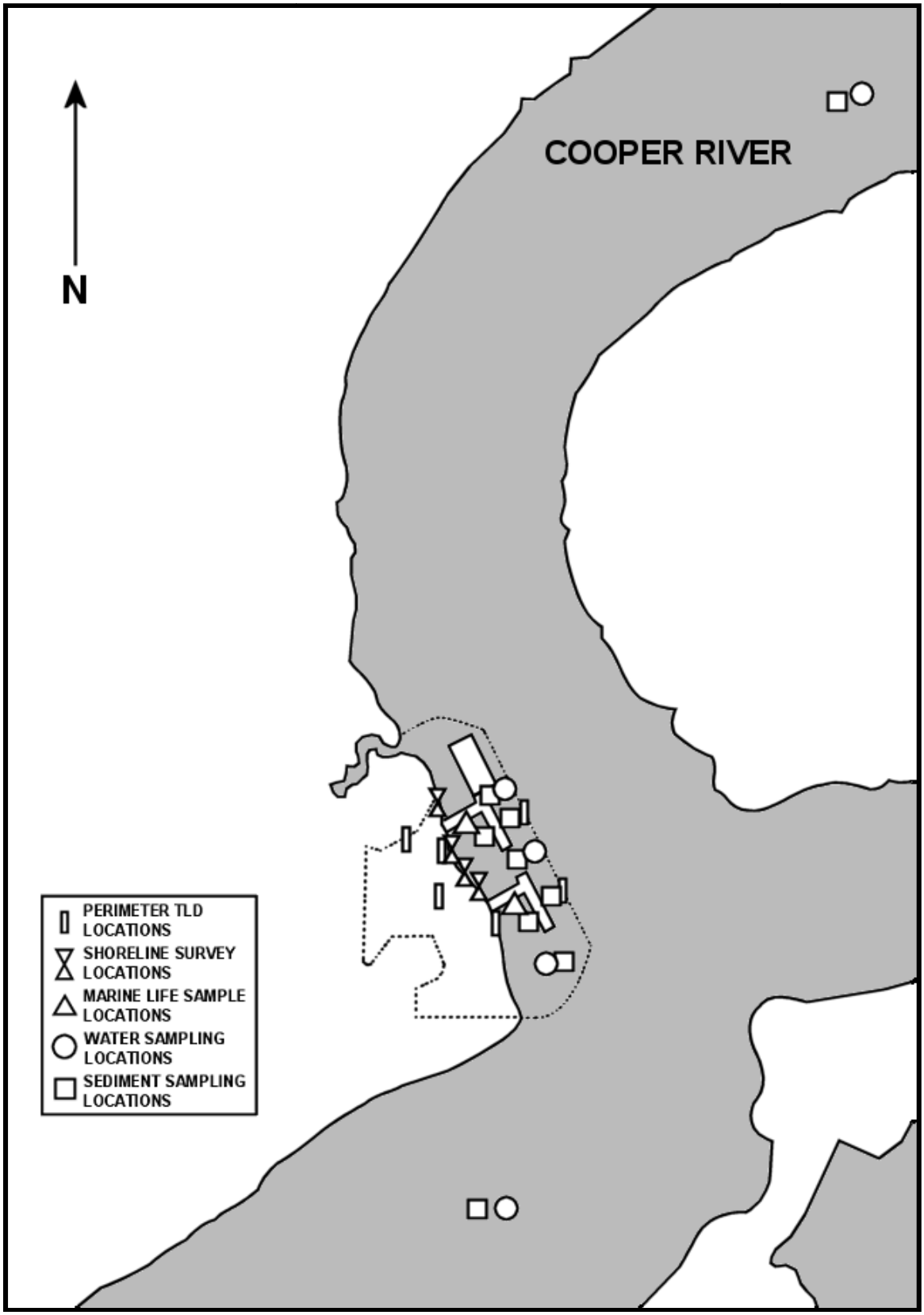


FIGURE 14
ENVIRONMENTAL MONITORING LOCATIONS AT
HUNTINGTON INGALLS INDUSTRIES - NEWPORT