

APPENDIX E

RADIOLOGICAL INVESTIGATIONS

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Attachment

E1	DRAFT FINAL PHASE III RADIATION INVESTIGATION REPORT
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ABBREVIATIONS AND ACRONYMS

AEC	U.S. Atomic Energy Commission
bgs	Below ground surface
EPA	U.S. Environmental Protection Agency
FUDS	Formerly Used Defense Site
GPS	Global positioning system
HLA	Harding Lawson Associates
HPS	Hunters Point Shipyard
IAS	Initial Assessment Study
NaI	Sodium iodide
NAREL	National Air and Radiation Environmental Laboratory
Navy	U.S. Department of the Navy
NRC	U.S. Nuclear Regulatory Commission
NRDL	Naval Radiological Defense Laboratory
pCi/g	picoCuries per gram
PRC	PRC Environmental Management
RASO	Radiological Affairs Support Office
RI	Remedial Investigation
RSS	Radiological Safety Section
SCRS	Surface confirmation radiation survey
SUPSHIP	Supervisor of Shipbuilding, Conversion, and Repair
Triple A	Triple A Machine Shop
U.C.	University of California
WESTEC	WESTEC Services, Inc.
yd ³	Cubic yard
μCi	microCurie

1.0 INTRODUCTION

Hunters Point Shipyard (HPS) was a center of shipbuilding and ship repair during World War II. Pure and applied radiological research performed by the Naval Radiological Defense Laboratory (NRDL) also played a major role in HPS history. These activities at HPS resulted in the routine use, storage, and disposal of radioactive materials. Two radiological concerns exist at HPS: (1) disposal of radium-containing devices generated during ship repair and maintenance activities, and (2) residual radioactive contamination resulting from former NRDL activities. The U.S. Department of the Navy (Navy) performed a three-phased radiological investigation at HPS to address these concerns. Phases I and II investigated the surface and subsurface extent of radium-containing devices present at HPS. Phase III investigated the former NRDL sites at HPS.

Section 1.1 presents a history of the disposal of radium-containing ship devices at Parcel E. Section 1.2 presents a history of NRDL activities at HPS. Section 2.0 describes the radiological investigations conducted at Parcel E. Section 3.0 presents conclusions of the radiological investigations at Parcel E. References are provided at the end of the document.

1.1 HISTORY OF THE DISPOSAL OF RADIUM-CONTAINING DEVICES AT PARCEL E

Areas at HPS where radium-containing devices may have been disposed or deposited due to movement of fill material consist of the Industrial Landfill (IR-01/21), the Bay Fill Area (IR-02), and the Oil Reclamation Ponds (IR-03). IR-01/21, located on the southwest shoreline of HPS, has historically been used as the disposal area for industrial waste generated at HPS. The Bay Fill Area (IR-02) is a large site comprising most of the southern shoreline of HPS. The southeastern portion of the Bay Fill Area (IR-02 Southeast) was used as a burn disposal area and was the location for an aboveground fuel oil storage tank. The central and northwestern portions of the Bay Fill Area (IR-02 Central and IR-02 Northwest, respectively) were used primarily as storage areas for construction materials and as disposal areas for construction and industrial debris. The boundaries of the Oil Reclamation Ponds (IR-03) lie within the Bay Fill Area. Because the land areas of IR-01/21, IR-02, and IR-03 were created with Artificial Fill, they are often referred to as "landfill" areas in historical documents; the ambiguity of this term has led to confusion in historical documents between the Industrial Landfill and the Bay Fill Area.

The Navy created most of the Parcel E land area by filling in the Bay margin with quarried materials consisting primarily of serpentinite bedrock from the HPS peninsula (PRC Environmental Management, Inc. [PRC] 1996b). Other materials used to create the landfills were not well documented but may have included sands, gravels, construction debris (such as brick, concrete, and wood), industrial debris (such as metal pipes, plastics, and tires), and sandblast waste (PRC 1996c). In addition, IR-01/21 and IR-02 Northwest have been extensively filled with waste generated during HPS industrial activities (PRC 1996a).

The filling history of the Parcel E land area is not well documented. Aerial photographs indicate that filling of the Bay began in the 1940s (PRC 1996b). However, aerial photographs for the years between 1938 and 1948 that would assist historical reconstruction of landfill placement activities have not been located (PRC 1996a). Review of available aerial photographs taken of HPS over the past 60 years indicates that the majority of the IR-02 land area was established by 1946 (PRC 1996c). Review of available aerial photographs also indicates that the eastern portion of the IR-01/21 land area was filled in the 1940s and that the western portion was filled primarily during the 1950s (PRC 1996b). A wide slough at IR-01/21 originally extended from the Bay to the north corner of the site; between 1958 and 1974, the Navy filled this slough area with industrial waste and construction debris (WESTEC Services, Inc. [WESTEC] 1984).

Photographic evidence indicates that IR-02 Northwest was used by the Navy as a disposal site for industrial waste. Aerial photographs taken during the period from 1948 to 1958 indicate that soils in this area were disturbed by periodic disposal activities; early Navy maps show this area at IR-02 Northwest referenced as the "disposal dump area" (PRC 1996a). In addition, Triple A Machine Shop (Triple A) excavated a disposal trench for solid and liquid industrial waste in the IR-02 Northwest area in the late 1970s; these activities may have uncovered and brought to the ground surface materials previously buried by the Navy at IR-02 Northwest (PRC 1996a).

Historical accounts indicate that during routine maintenance operations on Navy ships and submarines, unserviceable radium-containing devices were removed and disposed of at Parcel E (PRC 1996c). These devices included luminescent instrument dials, gauges, deck markers, and other electronic equipment components. Prior to the 1970s, most radium-containing devices used by the military contained radium-226 mixed into a phosphorescent paint base. The paint, which was applied to numerals and markers on ship equipment, produced a dull glow that made it easy to read instruments at night without additional

lighting. Until the late 1960s, it was common industrial practice to dispose of unserviceable radium-containing devices by shallow land burial (PRC 1996a).

The initial assessment study (IAS) performed at HPS in 1984 consisted of a visual site inspection and review of Navy and historical documents. The IAS report stated that 6,000 pounds of radium-containing devices were removed from ships during repair and maintenance activities and disposed of at the Industrial Landfill (IR-01/21) (WESTEC 1984). This finding was based on Navy records or other information that indicated disposal of the dials in the "landfill" area at Parcel E. Subsequent studies at Parcel E revealed that radium-containing devices were disposed of at the disposal dump area in IR-02 Northwest, rather than at IR-01/21 as reported in the IAS report (PRC 1996c). Section 2.0 of this appendix presents additional information on the location of this area.

Over time, buried radium-containing devices may decompose and release radium-226 into the environment. The radioactive decay of radium-226, which primarily emits alpha radiation, produces gamma-emitting radioactive daughters such as bismuth-214, lead-210, and lead-214. Buried radium-containing devices are commonly located using gamma spectroscopy to detect the gamma radiation emitted by these daughters. A device containing 1 microcurie (μCi) of radium-226 can usually be detected to depths of 1 foot below ground surface (bgs) using gamma spectroscopy.

During remedial investigation (RI) activities conducted by Harding Lawson Associates (HLA) in 1988, a preliminary surface radiation survey was performed to determine if elevated levels of radiation were present that would pose an exposure risk to RI field workers (HLA 1990). Measurements of beta, gamma, and X-ray radiation were obtained at surface locations at IR-01/21, IR-02, and IR-03. Measurements were also obtained at other HPS and San Francisco Bay area locations to determine background levels. Anomalously high gamma radiation readings were only observed within an area of IR-02 Northwest characterized by surface debris and machinery parts. These anomalies were observed at small, isolated locations, suggesting the presence of discrete point sources of radioactivity such as buried radium-containing devices (HLA 1990). Although the anomalous measurements were mapped, later use of the map was difficult since no permanent markers had been placed on the site (PRC 1992). Additional investigation of these surface anomalies was recommended.

In 1991, prior to the start of additional investigations, trenching activities were performed at Parcel E to delineate landfill boundaries. During these activities, buried slag-like materials exhibiting alpha and gamma activity were discovered (PRC 1992). Field gamma spectroscopic analysis performed by the U.S.

Department of Energy determined that radium-226 was the source of radioactivity in these materials (PRC 1992). The slag-like materials may have been produced by the decomposition of buried radium-containing devices.

Following the discovery of subsurface radium-226 during trenching, an air sampling study was performed in 1991 to measure concentrations of long-lived alpha and beta radiation emitters in the air at IR-01/21, IR-02, and adjacent areas. This study was performed to determine whether airborne particulates contained alpha or beta radioactivity that would pose a hazard to RI field workers. The results indicated that no such hazard existed; however, in December 1991 the Navy installed fences around IR-01, IR-02, IR-03, IR-05, IR-14, and IR-15 to prevent public access to these areas (PRC 1992).

As a result of these initial findings, radiation sites at HPS were further investigated. The Phase I investigation, conducted in 1991, was a surface confirmation radiation survey (SCRS). The Phase II investigation, conducted in 1993, evaluated the subsurface distribution of radium-containing devices at Parcel E landfill sites. Descriptions and findings of these phases of the radiation investigation are presented in Sections 2.1 and 2.2.

1.2 HISTORY OF NAVAL RADIOLOGICAL DEFENSE LABORATORY AT HUNTERS POINT SHIPYARD

In 1946, the Radiological Safety Section (RSS), a part of the San Francisco Naval Shipyard Industrial Laboratory, originated at HPS (PRC 1996b). One mission of this organization was to identify methods to decontaminate ships that had returned from nuclear weapons tests near Bikini Atoll in the Marshall Islands.

In 1948, the RSS became known as the NRDL. Its mission was to study the effects of nuclear weapons and to develop effective countermeasures against radiation. HPS was selected as the West Coast site for the NRDL because of its dry dock capacity and its proximity to the University of California's (U.C.) Crocker Radiation Laboratory and other Navy facilities. NRDL activities required the use of a cyclotron, a Van de Graaff generator, X-ray machines, radiological laboratories, support offices, and kennels for animals used in radiological studies (PRC 1996b).

In 1950, the NRDL became a separate Navy command. To support its mission, staffing was increased to over 100 military and almost 600 civilian personnel. Until 1955, NRDL laboratory operations were

conducted at various buildings and sites throughout HPS. All radioactive waste generated by the NRDL at HPS was reportedly disposed of off site in compliance with regulatory requirements (WESTEC 1984).

On April 25, 1969, the Navy announced the disestablishment of NRDL with a projected closure date of December 31, 1969. Part of the disestablishment of the NRDL was the termination of radioactive material licenses that had been issued to the Navy by the U.S. Atomic Energy Commission (AEC), which was the original agency responsible for tracking radioactive material, and later by the U.S. Nuclear Regulatory Commission (NRC). Radioactive material licenses issued to HPS consisted of three by-product material licenses (numbers 04-00487-03, 04-13488-01, and 04-00487-09); a source material license (number SNB-376) authorizing possession of natural uranium and thorium; and a special nuclear material license (number SNM-35) authorizing possession of plutonium and other radionuclides. All licenses issued to the NRDL by the AEC and NRC have been terminated (PRC 1996b).

To determine whether residual radioactive contamination associated with former NRDL activities was present at Parcel E, the Phase III radiation investigation was conducted in 1997. Section 2.3 and Attachment E1 of this appendix describe this investigation.

2.0 RADIATION INVESTIGATIONS AT PARCEL E

The investigation of radiation sites at Parcel E consisted of Phases I, II, and III. Phase I of the investigation was the SCRS conducted in 1991. Phase II of the investigation was conducted in 1993 and evaluated the subsurface distribution of radium-containing devices at the Parcel E landfill sites. Phase III of the investigation was conducted in early 1997 and surveyed former NRDL sites at HPS. These investigations are described in the following sections.

2.1 PHASE I INVESTIGATION AT PARCEL E

The Phase I radiation investigation was initiated in 1991 to determine the nature and surficial extent of radium-containing devices in the disposal dump area at IR-02 Northwest. Although anomalously high gamma readings were detected only at the disposal dump area at IR-02 Northwest during the 1988 survey, IR-01/21, IR-02 Central, IR-02 Southeast, IR-03, and portions of IR-11/14/15 were surveyed during the Phase I investigation due to their proximity to the disposal dump area at IR-02 Northwest.

A comprehensive surface gamma walkover survey was performed to establish the areal extent and locations of the anomalously high gamma readings detected by HLA in 1988. Soil samples were collected to establish whether radioisotopes other than radium-226 were present at Parcel E and to determine whether radium-226 from radium-containing devices had migrated to soil. Radon flux testing was performed to assess the presence of radon gas that might be associated with subsurface radium-containing devices. Air sampling was performed to evaluate whether airborne radioactive particulates impacted workers or the residential community around HPS. Groundwater samples were collected to determine whether the disposal of radium-containing devices had impacted groundwater at the site. The methodology, results, and conclusions and recommendations of the Phase I radiation investigation are presented in the following sections.

2.1.1 Phase I Methodology

A local grid coordinate system was developed to map and relocate radioactive material detected during the surface walkover survey. Each grid section was 300 feet by 300 feet square, with each section further subdivided into 30-foot by 30-foot subgrids. To detect gamma-emitting radioactive material within the landfill area, health physics technicians performed a surface gamma walkover survey using 2-inch by 2-inch sodium iodide (NaI) detectors coupled to ratemeters (PRC 1992). Based on field measurements collected at HPS and other naval facilities with similar landfill issues, the Navy determined that a 1 μCi radium-containing point source can be detected to a maximum depth of 12 inches using this instrumentation (PRC 1996a). During the Phase I investigation, gamma readings exceeding two times the background level were considered radioactive point source anomalies associated with buried radium-containing devices (PRC 1992). Background levels were determined on a subgrid-specific basis (PRC 1992).

When elevated gamma readings were observed, the location, gamma measurements, and exposure measurements were recorded and a "biased" soil sample was collected to identify the present radioisotopes (PRC 1992). To provide additional characterization information, "systematic" soil samples were also collected at random, "unbiased" locations throughout the Parcel E area at a frequency of one sample per 2 acres. All soil samples were analyzed at an off-site laboratory using gamma spectroscopy to identify and quantitate gamma-emitting radioisotopes.

Radon flux canisters were placed on the ground surface at selected locations at and around anomalous areas to detect radon, a radioactive gas emitted into the soil from the decay of radium-226. Increased radon concentrations may indicate the presence of subsurface radium-containing devices. Radon released during the radium-226 decay process was captured by adsorption to carbon in the flux canister. Canisters were removed 24 hours after placement at the ground surface and then analyzed at an off-site laboratory using gamma spectroscopy.

High-volume air sampling for gross alpha and gross beta radioactivity was performed to establish the concentration of airborne radioactive particulates. Sampling and analysis of groundwater for gross alpha and gross beta radioactivity was also conducted to determine if the presence of radium-containing devices in soil was impacting groundwater in the vicinity (PRC 1992).

2.1.2 Phase I Results

During the surface walkover survey, over 300 radium-containing point sources (such as instrument dials, glass beads, and gauges) were observed in a centralized area at IR-02 Northwest that extended about 50 feet across the site boundary into IR-02 Central; this area corresponds to the location of the disposal dump area used by the Navy for disposal of industrial waste (PRC 1992). The anomalous area was about 600 feet by 600 feet in size and was centered about 500 feet west of Building 600. In several instances, radium-containing devices were observed on the ground surface at IR-02 Northwest and were removed prior to soil sample collection. These radium-containing devices were placed in properly labeled drums and stored in the low-level radiation waste structure within Building 130 prior to disposal off site. A few anomalously high gamma radiation readings were observed in the intertidal area at IR-02 Northwest (PRC 1992).

A cluster of seven radioactive point source anomalies associated with radium-containing devices were observed in the southwestern portion of IR-01/21; two additional anomalies were observed at IR-01/21 northeast of the cluster (PRC 1992). One radioactive point source anomaly was observed at IR-02 Central east of the Building 600 parking lot. A few radioactive point source anomalies were observed at scattered locations at IR-02 Southeast, but no radium-containing devices were identified in these locations. Radioactive point source anomalies were not found at IR-03 or IR-11/14/15; a combination safe found at IR-11/14/15 had an anomalously high gamma activity associated with a dial on its door (PRC 1992).

Soil samples collected for radiochemical analysis contained radium-226, its daughter products, and some naturally occurring radioisotopes. Analysis of these samples demonstrated that other than radium-226 and its radioactive daughters associated with radium-containing devices, all radioisotopes present in these soil samples were within expected background levels (PRC 1992). A few samples from IR-01/21 and IR-02 Central and many samples collected from the disposal dump area at IR-02 Northwest contained radium-containing devices that were removed prior to laboratory analysis of the associated soil (PRC 1992). These radium-containing devices were placed in properly labeled drums and stored in the low-level radiation waste structure within Building 130 prior to disposal off site.

Radium-226 activities in background samples collected at HPS ranged from 0.50 to 2.4 picoCuries per gram (pCi/g), which is consistent with U.S. averages (PRC 1992). Radium-226 is present at about 0.7 pCi/g in the earth's crust and at about 1.4 pCi/g in granitic rock (PRC 1992). Thirteen soil samples collected from the disposal dump area at IR-02 Northwest exhibited radium-226 concentrations above background levels ranging from 4 to 3,900 pCi/g. One soil sample collected from IR-01/21 contained radium-226 at a concentration of 454.6 pCi/g and two soil samples collected from IR-02 Southeast contained radium-226 at concentrations of 39.69 and 412.1 pCi/g; these concentrations are above background levels. Soil samples collected from IR-02 Central, IR-03, and IR-11/14/15 did not contain radium-226 above background levels; concentrations of radium-226 in these samples ranged from less than 0.12 to 1.26 pCi/g (PRC 1992).

