2006 . 0000959

DIRECTOR, NAVAL REACTORS

1 June 2006

Dear Mr. Chairman,

Enclosed are the Naval Nuclear Propulsion Program's latest reports on environmental monitoring and radiological waste disposal, worker radiation exposure, and occupational safety and health, as well as a report providing an overview of the Program. These reports, issued annually, continue to show that (a) naval nuclear-powered ships and their support facilities have had no radiological impact on public health or the environment; (b) no Program personnel exceeded Federal radiation exposure limits; (c) the average occupational radiation exposure was much less than the yearly background exposure received by the average U.S. citizen; and (d) these facilities are consistently and substantially effective at promoting worker safety and health.

The enclosed reports recognize the Program's continued commitment to maintaining a high standard for protecting the environment and the workforce, while employing an unforgiving, complex, and challenging technology. These widely distributed annual reports have long been a matter of public record. As in the past, this year's reports demonstrate the results of our strict control of the Naval Nuclear Propulsion Program and our strong centralized oversight that continues to ensure the safe and effective operation of our nuclear-powered warships.

Sincerely,

K. H. DONALD
Admiral, U.S. Navy

A. J. Eggenberger, Ph.D., Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue NW, Suite 700
Washington DC 20004-2901

Enclosures

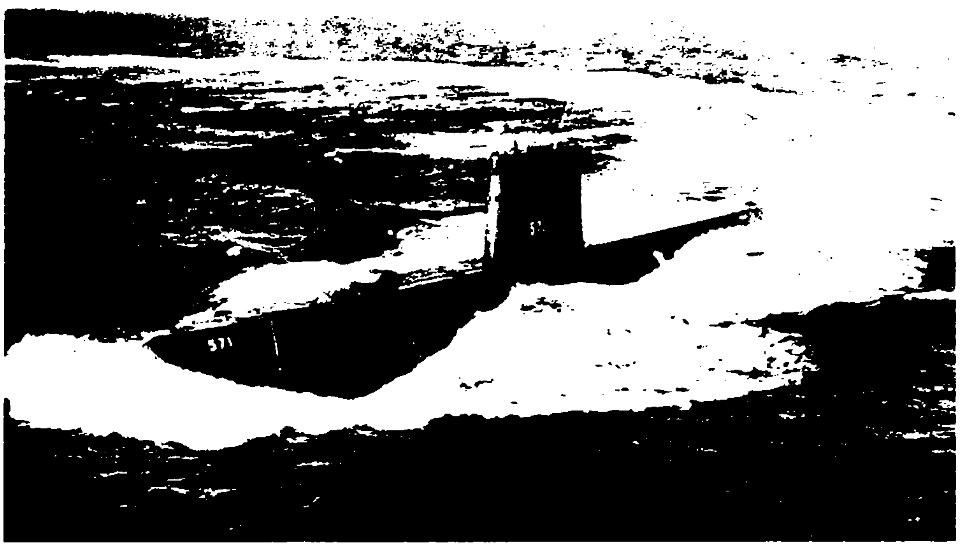
SEPARATION

PAGE

THE UNITED STATES NAVAL NUCLEAR PROPULSION PROGRAM

March 2006

Over 134 Million Miles Safely Steamed on Nuclear Power

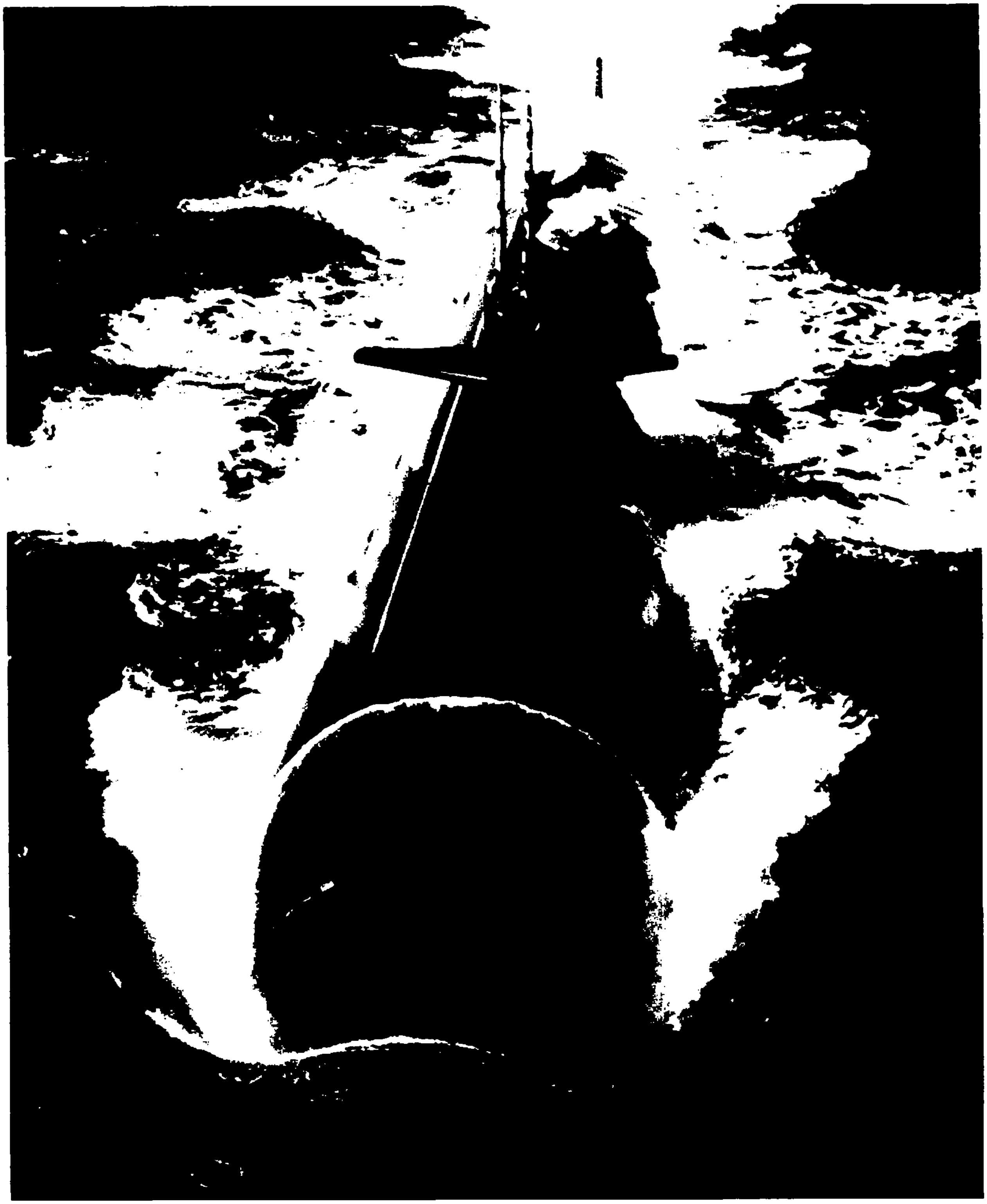


USS NAUTILUS (SSN 571) at Sea
NAUTILUS first went to sea "Underway on Nuclear Power" in 1955

DEPARTMENT OF ENERGY

This publication was printed on Recycled Paper

DEPARTMENT OF THE NAVY



THE UNITED STATES

NAVAL NUCLEAR

PROPULSION PROGRAM

United States of America

Congressional Record

PROCEEDINGS AND DEBATES OF THE 105TH CONGRESS, SECOND SESSION

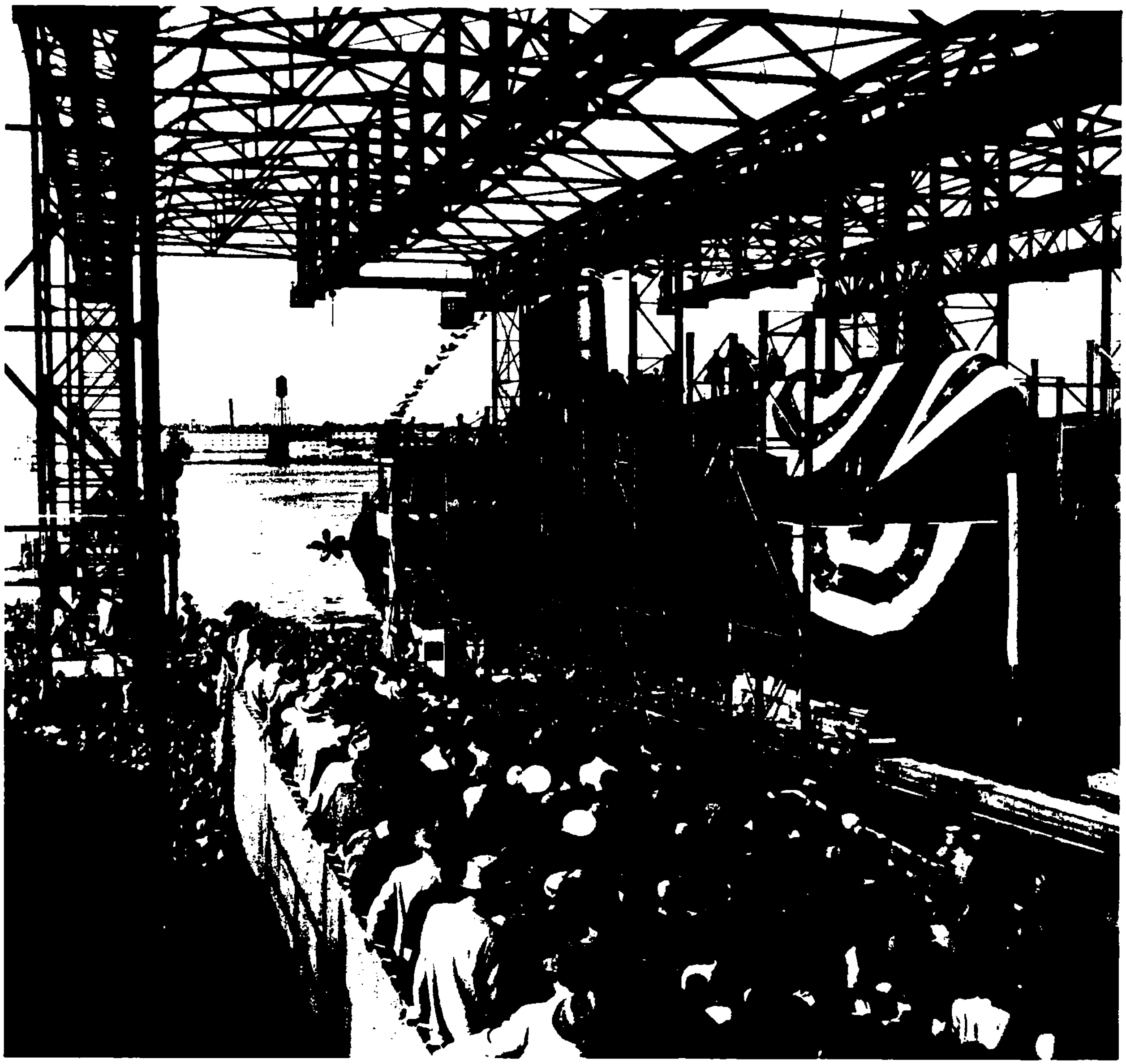
Vol. 144 WASHINGTON, FRIDAY, JULY 31, 1998 No. 106

THE SENATE RESOLVED THAT:

(1) the Senate commends the past and present personnel of the Naval Nuclear Propulsion Program for the technical excellence, accomplishment, and oversight demonstrated in the program and congratulates those personnel for the 50 years of exemplary service that has been provided to the United States through the program; and

(2) it is the sense of the Senate that the Naval Nuclear Propulsion Program should be continued into the next millennium to provide exemplary technical accomplishment in, and oversight of, Naval nuclear propulsion plants and to continue to be a model of technical excellence in the United States and the world.

Table of Contents



USS NAUTILUS Launching Ceremony
January 21, 1954

The Naval Nuclear Propulsion Program

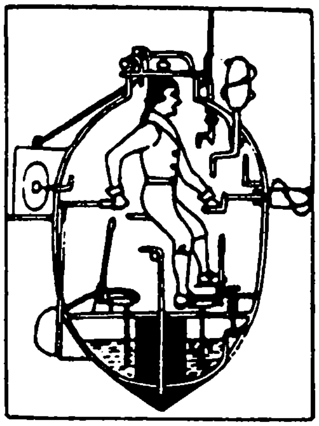
A strong Navy is crucial to the security of the United States, a nation with world-wide interests which conducts the vast majority of its trade via trans-oceanic shipment. Navy warships are deployed around the world every hour of every day to provide a credible "forward presence," ready to respond on-the-scene wherever America's interests are threatened. Nuclear propulsion plays an essential role in this, providing the mobility, flexibility, and endurance that today's smaller Navy requires to meet a growing number of missions. Approximately forty percent of the Navy's major combatants are nuclear-powered, including 10 aircraft carriers, 54 attack submarines, 14 strategic submarines – the Nation's most survivable deterrent, and 4 submarines removed from strategic service for conversion to a covert, high-volume, precision strike platform known as SSGN.

The mission of the Naval Nuclear Propulsion Program, also known as Naval Reactors, is to provide militarily effective nuclear propulsion plants and ensure their safe, reliable, and long-lived operation. This mission requires the combination of fully trained U.S. Navy men and women with ships that excel in endurance, stealth, speed, and independence from logistics supply chains.

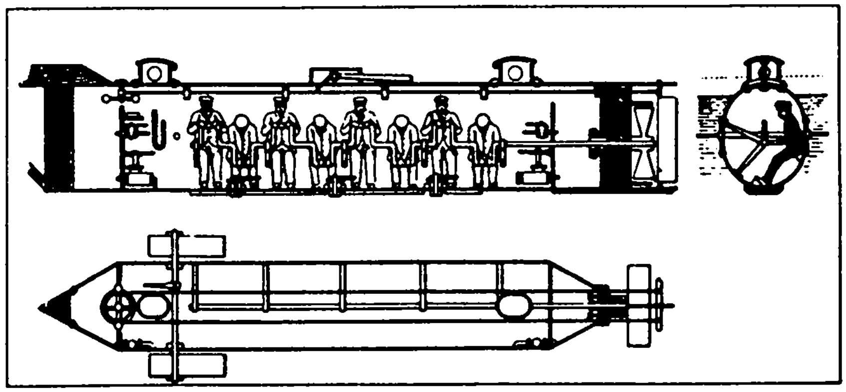
Presidential Executive Order 12344 and Public Law 106-65 set forth the total responsibility of Naval Reactors for all aspects of the Navy's nuclear propulsion, including research, design, construction, testing, operation, maintenance, and ultimate disposition of Naval nuclear propulsion plants. The Program's responsibility includes all related facilities, radiological controls, environmental safety, and health matters, as well as selection, training, and assignment of personnel. All of this work is accomplished by a lean network of dedicated research laboratories, nuclear-capable shipyards, equipment contractors and suppliers, and training facilities which are centrally controlled by a small headquarters staff. The Director of Naval Reactors is Admiral Kirkland H. Donald; he also serves as a Deputy Administrator in the National Nuclear Security Administration.

Naval Reactors maintains an outstanding record of over 134 million miles safely steamed on nuclear power. The Program currently operates 103 reactors and has accumulated over 5,700 reactor-years of operations. A leader in environmental protection, the Program has published annual environmental reports since the 1960s, which identify that the Program has not had an adverse effect on human health or the quality of the environment. Because of the Program's demonstrated reliability, U.S. nuclear-powered warships are welcomed in more than 150 ports of call in over 50 foreign countries and dependencies.

Since USS NAUTILUS (SSN 571) first signaled "Underway on nuclear power" over 50 years ago in 1955, our nuclear-powered ships have demonstrated their superiority in defending the country – from the Cold War, to today's unconventional threats, and beyond to future advances that will ensure the dominance of American sea power well into the future.



Bushnell's Turtle

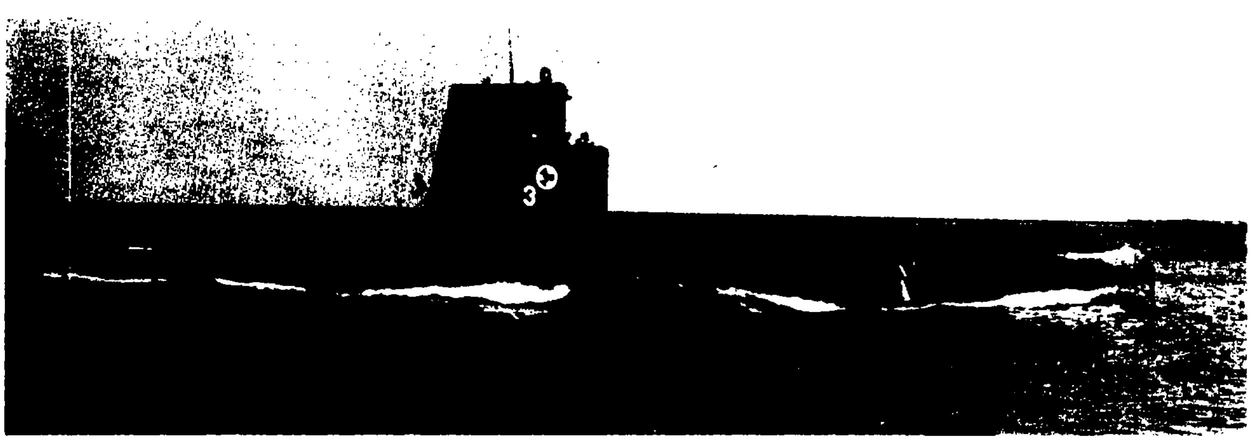


CSS H. L. HUNLEY

Advantages of Naval Nuclear Power

SUBMARINES: Before the advent of nuclear power, the submarine was, in reality, a small surface ship that could submerge for only short periods of time. The earliest versions of the submarine, Bushnell's Turtle (circa 1775) and the Confederate CSS H. L. HUNLEY (circa 1864), were propelled by human effort and were limited by human endurance and the amount of oxygen within the vessel upon submergence. Later versions of the submarine required oxygen and fossil fuel to operate engines which required drawing air and exhausting combustion products. This required the submarine either to be on the surface or close enough to the surface to use a snorkel, which made the ship susceptible to detection. To avoid detection, the ship had to submerge and rely on electric batteries, which depleted within several hours. The ship would then have to surface or snorkel again to start the diesel and recharge the batteries.

While diesel submarines can also be quiet when submerged on batteries, they have very limited endurance and power. There are also other forms of air independent propulsion for submarines which would allow a submarine to be submerged for weeks at a time if it remains at very low speeds. However, because of the large amount of oxygen that must be stored on board, these propulsion systems are insufficient for warships contributing to global maritime influence.



Diesel Submarine USS BARRACUDA (SST 3)

By eliminating the need for oxygen for propulsion, nuclear power offers a way to drive a submerged submarine at high speeds without concern for fuel consumption, to operate fully capable sensors and weapons systems during extended deployments, and to support a safe and comfortable living environment for the crew. Only a nuclear-powered submarine can operate anywhere in the world's oceans, including under the polar ice, undetected and at maximum capability for extended periods. Further, nuclear power provides endurance at high speeds, allowing strategic changes of missions from one location to another.

USS PINTADO (SSN 672) at the North Pole

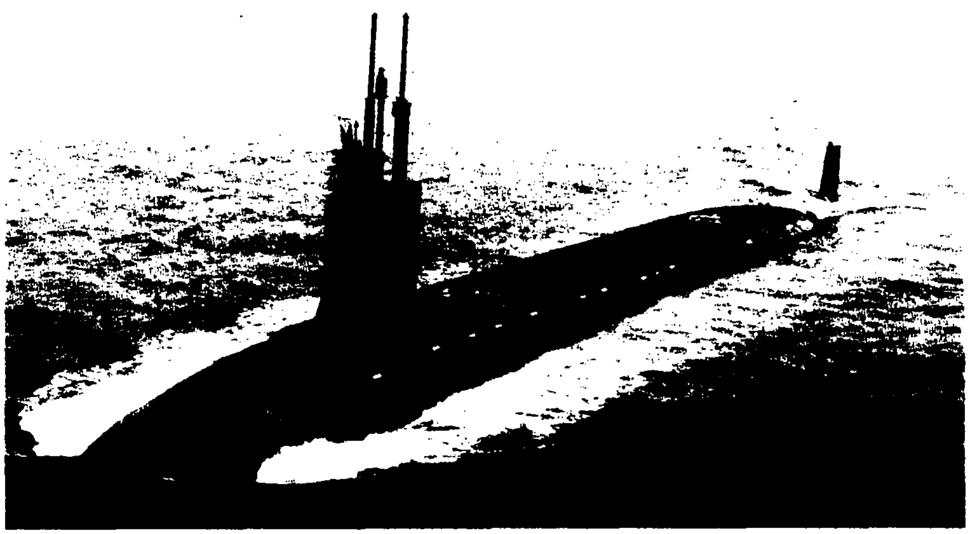
AIRCRAFT CARRIERS: With high-speed endurance to provide strategic flexibility, speed and responsiveness to provide tactical flexibility, and mobility while on station, nuclear-powered aircraft carriers can respond to crises more quickly, arrive in a higher condition of readiness, and stay on station longer with less logistics support than their fossil-fueled counterparts. Nuclear propulsion in aircraft carriers greatly enhances their military capability. Mobility and security of fuel supplies are among a fleet commander's greatest concerns. Nuclear propulsion dramatically reduces these concerns by providing the ship virtually unlimited high-speed propulsion endurance without dependence on fossil-fuel tankers or their escorts. Moreover, the compact, energy-dense nature of a nuclear propulsion plant eliminates large volume tankage requirements for propulsion fuel and reduces space devoted to combustion air and exhaust. This permits increased storage capacity for combat consumables (weapons, aircraft fuel, stores), which improves sustainability and reduces underway replenishment requirements.

Today's Mission

The Naval Nuclear Propulsion Program exists to provide the United States with the most capable warships in the world.

Nuclear-powered Submarines

Since USS NAUTILUS, successive classes of ever more capable U.S. *attack submarines* (SSN) have ensured a warfighting edge over any potential adversary. Attack submarines, forward-deployed, alone and unsupported or with strike groups, can exert influence throughout the world – protecting vital commercial sea lanes, providing protection for aircraft carrier and expeditionary strike groups, and creating tactical uncertainty for an enemy who must tie up fleet units in defensive roles. These submarines operate virtually undetected in all the world's oceans, even under the ice of the Arctic Ocean. Cruise missiles launched from an unseen, submerged submarine can reach targets deep inland. Perhaps most importantly, nuclear-powered submarines guarantee *access* – access to hostile areas for intelligence gathering, as well as "clearing the way" to ensure access for other U.S. Naval forces. With fewer bases overseas and decreasing fleet assets, these warships represent a stealthy, far-reaching force that will be called upon to shoulder a large part of the defense burden, even in low-intensity conflicts. Nuclear-powered submarines provide real-time, actionable intelligence to Combatant Commanders, and can quickly strike with precision or deploy special forces. Simply put, no other platform has the unmatched stealth, endurance, and mobility, or the mix of capabilities that a U.S. nuclear-powered submarine brings to the fight.



VIRGINIA (SSN 774) Returning to Electric Boat Following Successful Completion of Alpha Sea Trials

Today's active attack submarine fleet consists of 49 LOS ANGELES Class submarines, 3 SEAWOLF Class submarines, and 1 VIRGINIA Class submarine.

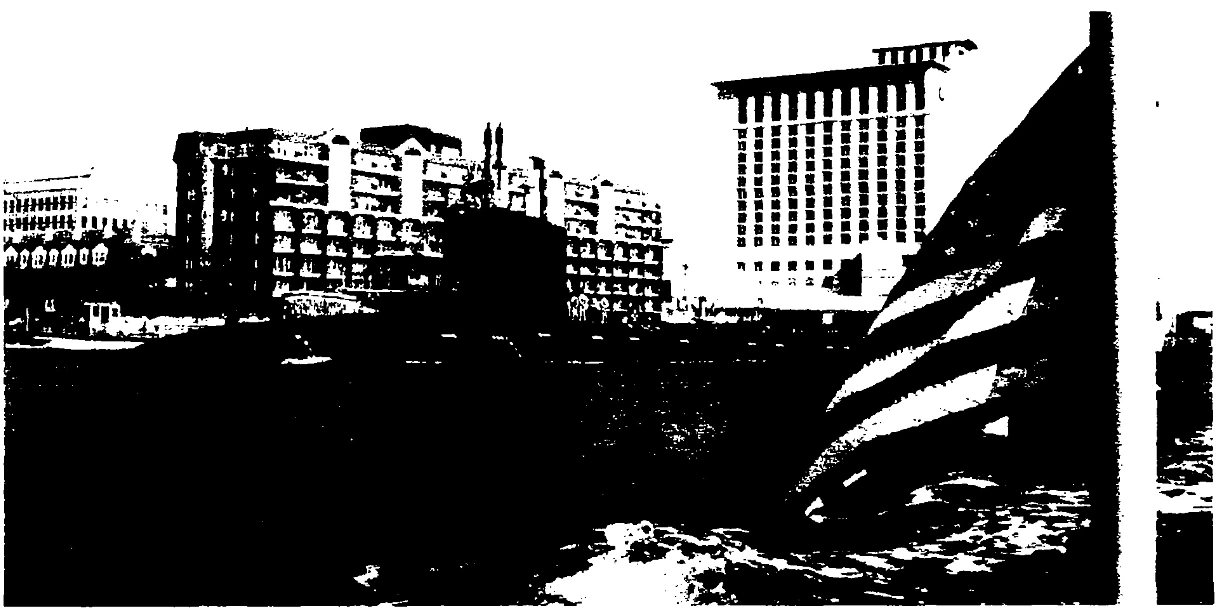
The VIRGINIA Class is the planned replacement for the LOS ANGELES Class, whose earliest boats were commissioned in the 1970s. The lead ship of the VIRGINIA

Class, USS VIRGINIA (SSN 774), was commissioned on October 23, 2004. VIRGINIA is the first major combatant delivered to the Navy designed with the post-Cold War security environment in mind, and is uniquely suited for dominance in both shallow and deep waters. VIRGINIA Class submarines can carry out a variety of missions in shallow water near land, from anti-submarine warfare to precision strike, covert intelligence gathering, minefield mapping and mine delivery, and Special Operations Force (SOF) delivery. These submarines have many innovations, such as an integrated command, control, communications, and intelligence (C3I) system, non hull-penetrating photonics masts, and a reconfigurable torpedo room to accommodate a large number of SOF personnel. VIRGINIA Class submarines are equipped with a nine-man lockout chamber and may be equipped with Advanced Seal Delivery System (ASDS) or Dry Deck Shelter (DDS) for SOF support.

The number of countries that are seeking or have obtained diesel, Air Independent Propulsion (AIP), and nuclear-powered submarines is an increasing concern to national security and the military balance in critical regions of the world. The superior stealth, mobility, endurance, and firepower of our nuclear-powered attack submarines will enable the United States to successfully combat these threats, whether in deep water or in the shallows.

The VIRGINIA Class has a reactor plant that is designed to last the entire planned 33-year life of the ship without refueling. This will help to reduce life-cycle cost while increasing the time the ship is available to perform missions. Naval Reactors is working on an advanced Transformational Technology Core to provide even greater energy to support demands for increased submarine operations.

The VIRGINIA Class's modular design allows each ship the flexibility to support future technology upgrades and advanced payloads. This flexibility will ensure that these submarines will maintain warfighting superiority over any adversary well into the 21st century.

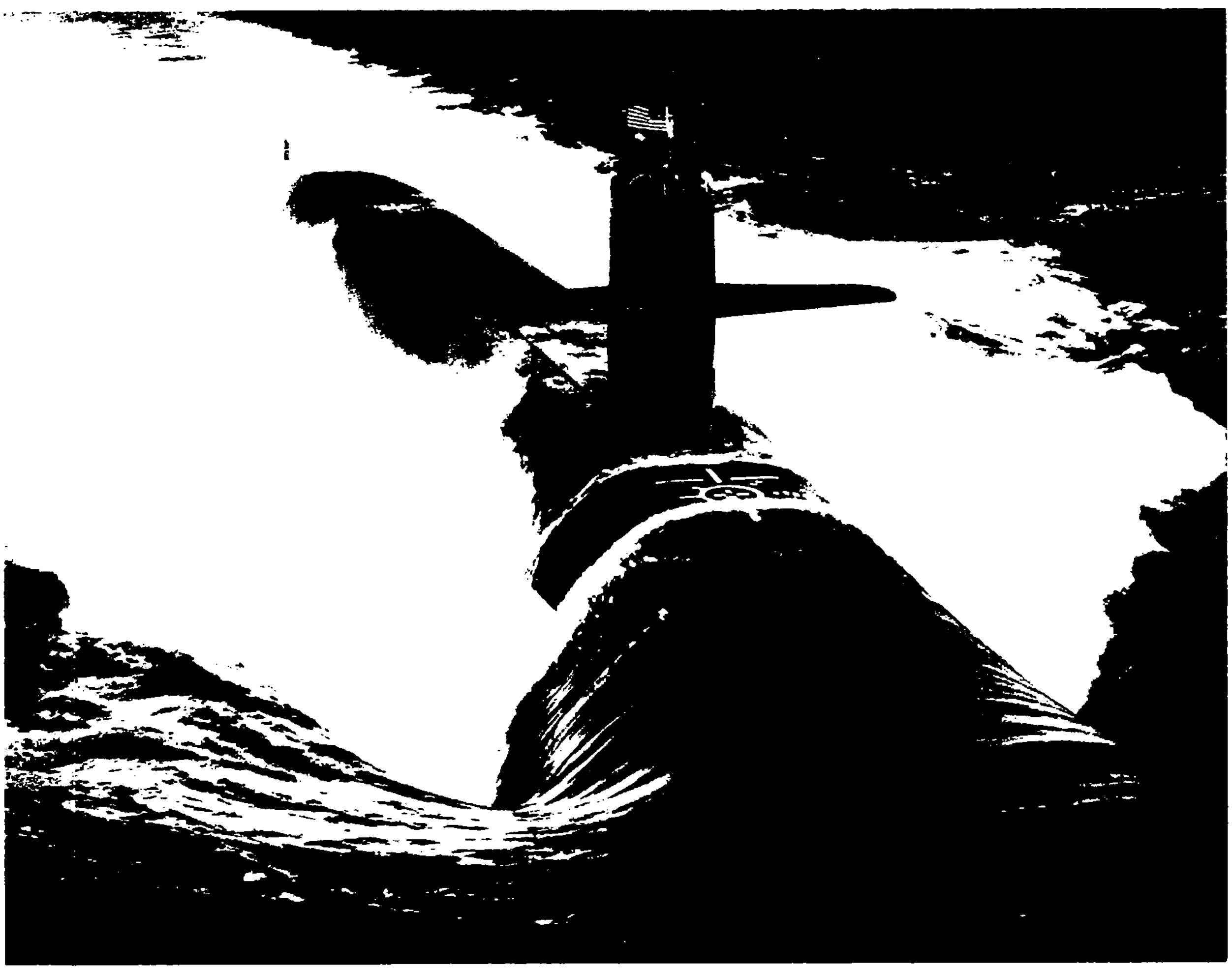


VIRGINIA (SSN 774) Passes the Skyline of Portsmouth, Virginia, on Its Way to Norfolk Naval Shipyard Following Successful Completion of Bravo Sea Trials, August 25, 2004

People ask, "How fast can you go? How deep can you go?" ...That war is over, and we won. So this war is about how slow can you go? How well can you control your submarine? Can you control it to a foot? Can you control it to an inch? This submarine is built for that.

CAPT David J. Kern
Commanding Officer, USS VIRGINIA (SSN 774)
October 2004

For over three decades, U.S. *ballistic missile submarines* (SSBN) have provided strategic deterrence. These warships are virtually undetectable while submerged, forming the least vulnerable component of the U.S. strategic deterrent. This force is comprised of 14 OHIO Class Ballistic Missile submarines, each capable of carrying 24 TRIDENT missiles. At 560 feet in length and 18,700 tons displacement, the TRIDENT is the largest U.S. nuclear-powered submarine.



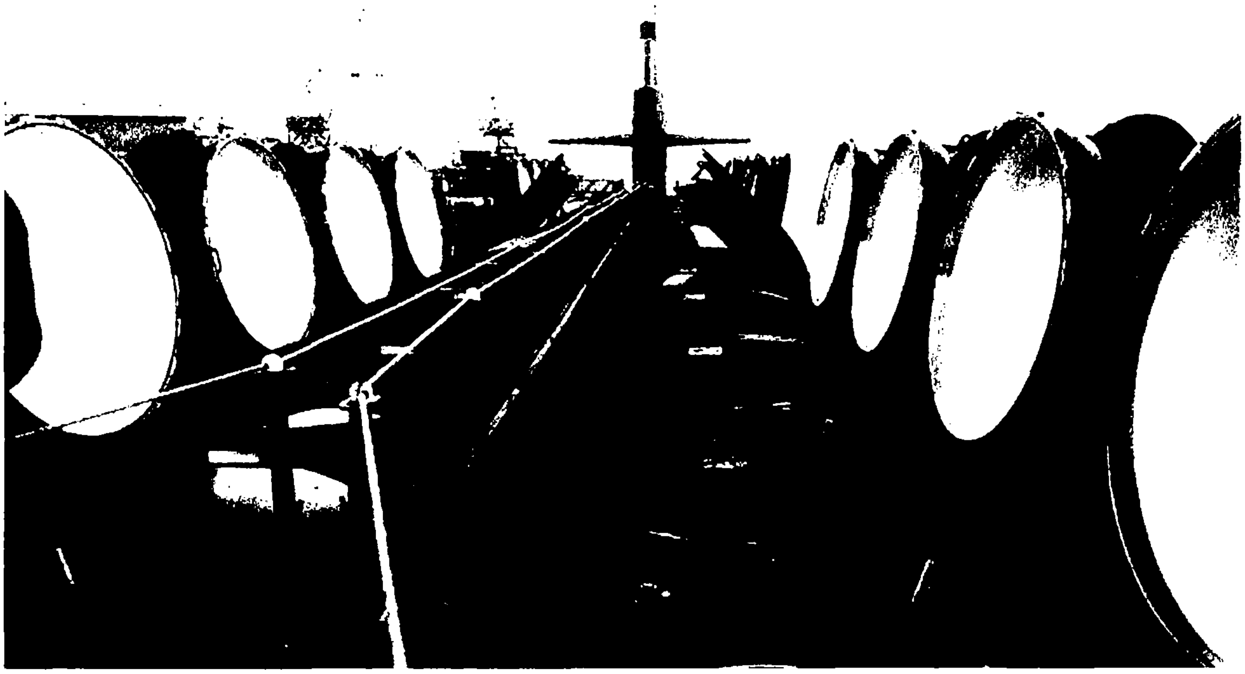
USS ALABAMA (SSBN 731)

Four ballistic missile submarines (SSBN) which are no longer needed to perform their strategic deterrence mission are being converted into *guided missile submarines* (SSGN). Each of an SSBN's twenty-four missile tubes has an inside diameter of over seven feet and can be converted to launch multiple Tomahawk guided missiles or deploy any of a number of large payloads, such as unmanned underwater vehicles (UUVs) and special sensors.

Each SSGN will be able to covertly enter a battle space carrying unconventional payloads and up to 154 guided missiles, plus a large number of Special Operations Forces personnel. This will provide battlefield commanders with more surprise strike options, clandestine information gathering methods, and communication pathways. By fulfilling these missions, the SSGNs will help free up other Navy ships and submarines to pursue other critical missions.

In January 2003, USS FLORIDA (SSGN 728) successfully demonstrated the feasibility of these revolutionary capabilities in an exercise involving Special Operations Forces, UUVs, and connectivity to aerial sensors, in addition to the SSGN's own tremendous firepower. In October 2004, a second exercise further explored the capabilities of the SSGN. In this exercise, USS GEORGIA (SSGN 729) served as the command and control center for a clandestine operation involving a network of Special Operations Forces sea-based in an SSGN and aided by advanced unmanned systems.

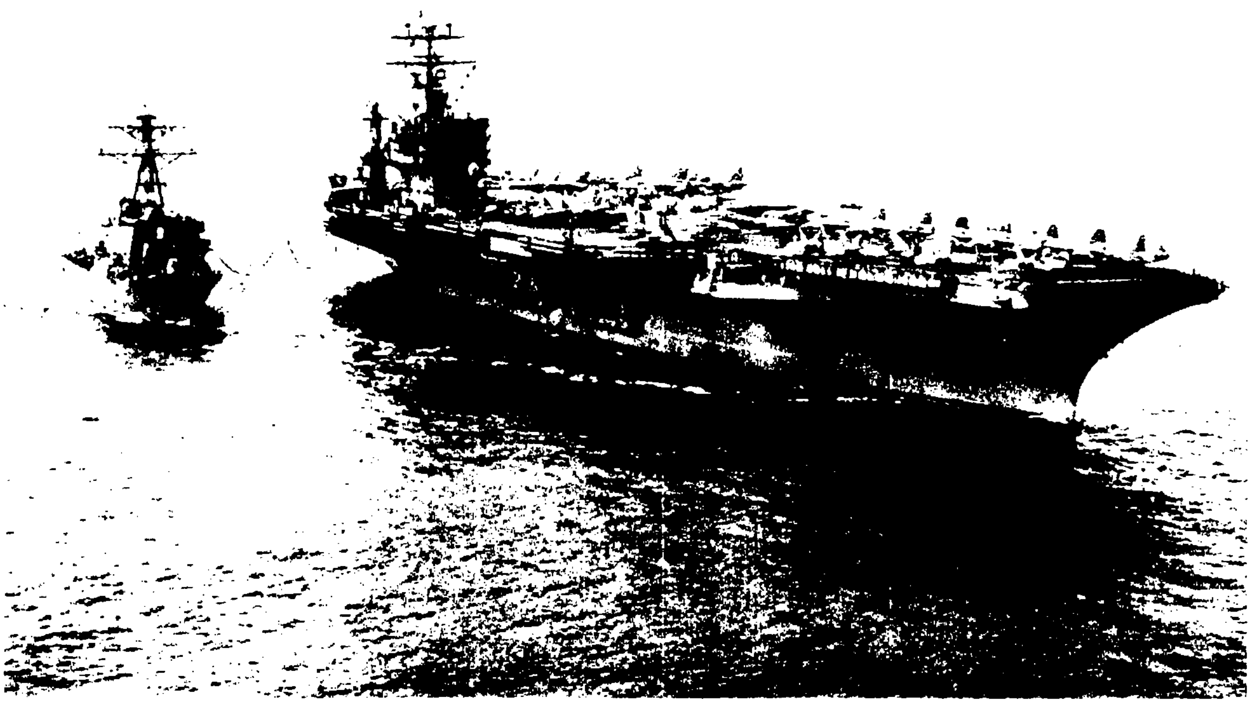
In November 2005, USS OHIO (SSGN 726) completed overhaul and conversion to an SSGN and returned to the fleet. The remaining three SSGNs are on schedule for delivery over the next two years.



USS OHIO (SSGN 726) with Its Missile Doors Open.
OHIO is One of the Four SSBNs Undergoing Conversion to SSGN.

Nuclear-powered Aircraft Carriers

"Where are the aircraft carriers?" is often one of the first questions asked by the President in times of crisis around the world. Each aircraft carrier provides the Nation four and one-half acres of highly mobile sovereign territory, unconstrained by local host nation considerations, from which to project flexible, rapid, visible, and credible American military power when needed to keep the peace, deter conflicts, protect American interests, or fight a war. Nuclear-powered aircraft carriers can transit to the scene without the logistics support needed for fossil-fueled aircraft carriers at sustained high speed and arrive fully ready to launch the awesome firepower of the air wing. They can then sustain that presence and response without immediate replenishment of combat consumables, with tactical mobility and flexibility free from the need for propulsion fuel replenishment. Nuclear-powered aircraft carriers have greater capacity for aviation fuel storage to sustain protracted flight operations, as well as to replenish the propulsion fuel requirements of their fossil-fueled escorts, as the logistics situation dictates.

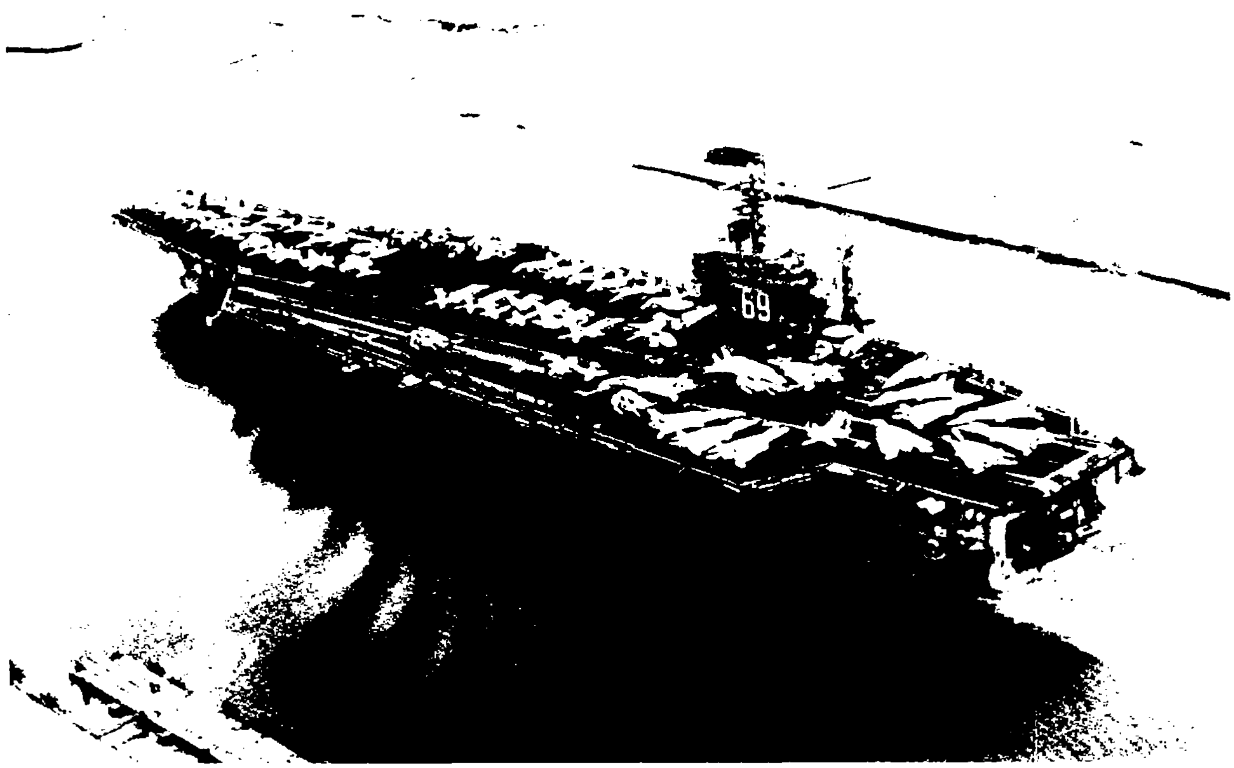


USS CARL VINSON (CVN 70) Refuels USS O'KANE (DDG 77)

> *Over the last half-century, Naval nuclear reactors have steamed over 110 million miles with an unmatched, absolutely flawless record of safety and performance. Today, nuclear-powered aircraft carriers reign as the centerpiece of America's strategy of forward presence, and nuclear-powered submarines remain a crown jewel of our nation's defense arsenal.*
>
> General Henry Shelton
> Chairman of the Joint Chiefs of Staff
> On the Program's 50th Anniversary, August 1998

Since 1967, when Congress authorized construction of USS NIMITZ (CVN 68), the nation has moved toward an all nuclear-powered aircraft carrier force. Today's nuclear-powered aircraft carrier fleet consists of USS ENTERPRISE (CVN 65), the first nuclear-powered aircraft carrier, and will include 10 NIMITZ Class aircraft carriers with the GEORGE H. W. BUSH (CVN 77) currently under construction, the largest warships of any Navy in the world. Nuclear propulsion provides unique tactical mobility and flexibility, responsiveness, and sustainability – key attributes in sustaining the ability of our aircraft carrier force to meet the demands of forward presence and crisis response in an era of shrinking resources. Thousands of airstrikes in Operations ENDURING FREEDOM and IRAQI FREEDOM were flown from nuclear-powered aircraft carriers, hitting targets far inland. GEORGE H. W. BUSH will serve as a transition ship from the NIMITZ Class to the new CVN 21 aircraft carrier design, and will feature new propulsion plant improvements.

CVN 21 represents the convergence of two paths: continuing to provide for current missions while transforming to meet future needs. Significant immediate advances in warfighting capabilities and transformational technologies – embodied in the nearly tripling of electrical power and in increased core energy, coupled with the manpower and cost savings planned for this class – make development of the CVN 21 Class a critical investment and enabler for 21st century capability. In addition to the integrated combat system, CVN 21 will incorporate an electromagnetic aircraft launching system (EMALS), and a new nuclear propulsion and electric plant. The CVN 21 nuclear propulsion plant will provide increased operational availability, enhanced survivability, improved reliability, a higher quality of life for the crew, greatly reduced acquisition and life-cycle costs, and tremendously improved flexibility for incorporation of warfighting technology envisioned for future ships.

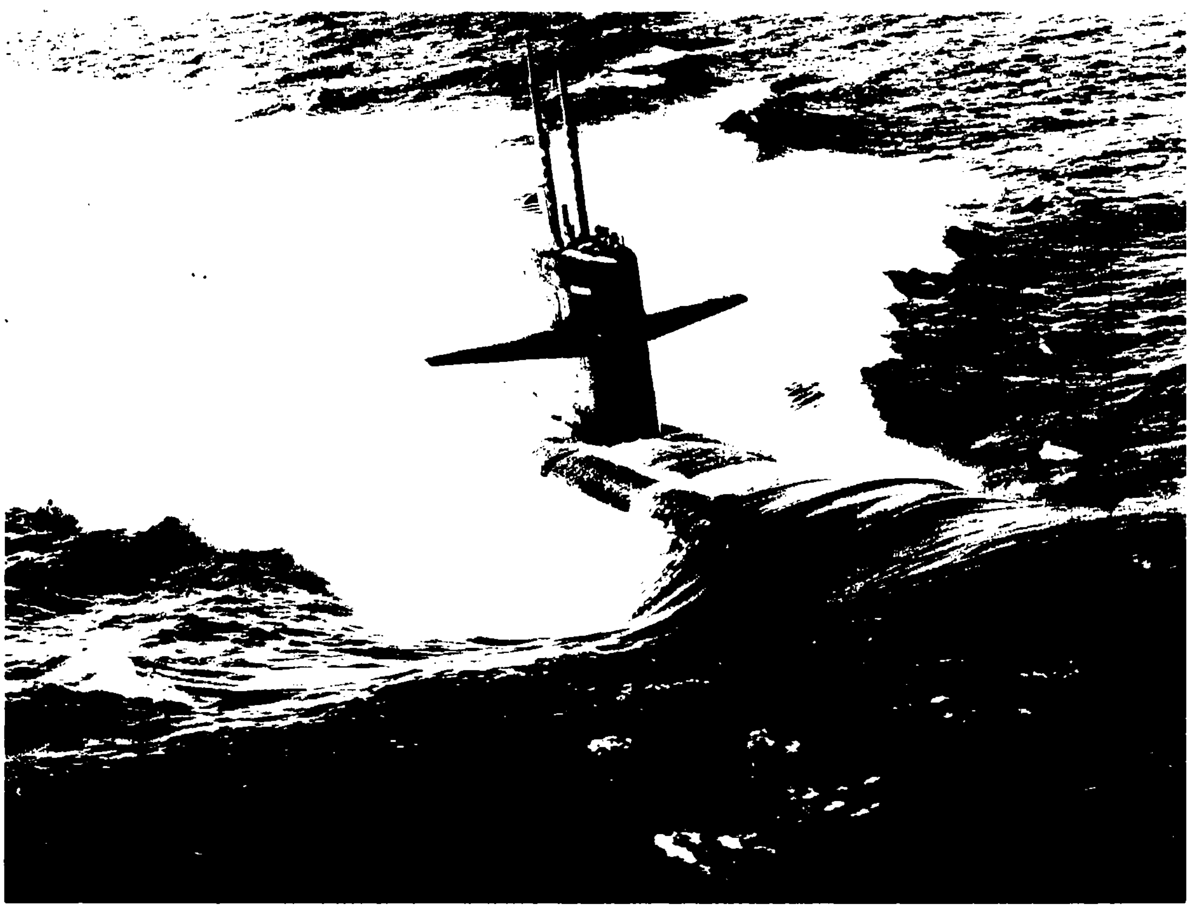


USS DWIGHT D. EISENHOWER (CVN 69) Transiting the Suez Canal

What Is the Naval Nuclear Propulsion Program?

The Naval Nuclear Propulsion Program is comprised of military personnel and civilians who design, build, operate, maintain, and manage the nuclear-powered ships and the many facilities which support the U.S. nuclear-powered Naval fleet. The Program has a broad mandate, maintaining responsibility for nuclear propulsion from cradle to grave. Program responsibilities are delineated in Presidential Executive Order 12344 of February 1, 1982, and prescribed by Public Laws 98-525 of October 19, 1984 (42 USC 7158) and 106-65 of October 5, 1999 (50 USC 2406). Program elements include:

- Research, development, and support laboratories;
- Contractors responsible for the design, procurement, and construction of propulsion plant equipment;
- Shipyards that construct, overhaul, and service the propulsion plants of nuclear-powered vessels;
- Navy support facilities and tenders;
- Nuclear power schools and Naval Reactors training facilities; and
- The Naval Nuclear Propulsion Program Headquarters organization and field offices.



USS NEWPORT NEWS (SSN 750) on Sea Trials

Research, Development, and Support Laboratories

The Government-owned, contractor-operated Bettis and Knolls Atomic Power Laboratories are research and engineering facilities devoted solely to Naval nuclear propulsion work. With combined staffs of over 5,500 engineers, scientists, technicians, and support personnel, their mission is to develop the most advanced Naval nuclear propulsion technology and to provide technical support for the continued safe, reliable operation of all existing Naval reactors. Knolls Atomic Power Laboratory (KAPL) operates prototype nuclear propulsion plants in New York for the operational testing of new designs and promising new technologies under typical operating conditions prior to introduction into the fleet. Both Bettis and KAPL offer post-graduate research opportunities through the Naval Nuclear Propulsion Fellowship Program.†

The Government-owned, contractor-operated Naval Reactors Facility (NRF), located within the Idaho National Laboratory (INL), examines Naval spent nuclear fuel and irradiated test specimens. The information derived from these examinations is used to develop new technology and to improve the cost-effectiveness of existing designs.

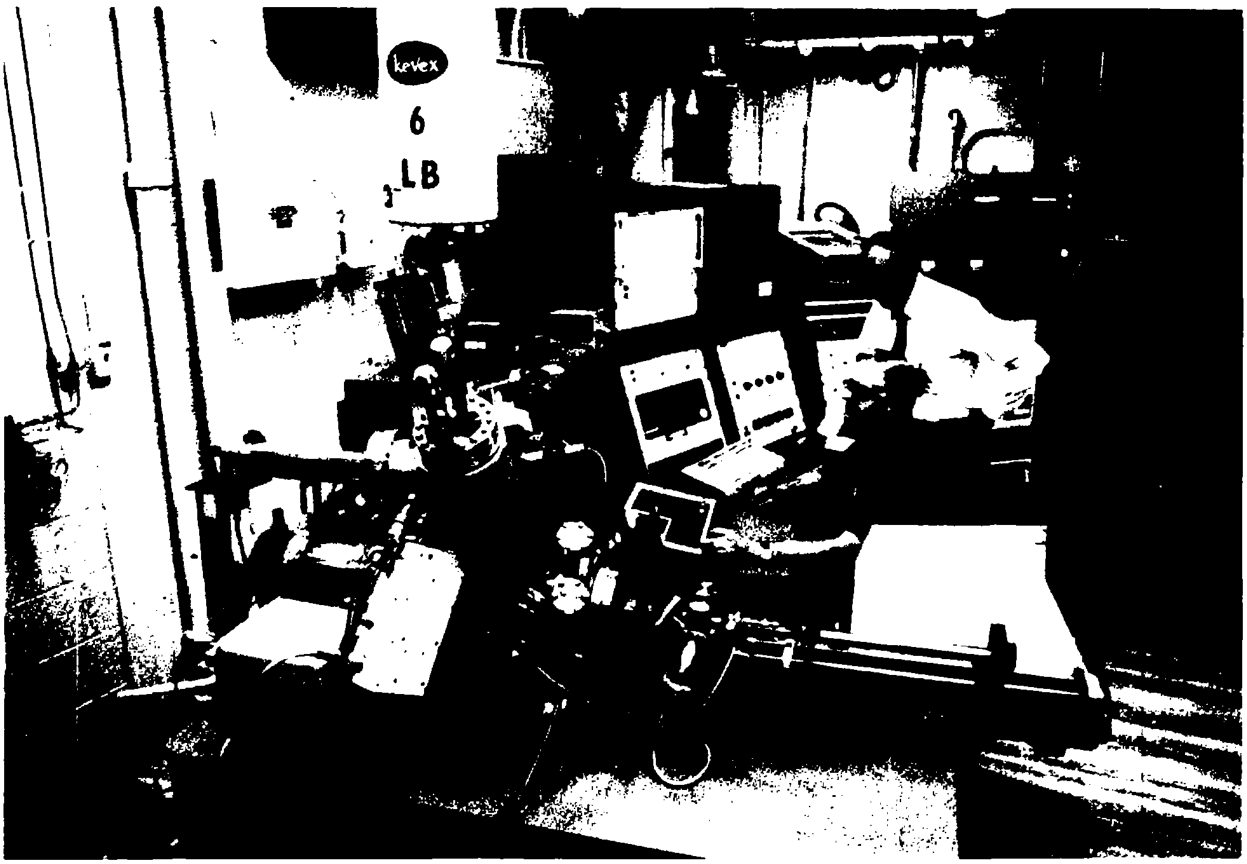
The combined efforts of the Naval Nuclear Propulsion Program's research, development, and support laboratories have led to tremendous advances in Naval reactor technology. For example, the first submarine core endurance was about 62,000 miles; today, submarine and aircraft carrier cores have an endurance of over 1,000,000 miles.

Spectrometer Examination

†For more information, write to: NNP Fellowship Program, Medical University of South Carolina, Special Programs Office, 159½ Rutledge Ave. – 2nd floor, P.O. Box 250218, Charleston, SC 29425.

Nuclear Component Procurement Organization

Since the late 1950s, the Naval Nuclear Propulsion Program has had dedicated prime contractor support to provide engineering, procurement, and technical oversight of Naval nuclear components. Currently, the prime contractor is Bechtel Plant Machinery, Inc. (BPMI), with locations in Pittsburgh, PA and Schenectady, NY. BPMI is involved in the design, purchasing, quality control, and delivery of major propulsion plant components for installation in nuclear-powered aircraft carriers, submarines, and prototype plants.



Electron Microprobe Scanning

Nuclear Equipment Suppliers

Multiple privately owned companies throughout the United States perform the actual design and fabrication of the major propulsion plant components. Manufacturing the heavy components used in Naval reactors requires four to five years of precision machining, welding, grinding, heat treatment, and nondestructive testing of large specialty metal forgings, under carefully controlled conditions. Standards for Naval applications are far more rigorous and stringent than those required for civilian nuclear reactors, since components on warships must be designed and built to accommodate battle shock, radiated noise limits, crew proximity to the reactor, and frequent, rapid changes in reactor power. Many of these equipment manufacturers have been contributing to the Program for several decades.

USS MICHIGAN (SSGN 727) Undergoing Testing in Dry Dock at Electric Boat

Shipyards

Two private shipyards build all of our nuclear-powered ships. These two shipyards, together with four public shipyards, provide the nation's capability to overhaul, repair, refuel, and inactivate nuclear-powered ships. These complicated tasks require an experienced and skilled work force specifically trained to do Naval nuclear propulsion work. With approximately 50,000 employees, these public and private facilities are unique industrial assets with capabilities found nowhere else in America.

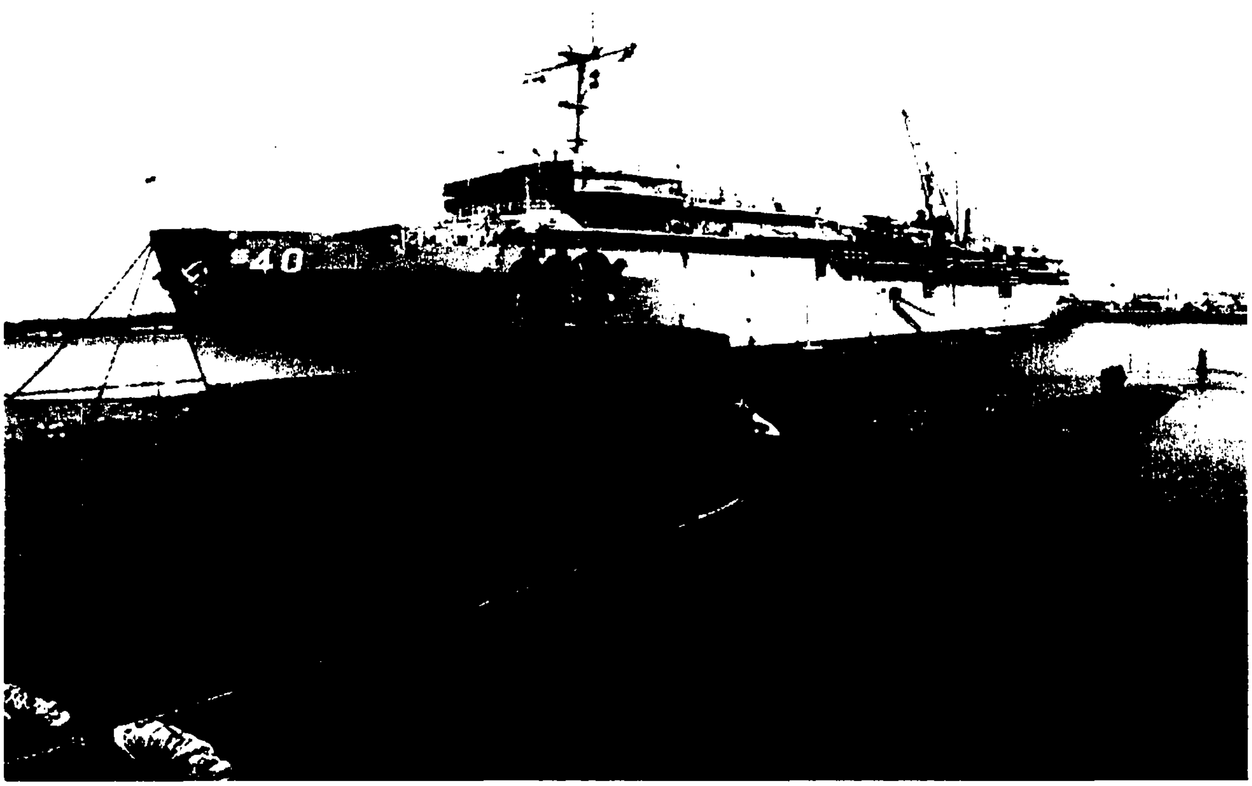
Shipyard	Sector	Location
Electric Boat	Private	Groton, CT
Norfolk Naval Shipyard	Public	Portsmouth, VA
Northrop Grumman Newport News	Private	Newport News, VA
Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility	Public	Pearl Harbor, HI
Portsmouth Naval Shipyard	Public	Kittery, ME
Puget Sound Naval Shipyard and Intermediate Maintenance Facility	Public	Bremerton, WA

It is a pleasure to note once again that personnel with the Naval Reactors' program continue to exhibit extraordinary standards in the performance of their work. Naval Reactors consistently maintains a model program for the design, construction, operation, and decommissioning of nuclear-powered vessels. The Board congratulates you for your sustained superior performance.

John T. Conway
Chairman, Defense Nuclear Facilities Safety Board
September 2003

Support Facilities and Tenders

Fleet Intermediate Maintenance Activities (deployed tenders and support facilities at major bases) perform maintenance and repair on nuclear-powered ships outside of major shipyard availability periods. Staffed by specially trained personnel, these facilities provide upkeep and resupply support for the fleet. The tenders are themselves sea-going military vessels which routinely perform their missions while deployed all over the world. Thus, the ability of the nuclear-powered fleet to remain on station is further enhanced by our ability to forward-deploy repair and maintenance activities.

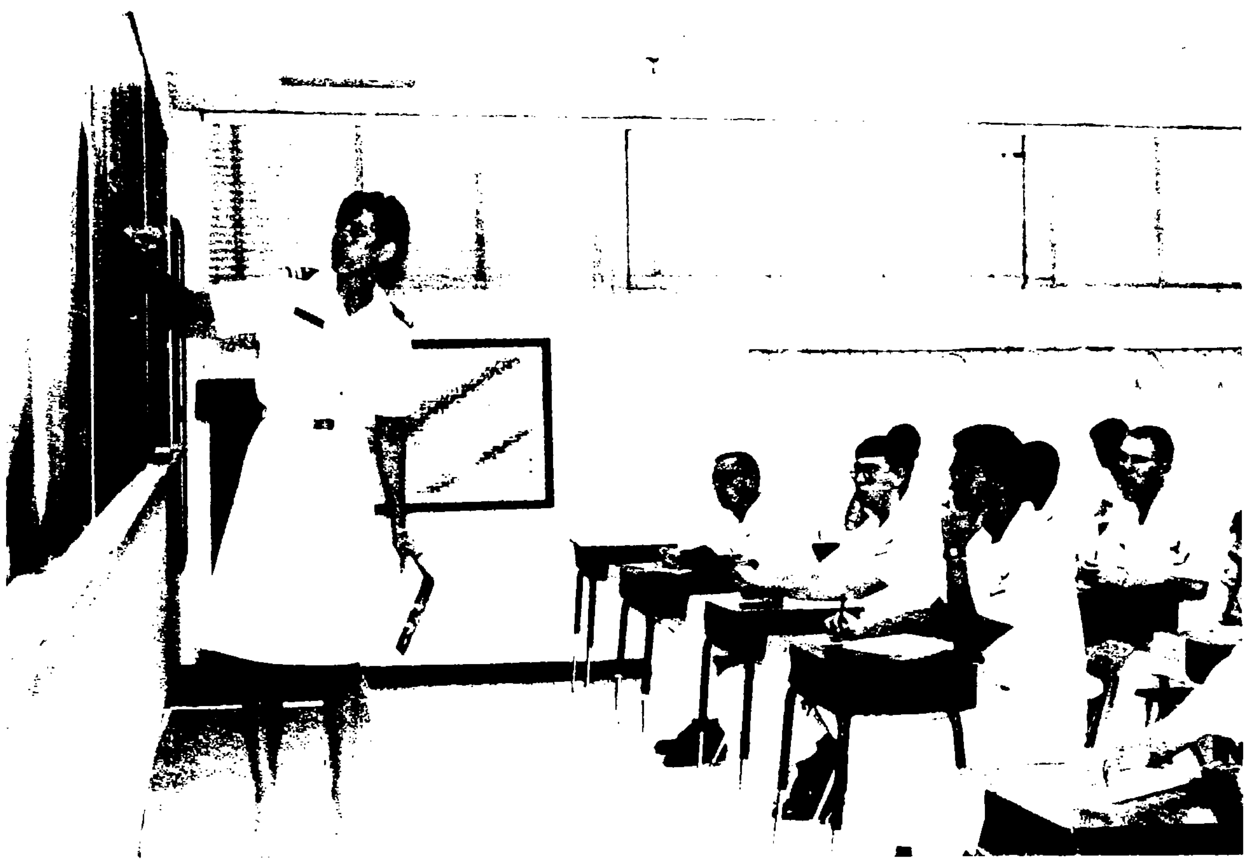


USS SALT LAKE CITY (SSN 716) Pulls Alongside the Submarine Tender USS FRANK CABLE (AS 40) in Apra Harbor, Guam

Schools and Training Facilities

The unique training requirements of the Naval Nuclear Propulsion Program are met by special purpose training facilities staffed by highly qualified instructors. These facilities include the Nuclear Field "A" School and Nuclear Power School in Charleston, South Carolina; and Moored Training Ships and land-based prototypes which provide hands-on training and ensure that prior to their first sea tour, every operator has qualified on an operating Naval nuclear propulsion plant.

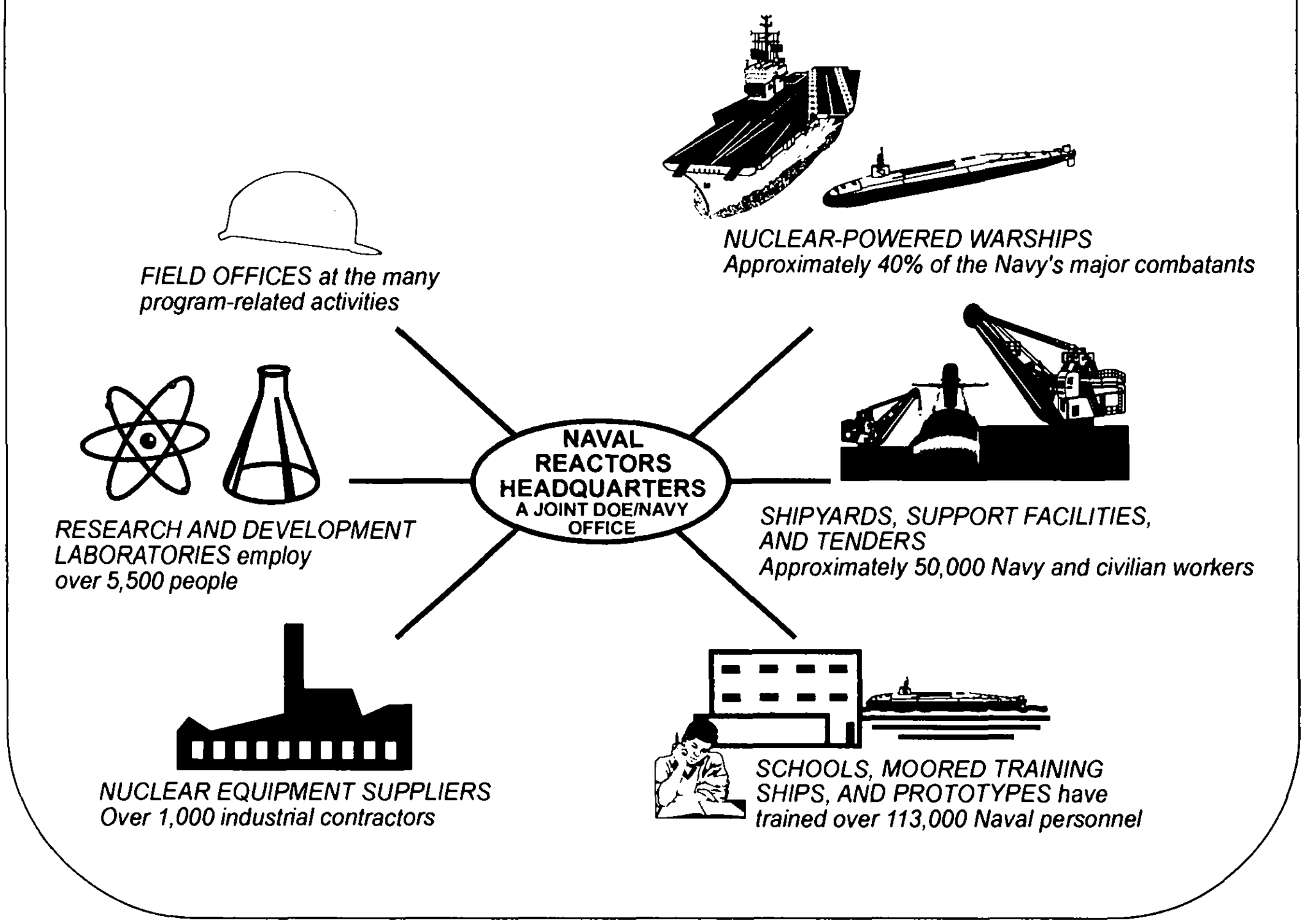
With the repeal of the Combat Exclusion Law in the 1994 Defense Authorization Act and the Navy decision to open combatant ships to women, the Program began accepting women into the training pipeline to be propulsion plant operators aboard nuclear-powered surface combatants. Female officer and enlisted personnel are now integral to the successful operation of these ships and their support organizations.



Enlisted Nuclear Power School Classroom

NAVAL NUCLEAR PROPULSION PROGRAM

Responsible for the research, design, development, operation, testing, maintenance, and disposal of Naval nuclear propulsion plants



Headquarters

Naval Nuclear Propulsion Program Headquarters provides oversight and direction for all elements of the Program. Because of the critical nature of nuclear technology, all major technical decisions regarding design, procurement, operations, maintenance, training, and logistics are made by a dedicated Government headquarters professional staff expert in nuclear technology. Headquarters engineers set standards and specifications for all Naval Nuclear Propulsion Program work, while on-site headquarters representatives monitor the work at the laboratories, prototypes, shipyards, and prime contractors.

Based on over five decades of engineering experience in nuclear propulsion, the headquarters organization exercises exacting control over all aspects of the Program, demanding technical excellence and discipline unique among nuclear programs.

Establishment of the Program

In 1946, at the conclusion of World War II, Congress passed the Atomic Energy Act, which established the Atomic Energy Commission (AEC) to succeed the wartime Manhattan Project, and gave it sole responsibility for developing atomic energy. At this time, Captain Hyman G. Rickover was assigned to the Navy Bureau of Ships, the organization responsible for ship design. Captain Rickover recognized the military implications of successfully harnessing atomic power for submarine propulsion and that it would be necessary for the Navy to work with the AEC to develop such a program. He and several officers and civilians were sent to the AEC laboratory at Oak Ridge, Tennessee, for one year to learn the fundamentals of nuclear reactor technology.

Although the concept of using a reactor to produce heat was understood, the technology to build and operate a shipboard nuclear propulsion plant did not exist. Though there were several reactor concepts, the real challenge was to develop the technology and transform theory into practical engineering. New materials had to be developed, components designed, and fabrication techniques worked out. Further, installing and operating a steam propulsion plant inside the confines of a submarine and under the unique deep-sea pressure conditions raised a number of technical difficulties. With these obstacles, the team at Oak Ridge knew that to build a Naval nuclear propulsion plant would require substantial commitment of resources and a new level of government and industry commitment.

Captain Rickover returned to Washington and used every opportunity from his post at the Bureau of Ships to argue the need to establish a Naval Nuclear Propulsion Program. Since there were many unknowns, he recommended undertaking two parallel reactor development projects: a pressurized-water cooled reactor and a liquid-metal cooled reactor. On August 4, 1948, the Navy created the new Nuclear Power Branch (Code 390) with Rickover as its head within the Bureau's Research Division.

By 1949, Captain Rickover had forged an arrangement between the AEC and the Navy under which he would proceed with both projects. In 1949, Rickover's new organization contracted with Westinghouse to develop a facility (the Bettis Atomic Power Laboratory) to work on the pressurized-water design. In 1950, he contracted with General Electric to determine whether a liquid-metal reactor design, which it was developing at the AEC's Knolls Atomic Power Laboratory, could be applied to Naval propulsion.

Captain Rickover recruited a strong technical staff from those who studied at Oak Ridge, others from past service in the Navy, and top young nuclear engineers right out of college. This core of engineers and Naval officers oversaw every aspect of the development of nuclear propulsion, including full-sized prototypes of submarine nuclear propulsion plants.

USS NAUTILUS, using the pressurized-water design, and USS SEAWOLF, using the liquid-metal design, were built, tested, commissioned, and put to sea in 1955 and 1957, respectively. While SEAWOLF successfully operated at sea until her first refueling, experience demonstrated that pressurized-water technology was preferable for Naval applications. It thus became the basis for all subsequent U.S. nuclear-powered warship designs. In less than seven years, Captain Rickover obtained

Congressional support to develop an industrial base in a new technology; pioneered new materials; designed, built, and operated a prototype reactor; established a training program; and took a nuclear-powered submarine to sea. The success and speed of this development revolutionized naval warfare and has given America undersea and nuclear propulsion superiority ever since.

Admiral Rickover Inspecting USS NAUTILUS (SSN 571)

For more than 34 years, Admiral Rickover headed the Naval Nuclear Propulsion Program. Upon retirement in 1982, he left behind a tradition of technical excellence and an organization staffed by experienced professionals dedicated to designing, building, and operating Naval nuclear propulsion plants safely and in a manner that protects people and the environment – legacies continued by his successors. The result is a fleet of nuclear-powered warships unparalleled in capability and a mature, highly disciplined infrastructure of government and private organizations that continue to build on Admiral Rickover's legacy.

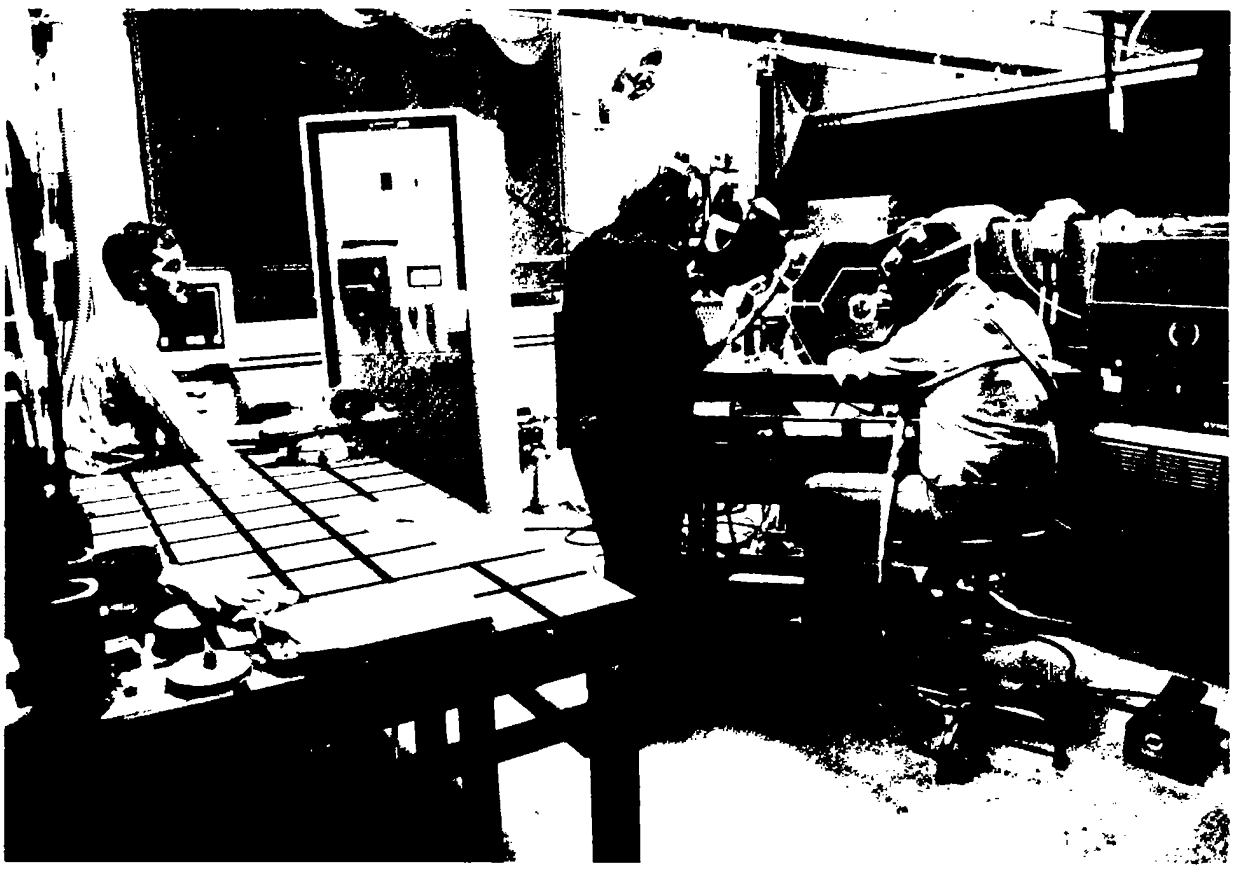
In the 1970s, Government restructuring moved the Naval Nuclear Propulsion Program from the AEC (which was disestablished) to what became the Department of Energy (DOE). In 2000, the Program became a part of the newly formed National Nuclear Security Administration within the DOE. During these transitions, the Program retained its dual agency responsibility and has maintained its basic organization, responsibilities, and technical discipline much as when it was first established.[1]

[1]For a more detailed history of the Naval Nuclear Propulsion Program, see Nuclear Navy, 1946-1962 by Richard G. Hewlett and Francis Duncan, 1974, University of Chicago Press, and Rickover and the Nuclear Navy: The Discipline of Technology by Francis Duncan, 1990, Naval Institute Press. For more information on Admiral Rickover, see Rickover: The Struggle for Excellence by Francis Duncan, 2001, Naval Institute Press.

Technical and Management Philosophy

Naval nuclear propulsion plants must be militarily capable and reliable in combat, as well as safe for the environment, the public, and those who operate and service them.

The Program has stayed at the forefront of technology to improve tactical speed, silencing, and reliability – characteristics that ensure a commanding edge in warfighting. Naval nuclear propulsion plants are rugged enough to sustain battle shock and keep operating; resilient enough to accommodate many years of frequent power changes; and designed to be operated and maintained by a highly trained Navy crew, without on-board scientists and engineers.

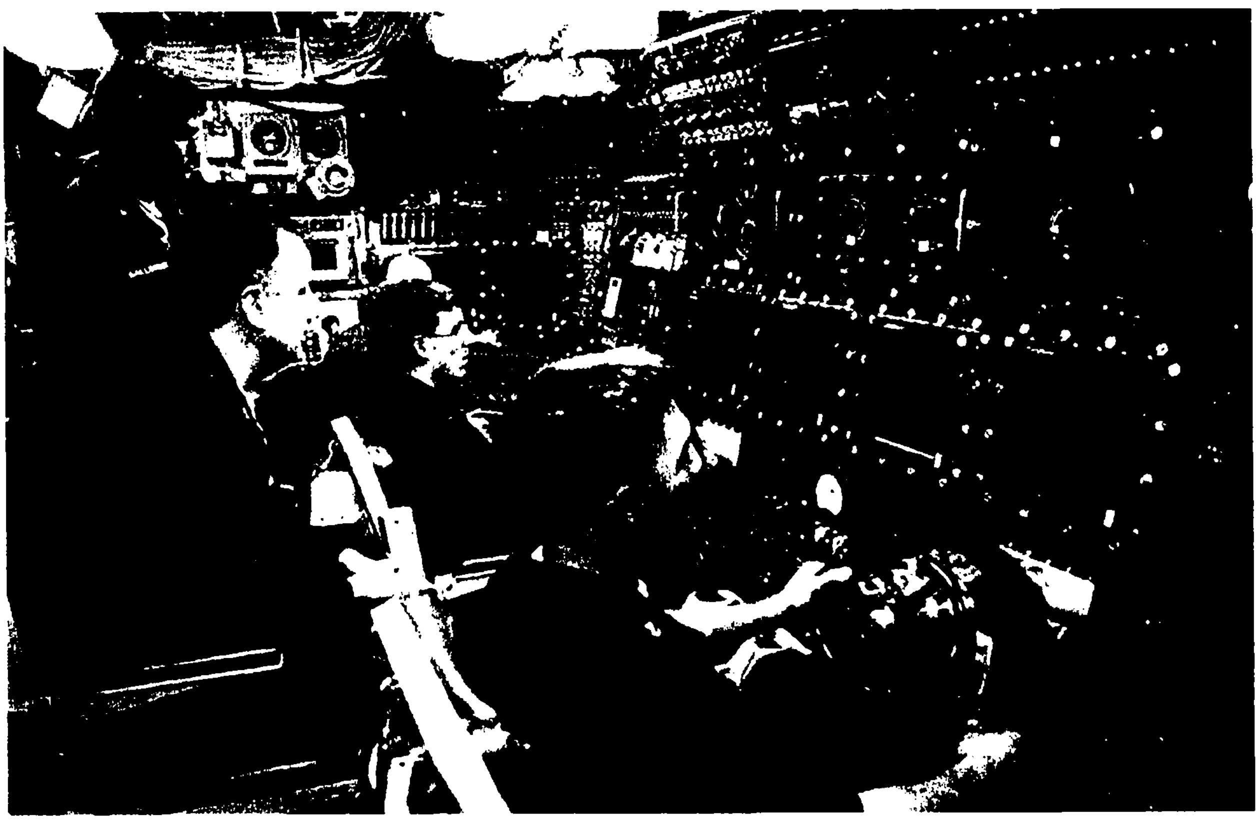


Laboratory Welding

The Program's small and relatively uncomplicated pressurized-water reactors are inherently stable and can respond to operational transients without the need for immediate operator action. Fission products are completely contained within high-integrity fuel elements that can withstand high shock loading. The reactor is so effectively shielded that a typical submarine propulsion plant operator receives less radiation exposure from the reactor during a two-month submerged patrol than he would receive from background radiation on shore in the same period.

The Naval Nuclear Propulsion Program's success is based on strong central technical leadership, thorough training, conservatism in design and operating practices, and an understanding that in every aspect of the Program, excellence must be the norm.[2] In addition, there is a recognition that individuals must accept responsibility for their actions to maintain these standards. Admiral Rickover said it this way:

> *Responsibility is a unique concept: it can only reside and inhere in a single individual. You may share it with others, but your portion is not diminished. You may delegate it, but it is still with you. You may disclaim it, but you cannot divest yourself of it. Even if you do not recognize it or admit its presence, you cannot escape it. If responsibility is rightfully yours, no evasion, or ignorance or passing the blame can shift the burden to someone else. Unless you can point your finger at the person who is responsible when something goes wrong, then you have never had anyone really responsible.*



The Ship's Control Party of USS SEAWOLF (SSN 21)

---

[2]For more on the Naval Nuclear Propulsion Program's technical and management philosophy, see The Rickover Effect by Theodore Rockwell, 1992, Naval Institute Press.

The Training Program

Over 113,000 Nuclear-Trained Sailors

From the inception of the Naval Nuclear Propulsion Program, Admiral Rickover recognized that nuclear propulsion plant operators must know more than simply *what* to do in any given situation, they must understand *why*. Thus, ever since the first crew of USS NAUTILUS reported to the Bettis Atomic Power Laboratory for nuclear training in July 1952, these Sailors have received in-depth technical training, both theoretical training and actual watchstanding experience under instruction. This training has been conducted at many different locations over the years, but the commitment to thorough, detailed understanding of the basics of chemistry, physics, thermodynamics, and plant characteristics has remained its foundation. Currently, the number of Sailors trained and qualified as nuclear propulsion plant operators is over 113,000.

Rickover Circle on the Campus of Naval Nuclear Power Training Command, Charleston, South Carolina, Serves as the Site for the Nuclear Power Training Unit, Charleston, Graduation Ceremony Marking 100,000 Nuclear-trained Sailors, June 1, 2000.

Thorough training minimizes problems, results in quick and efficient responses to emergencies, and helps ensure safety. Prospective plant operators must meet tough selection standards and successfully complete extensive nuclear propulsion training and qualification before reporting to a ship.

After selection for the nuclear propulsion program and completion of basic recruit training, enlisted personnel are assigned to Nuclear Field "A" School in Charleston, South Carolina, for initial in-rate instruction. In addition to a preparatory course in mathematics, each student receives extensive hands-on training in equipment laboratories specially designed to teach required technical skills. The 24-week Nuclear Power School follows, providing basic academic knowledge necessary to understand the theory and operation of a nuclear propulsion plant. The curriculum is presented at the first-year collegiate level and includes thermodynamics, reactor principles, radiological fundamentals, and other specialized subjects.

Rickover Center, Naval Nuclear Power Training Command, Charleston, South Carolina

The maintenance of high standards for the selection, training, and qualification of nuclear personnel is essential. Based on our observations, we conclude that the training of nuclear propulsion plant operators is highly effective.