NEWS SHIPBUILDING
NEWPORT NEWS, VA

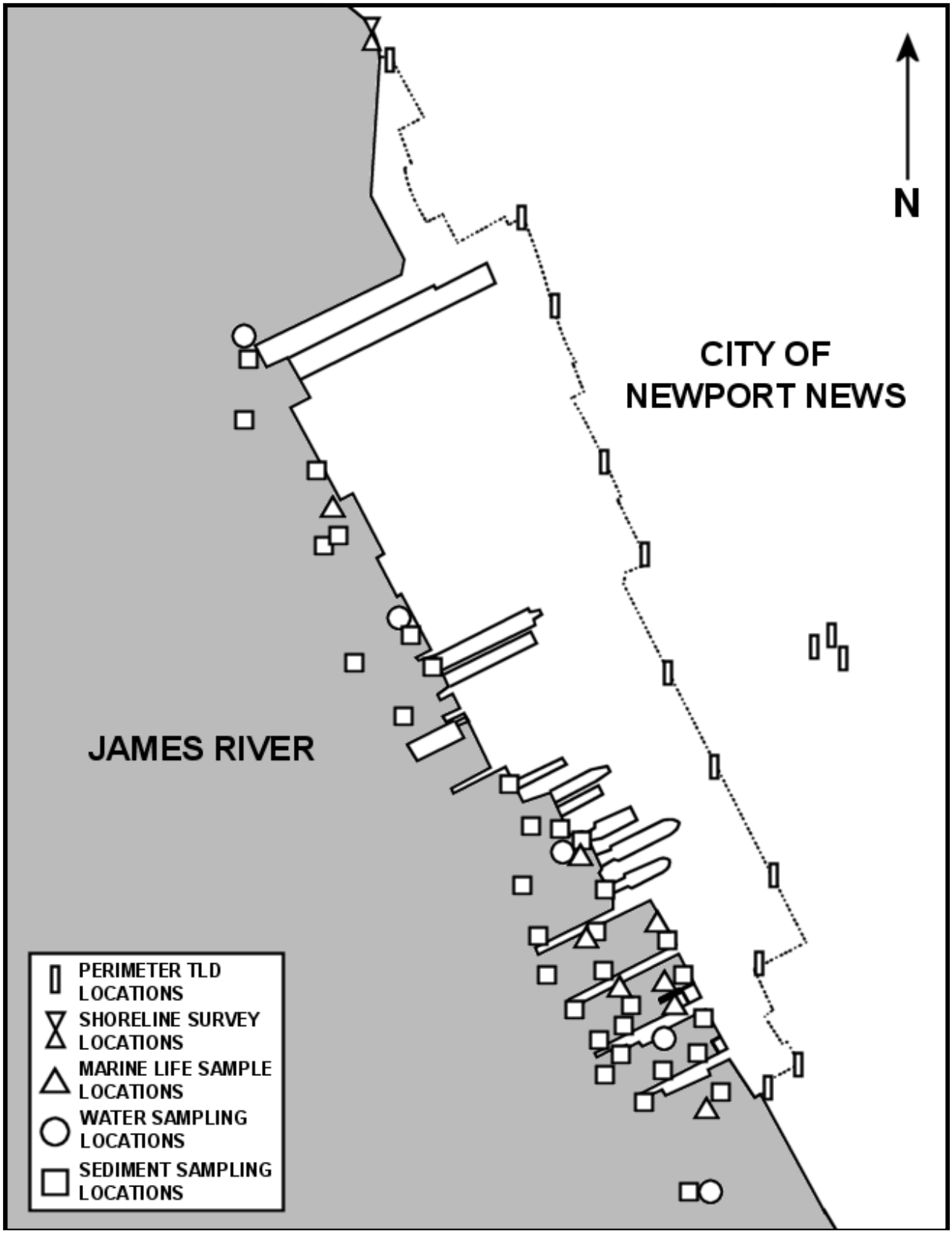


FIGURE 15
ENVIRONMENTAL MONITORING LOCATIONS AT