Elevated levels of radon gas were observed at locations where canisters were placed directly on top of radium-containing devices present at the ground surface; flux canisters placed at locations where radium-containing devices were not visible did not detect radon gas above background levels (PRC 1992). No elevated levels of gross alpha or gross beta radioactivity were detected in the air samples collected within and surrounding Parcel E (PRC 1992).

Groundwater samples were collected at three wells at IR-02 Northwest, one well at IR-02 Central, and two wells at IR-02 Southeast. These samples were analyzed for gross alpha and gross beta radioactivity. However, because the presence of dissolved and suspended solids in groundwater interfered with the analysis, the results were inconclusive (PRC 1992). In 1993, groundwater samples were analyzed for radioisotopes by the U.S. Environmental Protection Agency (EPA) National Air and Radiation Environmental Laboratory (NAREL); these results are presented in Section 2.4.1.

2.1.3 Phase I Conclusions and Recommendations

The Phase I radiation investigation concluded that the cause of elevated gamma activity at Parcel E was the presence of radium-containing devices in (1) surface soil at scattered locations at IR-01/21, and (2) in a centralized disposal dump area at IR-02 Northwest extending into IR-02 Central. In addition, the investigation concluded that radium-containing devices may be present in the subsurface environment of these landfill areas.

The Phase I report recommended investigating the subsurface distribution of radium-containing devices in soils within the disposal dump area at IR-02 Northwest (PRC 1992). Other recommendations were removing the combination safe from IR-11/14/15 and evaluating alternate methods for the analysis of gross alpha and beta radioactivity in groundwater samples. The combination safe was removed from IR-11/14/15, stored in the low-level radiation waste storage area at Building 130, and disposed of off site in 1996. Additional groundwater investigations are discussed in Section 2.4.1. The subsurface radiation investigation is discussed in Section 2.2.

2.2 PHASE II INVESTIGATION AT PARCEL E

The Phase II radiation investigation was conducted at Parcel E to delineate the subsurface distribution of radium-containing devices at the IR-01/21, IR-02 Northwest, and IR-02 Central landfill areas. Field activities included excavating trenches and test pits, collecting soil samples, and collecting air samples; these activities were conducted from January 21 through July 25, 1993. The methodology, results, and conclusions and recommendations of the Phase II radiation investigation are presented in the following sections.

2.2.1 Phase II Methodology

To delineate the subsurface distribution of radioactive point sources in the Parcel E landfill areas, 27 15-foot test pits and three 100-foot trenches were excavated at IR-02 Northwest; one of these trenches extended about 40 feet across the site boundary into IR-02 Central. Seven 15-foot test pits were excavated at IR-02 Central along the IR-02 Northwest site boundary. Six 15-foot test pits were excavated at IR-01/21. The excavation locations were chosen to include known and potential areas of anomalously high radiation, provide detailed soil stratigraphy data, and identify the types and depths of buried debris associated with radiation anomalies (PRC 1996a). The trenches and test pits were excavated until Bay

Mud or groundwater was encountered, or until the walls of the excavation became unstable. Trench and test pit depths ranged from 2.5 to 10.5 feet bgs, with an average depth of about 8 feet bgs. Buried radium-containing devices found in subsurface soils during excavation were removed, placed in properly labeled drums, and stored in the low-level radiation waste structure within Building 130 (PRC 1996a).

Using 2-inch by 2-inch NaI detectors to detect gamma-emitting radioactive material below the surface, health physics technicians scanned the walls of each excavation every 2 feet. When elevated gamma readings were observed, the location, gamma measurements, and exposure measurements were recorded. During the Phase II investigation, gamma count rates exceeding one and one-half times the background level were considered radioactive point source anomalies associated with buried radium-containing devices (PRC 1996a). Radioactive point source anomaly locations were further investigated by excavation; if radium-containing devices were found, soil samples were collected to identify the present radioisotopes (PRC 1996a). These samples were analyzed at an off-site laboratory using gamma spectroscopy to identify and quantitate gamma-emitting radioisotopes.

High-, medium-, and low-volume air sampling were performed during excavation activities to establish the concentration of airborne radioactive particulates.

2.2.2 Phase II Results

Excavation activities at the disposal dump area at IR-02 Northwest and IR-02 Central detected approximately 111 discrete subsurface gamma-emitting point sources (PRC 1996a). The subsurface distribution of radium-containing devices associated with these point sources was confined to an area of approximately 400 feet by 250 feet in size to a maximum depth of 9 feet bgs (PRC 1996a). The eastern portion of this area extended about 50 feet into IR-02 Central, where a few point sources were observed in the uppermost 1 foot of soil. Ninety percent of the point sources found at the disposal dump area during excavation activities were located in the uppermost 6.5 feet of soil; no sources were located below the Bay Mud (PRC 1996a).

Excavations at the disposal dump area at IR-02 Northwest revealed a large amount of industrial and construction debris mixed with the soils in this area. In addition, some municipal waste such as paper, bottles, and clothing was observed at IR-02 Northwest. Abundant debris was deposited in several pits in the area where most radium-containing point sources were detected during the Phase I investigation (PRC

1996a). Based on field observations, the radium-containing devices detected at IR-02 Northwest appear to be associated with the disposal of industrial debris (PRC 1996c).

Radium-containing devices and industrial debris were not detected in the subsurface at two test pits excavated in the beach and intertidal areas of IR-02 Northwest; this lack of detection indicates that the disposal dump area does not extend through the beach and intertidal areas to the shoreline at IR-02 Northwest (PRC 1996a). Although the beach area contained a small amount of construction debris, soil and debris types in this area differed significantly from those in the disposal dump area at IR-02 Northwest. Soils in the disposal dump area include many soil types, are often mixed with industrial and construction debris, and are indicative of disposal practices such as dumping and burying. In contrast, soils in the beach and tidal area represent natural shoreline conditions (PRC 1996a).

Radium-containing devices were not detected in subsurface soils at IR-01/21 (PRC 1996a).

Radium-containing devices observed at IR-02 Central were mainly associated with the disposal dump area at IR-02 Northwest; the eastern boundary of this area extends about 50 feet into IR-02 Central (PRC 1996a).

Subsurface soil samples collected for radiochemical analysis at IR-01/21 did not contain elevated concentrations of radium-226 (PRC 1996a). Subsurface soil samples collected at IR-02 Northwest contained elevated concentrations of radium-226 and its daughters. Radium-226 contamination was not observed more than 18 inches from any radium-containing device, even if the device had decomposed (PRC 1996a).

Statistical analysis and computer modeling of the data from the Phase II investigation were performed to help identify remedial alternatives for the site. The volume of affected soil at the disposal dump area at IR-02 Northwest and IR-02 Central was estimated to be 5,500 cubic yards (yd^3) (PRC 1996a). During the Phase II investigation, one radium-containing device was found for every 2 yd^3 of excavated soil; therefore, the total affected soil volume was calculated to contain approximately 2,750 radium-containing devices (PRC 1996a). Each radium-containing device contains about 1 μCi of radium-226. Therefore, the estimated radium-226 activity for the total volume of affected soil at the disposal dump area was calculated to be 2.8 millicuries (PRC 1996a).

Gross alpha or gross beta radioactivity was not detected above background levels during low-, medium-, and high-volume air sampling conducted during Phase II field activities (PRC 1996a).

2.2.3 Phase II Conclusions and Recommendations

The Phase II radiation investigation concluded that the disposal dump area at IR-02 Northwest and IR-02 Central was the primary disposal area for all radium-containing devices generated at HPS as a result of ship repair and maintenance activities (PRC 1996a). Radium-containing devices were detected when a significant percentage (at times more than 50 percent) of the volume of excavated material was industrial debris, indicating that radium-containing devices were disposed of along with other industrial debris in the disposal dump area (PRC 1996a). The disposal dump area was approximately 400 feet by 250 feet in size and did not extend through the beach and intertidal area to the shoreline. Radium-containing devices were disposed of in the uppermost 9 feet of soil at the disposal dump area (PRC 1996a).

Trenching performed during the Phase II investigation confirmed that radium-containing devices found at surface locations at IR-01/21 and the beach and intertidal areas at IR-02 Northwest were surface debris; no evidence is available to indicate that these devices were originally deposited in these areas. No radium-containing devices were found in the trenches excavated at IR-01/21 or at the beach and intertidal areas at IR-02 Northwest (PRC 1996a). Excavation activities conducted by Triple A in the disposal dump area in the late 1970s may have brought buried radium-containing devices to the ground surface at IR-02 Northwest. Radium-containing devices found at IR-01/21 and the beach and intertidal areas at IR-02 Northwest may have been inadvertently transported from the disposal dump area during the movement and disposal of soil, construction materials, and industrial debris (PRC 1996c).

Because elevated radium-226 concentrations in soil were not observed more than 18 inches from any radium-containing device, it appears that radium-226 contamination in soil is limited to the disposal dump area at IR-02 Northwest and IR-02 Central (PRC 1996a).

The data collected during the Phase I and II radiation investigations were sufficient to characterize the nature and extent of radium-containing devices in the surface and subsurface environments at Parcel E. Further trenching and sampling was not recommended.

2.3 PHASE III INVESTIGATION AT PARCEL E

The purpose of the Phase III radiation investigation at Parcel E was to address concerns regarding the use, storage, and disposal of radioactive material during past NRDL operations at HPS. The goal of this phase

of the radiation investigation was the eventual release of all remaining buildings and sites in Parcel E for unrestricted use. The Parcel E investigation included the three Formerly Used Defense Sites (FUDS).

Based on the recommendations of the Navy Radiological Affairs Support Office (RASO), radiation surveys were conducted during the Phase III investigation at sites where residual contamination was known to exist or where radiation surveys had not been performed as part of the termination process for a radioactive material license. Buildings and sites that met the following conditions were excluded from the Phase III investigation:

- The building or site was previously surveyed by NRDL, RASO, AEC, or NRC personnel and released for unrestricted use
- The radioactive material license for the building or site was terminated

Of the 12 FUDS and Parcel E sites proposed for radiological surveys in Phase III, the preliminary data-gathering stage indicated that surveys were not required at four sites because either no radioactive material was ever used or stored at the site or a radiation survey had already been performed and the site was subsequently released for unrestricted use by the AEC or NRC (PRC 1996d). The 12 FUDS and Parcel E sites proposed for radiological surveys in Phase III are listed in the following table.

Site	Area/Building	Former and Current Use	Phase III Investigation
IR-39	Building 708	Former NRDL biomedical facility (unoccupied)	No survey required because radioactive materials apparently were not used or stored in Building 708.
IR-74 (FUDS)	Building 815	Former main laboratory (occupied by Filesafe document storage)	No survey required because Building 815 was thoroughly decontaminated, surveyed, and released by NRC for unrestricted use.
IR-75 (FUDS)	Building 820	Former NRDL cyclotron building (currently occupied by Lowpensky Mouldings)	No survey required because radioactive materials were not used or stored in Building 820.
IR-76 (FUDS)	Buildings 830 and 831	Former NRDL animal kennels (currently occupied by U.C. San Francisco)	No survey required because radioactive materials were not used or stored in Buildings 830 and 831.
IR-11/14/15	Building 506	Former NRDL chemistry laboratory (building demolished)	-Gamma survey -Soil and asphalt sampling

(Continued)

Site	Area/Building	Former and Current Use	Phase III Investigation
IR-38	Building 507	Former NRDL biological laboratory (building demolished)	-Gamma survey -Soil sampling
IR-38	Building 508	Former NRDL health physics office (building demolished)	-Gamma survey -Soil sampling
IR-11/14/15	Building 509	Former NRDL animal irradiation site (building demolished)	-Gamma survey -Soil and asphalt sampling
IR-11/14/15	Building 510/510A	Former NRDL X-ray laboratory (building demolished)	-Gamma survey -Soil sampling
IR-11/14/15	Building 517	Former NRDL irradiation site (building demolished)	-Gamma survey -Soil sampling
IR-11/14/15	Building 529	Former NRDL radioisotope storage and Cockroft-Walton generator (building demolished)	-Gamma survey -Soil sampling
IR-39	Building 707 Concrete Pad	Former NRDL research animal colony and radioactive waste storage (currently unoccupied)	-Gamma survey (drum storage pad only) -Soil, asphalt, concrete, and wipe sampling

Notes:

FUDS Formerly Used Defense Sites
 NRC U.S. Nuclear Regulatory Commission
 NRDL Naval Radiological Defense Laboratory
 U.C. University of California

The preliminary data-gathering and Phase III investigation results are summarized in the following subsections. Section 2.3.1 summarizes the results of the preliminary data-gathering for the four sites where no radiation survey was performed during the Phase III investigation. Section 2.3.2 summarizes the results of the preliminary data-gathering and the Phase III investigation for the eight sites where radiation surveys were conducted. The draft final Phase III radiation investigation report is presented as Attachment E1 of this appendix.

2.3.1 Investigation Results for Phase III Non-Survey Sites

This section summarizes the results of preliminary data-gathering for the four former NRDL sites not included in the Phase III investigation. Site history, current site conditions, radiation survey results, and the rationale for not surveying the site during the Phase III investigation are presented in the following sections.

2.3.1.1 Building 708

Building 708 was used by the NRDL as a biomedical facility (PRC 1996b). The building, located northwest of the intersection of "J" and "R" Streets, is a Quonset hut constructed in 1953 (PRC 1996b). Building 708 is currently unoccupied. Little documentation related to this building exists; however, anecdotal information from former NRDL and RASO personnel familiar with past site operations indicates that radioactive materials were not used in Building 708. The building was apparently used as an instrumentation repair and general storage area in the years following the closure of the NRDL (PRC 1996b).

No historical evidence exists to indicate that radiological activities were performed in Building 708 (RASO 1995). The Navy performed a cursory health and safety survey of the building to allow naval personnel, contractors, and civilian tenants safe entry to the building. No elevated radioactivity or exposure levels were detected (PRC 1996d). Since no documentation or anecdotal information is available to indicate that radioactive material was used or stored in Building 708, this building was not surveyed during the Phase III investigation.

2.3.1.2 Building 815

Building 815 was used as the NRDL main laboratory between 1956 and 1969 (NRDL 1969). The building, located on Crisp Avenue across the street from the railway yard, was likely constructed in the early 1950s (PRC 1996b). The ownership of Building 815 was transferred from the Navy to nonmilitary owner Ted Lowpensky on December 12, 1984. Building 815 is currently leased to Filesafe, a civilian tenant that uses the building for document storage.

A range of activities involving the use of radioactive isotopes was performed in Building 815. Activities on the sixth floor, which was formerly occupied by the Nuclear Technology Division, involved the use of

liquid transuranic sources (NRDL 1969). Radioactive sources used on the fifth floor, which was formerly occupied by the Biological and Medical Sciences Division, included carbon-14 and tritium (NRDL 1969). Room 1109, located on the first floor of the building, was used for isotope storage (NRDL 1969). Activities on the second, third, and fourth floors of the building were primarily administrative; radioactive materials used in these areas were sealed and normally would not produce radioactive contamination (NRDL 1969)

In 1969, NRDL personnel conducted a detailed radiological survey of Building 815. All rooms in the building were surveyed for beta-gamma and alpha activity (NRDL 1969). Wipe samples were collected from all rooms in Building 815, including the administrative areas, to detect removable radioactivity (NRDL 1969). In addition, wipe samples were collected from work surfaces, fume hoods, fume hood filters, drain lines, vacuum lines, equipment, sink drains, and floors at locations where radioactive material was used (NRDL 1969).

Detectable contamination was found in eight rooms on the sixth floor and in Room 1109 (NRDL 1969). Contamination in these rooms was removed by washing affected areas and dismantling radioactive equipment (NRDL 1969). All radioactive waste, including dismantled equipment, generated during decontamination activities was properly packaged and disposed of off site (NRDL 1969). Following completion of decontamination activities, Building 815 was resurveyed by NRDL personnel; radioactive contamination was not detected (NRDL 1969). The AEC again surveyed Building 815 in November and December 1969 and detected no residual radioactivity (AEC 1970). Except for several rooms on the first and second floors still occupied by administrative staff, Building 815 was cleared by the AEC for unrestricted use in November and December 1969 (AEC 1970).

The Navy conducted an additional survey and decontamination of Building 815 from February through June 1979 (Supervisor of Shipbuilding, Conversion and Repair [SUPSHIP] 1979). Areas found to be contaminated based on revised clean-up levels underwent decontamination procedures. Low-level radioactive waste generated by decontamination procedures was properly packaged and disposed of off site (SUPSHIP 1979). In June 1979, a post-decontamination radiation survey was performed; the results met NRC guidelines and Building 815 was released for unrestricted use (NRC 1980).

Since Building 815 (1) was thoroughly decontaminated and resurveyed prior to its decommission and release for unrestricted use, and (2) met the criteria for termination of radioactive material licenses issued to NRDL, the building was not surveyed during the Phase III investigation. The regulatory agencies

concluded that sufficient survey and decontamination documentation exists and that additional investigation of Building 815 is not required (PRC 1993).