George E. Apostolakis
Chairman, Advisory Committee on Reactor Safeguards
September 2002

Your rigorous training is a shining example of the pursuit of excellence... This dedication to intensive training...has made our Nuclear Navy the best in the world, bar none...

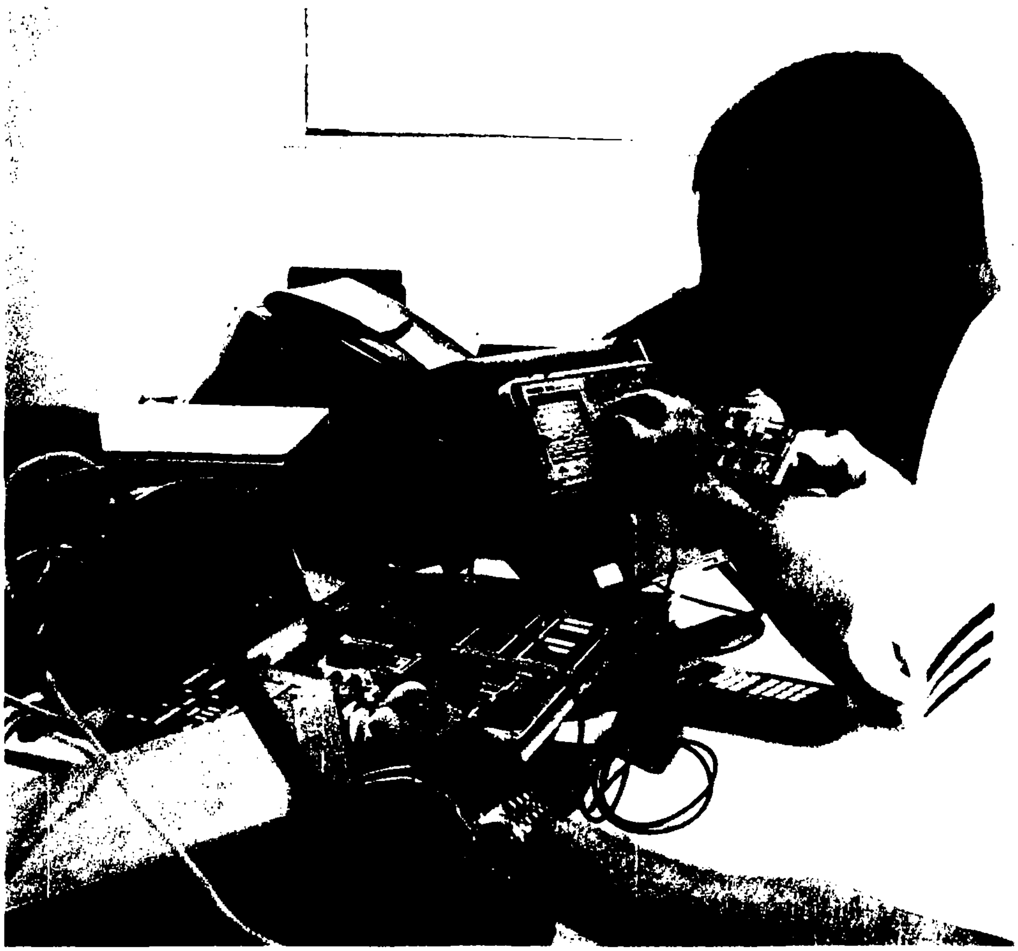
The Honorable John M. Spratt
U.S. Representative, South Carolina
May 2000

For officers, all of whom are college graduates with technical training, the first step is the 24-week graduate-level course at Nuclear Power School. Here, students receive highly technical instruction covering the theoretical background necessary to commence hands-on training on an operating reactor plant. Subjects include those taught in the enlisted curriculum (but in greater depth) as well as additional courses such as electrical engineering and reactor dynamics.

After Nuclear Power School, both officers and enlisted personnel are assigned to one of the Program's prototype propulsion plants or Moored Training Ships for 24 weeks of additional classroom training and actual watchstanding experience under instruction. Each student qualifies as a propulsion plant operator, attaining extensive watchstanding experience and a thorough knowledge of all propulsion plant systems and their operating requirements. Under the guidance of experienced operator instructors, students learn how to operate a Naval nuclear propulsion plant during normal and potential casualty situations. Before reporting to a ship, they must qualify on their watchstation on an operating reactor.

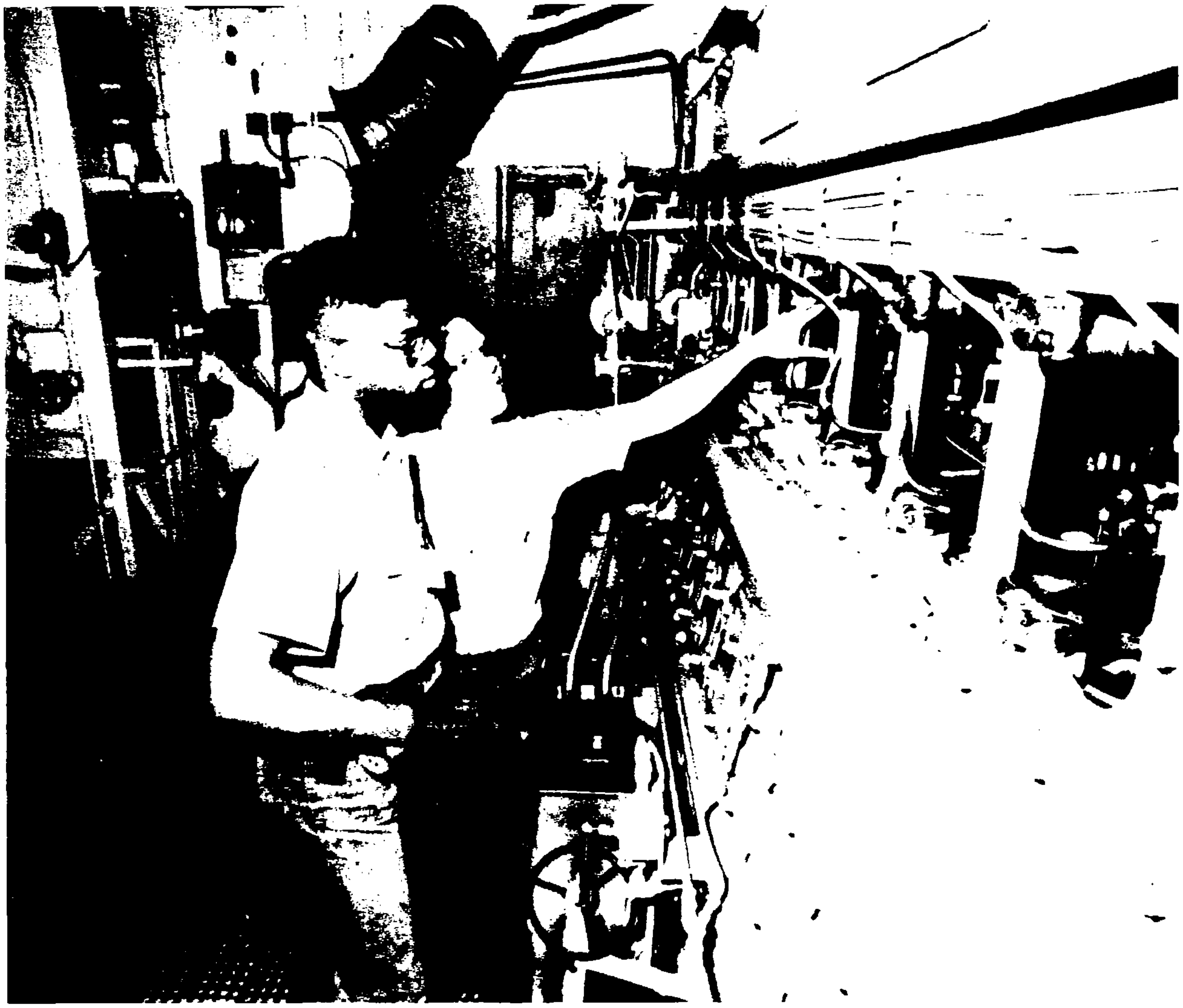
Nuclear Power School Classroom

Nuclear training onboard ship is every bit as demanding as the schools. Newly reporting officers and enlisted personnel must completely requalify as watchstanders and demonstrate their propulsion plant knowledge and operator ability at their new assignment. Even after shipboard qualification, shipboard operators participate in on-going Engineering Department training lectures, plant operational evolutions, and extensive casualty drills.



Nuclear Field "A" School Microprocessor Lab

> *Since the days of Admiral Rickover, the men and women of the Nuclear Propulsion Program have been recognized around the world for their high standards of achievement and performance, their commitment to professionalism, and their dedication to accountability. Fifty years later, these qualities remain the standard of the Nuclear Propulsion Program.*
>
> The Honorable Dirk Kempthorne
> Governor of Idaho
> July 1998



Prototype Training

To advance and assume greater responsibility, operators and officers must continue to demonstrate increasing proficiency and knowledge as they qualify and serve on more demanding watchstations. Shore training facilities provide operators advanced training in equipment repair and operation. All officers must qualify as Engineering Officer by successfully completing a comprehensive examination administered by Headquarters. Additionally, a rigorous advanced training program in nuclear propulsion plant operations is conducted at Headquarters for prospective Commanding Officers. The course must be successfully completed by any officer taking command of a nuclear-powered ship.

Nuclear Field "A" School Instrumentation & Control Lab

Nuclear Power School Physics Lecture

Training Is a Way of Life in the Nuclear Navy

Nuclear Power School Classroom

Nuclear Field "A" School Lube Oil Lab

What It Means to Be a Sailor in the Naval Nuclear Propulsion Program

One of the most rewarding jobs in today's military is that of a Sailor in the Naval Nuclear Propulsion Program. Those accepted into this unique Naval Program will face one of the most fulfilling and challenging career paths available. These individuals are intelligent, responsible, and motivated – the Program will accept no less. Since approximately forty percent of the U.S. Navy's combatants are nuclear-powered, there are many opportunities available to those interested in joining this elite group.

Naval nuclear propulsion plant operators are carefully screened, selected, and trained, and the standards of selection are high. To qualify for the Program, among other requirements, applicants must have a high school diploma or college degree, good academic scores, an interest in pursuing the challenge this highly technical field offers, and the capacity and motivation to work hard.

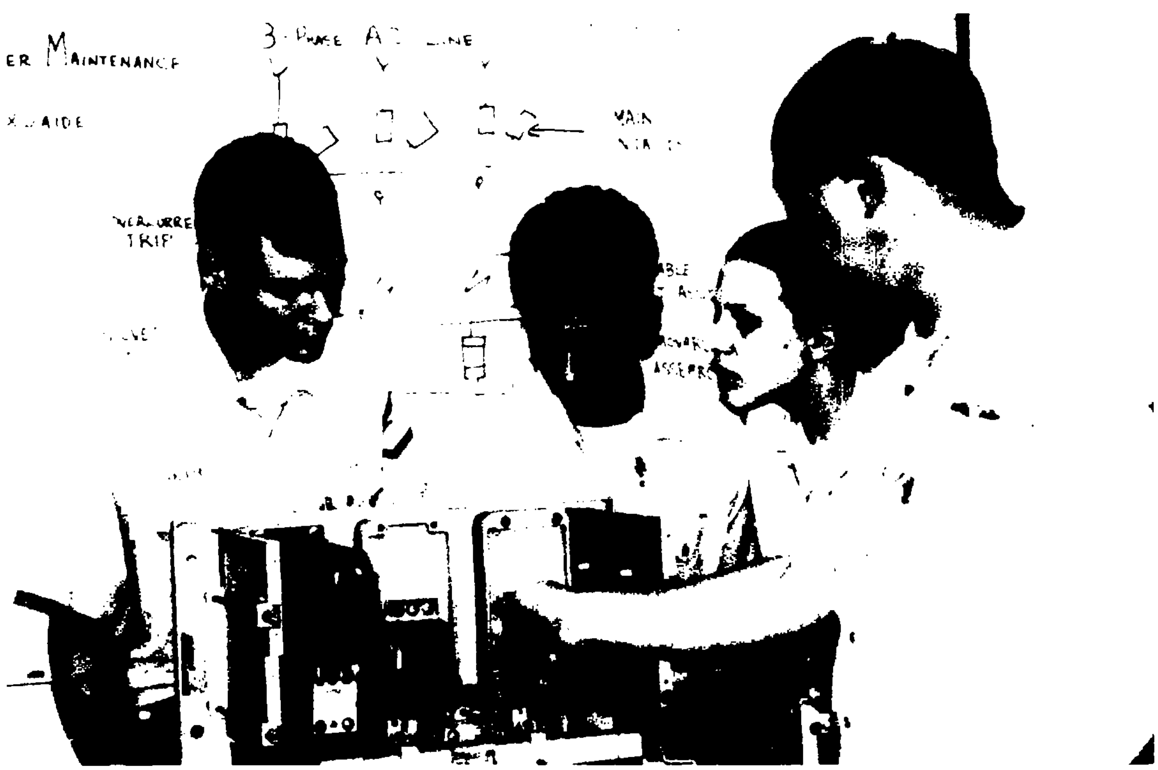
The training within the Program is respected worldwide; in fact, the quality of this training is recognized to an extent that many colleges give credit, up to 77 hours, for Program training and experience. After completing initial training, operators continue to gain experience and technical expertise in the many job opportunities onboard nuclear-powered ships. These jobs include operating, maintaining, and repairing equipment; component and system performance testing; standing watches to monitor propulsion plant performance; and eventually supervising and instructing junior personnel in propulsion plant operations.

A Nuclear-trained Petty Officer Inspecting Equipment in the Machinery Spaces Aboard a Nuclear-powered Aircraft Carrier

There are also many opportunities available to Sailors after they have completed their initial sea tour, such as returning to Nuclear Power School or one of the shore-based training facilities to teach new students, recruiting new Sailors to enter the Program, or working ashore in other commands supporting the Program. Whatever Sailors choose to do after their first sea tour, they can be assured that they will be highly sought after because of their training, competence, and professionalism.

There are also monetary benefits in being a part of the Naval Nuclear Propulsion Program. For example, those who are accepted in the Program can receive a generous entry bonus of up to $10,000. After joining, Sailors typically advance rapidly and receive more income as a result. Sailors in the Program also receive special duty pay for their unique skills.

Obviously, the Naval Nuclear Propulsion Program requires mature and dedicated people who are willing to work hard to achieve success. The Program ensures that those who qualify have a firm understanding of science and technology, and the ability and confidence to operate the most advanced nuclear propulsion plants in the world. Sailors who choose this career develop into highly competent, talented, and knowledgeable individuals, and in doing so provide an invaluable service to our country. If you are interested in becoming a part of the Naval Nuclear Propulsion Program, please contact your local Navy recruiter, call 1-800-USA-NAVY, or go to www.navy.com.



A Sea-experienced Nuclear-trained Petty Officer Instructing Several Students in Electrical Circuit Breaker Theory and Operation

Description of a Typical Naval Nuclear Propulsion Plant

In Naval nuclear propulsion plants, fissioning of uranium atoms in the reactor core produces heat. Since the fission process also produces radiation, shielding is placed around the reactor to protect the crew. During a submerged patrol, a typical crew member receives less exposure to radiation than one who remains ashore and works in an office building.

U.S. Naval nuclear propulsion plants use a pressurized-water reactor design which has two basic systems: the primary system and the secondary system. The primary system circulates ordinary water in an all-welded, closed loop consisting of the reactor vessel, piping, pumps, and steam generators. The heat produced in the reactor core is transferred to the water, which is kept under pressure to prevent boiling. The heated water passes through the steam generators where it gives up its energy. The primary water is then pumped back to the reactor to be heated again.

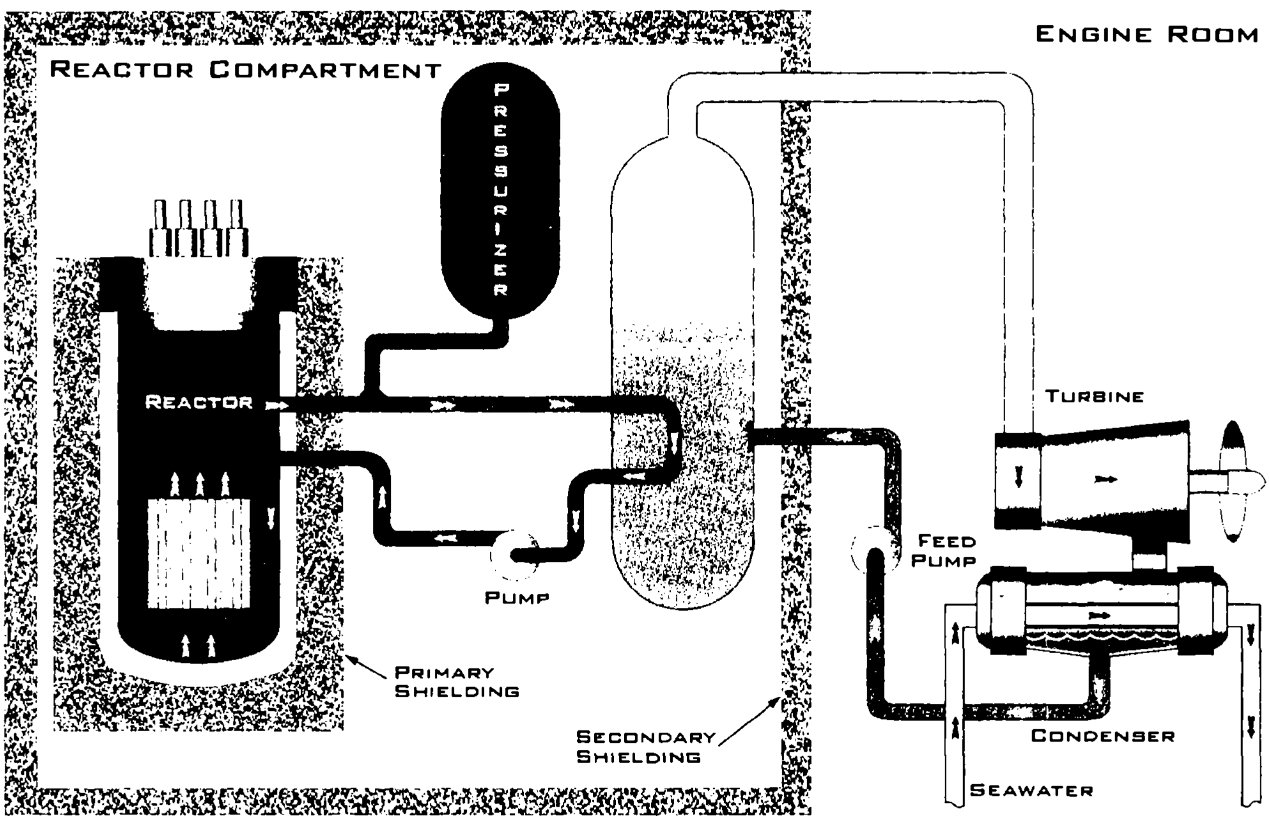
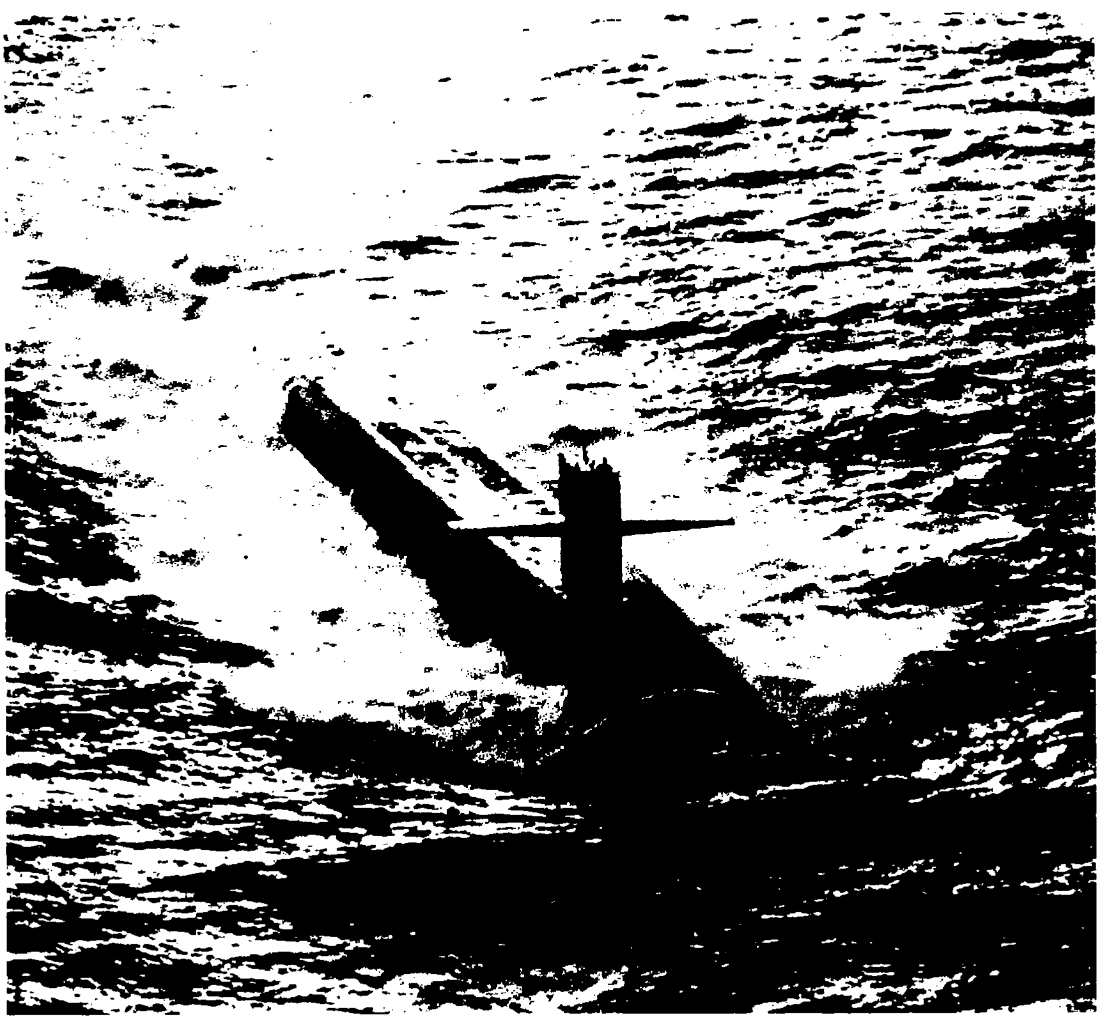


Diagram of a Typical Naval Nuclear Propulsion Plant

Inside the steam generators, the heat from the primary system is transferred across a water-tight boundary to the water in the secondary system, also a closed loop. The secondary water, which is at relatively low pressure, boils, creating steam. Isolation of the secondary system from the primary system prevents water in the two systems from intermixing, keeping radioactivity out of the secondary water.

In the secondary system, steam flows from the steam generators to drive the main propulsion turbines, which turn the ship's propeller and the turbine generators, which supply the ship with electricity. After passing through the turbines, the steam is condensed back into water, and feed pumps return it to the steam generators for reuse. Thus, the primary and secondary systems are separate, closed systems in which constantly circulating water transforms energy produced by the nuclear reaction into useful work.

There is no step in this process that requires the presence of air or oxygen. This, combined with the ship's capability to produce oxygen and purified water from seawater, enables the ship to operate completely independent of the earth's atmosphere for extended periods of time. In fact, the length of a submerged submarine patrol is limited primarily by the amount of food the ship can carry for the crew.



USS MAINE (SSBN 741) Underway

Protection of People

The policy of the U.S. Naval Nuclear Propulsion Program is to reduce personnel exposure to ionizing radiation associated with Naval nuclear propulsion plants to the lowest level reasonably achievable. In carrying out this policy, the Program has consistently maintained personnel radiation exposure standards more stringent than those in the civilian nuclear power industry or in other Government nuclear programs.

No civilian or military personnel in the Naval Nuclear Propulsion Program have ever exceeded the Federal lifetime radiation exposure limit or the Federal annual limit in effect at the time. Since 1968, no personnel have exceeded five rem per year, which was the Program's self-imposed limit until it became the Federal limit in 1994. Since 1980, the average annual radiation exposure for nuclear-powered ship operators has been less than one-sixth the average annual exposure a member of the American public receives from natural background radiation exposure. In recent years, the average annual radiation exposure for operators has dropped to about one-eighth of the average annual exposure a member of the American public receives from natural background radiation exposure. In 1987, the Yale University School of Medicine conducted an independent study of approximately 76,000 personnel assigned to submarine duty. In 1991, Johns Hopkins University conducted an independent study of over 70,000 shipyard personnel assigned to work on nuclear-powered ships. Neither study showed any cancer risks linked to radiation exposure.

The principles of personal responsibility, technical knowledge, rigorous training, and auditing have been applied to achieve the Program's strong nuclear safety record. These same principles are also applied to Occupational Safety, Health, and Occupational Medical (OSHOM) programs. Workers are provided comprehensive safety and health training, carefully engineered procedures, close supervision, and work-team backup. Inspection, oversight, and feedback mechanisms are designed to provide continual improvement. The Program's *injury and illness incidence rates* and *lost workdays rates* are about one-third of these rates for general industry.

In light of the September 11 terrorist acts, the use of nuclear-powered ships is now even more critical in defending our country. I am pleased that your program maintains a readiness while controlling risks and enhancing a culture of responsibility and performance.

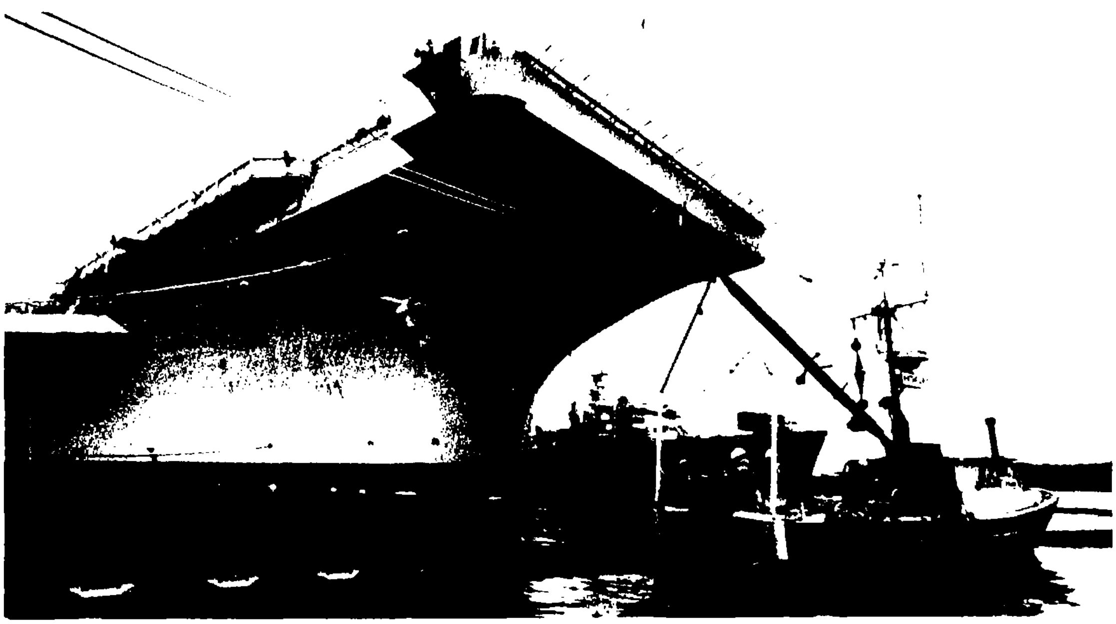
Elaine L. Chao
Secretary of Labor
August 2002

Concern for the Environment

Long before protection of the environment became a prevalent endeavor, it was a high priority in the Naval Nuclear Propulsion Program. From the beginning, the Program recognized that the environmental aspects of U.S. nuclear-powered ships and their operations would be key to their acceptance at home and abroad. The Program maintains the same rigorous attitude toward the control of radioactivity and protection of the environment as it does toward reactor design, testing, operation, and servicing. As a result, the Program has a well-documented record which demonstrates the absence of any adverse environmental effect from the operation of nuclear-powered warships. This record supports U.S. nuclear-powered ships being welcomed into over 150 ports in over 50 foreign countries and dependencies, as well as U.S. ports.

Environmental releases, both airborne and waterborne, are strictly controlled. As a result, the annual releases of long-lived gamma radioactivity from *all* Program activities are comparable to the annual releases from a typical U.S. commercial nuclear reactor operating in accordance with its NRC license. Through the entire history of the Program – over 5,700 reactor years of operation and more than 134 million miles steamed on nuclear power – there has never been a reactor accident, nor any release of radioactivity that has had an adverse effect on human health or the quality of the environment. The Program's standards and record surpass those of any other national or international nuclear program.

The Program has a comprehensive environmental monitoring program at each of its major installations and facilities, including nuclear-capable shipyards and the homeports of nuclear-powered ships. This monitoring program consists of analyzing water, sediment, air, and marine samples for radioactivity to verify that Program operations have not had an adverse effect on the environment. Independent surveys conducted by the EPA, State and local governments confirm that U.S. Naval nuclear-powered ships and support facilities have had no discernible effect on the radioactivity of the environment.



Environmental Monitoring at Puget Sound Naval Shipyard

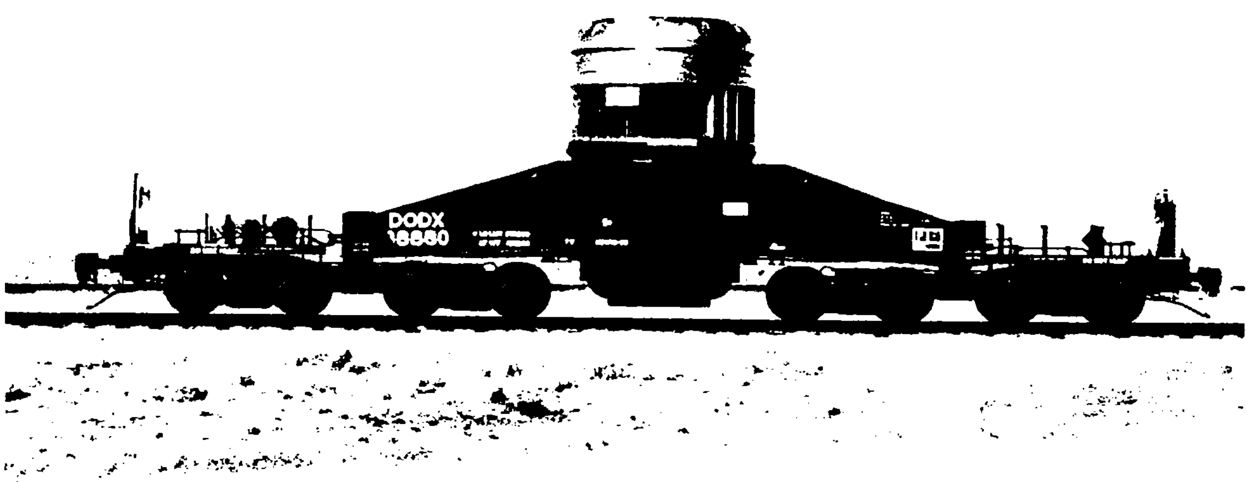
In the field of nuclear energy, not only has Naval Nuclear Propulsion made a contribution to national security of incalculable value, but has done so with a level of sustained excellence that is an outstanding example of Government serving its citizens. The Program's record of safety and environmental protection, started long before it was generally recognized how important these things are, is simply without equal.

Vice President Al Gore
On the Program's 50th Anniversary, August 1998

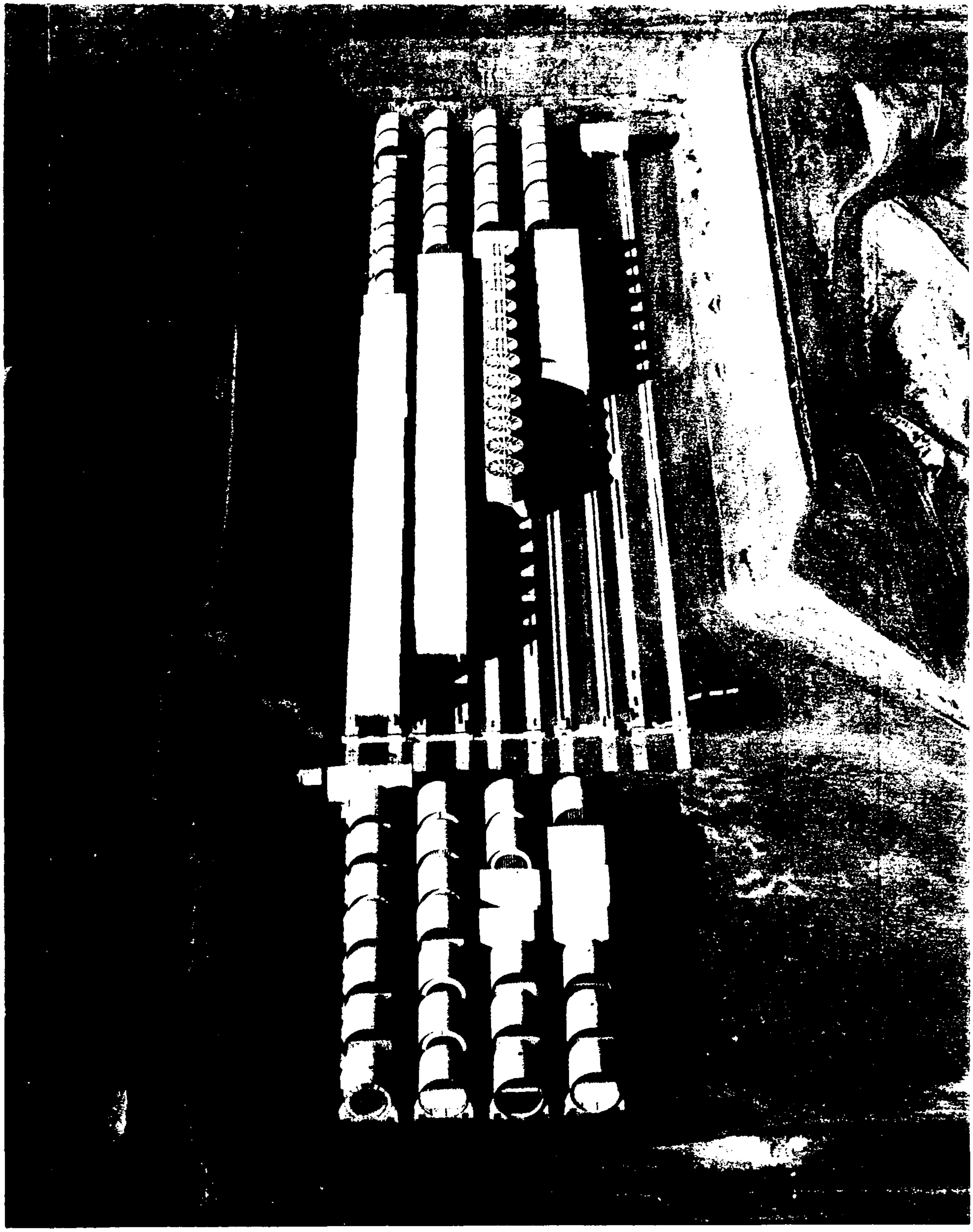
Ensuring proper environmental performance has also been a priority at Program DOE facilities, which are responsible for non-nuclear as well as nuclear environmental matters. Regular inspection of the Program's laboratory and prototype sites by the EPA and state officials in accordance with the Clean Air Act, the Resource Conservation and Recovery Act (RCRA), and the Clean Water Act, has shown no significant problems.

The Program's stewardship of the environment does not end when a facility ceases operations. For example, the Program has successfully released three former shipyards for unrestricted future use with respect to Program radioactivity: Ingalls Shipbuilding's radiological facilities in Pascagoula, Mississippi in 1982, and the former Charleston and Mare Island Naval Shipyards in South Carolina and California in 1996. These facilities' unrestricted releases from Program radiological controls were independently verified and agreed with by the respective states and the EPA. The successful inactivation and closure of these radiological facilities demonstrates that the stringent control exercised by the Program since its inception has been successful in protecting human health and the environment.

Finally, the Program exercises its environmental responsibilities from "cradle to grave" – from nuclear-powered warship design to ultimate disposal. The U. S. Navy's program to safely dispose of decommissioned nuclear-powered submarines and cruisers is an example. It involves defueling the reactor(s), inactivating the ship, removing the reactor compartment for land disposal, recycling the remainder of the vessel to the maximum extent practical, and disposing of the remaining non-recyclable materials. The spent nuclear fuel removed from nuclear-powered warships constitutes about 0.05% of all spent nuclear fuel in the United States today. Also, it is ruggedly designed to withstand combat conditions, and can be safely stored pending ultimate placement in a geologic repository. The Program has safely made over 769 container shipments of Naval spent nuclear fuel since 1957 using specially designed, rugged containers, such as the M-140 pictured below. To date, 108 nuclear-powered warships have been recycled with 114 defueled reactor compartments sent to the Department of Energy's Hanford Site, as shown on the next page.



M-140 Shipping Container Mounted on Railcar



Defueled Naval Reactor Compartments at the Department of Energy's Hanford Site, November 2004

Naval Nuclear Propulsion Program Emergency Preparedness

U.S. nuclear-powered warships are designed to the most exacting and rigorous standards. They are built to survive wartime attack, include redundant systems, and are operated by highly trained crews using rigorously applied procedures. These features enhance safety just as they contribute to the ability of the ship to survive attack in time of war.

Naval reactors are designed and operated in a manner that is protective of the crew, the public, and the environment. It is important to note that the crew lives in very close proximity to the reactor and is dependent on the energy generated by the reactor for air, water, heat, and propulsion. Thus, it is imperative to both the Navy and the crew that the reactor be well designed and safely operated. An equally important part of ensuring safety is developing, exercising, and evaluating the ability to respond to any emergency in the highly unlikely event one does occur.

Planning for emergencies is based on extensive Naval Nuclear Propulsion Program technical analysis, as well as recommendations and guidance provided by numerous agencies experienced in emergency planning, including the Department of Homeland Security (Federal Emergency Management Agency), the Navy, the Department of Energy, the Nuclear Regulatory Commission, the Environmental Protection Agency, the National Council on Radiation Protection and Measurements, and the International Atomic Energy Agency. Emergency planning for the public is based on the above guidance, as well as specific planning requirements of local civil authorities.

All Naval Nuclear Propulsion Program activities, both shipboard and ashore, have plans in place that define Naval Nuclear Propulsion Program responses to a wide range of emergency situations. These plans are regularly exercised to ensure that proficiency is maintained. These exercises consistently demonstrate that Naval Nuclear Propulsion Program personnel are well prepared to respond to emergencies regardless of location. Actions are taken to continually evaluate and improve emergency preparedness at all Naval Nuclear Propulsion Program activities.

If there ever were a radiological emergency, civil authorities would be promptly notified and kept fully informed of the situation. With the support of Naval Nuclear Propulsion Program personnel, local civil authorities would determine appropriate public actions, if any, and communicate this information via their normal emergency communication methods.

The Commission recognizes that since the NAUTILUS first signaled 'Underway on Nuclear Power' 50 years ago, nuclear-powered warships have steamed many millions of miles and have accumulated thousands of reactor-years of operation without a nuclear accident or any adverse radiological impact on the quality of the environment..

Nils J. Diaz
Chairman, Nuclear Regulatory Commission
September 2004

Due to the unique design and operating conditions of U.S. nuclear-powered ships, civil emergency response plans that are sufficient for protecting the public from industrial and natural events (for example, chemical spills or earthquakes) are also sufficient to protect the public in the highly unlikely event of an emergency onboard a nuclear-powered ship or at a Naval Nuclear Propulsion Program facility.

Members of the public who live in the vicinity of nuclear-powered ships or support facilities can be confident that in the event of an emergency, extensive resources are readily available to quickly respond to the situation.

Sailors and Emergency Response Personnel Work Together During an Emergency Preparedness Exercise at Naval Submarine Base, Groton, Connecticut

Naval Nuclear Propulsion Program Accomplishments

In addition to the military applications of nuclear power, technology developed by the Naval Nuclear Propulsion Program is the basis for civilian nuclear power around the world. Significant contributions include:

- The uranium-dioxide fuel system – now the most widely used system in nuclear power;
- The design for large pressurized-water reactor components and the cladding for large pressure vessels;
- Containment concepts and refueling techniques for power reactors;
- A system for preventing damage to a reactor core even if failures occur in the cooling system;
- The first successful method of radioactive decontamination of reactor plants;
- Zirconium, zirconium alloys, and hafnium materials for cladding and reactor control use;
- Numerous computer programs widely used for design safety, research, and testing;
- The first chemical cleaning process for nuclear plant steam generators;
- Ultrasonic inspection methods for evaluating the material status of the reactor vessel and major components;
- Nuclear fabrication standards, quality control requirements, and equipment specifications;
- Development and publication of the CHART OF THE NUCLIDES, used world-wide for nuclear research and development work;
- Increased performance of direct heat energy conversion technology; and
- Extensive use of solid-state electronics for instrumentation, control, and power distribution.

The Program also shares with industry information from its research in a variety of areas, including: corrosion and wear technology for components operating in high-temperature, high-pressure water; pressurized-water reactor heat transfer and fluid flow technology; methods for predicting performance of reactors in accident scenarios; and numerical analyses of reactor designs using digital computers. This has resulted in over 5,000 technical reports which have been made available to industry and the public.

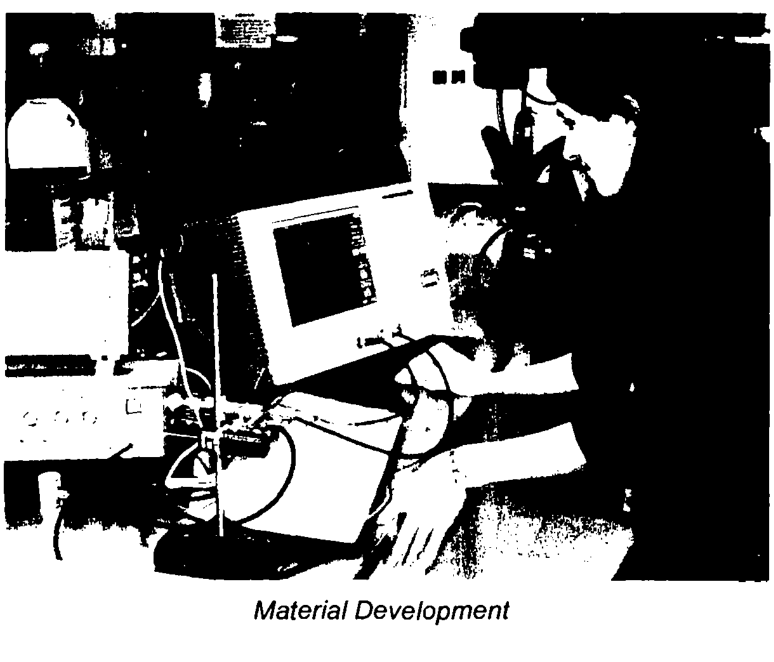
Perhaps the most important contribution to the civilian sector is the thousands of highly trained Program graduates who now play key roles in the operation and management of civilian nuclear power reactors.

The Future

The Naval Nuclear Propulsion Program continues to advance reactor technology while exploring new energy conversion and reactor concepts that even better serve the fleet.

Field Emission Gun Scanning Electron Microscopy

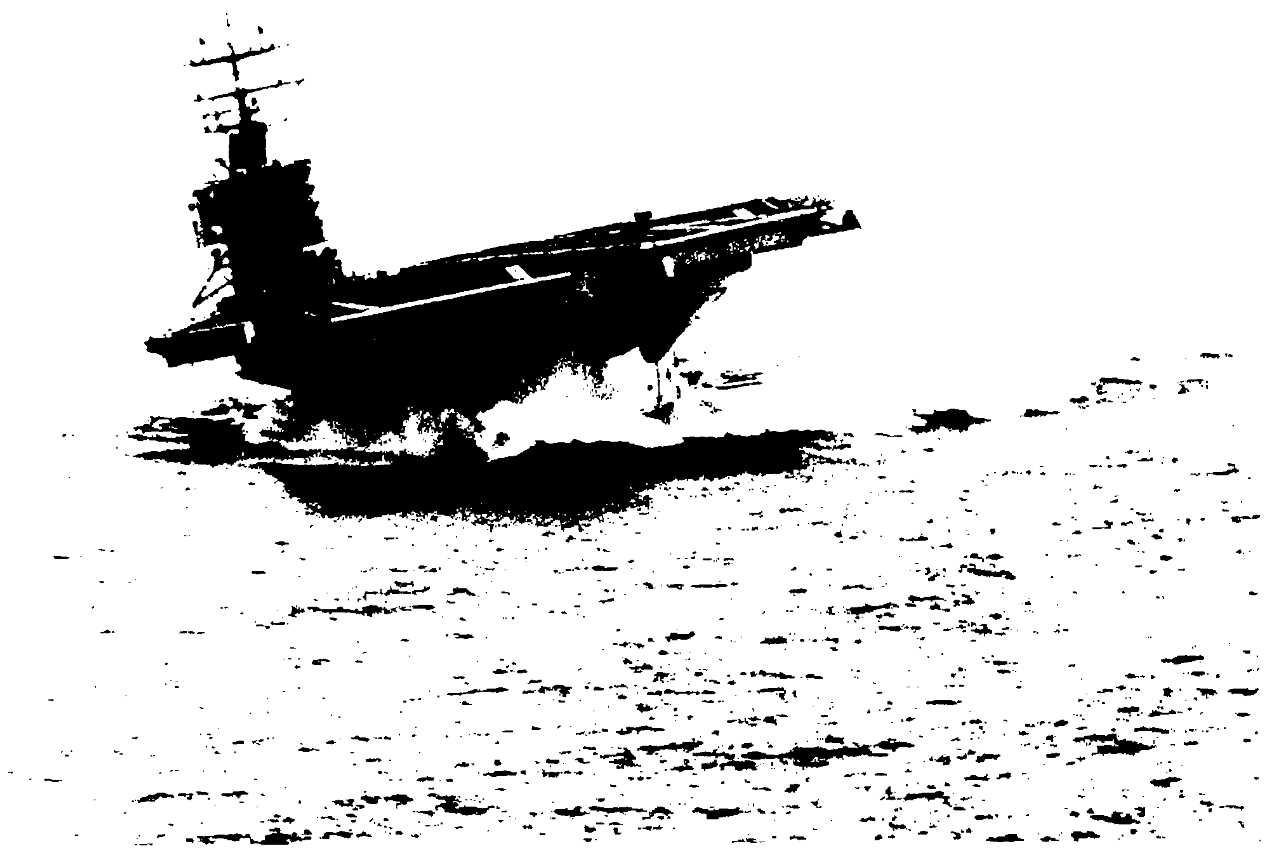
Program research seeks to make nuclear propulsion quieter, extend the life and efficiency of the nuclear core, further simplify operation of the reactor plant, reduce the already low life-cycle maintenance costs, and design propulsion plants with increased power output without increasing their size or cost.



Material Development

CVN 21

The follow-on design to the NIMITZ Class nuclear-powered aircraft carrier, CVN 21 will incorporate immediate warfighting benefits, reduce total ownership cost, and provide flexibility for future upgrades. Naval Reactors is directly contributing through development of a new propulsion plant with increased core energy and nearly three times the electric plant generating capacity of a NIMITZ Class aircraft carrier. This dramatic increase in electrical generating and distribution capacity will enable transformational warfighting technologies such as the Electromagnetic Aircraft Launching System, Unmanned Aerial Vehicles, and high-energy weapons, as well as removal of all steam auxiliaries and services, which are manpower and maintenance intensive. By eliminating these steam lines throughout the ship, battle damage survivability will be improved while reducing manning and maintenance costs. The new reactor plant design will also simplify systems throughout the plant, dramatically reducing the number of valves, pumps, and the amount of electrical cabling. This simpler design will reduce the reactor department manning by 50 percent and reduce propulsion plant life-cycle costs by over 20 percent.



USS JOHN C. STENNIS (CVN 74) is Shown Here Executing a High-speed Turn.
CVN 21 Will Have Improved Warfighting Capabilities Over NIMITZ Class Aircraft Carriers.

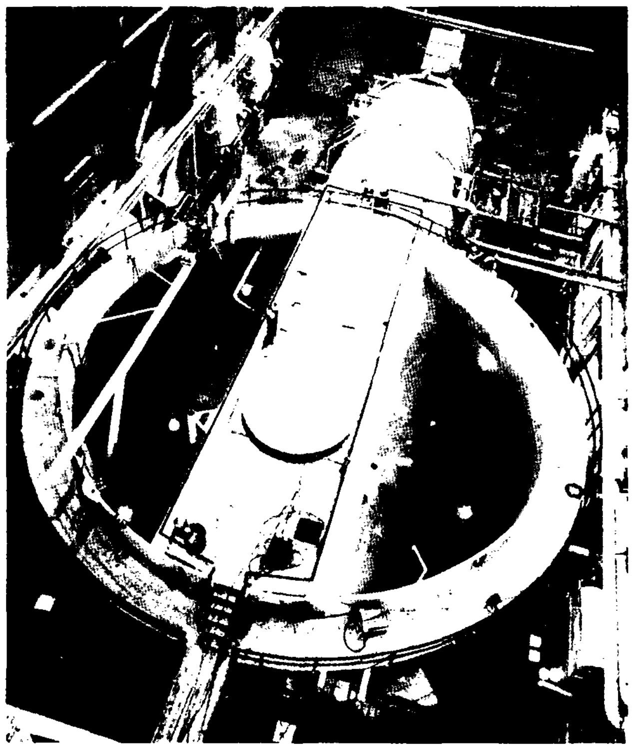
Appendix

The First Naval Nuclear Propulsion Plants

The First Prototype (S1W)

December 1948 The AEC contracts with Westinghouse to design, build, operate, and test a prototype pressurized-water, Naval nuclear propulsion plant (known alternatively as Submarine Thermal Reactor, Mark 1, or simply S1W).

1950-1953 S1W is constructed at the AEC's National Reactor Testing Station (now DOE's Idaho National Laboratory) inside a submarine hull surrounded by a 300,000-gallon tank of water simulating the ocean.



S1W Prototype with Water Tank to Simulate the Ocean Environment

March 30, 1953 S1W reaches criticality at 11:17 p.m., making the first significant quantities of useful nuclear power in the world.

June 25, 1953 S1W achieves full design power and commences a successful 96-hour sustained full-power run, simulating a submerged crossing of the Atlantic Ocean.

Late 1955 Following nearly two years of continuous operation and testing and a refueling, S1W completes a 66-day continuous full-power run – this could have propelled a submarine at high speed twice around the globe.

October 1989 DOE permanently shuts down S1W after 36 years of successful operation. The last 22 years of operation were performed using the same reactor core, setting a longevity record. Over 13,000 Navy officer and enlisted operators trained at S1W.

USS NAUTILUS (SSN 571)

With the endurance and stealth only nuclear propulsion could provide, NAUTILUS revolutionized undersea warfare by becoming the world's first *true* submarine, limited only by the amount of supplies she could carry.

August 1949 The CNO establishes a January 1955 "ready-for-sea" date for development of a submarine nuclear propulsion plant.

August 1950 President Harry S Truman signs Public Law 674, authorizing construction of NAUTILUS.

August 1951 Electric Boat begins construction of the first nuclear-powered submarine.

June 14, 1952 President Truman lays the keel of NAUTILUS.

September 30, 1954 NAUTILUS is commissioned in Groton, CT.

January 17, 1955 Under the command of CDR Eugene P. Wilkinson, USS NAUTILUS puts to sea for the first time – less than four years after construction began – signaling her historic message, "Underway on nuclear power."

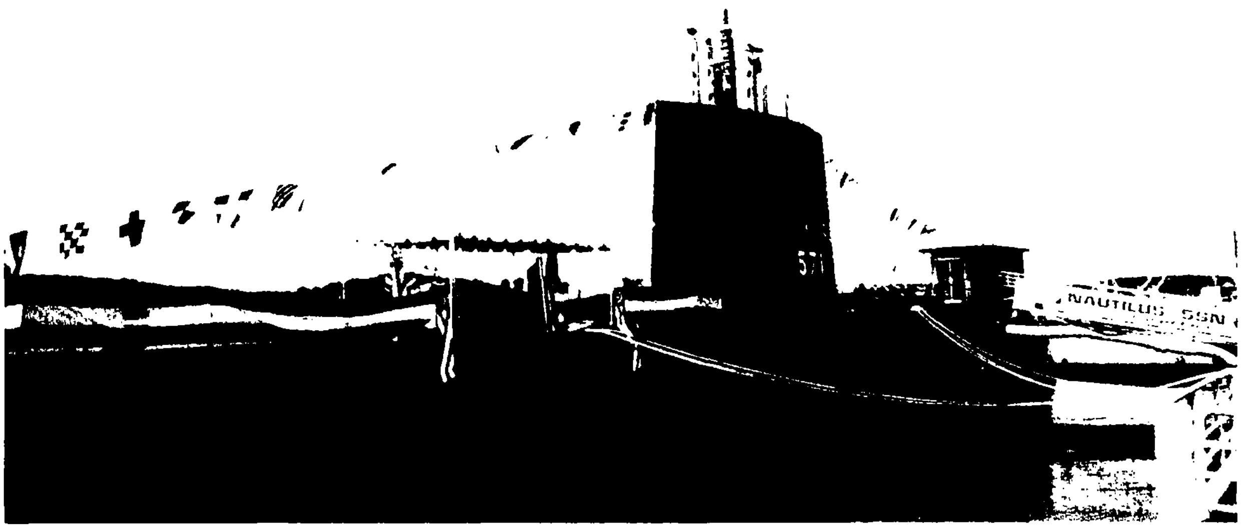
February 1955 NAUTILUS steams 1,300 submerged miles from New London, Connecticut, to San Juan, Puerto Rico in 84 hours – ten times farther than previously traveled by a submerged submarine. This is the first time that a submarine maintains a high speed (about 16 knots average) for longer than an hour.

1957 NAUTILUS is refueled after steaming over 62,000 miles on her first core. The ship was fully submerged for more than half the distance.

August 3, 1958 NAUTILUS, during an 1,800-mile, 96-hour historic trans-Polar voyage from Point Barrow, Alaska to the Greenland Sea, becomes the first ship to reach the geographic North Pole. For demonstrating the Arctic's strategic potential, President Eisenhower awards NAUTILUS the Presidential Unit Citation (the first such award in peacetime) and her commanding officer, CDR William R. Anderson, the Legion of Merit.

1960 NAUTILUS deploys to the Mediterranean and becomes the first nuclear-powered submarine assigned to the Sixth Fleet.

1960-1979 NAUTILUS participates in numerous defense missions, including the Naval quarantine on all offensive military equipment under shipment to Cuba during the 1962 Cuban missile crisis, and demonstrates U.S. technical capability through high-visibility visits to numerous foreign ports in the Atlantic and Mediterranean.



USS NAUTILUS Pierside at the Submarine Force Library and Museum in Groton, Connecticut, during a Ceremony Commemorating the 50th Anniversary of Her Commissioning, September 30, 2004

NAUTILUS DATA

Length – 320 feet

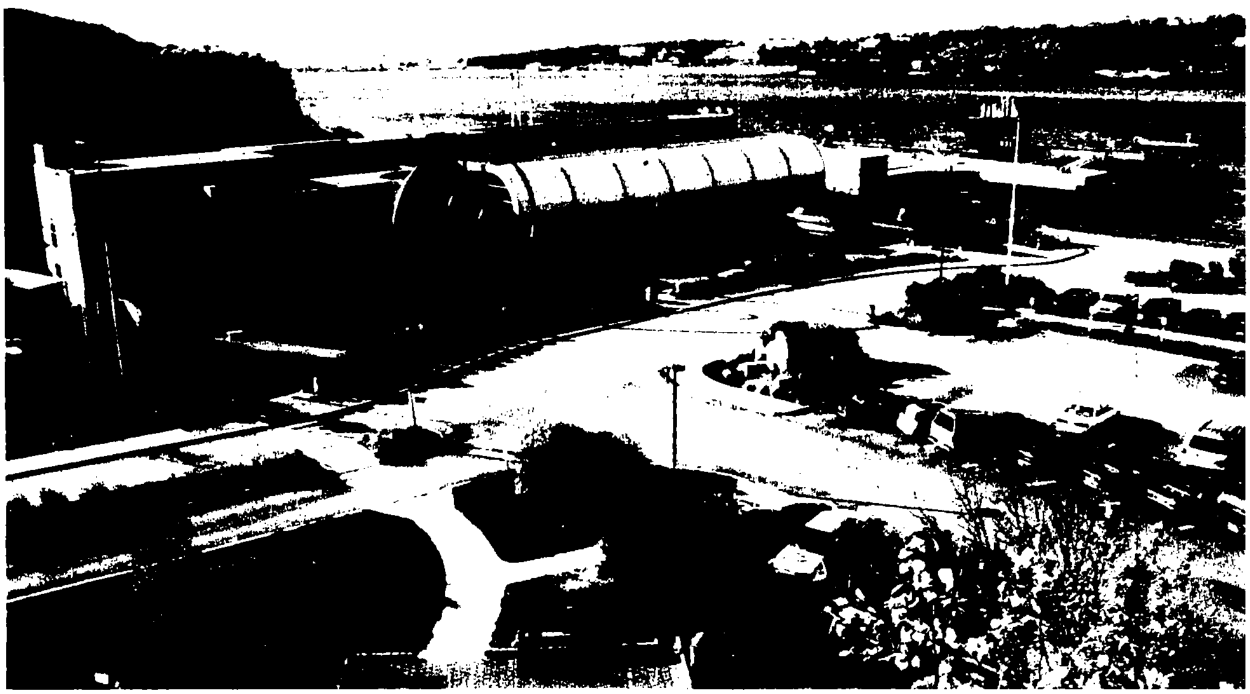
Beam – 28 feet

Displacement – Surfaced: 3,533 tons; Submerged: 4,092 tons

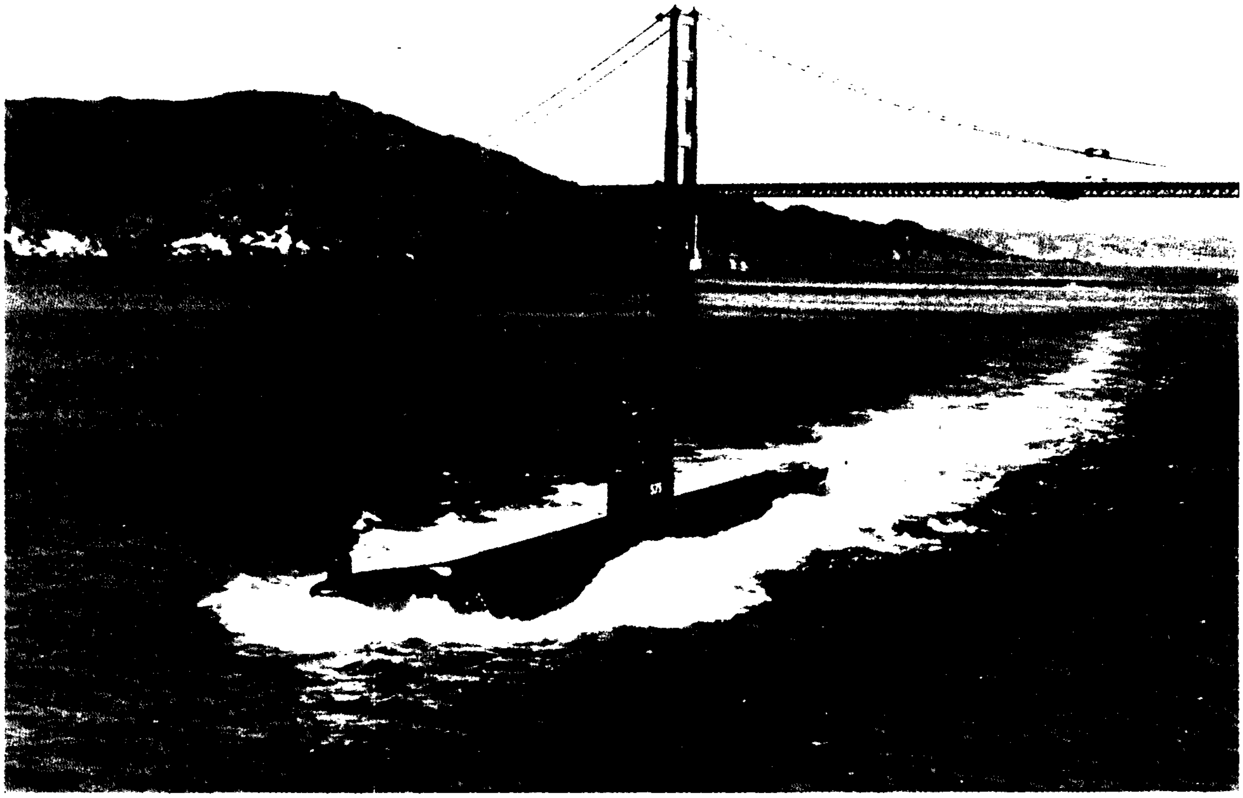
April 1979 NAUTILUS departs Groton, Connecticut, en route to California, for her final voyage. Completes her 2,500th dive and 510,000 miles on nuclear power.

May 1979 NAUTILUS enters Mare Island Naval Shipyard for inactivation and conversion as a historic ship for public display. Following this, NAUTILUS leaves California under tow for the Naval Submarine Base in Groton.

Today NAUTILUS is currently a National Historic Landmark, open to the public as part of the NAUTILUS Memorial and Submarine Force Library and Museum, Groton, Connecticut. (For additional information, write to Box 571, NAVSUBASE, Groton, CT 06349-5000, or view the NAUTILUS Museum website at *http://ussnautilus.org)*.



NAUTILUS Memorial and Submarine Force Library and Museum, Groton, Connecticut



USS SEAWOLF (SSN 575) Outbound in San Francisco Bay

USS SEAWOLF (SSN 575)

April 1950 General Electric begins design work on a liquid-sodium Naval nuclear propulsion plant as an alternative to pressurized water for a second nuclear-powered submarine – USS SEAWOLF.

September 1953 SEAWOLF's keel is laid at Electric Boat.

June 1956 The ship's reactor reaches criticality.

October 1958 While operating as an active unit of the Atlantic Fleet, SEAWOLF completes a record-breaking 60-day submerged run, traveling over 13,000 miles.

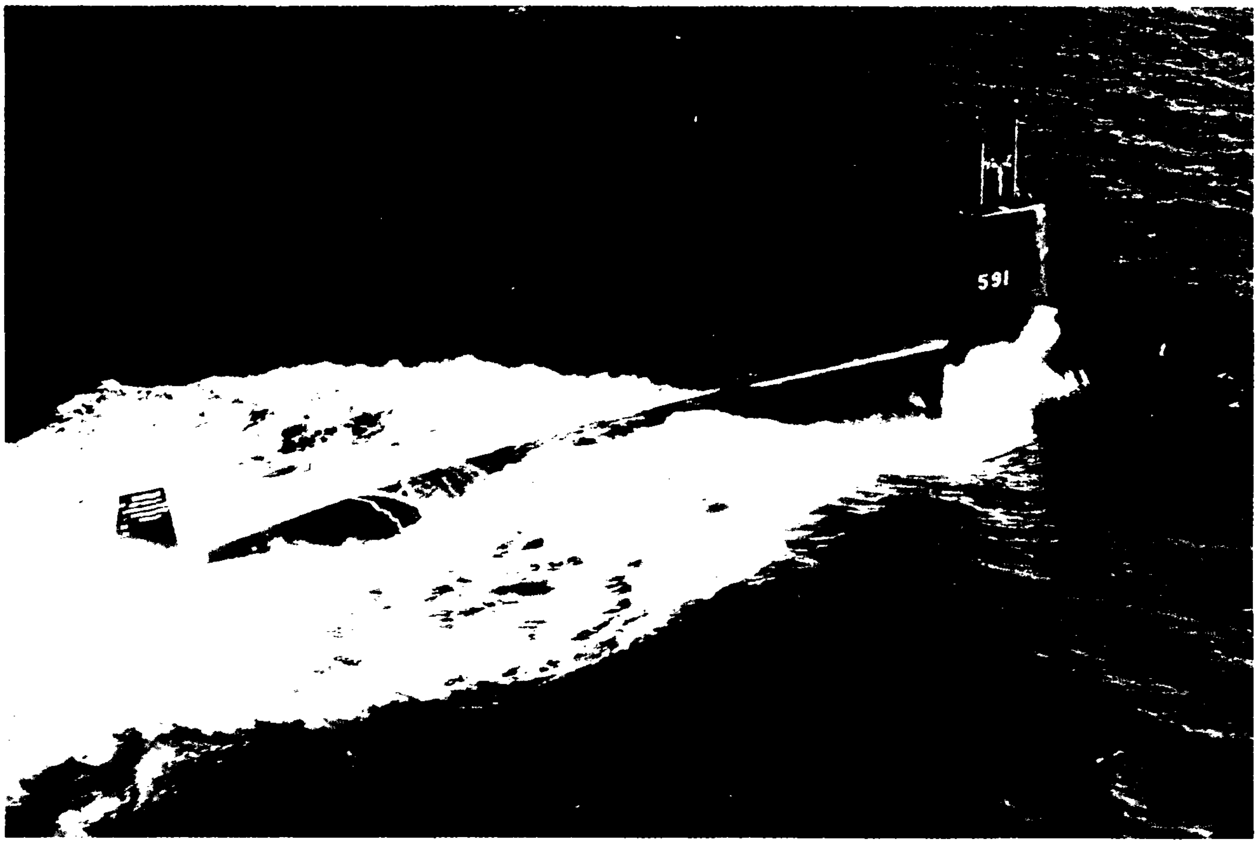
December 1958 Although operating satisfactorily for almost two years, SEAWOLF's sodium-cooled plant is significantly less attractive for Naval warships than pressurized-water alternatives. Therefore, the SEAWOLF plant is replaced with a pressurized-water plant (S2W) similar to that installed in NAUTILUS. SEAWOLF's sodium plant had steamed over 71,000 miles, fully submerged for over three-quarters of this distance.

March 1987 SEAWOLF is decommissioned after 30 years of operation and over 473,000 miles steamed on nuclear power.

Classes of Nuclear-powered Ships

Submarines

Early SSNs With the success of NAUTILUS, the Navy launched a series of attack submarine classes (SKATE, SKIPJACK, and PERMIT) which introduced different warfighting and design features.



USS SHARK (SSN 591) on Sea Trials

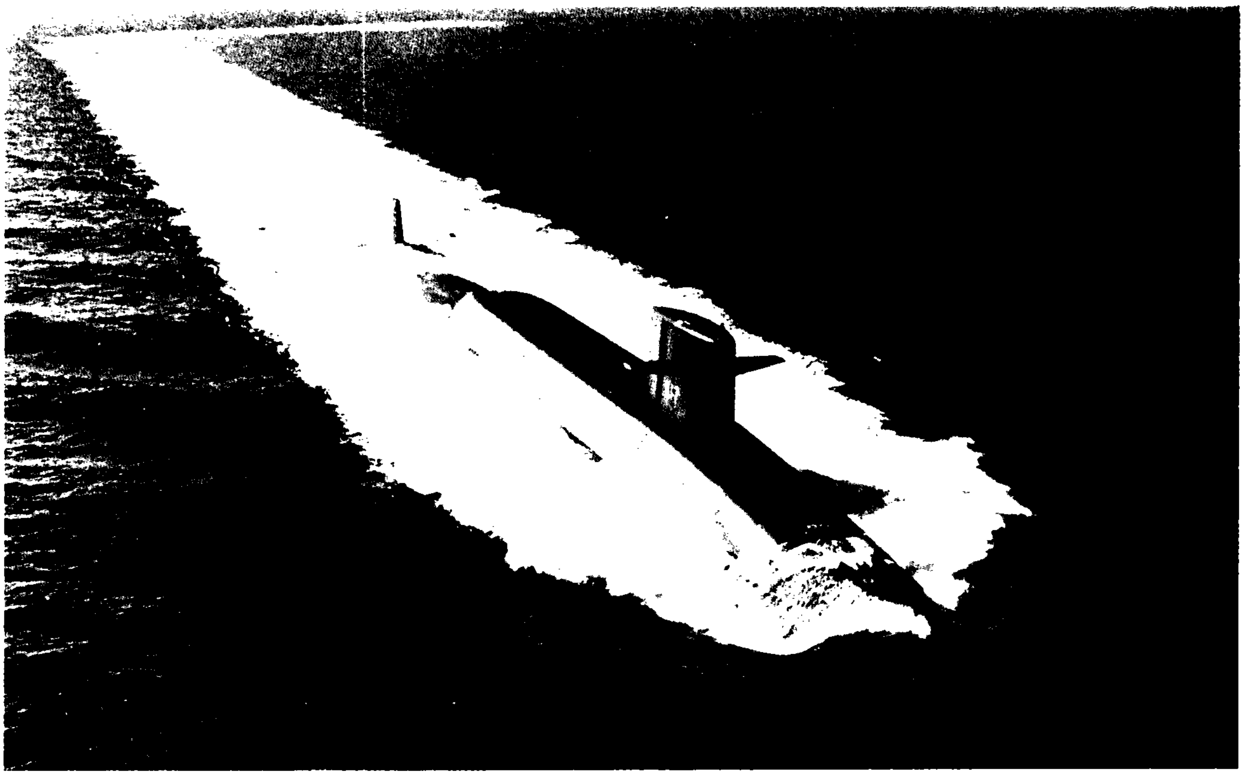
USS SHARK (SSN 591) DATA
(SKIPJACK Class)

Length – 249 feet

Beam – 32 feet

Displacement – Surfaced: 3,075 tons; Submerged: 3,500 tons

Fleet Ballistic Missile (FBM) Submarines With NAUTILUS still in operational testing, the Navy began developing a submarine ballistic missile system, which it brought from inception to deployment in five years. In the first Class of FBMs (GEORGE WASHINGTON), the Navy extended SSN hulls to add a missile compartment amidships. In the 1960s, subsequent FBM Classes (ETHAN ALLEN, LAFAYETTE, JAMES MADISON, and BENJAMIN FRANKLIN) were designed from the keel up as missile submarines. Each carried 16 POLARIS missiles, but were later back-fitted with the more powerful and accurate POSEIDON missile. All submarines of these classes have now been retired from strategic service and replaced by the more advanced TRIDENT ballistic missile submarines.



USS ALEXANDER HAMILTON (SSBN 617)

USS ALEXANDER HAMILTON (SSBN 617) DATA
(LAFAYETTE Class)

Length – 425 feet

Beam – 33 feet

Displacement – Surfaced: 7,250 tons; Submerged: 8,250 tons

USS HAMMERHEAD (SSN 663)

USS HAMMERHEAD (SSN 663) DATA
(STURGEON Class)

Length – 292 feet

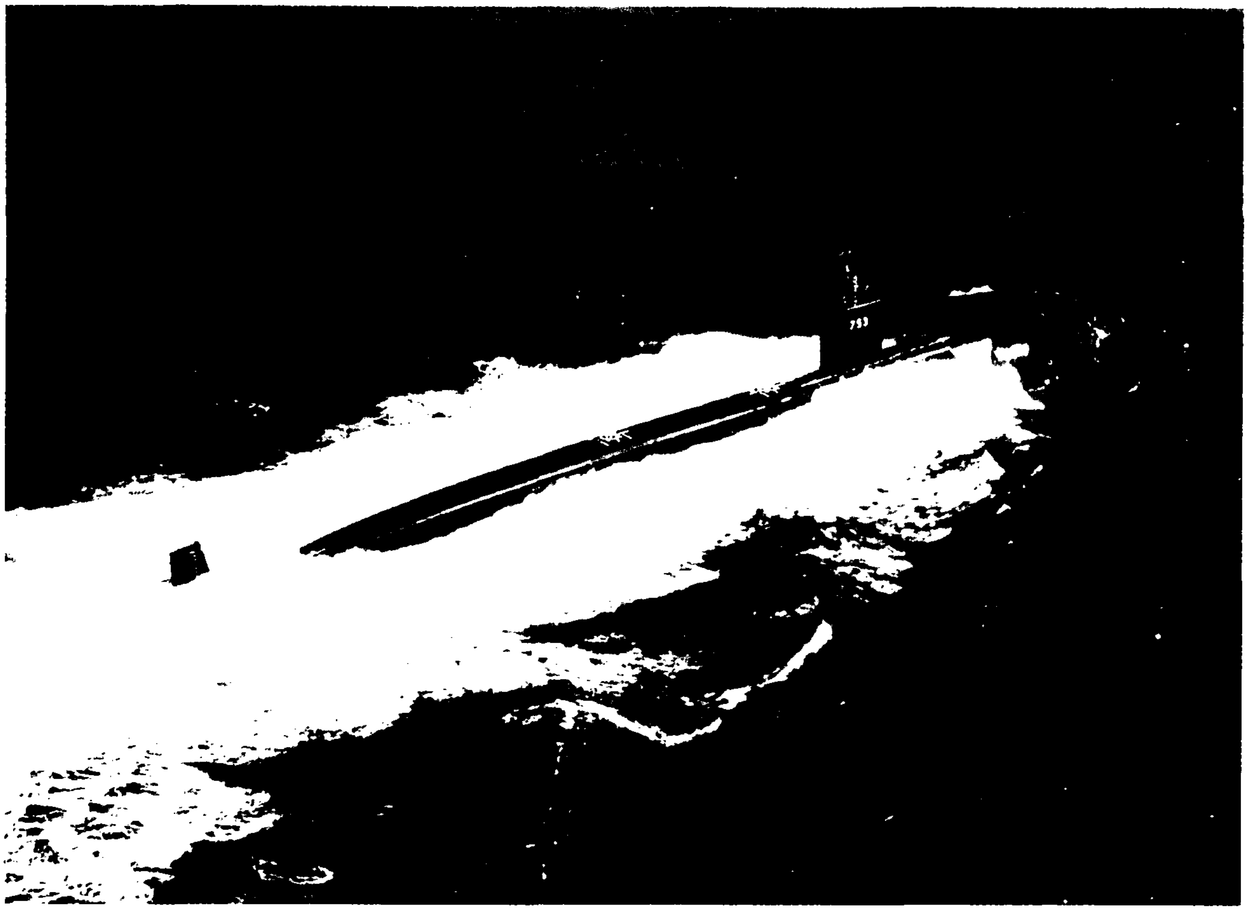
Beam – 32 feet

Displacement – Surfaced: 4,250 tons; Submerged: 4,780 tons

STURGEON Class After deployment of PERMIT Class submarines, the Navy began building STURGEON (SSN 637) Class submarines, which combined the most advantageous warfighting elements of the early SSN classes. With well-tested, quiet, and dependable propulsion plants, the thirty-seven STURGEON Class submarines were the mainstay of our nuclear fleet into the 1980s.

Single-ship Designs The Navy built several single-ship class submarines – USS TRITON (SSN 586), USS HALIBUT (SSN 587), USS TULLIBEE (SSN 597), USS NARWHAL (SSN 671), and USS GLENARD P. LIPSCOMB (SSN 685) – each to explore alternate propulsion plant concepts (for example, turbine electric drive and different reactor and propulsion turbine designs). Technology developed in these efforts became the basis for later classes.

LOS ANGELES Class With a high-power propulsion plant, advanced sonar, and improved torpedo fire control systems, LOS ANGELES (SSN 688) Class submarines provide high-speed escort, anti-submarine and anti-surface warfare roles with a minimum underwater noise signature. Beginning with USS SAN JUAN (SSN 751), LOS ANGELES Class submarines incorporate technological advances, including cruise missile vertical launch capability, a new combat system, and retractable bow planes. Additionally, these later boats do not need to be refueled over the entire life of the ship. The LOS ANGELES Class currently comprises more than 90 percent of our fast attack boats.



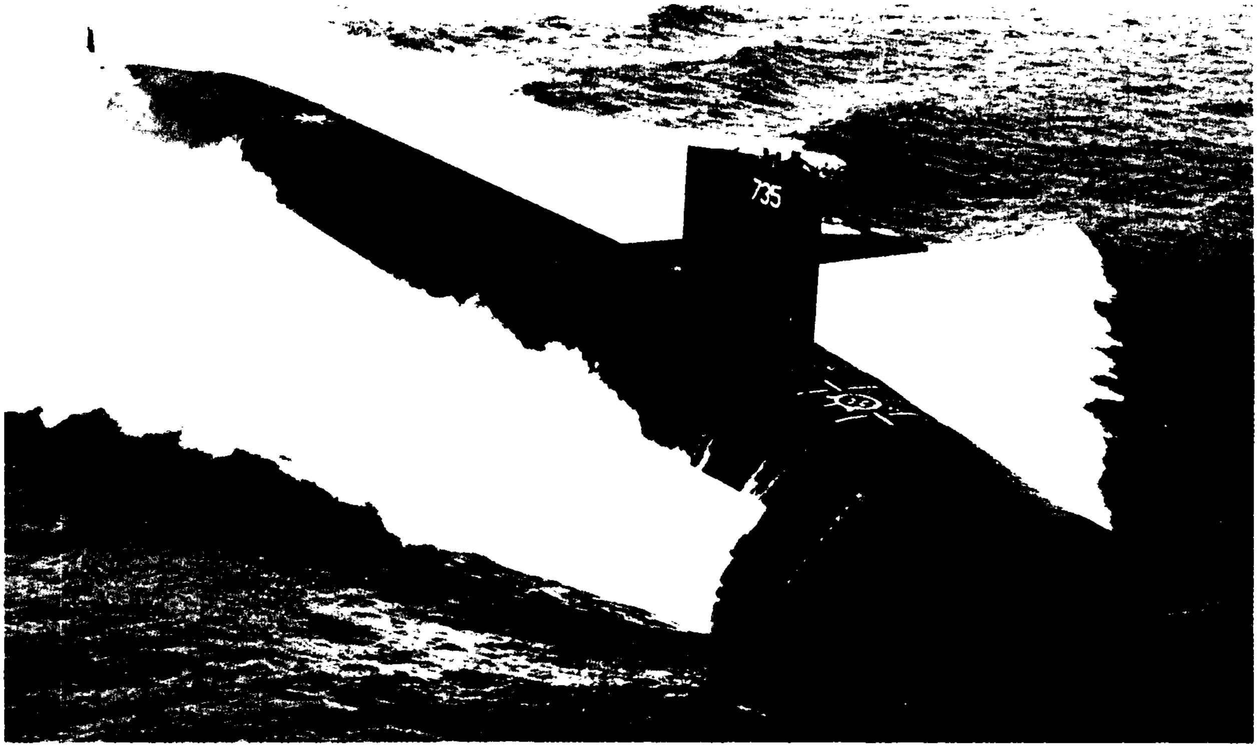
USS ALBANY (SSN 753)

USS ALBANY (SSN 753) DATA
(LOS ANGELES Class)

Length – 362 feet

Beam – 33 feet

Displacement – Surfaced: 6,000 tons; Submerged: 6,927 tons



USS PENNSYLVANIA (SSBN 735)

USS PENNSYLVANIA (SSBN 735) DATA
(OHIO Class)

Length – 560 feet

Beam – 42 feet

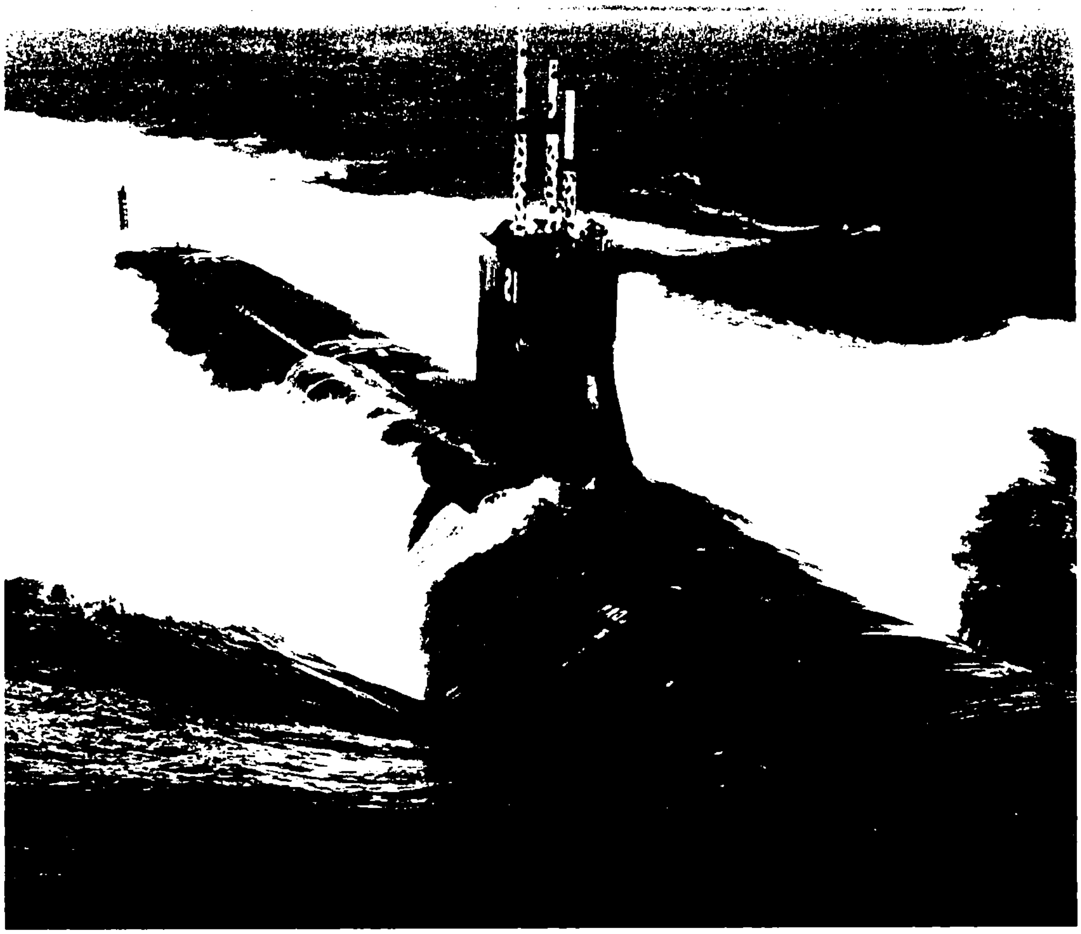
Displacement – Surfaced: 16,600 tons; Submerged: 18,700 tons

TRIDENT Ballistic Missile Submarines Virtually undetectable in the open ocean, TRIDENT submarines are quieter, better equipped, and have greater missile range than their predecessors. With an advanced-design, long-life reactor plant, and a unique, comprehensive program to ensure equipment reliability and material availability, TRIDENTs operate for long periods between servicings. TRIDENT's size (approximately 560 feet in length) provides room to incorporate future modifications and technological developments. Large hatches and a carefully planned equipment arrangement facilitate component servicing and replacement. This class comprises 14 ships.

Guided Missile Submarines Four ballistic missile submarines are being converted into guided missile submarines (SSGNs). Each SSGN will be able to covertly enter a battle space carrying unconventional payloads and up to 154 guided missiles, plus a large number of Special Operations Forces personnel. This will provide battlefield commanders with more surprise strike options, clandestine information gathering methods, and communication pathways.

SEAWOLF Class The SEAWOLF (SSN 21) Class goes faster, dives deeper and carries significantly more weapons than its predecessors. Technology developed for SEAWOLF enabling a high power-density propulsion plant, which can operate quietly over the ship's entire speed range, is being applied to future generations of nuclear-powered warships.

The newest and last of the SEAWOLF Class, USS JIMMY CARTER (SSN 23) has the same capabilities of her sister ships in addition to a unique, 100-foot, multi-mission platform (MMP). The MMP provides unprecedented payload access to the ocean, offering more flexibility and capability than conventional torpedo or vertical launch tubes in the shape or size of weapons, auxiliary vehicles, and sensors.