NORFOLK NAVAL SHIPYARD
PORTSMOUTH, VA

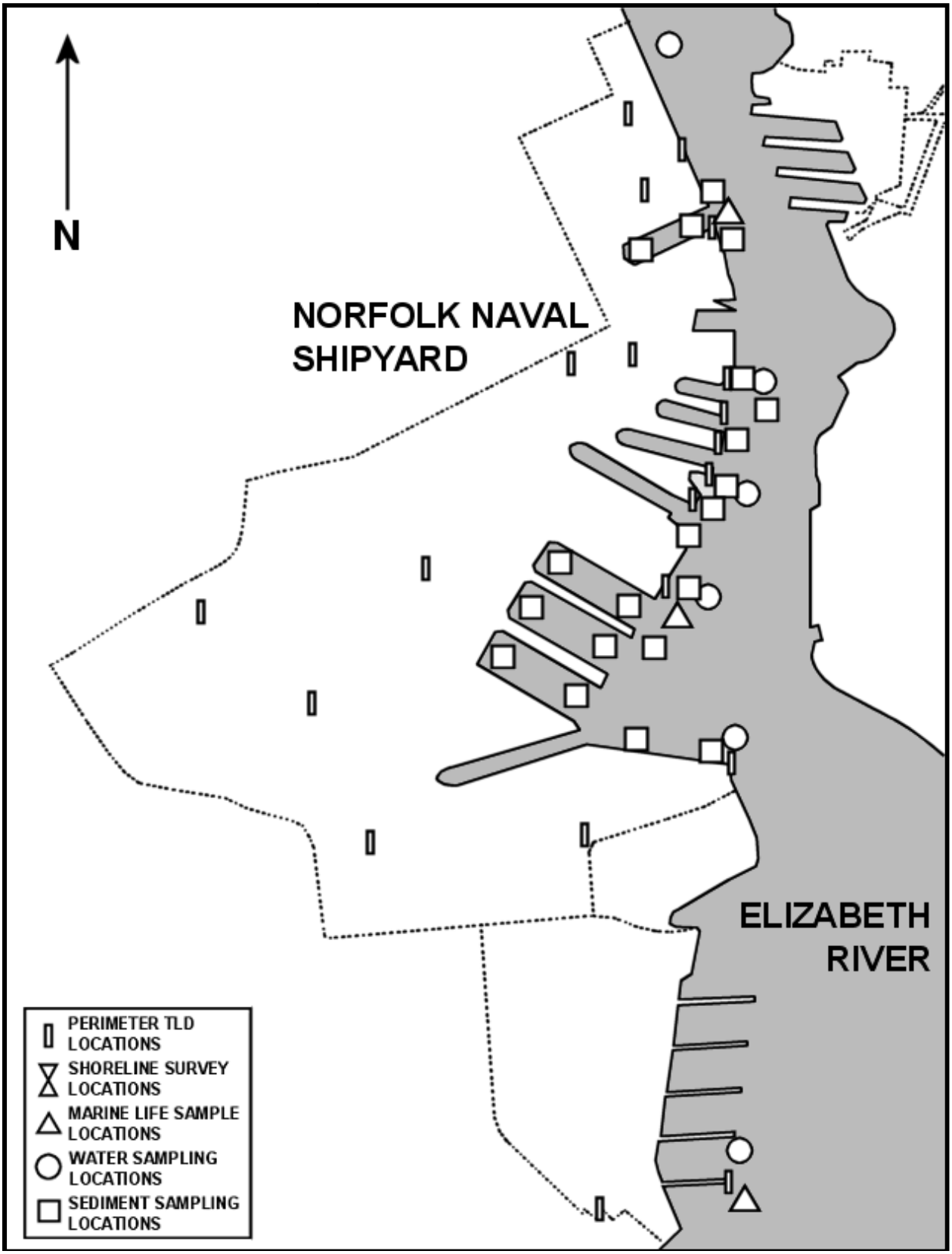


FIGURE 16
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION
NORFOLK, VA

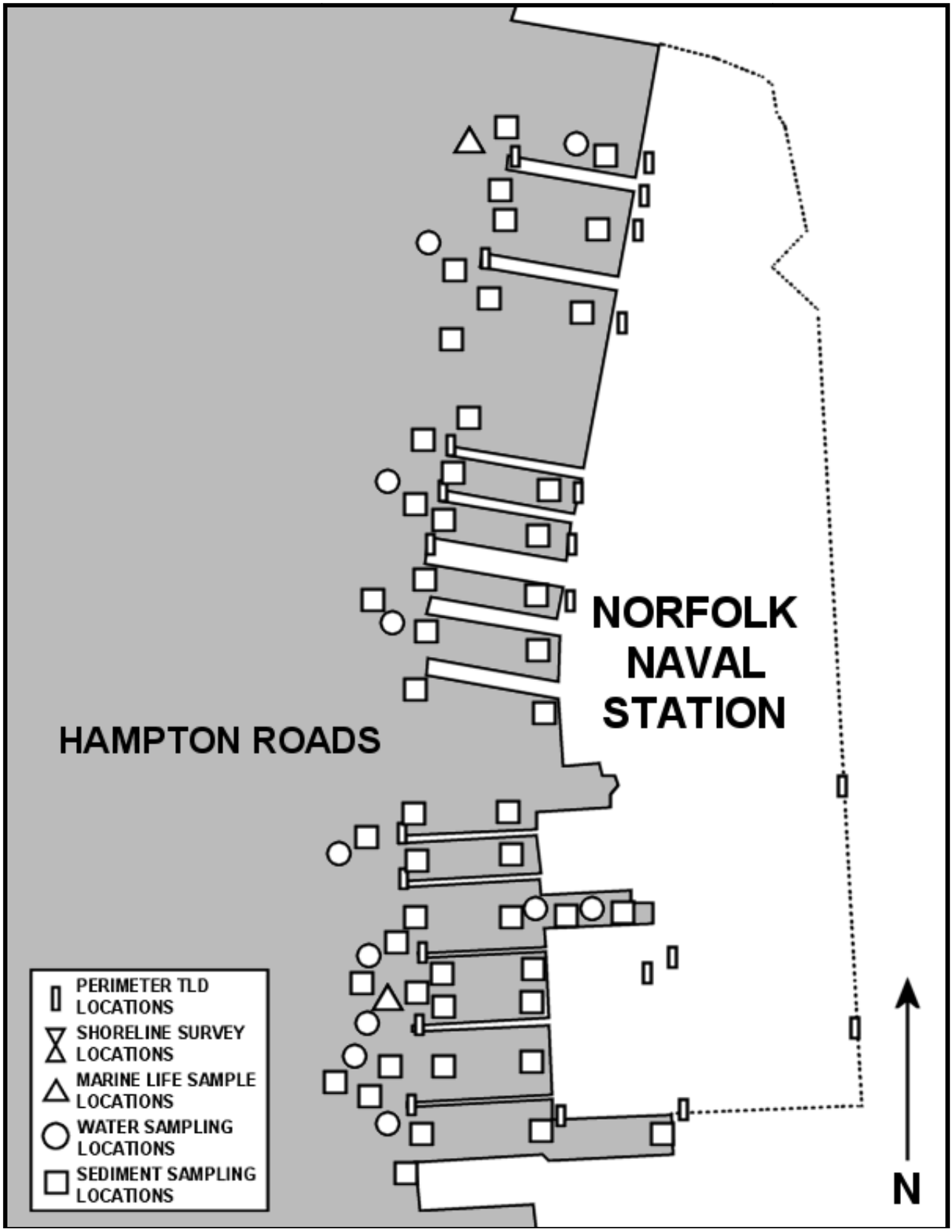


FIGURE 17
ENVIRONMENTAL MONITORING LOCATIONS AT