2.3.1.3 Building 820

Building 820 was used by the NRDL to house the cyclotron (PRC 1996b). The building, located at the northwest corner of HPS on Crisp Avenue a few hundred feet northwest of Building 830, was likely constructed in the early 1950s (PRC 1996b). The ownership of Building 820 was transferred from the Navy to nonmilitary owner Ted Lowpensky on July 17, 1981. Building 820 is currently occupied by Lowpensky Mouldings.

The cyclotron was never activated and radioactive material was never used in Building 820 (NRDL 1969). The cyclotron was removed from Building 820 sometime in the 1960s (PRC 1996d). Because radioactive material was never used or stored at Building 820, AEC surveys and clearance were not required (NRDL 1969). Additionally, Building 820 was not surveyed during the Phase III investigation. The regulatory agencies concurred that sufficient survey and decontamination documentation exists and that additional investigation of Building 820 is not required (PRC 1993).

2.3.1.4 Buildings 830 and 831

Buildings 830 and 831 were kennels for animals used in NRDL radiological experiments (PRC 1996d). Buildings 830 and 831, located adjacent to each other in the northwest corner of HPS on Crisp Avenue, were likely constructed in the early 1950s (PRC 1996b). The ownership of these buildings was transferred from the Navy to U.C. San Francisco on April 17, 1978. Buildings 830 and 831 are currently used as animal kennels by U.C. San Francisco.

Little documentation related to these buildings exists; however, anecdotal information from former NRDL and RASO personnel familiar with past site operations indicates radioactive materials were never used or stored in Buildings 830 and 831 (PRC 1997). Therefore, AEC surveys and clearance were not required and Buildings 830 and 831 were not surveyed during the Phase III investigation.

2.3.2 Phase III Investigation Results for Survey Sites

Based on recommendations provided by RASO, Buildings 506, 507, 508, 509, 510, 510A, 517, and 529, and the concrete pad at Building 707, required additional radiation surveys. These sites were surveyed

due to the nature of former NRDL operations at these locations, because the sites were not surveyed as part of the disestablishment of the NRDL and license termination process, or because survey documentation is unavailable.

Phase III field activities consisted of surface gamma walkover surveys and collection of soil, asphalt, concrete, and wipe samples. A local grid coordinate system was developed to map and relocate radioactive anomalies detected while performing the survey. Each grid section was 10 feet by 10 feet square. A surface gamma walkover survey was performed using a 2-inch by 2-inch NaI detector. In addition, a fixed-count surface gamma survey was performed using a global positioning system (GPS) for reference. When elevated gamma readings were observed, the location, gamma count rates, and exposure measurements were recorded and a sample was collected. In addition to samples collected at locations of elevated gamma readings, surface soil samples were collected in the vicinity of each Phase III site to determine whether gamma-emitting radioisotopes were present above background levels. Wipe samples were collected from the surface of the Building 707 concrete pad. All samples were analyzed by gamma spectroscopy at an off-site laboratory to determine the types and amounts of radioisotopes present in the samples.

This section summarizes the results of the preliminary data-gathering for each site, including the site background, current site conditions, and previous radiation survey results. This section also summarizes the Phase III investigation field activities and results for each site. The draft Phase III radiation investigation report is presented as Attachment E1 to this appendix.

2.3.2.1 Building 506

Building 506 was used by the NRDL as a chemistry laboratory (PRC 1996d). Building 506 was likely constructed prior to 1955 and demolished sometime in the late 1970s (PRC 1996b). Building 506 was located on the southwest side of "H" Street east of the intersection of "I" and "J" streets. Most of the early NRDL radiochemical analyses were performed at Building 506 (NRDL 1969). The building housed the controls of a low-voltage neutron generator. Rooms 35 and 35A were used to store tritium targets. Most operations in Building 506 were moved to Building 815 sometime in the late 1950s; most areas at Building 506 were decontaminated at that time (NRDL 1969).

During the time the laboratory was operational, a spill of an unknown radionuclide was observed just outside Building 506 by former NRDL employee Mr. Fil Fong. Although the exact spill location could

not be identified, Mr. Fong recalls the spill occurring in the parking lot located just outside the east wall of the building (PRC 1993).

In 1969, NRDL personnel conducted a radiological survey of Building 506 (NRDL 1969). Wipe samples collected in Rooms 35 and 35A indicated the presence of tritium contamination; several other areas and pieces of equipment at Building 506 were also contaminated with tritium (NRDL 1969). Detectable contamination in these rooms was removed by washing affected areas and dismantling contaminated equipment; contaminated areas were steam-cleaned following decontamination. All radioactive waste, including dismantled equipment, generated during decontamination activities was properly packaged and disposed of off site (NRDL 1969). Following completion of decontamination activities, Building 506 was resurveyed by NRDL personnel; results of wipe samples collected in affected areas indicated that the site was decontaminated to background levels (NRDL 1969). In December 1969, Building 506 was inspected and cleared by the AEC for unrestricted use (AEC 1970).

In 1997, the former location of Building 506 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former location of Building 506. All gamma activity measurements obtained in this area were below background levels. Twelve surface soil and three asphalt samples were collected at and near the former location of Building 506. These samples were analyzed at an off-site laboratory for strontium-90 and other radioisotopes. No radioisotopes were detected in samples collected from the former location of Building 506 at concentrations exceeding background concentrations.

2.3.2.2 Building 507

Building 507 was used by the NRDL as a biological laboratory (PRC 1996b). Building 507 was likely constructed prior to 1955 and demolished between 1977 and 1979 (HLA 1992). Building 507 was located on the northeast side of "H" Street in an area bounded by "H" Street to the west, Manseau Street to the north, Hussey Street to the east, and Mahan Street to the south. Operations in Building 507 were moved to Building 815 sometime in the late 1950s; most areas at Building 507 were decontaminated at that time (NRDL 1969). In December 1969, Building 507 was inspected and cleared by the AEC for unrestricted use (NRDL 1969).

In 1997, the former location of Building 507 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former

location of Building 507. All gamma activity measurements obtained in this area were below background levels. Six surface soil samples were collected at and near the former location of Building 507. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils near former Building 507. No radioisotopes were detected in samples collected from the former location of Building 507 at concentrations exceeding background concentrations.

2.3.2.3 Building 508

Building 508 is the former site of the NRDL health physics office (PRC 1996b). Building 508 was likely constructed prior to 1950 and demolished between 1977 and 1979 (HLA 1992). Building 508 was located on the southwest side of "H" Street in an area bounded by "H" Street to the west, Manseau Street to the north, Hussey Street to the east, and Mahan Street to the south. Operations in Building 508 were moved to Building 815 sometime in the late 1950s; most areas at Building 508 did not require decontamination at that time (RASO 1995). In December 1969, Building 508 was inspected and cleared by the AEC for unrestricted use (NRDL 1969).

In 1997, the former location of Building 508 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former location of Building 508. All gamma activity measurements obtained in this area were below background levels. Seven surface soil samples were collected at and near the former location of Building 508. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils near former Building 508. No radioisotopes were detected in samples collected from the former location of Building 508 at concentrations exceeding background concentrations.

2.3.2.4 Building 509

Building 509 was used by the NRDL as an animal irradiation site (PRC 1996b). Building 509 was constructed prior to 1955 and was likely demolished sometime in the late 1970s (PRC 1996b). Building 509 was located on the northeast side of "H" Street in an area bounded by "H" Street to the west, Manseau Street to the north, Hussey Street to the east, and Mahan Street to the south. Operations in Building 509 were moved to a newer facility in 1955; most areas in Building 509 were decontaminated at that time. In December 1969, Building 509 was inspected and cleared by the AEC for unrestricted use (NRDL 1969).

In 1997, the former location of Building 509 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former location of Building 509. All gamma activity measurements obtained in this area were below background levels. Five surface soil samples and one asphalt sample were collected at and near the former location of Building 509. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils near former Building 509. No radioisotopes were detected in samples collected from the former location of Building 509 at concentrations exceeding background concentrations.

2.3.2.5 Buildings 510 and 510A

Building 510 was used by the NRDL as an X-ray laboratory (PRC 1996b). Administrative support services for the X-ray laboratory were located in Building 510A. Buildings 510 and 510A were constructed as one building prior to 1955 and were likely demolished sometime in the late 1970s (PRC 1996b). These buildings were located on the southwest side of "H" Street in an area bounded by "H" Street to the east, Manseau Street to the north, "J" Street to the west, and Mahan Street to the south. Operations in Buildings 510 and 510A were moved to Building 815 in 1955; most areas in the buildings were decontaminated at that time. In December 1969, Buildings 510 and 510A were inspected and cleared by the AEC for unrestricted use (NRDL 1969).

In 1997, the former locations of Buildings 510 and 510A were surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former locations of Buildings 510 and 510A. All gamma activity measurements obtained in this area were below background levels. Eight surface soil samples were collected at and near the former locations of Buildings 510 and 510A. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils in this area. No radioisotopes were detected in samples collected from the former location of Buildings 510 and 510 at concentrations exceeding background concentrations.

2.3.2.6 Building 517

Building 517 was used by NRDL as an irradiation site (PRC 1996d). Building 517 was constructed prior to 1955 and was likely demolished sometime in the late 1970s (PRC 1996b). Building 517 was located on the northeast side of "H" Street in an area bounded by "H" Street to the west, Manseau Street to the

north, Hussey Street to the east, and Mahan Street to the south. In January 1970, Building 517 was inspected and cleared by the AEC for unrestricted use (AEC 1970).

In 1997, the former location of Building 517 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former location of Building 517. One gamma reading slightly above background was observed near the northeast corner of Building 517. Because gamma activity at this location did not exceed two times the background activity, soil in this area was not collected for analysis. Three surface soil samples were collected at other locations near former Building 517. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils in this area. No radioisotopes were detected in soil samples collected from the former location of Building 517 at concentrations exceeding background concentrations. The area of slightly elevated gamma activity near the northeast corner of Building 517 will be assessed for removal during the remedial action in Parcel E at the concrete pad adjacent to Building 707.

2.3.2.7 Building 529

Building 529 was used by the NRDL for radioisotope storage and to house the Cockcroft-Walton generator (PRC 1996b). Building 529 was likely constructed prior to 1950 and demolished sometime in the late 1970s (PRC 1996b). Building 529 was located on the southwest side of "H" Street east of the intersection of "I" and "J" streets. A stainless steel holding tank was formerly located on the north side of the building (NRDL 1969).

In 1969, NRDL personnel conducted a radiological survey of Building 529; radiation was not detected in the building (NRDL 1969). The stainless steel holding tank was decontaminated; results from subsequent wipe samples collected from the tank indicated that the tank was decontaminated to background levels (NRDL 1969). Following decontamination, the tank was removed from the vicinity of Building 529 (NRDL 1969). In December 1969, Building 529 was inspected and cleared by the AEC for unrestricted use (NRDL 1969).

In 1997, the former location of Building 529 was surveyed during the Phase III radiation investigation. During this investigation, surface gamma walkover surveys were performed at and near the former location of Building 529. One elevated gamma radiation reading was observed between former Buildings 529 and 520. Four surface soil samples were collected at and near the former location of Building 529.

These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soil in this area. No radioisotopes were detected in samples collected from the former location of Building 529 at concentrations exceeding background concentrations.

The location of the elevated gamma radiation reading was excavated to a depth of 12 inches bgs; gamma activity increased with depth and no source was found. Radioisotope concentrations in soil samples collected from this location did not exceed background. The elevated gamma reading may be the result of a radium-containing device buried more than 12 inches bgs, rather than surface contamination associated with past NRDL activities. Therefore, this location has been included in the Parcel E radiation risk assessment.

2.3.2.8 Building 707 Concrete Pad

Building 707 was used by the NRDL to breed and house research animals (PRC 1996b). A concrete pad adjacent to the west side of Building 707 was used by the NRDL to store drums of radioactive waste prior to their shipment to an off-site disposal facility (PRC 1996b). Building 707 and the concrete pad were constructed in 1950 and are currently in good condition; no obvious stains are present on the concrete pad (PRC 1996b). The building and concrete pad are located in a triangular area bounded by 6th Avenue on the northwest, "R" Street on the northeast, and "J" Street on the southwest. In January 1970, Building 707 was inspected and cleared by the AEC for unrestricted use (AEC 1970).

In 1997, the concrete pad adjacent to Building 707 was surveyed during the Phase III radiation investigation. During this investigation, a surface gamma walkover survey was performed on the concrete pad and a gamma survey using a fixed-count GPS was performed on and near the concrete pad. Two areas on the pad and two areas on asphalt near the pad exhibited gamma radiation readings above background. Asphalt and concrete samples collected from these areas exhibited levels of cesium-137, radium-226, thorium-228, and thorium-232 exceeding their respective screening criteria (see Attachment E1). The source of this residual contamination is likely surface spills from drums of radioactive waste stored on the concrete pad. As part of the remedial action in Parcel E, this area will be removed.

Thirteen asphalt, 16 surface soil, and 52 wipe samples were collected from other areas on and around the concrete pad. These samples were analyzed at an off-site laboratory to determine the types and amounts of radioisotopes present in soils in this area. No radioisotopes were detected in these samples at concentrations exceeding background concentrations.

2.4 ADDITIONAL INVESTIGATIONS

Additional radiation investigations performed at HPS are summarized in the following sections.

2.4.1 Groundwater Investigation

In 1993, PRC collected 25 groundwater samples from monitoring wells at IR-02 sites and sent them to EPA NAREL for analysis. These samples were analyzed for radium-226 by a coprecipitation method. These samples did not indicate concentrations of radium-226 above background levels (PRC 1995). Radium-226 contamination in Parcel E soils has apparently not migrated to groundwater.

2.4.2 Treatability Study

In 1994, EPA conducted soil sampling at Parcel E as part of a proposed treatability study for remediation technology to address radium contamination in soil. The EPA study consisted of collection of 13 soil samples; these samples were analyzed by NAREL for particle size and radium-226 distribution (EPA 1994). Ten soil samples contained background levels of radium-226 ranging from 0.3 to 3 pCi/g (EPA 1994). The elevated amount of radium-226 present in one soil sample was associated with a source present in the sample but not in the soil. Soil contamination in the remaining two samples was limited to smaller-sized soil fractions such as sands, silts, and clays; this contamination was attributed to fragmentation or oxidation of a source (EPA 1994). These findings indicated that most soil at Parcel E contained background concentrations of radium-226 and that limited soil contamination was associated with the presence of discrete point sources (EPA 1994). Selective removal of soil in the vicinity of identifiable sources and removal of the sources by particle-size separation was identified as a potential remedial alternative (EPA 1994).

3.0 CONCLUSIONS

All radium-containing devices generated at HPS during ship repair and maintenance activities were apparently disposed of in the disposal dump area at IR-02 Northwest; this area extends about 50 feet into IR-02 Central. Radium-containing devices were disposed of along with industrial debris in an area of approximately 400 feet by 250 feet to a maximum depth of 9 feet bgs. The disposal dump area does not extend through the beach and intertidal areas to the shoreline.

The few radium-containing devices and radium-contaminated soil samples found at other Parcel E locations (such as IR-01/21, IR-02 Central, IR-02 Southeast, and IR-11/14/15) do not appear to have been originally deposited in these areas. Excavation activities conducted by Triple A in the disposal dump area in the late 1970s may have brought buried radium-containing devices and radium-contaminated soil to the ground surface at IR-02 Northwest. Radium-containing devices found at IR-01/21, IR-02 Central, IR-02 Southeast, and IR-11/14/15 may have been inadvertently transported from the disposal dump area at IR-02 Northwest during the movement and disposal of soil, construction materials, and industrial debris.

The risk to human health posed by buried radium-containing devices at Parcel E has been evaluated in the radiation risk assessment presented in Appendix P of this RI report.

Residual radioactive contamination associated with former NRDL activities at Parcel E was found on and near the concrete pad adjacent to Building 707. No residual radioactive contamination was detected at any other former NRDL site during the Phase III radiation investigation. Surface contamination on the concrete pad adjacent to Building 707 will be removed during the remedial action at Parcel E and is therefore not included in the radiation risk assessment for Parcel E. In addition, one gamma reading slightly above background was observed near the northeast corner of Building 517 during the Phase III investigation. However, since gamma activity at this location does not exceed two times background activity, this area was not considered indicative of residual contamination. During the remedial action in Parcel E to be conducted at the concrete pad adjacent to Building 707, this area will be assessed for possible removal.