USS SEAWOLF (SSN 21)

USS SEAWOLF (SSN 21) DATA
(SEAWOLF Class)

Length – 353 feet (453 feet for SSN 23)

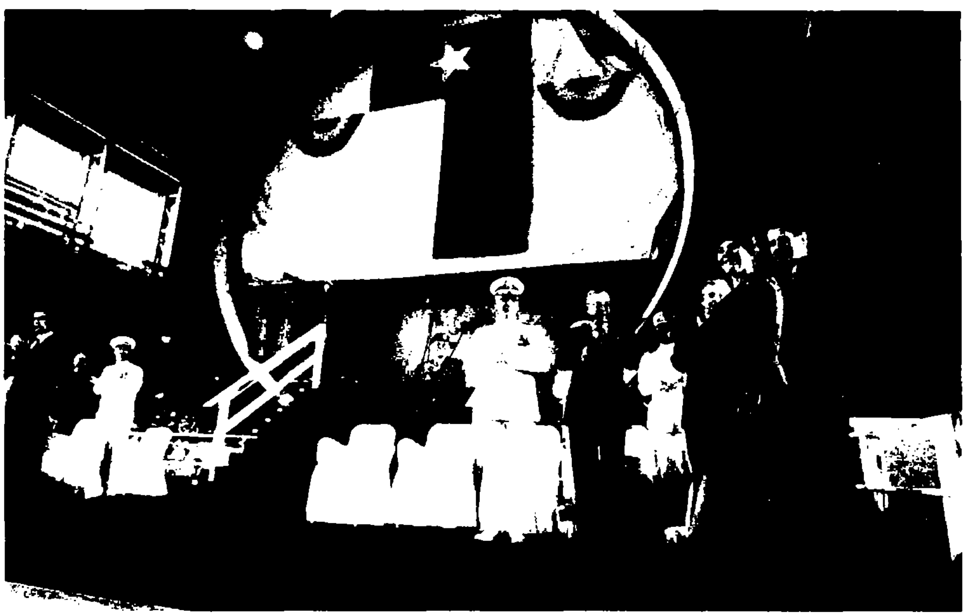
Beam – 40 feet

Displacement – Surfaced: 7,460 tons (10,860 tons for SSN 23);
Submerged: 9,150 tons (12,150 tons for SSN 23)

> *VIRGINIA's multi-mission capability is in high demand by the combatant commanders, is key to our Undersea Superiority Joint Integrating Concept and will greatly influence ongoing capabilities-based assessments.*
>
> General Richard B. Myers
> Chairman, Joint Chiefs of Staff
> September 2004

VIRGINIA Class USS VIRGINIA (SSN 774), the lead ship of this planned 30-ship class, was commissioned on October 23, 2004. VIRGINIA's delivery to the Navy in October 2004 met the schedule established by the original Acquisition Program Baseline over a decade ago. TEXAS (SSN 775), HAWAII (SSN 776), NORTH CAROLINA (SSN 777), NEW HAMPSHIRE (SSN 778), and NEW MEXICO (SSN 779), as well as seventh and eighth ships, yet to be named, are also currently under construction.

The VIRGINIA (SSN 774) Class is designed to excel in near-land ("littoral") operations while maintaining the U.S. Navy's superiority in "blue water" operations. By leveraging the technology successfully developed for the SEAWOLF program, the VIRGINIA Class will be as quiet and stealthy as the SEAWOLF Class. The VIRGINIA Class will have a reconfigurable torpedo room which can be optimized for a variety of missions, including anti-submarine warfare, strike with Tomahawk missiles, and Special Forces delivery. Technological advances have allowed significant improvements in mine detection and avoidance, sensors and surveillance, and communications.



First Lady Laura Bush at TEXAS Keel Laying Ceremony, July 12, 2002

USS VIRGINIA (SSN 774) DATA
(VIRGINIA Class)

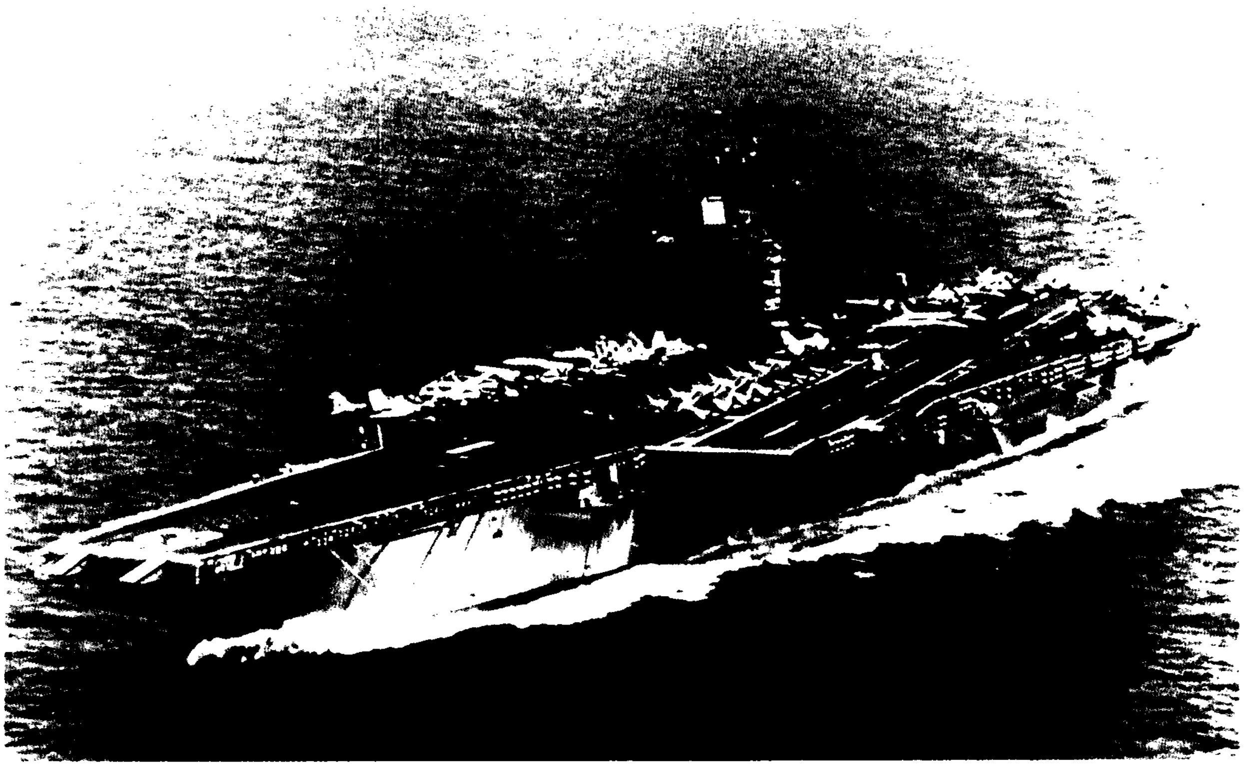
Length – 377 feet

Beam – 34 feet

Displacement – Surfaced: 6,970 tons; Submerged: 7,800 tons

Aircraft Carriers

The First Aircraft Carrier Prototype Built at the National Reactor Testing Station in southeastern Idaho, the A1W prototype plant consisted of two reactors and associated steam plant equipment necessary to drive one shaft of an aircraft carrier. A1W first operated at full power on September 15, 1959. The A1W prototype plant was permanently shut down on January 26, 1994, after more than 34 years of successful operations. Over 14,500 Navy officers and enlisted operators trained at A1W.



USS ENTERPRISE (CVN 65)

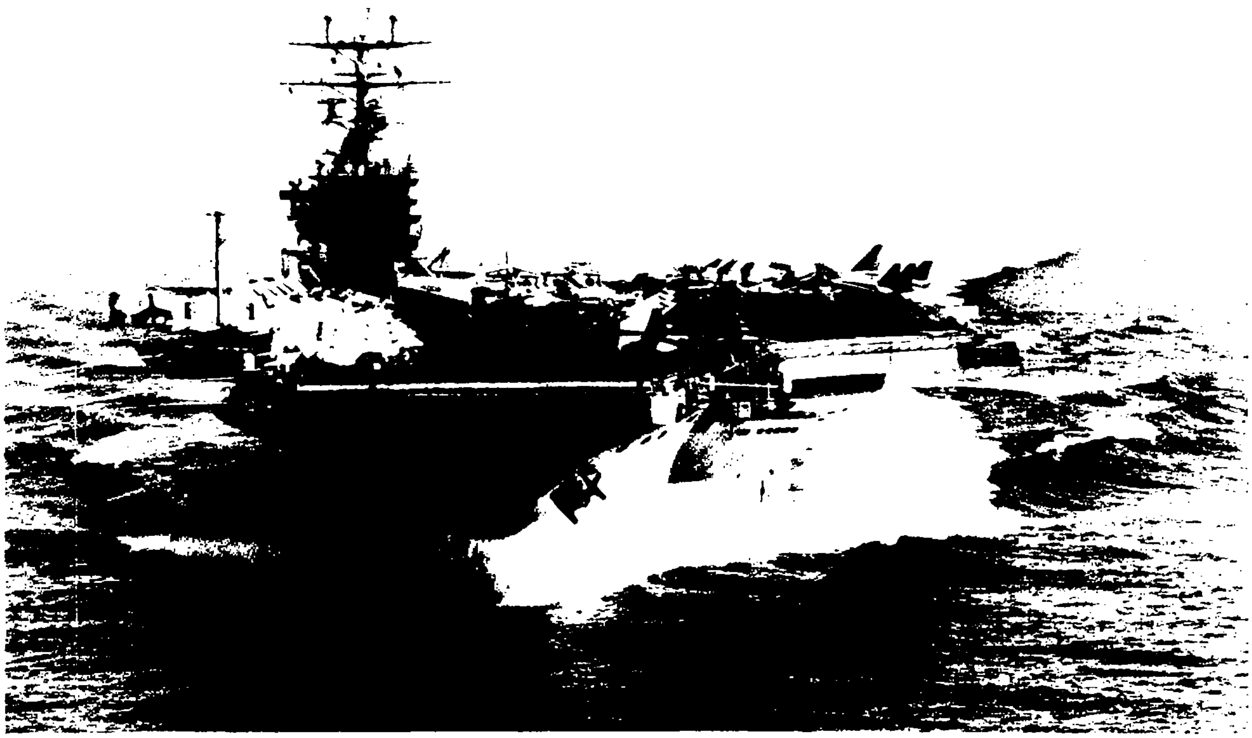
USS ENTERPRISE (CVN 65) DATA

Length – 1,123 feet

Overall Width – 257 feet

Combat Load Displacement – 93,000 tons

USS ENTERPRISE The world's first nuclear-powered aircraft carrier, USS ENTERPRISE put to sea in 1961 with eight reactors capable of propelling ENTERPRISE at speeds in excess of 30 knots. The original cores lasted three years; current ENTERPRISE cores have a life of nearly 20 years. ENTERPRISE is as tall as a 23-story building (keel to mast top), has four and a half acres of flight deck, and carries a crew (including her air wing) of over 5,000 personnel.



USS ABRAHAM LINCOLN (CVN 72) Northbound in the Arabian Sea

USS ABRAHAM LINCOLN (CVN 72) DATA
(NIMITZ Class)

Length – 1,092 feet

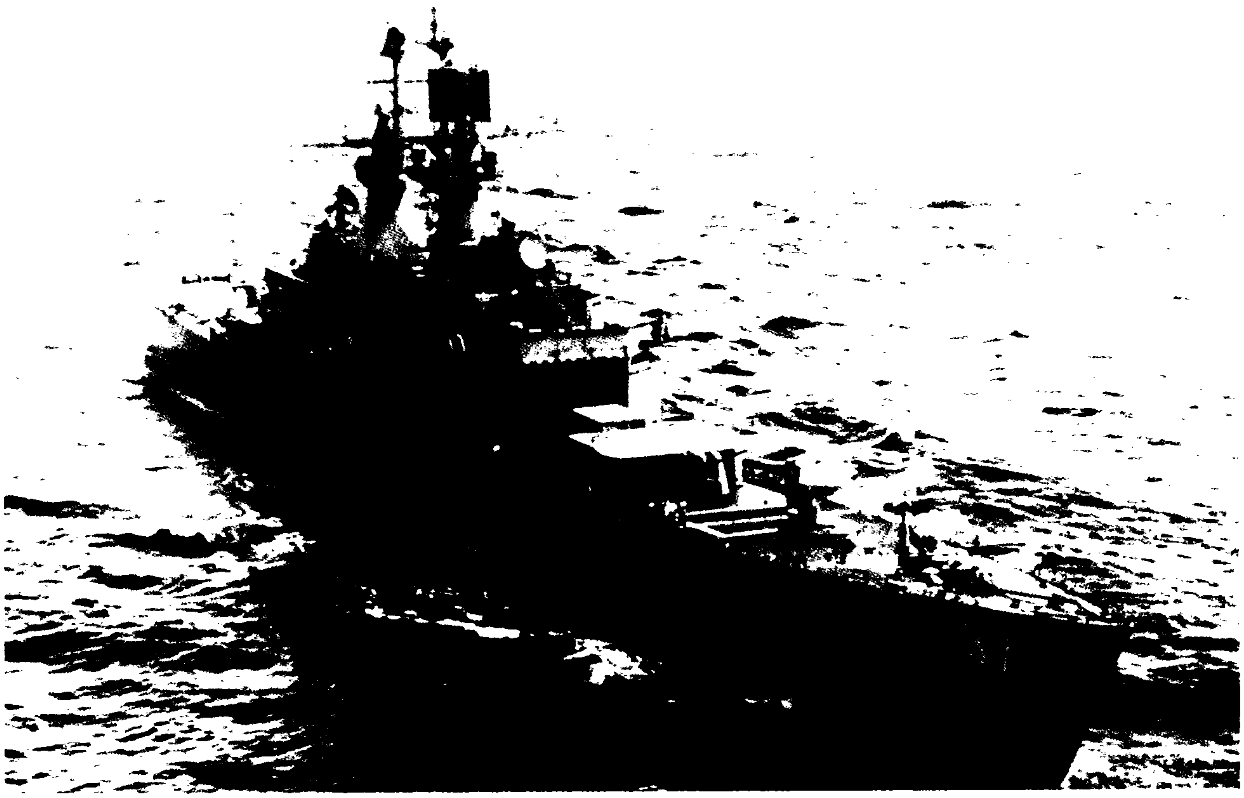
Overall Width – 257 feet

Combat Load Displacement – 97,500 tons

NIMITZ Class Success with USS ENTERPRISE led to the larger NIMITZ (CVN 68) Class aircraft carrier. A NIMITZ Class aircraft carrier's two reactors produce more power than ENTERPRISE's eight. She can store 50 percent more ammunition, can carry almost twice as much aviation fuel as the largest conventionally powered aircraft carrier, and can go over 20 years without refueling, thereby requiring only one refueling in the life of the ship. A NIMITZ Class aircraft carrier is over 18 stories tall and carries a crew (including her air wing) of over 5,500 personnel.

Cruisers

Beginning with the 17,000-ton USS LONG BEACH (CGN 9) and the 9,600-ton USS BAINBRIDGE (CGN 25), the Navy built several types of nuclear-powered cruisers. Nuclear power and multi-mission capability (anti-air, anti-surface, and anti-submarine) made these cruisers some of the most versatile ships afloat and an effective component of the Navy's Cold War force. Having proudly served, nuclear-powered cruisers have been removed from service as part of the post-Cold War downsizing of the fleet.



USS SOUTH CAROLINA (CGN 37) Underway in the Indian Ocean

USS SOUTH CAROLINA (CGN 37) DATA
(CALIFORNIA Class)

Length – 596 feet

Beam – 61 feet

Displacement – 11,320 tons

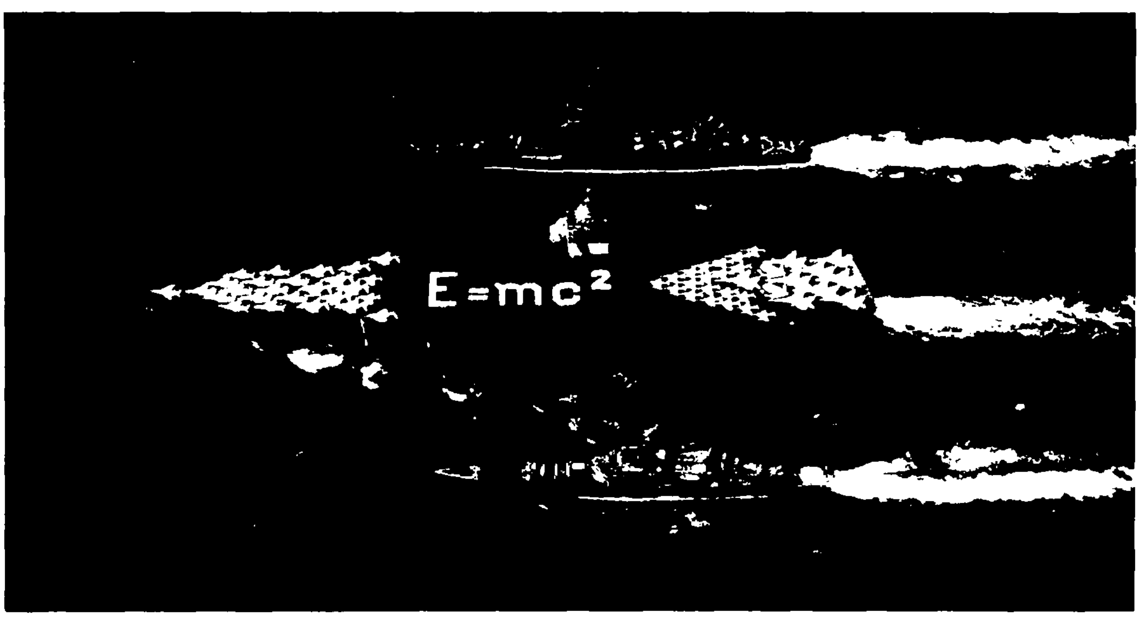
Operations

Today, U. S. Navy ships and their dedicated crews are forward-deployed around the globe, protecting the interests of the U. S. and its allies. Their forward presence provides the Nation with the cornerstone on which to build peacetime engagement, deterrence and crisis prevention, and conflict resolution. Sustaining and effectively utilizing this forward presence requires agility, mobility, flexibility, and technology. Time and again nuclear power proves itself as the power plant technology for fast response, self-sufficiency, and endurance.

Specific details of Naval nuclear-powered warship operations are classified. They cover a wide variety of activities, including thousands of ballistic missile submarine deterrent patrols; offensive and defensive exercises with other U. S. Navy and Allied units; intelligence gathering; amphibious support; escort service; special forces support; and acting as key elements in task force deployments to trouble spots around the world. The following examples are a matter of public record, and illustrate the versatility and endurance of nuclear-powered warships.

On July 31, 1964, USS ENTERPRISE (CVN 65), USS LONG BEACH (CGN 9), and USS BAINBRIDGE (CGN 25) departed the Mediterranean for a 65-day, 30,000-mile around-the-world cruise, which was carried out completely free from refueling or logistic support. The three ships, traveling under all kinds of weather conditions, made the 5,115-mile transit from Australia to Cape Horn at an average speed of better than 25 knots.

In August 1990 Iraq invaded Kuwait, resulting in an unprecedented military buildup in the Persian Gulf region to support Operation Desert Shield. Within days of the Iraqi invasion, the USS DWIGHT D. EISENHOWER (CVN 69) battle group transited the



USS ENTERPRISE (CVN 65), USS LONG BEACH (CGN 9), and USS BAINBRIDGE (CGN 25) Underway as Part of Operation Sea Orbit

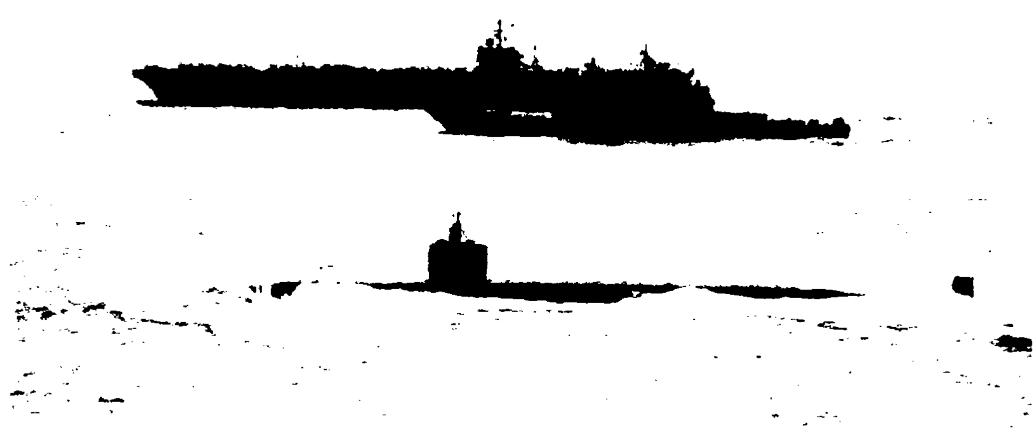
Suez Canal from the Mediterranean to the Red Sea, representing some of the first U. S. military assets to arrive on the scene. Over a dozen U. S. attack submarines conducted surveillance, reconnaissance, and other missions before and during the hostilities. As Desert Shield became Desert Storm, at least two submarines and two nuclear-powered cruisers launched Tomahawk cruise missiles against Iraq, and warplanes from USS THEODORE ROOSEVELT (CVN 71) participated in the air attack on Iraq.

During the subsequent monitoring of Iraq in 1998, increased military presence required nuclear-powered aircraft carrier USS JOHN C. STENNIS (CVN 74) to sprint from Virginia to the Persian Gulf (over 8,000 nautical miles) in 303 hours, arriving only 6 hours after her gas-turbine powered battle group escorts who left Virginia 4 days before her.

As tensions in the Persian Gulf fluctuated in the 1990s, aircraft carriers and submarines responded to add strength to our diplomacy and monitor military activities.

In March 1996, the USS NIMITZ (CVN 68) battle group was ordered from the Persian Gulf to the Taiwan Straits in response to heightened tension between China and Taiwan. Nuclear power allowed NIMITZ to remain on station in the Persian Gulf with one fossil-fueled escort, while the rest of the battle group began the transit toward East Asian waters. Five days later, NIMITZ departed the Gulf and, while enroute, refueled her escort and conducted proficiency flight operations prior to overtaking the rest of her battle group as they entered the Taiwan Straits. Several SSNs were already on station, helping to face down the crisis. Rapidly following the arrival of NIMITZ, China's maneuvers toward Taiwan ceased.

The Global War on Terrorism has again showcased the speed, independence from refueling supply chains, and on-station endurance of America's nuclear-powered warships. On September 11, 2001, the nuclear-powered aircraft carrier USS ENTERPRISE was on her way home from a six-month deployment when she learned of the deadly terrorist attacks on the U. S. via satellite TV. Even before receiving orders, ENTERPRISE executed a right full rudder order and was within



USS NIMITZ (CVN 68), Guided Missile Cruiser USS PORT ROYAL (CG 73), and USS ANNAPOLIS (SSN 760) in the North Persian Gulf striking distance of Afghanistan within eleven hours. The nuclear-powered aircraft carriers USS GEORGE WASHINGTON (CVN 73) and USS JOHN C. STENNIS quickly led battle groups to provide protection for both coasts of America. The USS CARL VINSON (CVN 70) and USS THEODORE ROOSEVELT aircraft carrier battle groups helped take the fight to the enemy, with nuclear-powered attack submarines assisting. Over the first several months of Operation ENDURING FREEDOM, over 70 percent of all precision strike missions flown into landlocked Afghanistan were launched from Navy nuclear-powered aircraft carriers, and about one-third of all Tomahawk precision missile strikes were launched from nuclear-powered submarines.

On March 19, 2003, USS CHEYENNE (SSN 773) began the second chapter in the Global War on Terrorism, Operation IRAQI FREEDOM, by launching Tomahawk missiles against the brutal regime of Saddam Hussein. When over 70 percent of the fleet surged to the theater, they arrived to a well-prepared battlespace based on intelligence and surveillance gathered by submarines, such as USS PITTSBURGH (SSN 720), and others that had been on station weeks and months before the first missiles were fired. At the end of major combat operations, nuclear-powered submarines accounted for about one-third of the more than 800 Tomahawk missiles launched against Saddam Hussein's regime, and nearly 8,000 combat and support sorties had been flown from aircraft carriers.

USS ABRAHAM LINCOLN (CVN 72) exemplified the endurance provided by nuclear propulsion with her 290-day deployment in support of Operations ENDURING FREEDOM, SOUTHERN WATCH, and IRAQI FREEDOM, in which she steamed over 100,000 miles on nuclear power. Her nearly 10-month deployment was the longest aircraft carrier deployment in 30 years. Today, nuclear-powered warships continue to bring their unique mix of capabilities to the Global War on Terrorism.

The versatility of NIMITZ Class aircraft carriers was demonstrated when ABRAHAM LINCOLN responded to the tsunami crisis in 2004, just days after being tasked, and when USS HARRY S TRUMAN (CVN 75) provided humanitarian assistance to the Gulf coast after Hurricane Katrina. Once on station, carriers provided much-needed supplies, including pure drinking water produced by nuclear power.

USS THEODORE ROOSEVELT (CVN 71)

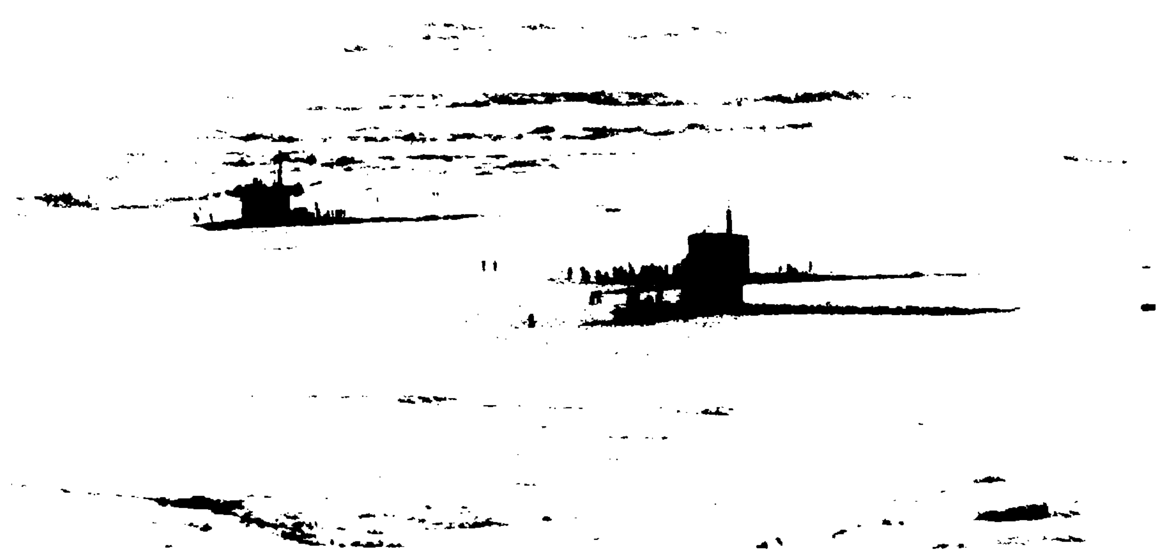
We marvel at the unparalleled stealth, speed and endurance of our Nation's submarine force. These ships, along with nuclear-powered aircraft carriers, provide our Nation with the strategic deterrence, forward presence, and capability for rapid responses to crises. To be sure, the contributions of the nuclear navy to the ongoing Global War on Terror are indisputable.

U.S. Representative Duncan Hunter
Chairman, House Armed Services Committee
September 2004

Arctic Operations

The Arctic Ocean is an important region from both a strategic and scientific standpoint. Strategically, the Arctic ice can be used as cover to approach the shores of bordering nations, including our own. Scientifically, Arctic ice and water holds information that can be used to better understand the world's ever changing environment.

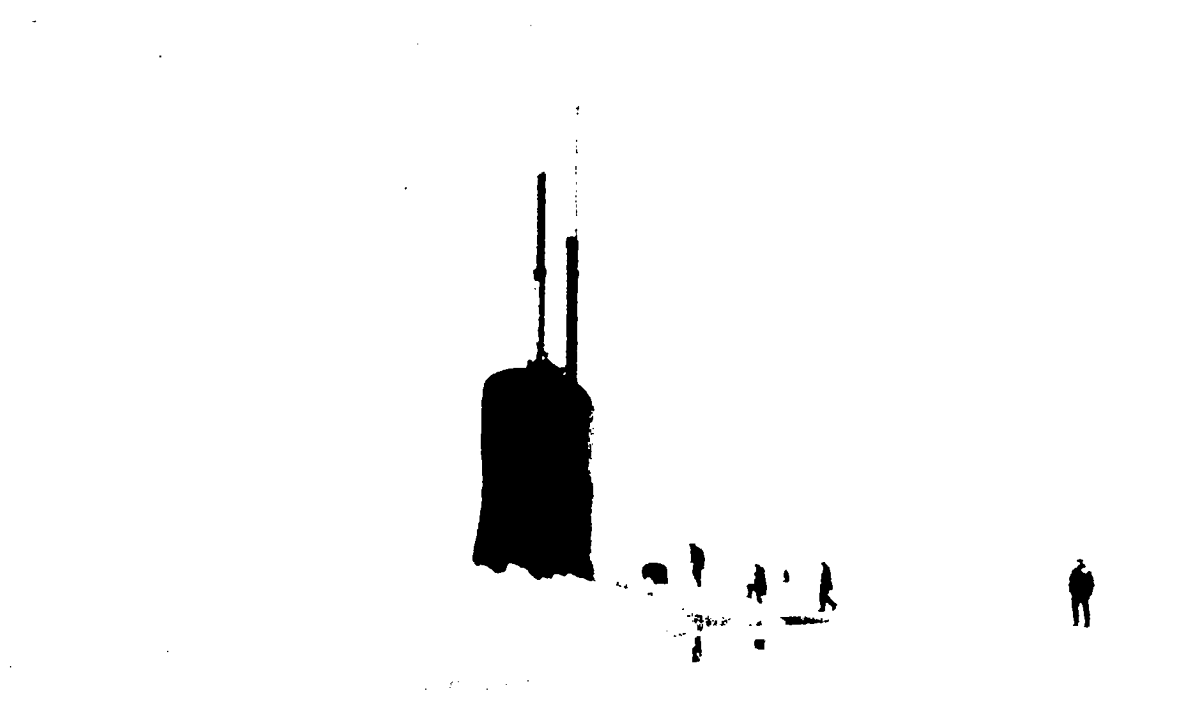
At the same time, the Arctic is one of the most challenging environments on the planet; perhaps nowhere else is the tactical flexibility provided by nuclear power more evident than in under-ice operations. A submarine operating under the ice must maneuver carefully, using special sonar equipment to avoid shifting ice packs, and keep track of clearances, not only below the ship, because the Arctic Ocean is quite shallow in many places, but above the ship as well, where thick ice extends downward. In addition, under-ice operations prevent submarine crews from relying on navigation satellites, commonly used in open waters to keep track of position, requiring instead the use of shipboard inertial navigation systems and computers which must be constantly updated through calculations based on the movement of the ship. Communication, if necessary in the Arctic, requires a submarine to locate an area of thin ice and then carefully break through to the surface.



USS RAY (SSN 653), USS HAWKBILL (SSN 666), and USS ARCHERFISH (SSN 678) Surfaced at the Geographic North Pole, May 6, 1986

The first U.S. submarine Arctic operations were conducted in 1946 when the diesel-powered submarine, USS ATULE (SS 403), conducted a brief excursion under the ice, limited by the need to recharge her batteries. In 1957, USS NAUTILUS (SSN 571) became the first nuclear-powered submarine to operate under the ice, and in 1958 she conducted the first submerged transpolar crossing, reaching the geographic North Pole on August 3, 1958. In 1959, USS SKATE (SSN 578) became the first ship to surface at the North Pole. In subsequent years, many U. S. nuclear-powered submarines have operated under, and surfaced through, the polar ice cap. In 2002, USS CONNECTICUT (SSN 22) became the first SEAWOLF Class submarine to surface from under Arctic ice.

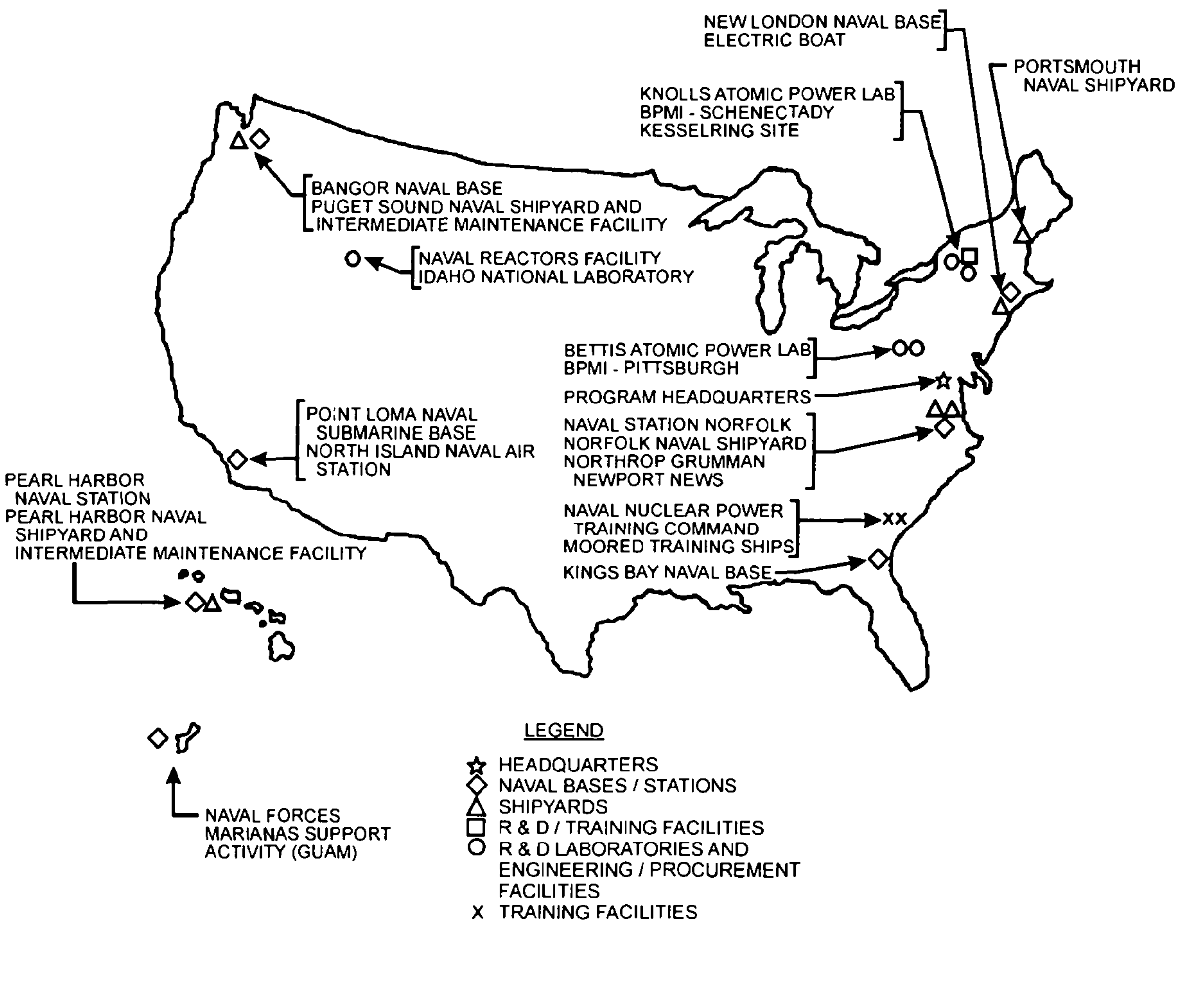
While conducting operations in the Arctic, U. S. submarines often collect data and samples for scientists to study. Occasionally, scientists embark on the submarines to carry out more sophisticated tests and experiments. In the spring of 1999, USS HAWKBILL (SSN 666) conducted an extensive mission to the Arctic to support numerous scientific studies and mapping. This mission successfully concluded a series of five Arctic expeditions conducted as a joint venture between the Navy and the National Science Foundation. As these trips under the polar ice demonstrate, nuclear power has significantly augmented our ability to explore the far reaches of our planet.



USS CONNECTICUT (SSN 22) Surfaced during ICEX 2003

Program Locations

As seen on the map below, Naval Nuclear Propulsion Program activities can be found throughout the United States. From the Portsmouth Naval Shipyard at Kittery, Maine to the submarine base at Pearl Harbor, Hawaii; from the training center at Charleston, South Carolina to the TRIDENT base at Bangor, Washington, Program interests criss-cross the nation. With submarines based in Guam and U.S. nuclear-powered vessels welcome in numerous ports throughout the world, the Navy's Nuclear Propulsion Program is truly global in scope.



Special Projects

Shippingport

Because of the Program's successful work with power reactors, President Eisenhower assigned the Program responsibility for developing the Shippingport Atomic Power Station — the world's first full-scale atomic power plant solely for the production of electricity. Operated by the Duquesne Light Company, Shippingport's pressurized water reactor (PWR) design and original cores became prototypes for the majority of commercial nuclear power stations. Other Shippingport achievements include:

- Providing power to Duquesne Light Company customers from 1957-1974 with PWR design cores.
- Available for operation about 65 percent of its life — higher than most other commercial plants at the time — despite numerous planned shutdowns for research and development purposes.
- First safeguards report for a nuclear power station.

Shippingport Atomic Power Station

Light Water Breeder Reactor (LWBR)

In the early 1960s, the AEC focused research and development efforts on liquid-metal breeder reactors which would generate more fissionable material than they would consume while producing power. Conventional wisdom was that breeding would not be possible in a PWR plant. The Program's successful development of a Light Water Breeder Reactor (LWBR) core at Shippingport dispelled that notion:

- In 1965, LWBR development began with uranium-233 as the "fissile" material, and thorium the "fertile" material. Successful use of thorium, a plentiful resource, would provide a source of energy many times greater than the known fossil fuel reserves.
- In 1977, the LWBR commenced operation at Shippingport, generating electricity for Duquesne Light Company for five years.
- The LWBR core was very reliable, achieving a level of on-line operation similar to its PWR predecessor.
- Extensive end-of-life testing confirmed that LWBR had operated as designed. In fact, breeding occurred at a rate higher than predicted. Core material performance was excellent.
- LWBR technical reports were made available to the commercial nuclear power industry.

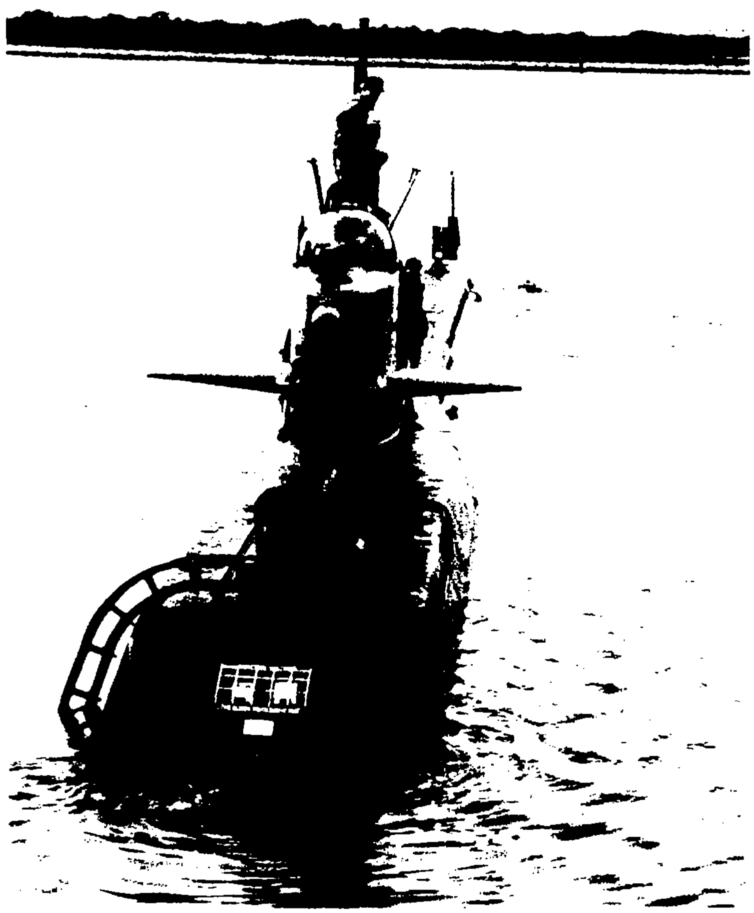
The Naval Nuclear Propulsion Program retained responsibility for Shippingport through end-of-life testing and defueling. In 1989, the Department of Energy decommissioned Shippingport, removing all radioactive components and returning the site to greenfield conditions.

Shippingport Site Today

NR-1

In 1965, the Program began development of a nuclear-powered deep-submergence research and ocean engineering vehicle, designated NR-1. The capability of this manned vehicle was far greater than any other research vessel planned or developed at that time because of the vastly increased endurance and independence from surface support made possible by nuclear power. Launched at Electric Boat, Groton in January 1969, NR-1 provides valuable service to the Navy, other U.S. Government agencies, and research and educational institutions. In addition to its small nuclear propulsion plant which provides virtually limitless submerged endurance, NR-1's characteristics include:

- A 400-ton submerged displacement, 150-foot length, and 12-foot diameter,
- Approximately 4-knot speed, two external electric motors,
- A 3,000-foot operating depth,
- Retractable bottoming wheels,
- Viewing ports, exterior lighting, and color television and still cameras for photographic studies, and
- An object recovery claw and manipulator with gripping and cutting capability.



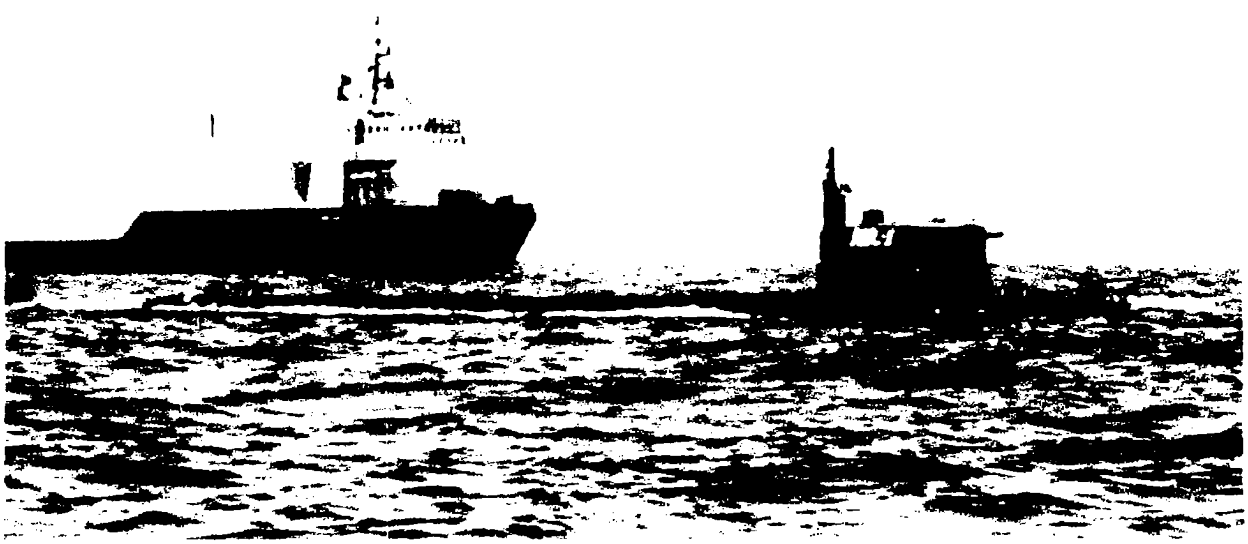
NR-1

NR-1 is equipped with sophisticated electronics and computers to aid her navigation, communications, and object location and identification. She can maneuver or hold a steady position on or close to the seabed or underwater ridges to detect and identify objects at a considerable distance and to lift objects off the ocean floor.

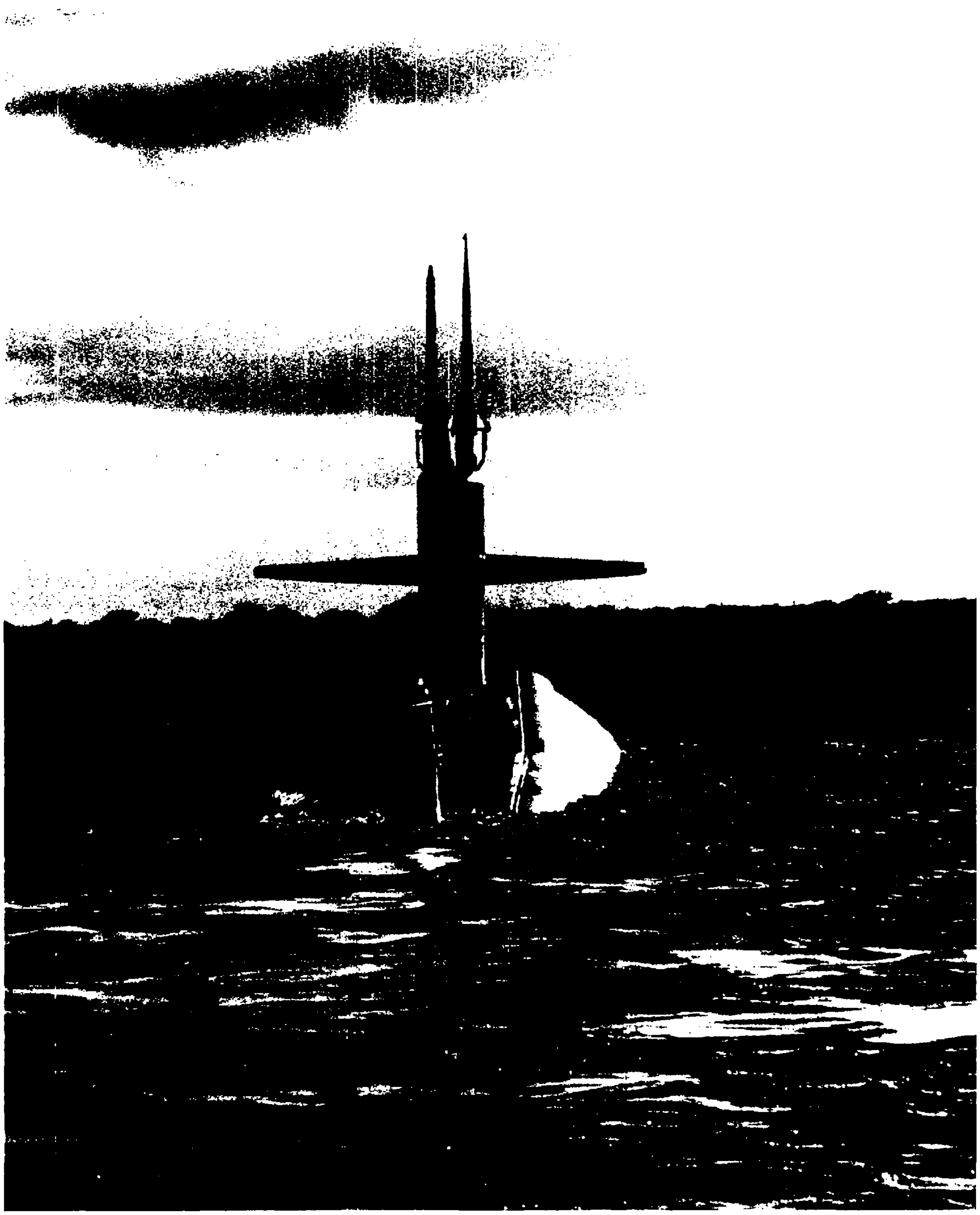
NR-1 carries a crew of five to ten specially-trained Navy volunteers and two scientists. Able to remain submerged and move at maximum speed for extended periods of time, she performs detailed studies and mapping of the ocean bottom, including temperature, currents, and other oceanographic data for military and scientific uses.

The unique capabilities of NR-1 put it in high demand in both the military and scientific communities. NR-1 can remain submerged for up to one month, allowing it to survey large areas even in inclement weather. The following are a few of NR-1's past scientific missions:

- Participating in the search, identification, and recovery of critical parts of the space shuttle CHALLENGER and Egypt Air Flight 990 wreckages;
- Exploring wreckage of RMS BRITANNIC (SS TITANIC's sister ship), which was lost in the Mediterranean during World War II under mysterious circumstances;
- Locating and surveying ancient Roman shipwrecks lost while on trading missions between Rome and Carthage;
- Participating in JASON PROJECT VII, a joint scientific and educational effort with an overall mission of engaging students in science and technology through the use of interactive telecommunications.



NR-1 with Its Support Vessel SSV CAROLYN CHOUEST Off Key Largo, Florida



USS SAN FRANCISCO (SSN 711) Underway Just Off Pearl Harbor

Program Directors – Past and Present

Admiral Hyman G. Rickover, U.S. Navy

Director:
August 4, 1948 - January 31, 1982

Admiral Rickover, the Father of the Nuclear Navy, was born in Makow, Russia, on January 27, 1900. At the age of six, he came to the United States, settling in Chicago, Illinois. Admiral Rickover entered the U.S. Naval Academy in 1918 and was commissioned an ensign in June 1922.

Following sea duty aboard the destroyer USS LA VALLETTE (DD-315) and the battleship USS NEVADA (BB-36), Admiral Rickover attended Columbia University, where he earned the degree of Master of Science in Electrical Engineering. From 1929 to 1933, he qualified for submarine duty and command aboard the submarines USS S-9 (SS 114) and USS S-48 (SS 159). In June 1937, he assumed command of the minesweeper USS FINCH (AM 9). Later that year, he was selected as an Engineering Duty Officer and spent the remainder of his career serving in that specialty.

During World War II, Admiral Rickover served as Head of the Electrical Section of the Bureau of Ships and later as Commanding Officer of the Naval Repair Base, Okinawa. In 1946, he was assigned to the Atomic Energy Commission laboratory at Oak Ridge, Tennessee and, in early 1949, to the Division of Reactor Development, U.S. AEC.

As director of the Naval Reactors Branch, Admiral Rickover developed the world's first nuclear-powered submarine, USS NAUTILUS (SSN 571), which went to sea in 1955. In the years that followed, Admiral Rickover directed all aspects of building and operating the nuclear fleet.

Admiral Rickover's numerous medals and decorations include the Distinguished Service Medal, Legion of Merit, Navy Commendation Medal, and the World War II Victory Medal. In recognition of his wartime service, he was made Honorary Commander of the Military Division of the Most Excellent Order of the British Empire.

Admiral Rickover was twice awarded the Congressional Gold Medal for exceptional public service. In 1980, President Jimmy Carter presented Admiral Rickover with the Presidential Medal of Freedom, the nation's highest non-military honor, for his contributions to world peace.

Admiral Rickover retired from the United States Navy on January 31, 1982, after over 63 years of service to his country and to 13 Presidents. His name is memorialized in the attack submarine USS HYMAN G. RICKOVER (SSN 709) and Rickover Hall at the U.S. Naval Academy. Admiral Rickover died on July 8, 1986, and is buried in Arlington National Cemetery. In December 1999, the Engineering Honor Society Tau Beta Pi named Admiral Rickover as one of the Top Ten Engineers of the Twentieth Century.

Admiral Kinnaird R. McKee, U.S. Navy

Director:
February 1, 1982 - October 21, 1988

Admiral Kinnaird R. McKee was born in Louisville, Kentucky, on August 14, 1929, and graduated from the United States Naval Academy in 1951. He served in the Pacific fleet destroyer USS MARSHALL (DD 676) during the Korean War and in eight submarines of the Atlantic fleet since that time. After completion of submarine training in 1953, he served in three diesel-powered submarines: USS PICUDA (SS 382), USS SEA CAT (SS 399), and USS MARLIN (SST-2). In 1956, Admiral McKee was ordered to command of USS X-1, a small experimental submarine. He graduated from nuclear power training in 1958 and joined the commissioning crew of USS SKIPJACK (SSN 585), the Navy's first high-performance nuclear-powered attack submarine. Assignment as Executive Officer of USS NAUTILUS (SSN 571) followed in 1961, then of the USS SAM HOUSTON (SSBN 609) in late 1962. After three deterrent patrols in SAM HOUSTON, he served in the Naval Reactors Division of the Atomic Energy Commission from 1964 to 1966.

Admiral McKee served as Commanding Officer of the nuclear-powered attack submarine USS DACE (SSN 607) from 1966 through 1969. The ship was twice awarded the Navy Unit Commendation and three times the Battle Efficiency Pennant for operations during that period. Following command of DACE, Admiral McKee served in the office of the Director, Navy Program Planning, where his responsibilities included strategic warfare, research and development, and submarine and anti-submarine warfare systems. In 1970, he was assigned to the immediate staff of the Chief of Naval Operations, where he established the CNO Executive Panel. As Commander, Submarine Group Eight, Admiral McKee served as the NATO and U. S. Submarine Commander in the Mediterranean from 1973 to 1975. On August 1, 1975, he became the forty-eighth Superintendent of the U.S. Naval Academy. Promoted to three-star rank in March 1978, Admiral McKee served as Commander, Third Fleet with headquarters in Pearl Harbor. He was then assigned as Director, Naval Warfare, Office of the Chief of Naval Operations concurrent with the expansion of the directorate from its original concentration on anti-submarine warfare to responsibility for all aspects of naval warfare. He developed and implemented the new organization.

On February 1, 1982, he relieved Admiral H. G. Rickover as the Director, Naval Nuclear Propulsion. On March 2, 1982, he was confirmed by the U.S. Senate for promotion to four-star rank.

Admiral McKee retired on October 31, 1988, after 41 years of service to his country.

Admiral McKee's decorations include the Distinguished Service Medal, five awards of the Legion of Merit, and three awards of the Navy Unit Commendation.

Admiral Bruce DeMars, U.S. Navy

Director:
October 22, 1988 - September 26, 1996

Admiral Bruce DeMars was born in Chicago, Illinois, on June 3, 1935, and graduated from the United States Naval Academy in 1957. Following commissioning, he served in the attack transports USS TELFAIR (APA 210) and USS OKANOGAN (APA 220) and, after Submarine School, the diesel-electric submarine USS CAPITAINE (SS 336). Following nuclear power training, he served in the nuclear-powered submarines USS GEORGE WASHINGTON (SSBN 598), USS SNOOK (SSN 592), and USS STURGEON (SSN 637) before reporting for duty as Commanding Officer of USS CAVALLA (SSN 684).

Shore duty tours included instructor duty at Nuclear Power School and Submarine School and attendance at the Armed Forces Staff College. Following staff duty with Squadron TEN, Admiral DeMars served as Senior Member of the Nuclear Propulsion Examining Board, U.S. Atlantic Fleet. He commanded Submarine Development Squadron TWELVE in New London, Connecticut and then served as Deputy Director, Attack Submarine Division in the Office of the Chief of Naval Operations, until selected for promotion to Rear Admiral in 1981.

As a flag officer, Admiral DeMars served as Commander, U.S. Naval Forces Marianas/Commander, U.S. Naval Base Guam; as Commander in Chief, Pacific Representative for Guam and the Trust Territory of the Pacific Islands; and as Deputy Assistant Chief and then Deputy Chief of Naval Operations for Submarine Warfare.

On September 30, 1988, he was confirmed by the U.S. Senate for promotion to four-star rank. On October 22, 1988, he relieved Admiral McKee as Director, Naval Nuclear Propulsion.

Admiral DeMars retired on October 1, 1996, after 43 years of service to his country.

Admiral DeMars' decorations include the Distinguished Service Medal, four awards of the Legion of Merit, two awards of the Meritorious Service Medal, two awards of the Navy Commendation Medal, the Navy Achievement Medal, and the Navy Unit Commendation.

Admiral Frank L. Bowman, U.S. Navy

Director:
September 27, 1996 - November 4, 2004

Admiral Frank L. "Skip" Bowman was born and grew up in Chattanooga, Tennessee. He was commissioned following graduation from Duke University. In 1973, he completed a dual master's program in nuclear engineering and Naval architecture/marine engineering at the Massachusetts Institute of Technology and was elected to the Society of Sigma Xi. Admiral Bowman serves on two visiting committees at MIT (Ocean Engineering and Nuclear Engineering), the Engineering Board of Visitors at Duke University, and the Nuclear Engineering Department Advisory Committee at the University of Tennessee.

His early assignments included tours in USS SIMON BOLIVAR (SSBN 641), USS POGY (SSN 647), USS DANIEL BOONE (SSBN 629), and USS BREMERTON (SSN 698). In 1983, Admiral Bowman took command of USS CITY OF CORPUS CHRISTI (SSN 705), which completed a seven-month circumnavigation of the globe and two special classified missions during his command tour. His crew earned three consecutive Battle Efficiency "E" awards. Admiral Bowman later commanded the tender USS HOLLAND (AS 32) from August 1988 to April 1990. During this period, the HOLLAND crew was awarded two Battle Efficiency "E" awards.

Ashore, Admiral Bowman has served on the staff of Commander, Submarine Squadron FIFTEEN, in Guam; twice in the Bureau of Naval Personnel in the Submarine Policy and Assignment Division; as the SSN 21 Attack Submarine Program Coordinator on the staff of the Chief of Naval Operations; on the Chief of Naval Operations' Strategic Studies Group; and as Executive Assistant to the Deputy Chief of Naval Operations (Naval Warfare). In December 1991, he was promoted to flag rank and assigned as Deputy Director of Operations on the Joint Staff (J-3) until June 1992, and then as Director for Political-Military Affairs (J-5) until July 1994. Admiral Bowman served as Chief of Naval Personnel from July 1994 to September 1996.

Admiral Bowman assumed duties as Director, Naval Nuclear Propulsion, on September 27, 1996, and was promoted to the four-star rank on October 1, 1996.

Admiral Bowman retired on January 1, 2005, after more than 38 years of service.

Under his command, his crews have earned the Meritorious Unit Commendation (three awards), the Navy Battle Efficiency "E" Ribbon (five awards), the Navy Expeditionary Medal (two awards), the Humanitarian Service Medal (two awards), the Sea Service Deployment Ribbon (three awards), and the Navy Arctic Service Ribbon. His personal awards include the Defense Distinguished Service Medal, the Navy Distinguished Service Medal, the Legion of Merit (with three gold stars), and the *Officier de l'Ordre National du Mérite* from the Government of France.

Admiral Kirkland H. Donald, U.S. Navy

Director:
November 5, 2004 - Present

Admiral Donald assumed duties as Director, Naval Nuclear Propulsion, on November 5, 2004.

Originally from Norlina, North Carolina, he graduated from the U.S. Naval Academy in 1975 with a Bachelor of Science in Ocean Engineering.

After nuclear power and submarine training, he served in USS BATFISH (SSN 681), USS MARIANO G. VALLEJO (SSBN 658), AND USS SEAHORSE (SSN 669).

Admiral Donald was Commanding Officer of USS KEY WEST (SSN 722) from October 1990 to February 1993. He served as Commander, Submarine Development Squadron Twelve from August 1995 to July 1997. From June 2002 to July 2003, he was assigned as Commander, Submarine Group 8; Commander, Submarine Force SIXTH Fleet (CTF 69); Commander, Submarines Allied Naval Forces South; and Commander, Fleet Ballistic Missile Submarine Force (CTF 164) in Naples, Italy. Most recently, he served as Commander, Naval Submarine Forces; Commander, Submarine Force, U.S. Atlantic Fleet; Commander, Allied Submarine Command; and Commander, Task Forces 84 and 144.

His shore assignments include the Pacific Fleet Nuclear Propulsion Examining Board and the staff of the Director, Naval Nuclear Propulsion. He also served at the Bureau of Naval Personnel, on the Joint Staff, and as Deputy Chief of Staff for C4I, Resources, Requirements and Assessments, U.S. Pacific Fleet.

Admiral Donald holds a Masters in Business Administration from the University of Phoenix and is a graduate of Harvard University's John F. Kennedy School of Government Senior Executive Fellows Program.

Admiral Donald is authorized to wear the Navy Distinguished Service Medal, Defense Superior Service Medal, Legion of Merit with four Gold Stars, and the Meritorious Service Medal with one Gold Star in addition to several other personal and unit awards.

Program Statistics

(As of March 2006)

Active Nuclear-powered Combat Submarines:	71
Active Nuclear-powered Aircraft Carriers:	10
Active Nuclear-powered Research Vessels:	1
Total Active Nuclear-powered Ships:	**82**
Total Nuclear-powered Ships Built	214
Number of Miles Steamed on Nuclear Power:	Over 134,000,000
Number of Reactor-years of Operation:	Over 5,700
Number of Officers Trained or in Training:	Over 20,000
Number of Enlisted Personnel Trained or in Training:	Over 96,100
Number of Civilians Trained or in Training:	Over 1,700
Total Number of Cores Taken Critical (including refuelings):	510
Number of Reactors Currently in Operation:	103
Percentage of Major Navy Combatants that are Nuclear-powered:	Approximately 40%

A 688 Class Attack Submarine Surfacing

U. S. Nuclear-powered Ship Program Summary

	Authorized By Congress	Under Construction	In Commission	Decommissioned
VIRGINIA (SSN 774) Class	10*	7	1	0
SEAWOLF (SSN 21) Class	3	0	3	0
LOS ANGELES (SSN 688) Class	62	0	50**	12
Other Fast Attack Submarines	68	0	0	69***
Total Fast Attack Submarines	**143**	**7**	**54****	**81**
TRIDENT/USS OHIO (SSBN 726) Class	18****	0	14****	0
POLARIS/POSEIDON submarines	41	0	0	40***
Total Ballistic Missile Submarines	**59**	**0**	**14********	**40******
SSBNs undergoing SSGN conversion	**0**	**0**	**4********	**0**
Total Submarines	**202**	**7**	**72****	**121**
Research Vessels (NR-1)	**1**	**0**	**1**	**0**
Nuclear-powered Aircraft Carriers	12	1	10	0
Nuclear-powered Guided Missile Cruisers	9	0	0	9
Total Nuclear-powered Surface Ships	**21**	**1**	**10**	**9**
Total Nuclear-powered Ships	**224**	**8**	**83**	**130**

*This includes five submarines authorized under multiyear procurement through FY 08.

**SSN 716 is undergoing inactivation but still in commission as of March 2006.

***One ship originally authorized by Congress as a Fleet Ballistic Missile submarine was converted to a fast attack submarine.

****Four SSBNs have been funded for conversion to SSGN. All four SSBNs have been removed from strategic service and designated SSGN.

U. S. Nuclear-powered Submarines

SSN–Fast Attack Submarine SSBN–Ballistic Missile Submarine

Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
SSN 571	NAUTILUS	**571**	Electric Boat	1952	6-14-52	1-21-54	9-30-54	3-3-80
SSN 575	SEAWOLF	**575**	Electric Boat	1953	9-15-53	7-21-55	3-30-57	3-31-87
SSN 578	SKATE	**578**	Electric Boat	1955	7-21-55	5-16-57	12-23-57	9-12-86
SSN 579	SWORDFISH	578	Portsmouth	1955	1-25-56	8-27-57	9-15-58	6-2-89
SSN 583	SARGO	578	Mare Island	1956	2-21-56	10-10-57	10-1-58	2-26-88
SSN 584	SEADRAGON	578	Portsmouth	1956	6-20-56	8-16-58	12-5-59	6-12-84
SSN 585	SKIPJACK	**585**	Electric Boat	1956	5-29-56	5-26-58	4-15-59	4-19-90
SSN 586	TRITON	**586**	Electric Boat	1956	5-29-56	8-19-58	11-10-59	5-3-69
SSN 587	HALIBUT	**587**	Mare Island	1956	4-11-57	1-9-59	1-4-60	6-30-76
SSN 588	SCAMP	585	Mare Island	1957	1-23-59	10-8-60	6-5-61	4-28-88
SSN 589	SCORPION	585	Electric Boat	1957	8-20-58	12-19-59	7-29-60	Lost at sea on 5-22-68
SSN 590	SCULPIN	585	Ingalls	1957	2-3-58	3-31-60	6-1-61	8-3-90
SSN 591	SHARK	585	Newport News	1957	2-24-58	3-16-60	2-9-61	9-11-90
SSN 592	SNOOK	585	Ingalls	1957	4-7-58	10-31-60	10-24-61	10-8-86
SSN 593	THRESHER	594	Portsmouth	1957	5-28-58	7-9-60	8-3-61	Lost at sea on 4-10-63
SSN 594	PERMIT	**594**	Mare Island	1958	7-16-59	7-1-61	5-29-62	7-18-91
SSN 595	PLUNGER	594	Mare Island	1958	3-2-60	12-9-61	11-21-62	1-3-90
SSN 596	BARB	594	Ingalls	1958	11-9-59	2-12-62	8-24-63	12-20-89
SSN 597	TULLIBEE	**597**	Electric Boat	1958	5-26-58	4-27-60	11-9-60	6-25-88
SSBN 598	GEORGE WASHINGTON	**598**	Electric Boat	1958	11-1-57	6-9-59	12-30-59	1-24-85
SSBN 599	PATRICK HENRY	598	Electric Boat	1958	5-26-58	9-22-59	4-9-60	5-25-84
SSBN 600	THEODORE ROOSEVELT	598	Mare Island	1958	5-28-58	10-3-59	2-13-61	2-28-81
SSBN 601	ROBERT E. LEE	598	Newport News	1959	8-25-58	12-18-59	9-16-60	11-30-83
SSBN 602	ABRAHAM LINCOLN	598	Portsmouth	1959	11-1-58	5-14-60	3-8-61	2-28-81
SSN 603	POLLACK	594	NY Shipbuilding	1959	3-14-60	3-17-62	5-26-64	3-1-89
SSN 604	HADDO	594	NY Shipbuilding	1959	9-9-60	8-18-62	12-16-64	6-12-91
SSN 605	JACK	594	Portsmouth	1959	9-16-60	4-24-63	3-31-67	7-11-90
SSN 606	TINOSA	594	Portsmouth	1959	11-24-59	12-9-61	10-17-64	1-15-92
SSN 607	DACE	594	Ingalls	1959	6-6-60	8-18-62	4-4-64	12-2-88
SSBN 608	ETHAN ALLEN	**608**	Electric Boat	1959	9-14-59	11-22-60	8-8-61	3-31-83

Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
SSBN 609	SAM HOUSTON	608	Newport News	1959	12-28-59	2-2-61	3-6-62	9-20-91
SSBN 610	THOMAS A. EDISON	608	Electric Boat	1959	3-15-60	6-15-61	3-10-62	11-30-83
SSBN 611	JOHN MARSHALL	608	Newport News	1959	4-4-60	7-15-61	5-21-62	7-22-92
SSN 612	GUARDFISH	594	NY Shipbuilding	1960	2-28-61	5-15-65	12-20-66	2-4-92
SSN 613	FLASHER	594	Electric Boat	1960	4-14-61	6-22-63	7-22-66	5-26-92
SSN 614	GREENLING	594	Quincy	1960	8-15-61	4-4-64	11-3-67	4-18-94
SSN 615	GATO	594	Quincy	1960	12-15-61	5-14-64	1-25-68	4-24-96
SSBN 616	LAFAYETTE	**616**	Electric Boat	1961	1-17-61	5-8-62	4-23-63	8-12-91
SSBN 617	ALEXANDER HAMILTON	616	Electric Boat	1961	6-26-61	8-18-62	6-27-63	2-23-93
SSBN 618	THOMAS JEFFERSON	608	Newport News	1961	2-3-61	2-24-62	1-4-63	1-24-85
SSBN 619	ANDREW JACKSON	616	Mare Island	1961	4-26-61	9-15-62	7-3-63	8-28-89
SSBN 620	JOHN ADAMS	616	Portsmouth	1961	5-19-61	1-12-63	5-12-64	3-24-89
SSN 621	HADDOCK	594	Ingalls	1961	4-24-61	5-21-66	12-22-67	4-7-93
SSBN 622	JAMES MONROE	616	Newport News	1961	7-31-61	8-4-62	12-7-63	9-25-90
SSBN 623	NATHAN HALE	616	Electric Boat	1961	10-2-61	1-12-63	11-23-63	11-3-86
SSBN 624	WOODROW WILSON	616	Mare Island	1961	9-13-61	2-22-63	12-27-63	9-1-94
SSBN 625	HENRY CLAY	616	Newport News	1961	10-23-61	11-30-62	2-20-64	11-6-90
SSBN 626	DANIEL WEBSTER[1]	616	Electric Boat	1961	12-28-61	4-27-63	4-9-64	2-4-93
SSBN 627	JAMES MADISON	**627**	Newport News	1962	3-5-62	3-15-63	7-28-64	11-20-92
SSBN 628	TECUMSEH	627	Electric Boat	1962	6-1-62	6-22-63	5-29-64	7-23-93
SSBN 629	DANIEL BOONE	627	Mare Island	1962	2-6-62	6-22-63	4-23-64	2-4-94
SSBN 630	JOHN C. CALHOUN	627	Newport News	1962	6-4-62	6-22-63	9-15-64	3-11-94
SSBN 631	ULYSSES S. GRANT	627	Electric Boat	1962	8-18-62	11-2-63	7-17-64	6-12-92
SSBN 632	VON STEUBEN	627	Newport News	1962	9-4-62	10-18-63	9-30-64	2-26-94
SSBN 633	CASIMIR PULASKI	627	Electric Boat	1962	1-12-63	2-1-64	8-14-64	3-7-94
SSBN 634	STONEWALL JACKSON	627	Mare Island	1962	7-4-62	11-30-63	8-26-64	2-9-95
SSBN 635	SAM RAYBURN[1]	627	Newport News	1962	12-3-62	12-20-63	12-2-64	8-28-89
SSBN 636	NATHANAEL GREENE	627	Portsmouth	1962	5-21-62	5-12-64	12-19-64	12-12-86
SSN 637	STURGEON	**637**	Electric Boat	1962	8-10-63	2-26-66	3-3-67	8-1-94
SSN 638	WHALE	637	Quincy	1962	5-27-64	10-14-66	10-12-68	6-25-96
SSN 639	TAUTOG	637	Ingalls	1962	1-27-64	4-15-67	8-17-68	4-10-97
SSBN 640	BENJAMIN FRANKLIN	**640**	Electric Boat	1963	5-25-63	12-5-64	10-22-65	11-23-93

[1]Removed from sea-going service and converted to training platforms: Moored Training Ship MTS-635 in 1989 and Moored Training Ship MTS-626 in 1993.

Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
SSBN 641	SIMON BOLIVAR	640	Newport News	1963	4-17-63	8-22-64	10-29-65	2-24-95
SSBN 642	KAMEHAMEHA[1]	640	Mare Island	1963	5-2-63	1-16-65	12-10-65	4-2-02
SSBN 643	GEORGE BANCROFT	640	Electric Boat	1963	8-24-63	3-20-65	1-22-66	9-21-93
SSBN 644	LEWIS AND CLARK	640	Newport News	1963	7-29-63	11-21-64	12-22-65	8-1-92
SSBN 645	JAMES K. POLK	640	Electric Boat	1963	11-23-63	5-22-65	4-16-66	7-9-99
SSN 646	GRAYLING	637	Portsmouth	1963	5-12-64	6-22-67	10-11-69	7-2-97
SSN 647	POGY	637	NY Shipbuilding/ Ingalls	1963	5-4-64	6-3-67	5-15-71	6-11-99
SSN 648	ASPRO	637	Ingalls	1963	11-23-64	11-29-67	2-20-69	3-31-95
SSN 649	SUNFISH	637	Quincy	1963	1-15-65	10-14-66	3-15-69	3-31-97
SSN 650	PARGO	637	Electric Boat	1963	6-3-64	9-17-66	1-5-68	4-14-95
SSN 651	QUEENFISH	637	Newport News	1963	5-11-64	2-25-66	12-6-66	11-8-91
SSN 652	PUFFER	637	Ingalls	1963	2-8-65	3-30-68	8-9-69	7-12-96
SSN 653	RAY	637	Newport News	1963	1-4-65	6-21-66	4-12-67	3-16-93
SSBN 654	GEORGE C. MARSHALL	640	Newport News	1964	3-2-64	5-21-65	4-29-66	9-24-92
SSBN 655	HENRY L. STIMSON	640	Electric Boat	1964	4-4-64	11-13-65	8-20-66	5-5-93
SSBN 656	GEORGE WASHINGTON CARVER	640	Newport News	1964	8-24-64	8-14-65	6-15-66	3-18-93
SSBN 657	FRANCIS SCOTT KEY	640	Electric Boat	1964	12-5-64	4-23-66	12-3-66	9-7-93
SSBN 658	MARIANO G. VALLEJO	640	Mare Island	1964	7-7-64	10-23-65	12-16-66	3-9-95
SSBN 659	WILL ROGERS	640	Electric Boat	1964	3-20-65	7-21-66	4-1-67	4-12-93
SSN 660	SAND LANCE	637	Portsmouth	1964	1-15-65	11-11-69	9-25-71	8-4-98
SSN 661	LAPON	637	Newport News	1964	7-26-65	12-16-66	12-14-67	8-18-92
SSN 662	GURNARD	637	Mare Island	1964	12-22-64	5-20-67	12-6-68	4-28-95
SSN 663	HAMMERHEAD	637	Newport News	1964	11-29-65	4-14-67	6-28-68	4-5-95
SSN 664	SEA DEVIL	637	Newport News	1964	4-12-66	10-5-67	1-30-69	10-16-91
SSN 665	GUITARRO	637	Mare Island	1965	12-9-65	7-27-68	9-9-72	5-29-92
SSN 666	HAWKBILL	637	Mare Island	1965	9-12-66	4-12-69	2-4-71	3-15-00
SSN 667	BERGALL	637	Electric Boat	1965	4-16-66	2-17-68	6-13-69	6-6-96
SSN 668	SPADEFISH	637	Newport News	1965	12-21-66	5-15-68	8-14-69	4-11-97
SSN 669	SEA HORSE	637	Electric Boat	1965	8-13-66	6-15-68	9-19-69	8-17-95
SSN 670	FINBACK	637	Newport News	1965	6-26-67	12-7-68	2-4-70	3-28-97
SSN 671	NARWHAL	**671**	Electric Boat	1964	1-17-66	9-9-67	7-12-69	1-31-00
SSN 672	PINTADO	637	Mare Island	1966	10-27-67	8-16-69	9-11-71	2-26-98
SSN 673	FLYING FISH	637	Electric Boat	1966	6-30-67	5-17-69	4-29-70	5-16-96

[1]USS KAMEHAMEHA (SSBN 642) was redesignated as an attack submarine on 8-31-92.

Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
SSN 674	TREPANG	637	Electric Boat	1966	10-28-67	9-27-69	8-14-70	6-1-99
SSN 675	BLUEFISH	637	Electric Boat	1966	3-13-68	1-10-70	1-8-71	5-31-96
SSN 676	BILLFISH	637	Electric Boat	1966	9-20-68	5-1-70	3-12-71	7-1-99
SSN 677	DRUM	637	Mare Island	1966	8-20-68	5-23-70	4-15-72	10-30-95
SSN 678	ARCHERFISH	637	Electric Boat	1967	6-19-69	1-16-71	12-17-71	3-31-98
SSN 679	SILVERSIDES	637	Electric Boat	1967	10-13-69	6-4-71	5-5-72	7-22-94
SSN 680	WILLIAM H. BATES	637	Ingalls	1967	8-4-69	12-11-71	5-5-73	2-11-00
SSN 681	BATFISH	637	Electric Boat	1967	2-9-70	10-9-71	9-1-72	8-1-99
SSN 682	TUNNY	637	Ingalls	1967	5-22-70	6-10-72	1-26-74	3-13-98
SSN 683	PARCHE	637	Ingalls	1968	12-10-70	1-13-73	8-17-74	7-18-05
SSN 684	CAVALLA	637	Electric Boat	1968	6-4-70	2-19-72	2-9-73	3-31-98
SSN 685	GLENARD P. LIPSCOMB	**685**	Electric Boat	1968	6-5-71	8-4-73	12-21-74	7-11-90
SSN 686	L. MENDEL RIVERS	637	Newport News	1969	6-26-71	6-2-73	2-1-75	5-10-01
SSN 687	RICHARD B. RUSSELL	637	Newport News	1969	10-19-71	1-12-74	8-16-75	6-24-94
SSN 688	LOS ANGELES	**688**	Newport News	1970	1-8-72	4-6-74	11-13-76	
SSN 689	BATON ROUGE	688	Newport News	1970	11-18-72	4-26-75	6-25-77	1-13-95
SSN 690	PHILADELPHIA	688	Electric Boat	1970	8-12-72	10-19-74	6-25-77	
SSN 691	MEMPHIS	688	Newport News	1971	6-23-73	4-3-76	12-17-77	
SSN 692	OMAHA	688	Electric Boat	1971	1-27-73	2-21-76	3-11-78	10-5-95
SSN 693	CINCINNATI	688	Newport News	1971	4-6-74	2-19-77	6-10-78	7-31-95
SSN 694	GROTON	688	Electric Boat	1971	8-3-73	10-9-76	7-8-78	11-7-97
SSN 695	BIRMINGHAM	688	Newport News	1972	4-26-75	10-29-77	12-16-78	12-23-97
SSN 696	NEW YORK CITY	688	Electric Boat	1972	12-15-73	6-18-77	3-3-79	4-30-97
SSN 697	INDIANAPOLIS	688	Electric Boat	1972	10-19-74	7-30-77	1-5-80	12-22-98
SSN 698	BREMERTON	688	Electric Boat	1972	5-8-76	7-22-78	3-28-81	
SSN 699	JACKSONVILLE	688	Electric Boat	1972	2-21-76	11-18-78	5-16-81	
SSN 700	DALLAS	688	Electric Boat	1973	10-9-76	4-28-79	7-18-81	
SSN 701	LA JOLLA	688	Electric Boat	1973	10-16-76	8-11-79	10-24-81	
SSN 702	PHOENIX	688	Electric Boat	1973	7-30-77	12-8-79	12-19-81	7-29-98
SSN 703	BOSTON	688	Electric Boat	1973	8-11-78	4-19-80	1-30-82	11-19-99
SSN 704	BALTIMORE	688	Electric Boat	1973	5-21-79	12-13-80	7-24-82	7-10-98
SSN 705	CITY OF CORPUS CHRISTI	688	Electric Boat	1973	9-4-79	4-25-81	1-8-83	
SSN 706	ALBUQUERQUE	688	Electric Boat	1974	12-27-79	3-13-82	5-21-83	

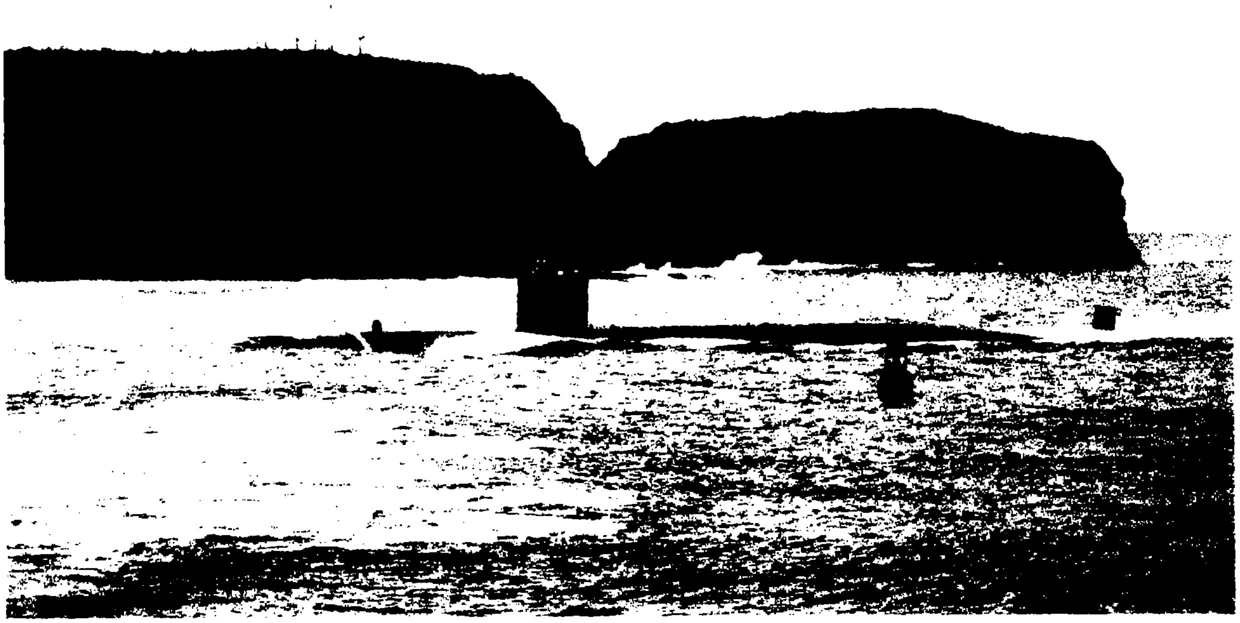
Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
SSN 707	PORTSMOUTH	688	Electric Boat	1974	5-8-80	9-18-82	10-1-83	8-15-05
SSN 708	MINNEAPOLIS-SAINT PAUL	688	Electric Boat	1974	1-30-81	3-19-83	3-10-84	
SSN 709	HYMAN G. RICKOVER	688	Electric Boat	1974	7-24-81	8-27-83	7-21-84	
SSN 710	AUGUSTA	688	Electric Boat	1974	4-1-82	1-21-84	1-19-85	
SSN 711	SAN FRANCISCO	688	Newport News	1975	5-26-77	10-27-79	4-24-81	
SSN 712	ATLANTA	688	Newport News	1975	8-17-78	8-16-80	3-6-82	12-16-99
SSN 713	HOUSTON	688	Newport News	1975	1-29-79	3-21-81	9-25-82	
SSN 714	NORFOLK	688	Newport News	1976	8-1-79	10-31-81	5-21-83	
SSN 715	BUFFALO	688	Newport News	1976	1-25-80	5-8-82	11-5-83	
SSN 716	SALT LAKE CITY[1]	688	Newport News	1977	8-26-80	10-16-82	5-12-84	
SSN 717	OLYMPIA	688	Newport News	1977	3-31-81	4-30-83	11-17-84	
SSN 718	HONOLULU	688	Newport News	1977	11-10-81	9-24-83	7-6-85	
SSN 719	PROVIDENCE	688	Electric Boat	1978	10-14-82	8-4-84	7-27-85	
SSN 720	PITTSBURGH	688	Electric Boat	1979	4-15-83	12-8-84	11-23-85	
SSN 721	CHICAGO	688	Newport News	1980	1-5-83	10-13-84	9-27-86	
SSN 722	KEY WEST	688	Newport News	1980	7-6-83	7-20-85	9-12-87	
SSN 723	OKLAHOMA CITY	688	Newport News	1981	1-4-84	11-2-85	7-9-88	
SSN 724	LOUISVILLE	688	Electric Boat	1981	9-16-84	12-14-85	11-8-86	
SSN 725	HELENA	688	Electric Boat	1982	3-28-85	6-28-86	7-11-87	
SSGN 726	OHIO[2]	726	Electric Boat	1974	4-10-76	4-7-79	11-11-81	
SSGN 727	MICHIGAN[2]	726	Electric Boat	1975	4-4-77	4-26-80	9-11-82	
SSGN 728	FLORIDA[2]	726	Electric Boat	1975	4-9-77	11-14-81	6-18-83	
SSGN 729	GEORGIA[2]	726	Electric Boat	1976	4-7-79	11-6-82	2-11-84	
SSBN 730	HENRY M. JACKSON	726	Electric Boat	1977	1-19-81	10-15-83	10-6-84	
SSBN 731	ALABAMA	726	Electric Boat	1978	8-21-81	5-19-84	5-25-85	
SSBN 732	ALASKA	726	Electric Boat	1978	3-9-83	1-12-85	1-25-86	
SSBN 733	NEVADA	726	Electric Boat	1980	8-8-83	9-14-85	8-16-86	
SSBN 734	TENNESSEE	726	Electric Boat	1981	6-9-86	12-13-86	12-17-88	
SSBN 735	PENNSYLVANIA	726	Electric Boat	1983	3-2-87	4-23-88	9-9-89	
SSBN 736	WEST VIRGINIA	726	Electric Boat	1984	12-18-87	10-14-89	10-20-90	
SSBN 737	KENTUCKY	726	Electric Boat	1985	12-18-87	8-11-90	7-13-91	
SSBN 738	MARYLAND	726	Electric Boat	1986	12-18-87	8-10-91	6-13-92	
SSBN 739	NEBRASKA	726	Electric Boat	1987	12-18-87	8-15-92	7-10-93	
SSBN 740	RHODE ISLAND	726	Electric Boat	1988	8-23-89	7-17-93	7-9-94	
SSBN 741	MAINE	726	Electric Boat	1989	7-20-90	7-16-94	7-29-95	
SSBN 742	WYOMING	726	Electric Boat	1990	11-30-91	7-15-95	7-13-96	
SSBN 743	LOUISIANA	726	Electric Boat	1991	12-5-92	7-27-96	9-6-97	
SSN 750	NEWPORT NEWS	688	Newport News	1982	3-3-84	3-15-86	6-3-89	
SSN 751	SAN JUAN	688i	Electric Boat	1983	8-16-85	12-6-86	8-6-88	

NOTE: 688i denotes Improved Los Angeles Class.
[1]Undergoing inactivation but still in commission as of March 2006.
[2]Removed from strategic service for SSGN conversion.

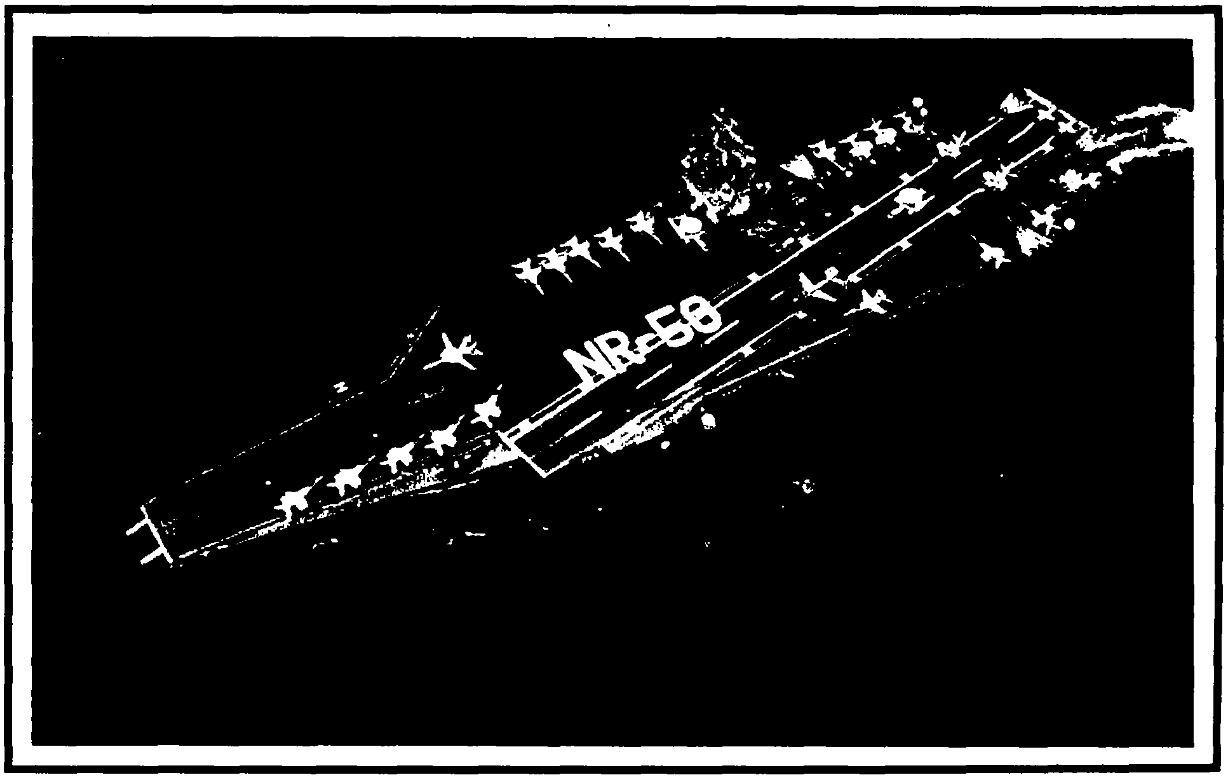
Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned
SSN 752	PASADENA	688i	Electric Boat	1983	12-20-85	9-12-87	2-11-89
SSN 753	ALBANY	688i	Newport News	1984	4-22-85	6-13-87	4-7-90
SSN 754	TOPEKA	688i	Electric Boat	1984	5-13-86	1-23-88	10-21-89
SSN 755	MIAMI	688i	Electric Boat	1984	10-24-86	11-12-88	6-30-90
SSN 756	SCRANTON	688i	Newport News	1985	8-29-86	7-3-89	1-26-91
SSN 757	ALEXANDRIA	688i	Electric Boat	1985	6-19-87	6-23-90	6-29-91
SSN 758	ASHEVILLE	688i	Newport News	1985	1-9-87	2-24-90	9-28-91
SSN 759	JEFFERSON CITY	688i	Newport News	1985	9-21-87	8-17-90	2-29-92
SSN 760	ANNAPOLIS	688i	Electric Boat	1986	6-15-88	5-18-91	4-11-92
SSN 761	SPRINGFIELD	688i	Electric Boat	1986	10-28-88	11-9-91	1-9-93
SSN 762	COLUMBUS	688i	Electric Boat	1986	4-28-89	8-1-92	7-24-93
SSN 763	SANTA FE	688i	Electric Boat	1986	5-25-91	12-12-92	1-8-94
SSN 764	BOISE	688i	Newport News	1987	8-25-88	3-23-91	11-7-92
SSN 765	MONTPELIER	688i	Newport News	1987	5-19-89	8-23-91	3-13-93
SSN 766	CHARLOTTE	688i	Newport News	1987	1-7-90	10-3-92	9-16-94
SSN 767	HAMPTON	688i	Newport News	1987	6-30-90	4-3-92	11-6-93
SSN 768	HARTFORD	688i	Electric Boat	1988	4-27-92	12-4-93	12-10-94
SSN 769	TOLEDO	688i	Newport News	1988	4-8-91	8-28-93	2-24-95
SSN 770	TUCSON	688i	Newport News	1988	9-20-91	3-19-94	9-9-95
SSN 771	COLUMBIA	688i	Electric Boat	1989	2-9-93	9-24-94	10-9-95
SSN 772	GREENEVILLE	688i	Newport News	1989	4-16-92	9-17-94	2-16-96
SSN 773	CHEYENNE	688i	Newport News	1990	10-6-92	4-1-95	9-13-96
SSN 21	SEAWOLF	21	Electric Boat	1989	10-25-89	6-24-95	7-19-97
SSN 22	CONNECTICUT	21	Electric Boat	1991	9-14-92	9-1-97	12-11-98
SSN 23	JIMMY CARTER	21	Electric Boat	1996	12-12-95	6-5-04	2-19-05
SSN 774	VIRGINIA	774	Electric Boat	1998	9-2-99	8-16-03	10-23-04
SSN 775	TEXAS	774	Newport News	1999	7-12-02	7-31-04	
SSN 776	HAWAII	774	Electric Boat	2001	8-27-04		
SSN 777	NORTH CAROLINA	774	Newport News	2002	5-22-04		
SSN 778	NEW HAMPSHIRE	774	Electric Boat	2003			
SSN 779	NEW MEXICO	774	Newport News	2004			
SSN 780	Yet to be named	774	Electric Boat	2005			
SSN 781	Yet to be named	774	Newport News	2006			
Deep Submergence Research Vehicle							
NR-1			Electric Boat	1965	N/A	1-25-69	N/A

U. S. Nuclear-powered Aircraft Carriers and Cruisers

Hull No.	Name	Class	Builder	Shipbuilding Program FY	Keel Laid	Launched	Commissioned	Decommissioned
Nuclear-powered Aircraft Carriers								
CVN 65	ENTERPRISE	**65**	Newport News	1958	2-4-58	9-24-60	11-25-61	
CVN 68	NIMITZ	**68**	Newport News	1967	6-22-68	5-13-72	5-3-75	
CVN 69	DWIGHT D. EISENHOWER	68	Newport News	1970	8-15-70	10-11-75	10-18-77	
CVN 70	CARL VINSON	68	Newport News	1974	10-11-75	3-15-80	3-13-82	
CVN 71	THEODORE ROOSEVELT	68	Newport News	1980	10-31-81	10-27-84	10-25-86	
CVN 72	ABRAHAM LINCOLN	68	Newport News	1983	11-3-84	2-13-88	11-11-89	
CVN 73	GEORGE WASHINGTON	68	Newport News	1983	8-25-86	7-21-90	7-4-92	
CVN 74	JOHN C. STENNIS	68	Newport News	1988	3-13-91	11-13-93	12-9-95	
CVN 75	HARRY S TRUMAN	68	Newport News	1988	11-29-93	9-14-96	7-25-98	
CVN 76	RONALD REAGAN	68	Newport News	1995	2-12-98	3-4-01	7-12-03	
CVN 77	GEORGE H. W. BUSH	68	Newport News	2001	9-6-03			
Nuclear-powered Cruisers								
CGN 9	LONG BEACH	**9**	Bethlehem	1957	12-2-57	7-14-59	9-9-61	5-1-95
CGN 25	BAINBRIDGE	**25**	Bethlehem	1959	5-15-59	4-15-61	10-6-62	9-13-96
CGN 35	TRUXTUN	**35**	NY Shipbuilding	1962	6-17-63	12-19-64	5-27-67	9-11-95
CGN 36	CALIFORNIA	**36**	Newport News	1967	1-23-70	9-22-71	2-16-74	7-9-99
CGN 37	SOUTH CAROLINA	36	Newport News	1968	12-1-70	7-1-72	1-25-75	7-30-99
CGN 38	VIRGINIA	**38**	Newport News	1970	8-19-72	12-14-74	9-11-76	11-10-94
CGN 39	TEXAS	38	Newport News	1971	8-18-73	8-9-75	9-10-77	7-16-93
CGN 40	MISSISSIPPI	38	Newport News	1972	2-22-75	7-31-76	8-5-78	7-28-97
CGN 41	ARKANSAS	38	Newport News	1975	1-17-77	10-21-78	10-18-80	7-7-98



USS CITY OF CORPUS CHRISTI (SSN 705) Off of Guam



USS ENTERPRISE (CVN 65) Salutes Naval Reactors on its 50th Anniversary in 1998

SEPARATION

PAGE

06.0959

REPORT NT-06-1
MARCH 2006

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

06.0959

Report NT-06-1
March 2006

ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES 2005

Prepared by
T. J. Mueller,
J. M. Steele, and T. Z. Wood
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 2005. 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. 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 are effective in protecting the environment and the health and safety of the general public. 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

LIST OF TABLES

LIST OF FIGURES

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 2005, the U.S. Navy had 73 nuclear-powered submarines, 10 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 30). 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 35 years is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single nuclear-powered submarine. In addition, if one person were able to drink the entire amount of radioactivity discharged into any harbor in any of the last 35 years, that person would not exceed the annual radiation exposure permitted by the Nuclear Regulatory Commission for an individual 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.

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 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 35 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 (reference 17).

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. Further, essentially all of the water is held onboard ship or transferred to shore facilities for processing and potential reuse and not discharged. 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.

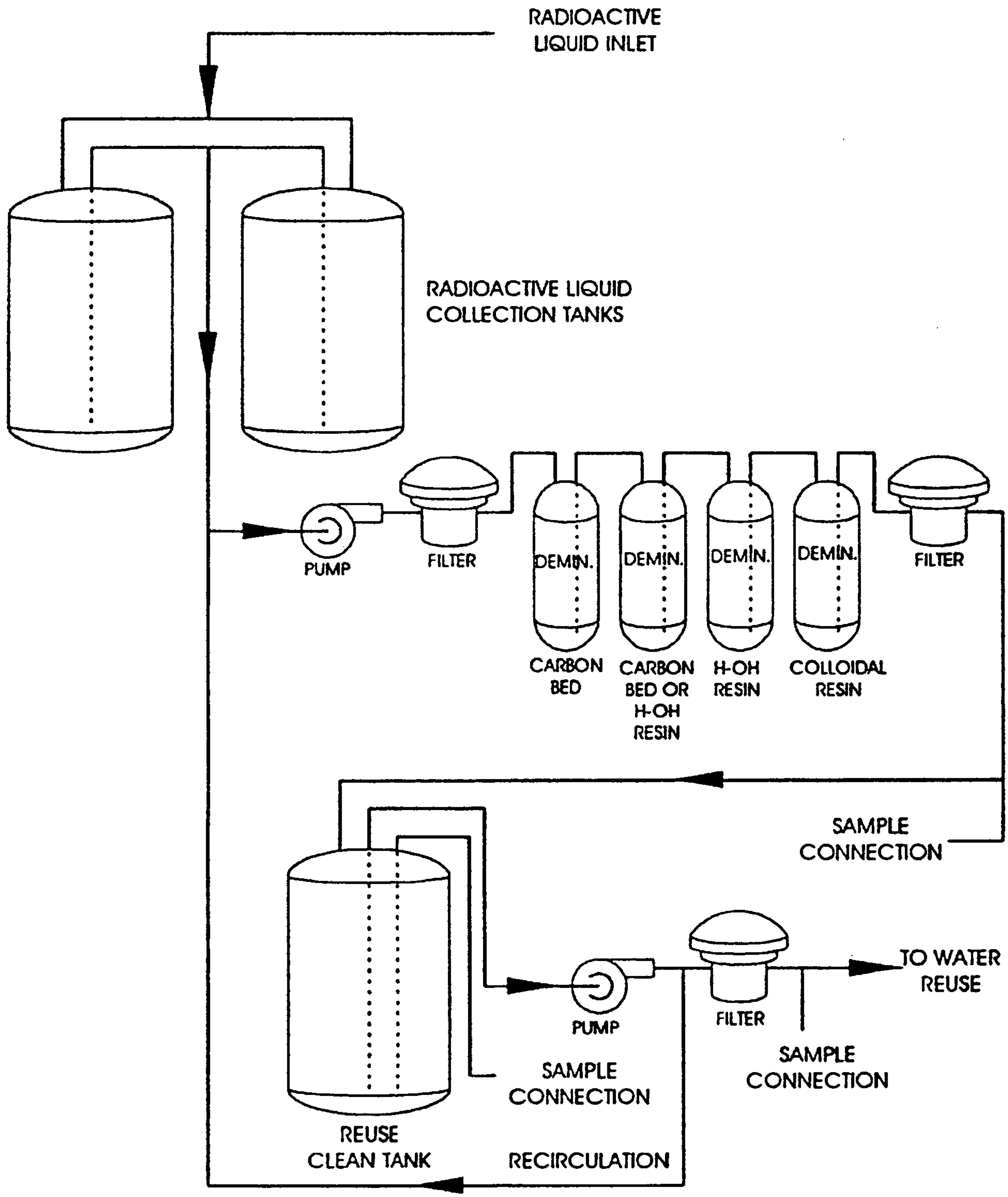


Figure 1:
Simplified Diagram of Radioactive Liquid Processing System

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 (reference 17) in a cube of seawater 100 yards on a side.

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, followup samples of water, sediment, and marine life were collected from near the THRESHER debris. In 1979, 1986, and 1998, followup 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 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 2005 by the entire Naval Nuclear Propulsion Program, as shown in Table 1, could be contained in a cube measuring about 10 yards on a side. The total annual volume is less than 0.5 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.

The Atlantic Compact site in Barnwell, South Carolina, currently accepts waste from every State. Over the next 2 years, however, the Barnwell site will limit waste acceptance from out-of-compact generators.

One other disposal site accepts low-level radioactive waste. 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.

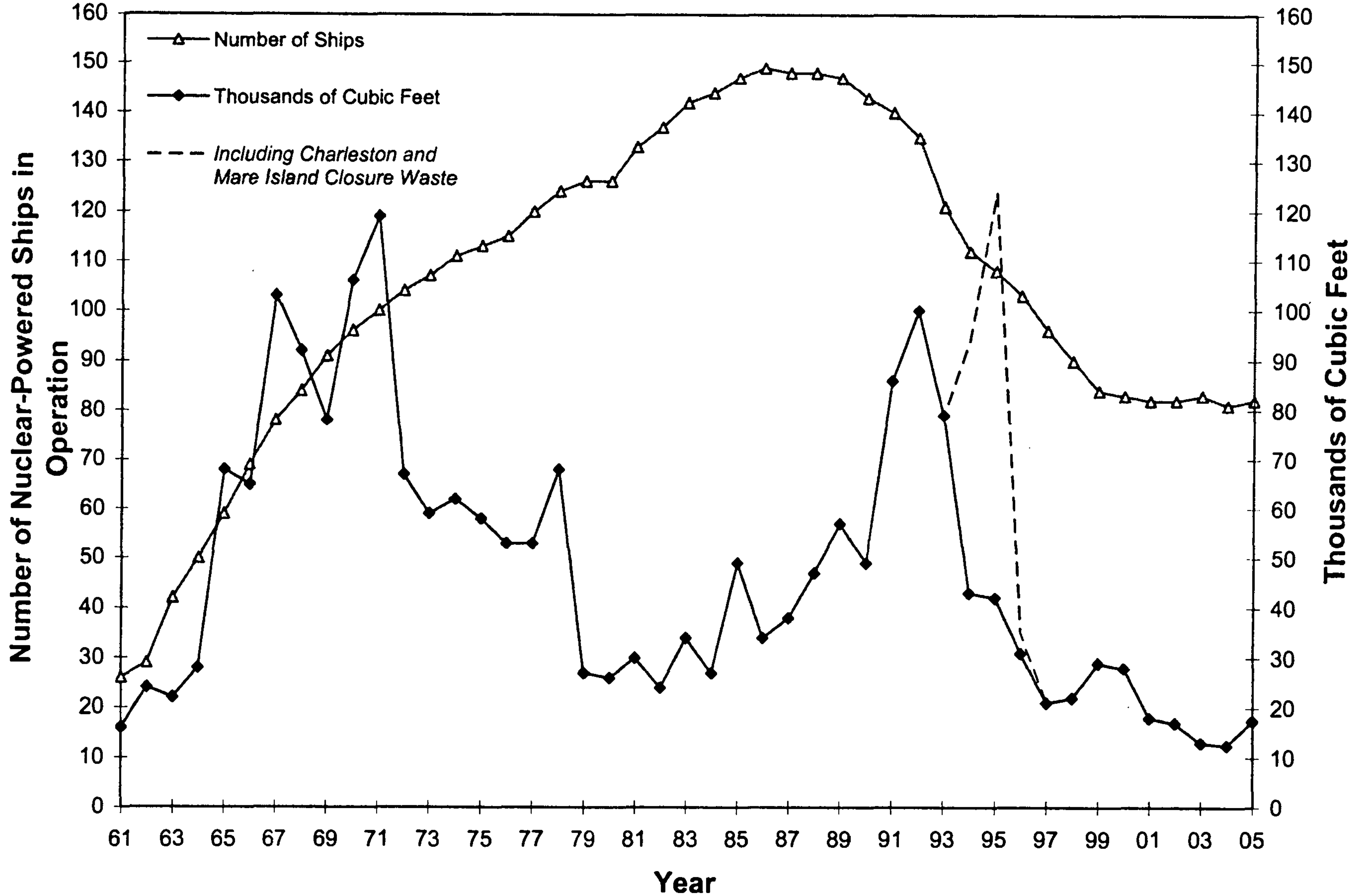
In view of the increased disposal fees and the uncertain future of low-level radioactive waste disposal sites, a concerted effort was made in the early 1990s to reevaluate radioactive equipment in storage for potential future use and to dispose of that equipment for which no specific future need was identified. For example, some of this equipment was no longer needed due to the declining size of the Fleet. In addition, the closure of Mare Island and Charleston Naval Shipyards resulted in the disposal of much of the equipment from these facilities. The volume of low-level radioactive waste shipped from these two shipyards accounted for 66 percent of the total volume shipped during 1995. As a result of all these factors, the amount of solid low-level radioactive waste shipped for disposal increased from 1990 through 1995, but has declined in recent years.

Table 1: Disposed Radioactive Solid Waste from U.S. Naval Nuclear-Powered Ships and Their Support Facilities for 2000 through 2005

FACILITY	2001		2002		2003		2004		2005	
	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	1.3	19	1.3	13	1.1	9	1.3	21	1.7	12
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	1.7	<1	1.0	<1	0.9	<1	1.9	<1	0.6	<1
Newport News, Virginia Newport News Shipbuilding	2.3	11	3.3	25	1.4	<1	1.1	<1	0.8	<1
Norfolk, Virginia Naval Shipyard and Base	2.7	153	1.9	281	1.9	80	2.2	26	2.7	58
San Diego, California Navy Bases	1.3	159	0.6	35	0.2	<1	0.5	<1	0.03	<1
Bremerton, Washington Puget Sound Naval Shipyard	6.5	19	8.9	21	3.8	69	4.3	40	6.9	20
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	2.1	49	0.3	39	3.7	74	1.2	79	4.7	109
TOTAL	**18.0**	**411**	**17.3**	**415**	**13.0**	**232**	**12.5**	**167**	**17.4**	**200**

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 1961–2005



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. For example, 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 2005, about 28 cubic meters of Program mixed waste is stored, pending shipment to Department of Energy (DOE) and commercial mixed waste treatment facilities. Mixed Waste Site Treatment Plans, approved by applicable Federal and State regulators pursuant to the requirements of the 1992 Federal Facility Compliance Act, identify specific treatment plans for each type of Program mixed waste.

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. In recent years, the rate of defueled reactor compartment shipments has declined as the wave of post-Cold War decommissioned ships has been worked off. As a result, the Naval Nuclear Propulsion Program did not ship any defueled reactor compartments in 2005, and the total number shipped remained 114. Reactor compartment shipments will resume in 2006.

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 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 Navy has issued standard instructions to further control shipments of radioactivity associated with U.S. naval nuclear propulsion plants. 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 local 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 to monitor compliance. 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 about 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 object, or limited quantity shipments. The predominant radionuclide associated with 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.

Approximately one-fifth 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. More than half the low-level shipments are anticontamination clothing, equipment, tools, and routine waste. The anticontamination laundry involves shipments of special outer clothing potentially contaminated with low levels of radioactivity while worn in controlled work areas. This laundry is shipped to NRC or agreement State-licensed contractors for cleaning. On average, one shipment of low-level radioactive waste is made every month from each Naval Nuclear Propulsion Program facility. About one-fourth of the low-level shipments are environmental and chemistry samples en route to analytical laboratories.

The remaining few shipments are new and spent naval fuel and radioactive components associated with reactors, and these are shipped by DOE. Such shipments are made infrequently 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 withstand extreme accident conditions, to withstand fire and water immersion, and to prevent release of the material to the environment in the event of an accident. 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 should not 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 less than 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 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 769 container shipments of spent fuel made through the end of 2005, 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. In general, the few accidents that have occurred involved incidents such as broken truck axles or slight external damage to a shipping container with no release of radioactivity. In one incident, a train collision resulted in minor denting of a new fuel shipping container; despite this damage, there was no loss of integrity of the container, no damage to the fuel, and no release of radioactivity. In the only two instances that involved loss of contents, 1-quart containers holding samples with small amounts of radioactivity were broken in shipment. In one case, this occurred when a cargo aircraft crashed. The other container was lost from a commercial ship. Both containers were recovered, and there was no measurable radioactivity released.

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.

ENVIRONMENTAL MONITORING

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.

Navy Environmental Monitoring Program

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 most harbors do 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 2005 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.

For comparison, references 39 and 40 contain evaluations by laboratories of the Georgia Department of Natural Resources and the Environmental Protection Agency (EPA) of the effects on the environment from the accumulation of radionuclides near points of discharge from several U.S. commercial nuclear facilities. The referenced reports conclude that radioactivity levels much greater than those shown in Table 2 for Naval Nuclear Propulsion Program facilities have caused no significant radiation exposure to the general public.

The maximum total radioactivity observed in a U.S. harbor is less than 0.01 curie of cobalt-60. This radioactivity is small compared to background. Based on the typical concentrations of naturally occurring radioactivity, such as potassium-40, radium, uranium, and thorium (which are described in reference 17 for marine sediment), the natural radioactivity in the sediment of a typical harbor amounts to hundreds of curies.

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 41 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.

Table 2: Summary of 2005 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	Range of Cobalt-60 Analytical Results (pCi/gm)	Number of Samples with Cobalt-60	
		less than 0.3 pCi/gm	greater than 0.3 pCi/gm
Kittery, Maine Portsmouth Naval Shipyard	<0.02 – <0.09	120	0
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	<0.03 – <0.08 0.02(4)	384	0
Newport News, Virginia Newport News Shipbuilding	<0.02 – <0.03	188	0
Norfolk, Virginia Naval Shipyard and Base	<0.02 – <0.05	280	0
Charleston, South Carolina Naval Nuclear Power Training Unit	<0.01 – <0.01	36	0
Kings Bay, Georgia	<0.01 – <0.04	100	0
San Diego, California Navy Bases	<0.01 – <0.05	252	0
Puget Sound, Washington Naval Shipyard and Bases	<0.01 – <0.05	392	0
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	<0.01 – <0.09	208	0
Apra Harbor, Guam	<0.01 – <0.03	108	0
Port Canaveral, Florida	<0.02 – <0.04	80	0

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) One square kilometer is roughly 0.4 square mile. Estimated total cobalt-60 in the top layer of sediment is 0.01 Ci. Samples from more than 12 inches deep from several harbors show that cobalt-60 present may be two to five times that measured in the surface layer.

(4) One sample had a detectable concentration of cobalt-60 of 0.02 pCi/gm. For perspective, this concentration of radioactivity is less than 1/50 of the concentration of natural radioactivity found in a banana.

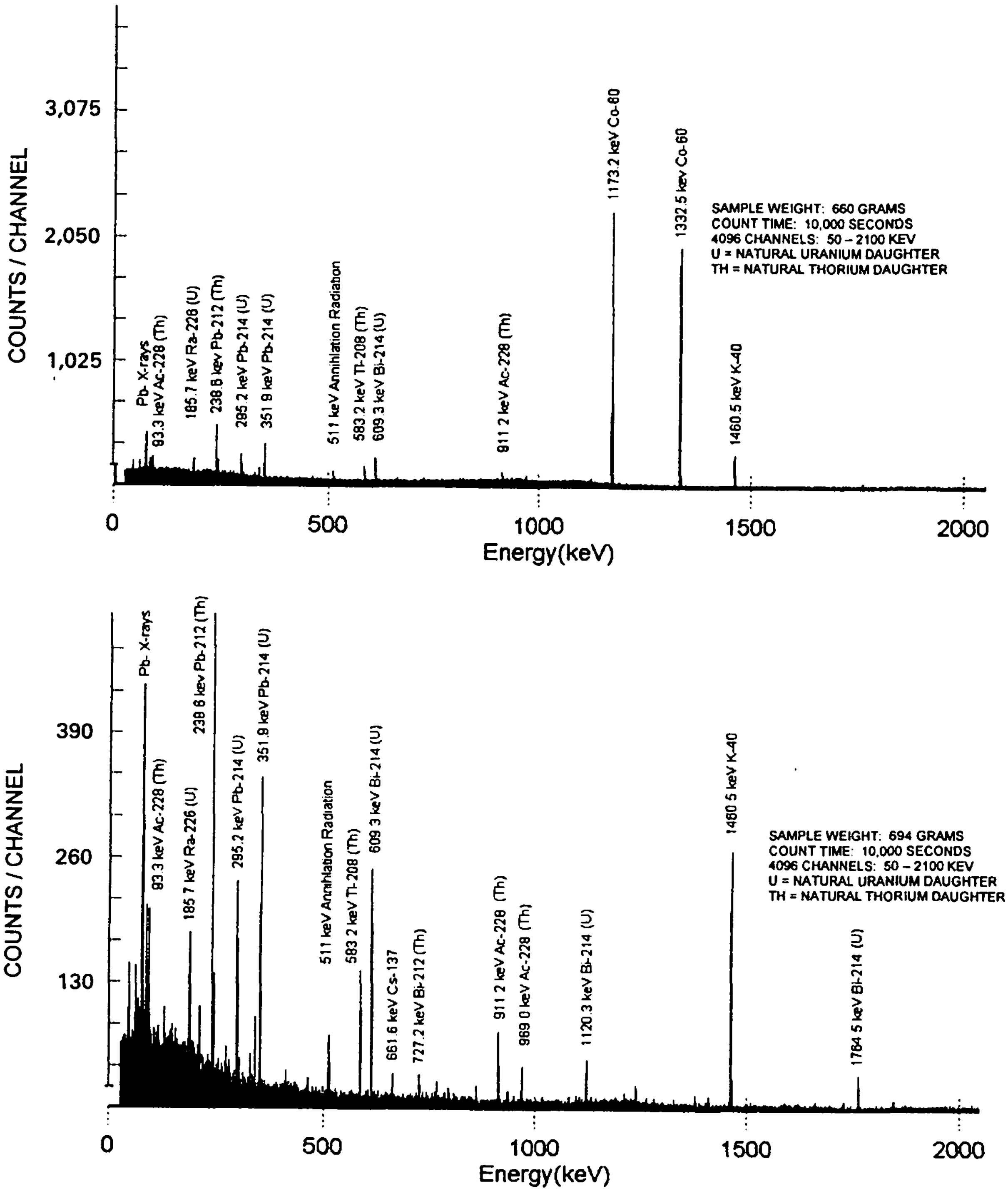


Figure 3:
Gamma Spectra of Harbor Bottom Sediment Samples
with a Germanium Detector

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 and 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 demonstrates that air exhausted from facilities actually contained a smaller amount of particulate radioactivity than it did when it was drawn from the environment.

Table 3: Summary of 2005 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	<0.07	<0.06	<0.09
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	<0.07	<0.05	<0.08
Newport News, Virginia Newport News Shipbuilding	<0.02	<0.02	<0.03
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	<0.02	<0.02	<0.03
San Diego, California Navy Bases	<0.04	<0.03	<0.05
Puget Sound, Washington Naval Shipyard and Bases	<0.04	<0.04	<0.04
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	Not Applicable	<0.07	<0.06
Apra Harbor, Guam	<0.01	<0.01	<0.03
Port Canaveral, Florida	<0.02	<0.01	<0.01

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 2005 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 Offsite Dosimeter (mrem/qtr)	Range of Offsite Dosimeter (mrem/qtr)	Average Perimeter Dosimeter (mrem/qtr)	Range of Perimeter Dosimeter (mrem/qtr)
Kittery, Maine Portsmouth Naval Shipyard	19	15 – 24	19	12 – 25
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	28	22 – 35	26	19 – 35
Newport News, Virginia Newport News Shipbuilding	15	10 – 23	15	11 – 24
Norfolk, Virginia Naval Shipyard and Base	22	12 – 30	19	12 – 30
Charleston, South Carolina Naval Nuclear Power Training Unit	17	11 – 23	16	11 – 20
Kings Bay, Georgia	21	14 – 33	24	12 – 31
San Diego, California Navy Bases	25	19 – 33	21	16 – 28
Puget Sound, Washington Naval Shipyard and Bases	17	14 – 22	16	12 – 20
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	22	18 – 25	21	12 – 25
Apra Harbor, Guam	19	16 – 23	18	15 – 22
Port Canaveral, Florida	19	14 – 27	20	13 – 28

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 42. 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 42.

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 or overhauled. Although there were no occurrences in 2005 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 in harbors where naval nuclear-powered ships are based or overhauled; the States' findings have been consistent with the Navy's.

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 2005. 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.

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 is detectable around a few operating base and shipyard piers from low-level liquid releases in the 1960s; however, these concentrations of cobalt-60 are less than those of naturally occurring radionuclides around these piers. Cobalt-60 is not detectable in general harbor bottom areas away from these piers. The maximum total radioactivity observed in a U.S. harbor, less than 0.01 curie of cobalt-60, is small compared to the naturally occurring radioactivity. Comparison to previous environmental data shows that these environmental cobalt-60 levels are decreasing.

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.

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 2004 published with the following numbers and dates: NT-02-1, March 2002; NT-03-1, March 2003; NT-04-1, March 2004; and NT-05-1, February 2005.

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

8. National Council on Radiation Protection and Measurements, Report No. 22, "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure" (published as National Bureau of Standards Handbook 69, issued June 1959, superseding Handbook 52).

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, "Radioactive Waste Disposal into the Sea," Safety Series No. 5, Vienna, 1961.

13. National Council on Radiation Protection and Measurements, Report No. 116, "Recommendations On Limits For Exposure to Ionizing Radiation," (supersedes Report No. 91) 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. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report to the General Assembly, "Sources and Effects of Ionizing Radiation," Volume I, Annex C

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 – 2005," T. J. Mueller, et al., NT-06-2, March 2006.

29. U.S. Department of Energy, Manifest Information Management System, Volume and Activity Summary, 2005, 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.londonconvention.org/London_Convention.htm.

39. Georgia Department of Natural Resources, Environmental Protection Division, "Environmental Radiation Surveillance Report 2000 – 2002," at http://www.ganet.org/dnr/environ/gaenviron_files/radiation_files/radrpt2002.htm.

40. U.S. Environmental Protection Agency Report, "Environmental Radiation Effects of Nuclear Facilities in New York State," by M. S. Terpilak and B. L. Jorgensen, issued in Radiation Data and Reports, July 1974.

41. 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.

42. 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."

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., Environmental Protection Agency 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, Environmental Protection Agency Report EPA-402-R-01-014, November 2001.

45. U.S. Environmental Protection Agency Report, "Radiological Survey of San Diego Bay," by R. Goodman, Environmental Protection Agency 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, Environmental Protection Agency Report 520/5 88-018, June 1989.

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

48. U.S. Environmental Protection Agency Report, "Radiological Survey Hampton Roads Harbor Facilities," Environmental Protection Agency 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," Environmental Protection Agency 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, Environmental Protection Agency 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, Environmental Protection Agency 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 1
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL AIR STATION NORTH ISLAND, SAN DIEGO, CA

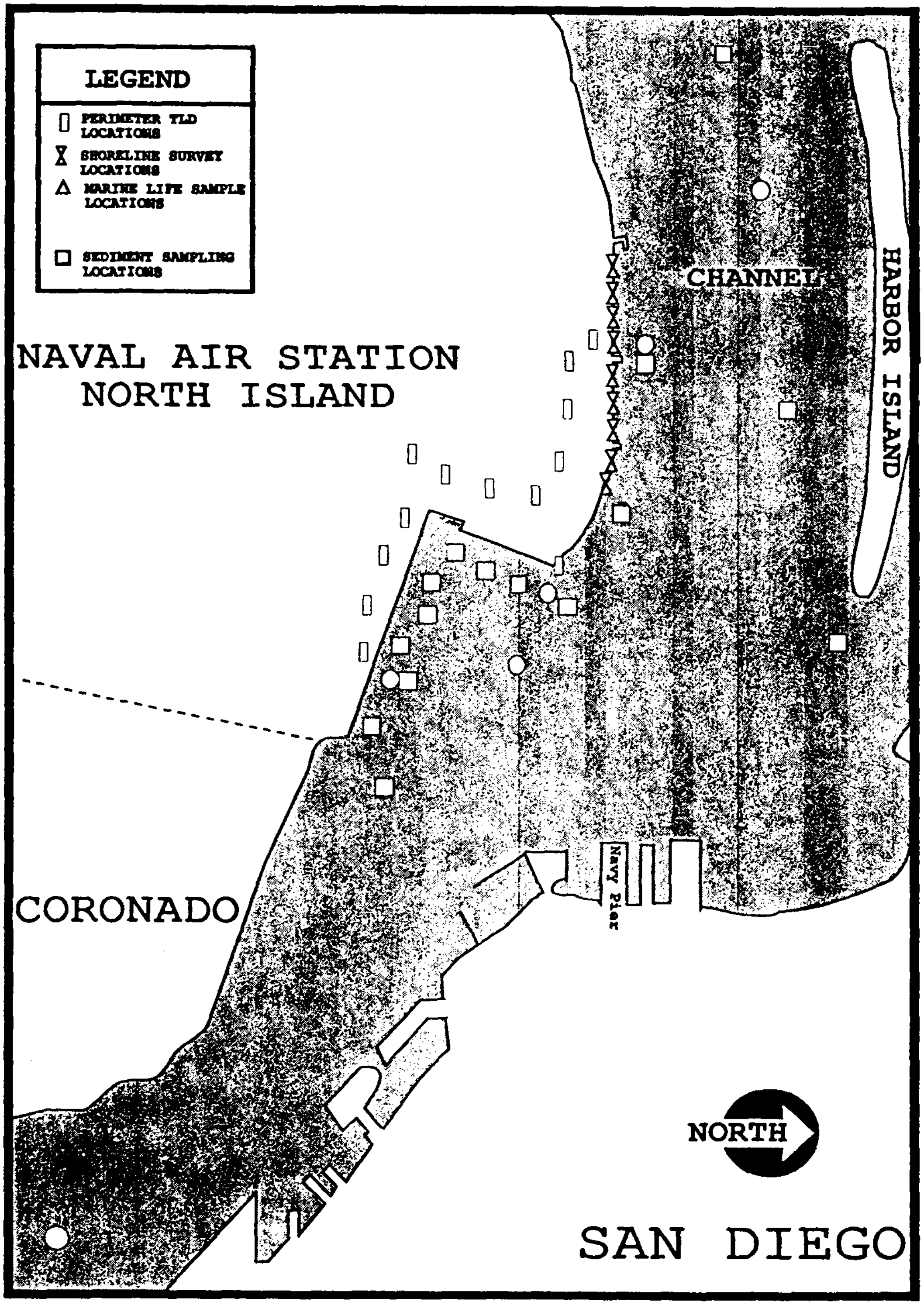


FIGURE 2
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, SAN DIEGO, CA

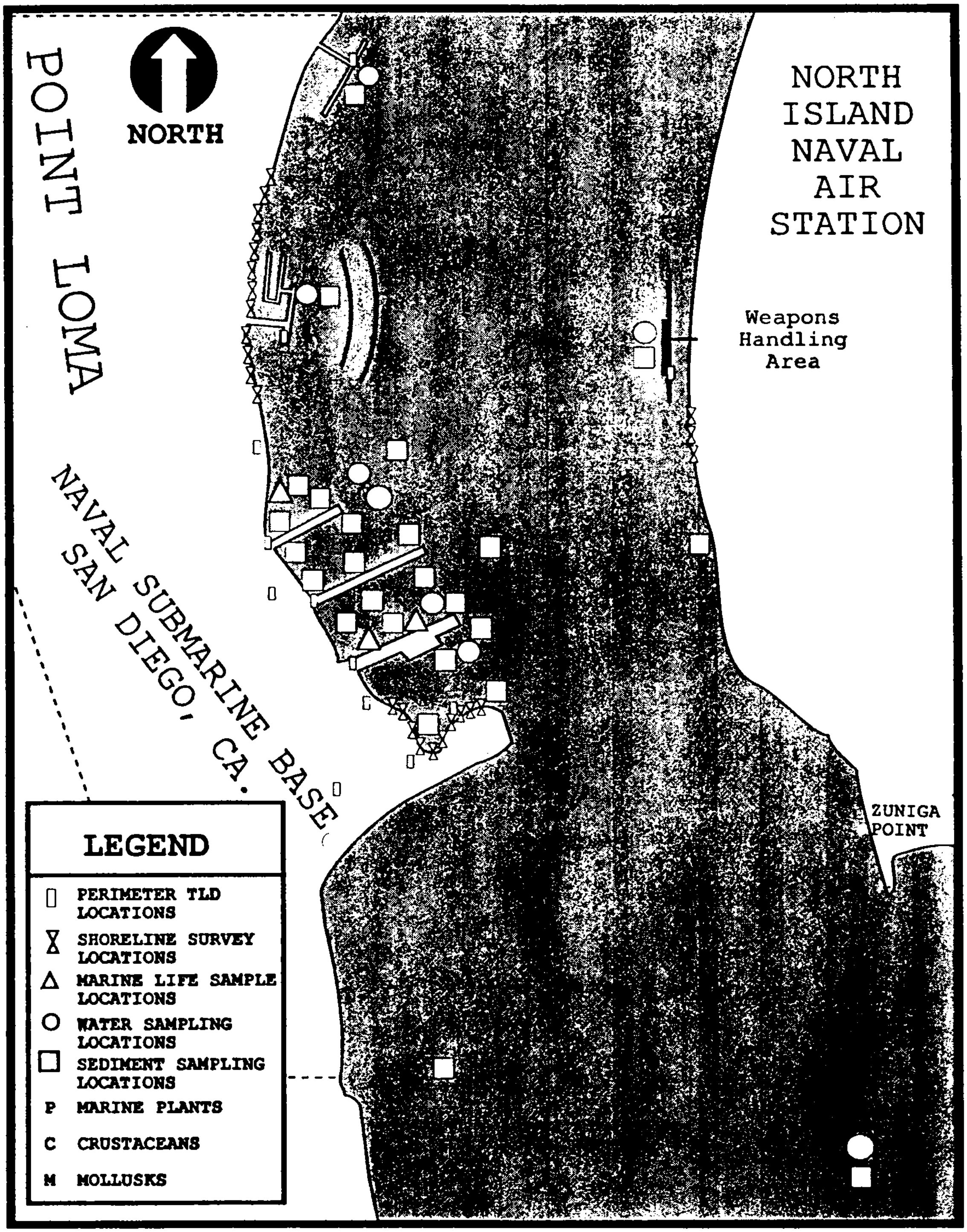


FIGURE 3
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION 32ND ST, SAN DIEGO, CA

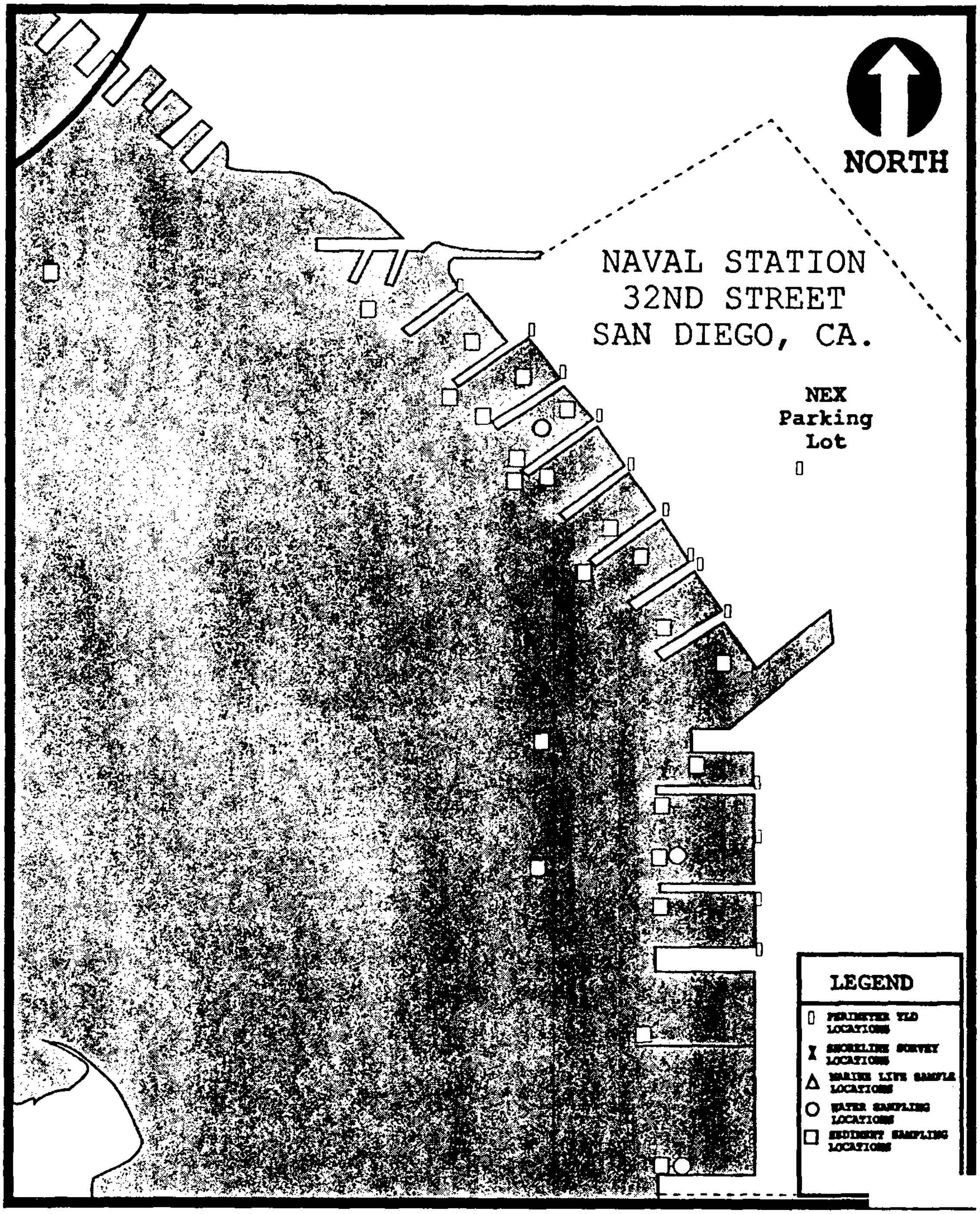


FIGURE 4
ENVIRONMENTAL MONITORING LOCATIONS AT
GENERAL DYNAMICS, ELECTRIC BOAT
GROTON, CT

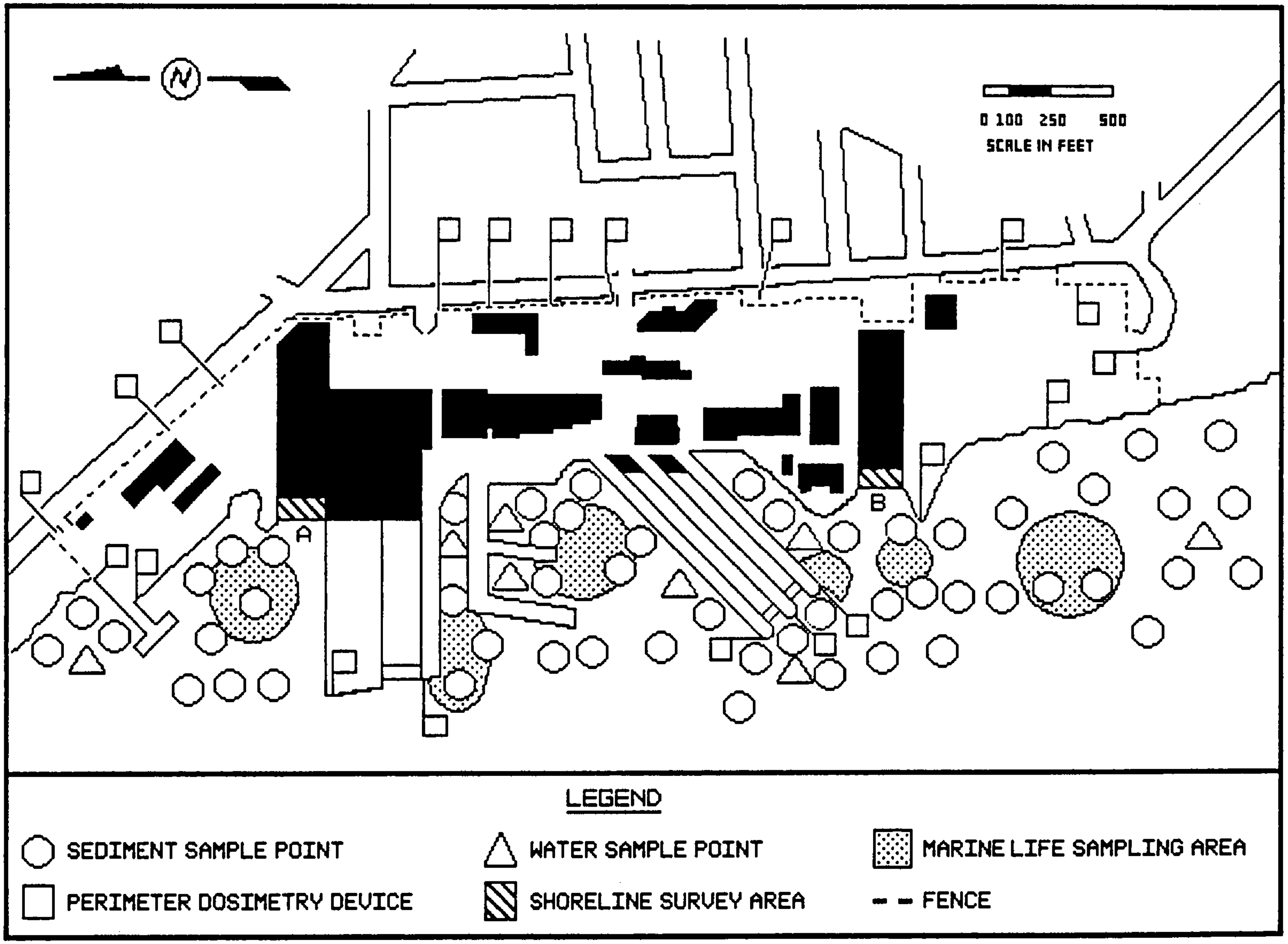


FIGURE 5
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, NEW LONDON, CT

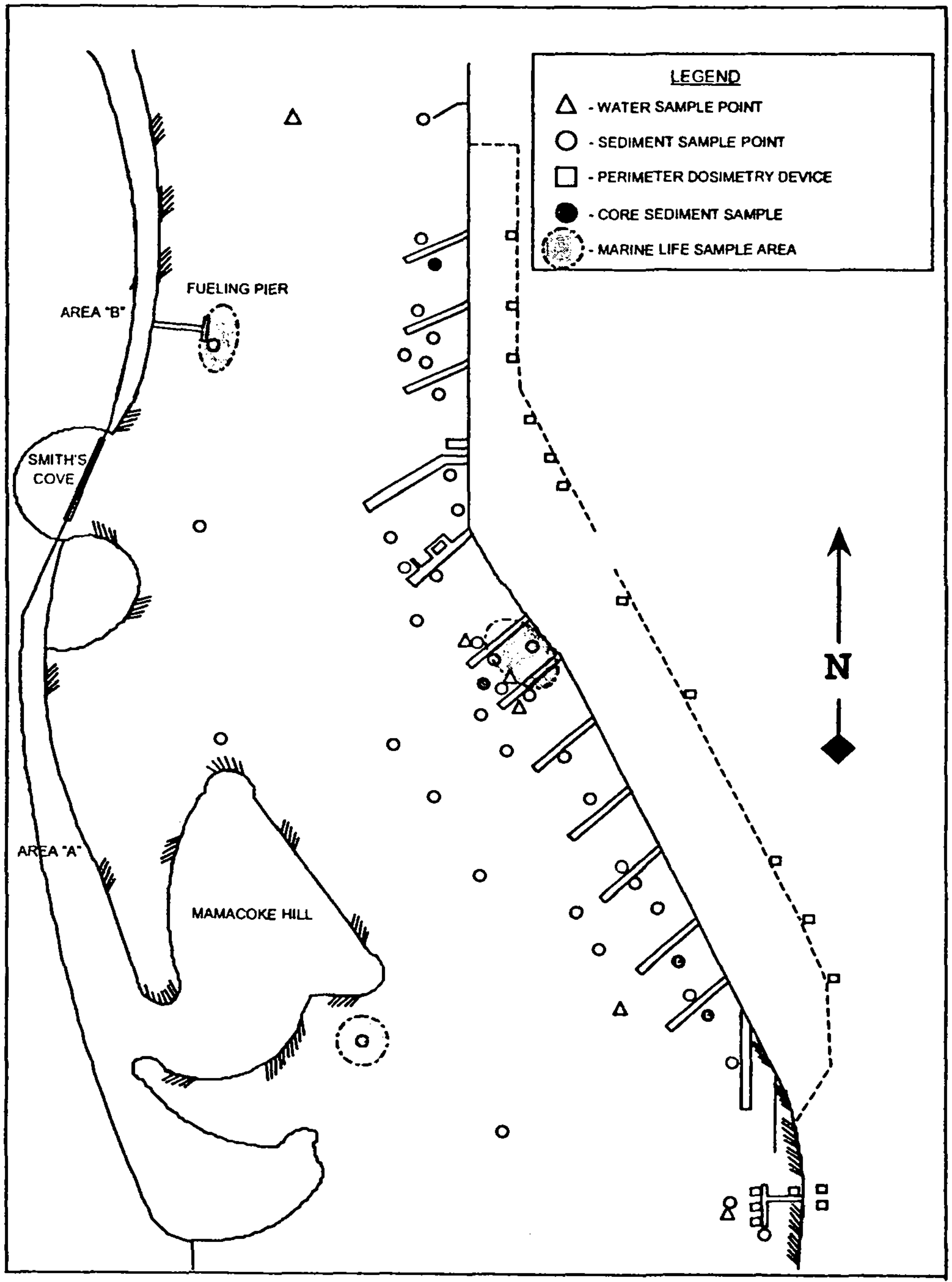


FIGURE 6
ENVIRONMENTAL MONITORING LOCATIONS AT
PORT CANAVERAL, FL

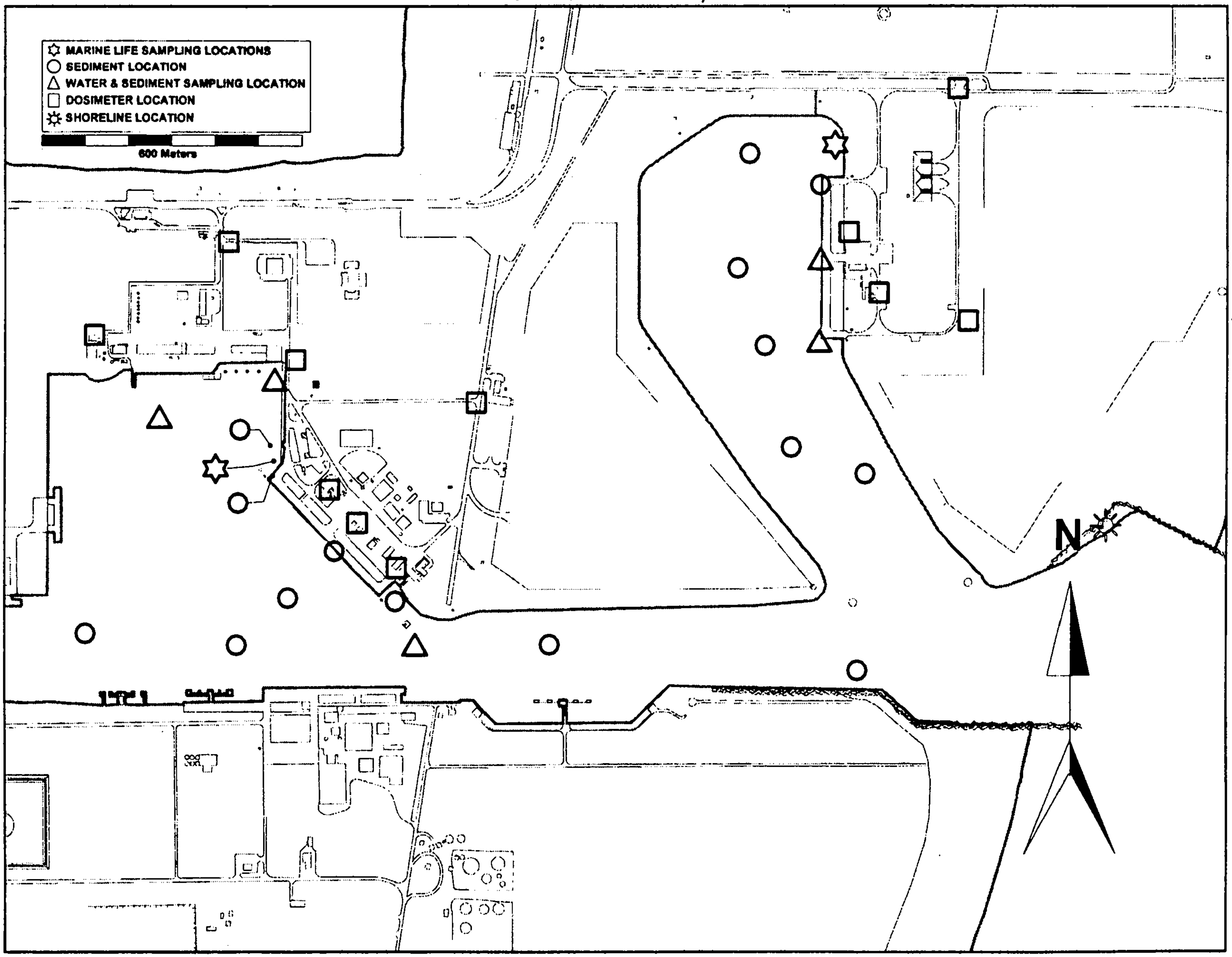
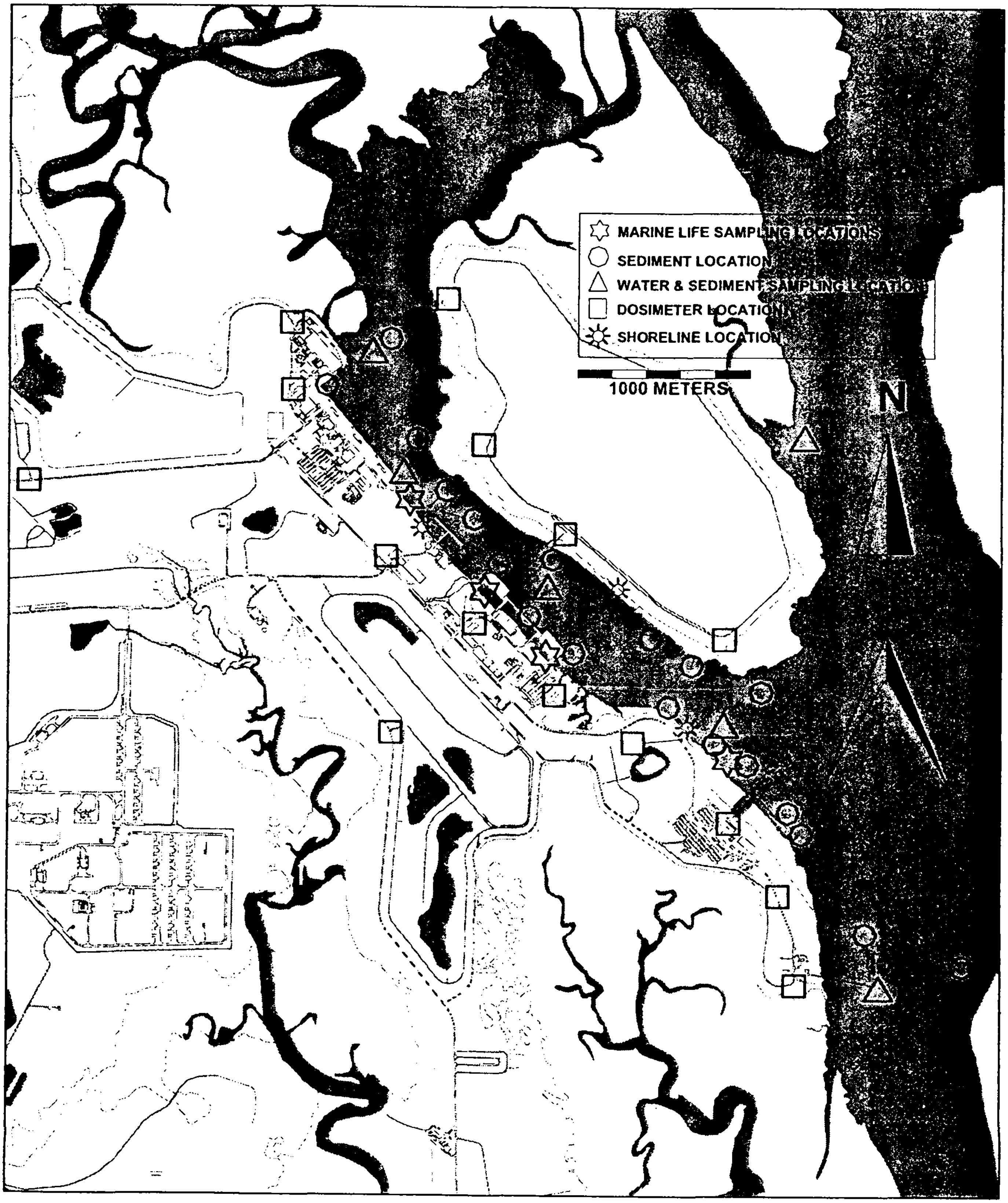


FIGURE 7
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, KINGS BAY, GA



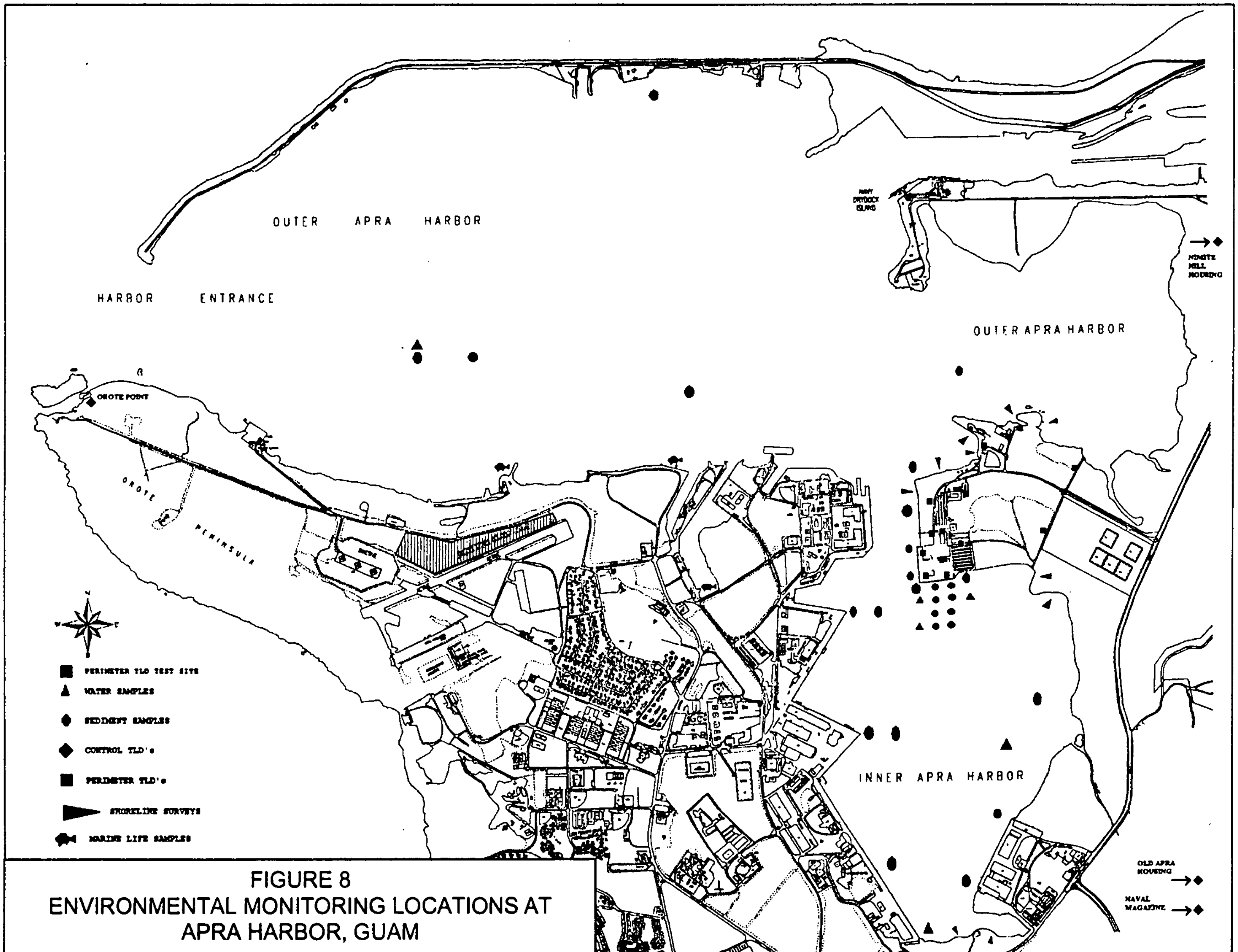


FIGURE 8
ENVIRONMENTAL MONITORING LOCATIONS AT
APRA HARBOR, GUAM

FIGURE 9
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR, HI

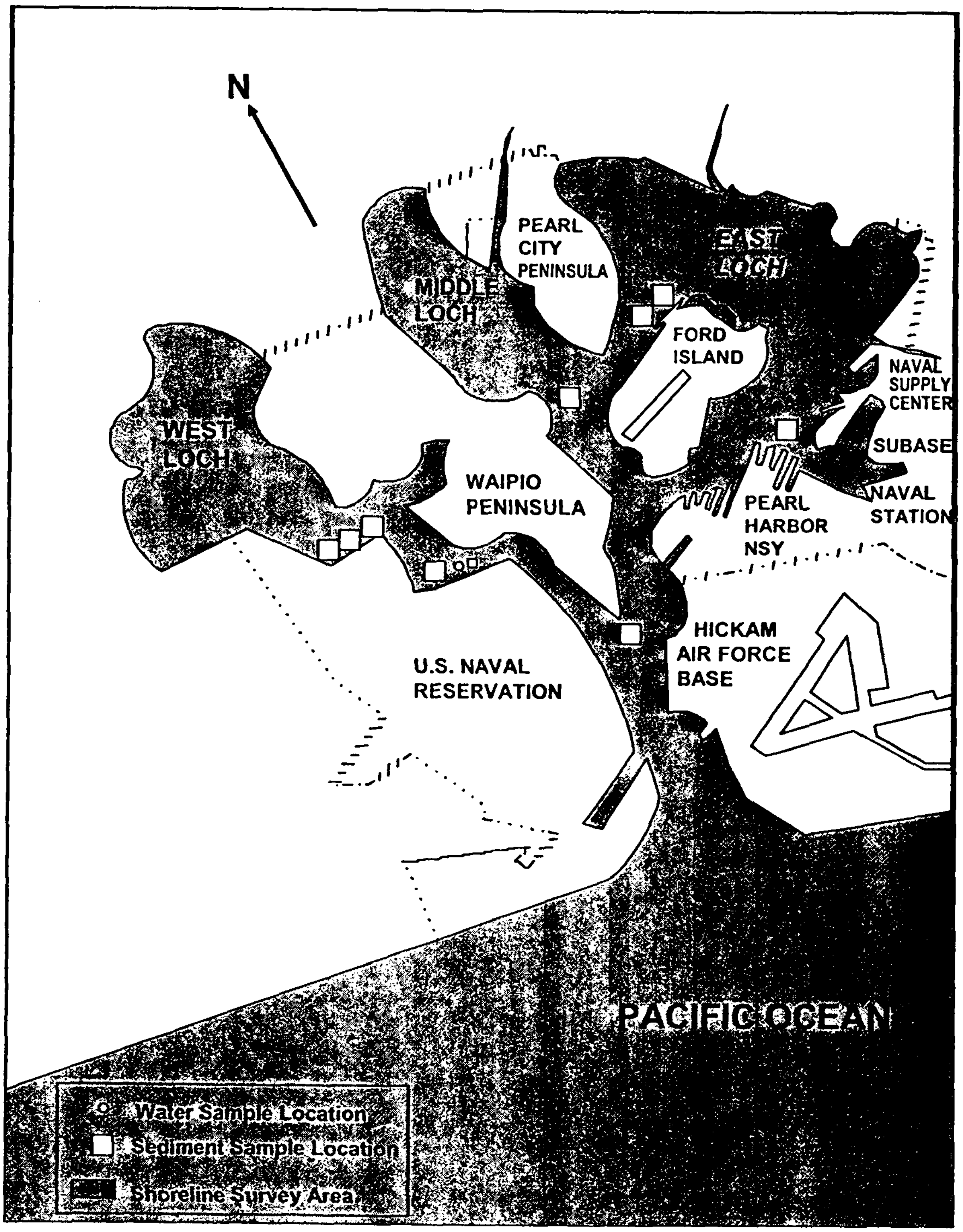


FIGURE 10
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR NAVAL SHIPYARD AND
INTERMEDIATE MAINTENANCE FACILITY — SHIPYARD AREA

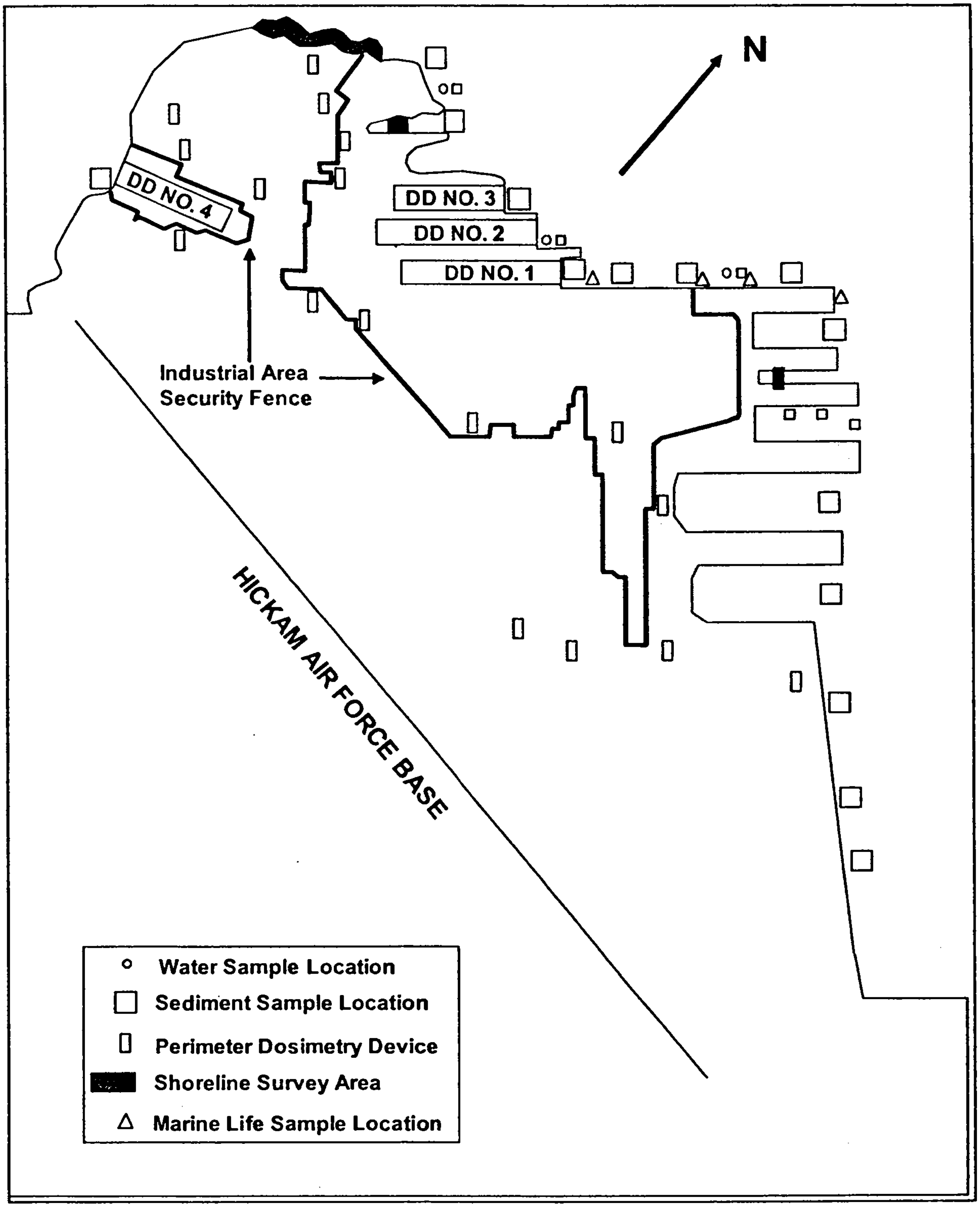


FIGURE 11
ENVIRONMENTAL MONITORING LOCATIONS AT PEARL HARBOR NAVAL SHIPYARD AND INTERMEDIATE MAINTENANCE FACILITY — SUBMARINE BASE AREA

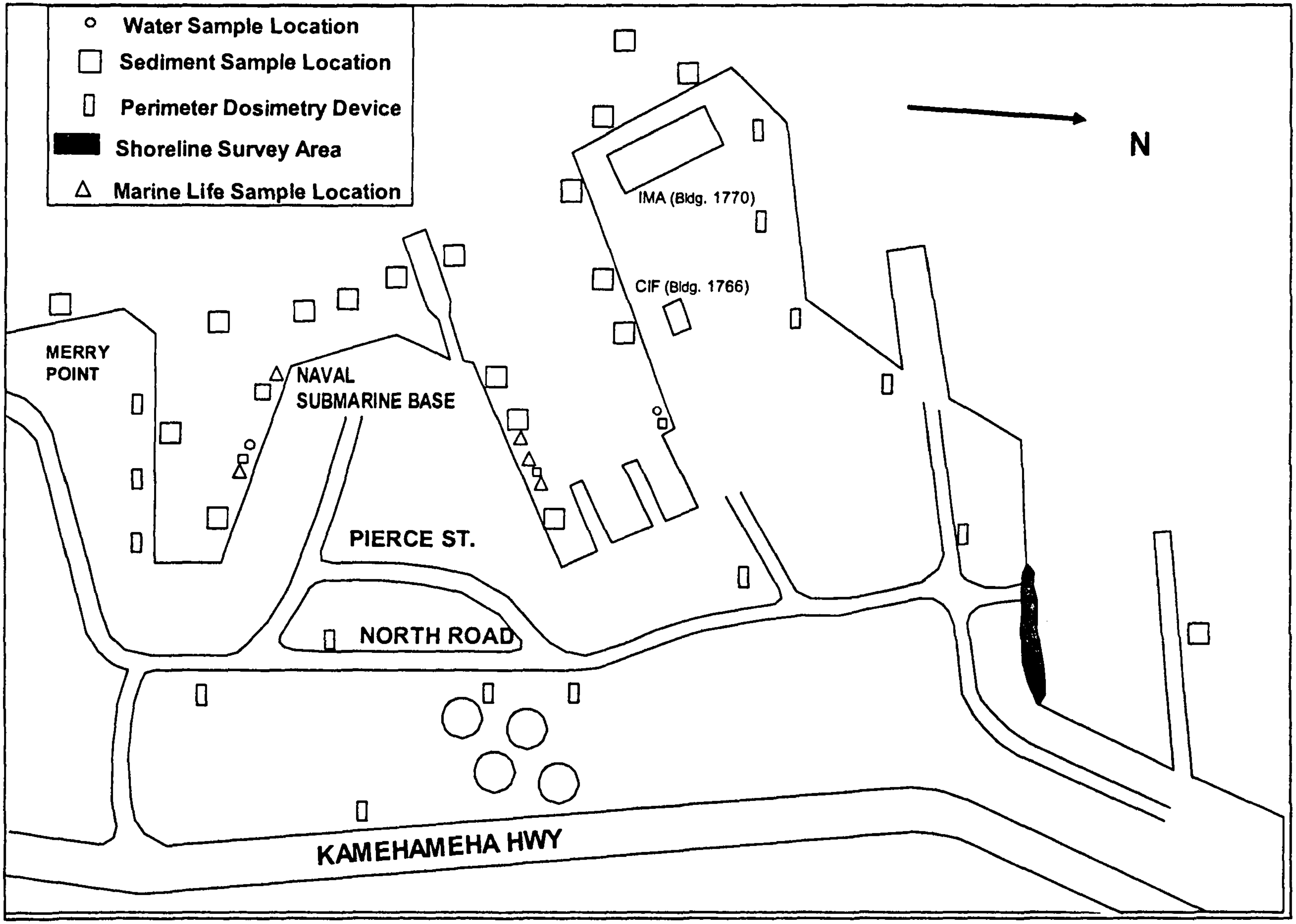


FIGURE 12
ENVIRONMENTAL MONITORING LOCATIONS AT
PORTSMOUTH NAVAL SHIPYARD
KITTERY, ME

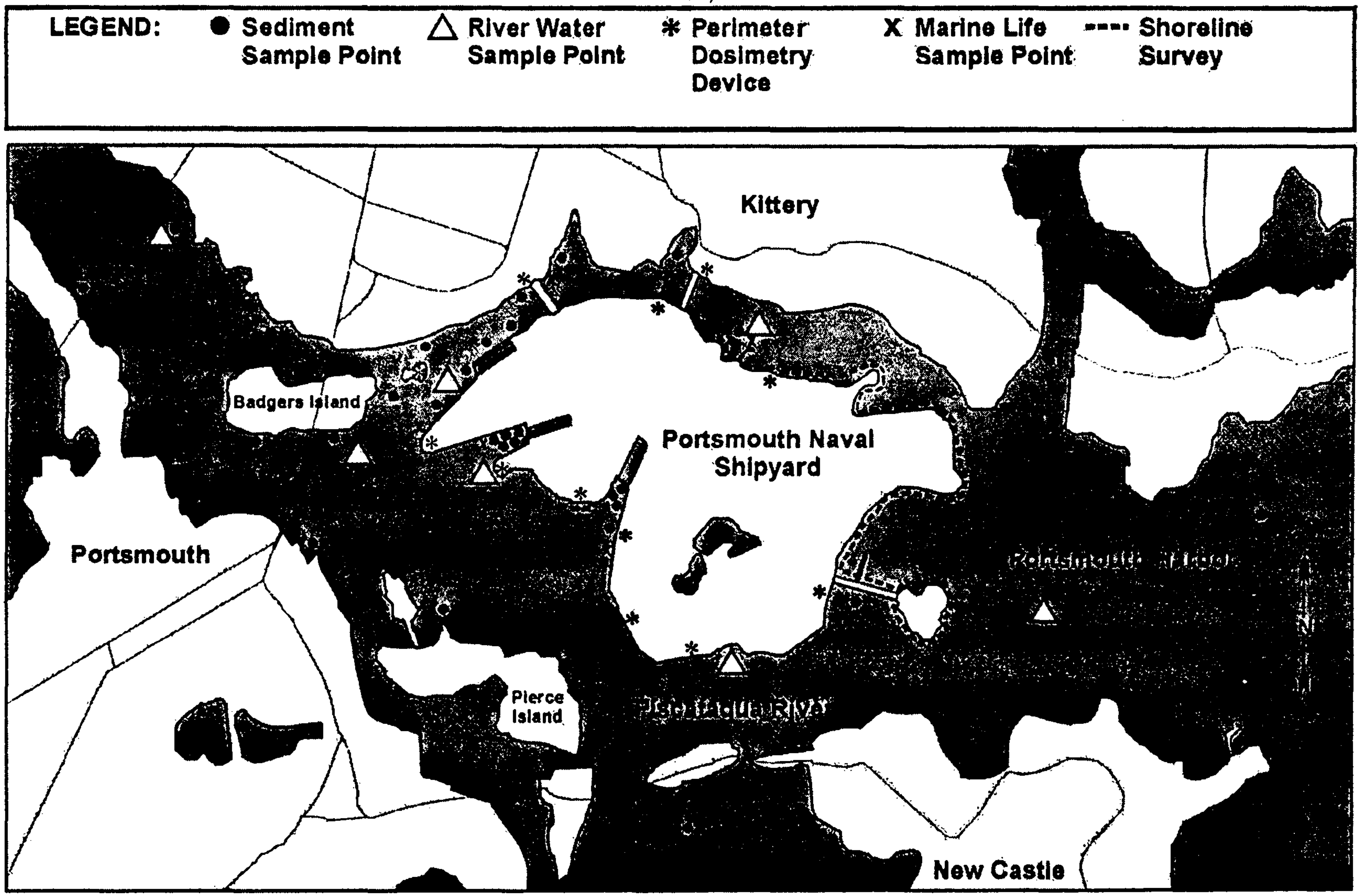


FIGURE 13
ENVIRONMENTAL MONITORING LOCATIONS AT
NAVAL NUCLEAR PROPULSION TRAINING UNIT, CHARLESTON, SC

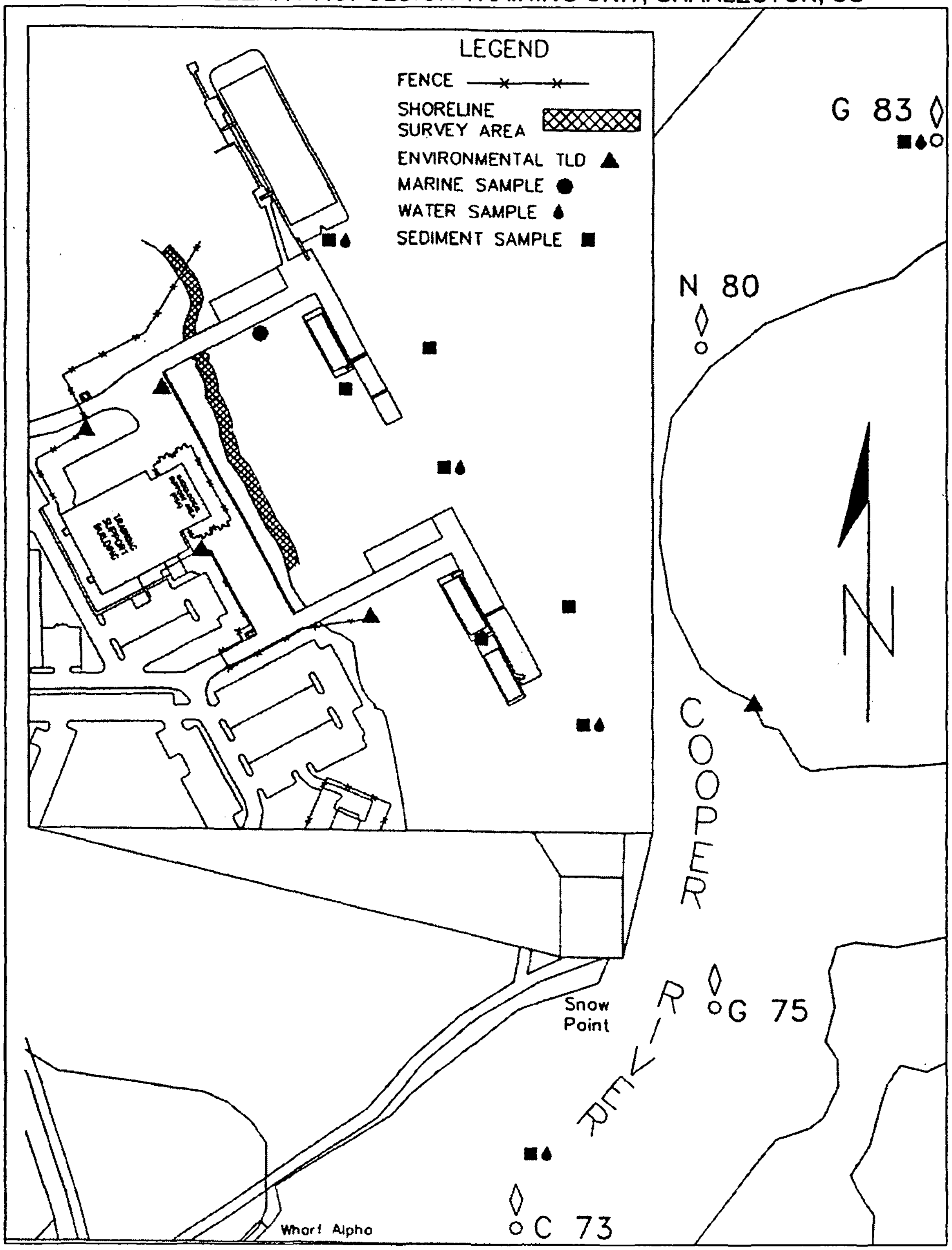


FIGURE 14
ENVIRONMENTAL MONITORING LOCATIONS AT
NORTHROP GRUMMAN NEWPORT NEWS, NEWPORT NEWS, VA

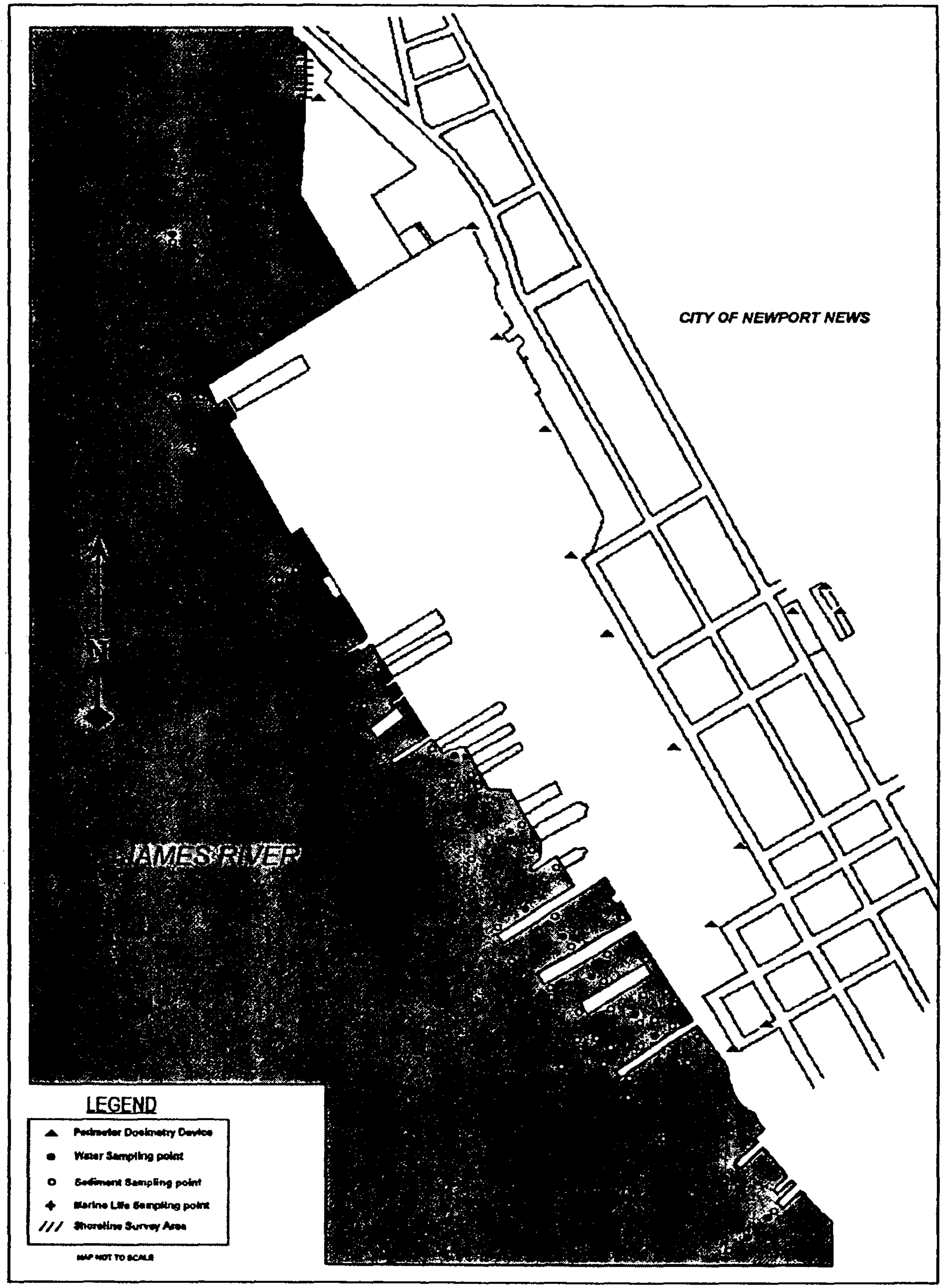


FIGURE 15
ENVIRONMENTAL MONITORING LOCATIONS AT
NORFOLK NAVAL SHIPYARD, PORTSMOUTH, VA

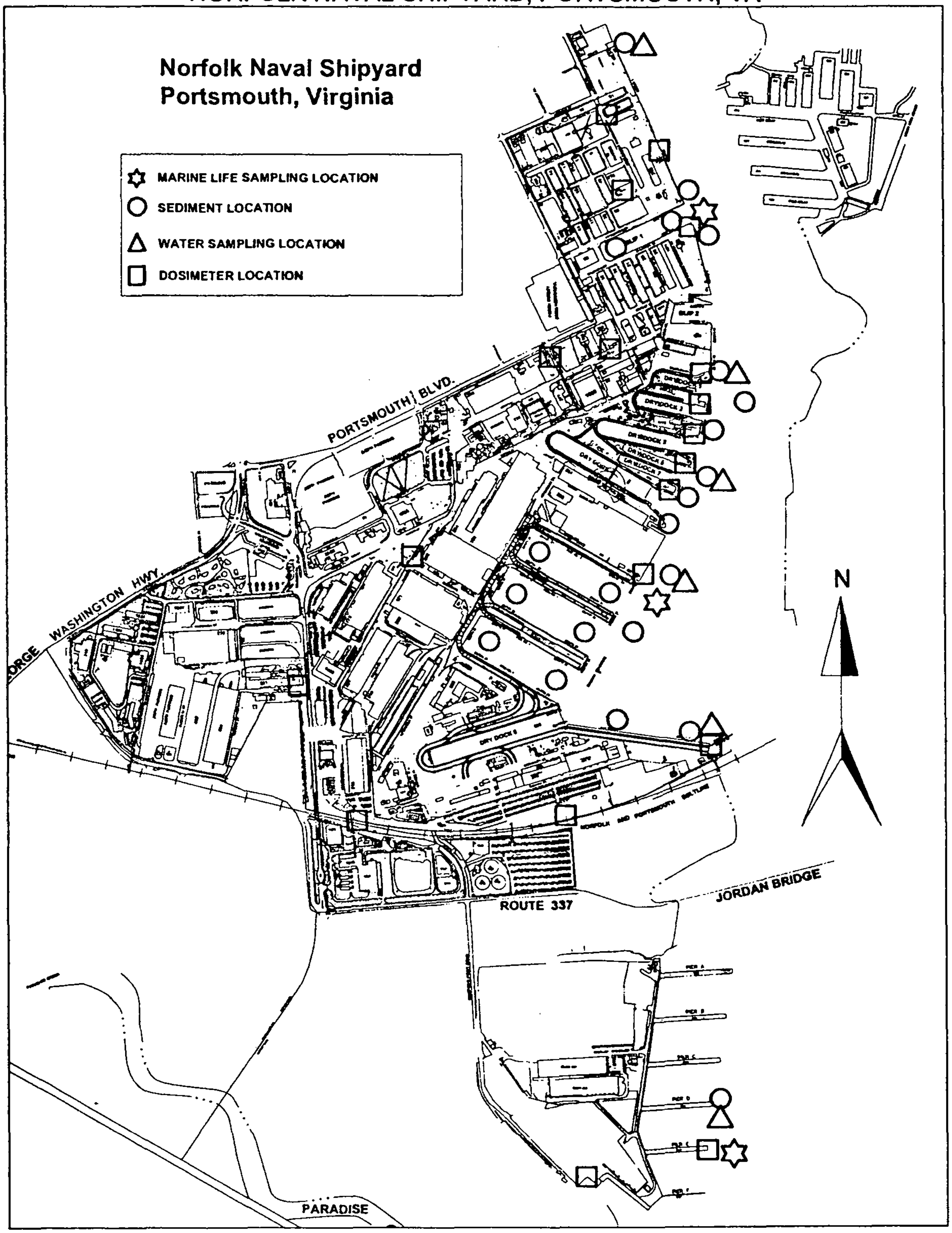
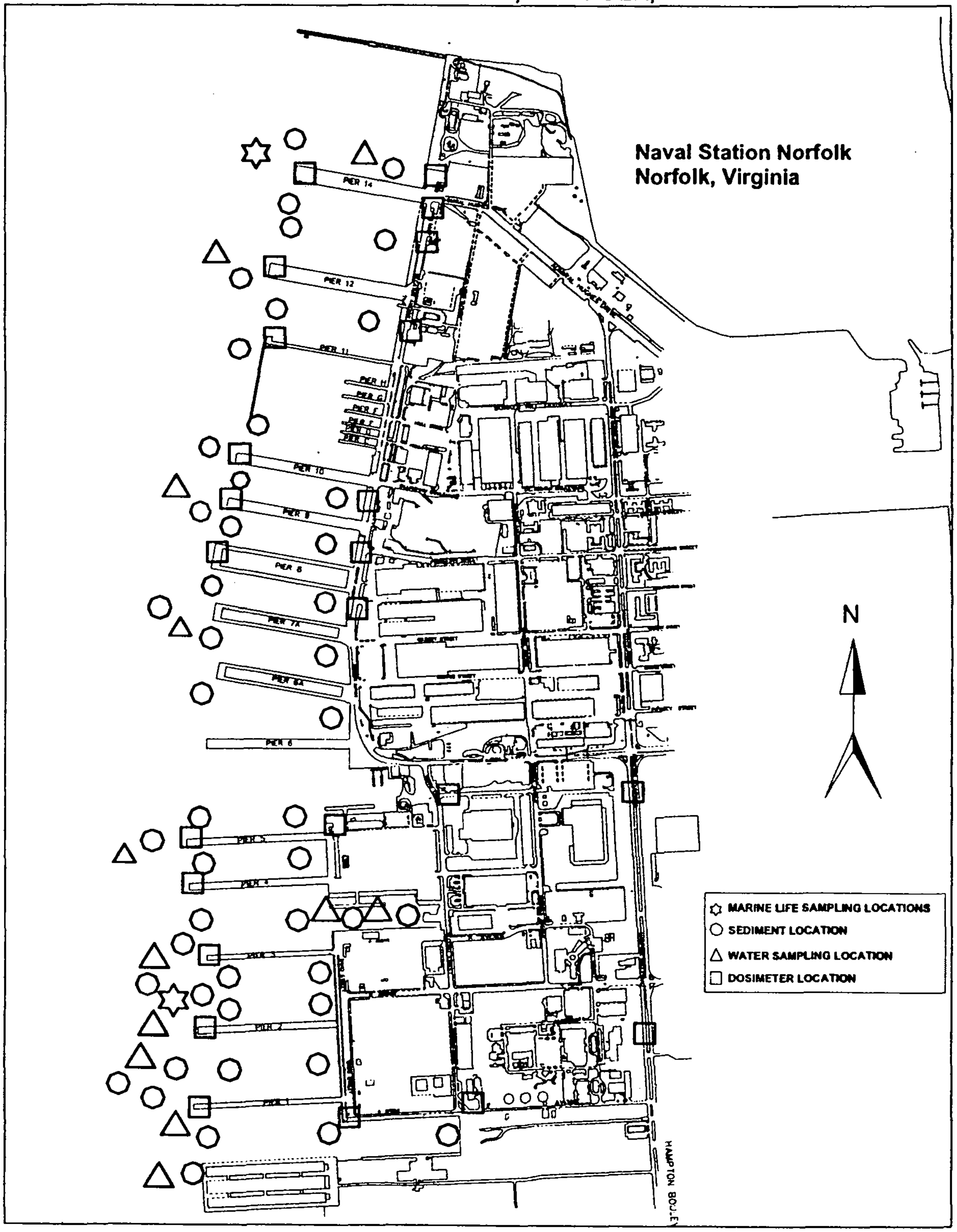