NORFOLK-PORTSMOUTH AREA, VA

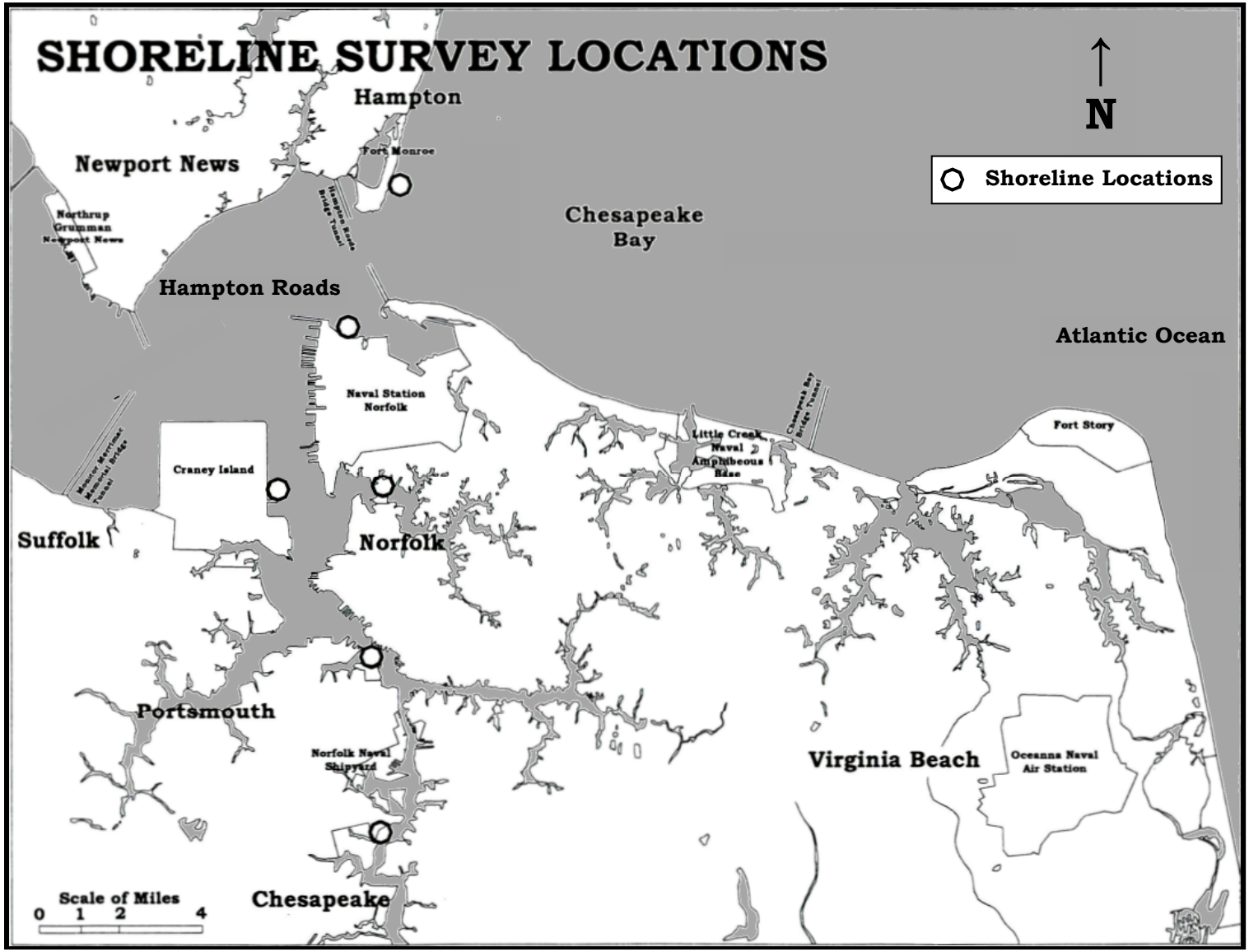


FIGURE 18
ENVIRONMENTAL MONITORING LOCATIONS AT