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ATTACHMENT E1

DRAFT FINAL PHASE III RADIATION INVESTIGATION REPORT

(66 Pages)

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ABBREVIATIONS AND ACRONYMS

AEC	U.S. Atomic Energy Commission
ags	Above ground surface
ASA	Acceptable surface activity
bgs	Below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Ci	Curie
cm	Centimeter
cm ²	Square Centimeter
cm/s	Centimeters per second
cpm	Counts per minute
cpm/mR/hr	Counts per minute per milliRoentgens per hour
CTO	Contract Task Order
DHS	California Department of Health Services
dpm/100 cm ²	Disintegrations per minute per 100 square centimeters
EFA West	Naval Facilities Engineering Command, Engineering Field Activity West
EPA	U.S. Environmental Protection Agency
GIS	Geographic information system
GM	Geiger-Mueller
GPS	Global positioning system
HPS	Hunters Point Shipyard
IR	Installation restoration
KeV	Kilo electronVolt
L _C	Critical Limit
L _D	Detection Limit
m ²	Square meter
mCi/mL	microCuries per milliliter
MDA	Minimum detectable activity
MeV	Million electronVolt
ml	Milliliter
mR	MilliRoentgens
mR/hr	MilliRoentgens per hour
mR/yr	MilliRoentgens per year
mV	MilliVolt
NaI	Sodium Iodide
Navy	U.S. Department of the Navy

ABBREVIATIONS AND ACRONYMS (Continued)

NIST	National Institute of Science and Technology
NRC	U.S. Nuclear Regulatory Commission
NRDL	Naval Radiological Defense Laboratory
pCi/100 cm ²	picoCuries per 100 square centimeters
pCi/g	picoCuries per gram
PRC	PRC Environmental Management, Inc.
RASO	Navy Radiological Affairs Support Office
RHB	Radiological Health Branch
SCRS	Surface confirmation radiation survey
TBC	U.S. Typical background concentration
TtEMI	Tetra Tech EM Inc.
μCi/L	microCuries per liter
μR/hr	microRoentgens per hour
μrem/hr	microrems per hour

EXECUTIVE SUMMARY

From January 13 through March 7, 1997, Tetra Tech EM Inc. formerly PRC Environmental Management, Inc., performed the Phase III radiation investigation at Hunters Point Shipyard (HPS). Former Naval Radiological Defense Laboratory (NRDL) sites were investigated because of radiological concerns regarding the former use, storage, and disposal of radioactive materials associated with past NRDL operations at HPS. The following former NRDL buildings and sites were investigated:

- Building 351A in Parcel D
- Building 364 low-level radioactive waste storage tank vault site in Parcel D
- Demolished Buildings 506, 507, 508, 509, 510, 510A, 517, and 529 in Parcel E
- Building 707 concrete drum storage pad in Parcel E

The Phase III radiation investigation was designed to meet U.S. Nuclear Regulatory Commission and California Department of Health Services criteria. Subsequently, it was determined to also meet U.S. Environmental Protection Agency criteria for radionuclides for protection of human health.

Surveys at the demolished NRDL building sites consisted of 1-minute gamma counts on a 10-foot by 10-foot grid using a global positioning system to locate grid nodes. These measurements were used to create radiation contour maps of the building sites. Soil samples were collected from around the demolished buildings to establish a radionuclide inventory. The investigation at the Building 707 concrete drum storage pad included the above survey, a 100 percent gamma scan survey, and swiping for removable alpha and beta activity. Drain pipes in work room 47 at Building 351A were swiped for removable alpha and beta activity. The site containing the low-level radioactive waste storage tank vault behind Building 364 was investigated for residual radioactive contamination. Surveys for total and removable alpha, beta, and gamma activity were performed at the site behind Building 364.

TtEMI recommends considering the following building sites for radiological free release and that Naval Facilities Engineering Command, Engineering Field Activities West forward these recommendations to the U.S. Department of the Navy (Navy) Radiological Affairs Support Office for approval so the Navy may authorize release of these sites for unrestricted public use from a radiological perspective:

- Building 351A in Parcel D
- Buildings 507 and 508 in Parcel E
- Buildings 510 and 510A in Parcel E

The following sites do not qualify for free release and further evaluation or remediation is recommended based on the findings of the Phase III radiation investigation:

- Building 364 low-level radioactive waste storage tank vault site in Parcel D, because cesium-137 and strontium-90 were detected at the site above established NRC acceptable surface activity criteria
- Buildings 506 and 529 in Parcel E because of a possible point source buried behind Building 529
- Buildings 509 and 517 in Parcel E because of an anomalous reading during the gamma count survey
- Building 707 concrete drum storage pad in Parcel E because cesium-137, radium-226, thorium-228, and thorium-232 were detected at the site above established NRC acceptable surface activity criteria.

1.0 INTRODUCTION

Tetra Tech EM Inc. (TtEMI), formerly PRC Environmental Management, Inc. (PRC), received Contract Task Order (CTO) No. 0285 under the Comprehensive Long-Term Environmental Action - Navy (CLEAN) Contract N62474-88-D-5086 from the U.S. Department of the Navy (Navy), Naval Facilities Engineering Command, Engineering Field Activity West (EFA West). Under this CTO, TtEMI was tasked to perform the Phase III radiation investigation at Hunters Point Shipyard (HPS) in San Francisco, California. Tasks 1a, 2, 3, and 4 of the scope of work for CTO No. 0285 required the performance of the Phase III radiological investigation of former Naval Radiological Defense Laboratory (NRDL) sites at HPS. This radiological investigation was performed to determine if all remaining NRDL buildings and sites formerly licensed pursuant to the Atomic Energy Act meet the extant regulatory criteria for radiological free release established by the U.S. Nuclear Regulatory Commission (NRC) and California Department of Health Services (DHS), Radiological Health Branch (RHB), the cognizant agreement state agency. This investigation is also sufficient to meet the protectiveness criteria established by U.S. Environmental Protection Agency (EPA) (EPA 1997) for cleanup of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) sites with radioactive contamination. This survey report describes the results of the Phase III radiation investigation at the following buildings and sites:

- Building 351A in Parcel D
- Building 364 low-level radioactive waste storage tank vault site in Parcel D
- Demolished buildings 506, 507, 508, 509, 510, 510A, 517, and 529 in Parcel E
- Building 707 concrete drum storage pad site in Parcel E (see Figure E1-1)

The above-mentioned building sites were included in this Phase III radiation investigation for the following reasons:

- The pipe drains in work room 47 had not been fully investigated at Building 351A in Parcel D
- Concerns regarding past spills of radiological materials at Building 506 in Parcel E and the Building 364 sump site in Parcel D

- Concerns of residual contamination due to past building operations at Buildings 507, 508, 509, 510, 510A, 517, and 529 in Parcel E
- Lack of previous survey data at the Building 707 concrete pad site in Parcel E
- Lack of proper building and site release documentation

2.0 BACKGROUND

In late 1946, a group of Navy personnel at HPS were detailed to arrange for the decontamination and disposition of several ships that had returned from nuclear weapons tests (Operation Crossroads-Baker at Bikini Atoll in the Marshall Islands). Shortly after the formation of the group, it was designated as the NRDL. From 1950 to 1969, HPS supported the NRDL in a series of projects designed to research the protection of personnel and properties against the effects of nuclear weapons. Broadly defined, these projects encompassed chemistry (studied decay, properties of fallout), biology (studied fallout effects on animals), and physics (studied instrumentation and shielding). At peak activity, NRDL staff consisted of nearly 600 civilians and over 100 military personnel (Smith undated). In 1969, all radioactivity studies ceased at HPS. The NRDL was disestablished and NRDL buildings were decontaminated and returned to HPS.

Two phases of the radiological characterization of HPS have been completed under the CLEAN I program. Phase I work, conducted in 1992 under CTO No. 0155, consisted of ambient air monitoring to evaluate radioactivity airborne particulate matter, a gamma radiation study to establish background activities at HPS, and a surface confirmation radiation survey (SCRS). Phase I work yielded recommendations for further investigations of the distribution of radioactive materials in the landfills and screening NRDL sites at HPS. Phase II work, conducted in 1994 under CTO No. 0155, consisted of investigating the distribution of radium-containing materials in the Industrial Landfill (installation restoration [IR] site-01/21) and the Bay Fill Area (IR-02). The Phase II work established that naturally occurring radioactive materials were the source of elevated gamma activity in the soils at the Submarine Base Area (IR-07) and the Waste Oil Disposal Area (IR-18).

The purpose and rationale for the Phase III radiation investigation are described in Section 2.1. Descriptions of the installation and building sites are provided in Section 2.2. Contaminants potentially present at building sites are identified in Section 2.3, instruments used in the Phase III radiation

investigation are described in Section 2.4, and the methodology used during the Phase III radiation investigation is described in Section 2.5.

2.1 PURPOSE AND RATIONALE

The purpose of the Phase III radiation investigation at HPS is to implement some of the recommendations detailed in the SCRS (Phase I) and the results of the subsurface radiation investigation in Parcels B and E (Phase II). Additionally, the Phase III radiological investigation was implemented to address concerns regarding the former use, storage, and disposal of radioactive material associated with past NRDL operations at HPS. The intent of this Phase III radiation investigation is to determine if specific portions of all former NRDL buildings and sites meet the extant criteria for free release established by DHS and NRC or the protectiveness criteria established by EPA. If these buildings and sites meet regulatory criteria, they may be used for any intended civilian reuse without further consideration of residual radioactivity in property lease, transfer, or land-use decisions.

In general, a radiological close-out survey is performed as a final demonstration that residual radioactive material associated with former Navy activities at any building is present only at or below criteria established by Radiological Affairs Support Office (RASO), NRC, and DHS. The work plan for the Phase III radiation investigation was designed so that the Phase III investigation would qualify as a radiological close-out survey, if the building sites meet the criteria for free release. This document may therefore qualify as the supporting documentation for the final release report for the former NRDL building sites investigated during the Phase III radiation investigation.

Where applicable, field measurements were compared to residual radioactivity contamination criteria established by NRC (1974) (formerly U.S. Atomic Energy Contamination [AEC]) and the DHS RHB (1988) for decommissioning licensed facilities. The guidelines PRC used to perform the Phase III radiation investigation are consistent with NRC guidance described in the *Manual for Conducting Radiological Surveys in Support of License Termination* (NRC 1992), modified as described in the work plan or in this report. The data have also been evaluated against the protectiveness criteria established by EPA, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination" (EPA 1997).

2.2 DESCRIPTIONS OF FORMER NAVAL RADIOLOGICAL DEFENSE LABORATORY BUILDING SITES

The following sections describe the former NRDL building sites in Parcels D and E.

2.2.1 Naval Radiological Defense Laboratory Building Sites at Parcel D

Two sites were investigated in Parcel D: (1) piping associated with a removed sink in work room 47 in Building 351A in IR-34, and (2) a storage tank for low-level radioactive waste housed in a subsurface concrete vault (sump) and associated utility and pipe trenches that connect the sump to Building 364 in IR-34.

2.2.1.1 Building 351A

NRDL records indicate that a portion of Building 351A was used as a radar and electronic repair facility (PRC 1996). During an AEC radiation survey in 1974, NRDL personnel discovered beta contamination in drain pipes in Building 351A. A sink in work room 47 was identified as contaminated and was removed, but records do not note decontamination efforts in the pipes associated with the sink. Currently, work room 47 is unoccupied and all equipment and instrumentation has been removed from the building.

Only the piping associated with the sink remains in work room 47. The associated piping consists of a Y-pipe attached to a 90-degree elbow pipe. The Y-pipe attaches to the main water pipe running horizontally above the floor.

2.2.1.2 Building 364 Sump Site: Low-Level Radioactive Waste Storage Tank Vault and Associated Utility and Pipe Trenches

Building 364 was formerly known as the "hot cell" and was used as a chemistry laboratory under the NRDL program. The hot cell contained a sealed cobalt-60 source. A former storage tank for radioactive effluent with an associated sump for secondary containment was housed in a partial subsurface concrete vault constructed on the east side of Building 364. The tank and sump operated as a storage facility for low-level radiation waste. This tank stored radioactive effluent from the laboratory in Building 364 and waste from other NRDL buildings until it could be properly disposed of off site. Utility vaults connect the sump to Building 364. The utility vaults housed the piping that transferred effluent from the

laboratory to the tank (see Figure E1-2). The tank within the sump and pipes associated with the utility vaults have been removed.

During a Navy walkover survey of the associated parking lot in 1993, an area of elevated gamma activity was identified (maximum 40,000 counts per minute [cpm]). A cesium-137 spill was discovered in the area adjacent to the sump about 12 feet south of the sump. A peanut-shaped area of asphalt was excavated to an average depth of 5 inches below ground surface (bgs). The final excavation area was about 5 feet by 16 feet in size. The asphalt and soil were placed into two 55-gallon drums and disposed of off site (see Attachment E1-4 for the cesium-137 spill removal report). NRDL records do not indicate a past spill in this area, but the spill may have occurred while the sump effluent waste was emptied from the sump for transport off site.

The following is additional information EPA provided to the Navy regarding the cesium-137 spill.

In 1985, after presenting a paper to the Waste Management Symposium on Hunters Point radiation contamination issues, EPA's Steve Dean was approached by a gentleman from the audience who claimed to have been an employee at the NRDL during the 1960s. He asked Mr. Dean if anyone had ever found the cesium-137 spill in the parking lot of Building 364. Mr. Dean informed him that it had been discovered and was being investigated as the "peanut-shaped hot spot." He then told Mr. Dean that the cesium was spilled there accidentally by a technician who dropped a beaker or laboratory flask containing the cesium in solution. The technician was taking a shortcut from the south wing of Building 364 through the parking lot to the southeast entrance of the building. While the technician's coworkers knew about the incident, the laboratory's management never found out. Mr. Dean gave the gentleman his business card and asked him to call to further discuss the details of the incident. However, he failed to contact Mr. Dean and no additional details were provided. Mr. Dean believes that the man's story provides the authentic account of how the cesium peanut spill occurred outside of Building 364.

The area containing the sump and utility trenches is fenced off and radiation signs are posted on the fence. The area around the sump was overgrown with bushes and brush which required clearing before the Phase III radiation investigation could be performed. Steel plates covering the utility trenches and an old wood cover on the sump were removed. Three feet of standing water was pumped from the sump into a Baker tank. Collected sediment was removed from the bottom of the sump to prepare for the survey. Sediment and debris collected in the utility trenches were also cleaned out.

Upon clearance of the bushes around the sump, two steel plate-covered pipe trenches were discovered that were not mentioned in the work plan. These two pipe trenches were incorporated into the Phase III

radiation investigation and called pipe trenches A and B (see Figure E1-2). According to NRDL records, these pipe trenches connected the sump to a pipe shed. The pipe shed was then connected to Building 364 probably by a buried pipe. The pipe shed was torn down during decontamination procedures in 1969 and all the associated piping was removed, including the pipes leading to the sump (Miller and Tochilin 1969). Pipe trenches A and B have since been filled in with concrete, probably during decontamination procedures at the site. No evidence remains of the pipe shed or pipes leading to Building 364 from the shed at the site.

2.2.2 Former Naval Radiological Defense Laboratory Building Sites at Parcel E

Five NRDL sites were investigated at Parcel E: (1) Buildings 506 and 529 in IR-11/14/15, (2) Buildings 507 and 508 in IR-38, (3) Buildings 509 and 517 in IR-11/14/15, (4) Buildings 510 and 510A in IR-11/14/15, and (5) Building 707 drum storage concrete pad in IR-39. All of the above-mentioned buildings were demolished sometime in the late 1970s or early 1980s.

2.2.2.1 Former Buildings 506 and 529

Building 506 (see Figure E1-3) was formerly used by the NRDL as a chemistry laboratory. This building was located in the middle of an area bounded by Manseau Street to the north, by "H" Street to the east, by Mahan Street to the south, and by "J" Street to the west. The building was mainly used to house the controls of a low-voltage neutron generator and to store tritium targets. After AEC completed decontamination procedures in 1969, all contaminated equipment was disposed of off site. After 1969, Building 506 was used as a Navy Exchange and offices until it was demolished. The building foundation is no longer present except for several small sunken concrete vaults.

During the time the laboratory was operating in Building 506, a spill was observed by an NRDL employee just outside the building. The exact location of the spill and radionuclide was not identified. Mr. Fil Fong, a former NRDL employee, recalls the spill occurred in the parking lot located on the east side of the building. After the building was demolished, the site was covered with about 1 foot of fill material from off site. The building foundation is no longer present except for several small sunken concrete vaults.

Currently, the site is strewn with debris, such as concrete rubble and rebar, and is overgrown with brush and grasses. Triple A Machine Shop used this area as a dump site for waste material, but it is unknown if site debris is the original building foundation material or dumped material. However, it is apparent debris and soil have been moved around extensively at this site in the past.

Building 529 (see Figure E1-3) was the former site of the NRDL Radioisotope Storage and Cockcroft-Walton Accelerator. Building 529 was a relatively small building on the northwest side of Building 506, bounded by the same streets as Building 506. A stainless steel holding tank on the north side of the building was decontaminated and removed. After the building was cleared by the AEC in 1969, it was used as a computer tape storage vault and later demolished. The building foundation is no longer identifiable from the surface.

2.2.2.2 Former Buildings 507 and 508

Building 507 (see Figure E1-5) is the former site of the NRDL biological laboratory. This building was located in the middle of an area bounded by "H" Street to the west, Manseau Street to the north, Mahan Street to the south, and Hussey Street to the east. After the building was cleared by the AEC in 1969, it was used as the Public Works office and later demolished. The building foundation is no longer present.

Currently, the northwest end of Building 507's former location is now paved and part of a fenced parking lot for Building 606, which was constructed in 1989. The former building area is now strewn with debris and is overgrown with brush and grasses.

Building 508 (see Figure E1-5) was the former NRDL health physics building. Building 508 was located directly behind Building 507, and was bounded by the same streets as Building 507. After Building 508 was cleared by the AEC in 1969, it was used as a locker club and later demolished. The building foundation is no longer present.

Currently, the upper northwest side of Building 508's former location is now paved and part of the fenced parking lot at Building 606. The former building area is now strewn with debris and is overgrown with brush, grasses, and trees.