FIGURE 16
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION, NORFOLK, VA



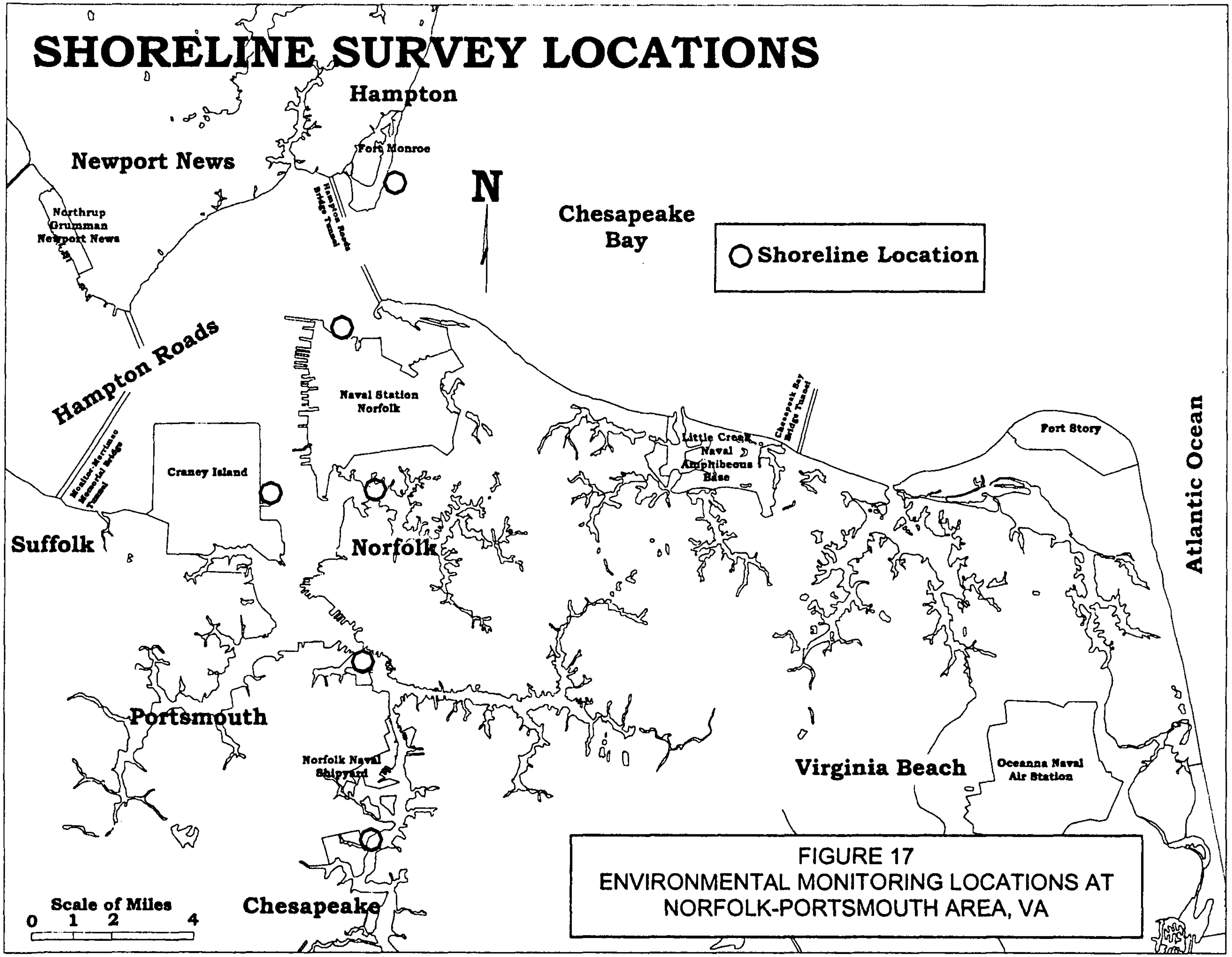


FIGURE 17
ENVIRONMENTAL MONITORING LOCATIONS AT NORFOLK-PORTSMOUTH AREA, VA

FIGURE 18
ENVIRONMENTAL MONITORING LOCATIONS AT
PUGET SOUND NAVAL SHIPYARD, BREMERTON, WA

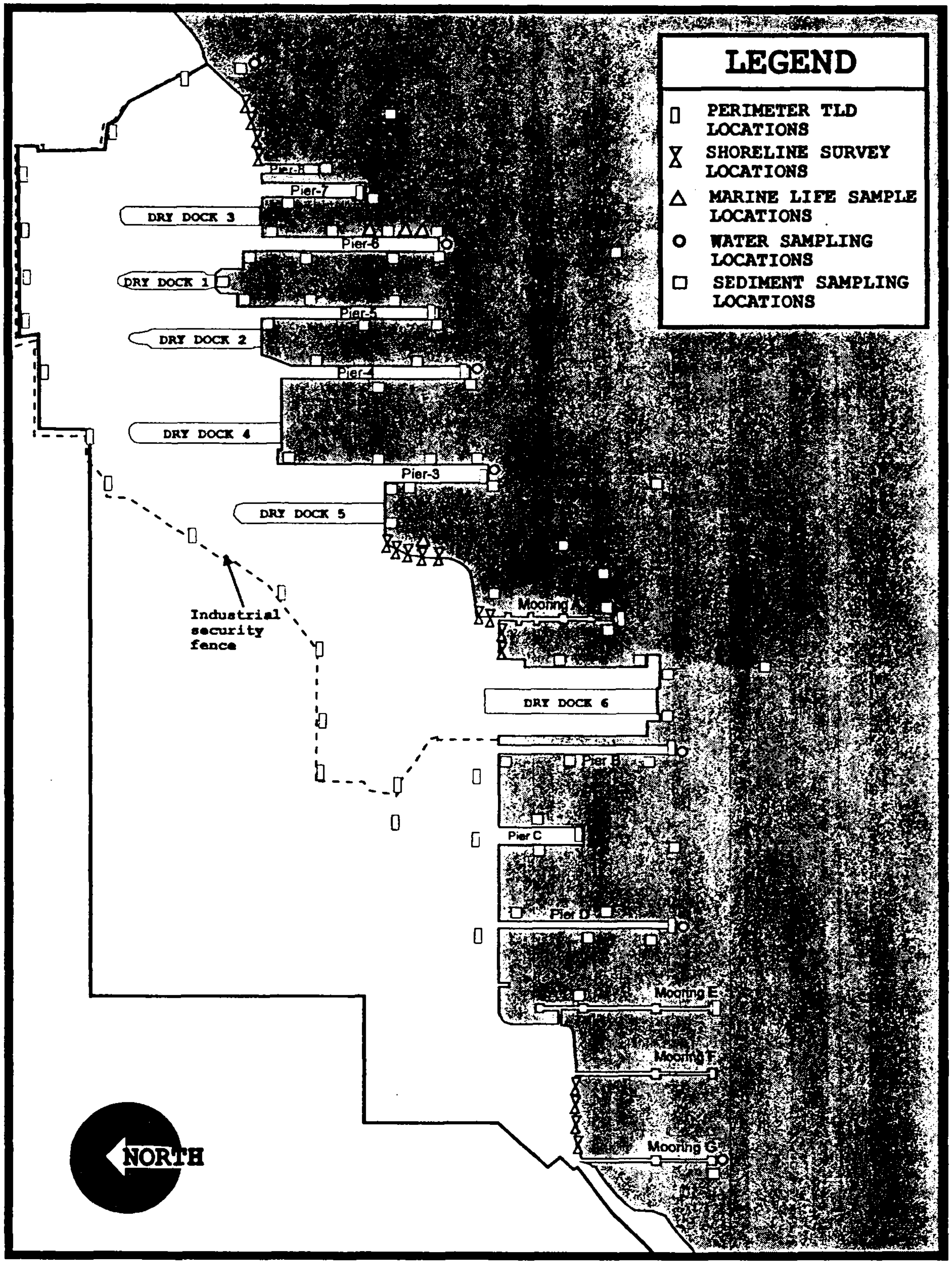


FIGURE 19
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, BANGOR, WA

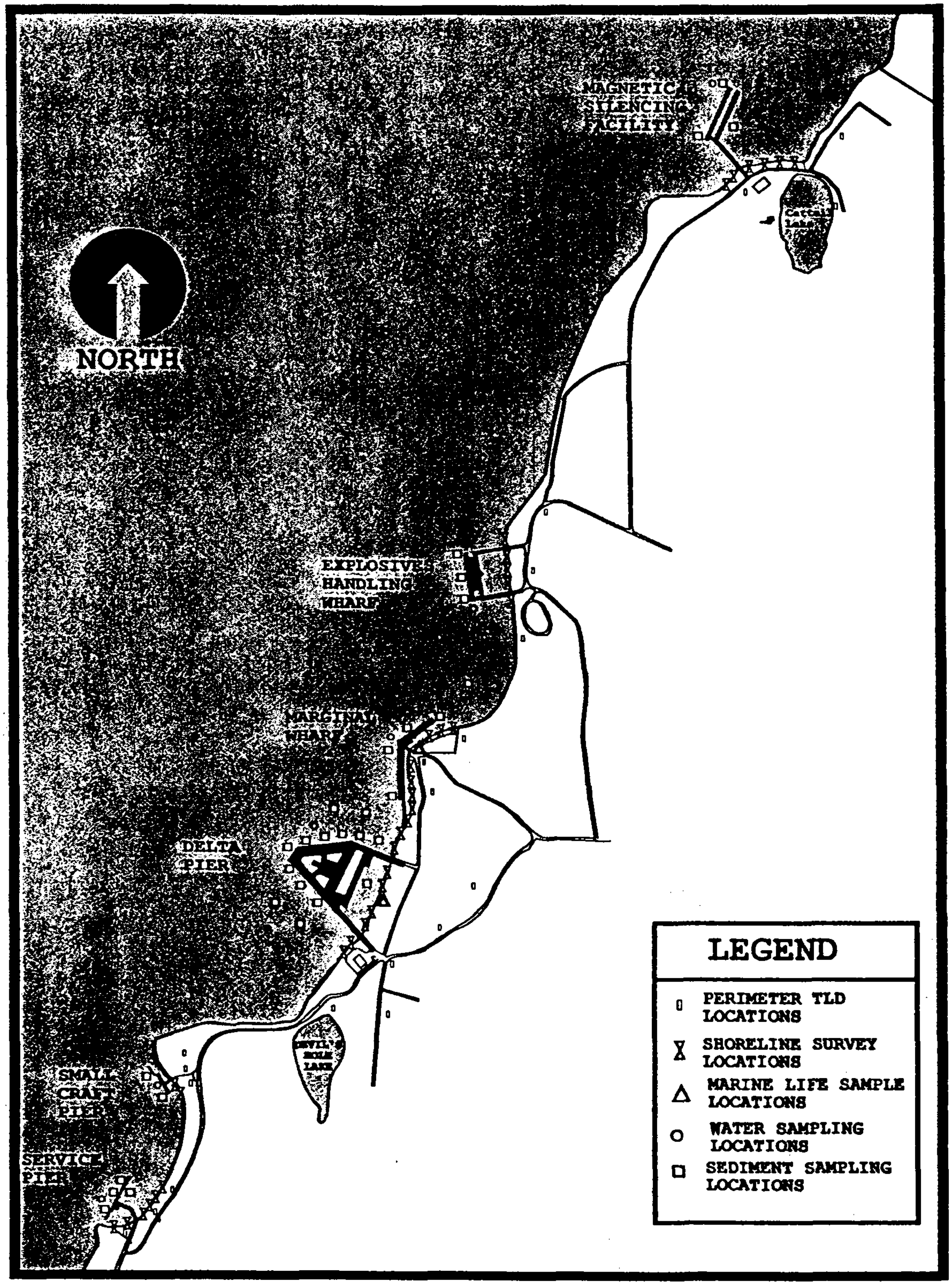
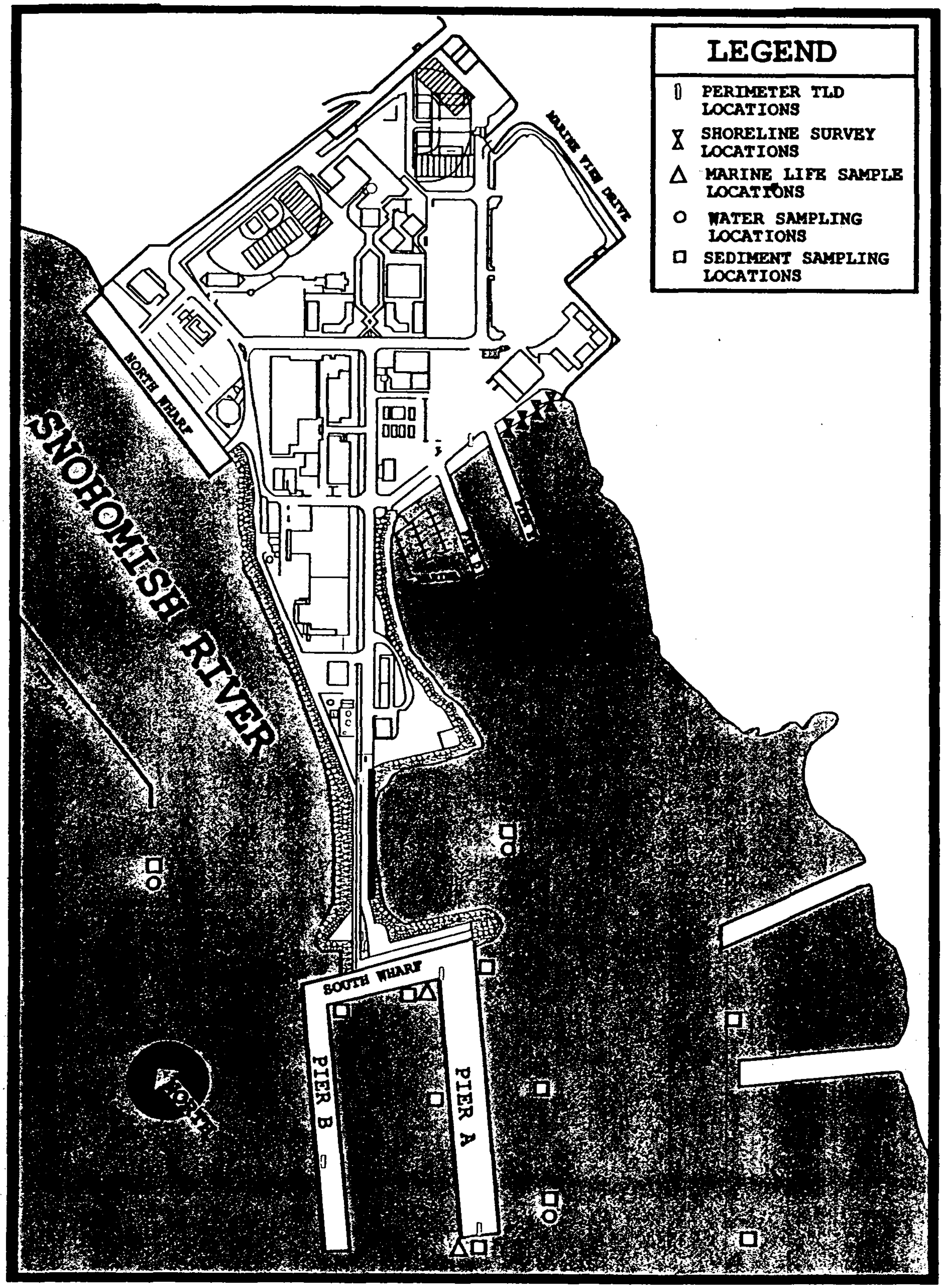


FIGURE 20
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION, EVERETT, WA



SEPARATION

PAGE

06.0959

REPORT NT-06-2
MARCH 2006

OCCUPATIONAL RADIATION EXPOSURE FROM U.S. NAVAL NUCLEAR PLANTS AND THEIR SUPPORT FACILITIES

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

This publication was printed on Recycled Paper

06.0959

Report NT-06-2
March 2006

OCCUPATIONAL RADIATION EXPOSURE FROM U.S. NAVAL NUCLEAR PROPULSION PLANTS AND THEIR SUPPORT FACILITIES

2005

Prepared by

T. J. Mueller,
W. S. Knoll, J. A. Jones, and B. P. McLane
Naval Nuclear Propulsion
Department of the Navy

Approved by

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Radiation exposures to Navy and civilian personnel monitored for radiation associated with U.S. naval nuclear propulsion plants are summarized in this report. As of the end of 2005, the U.S. Navy operated 73 nuclear-powered submarines, 10 nuclear-powered aircraft carriers, and 2 moored training ships. Facilities that build, maintain, overhaul, or refuel these nuclear propulsion plants include six shipyards, two tenders, and five naval bases. The benefits of nuclear propulsion in our most capable combatant ships have long been recognized, and our nuclear-powered ballistic missile submarines form the strongest element of the U.S. strategic deterrent.

Figure 1 shows that the total radiation exposure in 2005 is about 9 percent of the amount in the peak year of 1966, even though today there are about 20 percent more nuclear-powered ships in operation and more than 2½ times the number of ships in overhaul. Total radiation exposure in this figure is the sum of the annual exposures of each person monitored for radiation. In 2005, the number of ships in overhaul decreased by about 3 percent from 2004 and the total shipyard radiation exposure decreased from 1,127 rem in 2004 to 1,084 rem in 2005 (shipyard average annual rem per person decreased from 0.058 rem in 2004 to 0.056 rem in 2005). In 2005, the total Fleet radiation exposure decreased from 789 rem in 2004 to 749 rem in 2005 (Fleet average annual rem per person decreased from 0.038 rem in 2004 to 0.036 rem in 2005).

The current Federal annual occupational radiation exposure limit of 5 rem established in 1994 came 27 years after the Naval Nuclear Propulsion Program's (NNPP's) annual exposure limit of 5 rem per year was established in 1967. (Until 1994, the Federal radiation exposure lifetime limit allowed an accumulation of exposure of 5 rem for each year of age beyond 18.) From 1968 to 1994, no civilian or military personnel in the Program exceeded its self-imposed 5 rem annual limit, and no one has exceeded that Federal limit since then. In fact, no Program personnel have exceeded 40 percent of the Program's annual limit since 1980 (i.e., no personnel have exceeded 2 rem in any year in the last 25 years). And no civilian or military Program personnel have ever, in over 50 years of operation, exceeded the Federal lifetime limit.

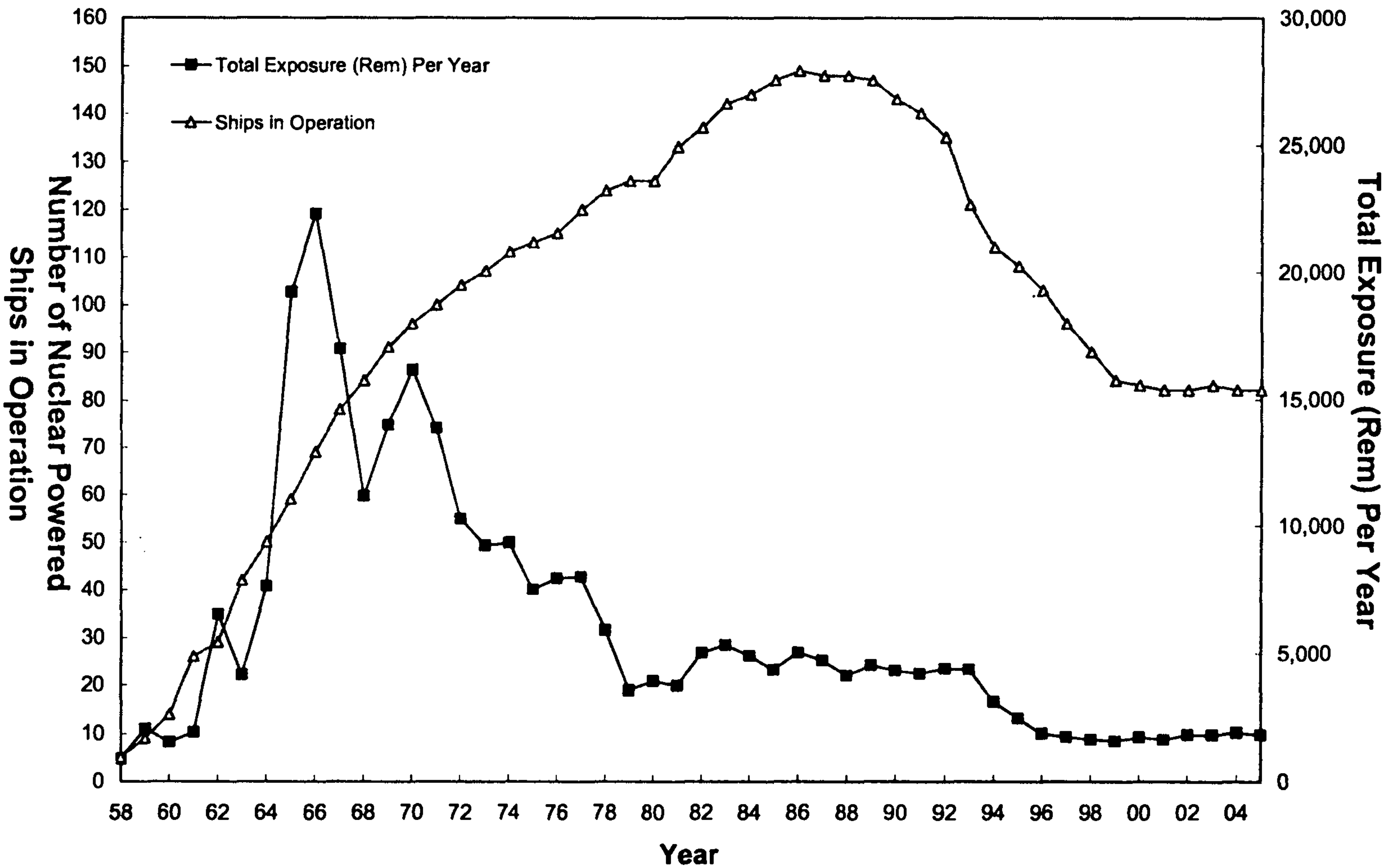
Personnel operating the Navy's nuclear-powered ships receive less radiation exposure in a year than the average U.S. citizen does from natural background and medical radiation exposure. For example, the exposure received by the average nuclear-trained sailor living onboard one of the Navy's nuclear-powered ships in 2005 was about a tenth of the radiation received by the average U.S. citizen from natural background and medical sources that year. This achievement is possible because of very conservative shielding designs on these ships (a tenet of the Program since it was founded in 1948), as well as the fact that shipboard personnel were generally shielded from natural background sources of radiation (i.e., earth and cosmic sources of radiation) while at sea.

Since 1962, no civilian or military personnel in the NNPP have ever received more than a tenth the Federal annual occupational exposure limit from internal radiation exposure caused by radioactivity associated with naval nuclear propulsion plants.

The average occupational exposure of each person monitored since 1954 for radiation associated with naval nuclear propulsion plants is less than 0.150 rem per year. The total lifetime average exposure during this 52-year period is about 1 rem per person.

According to the standard methods for estimating risk, the risk to the group of personnel occupationally exposed to radiation associated with naval nuclear propulsion plants is less than the risk these same personnel have from exposure to natural background radiation. This risk is small in comparison to both the risks accepted in normal industrial activities, and the risks regularly accepted in daily life outside of work.

FIGURE 1
TOTAL RADIATION EXPOSURE RECEIVED BY MILITARY AND CIVILIAN PERSONNEL IN THE NAVAL NUCLEAR PROPULSION PROGRAM 1958 - 2005



EXTERNAL RADIATION EXPOSURE

Policy and Limits

The policy of the U.S. Naval Nuclear Propulsion Program is to reduce exposure to personnel from ionizing radiation associated with naval nuclear propulsion plants to a level as low as reasonably achievable.

Prior to 1960, the Federal radiation exposure limit used in the U.S. for whole body radiation was 15 rem per year [1]. From 1960 to 1994, the Federal radiation exposure limits used in the U.S. for whole body radiation exposure were 3 rem per quarter year and 5 rem accumulated dose for each year beyond age 18. These limits were recommended in 1958 by the U.S. National Committee ("Committee" was changed to "Council" when the organization was chartered by the U.S. Congress in 1964) on Radiation Protection and Measurements (reference 1)[2] and by the International Commission on Radiological Protection (reference 2). They were adopted by the U.S. Atomic Energy Commission (AEC) and applied both within the AEC and to licensees in 1960 (reference 3). On May 13, 1960, President Eisenhower approved the U.S. Federal Radiation Council recommendation that these limits be used as guidance for Federal agencies (reference 4). The U.S. Department of Labor adopted these same limits. A key part of each of these standards has been emphasis on minimizing radiation exposure to personnel.

In 1965, the International Commission on Radiological Protection (reference 5) reiterated the quarterly and accumulated limits cited above, but suggested that exceeding 5 rem in 1 year should be infrequent. Although none of the other organizations referred to above changed their recommendations, the Naval Nuclear Propulsion Program adopted 5 rem per year as a rigorous limit, effective in 1967.

In 1971, the National Council on Radiation Protection and Measurements (reference 6) recommended that 5 rem be adopted as the annual limit under most conditions. In 1974, the AEC (now the Department of Energy) (reference 7) established 5 rem as its annual limit. In 1977, the International Commission on Radiological Protection (reference 8) deleted the accumulated limit and recommended 5 rem as the annual limit. In 1979, the Nuclear Regulatory Commission issued a proposed change to the Code of Federal Regulations, Title 10, Part 20, to require its licensees to use 5 rem as an annual limit. On January 20, 1987, revised guidance for Federal agencies was approved by President Reagan that eliminated the accumulated dose limit discussed above and established a 5 rem per year limit for occupational exposure to radiation (reference 9). The Nuclear Regulatory Commission approved the change to the Code of Federal Regulations, Title 10, Part 20, that made the 5 rem annual limit effective on or before January 1, 1994.

The Naval Nuclear Propulsion Program radiation exposure limits since 1967 have been:

3 rem per quarter
5 rem per year

1. 1 rem = 0.01 Sievert
2. References are listed on pp. 54-57.

Special higher limits are in effect, such as those for hands and feet; however, there have been few cases where these limits have been more restrictive than the whole body radiation exposure limits. Therefore, the radiation exposures discussed in this report are nearly all from whole body radiation. Controls are also in effect to minimize any occupational radiation exposure to the unborn child of a pregnant worker.

Each organization in the Naval Nuclear Propulsion Program is required to have an active program to keep radiation exposure as low as reasonably achievable.

Source of Radiation

The radiation discussed in this report originates from pressurized water reactors. Water circulates through a closed piping system to transfer heat from the reactor core to a secondary steam system isolated from the reactor cooling water. Trace amounts of corrosion and wear products are carried by reactor coolant from reactor plant metal surfaces. Some of these corrosion and wear products are deposited on the reactor core and become radioactive from exposure to neutrons. Reactor coolant carries some of these radioactive products through the piping systems where a portion of the radioactivity is removed by a purification system. Most of the remaining radionuclides transported from the reactor core deposit in the piping systems.

The reactor core is installed in a heavy-walled pressure vessel within a primary shield. This shield limits radiation exposure from the gammas and neutrons produced when the reactor is operating. Reactor plant piping systems are installed primarily inside a reactor compartment that is itself surrounded by a secondary shield. Access to the reactor compartment is permitted only after the reactor is shut down. Most radiation exposure to personnel comes from inspection, maintenance, and repair inside the reactor compartment. The major source of this radiation is cobalt-60 deposited inside the piping systems. Cobalt-60 emits two high-energy gammas and a low-energy beta for every radioactive decay. Its half-life is 5.3 years.

Neutrons (produced when reactor fuel fissions) are also shielded by the primary and secondary shields. Radiation exposure to personnel from these neutrons during reactor operation is much less than from gammas. After reactor shutdown, when shipyard and other support facility work is done, no neutron exposure is detectable. Therefore, the radiation exposures discussed in this report are nearly all from gamma radiation.

Control of Radiation During Reactor Plant Operation

Reactor plant shielding is designed to minimize radiation exposure to personnel. Shield design criteria establishing radiation levels in various parts of each nuclear-powered ship are personally approved by the Director, Naval Nuclear Propulsion.

Ship design is also controlled to keep locations such as duty stations, where personnel need to spend time, as far as practicable away from the reactor compartment shield. Special attention is paid to living quarters. For example, the shield design criteria were established such that a person would have to spend more than 48 hours per day in living quarters to exceed exposure limits (which is impossible, there being only 24 hours in a day).

Radiation resulting outside the propulsion plant spaces during reactor plant operation is generally not any greater than natural background radiation. For submarine personnel stationed outside the propulsion plant, the combination of low natural radioactivity in ship construction materials and reduced cosmic radiation under water results in less radiation exposure (from all sources including the nuclear reactor) at sea than the public receives from natural background sources ashore. Those who operate the nuclear propulsion plant receive more radiation exposure in port during maintenance and overhaul periods than they receive from operating the propulsion plant at sea.

Control of Radiation in Support Facilities

Special support ships called tenders for nuclear-powered ships are constructed so that radioactive material is handled only in specially designed and shielded nuclear support facilities. Naval bases and shipyards minimize the number of places where radioactive material is allowed. Stringent controls are in place during the movement of all radioactive material outside these nuclear support facilities. A radioactive material accountability system is used to ensure that no radioactive material is lost or misplaced in a location where personnel could unknowingly be exposed. Regular inventories are required for every item in the radioactive material accountability system. Radioactive material is tagged with yellow and magenta tags bearing the standard radiation symbol and the measured radiation level. Radioactive material removed from a reactor plant is required to be placed in yellow plastic, and the use of yellow plastic is reserved solely for radioactive material. All personnel assigned to a tender, naval base, or shipyard are trained to recognize that yellow plastic identifies radioactive material and to initiate immediate action if radioactive material is discovered out of place.

Access to radiation areas is controlled by signs and barriers. Personnel are trained in the access requirements, including the requirement to wear dosimetry devices to enter these areas. Dosimetry devices are also posted near the boundaries of these areas to verify that personnel outside these areas do not require monitoring. Frequent radiation surveys are required using instruments that are checked before use and calibrated regularly. Areas where radiation levels are greater than 0.1 rem per hour are called "high radiation areas" and are locked or guarded. Compliance with radiological controls requirements is checked frequently by radiological controls personnel, as well as by other personnel not affiliated with the radiological controls organization.

Dosimetry

Thermoluminescent dosimeters (TLDs) have been the dosimetry devices worn by personnel to measure their exposure to gamma radiation since 1974. Prior to 1974, film badges were used as described below. The TLD contains two chips of calcium fluoride with added manganese. It is characteristic of thermoluminescent material that radiation causes internal changes that make the material, when subsequently heated, give off an amount of light directly proportional to the radiation dose. In order to make it convenient to handle, these chips of calcium fluoride are in contact with a metallic heating strip with heater wires extending through the ends of a surrounding glass envelope. The glass bulb is protected by a plastic case designed to permit the proper response to gammas of various energies. Gammas of such low energy that they will not penetrate the plastic case constitute less than a few percent of the total gamma radiation present. To read the radiation exposure, a trained operator removes the glass bulb and puts it in a TLD reader, bringing the metal heater wires into contact with an electrical circuit. An electronically controlled device heats the calcium fluoride chips to several hundred degrees Celsius in a timed cycle, and the intensity of light emitted is measured and converted to a digital readout in units of rem. The heating cycle also anneals the calcium fluoride chips so that the dosimeter is zeroed and ready for subsequent use. The entire cycle of reading a TLD described here takes about 30 seconds. This rapid readout capability was one reason for changing from film badges to TLDs. The use of TLDs permits more frequent measurement of a worker's radiation exposure than film badges did. TLDs are required to be processed at least weekly in naval shipyards, and at least monthly aboard ship. Daily processing is required for anyone entering a reactor compartment or high radiation area.

To ensure accuracy of the TLD system, periodic calibration and accuracy checks are performed. For example, TLDs are checked when new, and once every 9 months thereafter, for accurate response to a known radiation exposure. Those that fail are discarded. TLD readers are calibrated once each year by one of several calibration facilities, using precision radiation sources and precision TLD standards. In addition, weekly, daily, and hourly checks of proper TLD reader operation and accuracy are performed when readers are in use, using internal electronic standards built into each reader.

In addition to these calibrations and checks, the Navy has an independent dosimetry quality assurance program to monitor the accuracy of TLDs and TLD readers in use at Program activities. Precision TLDs are pre-exposed to known amounts of radiation by the National Institute of Standards and Technology (formerly the National Bureau of Standards) and provided to Program activities for reading. The activity's results are then compared to the actual exposures. A random sample of dosimeters in use at the activity being tested is also selected and sent to a Navy shore facility for accuracy testing. To ensure objectivity, the activity being tested is not told of the radiation values to which the dosimeters have been exposed and is not permitted to participate in the selection of the dosimeter sample. If these tests find any inaccuracies that exceed established permissible error, appropriate corrective action (such as recalibration of a failed TLD reader) is immediately taken. The results of this program demonstrate that the radiation to which personnel are exposed is being measured by the TLD system with an average error of less than 10 percent.

The Naval Nuclear Propulsion Program dosimetry system is accredited under the National Voluntary Laboratory Accreditation Program. This voluntary program, sponsored by the National Institute of Standards and Technology, provides independent review of dosimetry services for consistency with accepted standards.

Pocket ionization chambers with an eyepiece permit wearers to read and keep track of their own radiation exposure during a work period. This pocket dosimeter is required in addition to a TLD when entering a reactor compartment or a high radiation area. The official record of radiation exposure is obtained from the TLD.

Dosimetry devices are worn on the trunk of the body, normally at the waist or chest. In some special situations additional dosimeters are worn at other locations, for example on the hands, fingers, or head.

Discrepancies between TLD and pocket dosimeter measurements are investigated. These investigations include making independent, best estimates of the worker's exposure using such methods as time spent in the specific radiation area and comparing the estimates with the TLD and pocket dosimeter measurements to determine which measurement is the more accurate.

In 1974, the conversion from film badges to TLDs for measuring radiation exposure was completed. Before 1974, film packets like those used for dental x-rays were placed in holders designed to allow differentiating between types of radiation. The darkness of the processed film was measured with a densitometer and converted to units of radiation exposure. When the first personnel radiation exposures were measured in the Naval Nuclear Propulsion Program, there already was widespread photodosimetry experience in the Navy and precise procedures existed to provide reproducible results.

Each film badge was clearly marked with a name or number corresponding to the individual to whom it was assigned. This number was checked by a radiological controls technician before a worker entered a high radiation area. In high radiation areas every worker also wore a pocket dosimeter, which was read by radiological controls personnel when the worker left the area. At the end of each month when the film badges were processed, the film badge measurements were compared with the sum of the pocket dosimeter readings. The film badge results were, with few exceptions, entered in the permanent personnel radiation exposure records. The few exceptions where film badge results were not entered into exposure records occurred when material problems with the film caused abnormal readings, such as film clouding. In such cases, a conservative estimate of exposure was entered.

Results of numerous tests conducted by shipyards under the same conditions that most radiation exposure was received showed that film measurements averaged 15 percent higher than actual radiation exposures. This was a conscious conservatism to ensure that even in the worst case, the film measurement was not less than the actual radiation exposure. Film response varies with the energy of the gamma radiation. The calibration of the film was performed at high energy where the film has the least response to radiation exposure. Radiation of lower energies corresponding to scattered radiation from shielded cobalt-60 caused the film to indicate more radiation exposure than actually present.

Data gathered in over 20 years of neutron monitoring aboard ships using neutron film badges demonstrated that the monitored individuals did not receive neutron exposure above the minimum detection level for neutron film. Naval nuclear-powered ships and their support facilities now use lithium fluoride TLDs to monitor neutron exposure of the few personnel exposed to neutron sources, such as for radiation instrument calibration and for reactor plant instrumentation source handling. These measured neutron exposures have been added to gamma exposures in the total whole body radiation exposure in this report; but because neutron exposures are so low, the radiation exposures in this report are almost entirely from gamma radiation.

Monitoring for beta radiation is not normally required, because betas cannot penetrate the metal boundaries of the reactor coolant system. Beta radiation needs to be considered in maintenance or repair operations only when systems are opened and personnel are close to surfaces that have been contaminated with radioactive corrosion products from reactor coolant. In these cases anticontamination clothing, faceshields, or plastic contamination control materials effectively shield the individual from beta radiation of the energies normally present. Support facilities routinely provide such materials to eliminate beta radiation exposure.

Monitoring for alpha radiation is not a normal part of operation or maintenance of naval nuclear propulsion plants. However, alpha monitoring is sometimes necessary to identify radon daughter products naturally present in the atmosphere.

Physical Examinations

Radiation medical examinations have been required since the beginning of the Naval Nuclear Propulsion Program for personnel who handle radioactive material or who could exceed in 1 year the maximum exposure allowed to a member of the general public (i.e., 0.1 rem). These examinations are conducted in accordance with the Navy's Radiation Health Protection Manual (reference 10). In these examinations the doctor pays special attention to any condition that might medically disqualify a person from receiving occupational radiation exposure or pose a health or safety hazard to the individual, to co-workers, or to the safety of the workplace.

Passing this examination is a prerequisite for obtaining dosimetry, which permits entry to high radiation and radiologically controlled areas and allows handling of radioactive material. Few of the military personnel who have already been screened by physical examinations fail this radiation medical examination. For civilian shipyard workers, the failure rate is a few percent. However, failure of this examination does not mean a shipyard worker will not have a job. Since shipyard workers spend most of their time on non-radioactive work, inability to qualify for radioactive work does not restrict their job opportunities. No shipyard worker in the Naval Nuclear Propulsion Program has been fired for inability to pass a radiation medical examination.

When required, radiation medical examinations are given prior to initial work, periodically thereafter depending on the worker's age, and at termination of radioactive work in the Naval Nuclear Propulsion Program (or at termination of employment). The periodic examinations are conducted in accordance with the following frequencies:

Age	Interval
18-24	Pre-placement
25-49	Every 5 years
50-59	Every 2 years
>60	Annually

A radiation medical examination includes review of medical history to determine among other things, past radiation exposure, history of cancer, and history of radiation therapy. In the medical examination, particular attention is paid to evidence of cancer or a precancerous condition. Laboratory procedures include urinalysis, blood analysis, and comparison of blood constituents to a specific set of standards. If an examination of naval civilian or military personnel disqualifies the individual, the individual is restricted from receiving occupational radiation exposure and the results of the examination are reviewed by the Bureau of Medicine and Surgery's Radiation Effects Advisory Board. Only after approval of the Board would the individual be permitted to receive occupational radiation exposure.

Shipyard, Tender, and Naval Base Training

Periodic radiological controls training is performed to ensure that all workers understand the general and specific radiological aspects they might encounter, their responsibility to the Navy and the public for safe handling of radioactive materials, the risks associated with radiation exposure, and their responsibility to minimize their own radiation exposure. Training is also provided on the biological risk of radiation exposure to the unborn child. Before being authorized to perform radioactive work, an employee is required to pass a radiological controls training course, including a written examination. Typical course lengths for workers range from 16 to 32 hours. In written examinations on radiological controls, short-answer questions (such as multiple choice or true-false) are prohibited. The following are the training requirements for a fully qualified worker:

1. Radiation Exposure Control:

   a. State the limits for whole body penetrating radiation. Explain that the rem is a unit of biological dose from radiation.

   b. Discuss the importance of the individual keeping track of his/her own exposure. Know how to obtain year-to-date exposure information.

   c. Know that local administrative control levels are established to keep personnel radiation exposure as low as reasonably achievable. Know his/her own exposure control level and who can approve changes to this level.

   d. Discuss procedures and methods for minimizing exposure, such as working at a distance from a source, reducing time in radiation areas, and using shielding.

   e. Know that a worker is not authorized to move, modify, or add temporary shielding without specific authorization.

   f. Discuss potential sources of radiation associated with work performed by the individual's trade.

   g. Discuss the action to be taken if an individual loses dosimetry equipment while in a posted radiation or high radiation area.

   h. Discuss how to obtain and turn in dosimetry equipment.

   i. Know that TLDs must be worn on the portion of the individual's body that receives the highest exposure and that pocket dosimeters are worn at the same location on the body as the TLD. Know that only radiological controls personnel can authorize movement of dosimetry equipment from areas of the body where dosimetry is normally worn (such as the chest or waist) to other areas of the body.

   j. Be aware of the seriousness of violating instructions on radiation warning signs and unauthorized passage through barriers.

   k. Explain how "stay times" are used.

   l. Know that naval nuclear work at a facility has no significant effect on the environment or on personnel living adjacent to or within the facility.

   m. Explain the risk associated with personnel radiation exposure. Know that any amount of radiation exposure, no matter how small, might involve some risk; however, exposure within accepted limits represents a risk that is small compared with normal hazards of life. (The National Council on Radiation Protection and Measurements has stated that while exposures of workers and the general population should be kept to the lowest practicable levels at all times, the presently permitted exposures limit the risk to a reasonable level in comparison to nonradiation risks.) Know that cancer is the main potential health effect of receiving radiation exposure. Know that any amount of radiation exposure to the unborn child, no matter how small the exposure, might involve some risk; however, exposure of the unborn child within accepted limits represents a risk that is small when compared with other risks to the unborn child. Know that the risk to future generations (genetic effect) is considered to be even smaller than the cancer risk and that genetic effects have not been observed in human beings.

n. Know how often an individual shall read his/her pocket dosimeter while in a posted high radiation area. Know that a worker shall leave a posted high radiation area when his/her pocket dosimeter reaches three quarters scale or when a preassigned exposure is reached, whichever is lower.

o. Know that stay times and predetermined pocket dosimeter readings are assigned when working in radiation fields of 1 rem/hour or greater. Know that the worker shall leave the work area when either the assigned stay time or pocket dosimeter reading is reached.

2. Contamination Control:

a. Discuss how contamination is controlled during radioactive work (e.g., containment in plastic bags and use of contamination containment areas). Explain that these controls keep exposure to internal radioactivity at insignificant levels.

b. Discuss how contamination is detected on personnel.

c. Discuss how contamination is removed from objects and personnel.

d. Discuss potential sources of contamination associated with work performed by the individual's trade.

e. State the beta-gamma surface contamination limit. Discuss the meaning of the units of the limit.

f. Explain what radioactive contamination is. Explain the difference between radiation and radioactive contamination.

g. For personnel who are trained to wear respiratory protection equipment, state the controls for use of such equipment. Know that the use of a respirator is based on minimizing inhalation of radioactivity. Know that the respirators used for radiological work are not used for protection in any atmospheres that threaten life or health. Therefore, know that the proper response to a condition in which supply air is lost or breathing becomes difficult is to remove the respirator.

h. Discuss the required checks to determine whether personnel contamination monitoring equipment is operational before conducting personnel monitoring. Discuss the action to be taken if the checks indicate the equipment is not operating properly.

i. Discuss the actions to be taken if personnel contamination monitoring equipment alarms while conducting personnel monitoring.

j. Discuss the procedure to package and remove a contaminated item from a controlled surface contamination area.

k. Know that if a worker's skin receives radioactive contamination associated with naval nuclear propulsion plants, no health effects are expected.

l. Discuss the procedures for donning and removing a full set of anticontamination clothing.

3. Accountability of Radioactive Materials: Know that radioactive materials are accounted for when transferred between radiologically controlled areas by tagging, tracking location, and using radioactive material escorts.

4. Waste Disposal:

   a. Discuss how individual workers can reduce the amount of radioactive liquid and solid waste generated for the specific type of duties performed.

   b. Discuss the importance of properly segregating non-contaminated, potentially contaminated, and contaminated material.

   c. Know what reactor plant reuse water is. Discuss the appropriate uses of reactor plant reuse water.

5. Radiological Casualties:

   a. Discuss the need for consulting radiological controls personnel when questions or problems occur. Understand the importance of complying with the instructions of radiological controls personnel in the event of a problem involving radioactivity.

   b. Discuss procedures to be followed in the event of a spill of material (liquid or solid) which is or might be radioactive.

   c. Discuss procedures to be followed when notified that airborne radioactivity is above the limit.

   d. Discuss procedures to be followed if a high radiation area is improperly controlled.

   e. Discuss actions to be taken when an individual discovers his/her pocket dosimeter is off-scale or has recorded a higher reading than expected.

6. Responsibilities of Individuals: Discuss actions required in order to fulfill the worker's responsibilities. Discuss the responsibility of the individual to notify the Radiation Health Department or the Medical Department of radiation medical therapy, medical diagnosis involving radioisotopes, open wounds or lesions, physical conditions that the worker feels affect his or her qualification to receive

occupational radiation exposure, or occupational radiation exposure from past or current outside employment. Discuss the responsibility of the individual to report to area supervision or radiological controls personnel any condition that might lead to or cause avoidable exposure to radiation.

7. Practical Ability Demonstrations: These demonstrations are performed on a mockup.

   a. Demonstrate the ability to read all types of pocket dosimeters used by the organization.

   b. For applicable workers, demonstrate the proper procedure for donning and removing a full set of anticontamination clothing.

   c. Demonstrate the proper procedures for entering and leaving a high radiation area, a radiologically controlled area, and a control point area, including proper procedures for self-monitoring. Demonstrate the ability to read and interpret posted radiation and contamination survey maps.

   d. For applicable workers, demonstrate the ability to properly package and remove an item from a controlled surface contamination area.

   e. Demonstrate action to be taken by one or two workers in the event of a spill of radioactive liquid.

   f. For personnel who will enter or remain in areas where respiratory protection equipment is required, demonstrate the proper procedure for inspection and use of the type(s) of respiratory equipment the individual will be required to wear as part of mockup training for the job. This includes demonstrating how to don and remove the type of respiratory equipment in conjunction with anticontamination clothing, if anticontamination clothing must be worn with the respiratory equipment. In addition, individuals who are trained to wear air-fed hoods demonstrate the proper response if supply air is lost while wearing one.

   g. For personnel who are trained to work in contamination containment areas, demonstrate the proper procedures for working in these areas. This demonstration includes a pre-work inspection, transfer of an item into the area, a work evolution in the area, and transfer of an item out of the area.

In addition to passing a written examination, completion of this training course requires satisfactory performance during basic types of simulated work operations. To continue as a radiation worker, personnel must requalify in a manner similar to the initial qualification at least every 2 years. Between these qualification periods, personnel are required to participate in a continuing training program, and the effectiveness of that continuing training is tested randomly and often. Training is also conducted by individual shop instructors in the specific job skills for radiation work within each trade. For complex jobs this is followed by special training for the specific job, frequently using mockups outside radiation areas.

Radiological controls technicians are required to complete a 6-12 month course in radiological controls, to demonstrate their practical abilities in work operations and drills, and to pass comprehensive written and oral examinations. Radiological controls supervisors are required to have at least the same technical knowledge and abilities as the technicians; however, passing scores for supervisors' examinations are either higher or more difficult to attain than they are for technicians. Oral examinations, which are conducted by radiological controls managers and senior supervisors, require personnel to evaluate symptoms of unusual radiological controls situations. The radiological controls technician or supervisor is required to evaluate initial symptoms, state immediate corrective actions required, state what additional measurements are required, and do a final analysis of the measurements to identify the specific problem. After qualification, periodic training sessions are required in which each radiological controls technician and supervisor demonstrates the ability to handle situations similar to those covered in the oral examinations. At least every 2½ years, radiological controls personnel have to requalify through written and practical abilities examinations similar to those used for initial qualification. Additionally, their first requalification includes an oral examination similar to the one required for initial qualification. Between qualification periods, radiological controls technicians and supervisors are required to be selected at random for additional written and practical abilities examinations. They also must participate in unannounced drills.

In addition to the above training for those who are involved in radioactive work, each shipyard employee not involved in radioactive work and each person assigned to a nuclear-powered ship or a support facility is required to receive basic radiological training which is repeated at least annually. This training is to ensure personnel understand the posting of radiological areas, the identification of radioactive materials, and not to cross radiological barriers. This instruction also explains that the radiation environment of personnel outside radiation areas and outside the ship or shipyard is not significantly affected by nuclear propulsion plant work.

Nuclear Power Training

Military personnel who operate naval nuclear propulsion plants are required to pass a 6-month basic training course at Nuclear Power School and a 6-month qualification course either at a land-based prototype of a shipboard reactor plant or at a moored training ship. Each nuclear-trained officer and enlisted person receives extensive radiological controls training, including lectures, demonstrations, practical work, radiological controls drills, and written and oral examinations. This training emphasizes the ability to apply basic information on radiation and radioactivity.

Those enlisted personnel who will have additional responsibilities for radiological controls associated with operation of nuclear propulsion plants are designated Engineering Laboratory Technicians and receive an additional 3 months of training after completion of the 1-year program. Engineering Laboratory Technicians and other selected nuclear-trained personnel who are assigned radiological controls duties at naval bases and tenders normally receive an additional intensive 4-month training program in the practical aspects of radiological controls associated with maintenance and repair work.

Before becoming qualified to head the engineering department of a nuclear-powered ship, a nuclear-trained officer must pass a written examination and a sequence of oral examinations conducted at Naval Nuclear Propulsion Program Headquarters. A key part of these qualification examinations is radiological controls.

Any officer who is to serve as commanding officer of a nuclear-powered ship must attend a 3-month course at the Naval Nuclear Propulsion Program Headquarters. The radiological controls portion of this course covers advanced topics and assumes the officer starts with detailed familiarity with shipboard radiological controls. The officer must pass both written and oral examinations in radiological controls during this course before assuming command of a nuclear-powered ship.

Radiation Exposure Reduction

Keeping personnel radiation exposures as low as reasonably achievable involves all levels of management in nuclear-powered ships and their support facilities. Operations, maintenance, and repair personnel are required to be involved in this subject; it is not left solely to radiological controls personnel. To evaluate the effectiveness of radiation exposure reduction programs, managers use a set of goals. Goals are established in advance to keep each worker's exposure under certain levels and to minimize the number of workers involved. Goals are also set for the total cumulative personnel radiation exposure for each major job, for the entire overhaul or maintenance period, and for the whole year. These goals are deliberately made hard to meet in order to encourage personnel to improve performance.

Of the various goals used, the most effective in reducing personnel radiation exposure has been the use of individual exposure control levels, which are lower than the Navy's quarterly and annual limits. Control levels in shipyards range from 0.5 rem to 2 rem for the year (depending on the amount of radioactive work scheduled), whereas 5 rem per year is the Navy limit.

To achieve the benefits of lower control levels in reducing total radiation exposure, it is essential to minimize the number of workers permitted to receive radiation exposure. Otherwise, the control levels could be met merely by adding more workers. Organizations are required to conduct periodic reviews to ensure that the number of workers is the minimum for the work that has to be performed.

The following is a synopsis of the checklist that has been in use for years to keep personnel radiation exposure as low as reasonably achievable during maintenance, overhaul, and repair.

Preliminary Planning

- Plan well in advance
- Delete unnecessary work
- Determine expected radiation levels

Preparation of Work Procedures

- Plan access to and exit from work area
- Provide for service lines (air, welding, ventilation, etc.)
- Provide communication (sometimes includes closed-circuit television)
- Remove sources of radiation
- Plan for installation of temporary shielding
- Decontaminate
- Work in lowest radiation levels
- Perform as much work as practicable outside radiation areas

- State requirements for standard tools
- Consider special tools
- Include inspection requirements (these identify steps where radiological controls personnel must sign before the work can proceed)
- Minimize discomfort of workers
- Estimate total radiation exposure

Temporary Shielding

- Control installation and removal by written procedure
- Inspect after installation
- Conduct periodic radiation surveys
- Minimize damage caused by heavy lead temporary shielding
- Balance radiation exposure received in installation against exposure to be saved by installation
- Shield travel routes
- Shield components with abnormally high radiation levels early in the maintenance period
- Shield the work area based on worker body position
- Perform directional surveys to improve design of shielding by locating sources of radiation
- Use mockup to plan temporary shielding design and installation

Rehearsing and Briefing

- Rehearse
- Use mockup duplicating working conditions
- Use photographs
- Brief workers

Performing Work

- Post radiation levels
- Keep excess personnel out of radiation areas
- Minimize beta radiation exposure (anticontamination clothing effectively shields cobalt-60 betas)
- Supervisors and workers keep track of radiation exposure
- Workers assist in radiation and radioactivity measurements
- Evaluate use of fewer workers
- Reevaluate reducing radiation exposures

Since its inception, the Naval Nuclear Propulsion Program has stressed the reduction of personnel radiation exposure. Beginning in the 1960s, a key part of the Program's effort in this area has involved minimizing radioactive corrosion products throughout the reactor plant, which in turn has significantly contributed to reducing personnel radiation exposure. Additional measures that have been taken to reduce exposure include standardization and optimization of procedures, development of new tooling, improved use of temporary shielding, and compliance with strict contamination control measures. For example, most work involving radioactive contamination is performed in containment. This practice minimizes the potential for spreading contamination and thus reduces work disruptions, simplifies working conditions, and minimizes the cost of—and the exposure during—cleanup.

Lessons learned during radioactive work and new ways to reduce exposure developed at one organization are made available for use by other organizations in the Naval Nuclear Propulsion Program. This effort allows all of the organizations to take advantage of the experience and developments at one organization and minimizes unnecessary duplication of effort.

The extensive efforts that have been taken to reduce exposure in the Naval Nuclear Propulsion Program have also had other benefits, such as reduced cost to perform radioactive work and improved reliability. Among other things, detailed work planning, rehearsing, total containment, special tools, and standardization have increased efficiency and improved access to perform maintenance. The overall result is improved reliability and reduced costs.

Radiation Exposure Data

Radioactive materials had been handled in shipyards for years before naval nuclear propulsion plant work started. Examples of such work include non-destructive testing using radiography sources and radiation instrument calibration using radioactive sources. Since this work is licensed by the Nuclear Regulatory Commission or by a State under agreement with the Nuclear Regulatory Commission, the radiation exposure from this licensed work has been excluded whenever practicable from this report of occupational exposure received from naval nuclear propulsion plants and their support facilities.

Table 1 shows the dates when radioactive work associated with naval nuclear propulsion plants started in each of the 11 shipyards. Seven of these shipyards have constructed naval nuclear-powered ships; however, little radiation exposure is received in new construction. The dates of starting reactor plant overhaul, therefore, are the significant dates for start of radioactive work.

The total occupational radiation exposure received by all Navy and shipyard personnel in the Naval Nuclear Propulsion Program in 2005 was 1,833 rem. Table 2 summarizes radiation exposure received in nuclear-powered ships and their supporting tenders and naval bases since the first nuclear-powered ship went to sea in January 1955. Most of the radiation exposure in this table results from inspection, maintenance, and repair work in the reactor compartments of ships. In general, radiation exposures for reactor compartment work increase as reactor plant radiation levels increase with the age of the plant.

Table 3 summarizes radiation exposures of shipyard personnel since the start of naval nuclear propulsion plant radioactive work in 1954. Figure 2 shows the total personnel radiation exposure alongside the amount of work at the shipyards. Since ship overhauls frequently overlapped calendar years, the number of ships in overhaul shown in Figure 2 were determined by dividing by 12 the total number of months each ship was in overhaul during a calendar year. Overhauls include defueling and inactivation of decommissioned ships.

Figure 2 shows that, from the peak in 1966 until the 1990s, total personnel radiation exposure was reduced in the shipyards while the amount of work had increased. In 2005, the number of ships in overhaul decreased by approximately 3 percent from 2004 and total shipyard radiation exposure decreased from 1,127 rem in 2004 to 1,084 rem in

2005. In 2005, the total Fleet radiation exposure decreased from 789 rem in 2004 to 749 rem in 2005.

The increase in the numbers of personnel monitored and total radiation exposure in the early years shows the increasing workload in reactor plant work as the number of ships increased. By 1962, four submarine reactor plants had been overhauled and major efforts were underway to reduce radiation levels. By 1966, the number of ships in overhaul had quadrupled, as indicated by the buildup to the peak in total radiation exposure. Subsequently, the number of ships in overhaul more than quadrupled again. Decreases in total annual exposures, numbers of personnel monitored, and numbers of personnel with annual exposures over 2 rem have been as a result of efforts to reduce radiation exposures to the minimum practicable. Since 1954, the total annual exposure for the shipyards has averaged less than 4,000 rem, and less than 1,530 rem for ships.

Since a worker usually is exposed to radiation in more than 1 year, the total number of personnel monitored cannot be obtained by adding the annual numbers. The total number of shipyard personnel monitored for radiation exposure associated with the Naval Nuclear Propulsion Program is about 170,000. Table 4 provides further information about the distribution of their radiation exposures. In 2005, more than 97 percent of those monitored for radiation in shipyards and more than 99 percent of those in ships received less than 0.5 rem in a year. Since 1954, the average exposure per year for each person monitored has been 0.216 rem in shipyards and 0.073 rem in ships, which are less than the 0.3 rem average annual exposure a person in the U.S. receives from natural background radiation (including the inhalation of radon and its progeny) (reference 11).

Table 4 also lists the numbers of personnel who have exceeded the 3 rem quarterly exposure limit. In no case did personnel exceed the pre-1994 Federal accumulated limit of 5 rem for each year of age over 18. The total number of persons who have exceeded the quarterly limit since the limit was imposed in 1960 is 37, of whom 4 were military personnel aboard ships. Of the 37 personnel, 30 had quarterly exposures in the range of 3 to 4 rem, and the highest exposure was 9.7 rem in a quarter. Navy procedures require any person who receives greater than 25 rem in a short time period to be placed under medical observation. No one has ever reached this level. Furthermore, since 1967 no person has exceeded the Federal limit, which allows up to 3 rem per quarter year. Additionally, since 1968 no person has exceeded the Navy's self-imposed limit of 5 rem per year for radiation associated with naval nuclear propulsion plants. The 5 rem per year limit was formally adopted as the Federal limit in 1994.

The average lifetime accumulated exposure from radiation associated with naval nuclear plants for all shipyard personnel is approximately 1.14 rem. Since the average annual exposure per person is 0.216 rem, this means that the average shipyard radiation worker is monitored because of naval nuclear propulsion plant work for approximately 6 years. The average lifetime accumulated exposure for the approximately 113,000 naval officers and enlisted personnel trained to date to operate a nuclear propulsion plant is approximately 0.71 rem. These radiation exposures are much less than the exposure the average American receives from natural background radiation or from medical diagnostic x-rays during a working lifetime (reference 11).

TABLE 1

SHIPYARD FIRST REACTOR PLANT OPERATION
AND FIRST RADIOACTIVE OVERHAUL WORK

Shipyard	Year First New Construction Reactor Started Operation	Year First Reactor Plant Overhaul Started
Electric Boat Division[3] Groton, Connecticut	1954	1957
Portsmouth Naval Shipyard Portsmouth, New Hampshire	1958	1959
Mare Island Naval Shipyard[4,5] Vallejo, California	1958	1962
Pearl Harbor Naval Shipyard Pearl Harbor, Hawaii	None	1962
Charleston Naval Shipyard[4,5] Charleston, South Carolina	None	1963
Newport News Shipbuilding Newport News, Virginia	1960	1964
Bethlehem Steel Shipbuilding[5] (Subsequently Electric Boat Division) Quincy, Massachusetts	1961	None
New York Shipbuilding Corporation[5] Camden, New Jersey	1963	None
Norfolk Naval Shipyard Portsmouth, Virginia	None	1965
Puget Sound Naval Shipyard[4] Bremerton, Washington	None	1967
Ingalls Shipbuilding Division[5] Pascagoula, Mississippi	1961	1970

3. Electric Boat Division performed overhauls from 1957 until 1977. Between 1978 and 2001, Electric Boat Division performed new construction work primarily. In 2001, Electric Boat Division began performing routine radioactive work on nuclear-powered ships.
4. Radioactive work of less extent than an overhaul began in Mare Island in 1958, in Charleston in 1961, and in Puget Sound in 1965.
5. Work on naval nuclear-powered ships was discontinued at Camden, New Jersey, in 1967; at Quincy, Massachusetts, in 1969; at Pascagoula, Mississippi, in 1980; at Vallejo, California, in 1996; and at Charleston, South Carolina, in 1996.

TABLE 2

OCCUPATIONAL RADIATION EXPOSURE RECEIVED BY PERSONNEL ASSIGNED TO TENDERS, BASES, AND NUCLEAR-POWERED SHIPS FROM OPERATION AND MAINTENANCE OF NAVAL NUCLEAR PROPULSION PLANTS

	Number of Persons Monitored Who Received Exposures in the Following Ranges of Rem for the Year						Total Personnel Monitored	Total Exposure (Rem)
Year	0-1	1-2	2-3	3-4	4-5	>5*		
1954	36	0	0	0	0	0	36	8
1955	90	11	0	0	0	0	101	25
1956	108	10	4	0	0	0	122	50
1957	293	7	1	0	0	0	301	60
1958	562	11	3	0	0	0	576	100
1959	1,057	41	8	3	0	0	1,109	200
1960	2,607	88	8	4	3	1	2,711	375
1961	4,812	106	31	4	4	0	4,957	680
1962	6,788	182	75	31	17	2	7,095	1,312
1963	9,188	197	39	14	3	1	9,442	1,420
1964	10,317	331	93	35	15	14	10,805	1,964
1965	11,883	592	224	96	30	27	12,852	3,421
1966	18,118	541	156	95	44	28	18,982	3,529
1967	21,028	339	139	48	11	0	21,565	3,084
1968	24,200	373	102	20	2	1	24,698	2,466
1969	26,969	577	127	39	6	0	27,718	2,918
1970	26,206	610	134	30	0	0	26,980	3,089
1971	26,090	568	122	31	2	0	26,813	3,261
1972	33,312	602	180	13	1	0	34,108	3,271
1973	30,852	600	102	15	1	0	31,570	3,160
1974	18,375	307	65	2	0	0	18,749	2,142
1975	17,638	330	28	1	0	0	17,997	2,217
1976	17,795	369	56	9	0	0	18,229	2,642
1977	20,236	346	95	36	3	0	20,716	2,812
1978	22,089	290	23	1	0	0	22,403	2,234
1979	21,121	75	1	0	0	0	21,197	1,528
1980	21,767	78	0	0	0	0	21,845	1,494
1981	23,781	27	0	0	0	0	23,808	1,415
1982	27,563	59	0	0	0	0	27,622	1,660
1983	27,593	52	0	0	0	0	27,645	1,832
1984	30,096	10	0	0	0	0	30,106	1,729
1985	31,447	18	0	0	0	0	31,465	1,549
1986	33,944	16	0	0	0	0	33,960	1,593
1987	34,987	2	0	0	0	0	34,899	1,536
1988	34,782	4	0	0	0	0	34,786	1,422
1989	35,116	52	0	0	0	0	35,168	1,599
1990	36,036	15	0	0	0	0	36,051	1,501
1991	35,669	0	0	0	0	0	35,669	1,332
1992	34,940	2	0	0	0	0	34,942	1,460
1993	32,521	3	0	0	0	0	32,524	1,452
1994	30,646	0	0	0	0	0	30,646	1,214
1995	28,825	0	0	0	0	0	28,825	1,125
1996	24,797	0	0	0	0	0	24,797	918
1997	23,793	0	0	0	0	0	23,793	818
1998	22,401	0	0	0	0	0	22,401	770
1999	21,918	0	0	0	0	0	21,918	711
2000	20,890	0	0	0	0	0	20,890	727
2001	19,527	0	0	0	0	0	19,527	723
2002	20,613	0	0	0	0	0	20,613	745
2003	20,821	0	0	0	0	0	20,821	808
2004	20,985	0	0	0	0	0	20,985	789
2005	20,552	0	0	0	0	0	20,552	749

Note: Data obtained from summaries rather than directly from original medical records. Total radiation exposure was determined by adding actual exposures for each individual monitored by each reporting command during the year. Total number monitored includes visitors to each reporting command. It is expected that the large effort to compile comparable radiation exposure data from original medical records would show differences no greater than 5 percent.
* Limit in the Naval Nuclear Propulsion Program was changed to 5 rem per year in 1967.

TABLE 3

OCCUPATIONAL RADIATION EXPOSURE RECEIVED BY SHIPYARD PERSONNEL FROM WORK ASSOCIATED WITH NAVAL NUCLEAR PROPULSION PLANTS

Year	Number of Persons Monitored Who Received Exposures in the Following Ranges of Rem for the Year						Total Personnel Monitored	Total Exposure (Rem)
	0-1	1-2	2-3	3-4	4-5	>5*		
1954	508	9	3	5	3	0	528	64
1955	2,563	80	25	6	3	2	2,679	344
1956	2,834	20	5	2	0	1	2,862	162
1957	3,473	97	31	1	2	4	3,608	495
1958	5,766	165	46	10	4	7	5,998	779
1959	10,388	221	133	78	49	23	10,892	1,864
1960	12,047	198	97	22	4	0	12,368	1,158
1961	13,383	198	91	44	14	3	13,733	1,241
1962	14,411	642	366	247	146	108	15,920	5,222
1963	19,164	446	159	71	34	28	19,902	2,725
1964	24,044	804	445	215	144	41	25,693	5,678
1965	22,630	2,306	1,314	814	618	525	28,207	15,829
1966	29,490	2,352	1,623	1,057	1,139	513	36,174	18,804
1967	29,853	2,388	1,563	1,096	733	1	35,634	13,908
1968	30,159	1,344	773	496	279	0	33,051	8,719
1969	25,672	1,790	1,080	753	375	0	29,670	11,077
1970	21,182	2,127	1,382	740	492	0	25,923	13,084
1971	20,041	1,928	1,066	650	240	0	23,925	10,616
1972	17,514	1,692	849	139	5	0	20,199	7,002
1973	13,036	1,403	604	203	6	0	15,252	6,083
1974	12,587	1,464	745	311	50	0	15,157	7,206
1975	12,825	1,116	598	82	42	0	14,663	5,285
1976	13,042	1,268	633	30	0	0	14,973	5,310
1977	13,835	1,277	586	25	0	0	15,723	5,199
1978	13,700	1,016	268	0	0	0	14,984	3,680
1979	15,032	227	7	0	0	0	15,266	2,024
1980	15,287	377	0	0	0	0	15,664	2,402
1981	17,414	304	0	0	0	0	17,718	2,310
1982	19,210	648	0	0	0	0	19,858	3,353
1983	20,407	714	0	0	0	0	21,121	3,506
1984	20,684	502	0	0	0	0	21,186	3,181
1985	20,940	412	0	0	0	0	21,352	2,796
1986	21,186	875	0	0	0	0	22,061	3,495
1987	21,404	788	0	0	0	0	22,192	3,187
1988	20,969	543	0	0	0	0	21,512	2,702
1989	23,789	633	0	0	0	0	24,422	2,941
1990	25,077	501	0	0	0	0	25,578	2,812
1991	24,873	492	0	0	0	0	25,365	2,866
1992	24,703	440	0	0	0	0	25,143	2,936
1993	23,542	572	0	0	0	0	24,114	2,913
1994	18,912	362	0	0	0	0	19,274	1,890
1995	16,422	212	0	0	0	0	16,634	1,355
1996	14,997	80	0	0	0	0	15,077	962
1997	14,501	87	0	0	0	0	14,588	935
1998	14,735	53	0	0	0	0	14,788	882
1999	16,238	60	0	0	0	0	16,298	863
2000	15,617	84	0	0	0	0	15,701	1,009
2001	16,358	84	0	0	0	0	16,442	915
2002	17,883	128	0	0	0	0	18,011	1,087
2003	18,109	112	0	0	0	0	18,221	1,017
2004	19,273	129	0	0	0	0	19,402	1,127
2005	19,327	74	0	0	0	0	19,401	1,084

Note: Data obtained from summaries rather than directly from original medical records. Total radiation exposure was determined by adding actual exposures for each individual monitored by each shipyard during the year. Total number monitored includes visitors to each shipyard. It is expected that the large effort to compile comparable radiation exposure data from original medical records would show differences no greater than 5 percent.

* Limit in the Naval Nuclear Propulsion Program was changed to 5 rem per year in 1967.

FIGURE 2
TOTAL RADIATION EXPOSURE RECEIVED BY SHIPYARD PERSONNEL FROM WORK ON NAVAL NUCLEAR PROPULSION PLANTS 1958 - 2005

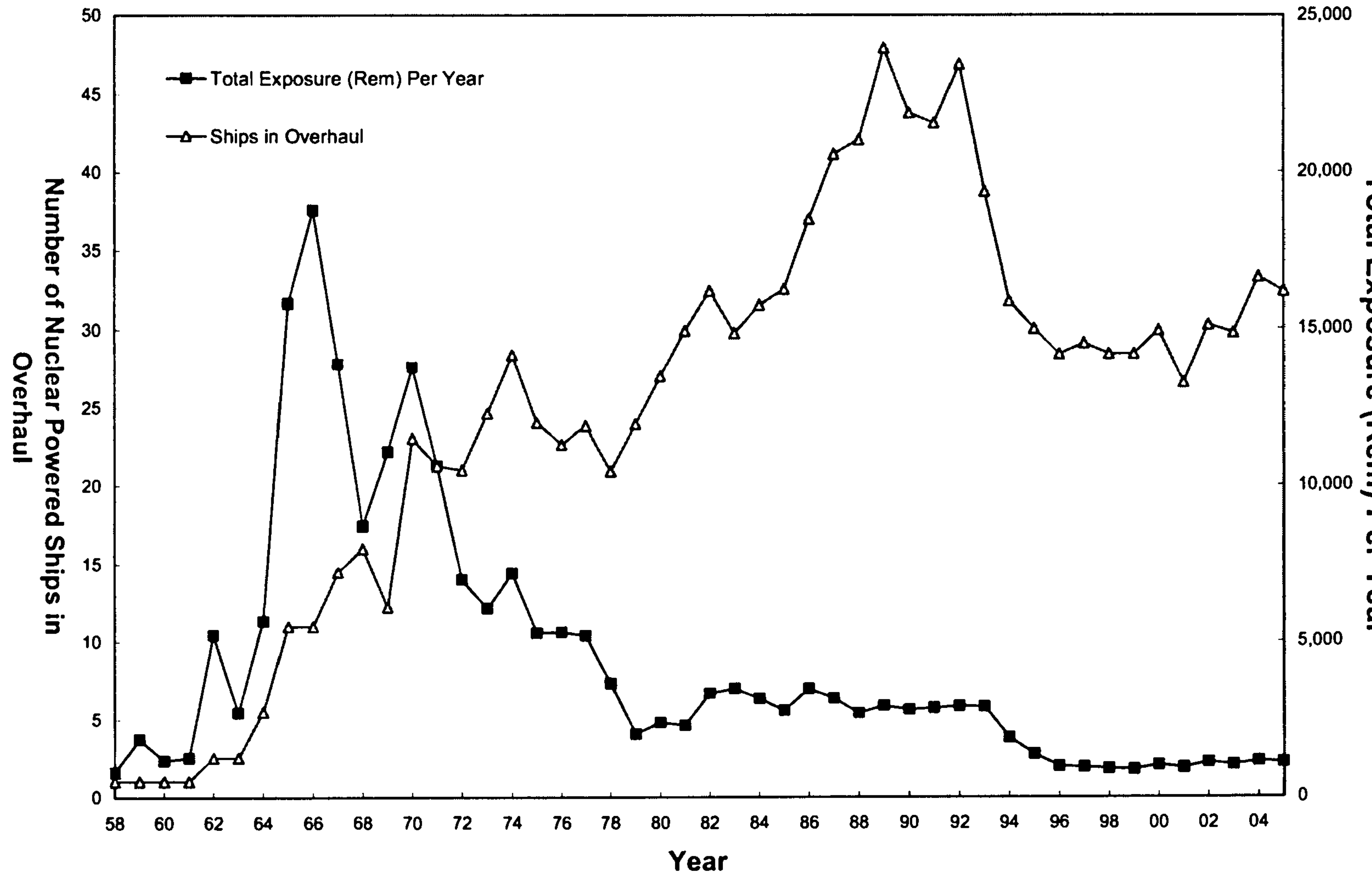


TABLE 4

SHIPYARD AND FLEET DISTRIBUTION OF PERSONNEL RADIATION EXPOSURE

Year	Average Rem Per Person Monitored		Percent of Personnel Monitored Who Received Greater Than 1 Rem		Number of Personnel Who Exceeded 3 Rem/Quarter
	Fleet	Shipyard	Fleet	Shipyard	
1954	.222	.121	0	3.8	0
1955	.248	.128	10.9	4.3	0
1956	.410	.057	11.5	1.0	0
1957	.199	.137	2.7	3.7	0
1958	.174	.130	2.4	3.9	0
1959	.180	.171	4.7	4.6	8
1960	.138	.094	7.5	2.6	0
1961	.137	.090	2.9	2.5	0
1962	.185	.328	4.3	9.5	9
1963	.150	.137	2.7	3.7	2
1964	.182	.221	4.5	6.4	4
1965	.266	.561	7.5	19.8	5
1966	.186	.520	4.6	18.5	6
1967	.143	.390	2.5	16.2	3
1968	.100	.264	2.0	8.8	0
1969	.105	.373	2.7	13.5	0
1970	.114	.505	2.9	18.3	0
1971	.122	.444	2.7	16.2	0
1972	.096	.347	2.3	13.3	0
1973	.100	.399	2.3	14.5	0
1974	.114	.475	2.0	17.0	0
1975	.123	.360	2.0	12.5	0
1976	.145	.355	2.4	12.9	0
1977	.136	.331	2.3	12.0	0
1978	.100	.246	1.4	8.5	0
1979	.072	.133	0.4	1.5	0
1980	.068	.153	0.4	2.4	0
1981	.059	.130	0.1	1.7	0
1982	.060	.169	0.2	3.3	0
1983	.066	.166	0.2	3.4	0
1984	.057	.150	0.0	2.4	0
1985	.049	.131	0.1	1.9	0
1986	.047	.158	0.0	4.0	0
1987	.044	.144	0.0	3.6	0
1988	.041	.126	0.0	2.5	0
1989	.045	.120	0.1	2.6	0
1990	.042	.110	0.0	2.0	0
1991	.037	.113	0.0	1.9	0
1992	.042	.117	0.0	1.8	0
1993	.045	.121	0.0	2.4	0
1994	.040	.098	0.0	1.9	0
1995	.039	.081	0.0	1.3	0
1996	.037	.064	0.0	0.5	0
1997	.034	.064	0.0	0.6	0
1998	.034	.060	0.0	0.4	0
1999	.032	.053	0.0	0.4	0
2000	.035	.064	0.0	0.5	0
2001	.037	.056	0.0	0.5	0
2002	.036	.060	0.0	0.7	0
2003	.039	.056	0.0	0.6	0
2004	.038	.058	0.0	0.7	0
2005	.036	.056	0.0	0.4	0
Average	.073	.216	0.95	6.5	
NNPP AVERAGE	0.140		3.6		

Table 5 provides information on the distribution of lifetime accumulated exposures for all personnel who were monitored in 2005 for radiation exposure associated with naval nuclear propulsion plants. The 5 rem annual Federal radiation exposure limit would allow accumulating 100 rem in 20 years of work, or 200 rem in 40 years. The fact that no one shown in Table 5 comes close to having accumulated this much radiation exposure is the result of deliberate efforts to keep lifetime radiation exposures low.