PUGET SOUND NAVAL SHIPYARD AND INTERMEDIATE MAINTENANCE FACILITY
BREMERTON, WA

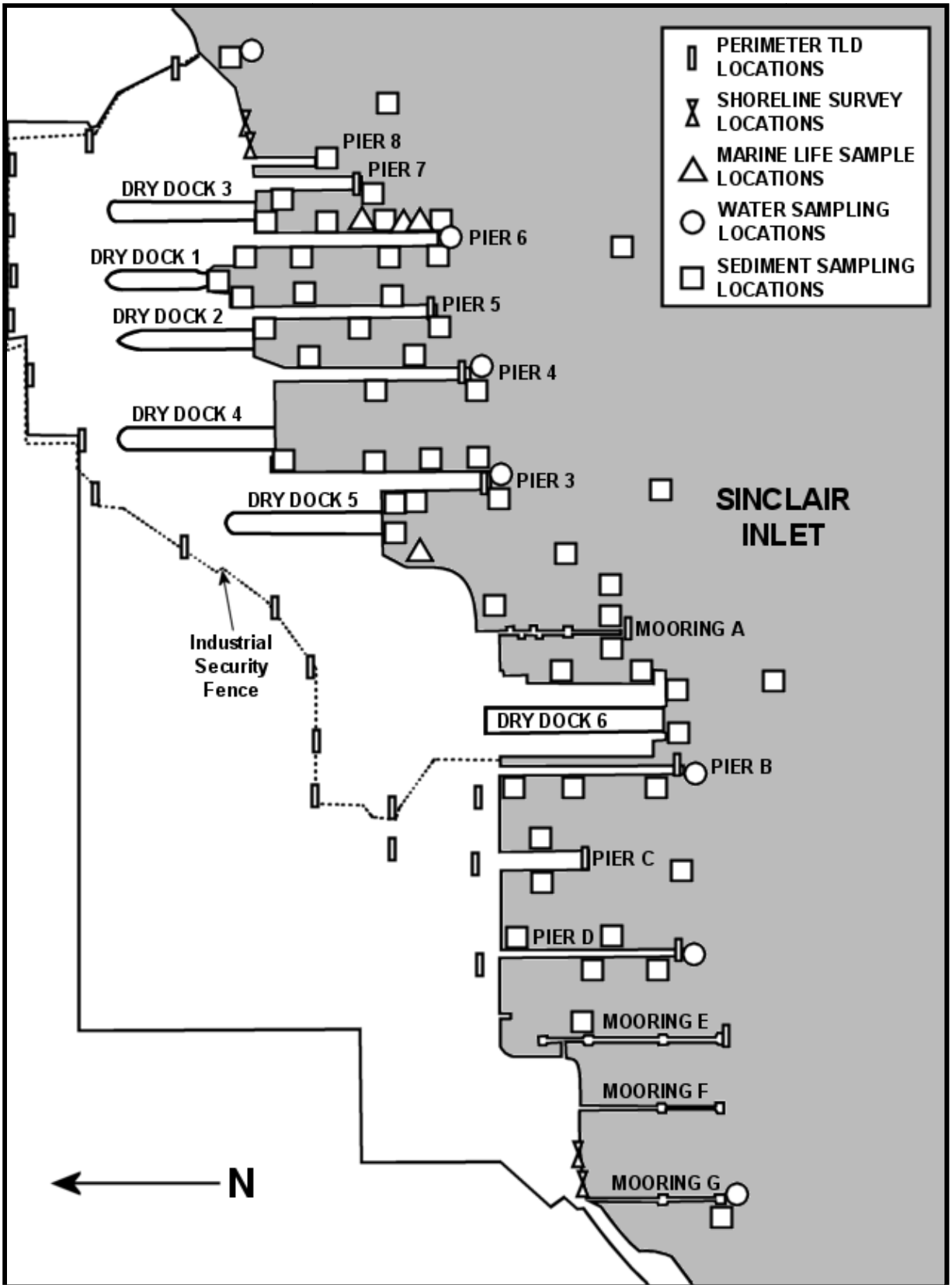