2.2.2.3 Former Buildings 509 and 517

Building 509 (see Figure E1-7) was used as an animal irradiation laboratory. Building 509 was east of Building 507, bounded by "H" Street to the east, Manseau Street to the north, Hussey Street to the east, and Mahan Street to the south. Building 509 was released in 1969 for unrestricted use by the AEC. It was used as a library and later demolished.

The outline of Building 509 is still present and old floor tile is visible in some areas. In other areas, it is possible to dig about 6 inches and find floor tiles still in place. The foundation of the building is not visible and may or may not be completely present under fill material.

Building 517 (see Figure E1-7) was the NRDL Cobalt-60 Irradiation Room and was bound by the same streets as Building 507. Building 517 was cleared and released in 1969 for unrestricted use by the AEC. It was used as a marine storage facility and later demolished.

The original concrete floor covered with old floor tiling still exists, and the outline of building is clearly visible. The area is strewn with some debris and floor tiles.

2.2.2.4 Former Buildings 510 and 510A

Building 510 (see Figure E1-9) is the former site of the radiation physics operation facility. The site is located at the southern end of the area bounded by "H" Street to the west, Manseau Street to the north, Hussey Street to the east, and Mahan Street to the south. Buildings 510A and 510 were constructed as one building. Operations in Building 510A included administrative support for a 1-million electronVolt (MeV) X-ray laboratory in Building 510. The buildings were cleared and released in 1969 for unrestricted use by the AEC. They were used as the Naval Investigation Service Office and Naval Ordnance Laboratory, and later demolished.

The building foundations are no longer present, and the area is overgrown extensively with brush and grasses. Some concrete debris and rebar is also scattered in the area.

2.2.2.5 Building 707 Concrete Drum Storage Pad

The concrete pad adjacent to Building 707 (animal kennel) was used by the NRDL as a storage area for drums of radioactive waste (see Figure E1-11). The concrete pad is in an area on the north side of "J" Street and the south side of 6th Avenue. Fifty-five-gallon steel drums stored at the concrete pad held solid radioactive waste from the chemistry and biology work areas. Solid wastes were placed in liners before they were placed into waste drums. The drums were then disposed of off site. The concrete pad is in fairly good condition. No obvious stains are apparent, but a variety of debris has been dumped on the pad such as ship anchoring ropes, roofing materials, and an exhaust fan housing unit.

2.3 CONTAMINATION EXPECTED AND IDENTIFIED AND REMEDIAL CRITERIA

NRDL operated under several radioactive licenses including a broad scope and special nuclear materials license. The contaminants expected or previously identified from NRDL background information and past Navy contractor investigations are discussed in the following sections. Radionuclides and principal emissions are provided in a table at the end of Section 2.3.5. Protectiveness criteria are established using current EPA guidance (EPA 1997). Concentration limits for identified contaminants of concern in volumetric sources are also described in the following subsections.

Remedial criteria and residual radioactivity levels will be formally addressed during the Record of Decision process. Proposed remedial criteria for volumetric sources were developed (TtEMI 1997) for support of characterization or interim remedial response decision making actions. Proposed remedial criteria are set forth in the following sections for large land areas and small hot spots for cesium-137 and strontium-90 in both soil and concrete/asphalt. These criteria should be considered as interim proposed values.

2.3.1 Miscellaneous Fission Products

Devices that historically relied on fission-product radioisotopes include electronic tubes and some devices relying on radioluminescent properties. These devices could have included isotopes of cobalt, cesium, and other beta-gamma-emitting radionuclides with half-lives typically ranging from 5 to 100 years. Such devices emit both beta and gamma radiation and can be detected by measurement of gamma radiation

when the device is intact or packaged. Detection of residual activity resulting from damaged, destroyed, or leaking devices is best performed by measurement of beta activity. These devices were commonly used in Navy facilities, but no specific indication of use or disposal was noted in historical records at the former NRDL sites investigated in the Phase III radiation investigation.

Screening criteria for residual radioactivity is 5 microrems per hour ($\mu\text{rem/hr}$) (as a tissue equivalent dose rate) at 1 meter height for large land areas (100 square meters [m^2] or greater) and 20 $\mu\text{rem/hr}$ for hot spots of areal extent less than 1 m^2 . This criteria is for radionuclides which are known and whose principal environmental radiation dose pathway is external gamma exposure and is based on NRC and EPA criteria (see Section 2.5.3.3).

2.3.2 Cesium-137 and Cobalt-60

Cesium-137 was used in NRDL studies in sealed sources, but NRDL was licensed to use cesium-137 in any form. Cesium-137 is a beta and gamma emitter.

Cobalt-60 was used in NRDL irradiation studies. NRDL was licensed to use cobalt-60 in sealed sources (Smith undated). The NRDL maintained at least five sealed cobalt-60 sources totaling 15,000 Curies that were used in experiments. Cobalt-60 is a beta and gamma emitter. The soil concentration criteria established for cesium-137 is 10 picoCuries per gram (pCi/g) for large areas and 100 pCi/g for hot spots of areal extent less than 1 m^2 . For cesium-137 in asphaltic or concrete media, the average concentration criteria is 20 pCi/g .

2.3.3 Radium, Thorium, and Uranium

Radium was widely used for providing self-illumination of gauges, instrument dials, and switches in the form of radioluminescent paint used on a wide range of military equipment and devices. Radium dials (radium-226) were dumped by the Navy in landfill areas at HPS in Parcel E. Thorium was used as a component of rare-earth optical glass, and certain electronic tubes, and as an alloying element in special metal products. Uranium may have been used as radiation shielding in certain munitions (in depleted form), and for other activities.

Each of these materials is characterized as a member of a natural decay series, and may be identified by alpha, beta, or gamma emissions of the parent isotope or any progeny. Half-lives for the long-lived isotopes all exceed 1,000 years. Dispersed activity resulting from damaged devices may be detected by measurement of alpha, beta, or gamma radiation, or by an instrument sensitive to all three types of activity. These radioisotopes are naturally present, as members of the uranium-238 and thorium-232 decay series. For radium-226, the soil criteria are 5 pCi/g (0 to 15 centimeters depth) and 15 pCi/g (below 15 centimeters) for areas less than 1 m². No criteria has been developed for concrete or asphaltic matrices.

2.3.4 Strontium-90

Strontium-90 was used for its radioluminescent properties. Strontium-90 emits a relatively strong beta particle, which can be easily detected with a gas proportional detector. Strontium-90 has a half-life of 28 years. NRDL was licensed to use strontium-90 in any form. Strontium-90 is ubiquitous in the environment as fallout from nuclear testing. The criteria for strontium-90 in asphaltic or concrete matrices are the same as those for cesium-137. For strontium-90, a criteria of 100 pCi/g in concrete/asphalt was proposed.

2.3.5 Tritium

Tritium was used at HPS as accelerator targets. Tritium has a short half-life of 12 years and only emits a weak beta particle. Field detection for beta emitters of tritium requires special instrumentation. Affected areas requiring 100 percent survey scans were swipe tested for removable tritium contamination and the swipes were analyzed at an off-site laboratory. No specific criteria for volumetric tritium contamination was proposed.

The following table lists radionuclides of interest in the Phase III radiation investigation and their principal emissions.

RADIONUCLIDES AND PRINCIPAL EMISSIONS

Nuclide	Isotope	Emissions	Particle Energies (Particle or Gamma Intensities) (MeV)		
			alpha	beta	gamma
Cesium	¹³⁷ Cs	β - γ		0.511 (94%) 1.176 (6%)	0.661 (84.8%)
Cobalt	⁶⁰ Co	β - γ		0.315 (99.87%) 1.488 (0.12%)	1.173 (100%) 1.332 (99.8%)
Potassium	⁴⁰ K	β - γ		1.33 (89%)	1.46 (11%)
Radium	²²⁶ Ra	α - γ	4.78 (94.5%) 4.59 (5.5%)		0.186 (3%)
Strontium	⁹⁰ Sr	β		0.546 (100%)	
Thorium	²²⁸ Th	α - γ	5.34 (28%) 5.43 (71%)		0.084 (1.6%) 0.214 (0.3%)
Thorium	²³² Th	α	4 (77%) 3.9 (23%)		
Tritium	³ H	β		0.018 (100%)	
Uranium	²³⁵ U	α - γ	4.6 (84%) 4.5 (4%)		0.110 (2.5%) 0.143 (11%) 0.185 (54%)
Uranium	²³⁸ U	α - γ	4.2 (77%) 4.15 (23 %)		0.048 (100%)

Notes:

α Alpha
β Beta
γ Gamma
MeV Million electronVolt

Reference: U.S. Department of Health, Education, and Welfare Public Health Services. 1970.

2.4 INSTRUMENTATION

The following sections describe the types of instrumentation selected, radiation detected, and related technical parameters. The global positioning system (GPS) used in this survey is also discussed in Section 2.4.6.

2.4.1 Detectors Sensitive to Alpha Radiation

An alpha scintillation detector was used to detect alpha radiation during the Phase III radiation investigation. The thin-window alpha detector has a large area (50 to 100 square centimeters [cm^2]) window, and a protected zinc sulfide or plastic scintillator coupled to a photomultiplier tube.

A scintillator is a material that when struck by an ionizing radiation emits visible light upon de-excitation. A photomultiplier tube converts the light pulses into an electronic signal. Each pulse is multiplied within the tube resulting in a signal which can be counted with a portable counter. An alpha detector is essentially sensitive only to alpha radiation, so may be used to assess alpha-emitting contaminants in a mixed alpha- and beta-gamma emitting environment. The count rate is a direct indicator of the surface alpha emission rate for the surface in contact with the detector.

2.4.2 Detectors Sensitive to Beta Radiation

For this survey, gas proportional detectors were used for detecting beta activity. A gas proportional detector is a sensitive detector that uses a gas mixture such as argon (10 percent) and methane (90 percent). This gas mixture is often referred to as a P10 gas mixture. The detector when operated with a high voltage bias is sensitive to beta-gamma activity (referred to as beta activity when using a gas proportional detector). As ionizing radiation passes through the gas in the detector, it transfers energy to orbital electrons of the gas, causing ionization of some gas atoms. This ionization results in the creation of ion pairs (one free electron and one positive gas atom). When a voltage is applied across the gas chamber in the detector, the ions produced in the gas move toward oppositely charged electrodes. In the proportional region, some gas multiplication takes place resulting in pulses which are counted in measured count rates. Each pulse represents the interaction of one particle or photon of radiation with the gas. This detector can be used to distinguish certain beta and alpha emitters from one another by using shielding in front of the detector and by proper setting of the detector bias and scalar discriminator.

2.4.3 Detectors Sensitive to Gamma Radiation

A sodium iodide (NaI) scintillation detector was used to detect gamma radiation during this survey. A NaI scintillator detector works well for finding radioactive contamination from gamma emitters such as cesium-137 and radium-226. NaI has a relatively high cross-section for gamma rays interaction, resulting in good sensitivity and in excitation with the NaI molecules emitting light. While NaI crystals can be

used to distinguish gamma radionuclides from one another through pulse height analysis, the Phase III radiation investigation surveys used gross count mode, which does not discriminate by energy.

2.4.4 Detectors Sensitive to Multiple Radiation

The thin-window pancake detector is an end-window detector in a "pancake" (window diameter is greater than detector depth) configuration (referred to as a pancake detector in this report). This detector is operated as a Geiger-Mueller (GM) counter so that detection of alpha or beta particles, or gamma photons within the detector are indistinguishable. Counting efficiencies for a typical pancake detector are as follows: (1) alpha at 5 MeV – 20 percent, (2) beta at an average of 0.5 MeV - 25 percent, and (3) low-energy gamma activity less than 5 percent. Actual beta and alpha efficiencies were determined by the Phase III radiation investigation team during calibration.

A pancake detector cannot be used for final release surveys where the principal radioisotopes of concern only emit alpha radiation. Areas of activity more than 10 times the alpha release criteria may be detected using the pancake detector. All areas identified with a pancake detector as having elevated activity were further investigated using an alpha scintillation detector and gas proportional detector.

2.4.5 Exposure Rate Meter

A Victoreen™ 450 air ionization chamber instrument calibrated in exposure rate units of microRoentgens per hour ($\mu\text{R/hr}$) was used to obtain exposure rate readings at the Building 364 sump site. The exposure rate meter was used in an integrate mode. The integrate mode allows for a more precise exposure reading because the exposure is averaged over a long time, reducing the detector variance from small signals.

2.4.6 Global Positioning System

A high accuracy real-time differential GPS was used during field survey of former NRDL building sites to continuously log locations of detector response during the grid traverse, and at 1-minute gamma radiation counts locations. Data were recorded directly from the rate meter through a RS-232 serial interface and automatically combined with the GPS location data using a microcomputer data logger. All equipment used is commercially available. A Trimble™ GPS Pathfinder Pro XR with Asset Surveyor was used to take location data for the grid traverse and for each 1-minute gamma count. This coupled with

post-processing of recorded positions system provided sub-meter accuracy for each positions. All location points are within plus or minus 3 feet of their true locations based on the World Geodetic System-84 ellipsoid and were converted to California State Plane Zone 3 coordinates for plotting. This system also permitted rapid calculation and setup for each location, and enabled the surveyor to go quickly to the building location even when foundations were overgrown or obliterated.

The GPS location and radiation data were downloaded into a geographic information system (GIS). The data were then used by the GIS system to produce contour maps of the gamma radiation measurements at each of the former NRDL building sites (see figures at the end of this attachment).

2.4.7 *In Situ* Gamma Spectroscopy

In situ gamma spectroscopic techniques were intended for use to identify any gamma-emitting isotopes on site when elevated count rates were observed. The gamma spectroscopic analysis would provide a radionuclide inventory at the site. This technique would not be used to assess activity concentration in materials at the site. However, *in situ* gamma spectroscopic techniques were not used in the Phase III radiation investigation because of the small number of anomalies identified during the survey. The Navy decided it would not be cost-effective to perform *in situ* gamma spectroscopy at this time.

2.5 METHODOLOGY

This section describes the methodologies used in the Phase III radiation investigation.

2.5.1 Detector Calibration

The method of calibration is described for each detector in the following subsections. Detector background for all detectors is determined for a single count at least 10 times the sample count time (10 minutes normally), except for the alpha count time, which was 20 minutes. Table E1-1-1 in Attachment E1-1 lists information used for calibration of the detectors. All sources are traceable to the National Institute of Science and Technology (NIST).

2.5.1.1 Gas Proportional Detectors

The gas proportional detectors are operated in a different voltage plateau region for beta-gamma (beta activity) sensitivity than that for alpha activity. The detectors operate at a higher voltage plateau and lower input sensitivity threshold when counting beta-gamma activity, and are also sensitive to alpha pulses; therefore, this counting region is commonly referred to as alpha-plus-beta mode.

The gas proportional detectors were operated exclusively in the higher voltage mode. The detector plateau is established (typically 1,750 volts) and the threshold set at approximately 4 milliVolts (mV), as specified by the manufacturer. A chlorine-36 source traceable to NIST and electroplated on stainless steel is positioned approximately 1 centimeter from the detector, and a count rate is determined. Uniformity of the detector across the active surface is checked by comparing the count rate in the center and detector corners. Nonuniformity is an indication that the detector has not been completely purged with counting gas. The efficiency is simply the ratio of net count rate to total source contained activity. At calibration, longer count times are used to determine the efficiency to a higher precision than for a routine measurement, and to protect the source. The efficiency was checked daily using another source for the measurement count time and was plotted on a control chart. The shorter count time is the primary factor in the control chart variability, but this check source ensures the instrument is not malfunctioning. For this survey, the 400-cm² gas proportional detector was kept on a continuous gas flow to keep the efficiency from dropping off. The 100-cm² gas proportional was charged with gas every 1 or 2 hours or whenever a fall-off in the background count rate was noted.

2.5.1.2 Alpha Scintillation Detector

A 100-cm² alpha scintillation detector was used during the investigation for detection of alpha activity. The detector plateau is established and the threshold is set at approximately 20 mV, as specified by the manufacturer. A thorium-230 source traceable to NIST and electroplated on stainless steel is positioned approximately 1 centimeter from the detector, and a count rate is determined. Uniformity of the detector across the active surface is checked by comparing the count rate in the center and detector corners. The efficiency is simply the ratio of net count rate to total source contained activity. The efficiency was checked daily and plotted on a control chart.

2.5.1.3 Sodium-Iodide Gamma Scintillation Detector

The 2-inch by 2-inch NaI detector was used for fixed count and scanning measurements as stated in the work plan (PRC 1996). The detector is sensitive to photons of energy ranging from 60 kilo electronVolts (KeV) to greater than 3 MeV.

Since this detector was used to identify relative increases in background activity and not to determine an exposure rate or precise activity, calibration is not required. The manufacturer's specification response of 900,000 cpm per milliRoentgen (mR) per hour (cpm/mR/hr) (Ludlum), should result in a background response of approximately 4,500 cpm in a 5 μ R/hr field. Each additional 900 cpm corresponds to 1 μ R/hr, or about 2 mR per year (mR/yr) for an occupational scenario, and 8.7 mR/yr for a continuous occupancy. Actual background is site-specific, depending on the specific detector operating voltage and threshold setting, as well as the location-specific radiation field. A normal background response is used to verify that the detector is performing normally.