TABLE 5

DISTRIBUTION OF TOTAL LIFETIME RADIATION EXPOSURE ASSOCIATED WITH NAVAL NUCLEAR PROPULSION PLANTS

Range of Accumulated Lifetime Radiation Exposures (Rem)	Percentage of Personnel Monitored in 2005 With Lifetime Accumulated Radiation Exposure Within that Range	
	FLEET	SHIPYARDS
0 – 5	99.89	91.82
5 – 10	0.10	6.20
10 – 15	0.01	1.47
15 – 20	0	0.36
20 – 25	0	0.09
25 – 30	0	0.05
30 – 40	0	0.01
40 – 60	0	0
> 60	0	0

The Federal radiation exposure limits used in the U.S. until the 1994 change to the Code of Federal Regulations, Title 10, Part 20, limited an individual's lifetime exposure to 5 rem for each year beyond age 18. With the recent change, lifetime exposure is not specifically limited, but is controlled as the result of the annual limit of 5 rem. In their most recent radiation protection recommendations, the National Council on Radiation Protection and Measurements (NCRP) recommends organizations control lifetime accumulated exposure to less than 1 rem times the person's age (reference 12). Among all personnel monitored in 2005, there is currently no worker with a lifetime accumulated exposure greater than the NCRP recommended level of 1 rem times his or her age from radiation associated with naval nuclear propulsion plants.

Table 6 provides a basis for comparison between the radiation exposure for light water reactors operated by the Navy and commercial nuclear-powered reactors licensed by the Nuclear Regulatory Commission. The 2004 data in this Nuclear Regulatory Commission table cover 104 licensed commercial nuclear-powered reactors with a total of 10,368 rem (reference 13). The 2004 average annual exposure of each worker at commercial nuclear-powered reactors was 0.094 rem. Licensees of commercial nuclear-powered reactors reported 279 overexposures to external radiation during the years 1971 through 2004. Numbers in excess of 5 rem are not necessarily overexposures; prior to January 1, 1994, Nuclear Regulatory Commission regulations permitted exposures of 3 rem each quarter (up to 12 rem per year) within the accumulated total limit of 5 rem for each year of a person's age beyond 18.

TABLE 6

PERSONNEL RADIATION EXPOSURE FOR COMMERCIAL NUCLEAR-POWERED REACTORS
LICENSED BY THE U.S. NUCLEAR REGULATORY COMMISSION

SUMMARY OF ANNUAL WHOLE BODY EXPOSURE BY INCREMENT

			NUMBER OF INDIVIDUALS BY EXPOSURE INCREMENT - REM												
YEAR	TOTAL MONITORED	NOT MEASURABLE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	TOTAL MAN-REM	NUMBER OF OVER-EXPOSURES
1971	9,581	8,996			315	137	105	17	11	0	0	0	0		2
1972	15,713	14,783			532	199	111	46	21	9	6	6	0		16
1973	33,823	19,043	9,798	2,468	1,584	422	251	125	71	38	16	7	0	13,963	19
1974	38,938	20,472	13,766	2,503	1,378	471	226	86	30	6	0	0	0	13,722	43
1975	44,343	18,854	18,289	3,948	1,872	691	423	169	60	24	12	0	1	20,879	14
1976	61,151	25,704	26,636	4,880	2,354	789	487	188	70	26	11	5	1	26,433	20
1977	61,673	22,688	28,165	5,660	2,858	1,290	661	186	89	47	23	6	0	32,521	27
1978	69,137	26,360	31,873	5,984	3,050	1,194	517	110	37	9	0	1	2	31,785	9
1979	100,834	40,535	47,196	7,574	3,401	1,403	545	117	42	17	3	1	0	39,908	23
1980	119,345	44,716	56,312	10,672	4,607	1,816	831	235	119	29	7	1	0	53,739	73
1981	116,030	39,258	58,047	11,174	4,809	1,999	533	103	93	9	3	1	1	54,163	7
1982	121,013	41,704	61,576	10,220	4,716	2,066	596	97	31	5	0	1	1	52,201	2
1983	126,736	47,027	59,878	11,342	5,334	2,270	716	121	38	8	2	0	0	56,484	8
1984	145,157	54,637	71,345	11,284	5,208	2,122	487	52	22	0	0	0	0	55,251	3
1985	146,551	59,625	72,150	10,042	3,574	1,002	157	1	0	0	0	0	0	43,048	3
1986	161,656	67,677	79,662	10,241	3,062	868	146	0	0	0	0	0	0	42,386	1
1987	181,401	85,170	82,882	10,611	2,192	477	69	0	0	0	0	0	0	40,406	1
1988	183,294	87,281	82,723	10,310	2,442	511	26	0	1	0	0	0	0	40,772	6
1989	184,038	83,954	89,432	8,633	1,615	370	34	0	0	0	0	0	0	35,931	1
1990	182,442	83,875	87,824	8,594	1,791	337	21	0	0	0	0	0	0	36,602	0
1991	178,333	87,247	83,935	5,977	938	219	17	0	0	0	0	0	0	28,519	0
1992	181,889	87,717	87,199	6,076	808	85	4	0	0	0	0	0	0	29,297	1
1993	169,259	83,066	80,152	5,322	638	76	5	0	0	0	0	0	0	26,364	0
1994	139,390	67,777	66,823	4,242	508	40	0	0	0	0	0	0	0	21,704	0
1995	132,266	61,445	66,179	3,912	595	133	2	0	0	0	0	0	0	21,688	0
1996	126,402	58,097	64,634	3,196	408	67	0	0	0	0	0	0	0	18,883	0
1997	126,781	58,409	65,446	2,599	286	41	0	0	0	0	0	0	0	17,149	0
1998	114,367	56,901	55,444	1,827	179	15	1	0	0	0	0	0	0	13,187	0
1999	113,916	54,885	56,874	1,894	245	18	0	0	0	0	0	0	0	13,599	0
2000	110,557	53,324	55,295	1,734	186	18	0	0	0	0	0	0	0	12,652	0
2001	104,928	52,636	50,626	1,392	221	53	0	0	0	0	0	0	0	11,109	0
2002	107,900	53,440	52,284	1,820	320	35	1	0	0	0	0	0	0	12,126	0
2003	109,990	54,023	54,114	1,651	184	18	0	0	0	0	0	0	0	11,956	0
2004	110,290	57,417	51,482	1,190	188	13	0	0	0	0	0	0	0	10,368	0

Figures shown for the years 1977-2004 have been adjusted by the NRC for the multiple reporting of transient individuals

INTERNAL RADIOACTIVITY

Policy and Limits

The Navy's policy on internal radioactivity for personnel associated with the Naval Nuclear Propulsion Program continues to be the same as it was more than five decades ago—to prevent significant radiation exposure to personnel from internal radioactivity. The limits invoked to achieve this objective are one-tenth of the levels allowed by Federal regulations for radiation workers. Radiological work in the Program is engineered to contain radioactivity at the source and keep exposure to airborne radioactivity below levels of concern (i.e., to preclude routine monitoring of personnel to determine internal dose, such that external radiation exposure is the limiting dose to Naval Nuclear Propulsion Program personnel). The results of this program have been that since 1962, no one has received more than one-tenth the Federal annual internal occupational exposure limits from internal radiation exposure caused by radioactivity associated with naval nuclear propulsion plants. As shown in Table 7, since 1980, only 20 personnel have had internally deposited radioactivity above 0.01 millionths of a curie of equivalent cobalt-60, and the equivalent whole body dose associated with each of these events was less than 0.020 rem (about one-fifteenth of the average annual radiation exposure a member of the general public receives from natural background sources in the U.S.). Although these events had no adverse impact on the health of the personnel involved, each of these events was thoroughly evaluated to prevent reoccurrence.

Prior to 1994, the basic Federal limit for radiation exposure to organs of the body from internal radioactivity was 15 rem per year. There have been higher levels applied at various times for thyroid and for bones; however, use of these specific higher limits was not necessary in the Naval Nuclear Propulsion Program.

The limit recommended for most organs of the body by the U.S. National Committee on Radiation Protection and Measurements in 1954 (reference 1), by the U.S. Atomic Energy Commission in the initial edition of reference (3) applicable in 1957, and by the International Commission on Radiological Protection in 1959 (reference 2) was 15 rem per year. This limit was adopted for Federal agencies when President Eisenhower approved recommendations of the Federal Radiation Council May 13, 1960.

In 1977, the International Commission on Radiological Protection revised its recommendations (reference 8), particularly regarding internal exposure. The new recommendations provided a method of combining, and controlling, exposure from internal radioactivity with exposure from external radiation. The effect of the 1977 recommendations was to raise the allowable dose to many organs, with no organ allowed to receive more than 50 rem in a year. In conjunction with these recommendations, more recent knowledge on the behavior and effect of internal radioactivity was used to derive new limits for its control (reference 14). The Federal guidance approved by the President in 1987 adopted these revised recommendations and methods, and were incorporated as Federal limits in 1994. As discussed below, cobalt-60 is the radionuclide of most concern for internal radioactivity in the Naval Nuclear Propulsion Program. The derived airborne radioactivity concentration limits for cobalt-60 established at the inception of the Program, which control exposure to below one-tenth the Federal annual internal occupational exposure limit, remain unchanged under the new recommendations and methodology.

Source of Radioactivity

Radioactivity can get inside the body through air, through water or food, and through surface contamination via the mouth, skin, or a wound. The radioactivity of primary concern is the activated metallic corrosion products on the inside surfaces of reactor plant piping systems. These are in the form of insoluble metallic oxides, primarily iron oxides. Reference 15 contains more details on why cobalt-60 is the radionuclide of most concern for internal radioactivity.

The design conditions for reactor fuel are much more severe for warships than for commercial power reactors. As a result of being designed to withstand the rigors of combat, naval reactor fuel elements retain fission products—including fission gases—within the fuel. Sensitive measurements are frequently made to verify the integrity of reactor fuel. Consequently, fission products such as strontium-90 and cesium-137 make no measurable contribution to internal exposure of personnel from radioactivity associated with naval nuclear propulsion plants. Similarly, alpha emitters such as uranium and plutonium are retained within the fuel elements and are not accessible to personnel operating or maintaining a naval nuclear propulsion plant.

Because of the high integrity of reactor fuel and because soluble boron is not used in reactor coolant for normal reactivity control in naval nuclear propulsion plants, the amount of tritium in reactor coolant is far less than in typical commercial power reactors. The small amount that is present is formed primarily as a result of neutron interaction with the deuterium naturally present in water. The radiation from tritium is of such low energy that the Federal limits for breathing or swallowing tritium are more than 300 times higher than for cobalt-60. As a result, radiation exposure to personnel from tritium is far too low to measure. Similarly, the low-energy beta radiation from carbon-14, which is formed in small quantities in reactor coolant systems as a result of neutron interactions with nitrogen and oxygen, does not add measurable radiation exposure to personnel operating or maintaining naval nuclear propulsion plants.

Control of Airborne Radioactivity

Airborne radioactivity is controlled in maintenance operations such that respiratory equipment is not normally required. To prevent exposure of personnel to airborne radioactivity when work might release radioactivity to the atmosphere, contamination containment tents or bags are used. These containments are ventilated to the atmosphere through high-efficiency filters that have been tested to remove at least 99.95 percent of particles of a size comparable to cigarette smoke. Radiologically controlled areas such as reactor compartments are also required to be ventilated through high-efficiency filters anytime work that could cause airborne radioactivity is in progress. Airborne radioactivity surveys are required to be performed regularly in radioactive work areas. Anytime airborne radioactivity above the limit is detected in occupied areas, work that might be causing airborne radioactivity is stopped. This conservative action is taken to minimize internal radioactivity even though the Naval Nuclear Propulsion Program's airborne radioactivity limit would allow continuous breathing for 40 hours per week throughout the year to reach an annual exposure to the lungs of one-tenth the Federal limit. Personnel are also trained to use respiratory equipment when airborne radioactivity above the limit is detected. However, respiratory equipment is seldom needed and is not relied upon as the first line of defense against airborne radioactivity.

It is not uncommon for airborne radioactivity to be caused by radon naturally present in the air. Atmospheric temperature inversion conditions can allow the buildup of radioactive particles from radon. Radon can also build up in sealed or poorly ventilated rooms in homes or buildings made of stone or concrete, or it can migrate from the surrounding ground. In fact, most cases of airborne radioactivity above the Naval Nuclear Propulsion Program's conservative airborne radioactivity limit in occupied areas have been caused by radioactive particles from atmospheric radon, which has a higher airborne concentration limit, and not from the reactor plant. Procedures have been developed to reduce the radon levels when necessary and to allow work to continue after it has been determined that the elevated airborne radioactivity is from naturally occurring radon.

Radon is also emitted from radium used for making luminous dials. There have been a number of cases where a single radium dial (such as on a wristwatch) has caused the entire atmosphere of a submarine to exceed the airborne radioactivity limit used for the nuclear propulsion plant. As a result, radium in any form was banned from submarines to prevent interference with keeping airborne radioactivity from the nuclear propulsion plant as low as practicable.

Control of Radioactive Surface Contamination

Perhaps the most restrictive regulations in the Naval Nuclear Propulsion Program's radiological controls program are those for controlling radioactive contamination. Work operations involving potential for spreading radioactive contamination use containments to prevent personnel contamination or the generation of airborne radioactivity. The controls for radioactive contamination are so strict that precautions sometimes have had to be taken to prevent tracking contamination from the world's atmospheric fallout and natural sources outside radiological areas *into* radiological spaces because the contamination control limits used in the nuclear areas were below the levels of fallout and natural contamination occurring outside in the general public areas.

Anticontamination clothing, including coveralls, hoods (to cover the head, ears, and neck), shoe covers and gloves, is provided when needed. However, the basic approach is to avoid the need for anticontamination clothing by containing the radioactivity. As a result, most work on radioactive materials is performed with hands reaching into gloves installed in containments, making it unnecessary for the worker to wear anticontamination clothing. In addition to providing better control over the spread of radioactivity, this method has reduced radiation exposure because the worker can usually do a job better and faster in normal work clothing. A basic requirement of contamination control is to monitor all personnel leaving any area where radioactive contamination could possibly occur. Workers are trained to survey themselves (i.e., frisk), and their performance is checked by radiological controls personnel. Frisking of the entire body is required, normally using sensitive hand-held survey instruments. Major work facilities are equipped with portal monitors, which are used in lieu of hand-held friskers. Personnel monitor before, not after, they wash. Therefore, washing or showering at the exit of radioactive work areas is not required. The basic philosophy is to prevent contamination, not wash it away.

Table 7 presents data concerning the number of personnel with detectable radioactive skin contamination since 1980. A radioactive skin contamination is an event where radioactive contamination above the Program's low limit for surface contamination is detected on the skin. For perspective, the Program's limit for surface contamination is less than the amount of naturally occurring radioactivity found in a banana spread over a 20 square centimeter area, which is the size of the typical survey probe. In each of these cases the radioactivity was quickly removed with simple methods (e.g., by washing with mild soap and warm water). Since 1980, a total of 494 instances of skin contamination occurred, with less than 15 percent of the total occurring since 1992. None of these occurrences caused personnel to exceed a tenth of the Federal limit for radiation exposure to the skin.

Trained radiological controls personnel frequently survey for radioactive contamination. These surveys are reviewed by supervisory personnel to provide a doublecheck that no abnormal conditions exist. The instruments used for these surveys are checked against a radioactive calibration source daily and before use, and they are calibrated at least every 9 months.

Control of Food and Water

Smoking, eating, drinking, and chewing are prohibited in radioactive areas. Aboard ship, drinking water is made from seawater, in some cases by distilling seawater using steam from the secondary plant steam system. However, the steam is not radioactive, because it is in a secondary piping system separate from the reactor plant radioactive water. In the event radioactivity were to leak into the steam system, sensitive radioactivity detection instruments (which operate continuously) would give early warning.

Wounds

Skin conditions or open wounds that might not readily be decontaminated are cause for temporary or permanent disqualification from performing radioactive work. Workers are trained to report such conditions to radiological controls or medical personnel, and radiological controls technicians watch for open wounds when workers enter radioactive work areas. In the initial medical examination prior to radiation work and in subsequent examinations, skin conditions are also checked. If the cognizant local medical officer determines that a wound is sufficiently healed or considers that the wound is adequately protected, he may remove the temporary disqualification.

There have been only a few cases of contaminated wounds in the Naval Nuclear Propulsion Program. In most years, none occurred. Examples of such injuries that have occurred in the past include a scratched hand, a metallic sliver in a hand, a cut finger, and a puncture wound to a hand. These wounds occurred at the same time the person became contaminated. Insoluble metallic oxides that make up the radioactive contamination remain primarily at the wound rather than being absorbed into the bloodstream. These radioactively contaminated wounds have been easily decontaminated. No case of a contaminated wound is known where the radioactivity present in the wound was as much as 0.1 percent of that permitted for a radiation worker to have in his or her body.

Monitoring for Internal Radioactivity

The radioactivity of most concern for internal radiation exposure from naval nuclear propulsion plants is cobalt-60. Although most radiation exposure from cobalt-60 inside the body will be from beta radiation, the gamma radiation given off makes cobalt-60 easy to detect. Complex whole body counters are not required to detect cobalt-60 at low levels inside the body. For example, one-millionth of a curie of cobalt-60 inside the lungs or intestines will cause a measurement of two times above the background reading with the standard hand-held survey instrument used for personnel frisking. This amount of internal radioactivity will cause the instrument to reach the alarm level. Every person is required to monitor the entire body upon leaving an area with radioactive surface contamination. Monitoring the entire body (not just the hands and feet) is a requirement in the Naval Nuclear Propulsion Program. Therefore, if a person had as little as one-millionth of a curie of cobalt-60 internally, it would readily be detected.

Swallowing one-millionth of a curie of cobalt-60 will cause internal radiation exposure to the gastro-intestinal tract of about 0.08 rem. The radioactivity will pass through the body and be excreted within a period of a little more than a day. Since 1994, Federal regulations limit organ exposure from internal radioactivity to 50 rem per year.

One-millionth of a curie of cobalt-60 still remaining in the lungs 1 day after an inhalation incident is estimated to cause a radiation exposure of about 2 rem to the lungs over the following year and 6 rem total over a lifetime, based on standard calculations recommended by the International Commission on Radiological Protection (reference 14). Since 1994, Federal regulations limit organ exposure from internal radioactivity to 50 rem per year. These techniques provide a convenient way to estimate the amount of radiation exposure a typical individual might be expected to receive from small amounts of internally deposited radioactivity. These techniques account for the gradual removal of cobalt-60 from the lungs through biological processes and the radioactive decay of cobalt-60 with a 5.3 year half-life. However, if an actual case were to occur, the measured biological elimination rate would be used in determining the amount of radiation exposure received.

In addition to the control measures to prevent internal radioactivity and the frisking frequently performed by those who work with radioactive materials, more sensitive internal monitoring is also performed. Procedures designed specifically for monitoring internal radioactivity use a type of gamma radiation scintillation detector, which will reliably detect inside the body an amount of cobalt-60 more than 100 times lower than the one-millionth of a curie used in the examples above. Shipyards typically monitor each employee for internal radioactivity as part of each radiation medical examination, which is given before initially performing radiation work, after terminating radiation work, and periodically in between. Tenders, bases, and nuclear-powered ships require personnel to be internally monitored before initially assuming duties involving radiation exposure and upon terminating from such duties.

During the year, shipyards, tenders, and bases also periodically monitor groups of personnel who did the work most likely to have caused spread of radioactive contamination. Any person—whether at a shipyard, tender, base, or aboard a nuclear-powered ship—who has radioactive contamination above the limit anywhere on the skin during regular monitoring at the exit from a radioactive area is monitored for internal radioactivity with the sensitive detector. Also, any person who might have breathed airborne radioactivity above limits is monitored with the sensitive detector.

Table 7 presents data concerning the number of personnel with internally deposited radioactivity since 1980. There have been 20 instances of internally deposited radioactivity above 0.01 millionths of a curie of equivalent cobalt-60 since 1980, with none since 1992. In each instance, the resulting exposure to the individual was less than 1 percent of the Federal equivalent whole body and organ exposure limits.

Internal monitoring equipment is calibrated each day the equipment is in use. This calibration involves checking the equipment's response to a known source of radiation. In addition, the Navy has an independent quality assurance program in which organizations performing internal monitoring are tested periodically. This testing involves monitoring a human-equivalent torso phantom, which contains an amount of radioactivity traceable to standards maintained by the National Institute of Standards and Technology. The exact amount of radioactivity in the test phantom is not divulged to the organization being tested until after the test is complete. Any inaccuracies found by these tests that exceed established permissible error limits are investigated and corrected.

Results of Internal Monitoring in 2005

During 2005, a total of 7,745 personnel were monitored for internally deposited radioactivity associated with naval nuclear propulsion plants. Equipment and procedures provide detection of at least 0.01 millionths of a curie of cobalt-60 (i.e., about 0.05 percent of the Federal annual limit on intake). No personnel monitored during 2005 had internal radioactivity above this level.

Table 7

Occurrences of Shipyard Personnel and Fleet Personnel Assigned to Tenders, Bases, and Nuclear-Powered Ships Radioactive Skin Contaminations and Internal Radioactivity Depositions

	Radioactive Skin Contamination		Internally Deposited Radioactivity[1]	
Year	Shipyard	Fleet	Shipyard	Fleet
1980	21	36	1	1
1981	15	36	1	0
1982	16	46	1	2
1983	14	18	0	0
1984	16	20	3	2
1985	8	29	1	0
1986	8	20	0	0
1987	9	14	0	0
1988	4	10	0	1
1989	7	11	1	0
1990	6	14	0	0
1991	10	11	0	0
1992	19	13	6	0
1993	14	3	0	0
1994	11	1	0	0
1995	8	3	0	0
1996	2	1	0	0
1997	2	4	0	0
1998	1	0	0	0
1999	2	0	0	0
2000	1	1	0	0
2001	2	1	0	0
2002	3	0	0	0
2003	2	0	0	0
2004	0	1	0	0
2005	0	0	0	0

Note:
1. Includes all occurrences of detectable internal radioactivity above 0.01 millionths of a curie of equivalent cobalt-60. The equivalent whole body dose associated with each of these events was less than 0.020 rem.

EFFECTS OF RADIATION ON PERSONNEL

Control of radiation exposure in the Naval Nuclear Propulsion Program has always been based on the assumption that any exposure, no matter how small, involves some risk; however, exposure within the accepted limits represents a risk small in comparison with the normal hazards of life. The basis for this statement is presented below.

Risks Associated with Radiation Exposure

Since the inception of nuclear power, scientists have cautioned that exposure to ionizing radiation in addition to that from natural background may involve some risk. The National Committee on Radiation Protection and Measurements in 1954 (reference 1) and the International Commission on Radiological Protection in 1958 (reference 2) both recommended that exposures should be kept as low as practicable and that unnecessary exposure should be avoided to minimize this risk. The International Commission on Radiological Protection in 1962 (reference 16) explained the assumed risk as follows:

> The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for occupational exposure.

The National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Atomic Radiation included similar statements in its reports in the 1956-1961 period and most recently in 1990 (reference 17). In 1960, the Federal Radiation Council stated (reference 4) that its radiation protection guidance did not differ substantially from recommendations of the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the National Academy of Sciences. This statement was again reaffirmed in 1987 (reference 9).

One conclusion from these reports is that radiation exposures to personnel should be minimized, but this is not a new conclusion. It has been a major driving force of the Naval Nuclear Propulsion Program since its inception in 1948.

Radiation Exposure Comparisons

The success of the Naval Nuclear Propulsion Program in minimizing exposures to personnel can be evaluated by making some radiation exposure comparisons.

Annual Exposure

One important measure of personnel exposure is the amount of exposure an individual receives in a year. Tables 2 and 3 show that since 1980, no individual has exceeded 2 rem in a year while working in the Naval Nuclear Propulsion Program. Also, from Table 4 it can be seen that the average exposure per person monitored has been on a downward trend the last 25 years and averaged about 0.043 rem for Fleet personnel and 0.105 rem for shipyard personnel since 1980. Fleet personnel monitored in 2005 received an average of 0.036 rem; shipyard personnel, an average of 0.056 rem. The following comparisons give perspective on these average annual exposures in comparison to Federal limits and other exposures:

- The Naval Nuclear Propulsion Program limits an individual's dose to 3 rem in one ***quarter***. No one in the Naval Nuclear Propulsion Program has exceeded 2 rem in one ***year*** since 1980—less than half the Federal annual limit of 5 rem.

- Annually, between 195 and 8,400 workers at NRC-licensed commercial nuclear-powered reactors have exceeded 2 rem in various years over this same period (reference 13).

- The average annual exposure of 0.043 rem since 1980 for Fleet personnel is:

  - less than 1 percent of the Federal annual limit of 5 rem.

  - less than one-half the average annual exposure of commercial nuclear power plant personnel (reference 13).

  - approximately one-fourth the average annual exposure received by U.S. commercial airline flight crew personnel due to cosmic radiation (reference 18).

- The average annual exposure of 0.105 rem since 1980 for shipyard personnel is:

  - approximately 2 percent of the Federal annual limit of 5 rem.

  - approximately one-half of the average annual exposure of commercial nuclear power plant personnel over the same time period (reference 13).

  - less than the average annual exposure received by U.S. commercial airline flight crew personnel due to cosmic radiation (reference 18).

For additional perspective, the annual exposures for personnel in the Naval Nuclear Propulsion Program may also be compared to natural background and medical exposures:

- The maximum annual exposure of 2 rem is less than half the annual exposure from natural radioactivity in the soils in some places in the world, such as Tamil Nadu, India, and Meaipe, Brazil (reference 17).

- The average annual exposure of 0.043 rem since 1980 for Fleet personnel is:

  - less than 15 percent of the average annual exposure to a member of the population in the U.S. from natural background radiation (reference 22).

  - less than the difference in the annual exposure due to natural background radiation between Denver, Colorado, and Washington, D.C. (reference 22).

- Fleet personnel operating nuclear-powered submarines receive less total annual exposure than they would if they were stationed ashore performing work not involving occupational radiation exposure. This exposure is less because of the low natural background radiation in a steel hull submerged in the ocean compared to the natural background radiation from cosmic, terrestrial, and radon sources on shore (and the effectiveness of the shielding aboard ship).

- The average annual exposure of 0.105 rem since 1980 for shipyard personnel is:
  - less than half the average annual exposure to a member of the population in the U.S. from natural background radiation (reference 22).
  - less than the exposure from common diagnostic medical procedures such as an x ray of the back (reference 23).

Collective Dose

The sum of all individual exposures gives the collective dose. Collective dose is used as a measure of the theoretical effect on the personnel occupationally exposed from the Naval Nuclear Propulsion Program taken as a group, and is an indicator of the effectiveness of the Program's efforts to minimize radiation exposure. From Tables 2 and 3, it can be seen that the collective dose received by all personnel in the Naval Nuclear Propulsion Program in 2005 was 1,833 rem. The following statements give perspective on this collective dose in comparison to collective doses from other occupations. This annual collective dose is:

- less than half the average annual collective dose received by a comparable number of commercial nuclear power plant personnel (reference 13).
- less than the average annual collective dose received by a comparable number of persons in the medical field (reference 18).
- approximately one-fourth the average annual collective dose received by a comparable number of commercial airline flight crew personnel (reference 18).

For even further perspective, the annual collective dose received by personnel in the Naval Nuclear Propulsion Program may also be compared to collective doses from radiation exposures not related to an individual's occupation. This annual collective dose is:

- approximately 15 percent of the average annual collective dose of 12,000 rem received by a comparable number of individuals in the U.S. population due to natural background radiation (reference 11).
- approximately one-third the average annual collective dose of 5,200 rem received by a comparable number of individuals in the U.S. population from diagnostic medical procedures such as x rays of the back (reference 23).
- less than four percent of the average annual collective dose of 52,000 rem received by a comparable number of individuals in the U.S. population due to the natural radioactivity in tobacco smoke (reference 11) (rough comparison due to the difficulty in estimating the average annual collective dose received from smoking).

Conclusions on Radiation Exposure to Personnel

The preceding statements show that occupational exposures to individuals working in the Naval Nuclear Propulsion Program are small when compared to other occupational exposures and limits and are within the range of exposures from natural background radiation in the U.S. and worldwide. Additionally, the total dose to all persons (collective dose) each year is small compared to the collective doses to workers in other occupations, and insignificant compared to the collective doses to the U.S. population from natural background radiation, medical procedures, and tobacco smoke. In reference 18 the National Council on Radiation Protection and Measurements reviewed the exposures to the U.S. working population from occupational exposures. This included a review of the occupational exposures to personnel from the Naval Nuclear Propulsion Program. Based on this review, the National Council on Radiation Protection and Measurements concluded:

> These small values [of occupational exposure] reflect the success of the Navy's efforts to keep doses as low as reasonably achievable (ALARA).

Studies of the Effects of Radiation on Human Beings

Observations on the biological effects of ionizing radiation began soon after the discovery of x rays in 1895 (reference 17).

Numerous references are made in the early literature to the potential biological effects of exposure to ionizing radiation. These effects have been intensively investigated for many years (reference 24). Although there still exists some uncertainty about the exact level of risk, the National Academy of Sciences has stated in reference 25:

> It is fair to say that we have more scientific evidence on the hazards of ionizing radiation than on most, if not all, other environmental agents that affect the general public.

A large amount of experimental evidence of radiation effects on living systems has come from laboratory studies on cell systems and on animals. However, what sets our extensive knowledge of radiation effects on human beings apart from other hazards is the evidence that has been obtained from studies of human populations that have been exposed to radiation in various ways (reference 25). The health effects demonstrated from studies of people exposed to high doses of radiation (that is, significantly higher than current occupational limits) include cancer, cataracts, sterility, and developmental abnormalities (from prenatal exposure). Results from animal studies indicate the potential for genetic effects.

Near the end of 1993, the Secretary of Energy requested the disclosure of all records and information on radiation experiments involving human subjects performed or supported by Department of Energy or predecessor agencies. The Naval Nuclear Propulsion Program has never conducted or supported any radiation experiments on human beings. As discussed in this report, the Program has adopted exposure limits recommended by national and international radiation protection standards committees (such as the National Council on Radiation Protection and Measurements, and the International Commission on Radiological Protection) and has relied upon conservative designs and disciplined operating and maintenance practices to minimize radiation exposure to levels well below these limits.

High-Dose Studies

The human study populations that have contributed a large amount of information about the biological effects of radiation exposure include the survivors of the atomic bombings of Hiroshima and Nagasaki, x-rayed tuberculosis patients, victims of various radiation accidents, patients who have received radiation treatment for a variety of diseases, radium-dial painters, and inhabitants of South Pacific islands that received unexpected doses from fallout due to early nuclear weapons tests. All of these populations received high or very high exposures.

The studies of atomic bomb survivors have provided the single most important source of information on the immediate and delayed effects of whole body exposure to ionizing radiation. The studies have been supported for over 40 years by the U.S. and Japanese Governments and include analysis of the health of approximately 90,000 survivors of the bombings. Continued followup of the Japanese survivors has changed the emphasis of concern from genetic effects to the induction of cancer (references 17 and 19).

The induction of cancer has been the major latent effect of radiation exposure in the atomic bomb survivors. The tissues most sensitive to the induction of cancer appear to be the blood-forming organs, the thyroid, and the female breast. Other cancers linked to radiation, but with a lower induction rate, include cancers of the lung, stomach, colon, bladder, liver, and ovary. A wave-like pattern of leukemia induction was seen over time beginning about 2 years after exposure, peaking within 10 years of exposure, and generally diminishing to near baseline levels over the next 40 years. For other cancers, a statistically significant excess was observed 5-10 years or more after exposure, and the excess risk continues to rise slowly with time (reference 19).

While it is often stated that radiation causes all forms of cancer, many forms of cancer actually show no statistically significant increase among atomic bomb survivors. These cancers include chronic lymphocytic leukemia, multiple myeloma, and cancers of the rectum, gall bladder, pancreas, larynx, prostate, cervix, and kidney (reference 19).

To understand the impact of cancer induction from the atomic bombings in 1945, it is necessary to compare the number of radiation-related cancers to the total number of cancers expected in the exposed group. In studies of 50,000 survivors with doses ranging from 0.5 to over 200 rem, nearly 6,900 cases of solid cancer have been identified as of 1994. Of these, roughly 700 are in excess of expectation (reference 20). Also, within this population, there were 4,565 solid cancer deaths and 176 leukemia deaths as of 1990 (reference 21). Of these, an estimated 376 solid cancer deaths and 78 leukemia deaths are in excess of expectation (reference 21). These studies did not reveal a statistically significant excess of cancer below doses of 6 rem (reference 19). The cancer mortality experience of the other human study populations exposed to high doses (referenced above) is generally consistent with the experience of the Japanese atomic bomb survivors (reference 19).

About 40 years ago, the major concern of the effects from radiation exposure centered on possible genetic changes. Ionizing radiation was known to cause such changes in many species of plants and animals. However, intense study of nearly 70,000 offspring of atomic bomb survivors has failed to identify any increase in genetic effects. Based on a recent analysis, human beings now appear less sensitive to the genetic effects from radiation exposure than previously thought (reference 17).

Radiation-induced cataracts have been observed in atomic bomb survivors and persons treated with very high doses of x rays to the eye. Based on this observation, potential cataract induction was a matter of concern. However, more recent research indicates that the induction of cataracts by radiation requires a high threshold dose. The National Academy of Sciences has stated that unless the protracted exposure to the eye exceeds the threshold of 800 rem, vision-impairing cataracts will not form. This exposure greatly exceeds the amount of radiation that can be accumulated by the lens through occupational exposure to radiation under normal working conditions (reference 17).

Radiation damage to the reproduction cells at very high doses can result in sterility. Impairment of fertility requires a dose large enough to damage or deplete most of the reproductive cells and is close to a lethal dose if exposure is to the whole body. The National Academy of Sciences estimates the threshold dose necessary to induce permanent sterility is approximately 350 rem in a single dose (reference 17). As in the case of cataract induction, this dose far exceeds that which can be received from occupational exposure under normal working conditions.

Among the atomic bomb survivors' children who received high prenatal exposure (that is, their mothers were pregnant at the time of the exposure), developmental abnormalities were observed. These abnormalities included stunted growth, small head size, and mental retardation. Additionally, recent analysis suggests that during a certain stage of development (the 8^{th} to 15^{th} week of pregnancy), the developing brain appears to be especially sensitive to radiation. A slight lowering of IQ might follow even relatively low doses of 10 rem or more (reference 17).

From this discussion of the health effects observed in studies of human populations exposed to high doses of radiation, it can be seen that the most important of the effects from the standpoint of occupationally exposed workers is the potential for induction of cancer (reference 17).

Low-Dose Studies

The cancer-causing effects of radiation on the bone marrow, female breast, thyroid, lung, stomach, and other organs reported for the atomic bomb survivors are similar to findings reported for other irradiated human populations. With few exceptions, however, the effects have been observed only at high doses and high dose rates. Studies of populations chronically exposed to low-level radiation have not shown consistent or conclusive evidence of an associated increase in the risk of cancer (reference 17). Attempts to observe increased cancer in human population exposed to low doses of radiation have been difficult.

One problem in such studies is the number of people needed to provide sufficient statistics. As the dose to the exposed group decreases, the number of people needed to detect an increase in cancer goes up at an accelerated rate. For example, for a group exposed to 1 rem (equivalent to the average lifetime accumulated dose in the Naval Nuclear Propulsion Program), it would take more than 500,000 people in order to detect an excess in lung cancers (based on current estimates of the risk [reference 26]). This is more than 2½ times the number of people who have performed nuclear work in all the naval shipyards over the last 52 years. Another limiting factor is the relatively short time since low-dose occupational exposure started being received by large groups of people. As discussed previously, data from the atomic bomb survivors indicate a long latency period between the time of exposure and expression of the disease.

There is also the compounding factor that cancer is a generalization for a group of approximately 300 separate diseases, many of which are relatively rare and have different apparent causes. With low-dose study data, it is difficult to eliminate the possibility that some factor other than radiation may be causing an apparent increase in cancer induction. This difficulty is particularly apparent in studies of lung cancer, for example, where smoking is (a) such a common exposure, (b) poorly documented as to individual habits, and (c) by far the primary cause of lung cancer. Because cancer induction is statistical in nature, low-dose studies are limited by the fact that an apparent observed small increase in a cancer may be due to chance alone.

Despite the above-mentioned problems and the lack of consistent or conclusive evidence from such studies to date, low-dose studies fulfill an important function. They are the only means available for eventually testing the validity of current risk estimates derived from data accumulated at higher doses and higher dose rates.

Low-dose groups that have been, and are currently being, studied include groups exposed as a result of medical procedures; exposed to fallout from nuclear weapons testing; living near U.S. commercial nuclear installations; living in areas of high natural background radiation; and occupational exposure to low doses of radiation. The National Academy of Sciences has reviewed a number of the low-dose studies in references 17 and 25. Their overall conclusion from reviewing these studies was:

> Studies of populations chronically exposed to low-level radiation, such as those residing in regions of elevated natural background radiation, have not shown consistent or conclusive evidence of an associated increase in the risk of cancer (reference 17).

This conclusion has been supported by studies that have been completed since reference 17 was published. For example, in 1990 the National Cancer Institute completed a study of cancer in U.S. populations living near 62 nuclear facilities that have been in operation prior to 1982. This study included commercial nuclear power plants and Department of Energy facilities that handle radioactive materials. The National Cancer Institute study concluded that there was no evidence that leukemia or any other form of cancer was generally higher in the counties near the nuclear facilities than in the counties remote from nuclear facilities (reference 27).

At the request of the Three Mile Island Public Health Fund, independent researchers investigated whether the pattern of cancer in the 10-mile area surrounding the Three Mile Island nuclear plant had changed after the TMI-2 accident in March 1979 and, if so, whether the change was related to radiation releases from the plant. A conclusion of this study was:

> For accident emissions, the authors failed to find definite effects of exposure on the cancer types and population subgroups thought to be most susceptible to radiation. No associations were seen for leukemia in adults or for childhood cancers as a group (reference 28).

Of particular interest to workers in the Naval Nuclear Propulsion Program are studies of groups occupationally exposed to radiation. A 1990 survey of radiation-worker populations in the U.S. showed that there were about 350,000 workers under study (reference 26). For more than a decade, Naval Nuclear Propulsion Program personnel, including those at shipyards and in the Fleet, have been included among populations being studied. These studies are discussed below.

In 1978, Congress directed the National Institute for Occupational Safety and Health (NIOSH) to perform a study of workers at the Portsmouth Naval Shipyard (PNSY) in response to an article in the *Boston Globe* newspaper describing research by Dr. T. Najarian and Dr. T. Colton, assisted by the *Boston Globe* staff. Their research suggested that PNSY workers who were occupationally exposed to low-level radiation suffered twice the expected rate of overall cancer deaths and five times the expected rate of leukemia deaths. Congress also chartered an independent oversight committee of nine national experts to oversee the performance of the study in order to ensure technical adequacy and independence of the results. The following is a NIOSH summary of the study and their results. This summary was prepared by NIOSH at the conclusion of their study phase in February 1986.

> In December 1980, NIOSH researchers completed the first report on a detailed study of the mortality among employees of the shipyard. Included in the study were all those who had been employed at Portsmouth Naval Shipyard since January 1, 1952 (the earliest date that records existed that could identify former employees). In this report it was concluded that "Excesses of deaths due to malignant neoplasms and specifically due to neoplasms of the blood and blood-forming tissue, were not evident in civilian workers at Portsmouth Naval Shipyard. . . ." in contrast to the results of the original study conducted by the physician. Later, in an investigation to determine why the physician's study results differed so greatly from the NIOSH study, a number of shortcomings in his original study were found that resulted in incorrect conclusions.
>
> To make more certain that workers who had died from leukemia did not die because of radiation exposures received at the shipyard, a second study was conducted. That study compared the work and radiation histories of persons who died of leukemia, with persons who did not. In this analysis, again, no relationship was found between leukemia and radiation, although the NIOSH researchers were unable to rule out the possibility of other occupational exposures having a role.
>
> In this current and third NIOSH paper, we investigated the role that radiation and other occupational exposures at the shipyard may have had in the development of lung cancer. This study is an outgrowth of an observation made in the 1980 NIOSH study referred to above. The observation was that persons with greater than 1 rem cumulative exposure to radiation had an increase in lung cancer.
>
> In this report entitled, "Case Control Study of Lung Cancer in Civilian Employees at the Portsmouth Naval Shipyard," we compared the work and radiation histories of persons who died of lung cancer with persons who did not. We found that persons with radiation exposures in excess of 1 rem had an excess risk of dying of lung cancer, but the radiation was in all likelihood not the cause. This was due to the fact that persons with radiation exposure tended also to have exposure to asbestos (a known lung carcinogen) and to welding by-products (suspected to contain lung carcinogens).

Thus, the earlier reports of excessive cancer rates among PNSY workers exposed to low-level radiation were not substantiated by NIOSH. The NIOSH studies were published in the scientific literature in references 29 through 32.

NIOSH published the results of an update to the 1980 study in the July 2004 edition of the *Journal of Occupational and Environmental Medicine* (reference 33). The cohort was expanded by including all Portsmouth Naval Shipyard workers employed through 1992 and included worker vital statistics up to December 1996. The NIOSH study found nothing to conclude that the health of shipyard workers has been adversely affected by low levels of occupational radiation exposure incidental to work on nuclear-powered ships. These findings are generally consistent with previous studies.

The study showed no statistically significant cancer risks linked to radiation exposure, when compared to the general U.S. population. Further, the overall death rate among PNSY occupational radiation workers was less than the death rate for the general U.S. population. Other key conclusions reached in the study include the following:

- The study found a slightly higher death rate for all types of cancer in personnel who were never radiation workers, when compared to the general U.S.

population. The study also found an equivalent slightly higher death rate for all types of cancer for those who received occupational radiation exposure when compared to the general U.S. population. Fewer deaths than expected were observed for tuberculosis, diseases of the heart, circulatory system, and digestive system, as well as for accidents and violence.

- Consistent with the 1981 NIOSH study, the current study did not find a statistically significant difference in the death rates from leukemia for shipyard and the general U.S. population. Although NIOSH concludes that the result is not statistically significant, the data suggest the potential for a small increase in the low risk of leukemia for workers receiving occupational radiation exposure. The small number of leukemia cases (34 out of 11,791 workers receiving occupational radiation exposure) reflects the low risk of this disease. The researchers considered this potential relationship of radiation exposure and leukemia to be considerably uncertain and to require additional study before any conclusions can be made.

- The study found a slightly higher death rate for lung cancer for workers that were never radiation workers, when compared to the general U.S. population. The study found a slightly higher death rate for lung cancer for workers receiving occupational radiation exposure, when compared to the general U.S. population. The researchers concluded that the slightly higher rates were accounted for by factors other than radiation exposure; the other factors were smoking, exposure to welding fumes, and asbestos work during the early years covered by the study when the hazard associated with asbestos was not so well understood as it is today.

Several additional analyses of the PNSY data have been performed by NIOSH, and in the December 2005 issue of *Radiation Research* (reference 34) NIOSH published the results of a case-control study of leukemia mortality and ionizing radiation. The study found that although the overall risk of leukemia mortality for radiation workers was the same as the general population, a small increase in risk was noted with increasing radiation dose. NIOSH estimated that the lifetime risk for leukemia mortality would increase from 0.33% to 0.36% for workers receiving the average lifetime radiation dose for shipyard workers (1.2 rem). The study also found a small increase in leukemia mortality associated with potential solvent exposure (benzene or carbon tetrachloride). NIOSH cautioned that the relatively small number of leukemia cases among radiation workers (34 cases in a population of 11,791 workers) makes it difficult to be certain of the findings. However, the risk estimate is consistent with other radiation epidemiologic study results.

In 1991, researchers from Johns Hopkins University, Baltimore, Maryland, completed a more comprehensive epidemiological study of the health of workers at the six naval shipyards and two private shipyards that serviced naval nuclear-powered ships (reference 35). This independent study evaluated a population of 70,730 civilian workers over a period from 1957 (beginning with the first overhaul of the first nuclear-powered submarine, USS NAUTILUS) through 1981, to determine whether there was an excess risk of leukemia or other cancers associated with exposure to low levels of gamma radiation.

This study did not show any cancer risks linked to radiation exposure. Furthermore, the overall death rate among radiation-exposed shipyard workers was actually less than the death rate for the general U.S. population. It is well recognized that many worker populations have lower mortality rates than the general population: the workers have to be healthy to do their jobs. This study shows that the radiation-exposed shipyard population falls into this category.

The death rate for cancer and leukemia among the radiation-exposed workers was slightly lower than that for non-radiation-exposed workers and that for the general U.S. population. However, an increased rate of mesothelioma, a type of respiratory system cancer linked to asbestos exposure, was found in both radiation-exposed and non-radiation-exposed shipyard workers, although the number of cases was small (reflecting the rarity of this disease in the general population). The researchers suspect that shipyard worker exposure to asbestos in the early years of the Program, when the hazards associated with asbestos were not so well understood as they are today, might account for this increase.

The Johns Hopkins study found no evidence to conclude that the health of people involved in work on U.S. naval nuclear-powered ships has been adversely affected by exposure to low levels of radiation incidental to this work. Additional studies are planned to investigate the observations and update the study with data beyond 1981.

In 1987, the Yale University School of Medicine completed a study (reference 36) sponsored by the U.S. Navy Bureau of Medicine and Surgery of the health of Navy personnel assigned to nuclear submarine duty between 1969 and 1981. The objective of the study, begun in 1979, was to determine whether the enclosed environment of submarines has had any impact on the health of these personnel. Although not strictly designed as a cancer study of a low-dose population, the study did examine cancer mortality as a function of radiation exposure. The study concluded that submarine duty has not adversely impacted the health of crewmembers. Furthermore, there was no correlation between cancer mortality and radiation exposure. These observations were based on comparison of death rates among the approximately 76,000 officers and enlisted submariners (all who served between 1969 and 1981) with an age-matched peer group. The results of this study were published in the Journal of Occupational Medicine (reference 37).

Table 8 below summarizes the Yale study results for enlisted submariners. The officer data show similar trends. (Note the SSBN population was larger than the fast-attack submarine [SSN] population, hence the larger number of expected cancer deaths. Also, SSBN & SSN is defined as "service aboard both types of submarines.") As seen in Table 8, cancer deaths among both SSBN and SSN Sailors are less than cancer deaths among their age-matched peers in the civilian population.

TABLE 8

YALE STUDY RESULTS

Enlisted Submariners (76,160)	Cancer Deaths Observed in Submarine Group	Cancer Deaths Expected in Age-Matched Group
SSBN	55	61
SSN	18	36
SSBN & SSN	4	12
Total	77	109

In 1996, New York University (NYU) was contracted to update the Yale Study by updating the vital statistics of the cohort through 1995. Updating the Yale study was appropriate because of the increased followup time and more statistical power provided by the aging cohort. NYU has completed their study update and provided a draft report to the Navy. Consistent with the Yale study, the NYU study team concluded that there is no evidence of increased cancer from chronic low doses of ionizing radiation associated with this cohort. NYU will publish the results in the near future.

Numerical Estimates of Risk from Radiation

One of the major aims of the studies of exposed populations as discussed above is to develop numerical estimates of the risk of radiation exposure. These risk estimates are useful in addressing the question of how hazardous is radiation exposure, evaluating and setting radiation protection standards, and helping resolve claims for compensation by exposed individuals.

The development of numerical risk estimates has many uncertainties. As discussed above, excess cancers attributed to radiation exposure can only be observed in populations exposed to high doses and high-dose rates. However, the risk estimates are needed for use in evaluating exposures from low doses and low-dose rates. Therefore, the risk estimates derived from the high-dose studies must be extrapolated to low doses. This extrapolation introduces a major uncertainty. The shape of the curve used to perform this extrapolation becomes a matter of hypothesis (that is, assumption) rather than observation. The inability to observe the shape of this extrapolated curve is a major source of controversy over the appropriate risk estimate.

Scientific committees, such as the National Academy of Science (reference 17), the United Nations Scientific Committee on the Effects of Atomic Radiation (reference 19), and the National Council on Radiation Protection and Measurements (reference 12) all conclude that accumulation of dose over weeks, or months, as opposed to in a single dose, is expected to reduce the risk. A dose rate effectiveness factor (DREF) is applied as a divisor to the risk estimates at high doses to permit extrapolation to low doses. The National Academy of Sciences (reference 17) suggested that a range of DREFs between 2 and 10 may be applicable and reported a best estimate of 4, based on studies of laboratory animals. The United Nations Scientific Committee on the Effects of Atomic Radiation (reference 19) suggested that a DREF of 2 or 3 would be reasonable based on available data. However, despite these conclusions by the scientific committees, some critics argue that the risk actually increases at low doses, while others argue that cancer induction is a threshold effect and the risk is zero below the threshold dose. As stated at the beginning of this section, the Naval Nuclear Propulsion Program has always conservatively assumed that radiation exposure, no matter how small, may involve some risk.

In 1972, both the United Nations Scientific Committee on the Effects of Atomic Radiation and the National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation issued reports (references 37 and 38) that estimated numerical risks for specific types of cancer from radiation exposure to human beings. Since then, international and national scientific committees have been periodically re-evaluating and revising these numerical estimates based on the latest data. The most recent risk estimates are from the same two committees and are contained in their 1990 and 2000 reports, respectively (references 17 and 19). Both committees re-evaluated risk estimates based on the use of new models for projecting the risk, revised dose estimates for survivors of the Hiroshima and Nagasaki atomic bombs, and additional data on the cancer experience both by atomic bomb survivors and by persons exposed to radiation for medical purposes. A risk estimate for radiation-induced cancer derived from the most recent analyses, references 17 and 19, can be briefly summarized as follows:

> In a group of 10,000 workers in the U.S., a total of about 2,000 (20 percent) will normally die of cancer. If each of the 10,000 received over his or her career an additional 1 rem, then an

estimated 4 additional cancer deaths (0.04 percent) might occur. Therefore, the average worker's lifetime risk of cancer has been increased nominally from 20 percent to 20.04 percent.

The above risk estimate was extrapolated from estimates applicable to high doses and dose rates using a DREF of about 2. This estimate may overstate the true lifetime risk at low doses and dose rates, because a DREF of 2 is at the low end of probable DREF values. The National Academy of Sciences (reference 17), in assessing the various sources of uncertainty, concluded that the true lifetime risk may be contained within an interval from 0 to about 6. The Academy points out that the lower limit of uncertainty extends to zero risk because "the possibility that there may be no risks from exposure comparable to external natural background radiation cannot be ruled out."

These statistics can be used to develop a risk estimate for personnel exposed to radiation associated with naval nuclear propulsion plants. As stated previously, the average lifetime accumulated exposure is approximately 1.14 rem for all shipyard personnel and approximately 0.71 rem for all Fleet personnel. Therefore, based on a Program-wide average of about 1 rem and the risk estimate presented above, the average worker's lifetime cancer risk in the Naval Nuclear Propulsion Program may be increased a very small amount, from 20 percent to 20.04 percent.

Risk Comparisons

Table 9 compares calculated risks from occupational exposure in the Naval Nuclear Propulsion Program to other occupational risks. This allows us to evaluate the relative hazard of this risk versus risks normally accepted in the workplace. It should be kept in mind that the radiation risk is calculated based on risk estimates, whereas the other occupational risks are based on actual death statistics for the occupation.

TABLE 9

LIFETIME OCCUPATIONAL RISKS

Occupation (reference 12)	Lifetime Risk[6] Percent
Agriculture	2.1
Mining, Quarrying	2.0
Construction	1.5
Transportation and Public Utilities	1.0
All Industries Average	0.4
Government	0.4
Services	0.2
Manufacturing	0.2
Trade	0.2
Radiation exposure associated with naval nuclear propulsion plants (risk estimate)	0.04

6. Assumes a working lifetime of 47 years (age 18 to 65).

Further perspective on the lifetime risk from radiation exposure in the Naval Nuclear Propulsion Program may be gained by comparison to other everyday risks as shown in Table 10.

TABLE 10

SOME COMMONPLACE LIFETIME RISKS

Risk (references 39 and 40)	Lifetime Risk[7] Percent
Tobacco	11.1
Poor Diet/Lack of Exercise	10.7
Infectious Agents	3.0
Accidents (all)	2.7
Firearms	1.5
Motor Vehicle Accidents	1.2
Falls	0.42
Accidental Poisoning	0.39
Drowning	0.09
Fires	0.08
Other Land Transport Accidents	0.03
Radiation exposure associated with naval nuclear propulsion plants (risk estimate)	0.04

Low-Level Radiation Controversy

A very effective way to cause undue concern about low-level radiation exposure is to claim that no one knows what the effects are on human beings. Critics have repeated this so often that it has almost become an article of faith. They can make this statement because, as discussed above, human studies of low-level radiation exposure cannot be conclusive as to whether or not an effect exists in the exposed groups, because of the extremely low incidence of an effect. Therefore, assumptions are needed regarding extrapolation from high-dose groups. The reason low-dose studies cannot be conclusive is that the risk, if it exists at these low levels, is too small to be seen in the presence of all the other risks of life.

In summary, the effect of radiation exposures at occupational levels is extremely small. There are physical limits to how far scientists can go to ascertain precisely how small. But instead of proclaiming how little is known about low-level radiation, it is more appropriate to emphasize how much is known about the small actual effects.

As stated earlier, the most important health effect observed in studies of humans exposed to high doses of radiation (such as survivors of the atomic bombings of Hiroshima and Nagasaki, patients with high doses from x rays or radiation treatments, and radium-dial painters) is the potential for the induction of cancer. While there are

7. For tobacco use, the risk assumes the population is at risk from age 18 to 76.5 (58.5 years). Other risks assume the population is at risk for a lifetime (76.5 years).

studies of the potential for cause and effect from low doses of radiation, the incidence of cancer in an individual who received occupational radiation exposure does not necessarily mean that occupational exposure was the cause. Reference 41 documents that the lifetime risk of being diagnosed with cancer for a person living in the United States is 45 percent for males and 39 percent for females. The median age for being diagnosed with cancer is 68 years old, meaning that half of those diagnosed with cancer are younger than 68 at the time of diagnosis. In addition, the lifetime risk of dying from cancer for a person living in the United States is 23 percent for males and 20 percent for females.

As discussed earlier, the Navy has participated in several epidemiology studies by authoritative scientists of mortality of personnel who served on naval nuclear-powered submarines or worked in shipyards. Each of these studies concluded that there was no discernable correlation between cancer mortality and the low-level radiation exposure associated with naval nuclear propulsion plants. The Navy continues to support updates to these studies.

Conclusions on the Effects of Radiation on Personnel

This perspective provides a better position to answer the question, "Is radiation safe?" If safe means "zero effect," then the conclusion would have to be that radiation may be unsafe. But to be consistent, background radiation and medical radiation would also have to be considered unsafe. Or more simply, being alive is unsafe.

"Safe" is a relative term. Comparisons are necessary for actual meaning. For a worker, *safe* means the risk is small compared to other risks accepted in normal work activities. Aside from work, *safe* means the risk is small compared to the risks routinely accepted in life.

Each recommendation on limits for radiation exposure from the scientific and advisory organizations referenced herein emphasized the need to minimize radiation exposure. Thus, the Naval Nuclear Propulsion Program is committed to keeping radiation exposure to personnel as low as reasonably achievable. Scientific and advisory organizations have not agreed on a radiation exposure level below which there is no effect. Similarly, it is difficult to find a single human activity for which the risk can be confidently stated as zero. However, the above summaries show that the risk from radiation exposure associated with naval nuclear propulsion plants is low compared to the risks normally accepted in industrial work and in daily life outside of work.

CLAIMS FOR RADIATION INJURY TO PERSONNEL

Personnel who consider they have or might have had occupational injury may file claims. Naval shipyard personnel are employees of the U.S. Government and therefore file claims with the U.S. Department of Labor's Office of Workers' Compensation. Shipyards hold no hearings on injury claims. They are not handled in an adversary procedure. The claim does not even have to be filed through the shipyard. The shipyard is not permitted to appeal a decision, but the employee may appeal. The primary consideration in the Federal laws and procedures set up for injury compensation is to take care of the Federal employee. The program to compensate Federal employees is well publicized.

In private shipyards injury compensation claims are handled under the Longshore and Harbor Workers' Compensation Act. The claim may be handled through the shipyard's insurance carrier or by a U.S. Department of Labor claims examiner. Either the employee or the employer may appeal.

Claims for military personnel concerning prior duty are handled through the VA.

In any case, the Naval Nuclear Propulsion Program would support any claim for radiation injury where it could be technically and scientifically shown that the injury was more likely than not caused by the individual's occupational radiation exposure from the Program.

There have been a total of 501 claims filed for injury from radiation associated with naval nuclear propulsion plants. Of these, 148 originated from employees of the naval shipyards, 71 from private shipyards, and 282 from Navy personnel. In 2005, 34 new claims were filed and none were awarded. As summarized in Table 11, about a fourth of the claims were filed for injuries other than cancer or leukemia. Approximately four-fifths of the claims filed for cancer or leukemia involved workers with lifetime radiation exposures less than 5 rem, which is the exposure a nuclear worker is permitted to receive in 1 year by Federal regulations.

TABLE 11

CLAIMS FOR RADIATION INJURY TO PERSONNEL

Injury Claimed	Claims Filed	Claims Awarded	Claims Denied	Claims Deferred	Claims Active
Leukemia	65	4	49	11	1
Cancer Other than Leukemia	293	3	267	19	4
Other	143	5	111	25	2
Total	501	12	427	55	7

Naval shipyard personnel workers' compensation claims are generally decided upon by the Office of Workers' Compensation within 1-2 years of filing. The Longshore and Harbor Workers' Compensation Act, however, will not require a decision on a case subsequent to filing unless it is actively pursued by the claimant. For cases that are not actively pursued, the claim may lie dormant for many years (theoretically to be pursued at a later date, whereupon a decision will be made). For the purpose of Table 11, claims which have had no activity in the last 5 years are listed as deferred.

Twelve claims have been awarded for which radiation was an alleged causal agent: four for leukemia in 1968, 1979, 1991, and 1999; four for cataracts in 1971, 1974, 1977, and 1982; one for leukocytosis in 1969; one for bile duct/pancreatic cancer in 1980; and one for metastatic carcinoma of undetermined origin in 1998; and one for lung cancer in 2004. The Office of Workers' Compensation awarded three claims, and the VA awarded nine claims. For VA claims, other considerations (such as whether the injury is reasonably considered to have occurred while the claimant was in the Armed Forces and other causal factors) are used when awarding claims. The Navy considers all 12 of these awards were unjustified on the basis of radiation exposure, as follows:

- One leukemia case had a lifetime occupational exposure of 5.38 rem. The claimant also received hundreds of rem in medical radiation exposure for adenoids. If radiation were to be selected as the cause of this leukemia, then the occupational exposure could not have been more than a tiny part of the total radiation exposure.

- The second leukemia case had a lifetime occupational exposure of 1.00 rem. This amount of radiation exposure is small and is less than 10 percent of the amount of exposure the claimant will receive during his life from natural background and medical radiation.

- The third leukemia case had a lifetime occupational exposure of 4.20 rem (2.98 rem of which was received while in the U.S. Navy). This amount of radiation exposure is less than 10 percent of the exposure the claimant was allowed under Federal limits for the 12 years he was occupationally exposed to ionizing radiation.

- The fourth leukemia case had a lifetime occupational exposure of 1.054 rem. Again, this amount of radiation exposure is small and is less than 10 percent of the amount of exposure the claimant will receive during his life from natural background and medical radiation.

- Two of the cataract cases had lifetime radiation exposures of about 3 rem, one case had less than 1 rem, and one case had 0.02 rem. Of these cases, even the highest exposure, 3 rem, is hundreds of times smaller than needed to produce cataracts in the eyes (reference 17).

- The leukocytosis (elevated white blood cell count) case had a lifetime occupational exposure of 15.5 rem, which was received over an 8-year period. This case was evaluated by the medical research center of a national laboratory, which concluded that the cause of the leukocytosis was unknown. In addition, leukocytosis has not been shown to be associated with low-level occupational radiation exposure.

- The bile duct and pancreatic cancer case was awarded for a lifetime occupational exposure of 2.37 rem. This amount of radiation is less than the quarterly limit of 3 rem and the annual limit of 5 rem. Further, this person received about four times the amount of his occupational exposure from natural background and medical exposures over his lifetime.

- The metastatic carcinoma case was awarded for a lifetime occupational exposure of 2.834 rem. This amount of radiation is less than the quarterly limit of 3 rem and the annual limit of 5 rem. Further, this person received over five times the amount of his occupational exposure from natural background and medical exposure over his lifetime.

- The lung cancer case had a lifetime exposure of 3.55 rem. This amount of radiation is less than the annual limit of 5 rem. Further, this person received over seven times the amount of his occupational exposure from natural background and medical exposures over his lifetime.

In addition to the above claims, six suits have been filed in court alleging injury from radiation. One suit involved leukemia; three involved other cancers; and the two others did not involve a cancer. Five of these suits were dismissed and one was settled.

AUDITS AND REVIEWS

Checks and cross-checks, audits, and inspections of numerous kinds have been shown to be essential in maintaining high standards of radiological controls. First, all workers are specially trained in radiological controls as it relates to their own job. Second, written procedures exist that require verbatim compliance. Third, radiological controls technicians and their supervisors oversee radioactive work. Fourth, personnel independent of radiological controls technicians are responsible for personnel radiation exposure records.

Fifth, a strong independent audit program is required, covering all radiological controls requirements. In all shipyards, this radiological audit group is independent of the radiological controls organization; the audit group's findings are reported regularly to senior shipyard management, including the shipyard commander or shipyard president. This group performs continuing surveillance of radioactive work. It conducts indepth audits of specific areas of radiological controls, and checks all radiological controls requirements at least annually.

Sixth, the U.S. Department of Energy assigns to each shipyard a representative who reports to the Director, Naval Nuclear Propulsion, at Headquarters. One assistant to this representative is assigned full-time to audit and review radiological controls, both in nuclear-powered ships and in the shipyard. Seventh, Naval Nuclear Propulsion Program Headquarters personnel conduct periodic inspections of radiological controls in each shipyard. Similarly, there are multiple levels of audits and inspections for the other naval shore facilities, tenders, and nuclear-powered ships.

In addition, various aspects of the Naval Nuclear Propulsion Program have been reviewed by other Government agencies. For example, the National Institute for Occupational Safety and Health conducted an evaluation of the radiological controls program at Portsmouth Naval Shipyard in conjunction with its mortality study at the shipyard (discussed earlier in this report). NIOSH published the results of its evaluation in a report (reference 43) in April 1983, which stated the following conclusions:

- The employee dose data provided NIOSH by Portsmouth Naval Shipyard is complete and provides a reasonable estimate of the individual worker's dose.
- The Portsmouth Naval Shipyard personnel dosimetry program provides accurate internal and external dose data.
- The external and internal doses received by Portsmouth Naval Shipyard personnel are low compared to present occupational exposure guidelines.
- The probability of unreported accidents/ incidents or undocumented exposures is extremely small.
- The radiological controls employed are adequate to protect the worker from internal and external hazards.
- The impact of the nuclear work at Portsmouth Naval Shipyard to the surrounding environment is minimal or negligible.
- Nuclear operations at Portsmouth Naval Shipyard are not contributing a significant radiation dose to the general public.

Another example of an independent governmental review of the Naval Nuclear Propulsion Program was the General Accounting Office (GAO) 14-month indepth review of various aspects of the Program's Department of Energy facilities. These Department of Energy facilities operate to the same radiological control requirements as other Naval Nuclear Propulsion Program (Naval Reactors) facilities. In August 1991 (reference 44), the GAO published the following conclusions:

- We believe Naval Reactors Laboratories are accurately measuring, recording, and reporting radiation exposures.

- Naval Reactors reported exposures show that exposures have been minimal and overall are lower than commercial nuclear facilities and other DOE facilities.

ABNORMAL OCCURRENCES

It is a fact of human nature that people make mistakes. The key to a good radiological controls program is to find the mistakes while they are small and prevent the combinations of mistakes that lead to more serious consequences. The preceding section on inspections supports the conclusion that the Naval Nuclear Propulsion Program gives more attention to errors and their prevention than to any other single subject. Requiring constant focus on improving performance of radiological work has proven effective in reducing errors.

In addition, radiological controls technicians are authorized and required to stop anyone performing work in a manner that could lead to radiological deficiencies. One definition of "deficiency" is a failure to follow a written procedure verbatim. However, the broadest interpretation of the term "deficiency" is used in the Navy's radiological controls program. *Anything involved with radiation or radioactivity that could have been done better* is also considered a radiological deficiency. All radiological deficiencies receive management attention.

Higher levels of deficiency are termed "radiological incidents." Incidents receive further management review, including evaluation by senior personnel at Headquarters and review by the Director, Naval Nuclear Propulsion. Improvement programs over the years have constantly aimed at reducing the numbers of radiological incidents. As improvements occurred, the definition of what constituted an incident was changed to define smaller and smaller deficiencies as incidents. These changes were necessary so that the incident reporting system would continue to play a key role in upgrading radiological controls. As a result, it is not practicable to measure performance over time merely by counting numbers of radiological incidents or deficiencies.

The Department of Energy and its predecessors have used a separate reporting system that has been nearly constant over time and therefore can be used as a basis for comparison. This system defines a Type A radiation exposure occurrence as an event that causes an individual's external radiation exposure to equal or exceed 25 rem (reference 45). The Nuclear Regulatory Commission uses similar criteria to define an abnormal occurrence; abnormal occurrences are included in the NRC's quarterly report to Congress. The Navy regularly evaluates radiological events using these criteria for comparison.

Since the beginning of operations in the Naval Nuclear Propulsion Program, there has never been a single radiation incident that met the criteria of a Type A or abnormal occurrence.

The policy of the Navy is to provide for close cooperation and effective communication with State radiological officials involving occurrences that might cause concern because of radiological effects associated with the ships or shore facilities. The Navy has reviewed radiological matters with State radiological officials in the States where naval nuclear-powered ships are based or overhauled. Although there has never been an abnormal occurrence resulting in radiological effects to the public outside these facilities or that resulted in radiological injury to residents of the States working inside these facilities, States were notified when inquiries showed public interest in the possibility such events had occurred.

(29) R. A. Rinsky, et. al, "Cancer Mortality at a Naval Nuclear Shipyard," The Lancet, January 31, 1981

(30) E. R. Greenburg et. al, "An Investigation of Bias in a Study of Nuclear Shipyard Workers," American Journal of Epidemiology, 1985; 121: 301-308

(31) F. B. Stern, et. al, "A Case-Control Study of Leukemia at a Naval Nuclear Shipyard," American Journal of Epidemiology, 1986; 123: 980-992

(32) R. S. Rinsky, et. al, "Case-Control Study of Lung Cancer in Civilian Employees at the Portsmouth Naval Shipyard, Kittery, Maine," American Journal of Epidemiology, 1988; 127: 55-64

(33) S.R. Silver, et. al, "Differences in Mortality by Radiation Monitoring Status in an Expanded Cohort of Portsmouth Naval Shipyard Workers" Journal of Occupational and Environmental Medicine 2004; 677-690

(34) T. L. Kubale, et al, "A Nested Case-Control Study of Leukemia Mortality and Ionizing Radiation at the Portsmouth Naval Shipyard," Radiation Research, 2005; 164:810-819

(35) G. M. Matanoski, et. al, "Health Effects of Low-Level Radiation in Shipyard Workers," Johns Hopkins University Department of Epidemiology School of Hygiene and Public Health, June 1991

(36) A. M. Ostfeld, et. al, "Out-of Service Mortality Among Nuclear Submariners Discharged 1969-1981," Yale University School of Medicine, April 1987

(37) P. Charperntier, et. al, "The Mortality of U.S. Nuclear Submariners, 1969-1982," Journal of Occupational Medicine, May 1993

(38) United Nations Scientific Committee on the Effects of Atomic Radiation, "Ionizing Radiation: Levels and Effects," 1972

(39) National Academy of Sciences-National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, 1972

(40) K. D. Kochanek, B. L. Smith. "Deaths: Preliminary Data for 2002." National vital statistics reports; Vol 52 no.13, Hyattsville, MD: National Center for Health Statistics, February 2004

(41) "Targeting Tobacco Use: The Nation's Leading Cause of Death At a Glance 2004" Center for Disease Control and Prevention, 2004

(42) Reis LAG, et al, "SEER Cancer Statistics Review, 1975-2000" National Cancer Institute, 2003. Bethesda, MD, http://seer.cancer.gov/csr/1975_2000, 2003

(43) National Institute for Occupational Safety and Health Report, "The Radiological Control Program of the Portsmouth Naval Shipyard," W. E. Murray & M. S. Terpilak, April 1983

(44) General Accounting Office Report GAO/RCED-91-157, "NUCLEAR HEALTH AND SAFETY - Environmental, Health, and Safety Practices at Naval Reactors Facilities," August 1991

(45) Department of Energy Order 225.1, "Accident Investigations"

SEPARATION

PAGE

06.0959

Report NT-06-3
March 2006

OCCUPATIONAL RADIATION EXPOSURE
FROM NAVAL REACTORS'
DEPARTMENT OF ENERGY FACILITIES

2005

Prepared by

T. J. Mueller,
W. S. Knoll, J. A. Jones, and A. A. Cohen
Naval Nuclear Propulsion Program
Office of Naval Reactors

Approved by

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The Naval Nuclear Propulsion Program is a joint Department of Energy / Department of the Navy Program with central control by a single headquarters organization. Within the Department of Energy, the organization is designated as the Office of Naval Reactors. It operates two Department of Energy laboratories; one Department of Energy site with two operating and two inactive prototype naval nuclear propulsion plants; one Department of Energy site that operates the Expended Core Facility (for examination and dispositioning of naval fuel and irradiation tests) and has three inactive prototype nuclear propulsion plants and two nuclear component engineering and procurement organizations. Table 1 shows the facilities that have conducted radioactive work associated with the Naval Reactors Program and the date when such work began. Naval Reactors' Department of Energy facilities provide research and development, engineering, training, and supply support for the Navy's 73 nuclear-powered submarines and 10 nuclear-powered aircraft carriers that were in operation at the end of 2005.

Radiation exposures to personnel monitored for radiation associated with Naval Reactors' Department of Energy facilities are summarized in this report. Also included in this report is radiation exposure information from the Shippingport Atomic Power Station, near Pittsburgh, Pennsylvania. Shippingport was developed by the Naval Reactors Program (in conjunction with Duquesne Light Company) as the world's first full-scale atomic power plant solely for the production of electricity. Shippingport began operation in 1957. Starting in 1974, the light water breeder reactor (LWBR) core was installed at Shippingport; this was the first reactor to prove that fuel breeding was possible in a water-cooled plant. Shippingport was shut down in 1982 and, following defueling, turned over to another Department of Energy office for dismantlement in 1984. Dismantlement was completed in 1989, removing all radioactive components and returning the site to unrestricted use.

Figure 1 shows that the total radiation exposure in 2005 of 79.1 rem is less than 2 percent of the amount in the peak year of 1975 and that the number of personnel monitored has decreased by more than 60 percent since 1975. The large increase in radiation exposure in 1975 was due to refueling operations at one of the prototype naval nuclear propulsion plants and to fabrication and installation of the LWBR core at Shippingport. LWBR was unique in this sense because the fissile material was uranium-233 rather than uranium-235. Total rem in this figure is the sum of the annual exposure of each person monitored for radiation.

The current Federal annual occupational radiation exposure limit of 5 rem (established in 1994) came 27 years after the Naval Nuclear Propulsion Program's annual exposure limit of 5 rem per year was adopted in 1967. (Until 1994, the Federal radiation exposure lifetime limit allowed an accumulation of exposure of 5 rem for each year of age beyond 18.) From 1968 to 1994, no civilian or military personnel in the Program exceeded its self-imposed 5 rem annual limit, and no one has exceeded that Federal limit since then. In fact, no Program personnel have exceeded 40 percent of the Program's annual limit since 1980 (i.e., no personnel have exceeded 2 rem in any year in the last 26 years). And no civilian or military Program personnel have ever, in over 50 years of operation, exceeded the Federal lifetime limit.

The average occupational exposure of each person monitored at Naval Reactors' Department of Energy facilities since 1958 is 0.111 rem per year. The lifetime accumulated exposure from radiation associated with Naval Reactors' Department of

Energy facilities to date for all personnel monitored has averaged less than 1 rem per person.

According to the standard methods for estimating risk, the risk to the group of personnel occupationally exposed to radiation associated with the Naval Reactors Program is less than the risk these same personnel have from exposure to natural background radiation. This risk is small compared to the risks accepted in normal industrial activities and to the risks regularly accepted in daily life outside of work.

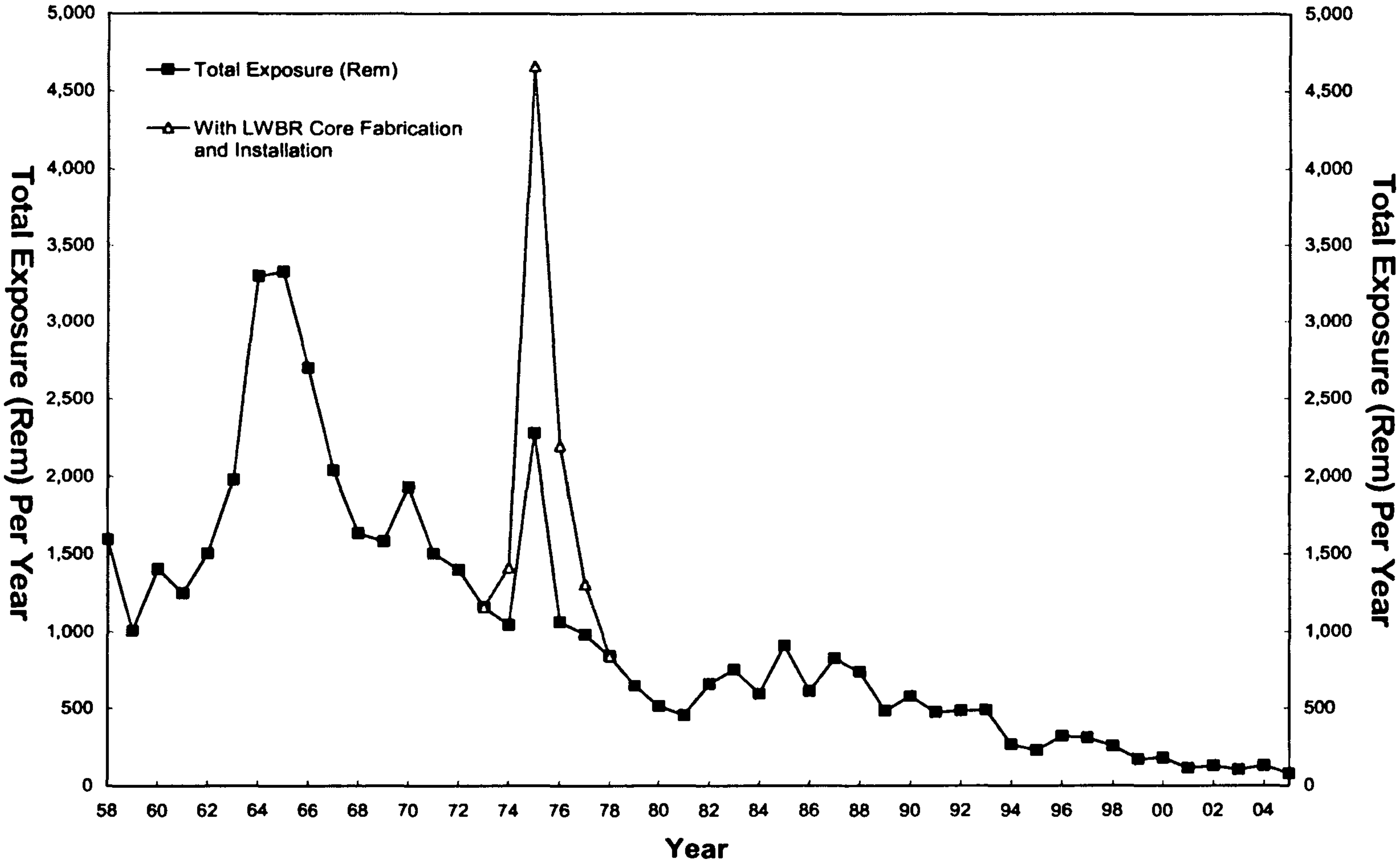
TABLE 1

INITIAL LABORATORY AND PROTOTYPE OPERATIONS

Location	Year Initial Operations Began Involving Radioactive Work
Bettis Atomic Power Laboratory West Mifflin, Pennsylvania	1950
Knolls Atomic Power Laboratory Schenectady, New York	1950[1]
Naval Reactors Facility Idaho Falls, Idaho	1953
Kenneth A. Kesselring Site Ballston Spa, New York	1955
Windsor Site Operation Windsor, Connecticut	1959[2]
Shippingport Atomic Power Station Beaver Falls, Pennsylvania	1957[3]
Bechtel Plant Machinery, Incorporated – Pittsburgh Monroeville, Pennsylvania	N/A[4]
Bechtel Plant Machinery ,Incorporated – Schenectady Schenectady, New York	N/A[4]

1. Naval Reactors Program work began at Knolls Atomic Power Laboratory in 1950. Non-Naval Reactors Program isotope separations process research work was performed at Knolls on behalf of the Atomic Energy Commission from 1947 through 1953.
2. In 1993, training operations at the Windsor Site Operation prototype stopped and the dismantlement of the prototype and support facilities began. Dismantlement was completed in 2000.
3. Shippingport Atomic Power Station was shut down in 1982 and turned over to another Department of Energy office for dismantlement in 1984. Dismantlement was completed in 1989.
4. No work involving radioactive materials is performed by Bechtel Plant Machinery, Incorporated. The small amount of radiation exposure received by personnel at these facilities is the result of visits to other Program facilities. Bechtel Plant Machinery, Incorporated – Schenectady, formerly known as Bechtel Machinery Apparatus Operation, was previously operated by Westinghouse and General Electric. Bechtel Plant Machinery, Incorporated – Pittsburgh, formerly known as Bechtel Plant Apparatus Division, was previously operated by Westinghouse.

FIGURE 1
TOTAL RADIATION EXPOSURE RECEIVED BY PERSONNEL AT NAVAL REACTORS' DEPARTMENT OF ENERGY FACILITIES
1958 - 2005



EXTERNAL RADIATION EXPOSURE

Policy and Limits

The policy of the Naval Reactors Program is to reduce exposure to personnel from ionizing radiation associated with Naval Reactors' Department of Energy facilities to a level as low as reasonably achievable.

Prior to 1960, the Federal radiation exposure limit used in the U.S. for whole body radiation was 15 rem[1] per year. From 1960 to 1994, the Federal radiation exposure limits used in the U.S. for whole body radiation exposure were 3 rem per quarter and 5 rem accumulated dose for each year beyond age 18. These limits were recommended in 1958 by the U.S. National Committee ("Committee" was changed to "Council" when the organization was chartered by the U.S. Congress in 1964) on Radiation Protection and Measurements (reference 1)[2] and by the International Commission on Radiological Protection (reference 2). They were adopted by the U.S. Atomic Energy Commission (AEC) and applied both within the AEC and to licensees in 1960 (reference 3). On May 13, 1960, President Eisenhower approved the U.S. Federal Radiation Council recommendation that these limits be used as guidance for Federal agencies (reference 4). A key part of each of these standards has been emphasis on minimizing radiation exposure to personnel.

In 1965, the International Commission on Radiological Protection (reference 5) reiterated the quarterly and accumulated limits cited above, but suggested that exceeding 5 rem in 1 year should be infrequent. Although none of the other organizations referred to above changed their recommendations, the Naval Reactors Program adopted 5 rem per year as a rigorous limit, effective in 1967.

In 1971, the National Council on Radiation Protection and Measurements (reference 6) recommended that 5 rem be adopted as the annual limit under most conditions. In 1974 the Atomic Energy Commission AEC (now the Department of Energy) (reference 7) established 5 rem as its annual limit. In 1977, the International Commission on Radiological Protection (reference 8) deleted the accumulated limit and recommended 5 rem as the annual limit. In 1979, the Nuclear Regulatory Commission (NRC) issued a proposed change to the Code of Federal Regulations, Title 10, Part 20, to require its licensees to use 5 rem as an annual limit. On January 20, 1987, revised guidance for Federal agencies was approved by President Reagan that eliminated the accumulated dose limit discussed above and established a 5 rem per year limit for occupational radiation exposure (reference 9). The Nuclear Regulatory Commission revised the Code of Federal Regulations, Title 10, Part 20, making the 5 rem annual limit effective on January 1, 1994.

The Naval Reactors Program radiation exposure limits since 1967 have been:

3 rem per quarter
5 rem per year

Special higher limits are in effect, such as those for hands and feet; however, there have been few cases where these limits have been more restrictive than the whole body

1. 1 rem = 0.01 Sievert
2. References are listed on pp. 51-53.

radiation exposure limits. Therefore, the radiation exposures discussed in this report are nearly all from whole body radiation. Controls are also in effect to minimize any occupational radiation exposure to the unborn child of a pregnant worker.

Each Naval Reactors' Department of Energy facility is required to have an active program to keep radiation exposure as low as reasonably achievable.

Sources of Radiation at Prototypes and Naval Reactors Facility

One of the Naval Reactors Department of Energy sites operates two prototype naval nuclear propulsion plants (Kesselring Site Operation, Ballston Spa, New York). This facility is engaged in testing nuclear propulsion plants for the U.S. Navy and training U.S. Navy propulsion plant operators. The other site [the Naval Reactors Facility on the Idaho National Laboratory (INL) site near Idaho Falls, Idaho] has prototype plants that have been inactivated. The Naval Reactors Facility also houses the Expended Core Facility. Personnel at the Expended Core Facility receive, examine, and prepare spent naval fuel modules for transfer to the Idaho Nuclear Technology Engineering Center, and prepare spent fuel for long-term storage in a geological repository. The Expended Core Facility also examines the Naval Reactors Program's irradiated material samples from the INL's Test Reactor Area.