FIGURE 19
ENVIRONMENTAL MONITORING LOCATIONS AT
NAVAL BASE KITSAP - BANGOR
BANGOR, WA

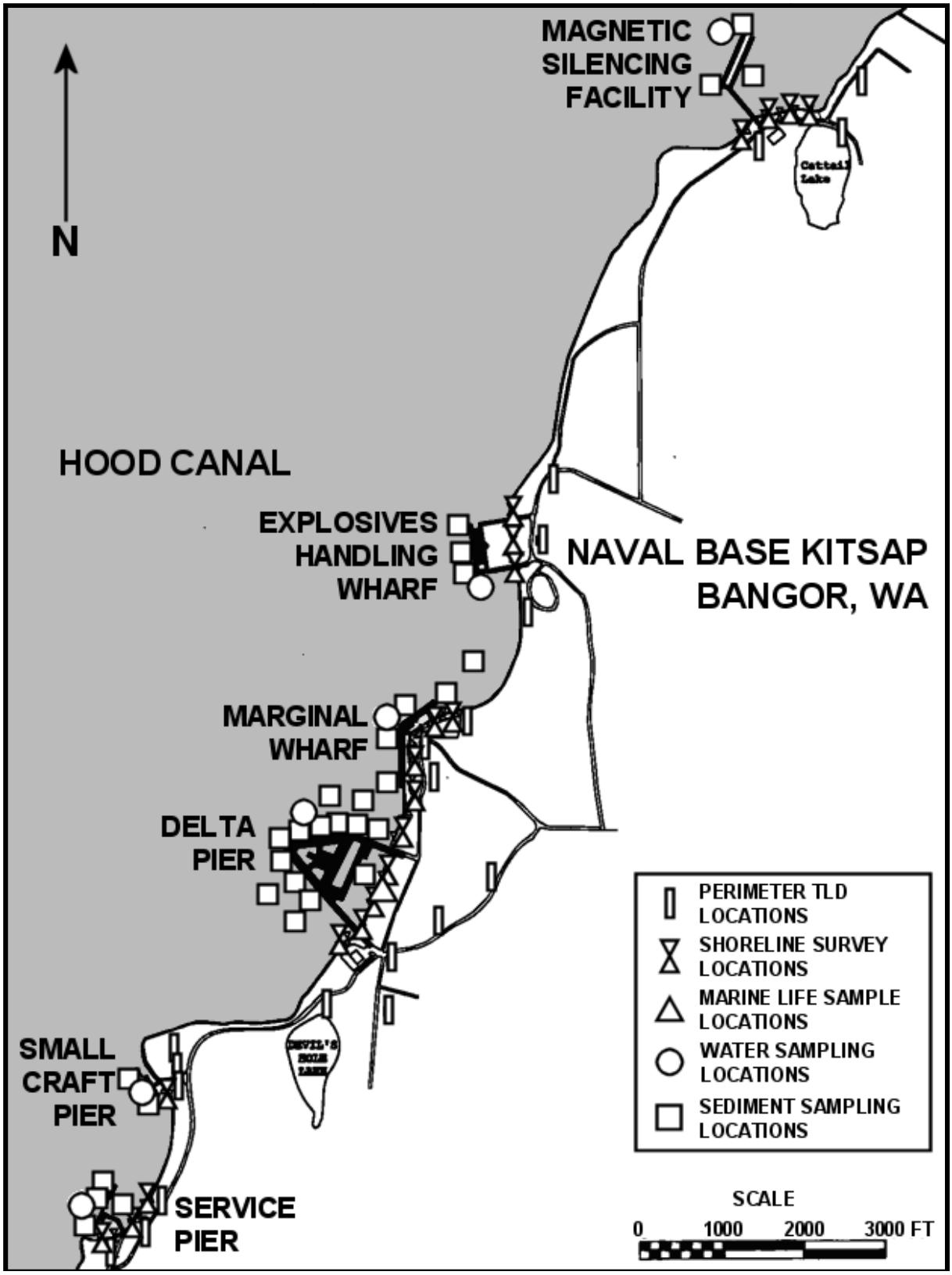