2.5.2 Detection Limits

Detection capabilities were determined for each instrument based on specific radiological background conditions and actual detector efficiencies determined at the time of the survey. Detection limits based on counting statistical considerations are calculated using the 95th percentile confidence interval (UCL_{95}) for both Type I and Type II errors using the formulas specified in the work plan (PRC 1996). Counting times were adjusted as necessary to provide for efficient allocation of survey time, and to achieve detection limits (minimum detectable activity [MDA]) specified in the PRC work plan (PRC 1996). As specified in the work plan, the detection limits were approximately 25 percent of the radiological release criteria specified in NRC Regulatory Guide 1.86 (1974).

Detection limits used include (1) the critical limit (L_C) that protects from the false positive or Type I error and is used to determine the criteria for reporting a positive activity, and (2) the detection limit (L_D) that protects from the false negative or Type II error, which is specified as the *a priori* L_D .

During the investigation, detection capabilities were within specifications for sensitivity.

2.5.2.1 Beta Activity

The detection limits for beta-gamma activity specified in the work plan (PRC 1996) were achieved for both field measurements. All detection limits were less than 25 percent of the NRC Regulatory Guide 1.86 (1974).

2.5.2.2 Alpha Activity

The detection limits for alpha activity specified in the work plan (PRC 1996) were achieved for both field measurements. All detection limits for swipes were less than 25 percent of the NRC regulatory guidance 1.86 (1974) criteria, and less than 25 percent for fixed counts.

2.5.2.3 Gamma Activity

Gamma activity is compared to the dose-rate criteria set forth in Section 2.3.1. For a nominal background of 4,500 cpm, the one-sided, UCL_{95} , based only on counting statistics, is 4,770 cpm, which corresponds to 0.25 μ R/hr or 1 mR/yr for an occupational scenario and 9.6 mR/yr for a continuous occupancy scenario. In addition, variability in the count rate caused by changes in the distribution of naturally occurring radioactive material is considered, when comparing specific measurements to background and small increments of potential contaminants are masked.

Background gamma activity and variability were established in the field during the investigation. See Section 2.5.3.3 for gamma background activity determination. Field variability is taken into account in establishing the MDA for field gamma radiation measurements.

2.5.3 Background Determination

The following sections discuss (1) background determination for instrumentation used during the Phase III radiation investigation, (2) background soil concentrations of radiological isotopes against which to screen analytical data, and (3) determination of background for gamma measurements.

2.5.3.1 Instrumentation Background Determination

Instrument background was determined at least once daily and more often as required to account for local variation in the background radiation field at different sites. Background was determined whenever an apparent change was noted by a surveyor. The detector background count rate was determined by obtaining a background count for at least 10 times the sampling count time. Detector faces were pointed away from possible sources when counting background. All background surface activities were measured as zero activity, meaning the activity inherent in the surface material is not subtracted from background. Therefore, all measurable activity above background is attributed to residual surface contamination.

2.5.3.2 Soil Analytical Background Determination

U.S. background concentrations for radiological isotopes published in the EPA Region IV Issue Paper on Radiation Background vs. Site-Related Background Radiation (1995) were considered as representative background activity concentrations for this project. These EPA-cited background concentrations were established based on a report by the National Council on Radiation Protection and Measurement. These values were consistent with previously collected on-site data (PRC 1992); therefore, additional samples were not required for this investigation.

2.5.3.3 Gamma Background Activity Determination

Thirty-six 1-minute fixed background gamma count measurements were made using a NaI detector at four individual locations at HPS. The background locations were chosen due to the ground surface composition and history of the location. Locations known not to have been used for NRDL activities and with no known historical exposure to radiological materials were chosen as background count sites. The following four sites were chosen: (1) a ground surface of asphalt near Buildings 110 and 101 in Parcel A, (2) behind the San Francisco police officers gym building in Parcel B, on ground surface of soil and grass, (3) a parking lot on a ground surface of asphalt on the north side of Building 251 in Parcel C, and (4) a ground surface of soil and fill in an open field on the east side of Building 606 in Parcel D at a parking lot on a ground surface of asphalt. Statistical considerations were based on a pooled standard deviation for the counts using each group of measurements by the type of surface covering. Measurements below the lower limits set forth below are considered statistically indistinguishable from background.

The standard deviation of the 36 counts was calculated and a one-sided UCL_{95} was applied to obtain upper bound confidence limits or critical limit. The standard deviation of the background measurement was plus or minus 943 cpm at a UCL_{95} , resulting in a L_c of 6,500 cpm. All activity above 6,500 cpm was considered different from the background sample population. The gamma measurements were screened against the upper confidence count limit or L_c of 6,500 cpm at the former NRDL building sites, or in statistical terms, a one-tailed Student's T-test was applied against the measurements.

The same statistical probability was applied to background counts made strictly on asphalt on "H" Street using a NaI detector. The standard deviation of the background measurement was plus or minus 650 cpm at a UCL_{95} resulting in a L_c of 7,600 cpm. The average background on asphalt was 6,550 cpm.

Based on the application of EPA protectiveness criteria, the gamma measurements were evaluated for suitability for monitoring at that activity level. Both NRC (1994) and EPA (1996) support use of the same type detector as used in this survey (NaI 2-inch by 2-inch detector) as having an adequate scan sensitivity minimum detectable concentration for cesium-137 in soil. Because over 85 percent of the radiation dose is from the external exposure pathway based on the default residential land-use scenario analyzed by NUREG-1500 (NRC 1994), direct measurement by gamma activity is an appropriate method for demonstrating compliance with the soil concentration criteria. Comparison of the criteria with both Federal Guidance Report-12 (EPA 1992) and modeling with RESRAD-BUILD (Argonne National Laboratory 1997) confirm this approach. For the activity measurements over soil, the background was 5,500 cpm. A 5 $\mu\text{rem/hr}$ increase corresponds to about 4,500 additional cpm and a 20 $\mu\text{rem/hr}$ increase corresponds to 18,000 additional cpm; therefore, an average of 10,000 cpm is acceptable for large areas and an average of 23,500 cpm is acceptable for hot spots. The L_D is approximately 1 $\mu\text{rem/hr}$ for this survey.

2.5.4 Analytical Data Results

The analytical results of asphalt, soil, water, and wipe samples from the off-site laboratory analyses are included in Tables E1-6 through E1-10 at the end of this attachment. Sampling locations are provided on building figures at the end of this attachment. All other supporting documentation is available upon request.

Analytical Data Conversion

Anomalous analytical data at the Building 364 sump site and Building 707 concrete pad were converted from volume activity (pCi/g) to surface activity (disintegrations per minute per 100 cm² [dpm/100 cm²]) to compare the anomalous results to NRC surface activity criteria. Conversion of volume activity to surface activity is a simple and protective (conservative) method for evaluating small amounts of residual activity contained within surficial layers of structural materials where no specific derived criteria are available or approved. The method is protective because, while the activity is contained within a matrix and obviously not removable (swipeable), the activity is evaluated as if it were fixed on the surface by comparison to the total surface activity limit for the same isotope. For areas less than 100 cm² in size, the surface activity derived in this manner is still limited to three times the average limit, and may be averaged over 1 m².

2.5.5 Field Data

Field notes with swipe locations and all site-specific, grid-specific count data, and other supporting documentation are available upon request.

2.5.6 Grid Surveys in Unaffected and Affected Areas

Areas under investigation for radiation are usually classified into affected and unaffected areas (NRC 1992). This classification is usually based on site history. Areas where known radioactive material has been used, no previous surveys have been performed, or the type of radioactive material is unknown, are usually classed as "affected." Areas previously surveyed and released, where documentation is available, may be classed as "unaffected." Areas where the possibility of radioactive contamination is considered low based on review of site history are also usually classified as "unaffected." Radiological surveys are more extensive at affected areas than unaffected ones.

The sump, utility, and pipe trenches at the Building 364 sump site were treated as affected areas because not all the radioisotopes used in the area were known. The steel plates, old sump cover and fenced area surrounding the sump and trenches were treated as unaffected areas. The steel plates, old sump cover, and fenced area surrounding the sump were treated as unaffected areas because the possibility of residual contamination from radioactivity is unlikely. The fenced area surrounding the sump was treated as

unaffected because it was not an area of concern in this investigation and previously has been investigated (cesium-137 spill, see Attachment E1-4). Unaffected areas received cursory (or limited surveys) consisting of spot checks with the pancake probe and alpha scintillator. Affected areas received 100 percent scans, fixed counts, swipes, and additional tests. Supporting documentation is available upon request.

2.5.7 Sample Collection

The following paragraphs describe collection of soil, asphalt, and swipe samples during the Phase III radiation investigation.

2.5.7.1 Soil

All surface soil samples were collected using a stainless steel trowel or soil auger and were placed in a 500-milliliter polyethylene jar for analysis. The trowel and auger were decontaminated after each sample was collected. Samples were sent to an off-site laboratory for analysis.

2.5.7.2 Asphalt

Asphalt was cored using an asphalt core drill with a diamond drill bit. Cores had an approximate diameter of 3 inches. Cores were placed in plastic freezer bags. The core drill bit was decontaminated after each core was drilled. Samples were sent to an off-site laboratory for analysis.

2.5.7.3 Swipes

Two types of swipe samples were collected to detect removable contamination activity. Most swipes collected for gross alpha and beta analyses were plain filter paper wipes. Swipes collected for carbon-14 and tritium analyses were collected on polyfoam, which becomes transparent in the scintillation medium. These swipes were moistened with 70 percent isopropyl alcohol and placed in a scintillation (20 milliliters) vial. Swipe samples were analyzed by an off-site laboratory.

2.5.8 Screening Criteria

The following paragraphs describe the criteria used in screening field and analytical results.

2.5.8.1 Gamma Survey GPS Screening Criteria

Based on the 36 background measurements collected during the investigation, a statistical t-test analysis was performed and a critical value selected as the one-sided UCL_{95} , giving a critical value of 6,500 cpm. The area with data points exceeding 6,500 cpm was compared to the 10,000 cpm average or 23,500 cpm hot spot-only criteria. No areas exceeding the 10,000 cpm average and 23,500 cpm hot spot criteria corresponding to approximately 5 and 20 $\mu\text{rem/hr}$, respectively, except for the Building 707 concrete pad.

2.5.8.2 Swipe Screening Criteria

The screening criteria used for evaluation of swipe results were the NRC's Regulatory Guide 1.86 (1974) criteria for acceptable removable surface contamination. Laboratory results were converted from pCi per 100 cm^2 ($\text{pCi}/100\text{ cm}^2$) to $\text{dpm}/100\text{ cm}^2$ so results could be compared to the criteria for acceptable removable surface contamination. The conversion factor is 1 pCi equals 2.22 dpm. Provided all measurements were within the criteria, statistical analysis was not required.

2.5.8.3 Fixed and Scan Measurement Criteria

The screening criteria used for evaluation of fixed and scan results were the NRC's Regulatory Guide 1.86 (1974) criteria for acceptable fixed surface contamination. Field results in units of $\text{dpm}/100\text{ cm}^2$ were compared to the criteria for acceptable fixed surface contamination. For activity conversion factors, see Table E1-1-1. All supporting documentation is available upon request.

2.5.8.4 Soil Screening Criteria

Soil sampling results were compared against typical background activity concentrations in U.S.-typical soil data taken from an EPA report citing National Council on Radiation Protection and Measurement values. Where necessary, soil samples were also compared to the residual activity criteria set forth in Section 2.3.

2.5.8.5 GPS Scan Measurements

Using a data logger, survey personnel recorded continuous gamma count rates between the grid nodes during the site traverse to record the fixed 1-minute gamma count grid point measurements. These scan data are not presented in this report, but are available upon request.

3.0 FIELD ACTIVITIES AND SURVEY RESULTS

The following sections describe the field activities and survey results for each NRDL site discussed in Section 2.2.

3.1 PARCEL D BUILDINGS AND SITES

Two sites were investigated at IR-34 in Parcel D: (1) piping associated with a sink removed from work room 47 in Building 351A, and (2) a storage tank for radioactive effluent housed in a subsurface concrete vault and associated utility and pipe trenches connecting the concrete vault to Building 364 on the east side of the building (referred to as the Building 364 sump site). The following sections discuss the results of the Phase III radiation investigation at Building 351A and the Building 364 sump site.

3.1.1 Building 351A

The main area of concern in Building 315A was residual beta contamination in the water drain pipes. The proposed investigation for work room 47 was to collect swipe samples from the first 2 inches of the pipe associated with the sink area and catch basin. The associated piping consisted of a Y-pipe attached to a 90°-elbow pipe. The Y-pipe attached to the main water pipe running horizontally above the floor. The 90°-elbow pipe was removed from the Y-pipe section, while the Y-pipe remained attached to the main water pipe. Both sections of the pipe were scanned and swiped for residual contamination. No catch basin was associated with the pipes in work room 47. The swipes were sent to an off-site laboratory for gross alpha, gross beta, carbon-14, and tritium analyses.

The screening criteria used for evaluation of swipe results were the NRC's Regulatory Guide 1.86 (1974) acceptable surface contamination criteria. Analyses of swipes, number of swipes, maximum activity

(pCi/100 cm²), average activity (pCi/100 cm²), and standard deviation activity (pCi/100 cm²) are summarized in the following table.

BUILDING 351A SWIPE RESULTS

Part 1				
Analyte	Number of Swipes	Maximum Activity (pCi/100 cm ²)	Average Activity (pCi/100 cm ²)	Standard Deviation of Activity (pCi/100 cm ²)
Gross alpha	3	0.06 ±0.11	0.12	±0.01
Gross beta	3	0.56 ±0.38	0.29	±0.02
Carbon-14	1	< MDA (2.2)	2.2	NA
Tritium	1	< MDA (2.5)	2.5	NA

Notes:

MDA Minimum detectable activity
 NA Not applicable
 pCi/100 cm² picoCuries per 100 square centimeters
 < Less than
 ± Plus or minus

Analyses of swipes, maximum activity (dpm/100 cm²), acceptable surface activity (ASA) (dpm/100 cm²), and number of swipes exceeding the ASA are summarized in Part 2 of the table. Results in Part 2 of the table have been converted from pCi/100 cm² to dpm/100 cm² so results could be compared to the ASA. The conversion factor is 1 pCi equals 2.22 dpm.

BUILDING 351A SWIPE RESULTS

Part 2			
Analyte	Maximum Activity (dpm/100 cm ²)	Removable ASA (dpm/100 cm ²)	Number of Samples Exceeding ASA
Gross alpha	0.14 ±0.24	20	0
Gross beta	1.24 ±0.84	1,000	0
Carbon-14	4.88	1,000	0
Tritium	5.55	1,000	0

Notes:

ASA Acceptable surface activity

dpm/100 cm² Disintegrations per minute per 100 square centimeters
± Plus or minus

Before the piping was swiped, it was screened for elevated surface activity. The piping was scanned with a pancake probe, but no elevated activity from alpha or beta radiation was detected above background activity.

Gross alpha, gross beta, tritium, and carbon-14 were not detected on any swipes above their removable ASA. Thus it is concluded that the piping in work room 47 had no residual contamination above the ASA.

All swipe analytical results for Building 351A are presented in Table E1-8 at the end of this attachment.

3.1.2 Building 364 Sump Site: Low-Level Radioactive Waste Storage Tank Vault

A sump used for storage of low-level radioactive waste was investigated at the Building 364 site. The proposed investigation for the sump and associated utility trenches and pipe trenches was as follows:

1. A water sample was collected from the tank vault to characterize the water for radiological constituents. Based on the analytical results, the water was pumped and properly disposed of off site.
2. A 100 percent surface survey of the utility vaults and the associated steel covers was performed using a GM detector, an alpha scintillation detector, and a NaI detector. Areas that exhibited elevated count rates were delineated, recorded, and a swipe sample was collected.
3. Exposure rate measurements were taken on the surface at 3 feet (1 meter) above ground surface (ags) at various locations at the site. Additional measurements were taken above and within the utility trenches and sump and at any areas that exhibited elevated activity.

One water sample was collected for gamma spectroscopy, gross alpha, and gross beta analyses. The sample was collected from the water in the sump after it had been pumped into an on-site Baker tank. The sump, utility trenches, and pipe trenches were opened up and cleaned out. The sediment and debris were placed in two 55-gallon drums and stored at the site awaiting disposal off site.

A 1-meter grid system was established for the sump, utility, and pipe trenches. Each 1-meter grid in the sump, utility, and pipe trenches was swiped for removable gross alpha and gross beta activity. Each 1-

meter grid in the utility vaults was swiped for removable carbon-14 and tritium activity. One swipe was collected for carbon-14 and tritium analyses in each of the two pipe trenches. A composite swipe was taken for carbon-14 and tritium analyses from each column of grids on the four walls and floor of the sump, consisting of three to four grids per column.

The sump, utility, and pipe trenches were all 100 percent scanned for alpha and beta activity. Fixed 2-minute and 30-second counts for alpha and beta activity, respectively, were taken at grid intersection points on the 1-meter grid system. A serpentine scan was performed, and fixed count measurements were performed with the NaI detector in the sump, utility trenches, pipe vaults, and fenced area. Integrated exposure rate measurements were performed at 1 meter ags in the sump, utility trenches, pipe trenches, and fenced area.

The steel plates and sump cover were scanned with a pancake probe and spot-checked for fixed alpha contamination with alpha probe. The outside concrete walls (3 feet ags) of the sump were swiped for gross alpha and beta activity, spot-checked for alpha activity with the alpha detector, and scanned for beta activity with the gas proportional detector.