The radiation exposures at the prototype sites originate primarily from pressurized water reactors. Water circulates through a closed piping system to transfer heat from the reactor core to a secondary steam system isolated from the reactor cooling water. Trace amounts of corrosion and wear products are carried by reactor coolant from reactor plant metal surfaces. Some of these corrosion and wear products are deposited on the reactor core and become radioactive from exposure to neutrons. Reactor coolant carries some of these radioactive products through the piping systems where a portion of the radioactivity is removed by a purification system. Most of the remaining radionuclides transported from the reactor core deposit in the piping systems.

The reactor core is installed in a heavy-walled pressure vessel within a primary shield. This shield limits radiation exposure from the gamma and neutron radiation produced when the reactor is operating. Reactor plant piping systems are installed primarily inside a reactor compartment that is itself surrounded by a secondary shield. Access to the reactor compartment is permitted only after the reactor is shut down. Most radiation exposure to personnel comes from inspection, maintenance, and repair inside the reactor compartment. The major source of this radiation is cobalt-60 deposited inside the piping systems. Cobalt-60 emits two high-energy gamma rays and a low-energy beta particle for every radioactive decay. Its half-life is 5.3 years.

Neutrons produced when reactor fuel fissions are also shielded from occupied areas by the primary and secondary shields. Radiation exposure to personnel from these neutrons during reactor operation is much less than from gamma radiation. After reactor shutdown, when maintenance and other support work is done, no neutron exposure is detectable. Therefore, the radiation exposures at prototypes are primarily from gamma radiation.

Radiation exposure at the Expended Core Facility is also due to gamma radiation emitted by irradiated reactor fuel and structural components that were inside the reactor vessel during operation and became radioactive by exposure to neutrons. Work on these components is performed remotely in either specially designed shielded cells or in deep water pits where many feet of water shield personnel.

Exposures listed in this report for prototype personnel include Department of Energy employees and contractors as well as exposure to Navy staff and students involved in training at the sites. The majority of the total radiation exposure for the Kesselring Site Operation is due to large numbers of Navy students who receive low doses associated with operating a naval nuclear propulsion plant. Since student training at the Naval Reactors Facility ended in 1995, the majority of radiation exposure there is due to work associated with shielded reactor fuel and servicing reactor fuel shipping containers.

In 2005, radiation exposure at the prototypes and Naval Reactors Facility was 64.5 rem. This is a decrease of 46.7 rem from 2004. This decrease was expected, because most of the major maintenance period on one of the prototypes at the Kesselring Site was completed in 2004.

Sources of Radiation at Laboratories

The two Naval Reactors' laboratories (Bettis Atomic Power Laboratory, near Pittsburgh, Pennsylvania; and Knolls Atomic Power Laboratory, near Schenectady, New York) conduct research and development work on improved nuclear propulsion plants for U.S. Navy warships. At the laboratories, external radiation exposure is attributable to examination and analysis of irradiated materials and fuel. Gamma radiation is the significant contributor to dose. Although alpha and beta radiation are present, they are generally well shielded. Neutron radiation contributes very little to doses at the laboratories.

Irradiated materials include mixed fission products and activation products. The activation products are identical to those discussed in the preceding section. Fission products are the radioactive species produced by the fissioning of nuclear fuel. Fission products generally emit both beta and gamma radiation and have half-lives ranging from hours to many years. In cases where these materials emit significant levels of radiation, the analyses and examinations are performed remotely using special tooling in shielded cells similar to those used at the Expended Core Facility. With regard to fuel, the preparation of fuel specimens involves the handling of unirradiated uranium. The dose rates from these materials are generally low. Irradiated fuel specimens are handled in the shielded cells.

Radiation exposures for the Shippingport Atomic Power Station are also included under the heading for laboratory personnel. The sources of radiation exposure at Shippingport were similar to those at the prototype sites. From 1974 to 1977, the Bettis Atomic Power Laboratory fabricated and installed the Light Water Breeder Reactor (LWBR) core for Shippingport. The fissile fuel for this core was uranium-233 and the fertile fuel was thorium-232. Enriched uranium-233 contains a significantly higher level of uranium-232 than enriched uranium-235. The radioactive decay chain of uranium-232, in turn, includes thallium-208, which emits a high-energy gamma ray with each decay; accordingly, the radiation exposure of personnel fabricating the LWBR core was much higher than for those fabricating traditional uranium-235 cores. In addition to fabrication, there was also significant radiation exposure due to LWBR installation inside the Shippingport powerplant.

Also included under the laboratory heading is the small amount of exposure to personnel assigned to the two Naval Reactors' Department of Energy nuclear component engineering and procurement organizations (Bechtel Plant Machinery, Incorporated – Pittsburgh, near Monroeville, Pennsylvania, and Bechtel Plant Machinery, Incorporated - Schenectady, near Schenectady, New York). In 2005, personnel at these facilities received a combined total of about 2.96 rem of occupational radiation exposure. Since no radioactive material is handled at these facilities, this exposure is the result of visits to other Naval Reactors Program activities where U.S. naval nuclear-powered ships are built and maintained.

In 2005, the total radiation exposure at the Naval Reactors' Department of Energy laboratories was 14.6 rem. This is a decrease of 4.7 rem from 2004.

Control of Radiation

Reactor plant shielding is designed to minimize radiation exposure to personnel. Shield design criteria establishing radiation levels in various parts of each prototype are personally approved by the Director, Naval Nuclear Propulsion. The director also personally approved the shield design criteria for the Shippingport Atomic Power Station.

Prototype design is also controlled to keep locations such as duty stations, where personnel need to spend time, as far as practicable away from the reactor compartment shield. In addition, radiation outside propulsion plant spaces during reactor plant operation is not generally any greater than natural background radiation.

Laboratories, prototype sites, and the Expended Core Facility are designed so that radioactive material outside of reactor plants is handled only in specially designed and shielded facilities. Naval Reactors' Department of Energy facilities minimize the number of places where radioactive material is allowed. Stringent controls are in place during the movement of all radioactive material. A radioactive material accountability system is used to ensure that no radioactive material is lost or misplaced in a location where personnel could unknowingly be exposed. Regular inventories are required for every item in the radioactive material accountability system. Radioactive material is tagged with yellow and magenta tags bearing the standard radiation symbol and the measured radiation level. Radioactive material has to be placed in yellow plastic, the use of which is reserved solely for radioactive material. All personnel assigned to Naval Reactors' Department of Energy facilities are trained to recognize that yellow plastic identifies radioactive material and to initiate immediate action if radioactive material is discovered out of place.

Access to radiation areas is controlled by posted signs and barriers. Personnel are trained in the access requirements, including the requirement to wear dosimetry devices to enter these areas. Dosimetry devices are also posted near the boundaries of these areas to verify that personnel outside these areas do not require monitoring. Frequent radiation surveys are required, using instruments that are checked before use and calibrated regularly. Areas where radiation levels are greater than 0.1 rem per hour are called "high radiation areas" and are locked or guarded. Compliance with radiological controls requirements is checked frequently by radiological controls personnel, as well as by other personnel not affiliated with the radiological controls organization.

Dosimetry

Thermoluminescent dosimeters (TLDs) are worn by personnel to measure their exposure to gamma, neutron, and beta radiation. (Before 1975, film badges were used, as described below.) The TLDs used at the prototypes contain two chips of calcium fluoride with added manganese. The TLDs used at the laboratories contain four chips of lithium fluoride. It is characteristic of thermoluminescent material that radiation causes internal changes that make the material, when subsequently heated, give off an amount of light directly proportional to the radiation dose.

Since the types of radiation to which personnel are exposed are different at the laboratories than at the prototypes and the Expended Core Facility, the design of the dosimeters is also different. At the prototypes and the Expended Core Facility, because the source of radiation exposure is high-energy gamma radiation, calcium fluoride TLDs are used. At the laboratories, high- and low-energy gamma radiation and beta radiation are present; therefore, lithium fluoride TLDs are used. Lithium fluoride TLDs were worn in addition to calcium fluoride TLDs at the Expended Core Facility from 1985 until 1998, when a review of monitoring data identified that the low-energy gamma and beta radiation doses were negligible compared to doses requiring monitoring by Federal standards; therefore, monitoring with lithium fluoride TLDs was determined to be no longer necessary for routine work. Shippingport used dosimeters similar to the ones used at the prototypes. At all facilities, separate TLDs are used for the few applications where neutron monitoring is required.

The calcium fluoride TLDs used at the prototypes and the Expended Core Facility are designed such that the two calcium fluoride chips are in contact with a metallic heating strip with heater wires extending through the ends of a surrounding glass envelope. The glass bulb is protected by a plastic case designed to permit the proper response to gamma radiation of various energies. The lithium fluoride TLDs used at the laboratories are designed such that the four lithium fluoride chips are encapsulated in teflon and mounted into pre-drilled holes in an aluminum card.

The calcium fluoride TLDs are processed (that is, read) manually. A trained operator removes the glass bulb from the plastic case and puts it in a TLD reader, bringing the metal heater wires into contact with an electrical circuit. An electronically controlled device heats the calcium fluoride chips to several hundred degrees Celsius in a timed cycle, and the intensity of light emitted is measured and converted to a digital readout in units of rem. The heating cycle also anneals the calcium fluoride chips so that the dosimeter is zeroed and ready for subsequent use. The entire cycle of reading a TLD described here takes about 30 seconds.

The laboratories' lithium fluoride TLDs are read automatically: the operator can load as many as 1,400 lithium fluoride cards into the reader, and the TLD reader automatically reads one TLD card at a time. To read the radiation exposure from the lithium fluoride TLDs, the operator removes the aluminum cards from the plastic cases and places them in cartridges that are loaded into the microprocessor-controlled TLD reader. To start the read process, one TLD card is automatically removed from the cartridge and moved to the read position where the bar code is scanned. The four chips are then simultaneously heated to several hundred degrees Celsius using four precisely temperature-controlled streams of hot nitrogen gas. When heated, the lithium fluoride TLDs (like the calcium fluoride TLDs) give off light in proportion to the radiation they received. The light is converted to a graphic and digital readout, as well as digitally stored on a computer hard disk. This heating cycle also anneals the TLD chips so that the dosimeter is zeroed and ready for subsequent use. After readout, the TLD is then automatically moved to a removal cartridge. The entire read cycle for one card takes, on the average, 30 seconds. After processing, the computer converts the light output to dose in units of rem.

The rapid readout of the calcium fluoride and lithium fluoride TLDs was one reason for changing from film badges to TLDs. Processing film badges was a time-consuming chemical process; TLDs permit more frequent measurement of a worker's radiation exposure than film badges did. TLDs are processed at least quarterly, and for those individuals who are expected to receive higher exposures, at least monthly. For those who enter a reactor compartment, the TLDs are processed daily.

To ensure accuracy of the TLD systems, periodic calibration and accuracy checks are performed. For example, all TLDs are checked when new. In addition, the lithium fluoride TLDs are checked, at a minimum, once a year for accurate response to known exposures; the calcium fluoride TLDs are checked, at a minimum, once every 9 months. The calcium fluoride TLD readers are calibrated once a year by one of several calibration facilities, using precision radiation sources directly traceable to the National Institute of Standards and Technology (NIST) and precision TLD standards. The lithium fluoride readers are calibrated to a local source at least once a week, and to a calibration source directly traceable to NIST every 2 years. In addition, checks on the readers are performed daily and during the reading of TLDs to ensure proper reader operation and accuracy, using both an internal electronic standard (built into each reader) and quality control dosimeters that have been exposed to a known exposure level.

In addition to these calibrations and checks, the laboratories and prototypes have an independent quality assurance program to monitor the accuracy of TLDs and the TLD readers in use. TLDs are pre-exposed to exact amounts of radiation by NIST or one of the laboratories and provided to the prototype and/or laboratory for reading. To ensure objectivity, the prototype or laboratory being tested is not told of the radiation values to which each dosimeter has been exposed. The results are then compared to the actual exposures. If these tests find any inaccuracies that exceed established permissible error, appropriate corrective action (such as recalibration of a failed TLD reader) is taken immediately. In addition, the laboratories participate in nationwide intercomparison studies as they are conducted. The results of this program demonstrate that the radiation to which personnel are exposed is being measured by the TLD system with an average error of less than 10 percent.

Although, the official record of radiation exposure is obtained from the TLD, pocket ionization chambers with an eyepiece permit wearers to read and keep track of their own radiation exposure during a work period. This pocket dosimeter is required in addition to a TLD when entering a reactor compartment or other high radiation area..

Dosimetry devices are worn on the trunk of the body, normally at the waist or chest. In some special situations, additional dosimeters are worn at other locations (for example, on the hands, fingers, or head).

Discrepancies that occur between TLD and pocket dosimeter measurements are investigated. These investigations include making independent, best estimates of the worker's exposure, using such methods as time spent in the specific radiation area and comparing the estimates with the TLD and pocket dosimeter measurements to determine which measurement is the more accurate.

In 1975, the conversion from film badges to TLDs for measuring radiation exposure was completed. Before 1975, film packets like those used for dental x rays were placed in holders designed to allow differentiating between types of radiation. The darkness of the processed film was measured with a densitometer and converted to units of radiation exposure. When the first personnel radiation exposures were measured by Naval Reactors' Department of Energy facilities, there already was widespread photodosimetry experience and precise procedures existed to provide reproducible results.

Each film badge was clearly marked with a name or number corresponding to the individual to whom it was assigned. In high radiation areas every worker also wore a pocket dosimeter, which was read when the worker left the area. At the end of each month when the film badges were processed, the film badge measurements were compared with the sum of the pocket dosimeter readings.

For about 20 years, neutron monitoring at the Naval Reactors' Department of Energy facilities was performed using neutron film badges. These facilities now use lithium fluoride TLDs to monitor neutron exposure of the few personnel exposed to neutron sources, such as for radiation instrument calibration and for reactor plant instrumentation source handling. These measured neutron exposures have been included with gamma radiation exposures in the total whole body radiation exposure discussed in this report; but because neutron exposures are so low, the radiation exposures in this report are nearly all from gamma radiation.

Because personnel at the laboratories can be exposed to both gamma and beta radiation, beta monitoring has been routinely performed using film badges or lithium fluoride TLDs. Monitoring for beta radiation is not normally required at the prototypes, because beta radiation does not penetrate the metal boundaries of the reactor coolant system. Beta radiation needs to be considered in maintenance or repair operations at the prototypes only when systems are opened and personnel are close to surfaces that have been contaminated with radioactive corrosion products from reactor coolant. At the Expended Core Facility, certain remediation operations involve exposure to beta radiation, which may require beta monitoring with lithium fluoride TLDs. In cases where shielding such as clothing, eyeglasses, or plastic contamination control materials can be used to effectively shield the individual from beta radiation, personnel are not monitored for beta radiation. In those cases where the beta radiation cannot be shielded, prototype and Expended Core Facility personnel are monitored with lithium fluoride TLDs provided by the laboratories.

Monitoring for personnel external exposure due to alpha radiation is not performed. Alpha radiation does not penetrate past the dead layer of a person's skin and therefore does not contribute to an individual's external radiation dose.

Physical Examinations

Radiation medical examinations have been required since the beginning of operations by Naval Reactors' Department of Energy facilities for personnel who perform work involving radioactive contamination or who could exceed in 1 year the maximum exposure allowed to a member of the general public (i.e., 0.1 rem). These examinations are conducted in accordance with standard protocols. In these examinations the doctor pays special attention to any condition that might medically disqualify a person from receiving occupational radiation exposure or pose a health risk or safety hazard to the individual or to co-workers, or detrimentally affect the safety of the workplace.

Passing this examination is a prerequisite for obtaining dosimetry, which permits entry to radiation and radiologically controlled areas and allows handling of radioactive material. Few of the military personnel who have already been screened by physical examinations fail this radiation medical examination. For civilian workers, the failure rate is a few percent. However, failure of this examination does not mean a worker will not have a job. Because workers spend most of their time performing non-radioactive work, an inability to qualify for radioactive work does not mean they cannot work at the facility in any capacity. No worker at Naval Reactors' Department of Energy facilities has been released solely for inability to pass a radiation medical examination.

When required, radiation medical examinations are given prior to initial work, periodically thereafter, and at termination of radioactive work in the Naval Reactors Program (or at termination of employment). The periodic examinations are conducted in accordance with the following frequencies:

Age	Interval
18-24	Pre-placement
25-49	every 5 years
50-59	every 2 years
≥60	annually

A radiation medical examination includes a review of medical history to determine (among other things), past radiation exposure, history of cancer, history of radiation therapy, and family history of cancer. In the medical examination, particular attention is paid to evidence of cancer or a pre-cancerous condition. Laboratory procedures include urinalysis, blood analysis, and comparison of blood constituents to a specific set of standards. If an examination disqualifies an individual, the individual is restricted from receiving occupational radiation exposure.

Radiological Controls Training

Periodic radiological controls training is performed to ensure that all workers understand (a) the general and specific radiological conditions which they might encounter, (b) their responsibility to the Naval Reactors Program and the public for safe handling of radioactive materials, (c) the risks associated with radiation exposure, and (d) their responsibility to minimize their own radiation exposure. Training is also provided on the biological risk of radiation exposure to the unborn child. Before being authorized to perform radioactive work, an employee is required to pass a radiological controls training course, including a written examination. A typical course for workers ranges from 16 to 32 hours. In written examinations on radiological controls, short answer questions (such as multiple choice and true-false) are prohibited. The following are the training requirements for a fully qualified worker:

1. Radiation Exposure Control

   a. State the limits for whole body penetrating radiation. Explain that the rem is a unit of biological dose from radiation.

   b. Discuss the importance of the individual keeping track of his/her own exposure. Know how to obtain year-to-date exposure information.

   c. Know that local administrative control levels are established to keep personnel radiation exposure as low as reasonably achievable. Know his/her own exposure control level and who can approve changes to this level.

d. Discuss procedures and methods for minimizing exposure, such as working at a distance from a source, reducing time in radiation areas, and using shielding.

e. Know that a worker is not authorized to move, modify, or add temporary shielding without specific authorization.

f. Discuss potential sources of radiation associated with work performed by the individual's trade.

g. Discuss the action to be taken if an individual loses dosimetry equipment while in a posted radiation or high radiation area.

h. Discuss how to obtain and turn in dosimetry equipment.

i. Know that TLDs must be worn on the portion of the individual's body that receives the highest exposure and that pocket dosimeters are worn at the same location on the body as the TLD. Know that only radiological controls personnel can authorize movement of dosimetry equipment from areas of the body where dosimetry is normally worn (such as the chest or waist) to other areas of the body.

j. Be aware of the seriousness of violating instructions on radiation warning signs and unauthorized passage through barriers.

k. Explain how "stay times" are used.

l. Know that naval nuclear work at a facility has no significant effect on the environment or on personnel living adjacent to the facility.

m. Explain the risk associated with personnel radiation exposure. Know that any amount of radiation exposure, no matter how small, might involve some risk; however, exposure within accepted limits represents a risk that is small compared with normal hazards of life. (The National Council on Radiation Protection and Measurements has stated that while exposures of workers and the general population should be kept to the lowest practicable levels at all times, the presently permitted exposures limit the risk to a reasonable level in comparison to nonradiation risks.) Know that cancer is the main potential health effect of receiving radiation exposure. Know that any amount of radiation exposure to the unborn child, no matter how small the exposure, might involve some risk; however, exposure of the unborn child within accepted limits represents a risk that is small when compared with other risks to the unborn child. Know that the risk to future generations (genetic effect) is considered to be even smaller than the cancer risk and that genetic effects have not been observed in human beings.

n. Know how often an individual shall read his/her pocket dosimeter while in a posted high radiation area. Know that a worker shall leave a posted high radiation area when his/her pocket dosimeter reaches three quarters scale or when a preassigned exposure is reached, whichever is lower.

o. Know that stay times and predetermined pocket dosimeter readings are assigned when working in radiation fields of 1 rem/hour or greater. Know that the worker shall leave the work area when either the assigned stay time or pocket dosimeter reading is reached.

2. Contamination Control

   a. Discuss how contamination is controlled during radioactive work (e.g., containment in plastic bags and use of contamination containment areas). Explain that these controls keep exposure to internal radioactivity at insignificant levels.

   b. Discuss how contamination is detected on personnel.

   c. Discuss how contamination is removed from objects and personnel.

   d. Discuss potential sources of contamination associated with work performed by the individual's trade.

   e. State the surface contamination limits. Discuss the meaning of the units of the limits.

   f. Explain what radioactive contamination is. Explain the difference between radiation and radioactive contamination.

   g. For personnel who are trained to wear respiratory protection equipment, state the controls for use of such equipment. Know that the use of a respirator is based on minimizing inhalation of radioactivity. Know that the respirators used for radiological work are not used for protection in any atmospheres that threaten life or health. Therefore, know that the proper response to a condition in which supply air is lost or breathing becomes difficult is to remove the respirator.

   h. Discuss the required checks to determine whether personnel contamination monitoring equipment is operational before conducting personnel monitoring. Discuss the action to be taken if the checks indicate the equipment is not operating properly.

   i. Discuss the actions to be taken if personnel contamination monitoring equipment alarms while conducting personnel monitoring.

   j. Discuss the procedure to package and remove a contaminated item from a controlled surface contamination area.

   k. Know that if a worker's skin receives radioactive contamination associated with naval nuclear propulsion plants, no health effects are expected.

   l. Discuss the procedures for donning and removing a full set of anticontamination clothing.

3. Accountability of Radioactive Materials: Know that radioactive materials are accounted for when transferred between radiologically controlled areas by tagging, tracking location, and using radioactive material escorts.

4. Waste Disposal

   a. Discuss how individual workers can reduce the amount of radioactive liquid and solid waste generated for the specific type of duties performed.

   b. Discuss the importance of properly segregating of non-contaminated, potentially contaminated, and contaminated material.

   c. Know what reactor plant reuse water is. Discuss the appropriate uses of reactor plant reuse water.

5. Radiological Casualties

   a. Discuss the need for consulting radiological controls personnel when questions or problems occur. Understand the importance of complying with the instructions of radiological controls personnel in the event of a problem involving radioactivity.

   b. Discuss procedures to be followed in the event of a spill of material (liquid or solid) that is or might be radioactive.

   c. Discuss procedures to be followed when notified that airborne radioactivity is above the limit.

   d. Discuss procedures to be followed if a high radiation area is improperly controlled.

   e. Discuss actions to be taken when an individual discovers his/her pocket dosimeter is off-scale or has recorded a higher reading than expected.

6. Responsibilities of Individuals: Discuss actions required in order to fulfill the worker's responsibilities. Discuss the responsibility of the individual to notify the Radiation Health Department or the Medical Department of radiation medical therapy, medical diagnosis involving radioisotopes, open wounds or lesions, physical conditions that the worker feels affect his or her qualification to receive occupational radiation exposure, or occupational radiation exposure from past or current outside employment. Discuss the responsibility of the individual to report to area supervision or radiological controls personnel any condition that might lead to or cause avoidable exposure to radiation.

7. Practical Ability Demonstrations: These demonstrations are performed on a mockup.

   a. Demonstrate the ability to read all types of pocket dosimeters used by the organization.

   b. For applicable workers, demonstrate the proper procedure for donning and removing a full set of anticontamination clothing.

   c. Demonstrate the proper procedures for entering and leaving a high radiation area, a radiologically controlled area, and a control point area, including proper procedures for self-monitoring. Demonstrate the ability to read and interpret posted radiation and contamination survey maps.

d. For applicable workers, demonstrate the ability to properly package and remove an item from a controlled surface contamination area.

e. Demonstrate action to be taken by one or two workers in the event of a spill of radioactive liquid.

f. For personnel who will enter or remain in areas where respiratory protection equipment is required, demonstrate the proper procedure for inspection and use of the type(s) of respiratory equipment the individual will be required to wear as part of mockup training for the job. This includes demonstrating how to don and remove the type of respiratory equipment in conjunction with anticontamination clothing, if anticontamination clothing must be worn with the respiratory equipment. In addition, individuals who are trained to wear air-fed hoods demonstrate the proper response to take if supply air is lost while wearing one.

g. For personnel who are trained to work in contamination containment areas, demonstrate the proper procedures for working in these areas. This demonstration includes a pre-work inspection, transfer of an item into the area, a work evolution in the area, and transfer of an item out of the area.

In addition to passing a written examination, completion of this course requires satisfactory performance during basic types of simulated work operations. To continue as a radiation worker, personnel must requalify in a manner similar to the initial qualification at least every 2 years. Between these qualification periods, personnel are required to participate in a continuing training program, and the effectiveness of that continuing training is tested randomly and often. Training is also conducted by individual shop instructors in the specific job skills for radiation work within each trade. For complex jobs this is followed by special training for the specific job, frequently using mockups outside radiation areas.

Radiological controls technicians are required to complete a 6-12 month course in radiological controls, to demonstrate their practical abilities in work operations and drills, and to pass comprehensive written and oral examinations. Radiological controls supervisors are required to have at least the same technical knowledge and abilities as the technicians; however, passing scores for supervisors' examinations are either higher or more difficult to attain than they are for technicians. Oral examinations, which are conducted by radiological controls managers and senior supervisors, require personnel to evaluate symptoms of unusual radiological controls situations. The radiological controls technician or supervisor is required to evaluate initial conditions, state the immediate corrective actions required, state what additional measures are required, and perform a final analysis of the measurements to identify the specific problem. After qualification, periodic training sessions are required in which all radiological controls technicians and supervisors demonstrate their continued ability to handle situations similar to those covered in the oral examinations. At least every 2½ years, radiological controls personnel must requalify through written and practical abilities examinations similar to those used for initial qualification. Additionally, their first requalification includes an oral examination similar to the one required for initial qualification. Between these qualification periods, radiological controls technicians and supervisors are selected at random for additional written and practical work examinations to assess their retention of knowledge and practical abilities. They also participate in unannounced drills.

In addition to the above training for those who are involved in radioactive work, each person not involved in radioactive work and each person assigned to a prototype (e.g., for training) must receive basic radiological training, which is repeated at least annually. This training is to ensure that personnel understand the posting of radiological areas, the identification of radioactive materials, and not to cross radiological barriers. This instruction also explains that the environment of personnel outside radiation areas and outside the facility is not significantly affected by nuclear work.

Nuclear Power Training

Before being assigned to a prototype naval nuclear propulsion plant for training, military and civilian personnel are required to pass a 6-month basic training course at the Navy's Nuclear Power School in Charleston, South Carolina. While at Nuclear Power School and continuing while at the prototype, these personnel receive extensive radiological controls training, including lectures, demonstrations, practical work, radiological controls drills, and written and oral examinations. This training emphasizes the ability to apply basic information on radiation and radioactivity.

Before becoming qualified as the shift supervisor of a naval nuclear propulsion prototype plant (that is, the senior contractor supervisor on each shift who is responsible for the timeliness and quality of all training conducted by personnel assigned to his or her crew), the shift supervisor candidate must pass several 8-hour written examinations and a sequence of oral examinations. A key part of these qualification examinations is radiological controls.

Before serving as plant manager of a naval nuclear propulsion prototype plant, the prospective plant manager attends a 3-month course at the Naval Reactors Program Headquarters. The radiological controls portion of this course covers advanced topics and assumes that the individual already has detailed familiarity with naval nuclear propulsion plant radiological controls. The prospective plant manager must pass both written and oral examinations in radiological controls during this course before assuming the position of plant manager of a naval nuclear propulsion prototype plant.

Radiation Exposure Reduction

Keeping personnel radiation exposures as low as reasonably achievable involves all levels of management at Naval Reactors' Department of Energy facilities. Operations, maintenance, and repair personnel are required to be involved in this subject; it is not left solely to radiological controls personnel. To evaluate the effectiveness of radiation exposure reduction programs, managers use a set of goals. Goals are established in advance to keep each worker's exposure under certain levels and to minimize the number of workers occupationally exposed to radiation. Goals are also set for the total cumulative personnel radiation exposure for each major job and for the whole year. These goals are deliberately made difficult to meet in order to encourage personnel to improve performance.

Of the various goals used, the most effective in reducing personnel radiation exposure has been the use of exposure control levels, which are lower than the Program's quarterly and annual limits. Control levels at Naval Reactors' Department of Energy facilities range from 0.1 rem to 2 rem for the year (depending on the amount of radioactive work scheduled), whereas 5 rem per year is the Program annual limit.

To achieve the benefits of lower control levels in reducing radiation exposure, it is essential to minimize the number of workers permitted to receive radiation exposure. Otherwise, the control levels could be met merely by adding more workers. Organizations are required to conduct periodic reviews to ensure that the number of workers is the minimum for the work that has to be performed.

The following is a synopsis of the checklist that has been in use for years to keep personnel radiation exposure as low as reasonably achievable during radiological work:

Preliminary Planning

- Plan well in advance
- Delete unnecessary work
- Determine expected radiation levels

Preparation of Work Procedures

- Plan access to and exit from work area
- Provide for service lines (air, welding, ventilation, etc.)
- Provide communication (sometimes includes closed-circuit television)
- Remove sources of radiation
- Plan for installation of temporary shielding
- Decontaminate
- Work in lowest radiation levels
- Perform as much work as practicable outside radiation areas
- State requirements for standard tools
- Consider special tools
- Include inspection requirements (these identify steps where radiological controls personnel must sign before the work can proceed)
- Minimize discomfort of workers
- Estimate radiation exposure

Temporary Shielding

- Control installation and removal by written procedure
- Inspect after installation
- Conduct periodic radiation surveys
- Minimize damage caused by heavy lead temporary shielding
- Balance radiation exposure received in installation against exposure to be saved by installation
- Shield travel routes
- Shield components with abnormally high radiation levels early in the maintenance period
- Shield the work area based on worker body position
- Perform directional surveys to improve design of shielding by locating sources of radiation
- Use mockup to plan temporary shielding design and installation

Rehearsing and Briefing

- Rehearse
- Use mockup duplicating working conditions

- Use photographs
- Brief workers

Performing Work

- Post radiation levels
- Keep excess personnel out of radiation areas
- Minimize beta radiation exposure (anticontamination clothing effectively shields most beta radiation)
- Supervisors and workers keep track of radiation exposure
- Workers assist in radiation and radioactivity measurements
- Evaluate use of fewer workers
- Reevaluate reducing radiation exposures

Since its inception, the Naval Reactors Program has stressed the reduction of personnel radiation exposure. Measures that have been taken to reduce exposure include standardization of procedures, development of new tooling, improved use of shielding, and compliance with strict contamination control measures. For example, most work involving radioactive contamination is performed in total containment. This practice minimizes the potential for spreading contamination and thus reduces work disruptions, simplifies working conditions, and minimizes the cost of and the exposure during cleanup.

Lessons learned during radioactive work and new ways to reduce exposure developed at one organization are made available for use by other organizations in the Naval Reactors Program. This effort allows all of the organizations to take advantage of the experience and developments at one organization and minimizes unnecessary duplication of effort.

The extensive efforts that have been taken to reduce exposure at Naval Reactors' Department of Energy facilities have also had other benefits, such as reduced cost to perform radioactive work and improved reliability. Among other things, detailed work planning, rehearsing, containment, special tools, and standardization have increased efficiency and improved access to perform maintenance. The overall result is improved reliability and reduced costs.

Radiation Exposure Data

The total occupational radiation exposure received by all personnel at Naval Reactors' Department of Energy facilities in 2005 was 79.1 rem. Tables 2 and 3 summarize radiation exposure received at Naval Reactors' Department of Energy facilities since 1958.

Figure 1 (on page 4) shows the total occupational radiation exposure received at Naval Reactors' Department of Energy facilities. The data show major increases in total radiation exposure in 1964 through 1966 and in 1975. In 1964 through 1966, and in 1975 the increase in the exposures was primarily due to an increase in reactor plant overhaul and refueling efforts. Increased occupational exposure occurred in 1974 through 1977 associated with a civil project: the fabrication and installation of the light water breeder reactor (LWBR) at the Shippingport Atomic Power Station. LWBR work was unique because the fuel was uranium-233 rather than uranium-235. In addition to fabrication, there was also increased radiation exposure due to LWBR installation inside the Shippingport power plant.

Decreases in total annual exposures, numbers of personnel monitored, and numbers of personnel with annual exposures over 2 rem have been achieved as a result of continuing efforts to reduce radiation exposures to the minimum practicable. Since 1979, the total annual exposure for the laboratories has averaged less than 37 rem and for all of the prototype sites has averaged about 389 rem.

Since a worker is exposed to radiation usually in more than 1 year, the total number of personnel monitored cannot be obtained by adding the annual numbers. The total number of personnel monitored for radiation exposure associated with Naval Reactors' Department of Energy facilities is about 165,000 (including approximately 97,000 Navy personnel trained as naval nuclear propulsion plant operators at the prototype sites). Table 4 provides further information about the distribution of their radiation exposures. In 2005, more than 99.8 percent of those monitored for radiation received less than 0.5 rem for that year. Since 1958, the average exposure per year for each person monitored has been 0.111 rem—less than the 0.3 rem average annual exposure a person receives from natural background radiation (including the inhalation of radon and its progeny) (reference 10).

Table 4 also lists the numbers of personnel who have exceeded the 3 rem quarterly exposure limit. The total number of persons who have exceeded the quarterly limit since the limit was imposed in 1960 is 14. Of these, 13 personnel had quarterly exposures in the range of 3 to 4 rem, and the person with the highest exposure received 8.1 rem in a quarter; no one has exceeded the quarterly limit since 1973. In none of these cases did personnel exceed the pre-1994 Federal accumulated limit of 5 rem for each year of age over 18, which was also established in 1960. Standard procedures require anyone who receives greater than 25 rem in a short time period to be placed under medical observation. No one at Naval Reactors' Department of Energy facilities has ever reached this level. Since it was adopted in 1967, no one has exceeded Naval Reactors' limit of 5 rem per year for radiation associated with the Naval Reactors Program. The 5 rem per year limit was formally adopted as the Federal limit in 1994.

The average lifetime accumulated radiation exposure for the 165,000 personnel who have been monitored at Naval Reactors' Department of Energy facilities is about 0.314 rem. Although they account for a large portion of the radiation exposure received at the prototype sites each year, the approximately 97,000 Navy personnel trained to date receive a small percentage of their lifetime exposure at the prototype sites. The bulk of their exposure is received later in their naval careers; therefore, their accumulated dose is not representative of the lifetime exposure received by personnel permanently assigned to these facilities. If the Navy trainees are subtracted from the total number of personnel monitored, the average lifetime accumulated exposure from radiation associated with Naval Reactors' Department of Energy facilities is about 1 rem. This radiation exposure is much less than the exposure the average American receives from natural background radiation during his or her working lifetime (reference 10).

TABLE 2
OCCUPATIONAL RADIATION EXPOSURE RECEIVED BY PERSONNEL
MONITORED AT NAVAL REACTORS' DEPARTMENT OF ENERGY LABORATORIES

Year	Number of Persons Monitored Who Received Exposures in the Following Ranges of Rem for the Year						Total Personnel Monitored	Total Exposure (Rem)[1]
	0-1	1-2	2-3	3-4	4-5	>5[2]		
1958	1,923	74	15	20	8	31	2,071	762
1959	2,050	94	21	16	4	0	2,185	586
1960	2,056	105	43	14	4	3	2,225	581
1961	3,717	120	57	27	9	4	3,934	671
1962	3,956	67	38	13	3	1	4,078	414
1963	5,124	135	47	27	6	1	5,340	647
1964	5,195	265	135	127	52	23	5,797	1,854
1965	5,586	188	36	33	2	0	5,845	977
1966	4,493	105	36	12	3	1	4,650	600
1967	5,006	120	52	34	13	0	5,225	668
1968	4,958	96	44	29	16	0	5,143	606
1969	5,589	72	49	42	26	0	5,778	754
1970	6,346	99	61	39	47	0	6,592	819
1971	7,378	109	48	32	5	0	7,572	646
1972	7,000	138	41	17	2	0	7,198	626
1973	6,867	68	7	0	0	0	6,942	368
1974	7,568	96	28	1	1	0	7,694	221 [3]
1975	4,719	290	151	57	68	0	5,285	280 [3]
1976	5,304	371	88	0	0	0	5,763	219 [3]
1977	4,639	81	5	0	0	0	4,725	201 [3]
1978	3,609	10	0	0	0	0	3,619	143
1979	3,367	4	0	0	0	0	3,371	100
1980	3,330	0	0	0	0	0	3,330	78
1981	2,510	0	0	0	0	0	2,510	72
1982	2,672	0	0	0	0	0	2,672	82
1983	2,717	6	0	0	0	0	2,723	93
1984	2,933	1	0	0	0	0	2,934	67
1985	2,338	4	0	0	0	0	2,342	59
1986	2,261	0	0	0	0	0	2,261	35
1987	2,189	0	0	0	0	0	2,189	27
1988	2,029	0	0	0	0	0	2,029	31
1989	2,108	0	0	0	0	0	2,108	31
1990	2,228	0	0	0	0	0	2,228	28
1991	2,216	0	0	0	0	0	2,216	28
1992	2,162	0	0	0	0	0	2,162	25
1993	2,066	0	0	0	0	0	2,066	22
1994	1,894	0	0	0	0	0	1,894	25
1995	1,853	0	0	0	0	0	1,853	30
1996	1,814	0	0	0	0	0	1,814	19
1997	1,795	0	0	0	0	0	1,795	18
1998	1,778	0	0	0	0	0	1,778	15
1999	2,017	0	0	0	0	0	2,017	17
2000	1,970	0	0	0	0	0	1,970	16
2001	1,856	0	0	0	0	0	1,856	14
2002	1,877	0	0	0	0	0	1,877	16
2003	1,862	0	0	0	0	0	1,862	13
2004	1,890	0	0	0	0	0	1,890	19
2005	1,972	0	0	0	0	0	1,972	15

1. Data for 1958-1962 do not include exposure information for personnel monitored at the Shippingport Atomic Power Station. Data are not available in summary format.
2. Limit for Naval Reactors' Department of Energy facilities was changed to 5 rem per year in 1967.
3. Total radiation exposure for 1974 through 1977 does not include exposure received as part of fabrication and installation of the Light Water Breeder Reactor core at the Shippingport Atomic Power Station. If this exposure is included, the totals become 588, 2,660, 1,354, and 524, respectively.

TABLE 3

OCCUPATIONAL RADIATION EXPOSURE RECEIVED BY PERSONNELMONITORED AT NAVAL REACTORS' DEPARTMENT OF ENERGY PROTOTYPE SITES AND NAVAL REACTORS FACILITY

Year	Number of Persons Monitored Who Received Exposures in the Following Ranges of Rem for the Year						Total Personnel Monitored	Total Exposure (Rem)[1]
	0-1	1-2	2-3	3-4	4-5	>5[2]		
1958	2,415	83	77	50	27	3	2,655	833
1959	2,390	63	18	3	1	0	2,475	420
1960	2,558	126	40	28	2	2	2,756	822
1961	2,600	79	42	13	2	0	2,736	576
1962	3,653	185	45	20	8	4	3,915	1,090
1963	4,354	270	74	29	12	0	4,739	1,332
1964	4,940	203	102	65	16	2	5,328	1,446
1965	5,595	267	110	80	73	58	6,183	2,351
1966	5,765	311	145	81	39	7	6,348	2,099
1967	6,409	241	72	35	12	0	6,769	1,372
1968	6,564	172	69	5	0	0	6,810	1,026
1969	5,713	188	57	9	0	0	5,967	827
1970	5,748	215	82	12	0	0	6,057	1,113
1971	5,499	148	26	1	0	0	5,674	856
1972	7,634	116	3	0	0	0	7,753	773
1973	7,518	181	28	0	0	0	7,727	791
1974	8,427	109	20	9	3	0	8,568	824
1975	7,515	270	131	98	83	0	8,097	1,998
1976	8,282	145	19	0	0	0	8,446	845
1977	8,813	101	17	2	0	0	8,933	782
1978	8,890	157	1	0	0	0	9,048	698
1979	9,908	64	0	0	0	0	9,972	546
1980	9,818	11	0	0	0	0	9,829	433
1981	9,679	2	0	0	0	0	9,681	381
1982	10,464	25	0	0	0	0	10,489	576
1983	10,816	77	0	0	0	0	10,893	660
1984	8,694	13	0	0	0	0	8,707	525
1985	9,136	127	0	0	0	0	9,263	851
1986	8,122	35	0	0	0	0	8,157	576
1987	9,021	47	0	0	0	0	9,068	798
1988	8,328	43	0	0	0	0	8,371	707
1989	7,261	12	0	0	0	0	7,273	451
1990	6,548	73	0	0	0	0	6,621	549
1991	6,369	57	0	0	0	0	6,426	444
1992	5,301	125	0	0	0	0	5,426	458
1993	4,934	133	0	0	0	0	5,067	466
1994	4,368	16	0	0	0	0	4,384	241
1995	3,645	0	0	0	0	0	3,645	203
1996[3]	3,221	37	0	0	0	0	3,258	304
1997	3,450	29	0	0	0	0	3,479	295
1998	3,379	27	0	0	0	0	3,406	241
1999	3,448	7	0	0	0	0	3,455	150
2000	3,216	14	0	0	0	0	3,230	165
2001	3,090	13	0	0	0	0	3,103	99
2002	2,947	22	0	0	0	0	2,969	113
2003	2,748	4	0	0	0	0	2,752	90
2004	3,110	18	0	0	0	0	3,128	111
2005	3,279	0	0	0	0	0	3,279	65

1. Data for 1958-1971 do not include Combustion Engineering personnel monitored at the Windsor Site Operation, who did not become employees of KAPL when operation of the Windsor Site was transferred from Combustion Engineering to General Electric.
2. Limit for Naval Reactors' Department of Energy facilities was changed to 5 rem per year in 1967.
3. Student training and prototype operation at NRF ended in 1995.

TABLE 4
NAVAL REACTORS' DEPARTMENT OF ENERGY FACILITIES
DISTRIBUTION OF PERSONNEL RADIATION EXPOSURE

Year	Average Rem Per Person Monitored[1]		Percent of Personnel Monitored Who Received Greater Than 1 Rem[1]		Personnel Who Exceeded 3 Rem/Quarter
	Prototype & NRF	Laboratory	Prototype & NRF	Laboratory	
1958	0.314	0.368	9.0	7.1	0
1959	0.170	0.268	3.4	6.2	0
1960	0.298	0.261	7.2	7.6	1
1961	0.211	0.171	5.0	5.5	0
1962	0.278	0.102	6.7	3.0	1
1963	0.281	0.121	8.1	4.0	0
1964	0.271	0.320	7.3	10.4	2
1965	0.380	0.167	9.5	4.4	1
1966	0.331	0.129	9.2	3.4	1
1967	0.203	0.128	5.3	4.2	1
1968	0.151	0.118	3.6	3.6	0
1969	0.139	0.130	4.3	3.3	0
1970	0.184	0.124	5.1	3.7	5
1971	0.151	0.085	3.1	2.6	1
1972	0.100	0.087	1.5	2.8	0
1973	0.102	0.053	2.7	1.1	1
1974	0.096	0.076	1.6	1.6	0
1975	0.247	0.503	7.2	10.7	0
1976	0.100	0.235	1.9	8.0	0
1977	0.088	0.111	1.3	1.8	0
1978	0.077	0.040	1.7	0.3	0
1979	0.055	0.030	0.6	0.1	0
1980	0.044	0.023	0.1	0.0	0
1981	0.039	0.029	0.0	0.0	0
1982	0.055	0.031	0.2	0.0	0
1983	0.061	0.034	0.7	0.2	0
1984	0.060	0.023	0.1	0.0	0
1985	0.092	0.025	1.4	0.2	0
1986	0.071	0.015	0.4	0.0	0
1987	0.088	0.012	0.5	0.0	0
1988	0.084	0.015	0.5	0.0	0
1989	0.062	0.015	0.2	0.0	0
1990	0.083	0.013	1.1	0.0	0
1991	0.069	0.013	0.9	0.0	0
1992	0.084	0.012	2.3	0.0	0
1993	0.092	0.011	2.6	0.0	0
1994	0.055	0.013	0.3	0.0	0
1995	0.056	0.016	0.0	0.0	0
1996[2]	0.093	0.011	1.1	0.0	0
1997	0.085	0.010	0.8	0.0	0
1998	0.071	0.008	0.8	0.0	0
1999	0.043	0.008	0.2	0.0	0
2000	0.051	0.008	0.4	0.0	0
2001	0.032	0.008	0.4	0.0	0
2002	0.038	0.009	0.7	0.0	0
2003	0.033	0.007	0.2	0.0	0
2004	0.036	0.010	0.4	0.0	0
2005	0.020	0.007	0.4	0.0	0
Average	0.114	0.107	2.3	2.7	0
Overall Average	0.111		2.5		

1. Laboratory data for 1958-1962 do not include exposure information for personnel monitored at the Shippingport Atomic Power Station. Data are not available in summary format. Prototype data for 1958-1971 do not include Combustion Engineering personnel monitored at the Windsor Site Operation, who did not become employees of KAPL when operation of the Windsor Site was transferred from Combustion Engineering to General Electric.
2 Student training and prototype operation at NRF ended in 1995.

Table 5 provides information on the distribution of lifetime accumulated exposures for all personnel who were monitored in 2005 for radiation exposure associated with Naval Reactors' Department of Energy facilities.

TABLE 5

LIFETIME RADIATION EXPOSURE ASSOCIATED WITH NAVAL REACTORS' DEPARTMENT OF ENERGY FACILITIES

Range of Accumulated Lifetime Radiation Exposures (Rem)	Percentage of Personnel Monitored in 2005 with Lifetime Accumulated Radiation Exposure Within that Range
0 – 5	97.33
5 – 10	2.06
10 – 15	0.40
15 – 20	0.11
20 – 30	0.10
30 – 40	0.00
40 – 50	0.00
50 – 60	0.00
> 60	0.00

Until the 1994 changes to the Code of Federal Regulations, Title 10, Part 20, the Federal radiation exposure limits used in the U.S. limited an individual's lifetime exposure to 5 rem for each year beyond age 18. With the 1994 changes, lifetime exposure is not specifically limited, but is controlled as the result of the annual limit of 5 rem. In their most recent radiation protection recommendations, the National Council on Radiation Protection and Measurements (NCRP) recommends that organizations control lifetime accumulated exposure to less than 1 rem times the person's age (reference 11). Among all personnel monitored in 2005, there is currently no worker with a lifetime accumulated exposure greater than the NCRP recommended level of 1 rem times his or her age from radiation associated with the Naval Reactors Program.

INTERNAL RADIOACTIVITY

Policy and Limits

Naval Reactors' policy on internal radioactivity for personnel associated with Naval Reactors' Department of Energy facilities continues to be the same as it was more than five decades ago—to prevent significant radiation exposure to personnel from internal radioactivity. The limits invoked to achieve this objective are one-tenth of the levels allowed by Federal regulations for radiation workers. Radiological work in the Program is engineered to contain radioactivity at the source and keep exposure to airborne radioactivity below levels of concern (i.e., to preclude routine monitoring of personnel to determine internal dose, such that external radiation exposure is the limiting dose to Naval Nuclear Propulsion Program personnel). Since 1972, no one has received more than one-tenth (10 percent) of the Federal annual internal occupational exposure limit from internal radiation exposure caused by radioactivity associated with work at Naval Reactors' Department of Energy facilities. Since 1980, 26 personnel have had internally deposited radioactivity greater than one-thousandth (0.1 percent) of the Federal annual limit on intake (ALI) from radioactivity associated with work at Naval Reactors' Department of Energy facilities or greater than 0.01 millionths of a curie of cobalt-60 (about 0.05 percent of the ALI). The equivalent whole body dose associated with each of these events was less than 0.050 rem (about one-sixth of the average annual radiation exposure a member of the general public receives from natural background sources in the U.S.). Table 6 includes a summary of internal contamination events at Naval Reactors Department of Energy Facilities. Although these occurrences had no adverse impact on the health of the personnel involved, each of these events was thoroughly evaluated to mitigate the potential for recurrence.

Before 1972, two individuals had internal depositions between 50 and 80 percent of the Maximum Permissible Lung Burden (MPLB), and three individuals had internal depositions ranging from 10 to 50 percent of the MPLB[1]; no one had a deposition that exceeded the MPLB. (The MPLB is the level of radioactivity retained in the individual's lung that would result in an exposure to the lung equal to the dose limit for the lung of 15 rem per year if the radioactivity level remained constant throughout the year.) Additionally, one individual received a very high localized exposure to his eardrum in 1955 as a result of a fine particle of radioactive material that became lodged in his ear canal for approximately 9 days. Although there is no explicit limit for radioactivity deposited in a person's ear, this case resulted in partial hearing loss. This case is discussed further on page 48.

As discussed above for the lungs, the basic Federal limit for radiation exposure to organs of the body from internal radioactivity was 15 rem per year prior to 1994. There have been higher levels applied at various times for thyroid and for bones; however, use of these specific higher limits was not necessary at Naval Reactors' Department of Energy facilities.

---

1. One Knolls Atomic Power Laboratory individual was reported to the Department of Energy in 1982 as exceeding 50 percent of the maximum permissible lung burden (MPLB) for the year 1969. In 1988, the Laboratory reassessed this case. The reassessment found that the original internal monitoring analysis, performed by a subcontractor, had a systemic high bias. Taking this high bias into account, the 1988 assessment was that no intake greater than 10 percent of the MPLB had occurred.

For most organs of the body, the limit recommended by the U.S. National Committee on Radiation Protection and Measurements in 1954 (reference 1), by the U.S. Atomic Energy Commission in the initial edition of reference 3 applicable in 1957, and by the International Commission on Radiological Protection in 1959 (reference 2) was 15 rem per year. This limit was adopted for Federal agencies when President Eisenhower approved recommendations of the Federal Radiation Council on May 13, 1960.

In 1977, the International Commission on Radiological Protection revised its recommendations (reference 8), particularly regarding internal exposure. The new recommendations provided a method of combining, and controlling, exposure from internal radioactivity with exposure from external radiation. The effect of the 1977 recommendations was to raise the allowable dose to many organs, with no organ allowed to receive more than 50 rem in a year. In conjunction with these recommendations, more recent knowledge on the behavior and effect of internal radioactivity was used to derive new limits for its control (reference 12). The Federal guidance approved by President Reagan in 1987 adopted these revised recommendations and methods (reference 9), and were incorporated as Federal limits in 1994.

Sources of Radioactivity at Prototypes and Naval Reactors Facility

Radioactivity can get inside the body through air, through water or food, and through surface contamination via the mouth, skin, or a wound. The radioactivity of primary concern at the prototypes is the activated metallic corrosion products on the inside surfaces of reactor plant piping systems. These are in the form of insoluble metallic oxides, primarily iron oxides. Reference 13 contains more details on why cobalt-60 is the radionuclide of most concern for internal radioactivity.

The design specifications for reactor fuel are much more stringent for warships than for commercial power reactors. Naval nuclear propulsion prototype plants are built to the same high standards as nuclear-powered warships. As a result of being designed to withstand the rigor of combat, naval reactor fuel elements retain fission products—including fission gases—within the fuel. Sensitive measurements are frequently made to verify the integrity of reactor fuel. Consequently, fission products such as strontium-90 and cesium-137 make no measurable contribution to internal exposure of personnel from radioactivity associated with naval nuclear propulsion prototype plants. Similarly, alpha-emitting radioisotopes (such as uranium and plutonium) are retained within the fuel elements and are not accessible to personnel operating or maintaining a naval nuclear propulsion prototype plant.

Because of the high integrity of reactor fuel and because soluble boron is not used in reactor coolant for normal reactivity control in naval nuclear propulsion prototype plants, the amount of tritium in reactor coolant is far less than in typical commercial power reactors. The small amount that is present is formed primarily as a result of neutron interaction with the deuterium naturally present in water. The radiation from tritium is of such low energy that the Federal limits for breathing or swallowing tritium are more than 300 times higher than for cobalt-60. As a result, radiation exposure to personnel from tritium is far too low to measure. Similarly, the low-energy beta radiation from carbon-14, which is formed in small quantities in reactor coolant systems as a result of neutron interactions with nitrogen and oxygen, does not add measurable radiation

exposure to personnel operating or maintaining naval nuclear propulsion prototype plants.
At the Expended Core Facility, the radioactivity of primary concern is from radionuclides associated with irradiated nuclear fuel. Highly trained, specialized personnel examine and evaluate the reactor cores removed from U.S. naval nuclear-powered submarines, aircraft carriers, and prototype plants. These evaluations are performed to obtain important technical data to verify and improve the design of nuclear cores. Although the quantity of radioactive material handled is large, advanced personnel radiological training, radiological engineering designs (e.g., shielded cells and special handling equipment), and radiological monitoring programs (e.g., air monitoring systems) prevent any significant internal exposure.

Sources of Radioactivity at Laboratories

The radionuclides of primary concern at the laboratories are those associated with the nuclear fuel process; these include the fuel itself (uranium-234, uranium-235, and uranium-238) and the principal fission products (strontium-90 and cesium-137). Radioactivity with more restrictive limits than the above radionuclides (e.g., thorium and plutonium) is also present at the laboratories, but only in isolated and specially controlled operations. Highly trained, specialized personnel design and test new fuel systems and verify the integrity of existing materials. Laboratory personnel handle only small quantities of fuel. The small quantities handled—coupled with advanced radiological training, radiological engineering designs (e.g., containment boxes), and radiological monitoring programs (e.g., air monitoring systems)—prevent any significant internal exposure.

Residues of the radionuclides described above are present at low levels in some laboratory equipment and facilities that were used for radioactive work in the past. Radiological cleanup is being undertaken to remove these radioactive materials. This effort is carefully controlled the radiological controls techniques followed during this work (e.g., special radiological training, formal procedures, radiological engineering designs) are designed to prevent any significant internal exposure.

Control of Airborne Radioactivity

Airborne radioactivity is controlled during routine operations such that respiratory equipment is not normally required. To prevent exposure of personnel to airborne radioactivity, contamination containment tents, bags, or boxes are used. These containments are ventilated to the atmosphere through high-efficiency filters that have been designed and tested to remove at least 99.95 percent of particles of a size comparable to cigarette smoke. Radiologically controlled areas such as reactor compartments are also required to be ventilated through high-efficiency filters whenever work that could cause airborne radioactivity is in progress. Airborne radioactivity surveys are required to be performed regularly in radioactive work areas. If airborne radioactivity above the limit is detected in occupied areas, work that might be causing airborne radioactivity is immediately stopped. This conservative action is taken to minimize internal radioactivity even though the Naval Reactors' airborne radioactivity limit would allow continuous breathing for 40 hours per week throughout the year to reach an annual exposure of one-tenth the Federal limit. Personnel are also trained to use respiratory equipment when airborne radioactivity above the limit is detected.

However, respiratory equipment is seldom needed and is not relied upon as the first line of defense against airborne radioactivity.

It is not uncommon for airborne radioactivity to be caused by radon naturally present in the air. Atmospheric conditions such as temperature inversions can allow the buildup of radioactive particles from radon. Radon can also build up in sealed or poorly ventilated rooms in homes or buildings made of stone or concrete, or it can migrate from the underlying ground. In fact, most cases of airborne radioactivity above Naval Reactors' conservative airborne radioactivity limit in occupied areas have been caused by atmospheric radon, which has a higher airborne concentration limit, and not from prototype plant or laboratory operations. Procedures have been developed to reduce the radon levels when necessary and to allow work to continue after it has been confirmed that the elevated airborne radioactivity is from naturally occurring radon.

Control of Radioactive Surface Contamination

Perhaps the most restrictive regulations in Naval Reactors' radiological controls program are those for controlling radioactive contamination. Work operations involving potential for spreading radioactive contamination use containments to prevent personnel contamination or the generation of airborne radioactivity. The controls for radioactive contamination are so strict that precautions sometimes have had to be taken to prevent tracking contamination from the world's atmospheric fallout and natural sources outside radiological areas *into* radiological spaces because the contamination control limits used in these areas were below the levels of fallout and natural contamination occurring outside in the general public areas.

Anticontamination clothing, including coveralls, hoods (to cover the head, ears, and neck), shoe covers and gloves, is provided when needed. However, the basic approach is to avoid the need for anticontamination clothing by containing the radioactivity. As a result, most work on radioactive materials is performed with hands reaching into gloves installed in containments, making it unnecessary for the worker to wear anticontamination clothing. In addition to providing better control over the spread of radioactivity, this method has reduced radiation exposure because the worker can usually do a job better and faster in normal work clothing. A basic requirement of contamination control is to monitor all personnel leaving any area where radioactive contamination could occur. Workers are trained to survey themselves (i.e., frisk), and their performance is checked by radiological controls personnel. Upon leaving an area with radioactive surface contamination, frisking of the entire body is required, normally using sensitive hand-held survey instruments. Major work facilities are equipped with portal monitors, which are used in lieu of hand-held friskers. Personnel monitor before, not after, they wash. Therefore, washing or showering at the exit of radioactive work areas is not required. The basic philosophy is to prevent contamination, not wash it away.

Table 6 presents data concerning the number of personnel with detectable radioactive skin contamination since 1980. A radioactive skin contamination is an event where radioactive contamination above the Program's low limit for surface contamination is detected on the skin. In each of these cases the radioactivity was quickly removed with simple methods (e.g., by washing with mild soap and warm water). Since 1980, a total of 194 instances of skin contamination occurred, with only 24 (less than 15 percent of that total) in the last 10 years.

Trained radiological controls personnel frequently survey for radioactive contamination. These surveys are reviewed by senior personnel to doublecheck that no abnormal conditions exist. The instruments used for these surveys are checked against a radioactive calibration source daily and before use, and they are calibrated at least annually.

Control of Food and Water

Smoking, eating, drinking, and chewing are prohibited in radiologically controlled areas. By prohibiting these hand-to-mouth contacts, the possibility of internal contamination is reduced even further.

Wounds

Skin conditions or open wounds, which might not readily be decontaminated, are cause for temporary or permanent disqualification from doing radioactive work. Workers are trained to report such conditions to radiological controls or medical personnel, and radiological controls technicians watch for open wounds when workers enter radioactive work areas. In the initial medical examination prior to radiation work and in subsequent examinations, skin conditions are also checked. If the cognizant local medical officer determines that a wound is sufficiently healed or considers the wound adequately protected, he or she may remove the temporary disqualification.

There have been only a few cases of contaminated wounds at Naval Reactors' Department of Energy facilities. In most years, none occur. Examples of such injuries that have occurred in the past include a scratched hand, a metallic sliver in a hand, a cut finger, and a puncture wound to a hand. These wounds occurred at the same time the person became contaminated. Insoluble metallic oxides that make up the radioactive contamination remain primarily at the wound site rather than being absorbed into the blood stream. Most contaminated wounds have been promptly and easily decontaminated.

Monitoring for Internal Radioactivity at Prototypes and Naval Reactors Facility

The radionuclide of most concern for internal radiation exposure from naval nuclear propulsion prototype plants is cobalt-60. Although most radiation exposure from cobalt-60 inside the body will be from beta radiation, the gamma radiation given off makes cobalt-60 easy to detect. Complex whole body counters are not required to detect cobalt-60 at low levels inside the body. For example, a microcurie (one-millionth of a curie) of cobalt-60 inside the lungs or intestines will cause a measurement of two times above the background reading with the standard hand-held survey instrument used for personnel frisking. This amount of internal radioactivity will cause the instrument to reach the alarm level. Every person is required to monitor the entire body upon leaving an area with radioactive surface contamination. Monitoring the entire body (not just the hands and feet) is a requirement at Naval Reactors' Department of Energy facilities. Therefore, if a person had as little as a microcurie of cobalt-60 internally, it would readily be detected.

Swallowing a microcurie of cobalt-60 will cause internal radiation exposure to the gastro-intestinal tract of about 0.08 rem. The radioactivity will pass through the body and be excreted within a period of a little more than a day. Since 1994, Federal regulations limit organ exposure from internal radioactivity to 50 rem per year.

A microcurie of cobalt-60 still remaining in the lungs 1 day after an inhalation incident is estimated to cause a radiation exposure of about 2 rem to the lungs over the following year and 6 rem total over a lifetime, based on standard calculations recommended by the International Commission on Radiological Protection (reference 12). These calculations provide a convenient way to estimate the radiation exposure a typical individual might be expected to receive from small amounts of internally deposited radioactivity. These techniques account for the gradual removal of cobalt-60 from the lungs through biological processes and the radioactive decay of cobalt-60, which has a half-life of 5.3 years. However, if an actual case were to occur, the measured biological elimination rate would be used in determining the amount of radiation exposure received.

In addition to the control measures to prevent internal radioactivity and the frisking frequently performed by those who work with radioactive materials, more sensitive internal monitoring is also performed. Equipment designed specifically for monitoring internal radioactivity uses a type of gamma scintillation detector that will reliably detect inside the body an amount of cobalt-60 more than 100 times lower than the a microcurie used in the examples above. Naval Reactors' prototype sites and the Naval Reactors Facility monitor each employee for internal radioactivity before initially performing radiation work, after terminating radiation work, and periodically in between.

Anyone at the prototype or Naval Reactors Facility who has radioactive contamination above the limit anywhere on the skin during regular monitoring at the exit from a radiologically controlled area is monitored for internal radioactivity with the sensitive internal monitoring equipment. Also, anyone who might have breathed airborne radioactivity above limits is monitored with the sensitive equipment.

Internal monitoring equipment is calibrated each work shift the equipment is in use. This calibration involves checking the equipment's response to a known source of radiation. In addition, Naval Reactors has an independent quality assurance program in which prototype organizations that perform internal monitoring are tested periodically. This testing involves monitoring a human-equivalent torso phantom, which contains an amount of radioactivity traceable to standards maintained by the National Institute of Standards and Technology. The exact amount of radioactivity in the test phantom is not divulged to the organization being tested until after the test is complete. Any inaccuracies found by these tests that exceed established permissible error limits are investigated and corrected.

<u>Monitoring for Internal Radioactivity at Laboratories</u>

The radionuclides of most concern for internal radiation exposure from laboratory operations include uranium isotopes (uranium-234, uranium-235, and uranium-238) and fission products (primarily strontium-90 and cesium-137). Uranium isotopes are principally alpha emitters. Alpha particles deposit their energy over a much shorter distance than beta or gamma rays because alpha particles are considerably larger in size and have a much greater charge. Fission products emit beta and gamma radiation similar to cobalt-60.

Although uranium-235 is principally an alpha emitter, it also emits several low-energy gamma rays. Thorium-234 (a daughter of uranium-238) also emits low-energy gamma radiation. This low-energy radiation can be detected with sensitive gamma scintillation or semiconductor detectors. For internal monitoring, each laboratory employs a state-of-the-art low-energy gamma radiation detection system in a shielded enclosure. These systems are designed to detect levels of uranium in the lungs at levels less than one billionth of a curie. In addition, other systems allow for the detection of higher energy, gamma radiation emitting fission products such as cesium-137 at roughly the same sensitivity as uranium-235. In addition to this type of internal exposure monitoring, personnel who work with certain forms of radioactivity are also required periodically to submit urine samples for extremely sensitive radionuclide analysis. Fecal analysis is also sometimes performed as discussed below. As a measure of the sensitivity of laboratory internal monitoring techniques, the systems used to measure radioactivity in urine and fecal samples can measure one ten-trillionth of a curie per liter for urine and one trillionth of a curie per gram for feces. The dose that corresponds to these levels is less than 0.015 rem to the lungs over the following year and 0.075 rem over a lifetime, when monitoring is conducted within 24 hours of a potential internal exposure event.

The laboratories require personnel to be internally monitored before initially assuming duties involving radiation exposure, upon terminating from such duties, and periodically in between. The frequency at which personnel are monitored is determined by their assigned duties: the more often they work with radioactive materials, the more often they are monitored. In addition, like the prototype sites, any person who has radioactive contamination above the limit anywhere on the skin or who might have been exposed to airborne radioactivity above the limit is immediately monitored with the sensitive detector system; these individuals are also required to submit urine and fecal samples (as appropriate) for the radionuclides involved.

Internal monitoring equipment is calibrated and the calibration is checked each day the equipment is in use. This process involves checking the equipment's response to a known source of radiation. In addition, background checks are performed daily during equipment use to further verify system performance.

Although internal monitoring is routinely performed at Naval Reactors' Department of Energy facilities, internal monitoring results are not used to control personnel radiation exposure below limits. Rather, work is engineered to prevent radioactivity from becoming internally deposited, and the monitoring is performed to verify that.

Results of Internal Monitoring in 2005

During 2005, a total of 2,348 personnel were monitored for internally deposited radioactivity. There was one internal contamination event at Naval Reactors' Department of Energy facilities during 2005, in which nine personnel monitored had internally deposited radioactivity detected greater than one-thousandth (0.1 percent) of the Federal annual limit on intake (ALI) from radioactivity. These personnel were exposed to a small localized release of airborne radioactivity contained inside a work facility at the Bettis Atomic Power Laboratory while performing decontamination and decommissioning work of a facility used to fabricate Shippingport Atomic Power Station fuel. The assigned Committed Effective Dose Equivalents resulting from this event ranged from 0.007 to 0.049 rem, which is still less than 1 percent of the Federal limit.

Table 6 includes a summary of radioactive skin contamination occurrences and internal deposits of radioactivity at Naval Reactor's Department of Energy facilities. Radioactive skin contaminations that have occurred over the years involved low levels of radioactive contamination associated with maintenance operations at prototype sites and from laboratory operations. Skin doses associated with these occurrences are well below Federal limits. Occurrences of internally deposited radioactivity at Naval Reactors' Department Of Energy facilities over the years have involved the uptake of very low levels of radioactivity. In each case, the resulting exposure to the individual has been less than 1 percent of the corresponding Federal limit.

Table 6
Occurrences of Personnel Radioactive Skin Contaminations and Internal Radioactivity Depositions

	Radioactive Skin Contaminations		Internally Deposited Radioactivity[1]	
Year	Prototypes and NRF	Laboratories	Prototypes and NRF	Laboratories
1980	15	4	0	0
1981	22	6	1	1
1982	18	4	0	0
1983	8	4	0	0
1984	5	2	0	0
1985	19	2	8	0
1986	7	6	0	0
1987	13	4	0	0
1988	9	1	1	0
1989	3	0	0	0
1990	2	1	0	0
1991	3	2	0	0
1992	2	1	0	0
1993	1	2	0	3
1994	3	1	0	0
1995	2	2	0	0
1996	2	3	0	0
1997	2	2	0	0
1998	2	0	0	0
1999	1	0	0	0
2000	0	0	0	0
2001	2	2	0	2
2002	1	1	0	1
2003	0	1	0	0
2004	0	1	0	0
2005	0	2	0	9

1 This table includes occurrences of internally deposited radioactivity that resulted in greater than a tenth of a percent (0.1 percent) of the Federal ALI from radioactivity associated with work at Naval Reactors' Department of Energy facilities or greater than 0.01 millionths of a curie of cobalt-60 (about 0.05 percent of the Federal ALI).

EFFECTS OF RADIATION ON PERSONNEL

Control of radiation exposure at Naval Reactors' Department of Energy facilities has always been based on the assumption that any exposure, no matter how small, may involve some risk; however, exposure within the accepted limits represents a risk small in comparison with the normal hazards of life. The basis for this statement is presented below.

Risks Associated with Radiation Exposure

Since the inception of nuclear power, scientists have cautioned that exposure to ionizing radiation in addition to that from natural background may involve some risk. The U.S. National Committee on Radiation Protection and Measurements in 1954 (reference 1) and the International Commission on Radiological Protection in 1958 (reference 2) both recommended that exposures should be kept as low as practicable and that unnecessary exposure should be avoided to minimize this risk. The International Commission on Radiological Protection in 1962 (reference 14) explained the assumed risk as follows:

> The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for occupational exposure.

The National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations included similar statements in its reports in the 1956-1961 period and most recently in 1990 (reference 15). In 1960, the Federal Radiation Council stated (reference 4) that its radiation protection guidance did not differ substantially from recommendations of the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the National Academy of Sciences. This statement was again reaffirmed in 1987 (reference 9).

One conclusion from these reports is that radiation exposures to personnel should be minimized, but this is not a new conclusion. It has been a major driving force of the Naval Reactors Program since its inception.

Radiation Exposure Comparisons

The success of Naval Reactors' Department of Energy facilities in minimizing exposures to personnel can be evaluated by making some radiation exposure comparisons.

Annual Exposure

One important measure of personnel exposure is the amount of exposure an individual receives in a year. Tables 2 and 3 show that since 1979, no individual has received more than 2 rem in a year as a result of working at Naval Reactors' Department of Energy facilities. Also, from Table 4 it can be seen that the average exposure per person monitored since 1979 is about 0.063 rem for prototype personnel and 0.017 rem for laboratory personnel; the overall average annual exposure is about 0.051 rem. The following comparisons give perspective on these individual annual doses in relation to Federal limits and other exposures:

- The Naval Nuclear Propulsion Program limits an individual's dose to 3 rem in one ***quarter***. No one in the Naval Reactors' Program has exceeded 2 rem in one ***year*** since 1979—less than half the Federal annual limit of 5 rem.
- Annually between 195 and 7,500 workers at NRC-licensed commercial nuclear-powered reactors have exceeded 2 rem in various years over this same period (reference 16).
- The average annual exposure since 1979 of 0.051 rem is:
  - approximately 1 percent of the Federal annual limit of 5 rem.
  - less than one-fourth the average annual exposure of commercial nuclear power plant personnel over the same time period (reference 16).
  - less than one-third the average annual exposure received by commercial airline flight crew personnel due to cosmic radiation (reference 17).

For additional perspective, the annual exposures for personnel at Naval Reactors' Department of Energy facilities may also be compared to natural background and medical exposures:

- The maximum annual exposure of 2 rem is less than half the annual exposure from natural radioactivity in the soils in some places in the world, such as Tamil Nadu, India and Meaipe, Brazil (reference 15).
- The average annual exposure since 1979 of 0.051 rem is:
  - one-sixth the average annual exposure to a member of the population in the U.S. from natural background radiation (reference 21).
  - less than half the exposure from common diagnostic medical x-ray procedures such as x rays of the back (reference 22).
  - less than the difference in the annual exposure due to natural background radiation between Denver, Colorado, and Washington, D.C. (reference 21).
- The average **annual** exposure since 1979 of 0.017 rem for laboratory personnel is less than the **monthly** exposure to a member of the population in the U.S. from natural background radiation (reference 21).

Collective Dose

The sum of all individual exposures gives the collective dose. Collective dose may be used as a measure of the theoretical effect on the personnel occupationally exposed at Naval Reactors' Department of Energy facilities taken as a group, and is an indicator of the effectiveness of the Program's efforts to minimize radiation exposure. From Tables 2 and 3, it can be seen that the collective dose received by all 5,251 personnel monitored at Naval Reactors' Department of Energy facilities in 2005 was 79.1 rem. The following statements give perspective on this collective dose in comparison to collective doses from other occupations. This annual collective dose is:

- less than one-sixth the average annual collective dose received by a comparable number of commercial nuclear power plant personnel (reference 16).
- less than one-quarter the average annual collective dose received by a comparable number of persons in the medical field (reference 17).
- less than one-tenth the average annual collective dose received by a comparable number of commercial airline flight crew personnel (reference 17).

For even further perspective, the annual collective dose to personnel at Naval Reactors' Department of Energy facilities may also be compared to collective doses from radiation exposures not related to an individual's occupation. This annual collective dose is:

- approximately 5 percent of the average annual collective dose of 1,575 rem received by a comparable number of individuals in the U.S. population due to natural background radiation (reference 21).
- less than 15 percent of the average annual collective dose of 682 rem received by a comparable number of individuals in the U.S. population due to diagnostic medical procedures such as x rays of the back (reference 22).
- less than 2 percent of the average annual collective dose of 6,800 rem received by a comparable number of average smokers due to the natural radioactivity in tobacco smoke (reference 10) (rough comparison due to the difficulty in estimating the average annual collective dose received from smoking).

Conclusions on Radiation Exposure to Personnel

The preceding statements show that occupational exposures to individuals working at Naval Reactors' Department of Energy facilities are small when compared to other occupational exposures and limits, and are within the range of exposures from natural background radiation in the U.S. and worldwide. Additionally, the total dose to all persons (collective dose) each year is small compared to the collective doses to workers in other occupations, and insignificant compared to the collective doses to the U.S. population from natural background radiation, medical procedures, and tobacco smoke. In reference 17 the National Council on Radiation Protection and Measurements reviewed the occupational exposures to the U.S. working population. This included a review of the occupational exposures to personnel from the Naval Nuclear Propulsion Program. Based on this review, the National Council on Radiation Protection and Measurements concluded:

> These small values [of occupational exposure] reflect the success of the Navy's efforts to keep doses as low as reasonably achievable (ALARA).

The same success achieved by the Naval Nuclear Propulsion Program for occupational radiation exposure to Navy personnel has also been achieved for the personnel at Naval Reactors' Department of Energy facilities.

Studies of the Effects of Radiation on Human Beings

Observations on the biological effects of ionizing radiation began soon after the discovery of x rays in 1895 (reference 15).

Numerous references are made in the early literature to the potential biological effects of exposure to ionizing radiation. These effects have been intensively investigated for many years (reference 23). Although there still exists some uncertainty about the exact level of risk, the National Academy of Sciences stated in reference 24:

> It is fair to say that we have more scientific evidence on the hazards of ionizing radiation than on most, if not all, other environmental agents that affect the general public.

A large amount of experimental evidence of radiation effects on living systems has come from laboratory studies on cell systems and on animals. However, what sets our extensive knowledge of radiation effects on human beings apart from other hazards is the evidence obtained from studies of human populations that have been exposed to radiation in various ways (reference 24). The health effects demonstrated from studies of people exposed to high doses of radiation (that is, significantly higher than current occupational limits) include cancer, cataracts, sterility, and developmental abnormalities from prenatal exposure. Animal studies indicate the potential for genetic effects.

Near the end of 1993, the Secretary of Energy requested the disclosure of all records and information on radiation experiments involving human subjects performed or supported by the Department of Energy or predecessor agencies. The Naval Reactors Program has never conducted or supported any radiation experiments on human beings. As discussed in this report, the Program has adopted exposure limits recommended by national and international radiation protection standards committees (such as the National Council on Radiation Protection and Measurements, and the International Commission on Radiological Protection) and has relied upon conservative designs and disciplined operating and maintenance practices to keep radiation exposure to levels well below these limits.

High-Dose Studies

The human study populations that have contributed a large amount of information about the biological effects of radiation exposure include the survivors of the atomic bombings of Hiroshima and Nagasaki, x-rayed tuberculosis patients, victims of various radiation accidents, patients who have received radiation treatment for a variety of diseases, radium-dial painters, and inhabitants of South Pacific islands that received unexpected doses from fallout due to early nuclear weapons tests. All of these populations received high or very high exposures.

The studies of atomic bomb survivors have provided the single most important source of information on the immediate and delayed effects of whole body exposure to ionizing radiation. The studies have been supported for over 40 years by the U.S. and Japanese Governments and include analysis of the health of approximately 90,000 survivors of the bombings. Continued follow-up of the Japanese survivors has changed the emphasis of concern from genetic effects to the induction of cancer (references 15 and 18).

The induction of cancer has been the major latent effect of radiation exposure in the atomic bomb survivors. The tissues most sensitive to the induction of cancer appear to be the blood-forming organs, the thyroid, and the female breast. Other cancers linked to radiation, but with a lower induction rate, include cancers of the lung, stomach, colon, bladder, liver, and ovary. A wave-like pattern of leukemia induction was seen over time beginning about 2 years after exposure, peaking within 10 years of exposure, and generally diminishing to near baseline levels over the next 40 years. For other cancers, a statistically significant excess was observed 5-10 years or more after exposure, and the excess risk continues to rise slowly with time (reference 18).

While it is often stated that radiation causes all forms of cancer, many forms of cancer actually show no increase among atomic bomb survivors. These include chronic lymphocytic leukemia, Hodgkin's disease, and cancers of the pancreas, prostate, cervix, and testes (reference 18).

To understand the impact of cancer induction from the atomic bombings in 1945, it is necessary to compare the number of radiation-related cancers to the total number of cancers expected in the exposed group. In studies of approximately 50,000 survivors with doses ranging from 0.5 to over 200 rem, approximately 6,900 cases of cancer have been identified as of 1994. Of these, roughly 700 are in excess of expectation (reference 19). Also within this population, there were 4,565 solid cancer deaths and 176 leukemia deaths as of 1990 (reference 20). Of these, an estimated 376 solid cancer deaths and 78 leukemia deaths are in excess of expectation (reference 20). These studies did not reveal a statistically significant excess of cancer below doses of 6 rem (reference 18). The cancer mortality experience of the other human study populations exposed to high doses (referenced above) is generally consistent with the experience of the Japanese atomic bomb survivors (reference 18).

About 40 years ago, the major concern of the effects from radiation exposure centered on possible genetic changes. Ionizing radiation was known to cause such effects in many species of plants and animals. However, intense study of nearly 70,000 offspring of atomic bomb survivors has failed to identify any increase in genetic effects. Based on a recent analysis, human beings now appear less sensitive to the genetic effects from radiation exposure than previously thought (reference 15).

Radiation-induced cataracts have been observed in atomic bomb survivors and persons treated with very high doses of x rays to the eye. Based on this observation, potential cataract induction was considered a matter of concern. However, more recent research indicates that the induction of cataracts by radiation requires a high threshold dose. The National Academy of Sciences has stated that unless the protracted exposure to the eye exceeds the threshold of 800 rem, vision-impairing cataracts will not form. This exposure greatly exceeds the amount of radiation that can be accumulated by the lens through occupational exposure to radiation under normal working conditions (reference 15).

Radiation damage to the reproduction cells at very high doses can result in sterility. Impairment of fertility requires a dose large enough to damage or deplete most of the reproductive cells and is close to a lethal dose if exposure is to the whole body. The National Academy of Sciences estimates the threshold dose necessary to induce permanent sterility is approximately 350 rem in a single dose (reference 15). As in the case of cataract induction, this dose far exceeds that which can be received from occupational exposure under normal working conditions.

Among the atomic bomb survivors' children who received high prenatal exposure (that is, their mothers were pregnant at the time of the exposure), developmental abnormalities were observed. These abnormalities included stunted growth, small head size, and mental retardation. Additionally, recent analysis suggests that during a certain stage of development (the 8th to 15th week of pregnancy), the developing brain appears to be especially sensitive to radiation. A slight lowering of IQ might follow doses of 10 rem or more (reference 15).

From this discussion of the health effects observed in studies of human populations exposed to high doses of radiation, it can be seen that the most important of the effects from the standpoint of occupationally exposed workers is the potential for induction of cancer (reference 15).

Low-Dose Studies

The cancer-causing effects of radiation on the bone marrow, female breast, thyroid, lung, stomach, and other organs reported for the atomic bomb survivors are similar to findings reported for other irradiated human populations. With few exceptions, however, the effects have been observed only at high doses and high dose rates. Studies of populations chronically exposed to low-level radiation have not shown consistent or conclusive evidence of an associated increase in the risk of cancer (reference 15). Attempts to observe increased cancer in a human population exposed to low doses of radiation have been difficult.

One problem in such studies is the number of people needed to provide sufficient statistics. As the dose to the exposed group decreases, the number of people needed to detect an increase in cancer goes up at an accelerated rate. For example, for a group exposed to 1 rem (equivalent to the average lifetime accumulated dose for an individual working at a Naval Reactors' Department of Energy facility), it would take more than 500,000 people in order to detect an excess in lung cancers (based on current estimates of the risk [reference 25]). This is more than three times the number of people who have performed radioactive work at all the Naval Reactors' Department of Energy facilities over the last 50 years. Another limiting factor is the relatively short time since low-dose occupational exposure started being received by large groups of people. As discussed previously, data from the atomic bomb survivors indicate a long latency period between the time of exposure and expression of the disease.

There is also the compounding factor that cancer is a generalization for a group of approximately 300 separate diseases, many being relatively rare and having different apparent causes. With low-dose study data, it is difficult to eliminate the possibility that some factor other than radiation may be causing an apparent increase in cancer induction. This difficulty is particularly apparent in studies of lung cancer, for example, where smoking is (a) such a common exposure, (b) poorly documented as to individual habits, and (c) by far the primary cause of lung cancer. Because cancer induction is statistical in nature, low-dose studies are limited by the fact that an apparent observed small increase in a cancer may be due to chance alone.

Despite the above-mentioned problems and the lack of consistent or conclusive evidence from such studies to date, low-dose studies fulfill an important function. They are the only means available for eventually testing the validity of current risk estimates derived from data accumulated at higher doses and higher dose rates.

Low-dose groups that have been, and are currently being, studied include groups exposed as a result of medical procedures; exposed to fallout from nuclear weapons testing; living near nuclear installations; living in areas of high natural background radiation; and occupationally exposed to low doses of radiation. The National Academy of Sciences has reviewed a number of the low-dose studies in references 15 and 24. Their overall conclusion from reviewing these studies was:

> Studies of populations chronically exposed to low-level radiation, such as those residing in regions of elevated natural background radiation, have not shown consistent or conclusive evidence of an associated increase in the risk of cancer (reference 15).

This conclusion has been supported by studies that have been completed since reference 15 was published. For example, in 1990 the National Cancer Institute completed a study of cancer in U.S. populations living near 62 nuclear facilities that had been in operation before 1982. This study included commercial nuclear power plants and Department of Energy facilities that handle radioactive materials. The conclusion of the National Cancer Institute study was that there was no evidence to suggest that the occurrence of leukemia or any other form of cancer was generally higher in the counties near the nuclear facilities than in the counties remote from nuclear facilities (reference 26).

At the request of the Three Mile Island Public Health Fund, independent researchers investigated whether the pattern of cancer in the 10-mile area surrounding the Three Mile Island (TMI) nuclear plant had changed after the TMI-2 accident in March 1979 and, if so, whether the change was related to radiation releases from the plant. A conclusion of this study was:

> For accident emissions, the authors failed to find definite effects of exposure on the cancer types and population subgroups thought to be most susceptible to radiation. No associations were seen for leukemia in adults or for childhood cancers as a group (reference 27).

Of particular interest to workers at Naval Reactors' Department of Energy facilities are studies of groups occupationally exposed to radiation. A 1990 survey of radiation worker populations in the U.S. showed that there were about 350,000 workers under study (reference 25). For more than a decade, Naval Reactors Program personnel have been among populations being studied. These studies are discussed below.

In 1978, Congress directed the National Institute for Occupational Safety and Health (NIOSH) to perform a study of workers at the Portsmouth Naval Shipyard. Congress also chartered an independent oversight committee of nine national experts to oversee the performance of the study in order to ensure technical adequacy and independence of the results. NIOSH concluded, "Excesses of deaths due to malignant neoplasms and specifically due to neoplasms of the blood and blood-forming tissue, were not evident in civilian workers at Portsmouth Naval Shipyard" (reference 28). NIOSH did two followup studies focusing on leukemia and lung cancer and also concluded that radiation exposure at Portsmouth Naval Shipyard could not be shown to have contributed to the number of deaths from these causes (references 29 and 30).

NIOSH published the results of an update to the 1980 study in the July 2004 edition of the *Journal of Occupational and Environmental Medicine* (reference 31). The cohort was expanded by including all Portsmouth Naval Shipyard workers employed through December 31, 1992, and included worker vital statistics obtained up to December 31, 1996. The NIOSH study found nothing to conclude that the health of shipyard workers has been adversely affected by low levels of occupational radiation exposure incidental to work on U.S. naval nuclear-powered ships. These findings are generally consistent with previous studies.

The study did not show any statistically significant cancer risks linked to radiation exposure, when compared to the general U.S. population. Further, the overall death rate among Portsmouth Naval Shipyard occupational radiation workers was less than the death rate for the general U.S. population.