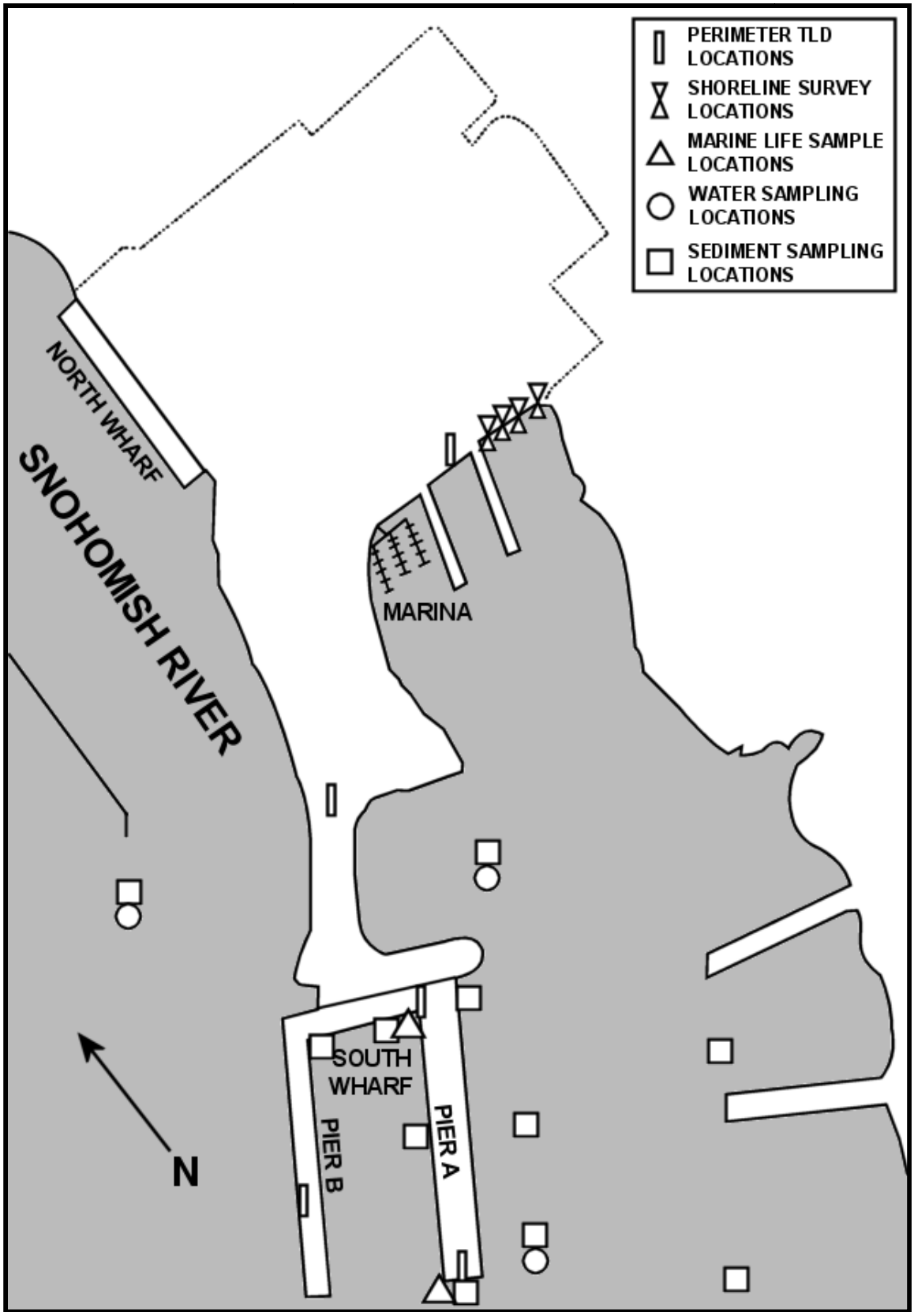



FIGURE 20
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION EVERETT
EVERETT, WA