Two elevated areas of beta activity were discovered: (1) one on one of the walls of the sump, and (2) one on the side wall of the utility trench wall leading into Building 364 (see Figure E1-2). Two concrete samples were taken from these surfaces and sent to the off-site laboratory for gamma spectroscopy and strontium-90 analyses.

3.1.2.1 Fixed Radiation Measurements in Affected Areas

This section summarizes the results of fixed or direct count measurements. Fixed count measurements were performed at all grid node intersections on the 1-meter grid system established in the sump, utility, and pipe trenches. Fixed 2-minute alpha and 30-second beta measurements were performed. Fixed 1-minute gamma counts at random spots were also performed. The screening criteria used for evaluation of fixed count results were the NRC's Regulatory Guide 1.86 (1974) criteria for acceptable fixed surface contamination. Site area, fixed count type, maximum direct count measured, maximum direct count activity, and the ASA criterion are summarized in the following table.

BUILDING 364 SUMP SITE FIXED COUNT MEASUREMENT RESULTS

Fixed Count Type	Maximum Gross Count (cpm)	Maximum Count Activity (dpm/100 cm²)	ASA (dpm/100 cm²)	Activity Meets ASA Criteria? (Yes or No)
Sump				
Alpha	4	30 ±26	100	Yes
Beta	554	700 ±150	1,000	Yes
Gamma	NA	NA	NA	NA
Utility Trenches				
Alpha	7.5	56 ±36	100	Yes
Beta	2,080*	4,240 ±300	1,000	No
Gamma	13,747*	NA	NA	NA
Pipe Trenches				
Alpha	3.5	27 ±24	100	Yes
Beta	1,100**	2,000 ±220	1,000	No
Gamma	NA	NA	NA	NA

Notes:

- ASA Acceptable surface activity
- cpm Counts per minute
- dpm/100 cm² Disintegrations per minute per 100 square centimeters
- NA Not applicable

* Count and corresponding activity were taken near an anomaly of residual contamination. All other counts outside anomaly surface area were below the ASA. See Section 3.1.2.7 for elevated anomaly results.

** The weighted average over the area was less than maximum ASA.

± Plus or minus

Alpha fixed counts did not exceed the acceptable surface activity of 100 dpm/100 cm² for any 2-minute count made in the sump, utility, or pipe trenches. Beta fixed counts exceeded the ASA of 1,000 dpm/100 cm² for 30-second counts taken in the utility and pipe trenches. The work plan identified elevated alpha, beta, and gamma activity on the north wall of the utility trench nearest Building 351A. No elevated alpha activity was detected on the wall. Elevated beta activity above the ASA was identified on the north wall of the utility trench nearest Building 351A. Section 3.1.2.7 summarizes the characterization of this anomaly.

3.1.2.2 Alpha and Beta Scans in Affected Areas

This section summarizes 100 percent scan results. The same screening criteria were used for evaluation of the scan results. Scan measurements were performed on all grids on the 1-meter grid system established in the sump, utility, and pipe trenches. The scanning speed for alpha activity was about 1 detector width per second and averaged about 2 minutes per 1-m² grid, using a detector with a 100 cm² surface area. The scanning speed for beta activity was about 1 centimeter per second (cm/s), averaged to about 1 minute per 1-m² grid using a detector with a 400 cm² surface area. Gamma scans were performed in a serpentine pattern over the floors and walls of the sump, utility, and pipe trenches. Site area, scan count type, maximum scan count measured, maximum scan activity, and ASA are summarized in the following table.

BUILDING 364 SUMP SITE SCAN MEASUREMENT RESULTS

Scan Count Type	Maximum Gross Count (cpm)	Maximum Count Activity (dpm/100 cm ²)	ASA (dpm/100 cm ²)	Activity Meets ASA Criteria? (Yes or No)
Sump				
Alpha	17	70 ±40	100	Yes
Beta	2,500*	970 ±60*	1,000	Yes
Gamma	7,500	NA	NA	NA
Utility Trenches				
Alpha	6	20 ±20	100	Yes
Beta	4,000*	1,930 ±80*	1,000	No
Gamma	22,000*	NA	NA	NA
Pipe Trenches				
Alpha	3	< MDA (20)	100	Yes
Beta	2,000	670 ±50	1,000	Yes
Gamma	7,500	NA	NA	NA

Notes:

ASA Acceptable surface activity
 cpm Counts per minute
 dpm/100 cm² Disintegrations per minute per 100 square centimeters

Notes (Continued):

MDA Minimum detectable activity

NA Not applicable

* Scan and corresponding activity were taken near an anomaly of residual contamination. All other scans outside the anomalous surface area were below the ASA. See Section 3.1.2.7 for anomaly results.

< Less than

± Plus or minus

All scan data were below the ASAs for alpha and beta activity except for the area on the utility trench wall. The above counts and corresponding activities were located in two areas of the sump and utility trench, showing activity much higher than other scan data from the site. These elevated activity areas are discussed in Section 3.1.2.7.

3.1.2.3 Gross Alpha and Beta, Tritium, and Carbon-14 Swipes

This section summarizes swipe analytical results. The screening criteria used for evaluation of swipe results were the NRC's Regulatory Guide 1.86 (1974) criteria for acceptable removable surface contamination. Analytes of swipes, number of wipes, maximum activity (pCi/100 cm²), average activity (pCi/100 cm²), and standard deviation (pCi/100 cm²) are summarized in Part 1 of the following table.

BUILDING 364 SUMP SITE SWIPE RESULTS

Part 1				
Analyte	Number of Swipes	Maximum Activity (pCi/100 cm²)	Average Activity (pCi/100 cm²)	Standard Deviation of Activity (pCi/100 cm²)
Sump				
Gross alpha	77	0.46 ±0.22	0.12	0.05
Gross beta	77	0.98 ±0.37	0.43	0.18
Carbon-14	22	6.5 ±2.9	1.61	1.42
Tritium	22	0.25 ±0.98	1.1	0.26

**BUILDING 364 SUMP SITE SWIPE RESULTS
(Continued)**

Part 1				
Analyte	Number of Swipes	Maximum Activity (pCi/100 cm²)	Average Activity (pCi/100 cm²)	Standard Deviation of Activity (pCi/100 cm²)
Utility Trenches				
Gross alpha	17	0.16 ±0.16	0.11	0.01
Gross beta	17	0.58 ±0.34	0.36	0.08
Carbon-14	17	3.5 ±0.60	0.86	0.78
Tritium	17	6.4 ±3.1	3.0	1.52
Pipe Trenches				
Gross alpha	3	0.07 ±0.12	0.12	0.02
Gross beta	3	0.69 ±0.36	0.41	0.14
Carbon-14	1	4.0 ±1.9	2.58	NA
Tritium	1	<MDA (1.38)	1.38	NA

Notes:

MDA Minimum detectable activity
 NA Not applicable
 pCi/100 cm² picoCuries per 100 square centimeters
 < Less than
 ± Plus or minus

Analyses of swipes, maximum activity (dpm/100 cm²), ASA (dpm/100 cm²), and number of swipes exceeding the acceptable surface activity are summarized in Part 2 of the table. Results in Part 2 of the table have been converted from pCi/100 cm² to dpm/100 cm² so results could be compared to the ASA.

BUILDING 364 SUMP SITE SWIPE RESULTS

Part 2			
Analyte	Maximum Activity (dpm/100 cm²)	ASA (dpm/100 cm²)	Number of Samples Exceeding Removable ASA
Sump			
Gross alpha	1.02 ±0.49	20	0
Gross beta	2.18 ±0.82	100	0
Carbon-14	14.4 ±6.44	100	0
Tritium	0.56 ±2.18	100	0
Utility Trenches			
Gross alpha	0.36 ±0.36	20	0
Gross beta	1.29 ±0.75	100	0
Carbon-14	7.77 ±1.33	100	0
Tritium	14.2 ±6.88	100	0
Pipe Trenches			
Gross alpha	0.16 ±0.27	20	0
Gross beta	1.53 ±0.8	100	0
Carbon-14	8.88 ±4.22	100	0
Tritium	3.06	100	0

Notes:

- ASA Acceptable surface activity
- dpm/100 cm² Disintegrations per minute per 100 square centimeters
- ± Plus or minus

Gross alpha, gross beta, tritium, and carbon-14 were not detected on any swipes above their removable ASAs. The sump, utility, and pipe trenches have no residual removable surface contamination from gross alpha and beta activity or from carbon-14 and tritium.

All analytical results for Building 364 sump site are presented in Table E1-8 at the end of this attachment.

3.1.2.4 Alpha, Beta, and Gamma Measurements in Unaffected Areas

The following were considered unaffected areas in the survey at the Building 364 sump site: (1) steel plates covering the utility and pipe trenches, (2) old sump cover, (3) outside wall of the sump, and (4) the fenced area around the sump and trenches. The steel plates and old sump cover were scanned with a pancake probe and spot-checked for alpha contamination. The outside of the sump was swiped for gross alpha and beta activity, spot-checked for alpha activity, and scanned for beta activity. The fenced area around the sump and trenches was scanned in a serpentine pattern and random 1-minute fixed gamma and beta counts were taken with a NaI and gas proportional detector, respectively.

No elevated alpha or beta activity were detected on the steel plates or old sump cover. No elevated activity was present on the outside portion of the sump.

Background gamma activity in the sump area is about 7,500 cpm. Background gamma activity for HPS ranges from 3,400 to 6,500 cpm (see Section 2.5.3.3 for background discussion). The background activity at the sump is likely higher due to the asphalt-concrete pavement covering the site. The gamma activity in the yard ranges from 7,000 to 9,000 cpm. A count rate of 22,000 cpm was detected in the northwest side of the yard where the elevated beta activity was detected on the utility trench wall. Random fixed 1-minute beta counts were also performed at the yard. Additional random fixed 1-minute counts at the yard ranged from 440 to 1,450 dpm/100 cm². The activity was below the beta ASA criterion of 5,000 dpm/100 cm² with the exception of one hot spot above the utility trench wall (affected area).

None of the unaffected areas of the site had residual activity above the ASA criterion.

3.1.2.5 Exposure Rate Measurements

Exposure rate measurements were taken at 3 feet (1 meter) ags at various locations at the Building 364 sump site. Exposure rate measurements at the site ranged from 0.134 mR/hr to 1.250 mR/hr. Exposure rates measured at elevated areas of activity are discussed in Section 3.1.2.7.

3.1.2.6 Waste Storage Tank (Sump) Water Sampling

One water sample was analyzed for gamma-emitting radionuclides (gamma spectroscopy), gross alpha, and gross beta; it was collected from the water in the sump after the water was pumped into an on-site Baker tank. The following table summarizes the analytical results.

BUILDING 364 SUMP SITE SUMP WATER RESULTS

Analyte	Result (pCi/L)	Result (μCi/mL)	MDA (pCi/L)
Gross alpha	< MDA (1.2)	$< 1 \times 10^{-9}$	1.2
Gross beta	12 ±1.6	1.2×10^{-8}	2.1
Cesium-137	< MDA (8.5)	$< 8 \times 10^{-9}$	8.5
Cobalt-60	< MDA (10)	$< 1 \times 10^{-8}$	10
Potassium-40	< MDA (100)	$< 1 \times 10^{-7}$	100
Radium-226	< MDA (16)	$< 1.6 \times 10^{-8}$	16
Thorium-288	< MDA (12)	$< 1.2 \times 10^{-8}$	12
Thorium-232	< MDA (52)	$< 5.2 \times 10^{-8}$	52

Notes:

MDA Minimum detectable activity

pCi/L picoCuries per liter

μCi/mL microCuries per milliliter

< Less than

± Plus or minus

The analytical results of the gross alpha and all radionuclide isotopes identified in the sump water sample were below their minimum detectable activities. The gross beta analytical result was above the analytical MDA, but below the sewer discharge criteria for unknown beta emitters of 1×10^{-7} microCuries per milliliter (μCi/mL) established by the NRC (Title 10 of the Code of Federal Regulations 20, Appendix B [NRC 1995]). No elevated activity was detected in the water sample from the sump. The water in the sump is apparently rainwater which has leaked in from the utility trenches. RASO in its letter dated May 6, 1997, approved the sump water to be released as normal waste (RASO 1997). The water will be released into HPS sewer system.

All analytical results for Building 364 sump water are presented in Table E1-9 in at the end of this attachment.

3.1.2.7 Elevated Areas of Activity Identified

The following two areas exhibited elevated beta activity at the Building 364 sump site: (1) the southwest wall of the sump, about 2.5 meters up from the bottom of the sump under a small concrete-filled pipe in the wall; and (2) the northeast side wall of the utility trench leading into Building 364 (see Figure E1-2). All analytical results for the above anomalies are presented in Table E1-10 at the end of this attachment.

The maximum beta activity detected on the surface of the sump wall before sampling was 1,588 dpm/100 cm². The concrete in this area was chipped and sampled. The sample was sent to the off-site laboratory for gamma spectroscopy and strontium-90 analyses. The exposure rate in the sump near the wall was 0.134 mR/hr.

The average area-weighted surface activity over a surface area of approximately 1-m² on the utility vault wall was 4,670 dpm/100 cm². The concrete in this area was chipped and sampled. The sample was sent to the off-site laboratory for gamma spectroscopy and strontium-90 analyses. The exposure rate in the trench near the wall was 0.1 mR/hr.

The elevated activity in both areas appears to be fixed surface activity. The areas were rescanned after sampling and the surface activity for both areas had dropped to below or near the ASA. The sump wall was rescanned and exhibited an average-weighted activity of 977 dpm/100 cm² over a 1-m² area and was below the average ASA criterion of 1,000 dpm/100 cm² for strontium-90, the suspected isotope of concern. The activity on the utility trench wall dropped significantly, but was still above the ASA criterion for strontium-90 in some sections. In effect, the chip sampling partially decontaminated these two elevated areas. The final clearance criteria and recommendation for remediation of these anomalies are based on the analytical results reported in this document.

The following table summarizes the analytical results of the concrete chip sampling. The analytical results were converted to dpm/100 cm² for comparison to the ASA criterion. This comparison assumes that all the activity is at the surface of the contaminated surface. The activity was multiplied by

the weight of the sample, and then divided by the assumed area of the contaminated zone in units of 100 cm² (see Section 2.5.4.1).

BUILDING 364 SUMP SITE ANOMALY ANALYTICAL RESULTS

Analyte	Activity Concentration (pCi/g)	Surface Activity (dpm/100 cm ²)
Sump Anomaly - 285364001^a		
Cesium-137	19 ±0.48	1,126
Cobalt-60	<MDA (0.23)	<MDA (14)
Europium-152	1.3 ±0.45	77
Radium-226	<MDA (0.34)	<MDA (20)
Strontium-90	43 ±0.64	2,549
Thorium-228	<MDA (0.32)	<MDA (19)
Thorium-232	<MDA (0.56)	<MDA (33)
Utility Vault Anomaly - 285364002^b		
Cesium-137	210 ±1	11,282
Cobalt-60	<MDA (0.06)	<MDA (3.2)
Radium-226	0.43 ±0.33	23
Strontium-90	1.6 ±0.16	86
Thorium-228	<MDA (0.36)	<MDA (19)
Thorium-232	0.35 ±0.28	19

Notes:

dpm/100 cm² Disintegrations per 100 square centimeters

MDA Minimum detectable activity

pCi/g picoCuries per gram

a Anomaly 285364001, sample weight is 26.7 grams and contaminated area is 100 cm²

b Anomaly 285364002, sample weight is 72.6 grams and contaminated area is 300 cm²

< Less than

± Plus or minus

Cesium-137, europium-152, and strontium-90 were detected in sump anomaly sample 285364001.

Surface activities for cobalt-60, radium-226, thorium-228, and thorium-232 were below their respective MDAs. The surface activity for cesium-137 of 1,126 dpm/100 cm² on the surface of sump wall did not

exceed the average ASA criterion of 5,000 dpm/100 cm². The surface activity for strontium-90 of 2,549 dpm/100 cm² exceeded the average ASA criterion of 1,000 dpm/100 cm². Europium-152 is a fission product which is a beta-gamma emitter. The surface activity of Eu-152 for 77 dpm/100 cm² did not exceed the average ASA criterion of 5,000 dpm/100 cm².

Cesium-137, radium-226, and strontium-90 were detected in utility trench anomaly sample 285364002. Surface activities for cobalt-60 and thorium-228 were below their respective MDAs. Thorium-232 was detected below the U.S. typical background concentration (TBC) of 0.87 pCi/g for thorium-232 in soil. The surface activity for cesium-137 of 11,282 dpm/100 cm² exceeded the average ASA criterion of 5,000 dpm/100 cm². The surface activity for radium-226 of 23 dpm/100 cm² did not exceed the average ASA criterion of 100 dpm/100 cm². The surface activity for strontium-90 of 86 dpm/100 cm² did not exceed the average ASA criterion of 1,000 dpm/100 cm². Exposure rates will be reevaluated following remediation.

3.1.3 Conclusions and Recommendations

Based on the results of the Phase III radiation investigation in Parcel D, PRC recommends the following for Building 351A and the Building 364 sump site:

Building 351A

The drain pipes in work room 47 at Building 351A were below the established criteria or residual surface activity; therefore, the building may be considered for release by the Navy for unrestricted public use.