Several additional analyses of the Portsmouth Naval Shipyard data have been performed by NIOSH, and in the December 2005 issue of *Radiation Research* (reference 32) NIOSH published the results of a case-control study of leukemia mortality and ionizing radiation. The study found that although the overall risk of leukemia mortality for radiation workers was the same as the general population, a small increase in risk was noted with increasing radiation dose. NIOSH estimated that the lifetime risk for leukemia mortality would increase from 0.33 percent to 0.36 percent for workers receiving the average lifetime radiation dose for shipyard workers (1.2 rem). The study also found a small increase in leukemia mortality associated with potential solvent exposure (benzene or carbon tetrachloride). The NIOSH report cautioned that the relatively small number of leukemia cases among radiation workers (34 cases in a population of 11,791 workers) makes it difficult to be certain of the findings. However, the risk estimate is consistent with other radiation epidemiologic study results.

In 1991, researchers from Johns Hopkins University in Baltimore, Maryland, completed a more comprehensive epidemiological study of the health of workers at the six naval shipyards (including Portsmouth Naval Shipyard, discussed above) and two private shipyards that serviced U.S. naval nuclear-powered ships (reference 32). This independent study evaluated a population of 70,730 civilian workers over a period from 1957 (beginning with the first overhaul of the first nuclear-powered submarine, USS NAUTILUS) through 1981, to determine whether there was an excess risk of leukemia or other cancers associated with exposure to low levels of gamma radiation. This study is of particular interest to workers at Naval Reactors' Department of Energy facilities because the type of radioactivity, level of exposure, and method of radiological controls at these shipyards are similar to Naval Reactors' Department of Energy facilities.

This study did not show any cancer risks linked to radiation exposure. Furthermore, the overall death rate among radiation-exposed shipyard workers was actually less than the death rate for the general U.S. population. It is well recognized that many worker populations have lower mortality rates than the general population: the workers have to be healthy to do their jobs. This study shows that the radiation-exposed shipyard population falls into this category.

The death rate for cancer and leukemia among the radiation-exposed workers was slightly lower than that for non-radiation-exposed workers and that for the general U.S. population. However, an increased rate of mesothelioma, a type of respiratory system cancer linked to asbestos exposure, was found in both radiation-exposed and non-radiation-exposed shipyard workers, although the number of cases was small (reflecting the rarity of this disease in the general population). The researchers suspect that shipyard worker exposure to asbestos in the early years of the Program, when the hazards associated with asbestos were not so well understood as they are today, might account for this increase.

The Johns Hopkins study found no evidence to conclude that the health of people involved in work on U.S. naval nuclear-powered ships has been adversely affected by exposure to low levels of radiation incidental to this work. The average annual radiation exposure from 1957 to 1981 for these shipyard workers is over 2½ times higher than the average annual exposure of 0.114 rem received by personnel assigned to Naval Reactors' Department of Energy facilities since 1958. Additional studies are planned to investigate the observations and update the shipyard study with data beyond 1981.

In 1994, NIOSH began conducting an epidemiological study of the health of workers at the Idaho National Laboratory (INL) who are occupationally exposed to radiation. This study includes civilian workers at the Naval Reactors Facility (NRF), which is located within INL. NIOSH has announced completion of this study. Initial conclusions suggest no changes to past findings.

Numerical Estimates of Risk from Radiation

One of the major aims of the studies of exposed populations as discussed above is to develop numerical estimates of the risk of radiation exposure. These risk estimates are useful in addressing the question of how hazardous radiation exposure is, evaluating and setting radiation protection standards, and helping resolve claims for compensation by exposed individuals.

The development of numerical risk estimates has many uncertainties. As discussed above, excess cancers attributed to radiation exposure can only be observed in populations exposed to high doses and high-dose rates. However, the risk estimates are needed for use in evaluating exposures from low doses and low-dose rates. Therefore, the risk estimates derived from the high-dose studies must be extrapolated to low doses. This extrapolation introduces a major uncertainty. The shape of the curve used to perform this extrapolation becomes a matter of hypothesis (that is, an assumption) rather than observation. The inability to observe the shape of this extrapolated curve is a major source of controversy over the appropriate risk estimate.

Scientific committees—such as the National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations (reference 15), the United Nations Scientific Committee on the Effects of Atomic Radiation (reference 18), and the National Council on Radiation Protection and Measurements (reference 11)—all conclude that accumulation of dose over weeks, or months, as opposed to in a single dose, is expected to reduce the risk appreciably. A dose rate effectiveness factor (DREF) is applied as a divisor to the risk estimates at high doses to permit extrapolation to low doses. The National Academy of Sciences (reference 15) suggested that a range of DREFs between 2 and 10 may be applicable and reported a best estimate of 4, based on studies of laboratory animals. The United Nations Scientific Committee on the Effects of Atomic Radiation (reference 18) suggested that a DREF of 2 or 3 would be reasonable based on available data.

However, despite these conclusions by the scientific committees, some critics argue that the risk actually increases at low doses, while others argue that cancer induction is a threshold effect and the risk is zero below the threshold dose. As stated at the beginning of this section, the Naval Reactors Program has always conservatively assumed that radiation exposure, no matter how small, may involve some risk.

In 1972, both the United Nations Scientific Committee on the Effects of Atomic Radiation and the National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations issued reports (references 34 and 35) that estimated numerical risks for specific types of cancer from radiation exposures to human beings. Since then, international and national scientific committees have been periodically re-evaluating and revising these numerical estimates based on the latest data. The most recent risk estimates are from the same two committees and are contained in their 1990 and 2000 reports, respectively (references 15 and 18). Both committees re-evaluated risk estimates based on the use of new models for projecting the risk, revised dose estimates for survivors of the Hiroshima and Nagasaki atomic bombs, and additional data on the cancer experience both by atomic bomb survivors and by persons exposed to radiation for medical purposes. A risk estimate for radiation-induced cancer derived from the most recent analyses, references 15 and 18, can be briefly summarized as follows:

> In a group of 10,000 workers in the U.S., a total of about 2,000 (20 percent) will normally die of cancer. If each of the 10,000 received over his or her career an additional 1 rem, then an estimated 4 additional cancer deaths (0.04 percent) might occur. Therefore, the average worker's lifetime risk of cancer has been increased nominally from 20 percent to 20.04 percent.

The above risk estimate was extrapolated from estimates applicable to high doses and high dose rates using a DREF of about 2. This estimate may overstate the true lifetime risk at low doses and dose rates, because a DREF of 2 is at the low end of probable DREF values. The National Academy of Sciences (reference 15), in assessing the various sources of uncertainty, concluded that the true lifetime risk may be contained within an interval from 0 to about 6. The Academy points out that the lower limit of uncertainty extends to zero risk because "the possibility that there may be no risks from exposures comparable to external natural background radiation cannot be ruled out."

These statistics can be used to develop a risk estimate for personnel exposed to radiation associated with Naval Reactors' Department of Energy facilities. As stated previously, the average lifetime accumulated exposure for these personnel is about 1 rem. Therefore, based on the risk estimate presented above, the average worker's lifetime cancer risk at Naval Reactors' Department of Energy facilities may be statistically increased by about four one-hundredths of one percent, or from 20 percent for the general population to 20.04 percent for a worker at Naval Reactors' Department of Energy facilities.

<u>Risk Comparisons</u>

Table 7 compares calculated risks from occupational exposure at Naval Reactors' Department of Energy facilities to other occupational risks. This permits evaluation of the relative hazard of this risk versus risks normally accepted in the workplace. It should be kept in mind that the calculated radiation risk is based on risk estimates, whereas the other occupational risks are based on actual death statistics for the occupation.

TABLE 7

LIFETIME OCCUPATIONAL RISKS

Occupation (reference 11)	Lifetime Risk[1] Percent
Agriculture	2.1
Mining, Quarrying	2.0
Construction	1.5
Transportation and Public Utilities	1.0
All Industries Average	0.4
Government	0.4
Services	0.2
Manufacturing	0.2
Trade	0.2
Radiation exposure associated with Naval Reactors' Department of Energy facilities (risk estimate)	0.04

Further perspective on the lifetime risk from radiation exposure at Naval Reactors' Department of Energy facilities may be gained by comparison to other everyday risks, as shown in Table 8.

TABLE 8

SOME COMMONPLACE LIFETIME RISKS

Risk (reference 36 and 37)	Lifetime Risk[2] Percent
Tobacco	11.1
Poor Diet/Lack of Exercise	10.7
Infectious Agents	3.0
Accidents (all)	2.7
Firearms	1.5
Motor Vehicle Accidents	1.2
Falls	0.42
Accidental Poisoning	0.39
Drowning	0.09
Fires	0.08
Other Land Transport Accidents	0.03
Radiation exposure associated with naval nuclear propulsion plants (risk estimate)	0.04

1. Assumes a working lifetime of 47 years (age 18 to 65).
2. For tobacco use, the risk assumes the population is at risk from age 18 to 76.5 (58.5 years). Other risks assume the population is at risk for a lifetime (76.5 years).

Low-Level Radiation Controversy

A very effective way to cause undue concern about low-level radiation exposure is to claim that no one knows what the effects are on human beings. Critics have repeated this so often that it has almost become an article of faith. They are able to make this statement because, as discussed above, human studies of low-level radiation exposure cannot be conclusive as to whether or not an effect exists in the exposed groups, because of the extremely low incidence of an effect. Therefore, assumptions are needed regarding extrapolation from high-dose groups. The reason low-dose studies cannot be conclusive is that the risk, if it exists at these low levels, is too small to be seen in the presence of all the other risks of life.

In summary, the effect of radiation exposures at occupational levels is extremely small. There are physical limits to how far scientists can go to ascertain precisely how small but instead of proclaiming how little is known about low-level radiation, it is more appropriate to emphasize how much is known about the small actual effects.

Again, the most important health effect observed in studies of humans exposed to high doses of radiation (such as survivors of the atomic bombings of Hiroshima and Nagasaki, patients with high doses from x rays or radiation treatments, and radium dial painters) is the potential for the induction of cancer. While there are studies of the potential for cause and effect from low doses of radiation, the incidence of cancer in an individual who received occupational radiation exposure does not necessarily mean that occupational exposure was the cause. Reference 38 documents that the lifetime risk of being diagnosed with cancer for a person living in the United States is 45 percent for males and 39 percent for females. The median age for being diagnosed with cancer is 68 years old, meaning that half of those diagnosed with cancer are younger than 68 at the time of diagnosis. In addition, the lifetime risk of dying from cancer for a person living in the United States is 23 percent for males and 20 percent for females.

As discussed earlier, the Navy has participated in several epidemiology studies by authoritative scientists of mortality of personnel who served on U.S. naval nuclear-powered submarine or worked in shipyards. Each of these studies concluded that there was no discernable correlation between cancer mortality and the low-level radiation exposure associated with naval nuclear propulsion plant. The Navy continues to support updates to these studies.

Conclusions on the Effects of Radiation on Personnel

This perspective provides a better position to answer the question, "Is radiation safe?" If safe means "zero effect," then the conclusion would have to be that radiation may be unsafe. But to be consistent, background radiation and medical radiation would also have to be considered unsafe. Or more simply, being alive is unsafe.

"Safe" is a relative term. Comparisons are necessary for actual meaning. For a worker, safe means the risk is small compared to other risks accepted in normal work activities. Aside from work, safe means the risk is small compared to the risks routinely accepted in life.

Each recommendation on limits for radiation exposure from the scientific and advisory organizations referenced herein has emphasized the need to minimize radiation exposure. Thus, the Naval Reactors Program is committed to keeping radiation exposure to personnel as low as reasonably achievable. Scientific and advisory organizations have not agreed on a radiation level below which there is no effect. Similarly, it is difficult to find a single human activity for which the risk can be confidently stated as zero. However, the above summaries show that the risk from radiation exposure associated with Naval Reactors' Department of Energy facilities is low compared to the risks normally accepted in industrial work and in daily life outside of work.

AUDITS AND REVIEWS

Checks and cross-checks, audits, and inspections of numerous kinds have been shown to be essential in maintaining high standards of radiological controls. To that end, the Naval Reactors Program has from its inception established a rigorous system of audits and reviews. First, all workers are specially trained in radiological controls as it relates to their own job. Second, written procedures exist that require verbatim compliance. Third, radiological controls technicians and their supervisors oversee radioactive work. Fourth, personnel independent of radiological controls technicians are responsible for processing personnel dosimeters and maintaining radiation exposure records.

Fifth, a strong independent audit program covers all radiological controls requirements. In all facilities this radiological audit group is independent of the radiological controls organization; the audit group's findings are reported regularly to senior management. This group performs continuing surveillance of radioactive work. It conducts in depth audits of specific areas of radiological controls, and checks all radiological controls requirements at least annually.

Sixth, the Department of Energy assigns to each facility a representative who reports to the Director, Naval Nuclear Propulsion. One assistant to this representative is assigned full-time to audit and review radiological controls. Seventh, Naval Reactors Headquarters personnel conduct periodic inspections of radiological controls in each facility.

In addition, various aspects of the Naval Reactors Program have been reviewed by other Government agencies. For example, the General Accounting Office (GAO) performed a 14-month in depth review of various aspects of Naval Reactors' Department of Energy facilities. In August 1991 (reference 39), GAO published the following conclusions:

- We believe Naval Reactors Laboratories are accurately measuring, recording, and reporting radiation exposures.

- Naval Reactors' reported exposures show that exposures have been minimal and overall are lower than commercial nuclear facilities and other Department of Energy facilities.

CLAIMS FOR RADIATION INJURY TO PERSONNEL

Personnel who believe they have received an occupational injury may file claims. The personnel who operate Naval Reactors' Department of Energy facilities are employees of corporations operating facilities under contract to the Department of Energy. These personnel file claims under State workmen's compensation laws. The claim may be handled through the contractor's insurance carrier or adjudicated by an administrative law judge. Either the employee or the contractor may appeal the judge's decision. In any case, the Naval Reactors Program would support any claim for radiation injury where it could be technically and scientifically shown that the injury was more likely than not caused by the individual's occupational radiation exposure from the Program.

A case does not require a decision after filing unless it is actively pursued. A claim may lie dormant for many years theoretically to be pursued at a later date, whereupon a decision will be made. For the purpose of this report, claims that have had no activity in the last 5 years are counted as deferred.

There have been a total of five claims filed for injury from radiation associated with Naval Reactors' Department of Energy facilities. Of these claims, one was awarded and four have either been denied or deferred. The one case that was awarded occurred in 1955 and involved loss of hearing. A fine particle of radioactive material had entered the individual's ear canal and become lodged. The particle remained in the ear canal for approximately 9 days; as a result, the individual received a very high localized exposure to the eardrum. Following this incident, the individual suffered a 65 percent hearing loss in the affected ear. The claim was awarded in 1959. In 2005, no new claims were filed or awarded.

Energy Employees Occupational Illness Compensation Program Act

In 2000, Congress passed the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) to provide an alternative Federal compensation program for workers whose health was impacted as a result of nuclear weapons related work for Department of Energy contractors. The EEOICPA generally covers contractors and Department of Energy employees, as designated by the Secretary of Energy, who worked in facilities that processed or produced radioactive material for use in the production of atomic weapons. The current list of covered facilities begins on page 51,825 of reference 40.

Because of the effectiveness of Naval Reactors' worker protection, worker training, and workplace monitoring programs, employees who performed Naval Reactors' related work at Naval Reactors' Department of Energy facilities were not included in the EEOICPA. As discussed earlier, the GAO reported to Congress in 1991 that "Naval Reactors Laboratories are accurately measuring, recording, and reporting radiation exposures," and "exposures have been minimal and overall are lower than commercial nuclear facilities and other Department of Energy facilities." This longstanding record of effectiveness supports the conclusion by Congress that workers at Naval Reactors' Department of Energy facilities did not need the compensation alternatives created for workers in the nuclear weapons complex by the EEOICPA.

Some personnel who were employed at Naval Reactors' Department of Energy facilities during certain periods are covered by the EEOICPA because those facilities performed nuclear weapons work unrelated to the Naval Reactors Program. These facilities include the Separations Process Research Unit at the Knolls Atomic Power Laboratory, the Peek Street Facility in Schenectady, New York; the Sacandaga Facility in Glenville, New York; and the decommissioning work of the Shippingport Atomic Power Station. Each of these facilities is discussed in more detail below.

The Separations Process Research Unit at the Knolls Atomic Power Laboratory involved laboratory testing of radionuclide separation processes eventually used in production processes at the Atomic Energy Commission's Hanford Site in Washington and at the Savannah River Plant in South Carolina. This work began in the 1940s and was initially conducted under the direction of the Atomic Energy Commission. Following completion of this research in 1953, remediation of related work areas and waste products began; most of the cleanup work was completed by 1965. Areas requiring additional remediation have been maintained in protective layup pending final remediation. In March 1965, the radiological controls previously used for this work under the Atomic Energy Commission were supplanted by controls specifically approved by Naval Reactors. Therefore, work after March 1965 to maintain Separation Process Research Unit facilities in protective layup were under the authority of Naval Reactors and outside the scope of the EEOICPA.

In the late 1940s and early 1950s, the General Electric Company operated two Federal Government facilities in support of developmental programs for the Atomic Energy Commission. These two facilities were the Peek Street Facility and the Sacandaga Facility. Though these sites were decontaminated, decommissioned, and sold to private parties in the mid-1950s, Naval Reactors resurveyed these sites between 1988 and 1991 to ensure compliance with current Department of Energy guidelines. Based on those surveys, additional minor remediation was completed by Naval Reactors in 1994. Therefore, work at the Peek Street Facility and the Sacandaga Facility in the 1980s and 1990s was under the regulatory oversight of Naval Reactors and is outside the scope of the EEOICPA.

As discussed elsewhere in this report, Naval Reactors was responsible for regulatory oversight throughout the construction and operation of the Shippingport Atomic Power Station. When operation of the station ended and defueling was completed in September 1984, Naval Reactors transferred oversight responsibility for the station to the Department of Energy Office of Terminal Waste Disposal and Remedial Action. Therefore, work at the Shippingport Atomic Power Station before September 1984 is outside the scope of the EEOICPA.

Naval Reactors and its contractors maintain custody of employment and radiation exposure records for personnel who worked at the Peek Street Facility, the Sacandaga Facility, and the Separation Process Research Unit. When requested by the Department of Energy or the National Industrial Occupational Safety and Health (NIOSH) division of the Department of Health and Human Services, Naval Reactors provides employment verification and radiation exposure information in accordance with the procedures required by the EEOICPA.

As defined in the EEOICPA, the Department of Labor determines the eligibility of personnel filing a compensation claim; and if needed, NIOSH performs a radiation dose reconstruction to support a determination of causation and ultimate award or denial of benefits. Through December 2005, Naval Reactors has provided dose information to NIOSH for 31 claims for personnel whose employment included non-Naval Nuclear Propulsion Program work at facilities now under Naval Reactors cognizance.

ABNORMAL OCCURRENCES

It is a fact of human nature that people make mistakes. The key to a good radiological controls program is to find the mistakes while they are small and prevent the combinations of mistakes that lead to more serious consequences. The preceding section on inspections supports the conclusion that the Naval Reactors Program gives more attention to errors and their prevention than to any other single subject. Requiring constant focus on improving performance of radiological work has proven effective in reducing errors.

In addition, radiological controls technicians are authorized and required to stop anyone performing work in a manner that could lead to radiological deficiencies. One definition of "deficiency" is a failure to follow a written procedure verbatim. However, the broadest interpretation of the term "deficiency" is used in Naval Reactors' Department of Energy facilities' radiological controls program. *Anything involved with radiation or radioactivity that could have been done better* is also considered a radiological deficiency. All radiological deficiencies receive management attention.

Higher levels of deficiency are defined as "radiological incidents." Incidents receive further management review, including evaluation by senior personnel at Naval Reactors Headquarters and review by the Director, Naval Nuclear Propulsion. Improvement programs over the years have consistently aimed at reducing the number of radiological incidents. As improvements occurred, the definition of what constitutes a Naval Reactors incident was changed to define smaller and smaller deficiencies as incidents. These changes were made so that the incident reporting system would continue to play a key role in upgrading radiological controls. As a result, it is not practicable to measure performance over time merely by counting numbers of radiological incidents or deficiencies.

The Department of Energy and its predecessors have used a separate reporting system that has been nearly constant over time and therefore can be used as a basis for comparison. This system defines a Type A radiation exposure occurrence as an event that causes an individual's external radiation exposure to equal or exceed 25 rem (reference 41). The Nuclear Regulatory Commission uses similar criteria to define a radiation-related abnormal occurrence; abnormal occurrences are included in the NRC's quarterly report to Congress. Naval Reactors regularly evaluates radiological events using these criteria for comparison.

Since the beginning of operations at Naval Reactors' Department of Energy facilities, there has never been a single radiation incident that met the criteria of a Type A or abnormal occurrence.

The policy of the Naval Reactors Program is to provide for close cooperation and effective communication with State radiological officials involving occurrences that might cause concern because of radiological effects associated with Program facilities. The Naval Reactors Program has reviewed radiological matters with State radiological officials in the States where Naval Reactors' Department of Energy facilities operate. Although there has never been an abnormal occurrence that has resulted in radiological effects to the public outside these facilities or that resulted in radiological injury to residents of the States working inside these facilities, States were notified when inquiries showed public interest in the possibility such events had occurred.

REFERENCES

1 National Committee on Radiation Protection and Measurements Report 17, "Permissible Dose from External Sources of Ionizing Radiation," including April 15, 1958 Addendum "Maximum Permissible Radiation Exposures to Man" (originally published in 1954 as National Bureau of Standards Handbook 59)

2 International Commission on Radiological Protection Publication 2, "Recommendations of the International Commission on Radiological Protection" (Adopted September 9, 1958), Pergamon Press, 1959

3 Code of Federal Regulations Title 10 (Energy), Part 20, "Standards for Protection Against Radiation"

4 Federal Radiation Council, "Radiation Protection Guidance for Federal Agencies," approved by President Eisenhower May 13, 1960, printed in Federal Register May 18, 1960

5 International Commission on Radiological Protection Publication 9, "Recommendations of the International Commission on Radiological Protection" (Adopted September 17, 1965), Pergamon Press, 1966

6 National Council on Radiation Protection and Measurements Report 39, "Basic Radiation Protection Criteria," January 15, 1971

7 Department of Energy Order 5480.1, Chapter XI, "Requirements for Radiation Protection"

8 International Commission on Radiological Protection Publication 26, "Recommendations of the International Commission on Radiological Protection" (Adopted January 17, 1977), Pergamon Press, 1977

9 Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," approved by President Reagan January 20, 1987, printed in Federal Register, Vol. 52, No. 17, Page 2822, January 27, 1987

10 National Council on Radiation Protection and Measurements Report 93, "Ionizing Radiation Exposure of the Population of the United States," September 1, 1987

11 National Council on Radiation Protection and Measurements Report 116, "Limitation of Exposure to Ionizing Radiation," March 31, 1993

12 International Commission on Radiological Protection Publication 30, "Limits for Intakes of Radionuclides by Workers" (Adopted July 1978), Pergamon Press, 1979

13 U.S. Navy Report, "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities - 2004," T. J. Mueller, et al, NT-05-1, February 2005

14 International Commission on Radiological Protection Publication 6, "Recommendations of the International Commission on Radiological Protection," Pergamon Press, 1962

15 National Academy of Sciences-National Research Council, "Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V," Report of the Committee on the Biological Effects of Ionizing Radiations, 1990

16 U.S. Nuclear Regulatory Commission, "Occupational Radiation Exposures at Commercial Nuclear Power Reactors and Other Facilities -2004," NUREG-0713, Volume 26, November 2005

17 National Council on Radiation Protection and Measurements Report 101, "Exposure of the U.S. Population from Occupational Radiation," June 1, 1989

18 United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation," 2000

19 D. A. Pierce and D. L. Preston, "Cancer Risks at Low Doses Among A-Bomb Survivors," RERF Update, Spring-Summer 2001, Volume 12, Issue 1

20 D. A. Pierce, et al, "Studies of the Mortality of Atomic Bomb Survivors, Report 12, Part I, Cancer 1950-1990," Radiation Effects Research Foundation Report No. 11-95, 1996

21 National Council on Radiation Protection and Measurements Report 94, "Exposure of the Population in the United States and Canada from Natural Background Radiation," December 30, 1987

22 National Council on Radiation Protection and Measurements Report 100, "Exposure of the U.S. Population from Diagnostic Medical Radiation," May 1, 1989

23 A. C. Upton, "The Biological Effects of Low Level Ionizing Radiation," Scientific American, February 1982

24 National Academy of Sciences-National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Committee on the Biological Effects of Ionizing Radiations, 1980

25 R. E. Shore, "Occupational Radiation Studies, Status, Problems, and Prospects," Health Physics, July 1990

26 National Cancer Institute, "Cancer in Populations Living Near Nuclear Facilities," NIH Publication No. 90-874, July 1990

27 M. C. Hatch, et al, "Cancer Near the Three Mile Island Nuclear Plant: Radiation Emissions," American Journal of Epidemiology, September 1990

28 R. A. Rinsky, et al, "Cancer Mortality at a Naval Nuclear Shipyard," The Lancet, January 31, 1981

29 R. S. Rinsky, et al, "Case-Control Study of Lung Cancer in Civilian Employees at the Portsmouth Naval Shipyard, Kittery, Maine," American Journal of Epidemiology, 1988; 127: 55-64

30 F. B. Stern, et al, "A Case-Control Study of Leukemia at a Naval Nuclear Shipyard," American Journal of Epidemiology, 1986; 123: 980-992

31 S. R. Silver, et al, "Differences in Mortality by Radiation Monitoring Status in an Expanded Cohort of Portsmouth Naval Shipyard Workers" Journal of Occupational and Environmental Medicine 2004; 677-690

32 G. M. Matanoski, et al, "Health Effects of Low-Level Radiation in Shipyard Workers," Johns Hopkins University, June 1991

33 T. L. Kubale, et al, "A Nested Case-Control Study of Leukemia Mortality and Ionizing Radiation at the Portsmouth Naval Shipyard," Radiation Research, 2005; 164:810-819

34 United Nations Scientific Committee on the Effects of Atomic Radiation, "Ionizing Radiation: Levels and Effects," 1972

35 National Academy of Sciences-National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, 1972

36 K. D. Kochanek, B. L. Smith. "Deaths: Preliminary Data for 2002." National vital statistics reports; Vol 52 no. 13, Hyattsville, MD: National Center for Health Statistics, February 11, 2004

37 "Targeting Tobacco Use: The Nation's Leading Cause of Death At a Glance 2004" Center for Disease Control and Prevention, 2004

38 Reis LAG, et al, "SEER Cancer Statistics Review, 1975-2000" National Cancer Institute, 2003. Bethesda, MD, http://seer.cancer.gov/csr/1975_2000, 2003

39 General Accounting Office Report GAO/RCED-91-157, "NUCLEAR HEALTH AND SAFETY - Environmental, Health, and Safety Practices at Naval Reactors Facilities," August 1991

40 Federal Register, Volume 69, Number 162, page 51,825, dated August 23, 2004

41 Department of Energy Order 225.1A, "Accident Investigations"

SEPARATION

PAGE

REPORT RA-06-1
MARCH 2006

OCCUPATIONAL SAFETY, HEALTH, AND OCCUPATIONAL MEDICINE REPORT

NAVAL NUCLEAR PROPULSION PROGRAM
OFFICE OF NAVAL REACTORS
WASHINGTON, D.C. 20585

DEPARTMENT OF THE NAVY
WASHINGTON, D.C. 20350

This publication was printed on Recycled Paper

06.0959

REPORT RA-06-1
MARCH 2006

OCCUPATIONAL SAFETY, HEALTH, AND OCCUPATIONAL MEDICINE REPORT

Prepared by

J. M. McKenzie,
G. E. Jensen, and W. G. Sopkowicz
Naval Nuclear Propulsion Program
Office of Naval Reactors

Approved by

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

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

The Naval Reactors Program is a joint Department of Energy (DOE)/Department of the Navy Program with central control by a single headquarters organization. The Program is responsible for two DOE laboratories, one DOE site with two prototype naval nuclear propulsion plants, one DOE site which operates the Expended Core Facility (for examining and dispositioning naval fuel and irradiation tests), and one naval training facility with two moored training ships.

The Program faces the unique challenge of integrating and managing DOE testing and Navy training responsibilities, DOE and Navy facilities, civilian and military personnel, and DOE and Navy health and safety standards. Successful integration requires special technical knowledge and experience in selecting and implementing standards that ensure the safe training of Navy personnel in an environment as realistic as possible.

The same principles of personal responsibility, technical knowledge, rigorous training, and auditing that have been applied to achieve the Program's strong nuclear safety record are applied to Occupational Safety, Health, and Occupational Medicine (OSHOM) programs. A multi-tier approach, incorporating safety in all levels of work, is used throughout the Program. Primary responsibility for employee safety and health resides with operations management and the workers themselves, with assistance and oversight from industrial hygiene, safety, and medical professionals. Workers undergo safety and health training and work to written requirements. Inspection, oversight, and feedback systems are designed to provide continual improvement.

This annual report describes the non-radiological aspects of OSHOM programs at Naval Reactors' DOE laboratories and prototype training facilities and at the naval training facility. Included in this report are performance indicators that measure the effectiveness of OSHOM programs. Performance indicators, such as injury and illness incidence rate, restricted workday case rate, and days away from work case rate, are provided for a 5-year period through 2005 in figures 1 through 4. These indicators, when compared for the Program, DOE, and general industry, show that the Program has maintained rates significantly less than the incidence rates of general industry in all categories and is generally below overall DOE incidence rates.

A 14-month comprehensive assessment of the Program's environmental, safety, and health practices was conducted by the General Accounting Office (GAO) in 1990-1991. The GAO reported that there were no significant deficiencies. Such a finding is independent evidence that the Naval Reactors Program is providing a safe and healthy workplace while meeting the challenges of integrating civilian and military standards in a unique research and training environment.

NAVAL REACTORS PROGRAM BACKGROUND, MISSION, AND FACILITIES

Background

The Naval Reactors Program (hereafter referred to as "the Program") is comprised of military personnel and civilians who design, build, operate, maintain, and oversee operation of naval nuclear-powered ships and associated support facilities. The Program has a broad mandate, maintaining responsibility for nuclear propulsion matters from cradle to grave. Program responsibilities are delineated in Presidential Executive Order 12344 of February 1, 1982, and Public Law 106-65 of October 5, 1999 (50 U.S.C. § 2406). These responsibilities encompass:

- The Navy's nuclear-powered warships.
- Two research and development laboratories.
- Contractors responsible for the design, procurement, and construction of propulsion plant equipment.
- Shipyards that construct, overhaul, and service the propulsion plants of nuclear-powered vessels.
- Navy support facilities and tenders.
- Nuclear power schools and Naval Reactors training facilities.
- The Naval Nuclear Propulsion Program Headquarters organization and field offices.

The Government-owned/contractor-operated Bettis and Knolls Atomic Power Laboratories are research and development laboratories devoted solely to naval nuclear propulsion work. With combined staffs of over 5,500 engineers, scientists, technicians, and support personnel, these laboratories develop advanced naval nuclear propulsion technology and provide technical support for the continued safe, reliable operation of all existing naval reactors.

The Bettis Atomic Power Laboratory operates the Expended Core Facility at the Naval Reactors Facility in Idaho. At the Expended Core Facility, naval spent nuclear fuel from nuclear-powered warships and the Program's prototypes is examined for evidence of any unusual conditions such as unexpected corrosion, unexpected wear, or structural defects. The examinations provide data on current reactor performance, validate models used to predict performance, and support research to improve reactor design. Following examination, this facility also prepares naval spent nuclear fuel for long term storage in a geological repository.

The Knolls Atomic Power Laboratory operates land-based prototype nuclear propulsion plants in New York. Prototype facilities provide platforms for the operational testing of new designs and promising new technologies under typical operating conditions before introduction into the Fleet. The prototype facilities also support the unique training requirements of the Program and are staffed by highly qualified instructors. These facilities provide hands-on training so that, before their first sea tour, all operators have qualified on an operating nuclear reactor.

The Knolls and Bettis laboratories are also responsible for shutdown prototype nuclear propulsion plants in New York and Idaho, which are in various stages of inactivation and dismantlement.

To augment its hands-on training resources, the Program established the Moored Training Ship facility at the Naval Weapons Station in Charleston, South Carolina, in 1990. Two nuclear-powered submarines, which have been decommissioned and converted for training, are moored at the facility. Navy personnel operate the facility with the assistance of a technical staff from Bettis Atomic Power Laboratory.

Scope of Report

The Program is solely responsible for OSHOM matters at its DOE laboratories and prototype facilities, which are operated exclusively for the Program. Within the Navy Occupational Safety and Health (NAVOSH) Program, the Naval Reactors Program is responsible for OSHOM matters at the Moored Training Ship facility. Non-radiological OSHOM matters at other Navy facilities (e.g., shipyards or support facilities) are the primary responsibility of other Navy organizations (although the Program often works with these organizations on OSHOM matters that could affect naval nuclear propulsion plant operations and maintenance). Therefore, this report focuses on the OSHOM programs at Program laboratories, their associated prototype training facilities, and the Moored Training Ship facility.

As stated in the summary, this report covers non-radiological OSHOM programs at Program facilities. The Program is also responsible for radiological health and safety at all Program DOE and Navy facilities and ships where naval nuclear propulsion work is performed. Radiological safety and health information for the Program is described in detail in two other publicly available reports (references 1 and 2).

This report covers calendar year 2005. Occupational safety and health data for calendar years 2001 through 2005 are included to allow comparison to Program performance in recent years.

Past Operations

Safety, Industrial Hygiene, and Occupational Medicine programs were developed and implemented in the earliest years of the Program in the form of documented principles, practices, procedures, and facility safety manuals. The Atomic Energy Act of 1954 assigned to the Atomic Energy Commission (AEC), the predecessor to the DOE, responsibility for regulation of activities conducted pursuant to the Act to protect safety and health. Basic requirements were promulgated by the AEC Manual, part 0500 (Health and Safety), which established standards applicable to all AEC contractor operations. OSHOM programs were staffed with individuals dedicated to these functions.

Since passage of the Williams-Steiger Occupational Safety and Health Act of 1970 (OSH Act), the national standard of care for occupational safety and health has improved. Under the OSH Act, the Program retained authority for OSHOM programs of its contractors and has mandated proactive programs and practices at least as stringent as those required by the Occupational Safety and Health Administration for commercial facilities. The various contractor safety, industrial hygiene, and medical programs have been dynamic and have grown substantially since their inception.

Militarily Unique Mission and Facilities

As previously stated, a major responsibility of the Program is to train naval personnel to operate naval nuclear propulsion plants. At the Moored Training Ship facility, this training is conducted aboard specially modified, moored nuclear-powered submarines that have been decommissioned and converted for training. At one Program DOE facility, training of naval personnel is conducted in land-based prototype naval nuclear propulsion plants, which are representative of the engineering spaces aboard naval nuclear-powered warships. Naval and contractor personnel who meet the same qualification standards conduct the training.

Procedures used by the Program to operate the nuclear reactors and associated systems in the land-based prototype propulsion plants are identical to those used in warships. This includes the use of the same Navy shipboard occupational safety and health requirements as those applied in the Fleet. The Navy safety and health requirements are tailored to meet the militarily unique aspects of the "sea services" and combat roles of warships. Training naval personnel in settings and operations identical to those encountered at sea is a fundamental tenet of the Program that directly contributes to the safe operation of naval shipboard reactors.

In implementing the OSH Act, Executive Order 12196 and 29 CFR 1960 recognized the unique equipment and operations used by the military and exempted militarily unique equipment and operations from coverage by OSH Act regulations. Heat stress, lock-out/tag-out procedures, and structural safety requirements (e.g., hand rails) are examples of areas where civilian OSHOM requirements must be reconciled with the configuration and operational requirements of militarily unique equipment. For such equipment and operations, the Department of Defense occupational safety and health programs ensure that military personnel are protected.

POLICY AND IMPLEMENTATION

Naval Reactors Program Policy

It is the policy of the Program to eliminate or control workplace hazards at Program facilities such that all employees are provided with a safe and healthful workplace.

OSHOM Program Elements

The control of hazards is accomplished through technical and managerial techniques that are recognized as industry standards. These techniques include:

- Establishment of responsibilities: All levels of management and supervision are assigned accountability for the safety and health of their workers and peers.

- Qualified Professional Staffing: The OSHOM programs at Program facilities include certified professionals in the disciplines of Occupational Safety, Industrial Hygiene, and Occupational Medicine. In addition, numerous other site personnel are assigned collateral OSHOM duties, such as workplace safety monitors.

- OSHOM Training of Management and Workers: Facility management, supervisors, and employees are trained on policies and procedures, physical and chemical hazard recognition, control strategies and requirements, emergency procedures, and employee information/concern resolution processes. Furthermore, all employees receive behavior-based safety training to help them recognize and correct at-risk behavior patterns that could lead to mistakes and injuries.

- Planning: Facility OSHOM professionals review work plans and specifications to identify and eliminate or mitigate hazards.

- Emergency Planning: Emergency procedures are well documented. Emergency responders and supervisors must pass initial qualifications and routinely drill to maintain and improve their response skills. Trained personnel are available around the clock to respond to emergency situations and provide first-aid.

- Extension of OSHOM Program to Subcontractor Employees: Subcontractors working at Program facilities are required by contract to work to safety and health requirements as stringent as those implemented for Program facility employees. Subcontractor compliance with safety and health requirements is overseen by facility personnel.

- Written Requirements: Employees work to written requirements, such as manuals and procedures, which incorporate safety and health requirements.

- Routine, Independent OSHOM Evaluation: Naval Reactors Headquarters and field office personnel, as well as dedicated auditors within the facility's organization, independently evaluate OSHOM Programs. Assessments are detailed, formal, and documented; corrective actions are tracked to closure.

Hazard Assessment Systems

Methods of assessing hazards include:

- Baseline safety and industrial hygiene surveys.
- Routine self-inspection and self-appraisal programs.
- Hazard analysis, which evaluates potential hazards associated with certain job categories or specific tasks.
- Industrial hygiene monitoring programs that use state-of-the-art equipment and independent laboratory analysis in accordance with nationally recognized procedures.
- Accident investigation systems, which ensure timely review, provide written reports, and ensure responsive actions are tracked to closure.
- Preventive maintenance programs that ensure safety systems function as designed.

Worker Participation

Workers participate in various committees, internal programs, and site audits and inspections. Employees are encouraged to report their concerns to management or OSHOM staff or formally document them via an employee concern program (reference 3). Employee/management communications include followup and tracking of employee concerns and of issues identified during inspections, audits, or committee meetings.

OSHOM REQUIREMENTS

Naval Reactors Program Authority and Responsibility for Occupational Safety and Health

Under the Atomic Energy Act of 1954, the DOE is assigned authority to set and enforce occupational safety and health standards for facilities and activities covered by the Act. Within the DOE, authority to set and enforce these standards at Program facilities is assigned to the Deputy Administrator for Naval Reactors, pursuant to Executive Order 12344, Public Law 106-65 (reference 4), and 42 U.S.C. § 7158. These documents establish that the director of the Program is responsible for all matters pertaining to naval nuclear propulsion. The Program establishes and enforces OSHOM requirements at Naval Reactors DOE facilities, independent of other DOE organizations (e.g., nuclear fuel and weapons production operations). This ensures that OSHOM standards support the militarily unique training mission (discussed earlier) and that they are consistently applied and technically sound.

For nearly all other civilian workplaces, the Occupational Safety and Health Act of 1970 provides authority to set occupational safety and health standards. The OSH Act excludes from its scope activities that are regulated under separate statutory authority, such as the Atomic Energy Act discussed above. For Federal workplaces, each Federal agency (e.g., the Department of the Navy) is responsible under the OSH Act for establishing and maintaining an effective and comprehensive occupational safety and health program consistent with the OSH Act. The Navy's program and standards are documented in OPNAV Instruction 5100.23 (reference 5). Consistent with Executive Order 12344, the Program enforces the implementation of these requirements, as well as the militarily unique requirements in OPNAV Instruction 5100.19 (reference 6), at Program moored training ships and prototype training facilities.

Health and Safety Standards Reference Document (HSSRD)

To facilitate a clear definition of applicable requirements and to accomplish the difficult task of integrating civilian and Navy requirements, the Program has developed the HSSRD. The HSSRD contains a listing of all OSHOM standards to be implemented at Program facilities in each specific topical area of safety and health. The HSSRD contains a description of the primary elements of safety and health standards selected for implementation at each Program facility. It also allows the user to trace those standards to Federal regulations, DOE directives, NAVOSH program requirements, or Program directives. This document is updated as necessary to ensure that the most current standards are applied to facility OSHOM programs.

Implementation of DOE Directives and Navy Occupational Safety and Health Program Requirements

The Program uses DOE directives to set the standards for its DOE facilities. Since DOE directives are focused on non-military activities, some of the requirements may not be directly applicable to Program activities. Such requirements are modified by the Program as necessary to integrate the requirements with militarily unique systems and operations, in order to prevent conflicts with Navy training requirements and to maintain the prototypes' ship-like environment.

Because the Moored Training Ships are naval facilities, Navy occupational safety and health requirements are applied (references 5 and 6).

Occupational Medicine Program Requirements

The Program occupational medicine requirements for contractor and Federal employees at DOE facilities are consistent with the DOE's occupational medicine requirements (references 7 and 8). Occupational medicine requirements applicable to naval personnel at DOE facilities and to the Moored Training Ship facility are those of the Navy (references 5 and 6).

PERSONNEL

Contractor Health and Safety Council

The Program maintains the Contractor Health and Safety Council, whose membership includes senior safety and health professionals from each Program facility. The purposes of the Council are (1) to provide a forum in which experiences and information can be exchanged, and new safety and health initiatives can be identified and quickly implemented, and (2) to maintain the HSSRD. The Council accomplishes these functions during conferences held at least monthly. In addition, the Council meets annually with Program Headquarters personnel to review performance and establish objectives for the coming year.

Professional Staffing

Adequate professional staffing is assigned to OSHOM programs to ensure a safe and healthful workplace at all Program facilities. All key professional occupational safety and health staff personnel satisfy, at a minimum, the requirements contained in the Office of Personnel Management standards for Safety and Occupational Health Manager, Safety Engineer, or Industrial Hygienist. Each Program activity is staffed by, or has contractual arrangements with, one or more physicians who are board-certified or experienced in occupational medicine.

The Program's occupational safety and health personnel are qualified by their academic backgrounds and experience to perform workplace evaluations, technical monitoring, testing, consulting, and other essential functions of their professions. Involvement with professional organizations is supported, and facility staff hold memberships in a variety of major safety and industrial hygiene professional societies.

Professional staff hold certifications from the American Board of Industrial Hygiene and/or the Board of Certified Safety Professionals. These professionals must pass rigorous examinations to certify that they are specially trained, knowledgeable, and competent in industrial hygiene and/or safety.

The capabilities of all professional staff members are enhanced by attendance at professional technical society meetings, participation in continuing education programs at universities and other recognized training centers, and involvement with internal education and training programs developed by individual Program sites. These activities are designed to improve the safety and health professional's ability to recognize potential workplace hazards; measure, analyze, and evaluate occupational safety and health trends; and define and implement effective controls.

OSHOM managers are experienced individuals with extensive education and rigorous training that specially qualify them to manage these programs. Although these managers report to the site manager (commanding officer at the Moored Training Ship facility), their oversight role remains independent from production concerns.

The occupational safety and health professionals at Program facilities monitor the workplace, evaluate workplace hazards, implement appropriate controls, review work procedures for proper safety controls, analyze safety and health performance indicators, and maintain appropriate records. In general, however, the safety and health staff is not directly involved in site operations unless specific safety issues arise. In such cases, the safety and health staff work with the facility operations staff and Navy personnel to resolve the issue.

Operations Personnel

First-level operations supervisors, such as work-area managers and supervisors, are given primary responsibility for the safety and health of their subordinates. Operations personnel implement standards and procedures developed by the facility's safety and health professional staff. Operations personnel are provided general and job-specific safety training to enable them to identify safety hazards and unsafe work practices.

Upper-level operations management staff at Program facilities are also responsible for the safety and health of their personnel. They reinforce the importance of safety and health requirements by establishing applicable policies and objectives and assigning appropriate responsibility and authority to all levels of management and supervision.

Each operating facility also maintains a Safety Representative program, in which an individual from a work area (such as a department) serves as a safety representative. The safety representatives are given additional training, attend periodic meetings, and are tasked with monitoring their work area to identify any hazards or unsafe work practices to facility OSHOM personnel.

Naval Reactors Field Representatives

All Program facilities have a co-located Naval Reactors field office. The field office is staffed with Naval Reactors personnel who report directly to Headquarters and whose function is to ensure contractor compliance with Program requirements. The field office representatives provide independent oversight of facility operations, thereby allowing Naval Reactors Headquarters to maintain close surveillance of events occurring at the facilities. Each field office has personnel with specific responsibilities in OSHOM matters to oversee facility OSHOM programs effectively.

Navy Personnel Assigned to Naval Reactors DOE Facilities

Active-duty Navy personnel are assigned to Naval Reactors DOE prototype sites to conduct and receive training in the operation of naval nuclear propulsion plants. The safety and health of these personnel is the overall responsibility of the Commanding Officer, Nuclear Power Training Unit (located on site). Each prototype plant has safety representatives who are responsible for ensuring that safety and health requirements are implemented and followed. The safety representatives have access to, and work with, the professional safety and health staff at the facility to resolve any OSHOM issues.

The commanding officer also maintains a liaison with a nearby Naval Branch Medical Clinic, which provides occupational medicine support services to Navy personnel. The facility OSHOM personnel work with the affiliated Naval Branch Medical Clinic to ensure the safety and health of Navy personnel.

Emergency Response Capability

Each Program facility has emergency response capabilities for significant events. At each site, qualified individuals are assigned to respond to the scene of any emergency that may occur, evaluate the circumstances, and initiate appropriate corrective actions. When necessary, a separate site emergency control center is manned with personnel specially trained to handle a variety of emergencies.

Individuals are assigned to site emergency response teams on the basis of their expertise and experience. Emergency responders frequently train and drill to improve their skills and maintain their qualifications. Major drills involving the entire site emergency response team are conducted periodically; smaller drills involving limited participation are conducted more frequently.

Each operating facility has personnel qualified to provide emergency medical care. Most sites are also staffed with one or more medical doctors during day shifts. Additional groups of individuals (e.g., emergency medical technicians) are specifically trained and assigned to provide medical assistance. Each site has arrangements with a local hospital to provide emergency medical care beyond the capabilities of facility medical personnel.

HAZARD IDENTIFICATION AND ANALYSIS

Regulations, Requirements, and Technical Information

To maintain a current level of knowledge and expertise in this area, members of the occupational safety and health staff:

- Review the Federal Register and subscribe to review services to identify new or proposed regulations and determine their applicability to Program facilities. The results of these reviews are provided to OSHOM and operations personnel.

- Review and incorporate applicable safety and health requirements and lessons learned into site procedures. Such requirements and lessons learned are found in DOE and Navy safety and health bulletins and other relevant documents.

- Maintain professional certification in the fields of safety, industrial hygiene, or occupational health.

- Participate in professional societies (e.g., the American Industrial Hygiene Association, American Society of Safety Engineers, American College of Occupational and Environmental Health, and the American Association of Occupational Health Nurses) that provide information via publication of professional journals, national conferences, seminars, and society meetings.

- Discuss and resolve safety and health issues in the Naval Reactors Program Contractor Health and Safety Council conferences.

Project Evaluation

Facility projects involving work that could affect the safety and health of personnel are reviewed and evaluated by the respective facility safety and health organization. These evaluations typically involve review of the work project from initial concept through the development of detailed work procedures or construction plans and technical specifications. One of the primary functions of this conceptual review is to identify alternate methods or materials that can eliminate or reduce the hazards associated with the project under review. Safety and health personnel must signify that applicable safety and health practices are integrated into written work procedures and must ensure that all applicable fire and life safety code requirements are satisfied.

The qualifications and work practices of subcontractors to perform specific facility project work are evaluated by safety and health personnel to ensure that subcontractor work meets Program standards. The safety and health standards that subcontractors must use are incorporated directly into the contractual requirements set forth in requests for proposals and purchase orders.

Procurement Reviews

Each Program facility has a formal system to evaluate equipment and chemicals proposed for purchase to minimize or eliminate safety and health hazards. This system includes approval by safety and health organizations of requests for materials or new equipment. Material Safety Data Sheets (MSDSs) for all products or materials proposed for use are reviewed by the facility's safety and health organization before their initial use. This allows facility safety and health personnel to identify potential hazards and specify proper protective measures to reduce these hazards.

Hazard Analyses

Hazard analyses, such as job safety analyses or task analyses, are processes used throughout the Program to review work practices and identify concerns associated with overall work procedures.

Various job categories or facets of complex jobs are evaluated to identify potential hazards. Once potential hazards are identified, actions are taken to minimize the hazard and communicate appropriate precautions. Cognizant supervisors are responsible for ensuring that hazards are addressed and that corresponding tasks, equipment, or material changes are implemented. Safety and health professionals may help supervisors prepare hazard analyses, and in all cases shall review them for accuracy and completeness.

Hazard analyses are used in training individual employees, preparing for planned safety observations, reviewing job procedures, and studying the job for improvements in safety and health methods. Whenever a significant safety or health issue arises, further analyses are conducted; procedures may be altered to incorporate the lessons learned.

Pertinent information is forwarded to the occupational medicine department for use in evaluating the workplace environment and/or hazards applicable to each employee.

Industrial Hygiene and Medical Workplace Hazard Evaluations

The basic elements of industrial hygiene and occupational medicine workplace hazard evaluations at Program facilities include:

- Use of appropriate exposure limits established by the Navy Occupational Safety and Health (NAVOSH) program, Occupational Safety and Health Administration (OSHA), and American Conference of Governmental Industrial Hygienists (ACGIH) (references 5, 6, 9, and 10).

- Regular worksite assessments by industrial hygiene and medical staff to evaluate potential health hazards.

- Documented review of materials, processes, work practices, and procedures used on specific jobs to determine hazard exposure potentials. These reviews determine specific job tasks that warrant routine or non-routine exposure monitoring, the use of personal protective equipment, or development of standardized work procedures to characterize and mitigate hazard exposure.

- Establishment of workplace exposure monitoring programs that characterize potential hazard exposures during normal job activities throughout the facilities. Exposures are determined using standard exposure monitoring protocols as defined by the National Institute of Occupational Safety and Health (reference 11) and other recognized formats.

- Submission of validated exposure data to the occupational medical staff for evaluation and incorporation into DOE facility personnel medical records. For Navy personnel, relevant exposure data are sent to the Naval Branch Medical Clinic for inclusion in personnel medical records.

- Feedback to supervisory and management personnel on the results of employee exposure evaluations and monitoring so that procedural changes can be made if required.

- Medical examinations of personnel, based on potential exposures determined by the processes noted above.

Trend Analysis

Injury/illness documentation, medical records, and other records are reviewed frequently to ensure problem areas are identified and corrective actions are appropriate. At Program DOE facilities, injury and illness data for civilian personnel and subcontractors are compiled quarterly and submitted to the DOE. Accident reports for naval personnel at DOE facilities and at the Moored Training Ship facility are submitted to the Navy in accordance with NAVOSH requirements (references 5 and 6).

Analyzing trends is one of the most effective ways to identify problem areas and institute appropriate corrective measures to reduce accidents. Evaluations of each reportable occurrence are factored into continual trend analysis by process/operation, type of injury/illness, or any other categorization needed to focus improvement actions at the root causes. In addition, workers' compensation records and medical clinic records provide supplemental accident history, which may be used in reviewing injuries and illnesses. Following review, corrective actions (such as procedure revision, evaluation of work practices, additional training, and/or hazard analysis updating) are taken. Program facilities analyze even minor injury/illness events so that improvements may be implemented to prevent more serious injuries.

Critiques and Event Reporting

The Program evaluates and/or critiques significant events that caused or could have caused injury to personnel. Critiques are formal evaluations of an event conducted by qualified individuals at each facility, with Naval Reactors field office personnel in attendance. Pertinent facts are reviewed and corrective actions are established and documented. For more serious events, and for events that have Program-wide significance, formal reports are issued and reviewed by Naval Reactors Headquarters.

The Contractor Health and Safety Council conducts frequent teleconferences so that facilities may discuss health and safety events and lessons learned from those events.

HAZARD CONTROL

OSHOM Manuals

All Naval Reactors Program facilities have written procedures defining programs to control potential safety and health hazards. These procedures are compiled into each facility's safety, industrial hygiene, and occupational medicine manuals. Operations personnel prepare detailed written operating procedures and maintenance/repair manuals that incorporate safety and health procedures from these OSHOM manuals.

New Employee Indoctrination

Program facilities indoctrinate all new employees in occupational safety and health matters. This training includes facility safety instructions, procedures for reporting injuries and concerns, employee responsibilities, personal protective equipment, introduction to the facility's OSHOM program, and an overview of various facility emergency procedures.

Hazard Communication and Awareness Training

Hazard communication programs train workers to recognize workplace hazards through chemical labeling, manufacturer's material safety data sheets, and discussions of hazards associated with certain job tasks or work areas. Hazard communication programs also train workers in the appropriate protective measures needed to minimize exposure to identified hazards.

In addition to hazard communication programs, awareness training is conducted to sensitize workers to look for and correct unsafe practices that could result in injury. Awareness training emphasizes and reinforces the concept that thoughtful action and attention to detail will significantly reduce the chance of personal injury.

Continuing Training Programs

Training on OSHOM programs, as well as on many other aspects of each employee's job assignment, is regularly conducted at Program facilities. Continuing training provides updates on new requirements and ensures necessary skills and qualifications are maintained.

Navy Student and Instructor Training

Navy students and their instructors make up a large portion of the Program population at the New York prototype site and the majority of the population at the Moored Training Ship facility in South Carolina. The rigorous training and qualification program for all naval nuclear propulsion plant operators includes key shipboard occupational safety and health requirements such as electrical safety, chemical use, emergency response actions, protective equipment, lock-out/tag-out, and other related safety requirements.

Informational Bulletins

Informational bulletins (including DOE and Navy newsletters, training course schedules, defective materials notifications, and other sources of OSHOM news) are distributed to Contractor Health and Safety Council members and the Naval Reactors field offices. These bulletins help Council members stay up to date with the latest OSHOM developments and pass this information on to facility personnel. Each facility subscribes to a number of OSHOM publications.

Safety Representatives/Observers

Each Program facility has a safety representative or observer program. Safety representatives perform work area surveillances and submit written reports to work area management for improvement actions. These representatives also act as a conduit through which other employees express concerns. Employee suggestions are actively solicited and evaluated for potential implementation. Representatives meet regularly to receive training, discuss concerns, and provide the OSHOM staff and operations management with recommendations for improvements to facility OSHOM programs.

Concern Reporting

All Naval Reactors facilities have a civilian employee concerns program in place (reference 3). Employee concerns programs enable employees to raise safety and health concerns to the attention of management or occupational safety and health departments for corrective actions. Under these programs, employees may choose to report concerns anonymously. If the employee chooses not to report anonymously, the employee is informed of the status of corrective actions associated with the concern.

If an employee is not satisfied with the problem resolution, the concern will proceed to the next higher level of management. If the employee is not satisfied with the resolution from the facility management chain, a procedure is in place to file concerns directly with Naval Reactors field office representatives. Employees may also bypass the management chain and file concerns directly with DOE.

Navy personnel concerns are handled through the military chain of command (references 5 and 6).

Tracking and Followup Systems

All Program facilities have a systematic process for ensuring the prompt resolution of safety and health issues. Safety and health hazards are corrected immediately, if possible, or stabilized to minimize associated hazards and then formally documented for tracking until final resolution. To ensure that all issues are resolved promptly, open issues are prioritized by hazard severity, and appropriate time limits are assigned to complete corrective actions.

Subcontractor Performance at Program Facilities

Each Program facility has procedures established for subcontractor work, including bidding, specification, and oversight requirements. Subcontractors performing work at Program facilities are required by contract to comply with the same safety and health standards normally invoked at those facilities.

A multi-year subcontract has been placed with Electric Boat Corporation to complete prototype inactivation work at the Knolls Atomic Power Laboratory site in New York. This subcontractor has extensive experience in the construction and servicing of naval nuclear-powered vessels. In addition to the oversight provided by the prime contractor responsible for site operations, this subcontractor employs full-time, onsite safety and health professionals who implement OSHOM programs for their work analogous to those instituted by the primary contractor. Additional subcontractors are also used at Program sites to complete construction projects and perform maintenance work that exceeds the capabilities of in-house work forces.

All subcontractors at Program facilities are responsible for the safety and health of their employees and their subcontractors, and for taking corrective action on safety and health deficiencies resulting from their operations.

Subcontractor Worksite Overview

Subcontractors performing work at Program facilities are responsible for indoctrinating their personnel on all safety and health requirements, and on any job-specific requirements. The facility safety and health organization may assist in these indoctrinations. All subcontractors are required to assign one of their employees as a safety coordinator. For major subcontractors, full-time health, safety, and/or medical professionals may be required, and regular formal meetings between the subcontractor and various site organizations are held.

For each subcontract, there is a qualified facility employee who is responsible for day-to-day oversight and coordination of subcontractor operations. In addition to tracking the progress of the work, this individual checks the adequacy of the subcontractor's safety and health programs. Each facility's safety and health organization also monitors the subcontractor's compliance by conducting inspections and assessments of work areas. Corrective actions are formally communicated to the subcontractor and tracked in the same way as other such actions at the facility.

HEALTH EVALUATION, DIAGNOSIS, AND TREATMENT

The occupational medicine programs at Program sites are integrated into operations to ensure adequate assessment of factors that affect personnel health and well being. Each facility's occupational medicine program elements are documented in the respective site's occupational medicine plan and include routine employee health examinations, as well as diagnosis and treatment of occupationally related injury or illness.

Employee Health Examinations

Regular, routine health examinations are given to facility employees in order to:

- Determine whether the employee's physical and mental health are compatible with the safe and reliable performance of assigned job tasks, including compliance with the Americans with Disabilities Act of 1990 (reference 12).

- Detect evidence of illness/injury and determine if there appears to be an occupational relationship.

- Contribute to employee health through prevention or early detection and treatment of occupationally related injury or illness.

Comprehensive health examinations are conducted by a licensed physician or by an Occupational Health Examiner under the direction of a licensed physician, in accordance with current accepted medical practices.

Routine health examinations/evaluations occur throughout an employee's career under the following circumstances:

- Preplacement Evaluation — Medical evaluations of job applicants are conducted before initial performance of job duties and, in the case of current employees, before a job transfer. The health and fitness for duty of individuals are determined to ensure that assigned duties can be performed safely and reliably. Evaluations include review of applicable hazard analyses pertaining to the applicant/employee.

- Medical Surveillance Examinations and Health Monitoring — Special health examinations and health monitoring are conducted for employees who work in jobs involving specific physical, chemical, or biological hazards.

- Qualification Examinations — Examinations are conducted to qualify employees for job assignments for which specific medical qualification standards exist (e.g., special vehicle drivers, protective force personnel, and respirator wearers).

- Voluntary Periodic Examinations — Voluntary periodic examinations are offered to employees. The frequency and type of examination offered are determined by the individual's age and work exposures.

- Return to Work from Occupational Injury or Illness — All employees with occupationally related injuries or illnesses are evaluated before they may return to work. The scope of this evaluation is determined by the Occupational Health Examiner based on the nature and extent of the injury or illness and is designed to ensure that the employee may return to work without undue health risk to himself or herself, or to others.

- Return to Work from Non-occupational Injury or Illness — Employees with significant non-occupationally related injuries or illnesses are evaluated before returning to work. The scope of the evaluation is dependent upon the nature of the injury or illness, and is undertaken to ensure that the employee may return to work without undue risk to himself or herself, or to others.

- Termination Health Evaluations — For employees leaving the Program, a health examination is given, whenever possible, to those who have known occupational illnesses or injuries; to those with documented or presumed exposures requiring evaluation by OSHA regulations (reference 9); or to those who have not been examined for more than a year. A health status review is available for all terminating employees.

Diagnosis and Treatment of Injury or Illness

All occupational injuries or illnesses, no matter how slight, are evaluated by medical personnel. Diagnosis and treatment of occupational injury or illness is prompt, emphasizing rehabilitation and return to work at the earliest time compatible with employee health and job safety.

A close liaison exists between the medical and safety/health communities to ensure that the causes of occupational injury or illness are fully evaluated and promptly acted upon.

Medical Services for Navy Personnel

Medical evaluation and care for Navy personnel are the responsibility of the local Naval Branch Medical Clinic. Immediate and emergency medical treatment for injuries or illnesses at DOE sites is provided by the facility medical staff, with immediate followup consultation with Navy medical personnel. If further diagnosis or treatment is warranted, the patient will be transported to a nearby military or civilian medical facility. Followup medical treatment or evaluation is provided by naval medical services.

Communication between DOE prototype facility personnel and naval medical staff is coordinated through the Commanding Officer, Nuclear Power Training Unit, located at that facility. Navy medical staff visit the Program DOE facilities periodically and communicate directly with facility medical staff as appropriate to assist in the treatment of naval personnel.

At the Moored Training Ship facility, personnel are served by the onsite medical department and by the Naval Branch Medical Clinic on Charleston Naval Weapons Station.

ACCOUNTABILITY

Independent Overview and Investigation

Naval Reactors field offices conduct frequent inspections and audits of OSHOM Programs to ascertain compliance with applicable requirements, to determine strengths and weaknesses, and to identify areas for improvement. These audits are complemented and augmented by a biennial program review by Naval Reactors Headquarters personnel and representatives from other Naval Reactors field offices.

If significant safety or health events concerning civilian or Navy personnel at Program facilities occur, a formal independent investigation board is convened that includes senior personnel knowledgeable in the topical area and Naval Reactors field office or Headquarters personnel (references 5, 6, and 13). Such a board typically involves several man-weeks of factfinding and evaluation.

General Accounting Office Evaluation

In the late 1980s allegations were made concerning environmental, health, and safety practices at some Program facilities. Allegations involved employee overexposure to radiation, unsafe reactor design, problems with asbestos work practices, and improper radioactive and hazardous waste disposal. In response to these allegations, the Chairman of the House Environment, Energy, and Natural Resources Subcommittee, House Committee on Government Operations in 1989 requested a comprehensive General Accounting Office review of the Program's environmental, safety, and health practices. The review of Program facilities focused on:

- Worker health and safety.
- Radiological controls.
- Reporting.
- Environmental compliance.
- Reactor safety.
- Adequacy of oversight.
- Classification of information to prevent disclosure of problems.

The GAO had unrestricted access to documents, facilities, and personnel within the Program, and talked in confidence with anyone who wished to discuss concerns during their 14-month investigation. In 1991, following the review, the GAO testified in a joint hearing before the Department of Defense Nuclear Facilities Panel and the Seapower Subcommittee of the House Armed Services Committee.

In their testimony and report, the GAO said:

> [From the reference 14 testimony] In the past we have testified many times before this Committee regarding problems in the Department of Energy. It is a pleasure to be here today to discuss a positive program in DOE. In summary, Mr. Chairman, we have reviewed the environmental, health, and safety practices at Naval Reactors laboratories and sites and have found no significant deficiencies.
>
> . . . .
>
> [W]e were given full and complete access to all classified and other information needed during our work. We reviewed thousands of classified documents and could find no trend or indication that information was classified to prevent public embarrassment.
>
> [From the reference 15 report] GAO's review of specific environmental and safety programs at Naval Reactors facilities show no basis for allegations that unsafe conditions exist there or that the environment is being adversely affected by activities conducted there.

Given the breadth and depth of the GAO review, their conclusion represents a strong independent endorsement of the excellence and effectiveness of OSHOM programs at Program facilities.

Internal Overview and Self-Appraisals

OSHOM organizations at each Program facility perform frequent and detailed inspections to determine how well the facility's operating personnel are implementing OSHOM programs. Similarly, the OSHOM organizations self-assess their own activities and programs to identify areas for improvement. The minimum acceptable standard of performance is full compliance with applicable rules, regulations, and standards as defined in the HSSRD.

MEASURES OF PERFORMANCE

Program facilities track numerous performance indicators to measure OSHOM effectiveness. The indicators used are consistent with those employed by general industry and the DOE. These indicators are developed using criteria established by OSHA and supplemented by the Bureau of Labor Statistics (BLS) in their Recordkeeping Guidelines (reference 16). The data provided for general industry, based on BLS criteria, were obtained from BLS (reference 17). BLS data for 2005 are not currently available. Effective January 1, 2002, OSHA established new occupational injury and illness reporting criteria (reference 16). Based on this change, figures 2 and 3 have been changed to restricted workday case rate and days away from work case rate (in lieu of lost workdays and lost workday case rate). Although different from previous years' reports, these statistics provide a standard measure of the Program's trends relative to the DOE and general industry. The DOE data in figures 1-3 in this report are taken from injury and illness data as presented by the DOE (reference 18).

Fatalities

The Program has experienced no occupationally related fatalities of civilian or military personnel resulting from current operations at its facilities for the 5 years covered by this report and has experienced three fatalities (all of which were subcontractor personnel) since the passage of the OSH Act in 1970. Two of the fatalities were due to falls; the third was an onsite suicide.

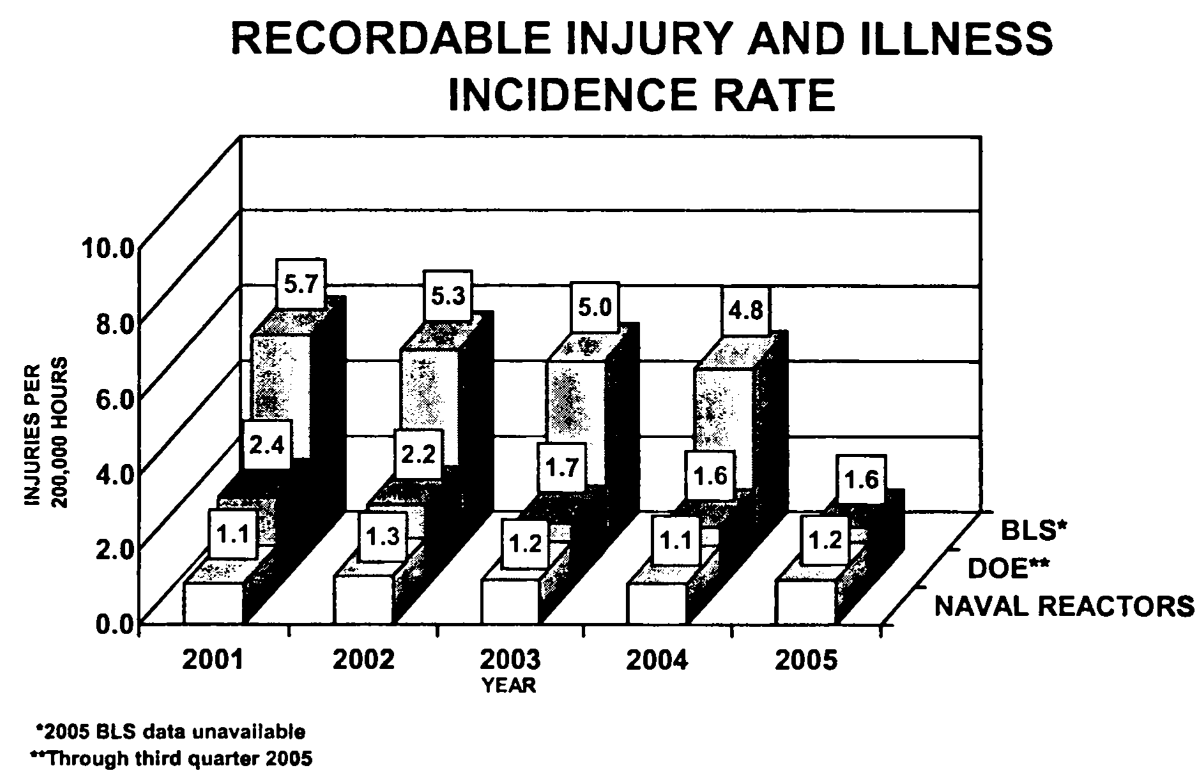


Figure 1

Recordable Injury and Illness Incidence Rate

The total recordable injury and illness incidence rates for the civilian work force in the Naval Reactors Program[1], DOE, and general industry (BLS) are shown in figure 1. As shown by figure 1, the Program's injury and illness rates have remained lower than the comparable DOE rates and substantially lower than the BLS total industry rates.

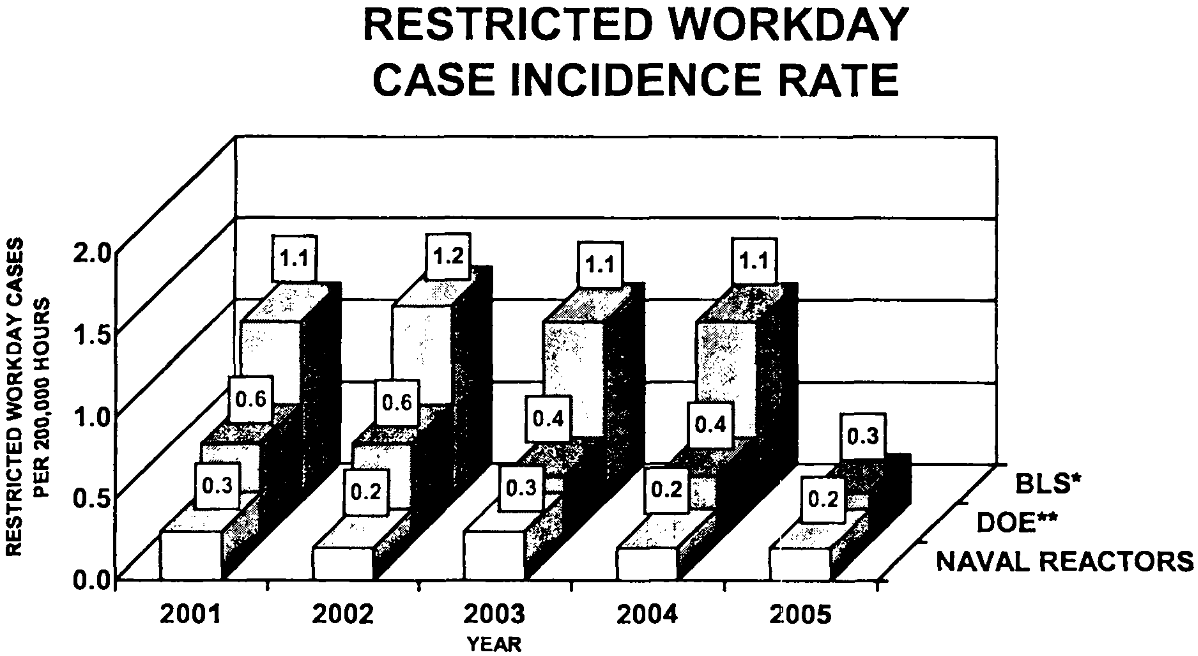


Figure 2

Restricted Workday Case Incidence Rate and Days Away From Work Case Incidence Rate

The BLS recording criteria require the recording of all cases involving work-related injuries or illnesses that need treatment beyond first aid. However, this does not indicate the severity of an injury or illness; it merely shows that an injury or illness has occurred. For example, a cut requiring sutures, a broken arm, or a disabling back injury is not distinguishable in the reporting system; each of these would be counted as one injury in the reported data. The severity of recordable cases is indicated by two other means: the number of cases that cause individuals to have their work activity restricted and the number of cases that require one or more days away from work.

Injuries and illnesses reported in the Program are generally minor, such as cuts and abrasions, and require little or no time lost from work. Figure 2 shows the Program, DOE, and general industry (BLS) rates of occupational injury or illness cases that caused individuals to have their work activity restricted one or more workdays. Figure 2

[1]Naval Reactors Program civilian workforce data in figures 1-4 consist of data for civilian prime contractor and subcontractor personnel.

includes cases that have only restricted days. (If the cases have days away from work and restricted days, the cases are in figure 3.) Figure 2 shows that the Program's restricted workday case incidence rates are lower than the DOE rates and substantially lower than the BLS general industry rates.

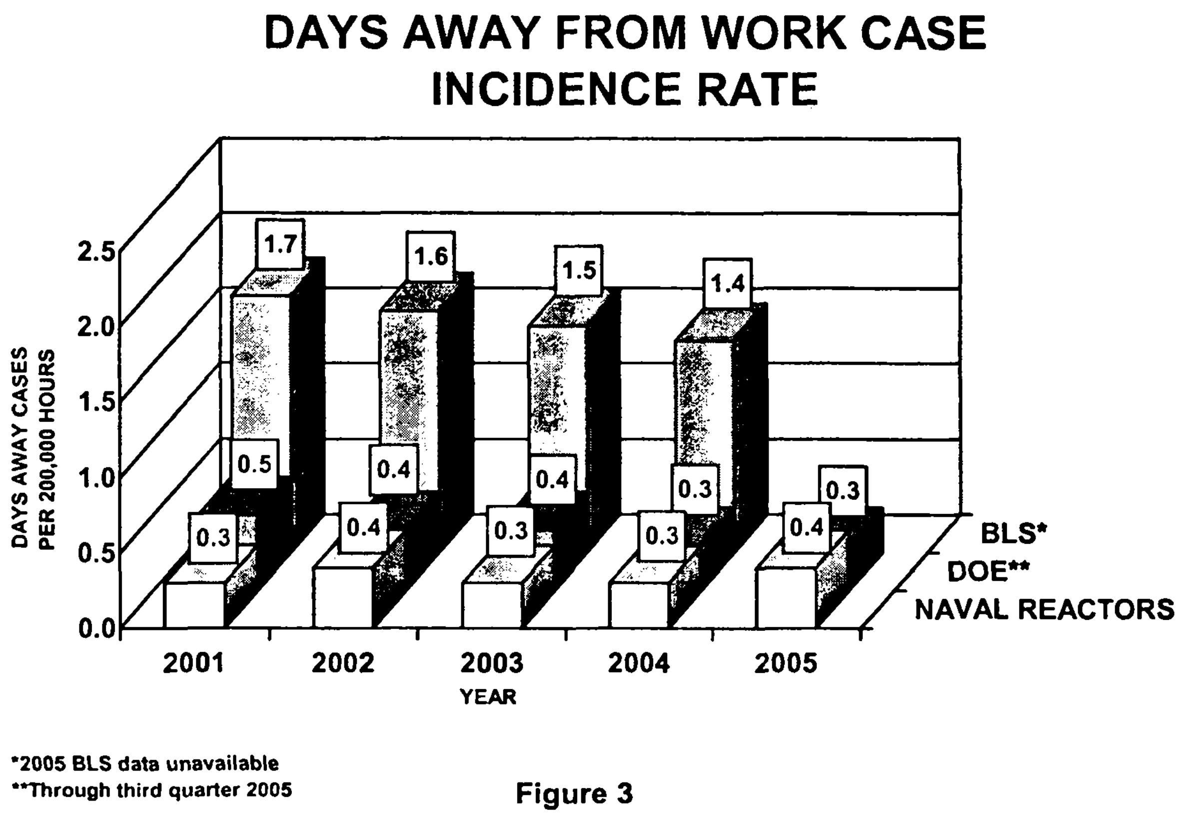


Figure 3

Figure 3 shows the rates of days away from work cases. These cases resulted in one or more days away from work due to occupational injuries and illnesses. This figure shows that the rate of days away from work cases at Program facilities is generally consistent with the DOE rates and significantly below that of general industry.

Because significant differences exist between Navy injury and illness reporting criteria and the BLS criteria (e.g., the Navy has a higher threshold than that used by the BLS), combining civilian and military injury and illness data is not meaningful, nor is it a direct comparison of Navy performance indicators (reference 19 and 20) to DOE or BLS indicators. Therefore, the data for the Naval Reactors Program shown in figures 1-3 do not include Navy personnel.

However, the Program tracks active-duty Navy personnel injury and illness recordable case rates and lost workday case incident rates using the BLS criteria. For 2005, the injury and illness recordable incidence rate for Navy personnel at Program facilities was 1.1 per 200,000 hours worked. The restricted workday case incidence rate was 0.2 cases that required one or more restricted workdays per 200,000 hours worked. The days away case incidence rate was 0.2 cases that required one or more days away from work per 200,000 hours worked.

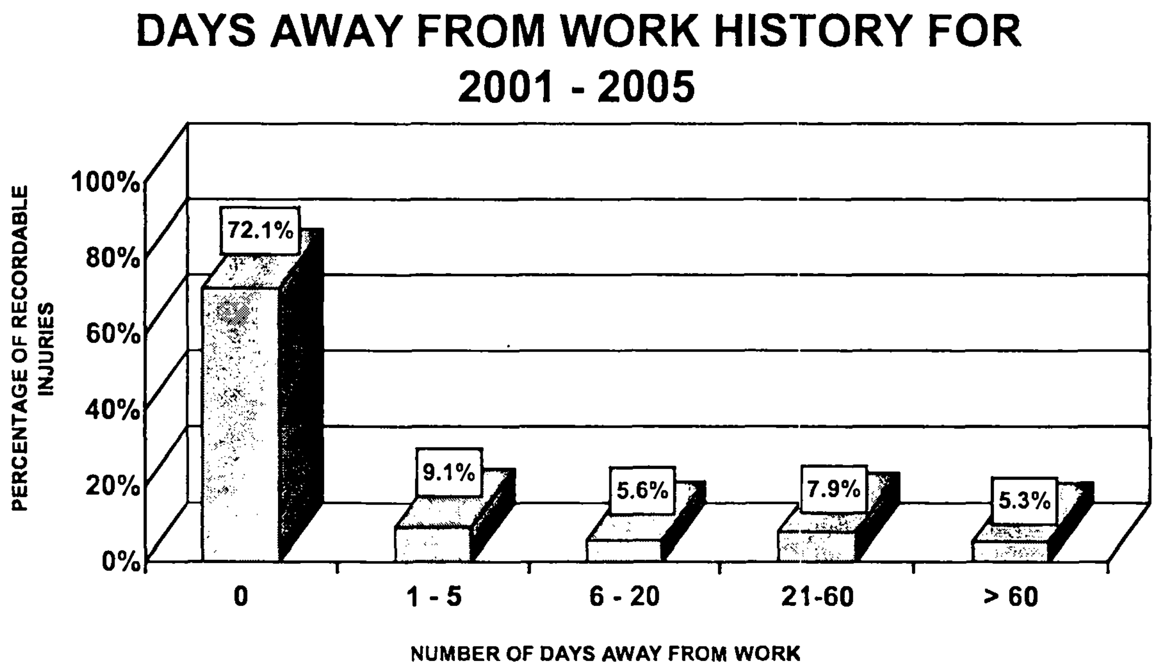


Figure 4

History of Cases Involving Days Away From Work

A further indication of Program injury and illness severity comes from a review of the history of cases resulting in days away from work (excluding cases with only restricted workdays). Figure 4 shows the Program's history of recordable injury and illness cases that were reported from 2001 to 2005 and the corresponding number of days away. As shown in figure 4, about 81 percent of all recordable injuries and illnesses resulted in either no days or fewer than 6 days away from work.

Accident Investigations

The Program participates in a DOE formal, structured process to evaluate serious accidents involving civilian or military personnel at Program DOE facilities. These events are categorized and investigated depending on the nature and severity of the occurrence. Type A accidents are the most severe, involving fatalities, major radiation exposures, or damage to property or the environment. Type B accidents have less severe consequences in the same general criteria. A third category is for less serious events subject to routine investigation by contractor personnel (reference 22). A similar classification system exists in the Navy's NAVOSH program (references 5 and 6).

No Type A accident investigations were conducted during the 5 years covered by this report. During this same period, one Type B accident investigation was conducted. This compares to 12 Type A and Type B accident investigations for such events at DOE-wide operations during the 3-year period ending in 2003 as reported by DOE (reference 21). Note that 2004 and 2005 DOE data on Type A and Type B accident investigations were not available at the time of printing.

The one Type B accident investigation involved a personnel injury that occurred on February 17, 2004, at the Bettis Atomic Power Laboratory in Pittsburgh, Pennsylvania. The injury occurred when an employee tripped and fell on uneven pavement in an area of the employee parking lot designated as a pedestrian walkway. The resulting minor injuries, originally requiring only first-aid treatment, are believed to have aggravated pre-existing medical conditions. Medical complications ensued that resulted in an extended hospital stay for intensive medical treatment and physical rehabilitation.

Another significant accident occurred in the Program during the period covered by this report. Although the damage associated with this accident did not meet the DOE criteria for an official Type A or Type B investigation (reference 13), the Program nevertheless concluded that a formal accident investigation was warranted. On September 11, 2002, four improperly braced concrete wall panels from a building under construction by a subcontractor at Knolls Atomic Power Laboratory fell during high winds. There were no injuries. Damage was limited to the panels that fell and to the wall of an adjacent warehouse that was struck by two of the panels.

As a result of these events and the lessons learned, corrections have been implemented at all Program sites to improve worker safety.

REFERENCES

(1) U.S. Navy Report, "Occupational Radiation Exposure from U.S. Naval Nuclear Plants and Their Support Facilities," T. J. Mueller, et al., NT-06-2, March 2006.

(2) U.S. Department of Energy Report, "Occupational Radiation Exposure from Naval Reactors' Department of Energy Facilities," T. J. Mueller, et al., NT-06-3, March 2006.

(3) U.S. Department of Energy Order 442.1A, "Department of Energy Employee Concerns Program."

(4) Presidential Executive Order 12344, Feb. 1, 1982, set forth in Public Law 106-65 of October 5, 1999 (50 U.S.C. § 2406).

(5) OPNAV Instruction 5100.23, "Navy Occupational Safety and Health (NAVOSH) Program Manual."

(6) OPNAV Instruction 5100.19, "Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat."

(7) U.S. Department of Energy Order 440.1A, "Worker Protection Management for DOE Federal and Contractor Employees."

(8) U.S. Department of Energy Order 341.1, "Federal Employee Health Services."

(9) Code of Federal Regulations Title 29 (Labor) Parts 1910, "Occupational Safety and Health Standards" and 1926, "Safety and Health Regulations for Construction."

(10) American Conference of Governmental Industrial Hygienists, "Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices," current edition.

(11) National Institute for Occupational Safety and Health, "NIOSH Manual of Analytical Methods."

(12) Americans with Disabilities Act of 1990, Title 1 "Employment Provisions."

(13) U.S. Department of Energy Order 225.1A, "Accident Investigations."

(14) GAO/T-RCED-91-24, "Environmental, Health and Safety Practices at Naval Reactors Facilities," GAO Testimony.

(15) GAO/RCED-91-157, "Environmental, Health and Safety Practices at Naval Reactors Facilities," GAO Report.

(16) OMB Report No. 1220-0029, "Recordkeeping Guidelines for Occupational Injuries and Illnesses." (2001).
29 CFR 1904, "Recording and Reporting Occupational Injuries and Illnesses." (2002-2005).

(17) U.S. Department of Labor, Bureau of Labor and Statistics, "Table 1, Incidence Rates of Nonfatal Occupational Injuries and Illnesses by Industry and Case Types." (As of 10 January 2006).

19 December 2002: http://stats.bls.gov/iif/oshwc/osh/os/osnr0016.pdf

18 December 2003: http://stats.bls.gov/iif/oshwc/osh/os/osnr0018.pdf

14 December 2004: http://stats.bls.gov/iif/oshwc/osh/os/osnr0021.pdf

17 November 2005: http://stats.bls.gov/iif/oshwc/osh/os/osnr0023.pdf

(18) U.S. Department of Energy, "DOE and Contractor Injury and Illness Experience By Year and Quarter, 2000-2005 3rd Quarter." 10 December 2005. http://www.eh.doe.gov/cairs/cairs/dataqtr/menu.html (As of 10 January 2006).

(19) "Department of Navy Occupational Safety and Health Program, Fiscal Year 2004 Annual Agency Report." Assistant Secretary of the Navy.

(20) Naval Safety Center, Statistics Division, "Fatality/Injury Mishap Report Card" and "NAVOSH Report Card." http://safetycenter.navy.mil/osh/downloads/RC92-02.xls

(21) U.S. Department of Energy Report, "2003 Annual Environment Safety and Health Report." Office of Environment, Safety and Health, June 2004.

(22) U.S. Department of Energy Order 231.1A, "Environment, Safety, and Health Reporting."