Building 364 Sump Site

1. The anomaly on the wall of the sump did not meet acceptable surface contamination levels for strontium-90. The sump wall should be further decontaminated by chipping or other methods and the wall rescanned for surface activity above background.
2. The anomaly on the utility trench wall did not meet acceptable surface contamination levels for cesium-137. The utility trench wall should be further decontaminated by chipping or other methods and the wall rescanned for surface activity above background.

Building 351A may be considered for release by the Navy for unrestricted public use. Building 364 sump site is not available for release and requires further remediation.

3.2 FORMER NAVAL RADIOLOGICAL DEFENSE LABORATORY BUILDING SITES AT PARCEL E

Five former NRDL sites were investigated in Parcel E: (1) former NRDL Buildings 506 and 529 in IR-11/14/15; (2) former NRDL Buildings 507 and 508 in IR-38; (3) former NRDL Buildings 509 and 517 in IR-11/14/15; (4) former NRDL Buildings 510 and 510A in IR-11/14/15; and (5) the Building 707 drum storage pad in IR-39. The above-mentioned buildings have all been demolished. The following sections discuss the results of the Phase III radiation investigation at these sites.

3.2.1 Former Buildings 506 and 529 in IR-11/14/15

The Phase III radiation investigation at former NRDL Buildings 506 and 529 consisted of the following:

1. A radiological survey of the surface soil within and surrounding the former Buildings 506 and 529 to (1) identify areas exhibiting elevated count rates, (2) determine if strontium-90 had contaminated the soil surrounding the former Building 506, and (3) determine if gamma-emitting radionuclides were present around former Building 529. One-minute gamma counts were performed at 10-foot by 10-foot grid intersects using a 2-inch by 2-inch NaI detector. The grid was established in the field prior to the survey and sampling activities. All elevated soils were delineated, recorded, and sampled. Detector responses were continuously recorded during grid transects.
2. Sixteen soil sampling locations were identified and sample, and the samples analyzed for strontium-90. All sample and gamma activity counts were identified in the field using a GPS system and a 2-inch by 2-inch NaI detector.
3. Four locations were identified for sampling for gamma-emitting radionuclides (gamma spectroscopy) remaining at the site above background. All sample and gamma activity counts were identified in the field using a GPS system and a 2-inch by 2-inch NaI detector.

Buildings 506 and 529 were surveyed on the same 10-foot by 10-foot grid due to their proximity to each other. A GPS was used to identify soil sampling and gamma count grid node locations. Three of 16 surface soil sampling locations were on asphalt at Building 506 (B506SS10, B506SS11, and B506SS15). At these locations, asphalt was cored and the cores sent to the off-site laboratory for analysis. When possible at these locations, soil under the asphalt was also sampled. Soil under two of

the three asphalt sampling locations was sampled (B506SS10 and B506SS11). All soil and asphalt samples were analyzed for strontium-90. At Building 529, four out of four surface soil samples were sampled for gamma-emitting radionuclides remaining at the site above background. Section 3.2.1.2 discusses the soil analytical results for Buildings 506 and 529.

3.2.1.1 Gamma Survey Using GPS

Figure E1-3 presents the approximate 10-foot by 10-foot grid system used for taking fixed 1-minute grid node gamma measurements at former NRDL Buildings 506 and 529. Figure E1-4 indicates the grid node locations, corresponding gamma 1-minute measurements, and the contours resulting from the data.

Several 1-minute gamma count measurements exceeded the L_c of 6,500 cpm at Buildings 506 and 529. Most of the counts that exceeded were in fact taken on asphalt and did not exceed the L_c of 7,600 cpm for asphalt cover. At a few locations, the gamma measurement exceeded both background L_c values, however, they could not be associated with an anomaly, and may be due to variances in background activity. Table E1-1 lists the gamma measurements exceeding 6,500 cpm and their associated surface coverings. These measurements did not exceed the dose rate criteria set forth in Section 2.0.

One area of elevated gamma activity containing one radiation anomaly exceeded the upper limit of the established background range by two times. The anomaly was detected at the southwest corner of the grid survey at former NRDL Buildings 506 and 529. The anomaly appears approximately between Buildings 529 and 520 in an area that was probably formerly paved asphalt. At the surface, the gamma count reading was 11,205 cpm, at 4 inches bgs the gamma count reading was 13,130 cpm, and at 8 inches bgs the gamma count reading was 18,394 cpm. At this location asphalt debris was encountered at 4 inches bgs. The anomaly was flagged and further investigated. The anomaly area and buried asphalt debris were scanned using a pancake probe to see if increased beta activity was present. No elevated beta activity was detected. The NaI detector was used to further characterize the anomaly, and detector readings continued to increase with depth. Count rates increased significantly beyond what would be expected from a change in geometry leading investigators to conclude that a buried point source may be present below 12 inches bgs. At 12 inches bgs, the count rate was about 20,000 cpm. Further excavation is required to recover the possible point source.

3.2.1.2 Soil and Asphalt Sampling

Soil

Radionuclide isotopes detected in surface soil samples taken at Buildings 506 and 529 were cesium-137, potassium-40, radium-226, strontium-90, thorium-228, and thorium-232. The following table summarizes the analytical soil results, listing the number of samples, as well as maximum, average, and standard deviation activity of concentrations.

BUILDINGS 506 AND 529 SOIL ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 506				
Strontium-90	15	0.25 ±0.13	0.10	0.04
Building 529				
Cesium-137	4	0.15 ±0.03	0.08	0.04
Potassium-40	4	13.0 ±0.74	8.88	2.52
Radium-226	4	0.42 ±0.06	0.38	0.05
Thorium-228	4	0.49 ±0.05	0.42	0.06
Thorium-232	4	0.64 ±0.16	0.49	0.1

Notes:

pCi/g picoCuries per gram

± Plus or minus

The following table summarizes the number of soil samples exceeding the screening criteria for TBC for soil activity in the U.S. for the above-mentioned isotopes (EPA 1995).

BUILDINGS 506 AND 529 SOIL RESULTS VERSUS TBCs

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 506				
Strontium-90	15	0.25 ±01	0.7	0
Building 529				
Cesium-137	4	0.15 ±0.03	0.7	0
Potassium-40	4	13.0 ±0.74	10.0	1
Radium-226	4	0.42 ±0.06	1.0	0
Thorium-228	4	0.49 ±0.05	0.87	0
Thorium-232	4	0.64 ±0.16	0.87	0

Notes:

- pCi/g picoCuries per gram
- TBC U.S. typical background concentration
- ± Plus or minus

Radiological isotopes detected in surface soil samples at Buildings 506 and 529 were below their respective TBCs, except for potassium-40 in one sample detected at an activity concentration of 13 pCi/g in a sample collected at Building 529. Potassium-40 is a naturally occurring primordial radiological isotope in the environment and background activity concentrations in the TBCs range from 3 to 20 pCi/g in soil. The detected outlier falls within the background range for potassium-40 in soil. Potassium-40 is not a nuclide of potential concern.

All radiological isotopes detected in soil samples at Building 506 and 529 were at background activity concentrations. All soil analytical results for Building 506 and 529 are presented in Table E1-1.

Asphalt

Asphalt core samples from locations B506SS10, B506SS11, and B506SS15 were analyzed for strontium-90. Strontium-90 was not detected above any of the sample-specific MDAs. The average MDA for these samples was 0.195 pCi/g.

No strontium-90 was detected in asphalt samples at Building 506. All asphalt analytical results for Building 506 are presented in Table E1-7 at the end of this attachment.

3.2.2 Former Buildings 507 and 508 in IR-38

The Phase III radiation investigation at former NRDL Buildings 507 and 508 consisted of the following:

1. A radiological survey of the surface soil within and surrounding former Buildings 507 and 508 was conducted to identify areas exhibiting elevated gamma count rates. One-minute gamma count rates were performed at 10-foot by 10-foot grid intersects using a 2-inch by 2-inch NaI detector. The grid was established in the field prior to the survey and sampling activities. All soils that exhibited elevated activity were delineated, recorded, and sampled.
2. Eight surface soil sampling locations at Building 507 and eight surface soil sampling locations at Building 508 were identified to be sampled for gamma-emitting radionuclides (gamma spectroscopy) remaining at the site above background. All sample and gamma activity count locations were identified in the field using a GPS.

Buildings 507 and 508 were surveyed on the same 10-foot by 10-foot grid due to their proximity to each other. A GPS was used to identify soil sampling and gamma count grid node locations. Six out of eight surface soil samples from Building 507 were tested for gamma-emitting radionuclides. Sampling locations B507SS01 and B507SS08 are within the fenced area near Building 606. Seven out of eight surface soil samples were collected at Building 508 and were analyzed for gamma-emitting radionuclides. Sampling location B508SS03 was located within the fenced area near Building 606. Since residual contamination due to gamma-emitting radionuclides was unlikely, and the three sampling locations were under newly paved asphalt, the locations were not sampled. The fenced parking lot for Building 606 was surveyed using the NaI detector. Section 3.2.1.2 discusses the soil analytical results for Buildings 507 and 508.

3.2.2.1 Gamma Survey Using GPS

Figure E1-5 presents the approximate 10-foot by 10-foot grid system used for taking fixed 1-minute grid node gamma measurements at former Buildings 507 and 508. Figure E1-6 indicates the grid node locations, corresponding gamma 1-minute measurements, and the contours resulting from the data.

Several one-minute gamma count measurements exceeded the L_c of 6,500 cpm at Buildings 507 and 508. However, most of the gamma counts that exceeded the L_c of 6,500 cpm were in fact taken on asphalt and did not exceed the L_c of 7,600 cpm for asphalt cover. These few gamma measurements were not associated with an anomaly and may be due to background activity. Table E1-2 lists gamma measurements exceeding 6,500 cpm and their associated surface coverings.

No anomalous areas of elevated activity were found. No residual radiological activity above background was detected at this site.

3.2.2.2 Soil Sampling

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in surface soil samples taken at Buildings 507 and 508. The following table summarizes the analytical soil results, listing the number of samples, and maximum, average, and standard deviation of activity concentrations.

BUILDINGS 507 AND 508 SOIL ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 507				
Cesium-137	6	0.08 ±0.04	0.03	0.02
Potassium-40	6	11.0 ±1.1	7.75	2.24
Radium-226	6	0.35 ±0.08	0.27	0.06
Thorium-228	6	0.46 ±0.07	0.34	0.08
Thorium-232	6	0.42 ±0.16	0.35	0.06

**BUILDINGS 507 AND 508 SOIL ANALYTICAL RESULTS
(Continued)**

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 508				
Cesium-137	7	< MDA (0.02)	0.02	0.001
Potassium-40	7	9.6 ± 0.84	7.6	1.04
Radium-226	7	0.44 ± 0.07	0.3	0.07
Thorium-228	7	0.48 ± 0.05	0.34	0.07
Thorium-232	7	0.56 ± 0.18	0.35	0.10

Notes:

MDA Minimum detectable activity

pCi/g picoCuries per gram

< Less than

± Plus or minus

The following table summarizes the number of soil samples exceeding the screening criteria for TBCs for soil activity in the U.S. for the above-mentioned isotopes.

BUILDINGS 507 AND 508 SOIL RESULTS VERSUS TBCs

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 507				
Cesium-137	6	0.08 ± 0.04	0.7	0
Potassium-40	6	11.0 ± 1.1	10.0	1
Radium-226	6	0.35 ± 0.08	1.0	0
Thorium-228	6	0.46 ± 0.07	0.87	0
Thorium-232	6	0.42 ± 0.16	0.87	0

**BUILDINGS 507 AND 508 SOIL RESULTS VERSUS TBCs
(Continued)**

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 508				
Cesium-137	7	< MDA (0.02)	0.7	0
Potassium-40	7	9.6 ±0.84	10.0	0
Radium-226	7	0.44 ±0.07	1.0	0
Thorium-228	7	0.48 ±0.05	0.87	0
Thorium-232	7	0.56 ±0.18	0.87	0

Notes:

- MDA Minimum detectable activity
- pCi/g picoCuries per gram
- TBC U.S. typical background concentration
- < Less than
- ± Plus or minus

Radiological isotopes detected in surface soil samples at Building 507 were below their respective TBCs, except for potassium-40 in one sample detected at an activity concentration of 11 pCi/g. Potassium-40 is a naturally occurring radiological isotope in the environment and background activity concentrations in the TBCs range from 3 to 20 pCi/g in soil. This outlier falls within the background range for potassium-40 in soil. Potassium-40 is not a nuclide of potential concern. None of the seven surface soil samples at Building 508 exceeded their respective TBCs. All radiological isotopes detected in the soil at the former NRDL Building 508 were present at background activity concentrations.

All radiological isotopes detected in soil samples at Buildings 507 and 508 were at background activity concentrations. All soil analytical results for Buildings 507 and 508 are presented in Table E1-1 at the end of this attachment.

3.2.3 Former Buildings 509 and 517 in IR-11/14/15

The Phase III radiation investigation at former NRDL Buildings 509 and 517 consisted of the following:

1. A radiological survey of the surface soil within and surrounding former Buildings 509 and 517 was conducted to identify areas exhibiting elevated gamma count rates. One-minute gamma count rates were performed at 10-foot by 10-foot grid intersects using a 2-inch by 2-inch NaI detector. The grid was established in the field prior to the survey and sampling activities. All soil that exhibited elevated activity were delineated, recorded, and sampled.
2. Five surface soil sampling locations at Building 509 and three surface soil sampling locations at Building 517 were identified to be sampled for gamma-emitting radionuclides (gamma spectroscopy) remaining at the site above background. All sample and gamma activity counts were identified in the field using a GPS.

Buildings 509 and 517 were surveyed on the same 10-foot by 10-foot grid due to their proximity to each other. A GPS was used to identify soil sampling and gamma count grid node locations. One of five surface soil sampling locations was collected at Building 509 (B509SS05). At this location, an asphalt core was taken and sent to the off-site laboratory for analysis. It was impractical to sample the soil under the asphalt core because only gravel fill was present. All soil and asphalt samples were analyzed for gamma-emitting radionuclides (gamma spectroscopy). At Building 517, three out of three surface soil samples were collected for analysis for gamma-emitting radionuclides remaining at the site above background. Section 3.2.3.2 discusses the soil analytical results for Buildings 509 and 517.

3.2.3.1 Gamma Survey Using GPS

Figure E1-7 presents the approximate 10-foot by 10-foot grid system used for taking fixed 1-minute grid node gamma measurements at former NRDL Buildings 509 and 517. Figure E1-8 indicates the grid node locations, corresponding 1-minute gamma measurements, and the contours resulting from the data.

Several 1-minute gamma count measurements exceeded the L_c of 6,500 cpm at Buildings 509 and 517. However, most of the gamma counts that exceeded the L_c of 6,500 cpm were in fact taken on asphalt and did not exceed the L_c of 7,600 cpm for asphalt cover. At a few locations, the gamma measurements exceeded both background and L_c values, but they could not be associated with an anomaly and may be attributed to variances in background activity. Table E1-3 lists the gamma measurements exceeding 6,500 cpm and their associated surface coverings. One count of 9,374 cpm was measured in the upper northeast region of the grid near Building 517. The area was within the criteria set forth in Section 2.0.

3.2.3.2 Soil and Asphalt Sampling

Soil

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in surface soil samples taken at Buildings 509 and 517. The following table summarizes the analytical soil results, listing the number of samples, and maximum, average, and standard deviation of activity concentrations.

BUILDINGS 509 AND 517 SOIL ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 509				
Cesium-137	5	0.1 ±0.04	0.06	0.03
Potassium-40	5	15.0 ±1.1	9.43	3.28
Radium-226	5	0.31 ±0.07	0.29	0.02
Thorium-228	5	0.49 ±0.06	0.36	0.08
Thorium-232	5	0.49 ±0.15	0.34	0.11
Building 517				
Cesium-137	3	< MDA (0.02)	0.02	0.001
Potassium-40	3	9.10 ±0.79	8.17	0.87
Radium-226	3	0.6 ±0.07	0.4	0.16
Thorium-228	3	0.81 ±0.05	0.52	0.21
Thorium-232	3	0.96 ±0.18	0.61	0.26

Notes:

MDA Minimum detectable activity < Less than
 pCi/g picoCuries per gram ± Plus or minus

The following table summarizes the number of soil samples exceeding the screening criteria for TBCs for soil activity in the U.S. for the above-mentioned isotopes.

BUILDINGS 509 AND 517 SOIL RESULTS VERSUS TBCs

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 509				
Cesium-137	5	0.1 ±0.04	0.7	0
Potassium-40	5	15.0 ±1.10	10.0	1
Radium-226	5	0.31 ±0.07	1.0	0
Thorium-228	5	0.49 ±0.06	0.87	0
Thorium-232	5	0.49 ±0.15	0.87	0
Building 517				
Cesium-137	3	< MDA (0.02)	0.7	0
Potassium-40	3	9.1 ±0.79	10.0	0
Radium-226	3	0.6 ±0.07	1.0	0
Thorium-228	3	0.81 ±0.05	0.87	0
Thorium-232	3	0.96 ±0.18	0.87	1

Notes:

MDA Minimum detectable activity
 pCi/g picoCuries per gram
 TBC U.S. typical background concentration

< Less than
 ± Plus or minus

Radiological isotopes detected in surface soil samples at Building 509 were below their respective TBCs, except for potassium-40 in one sample detected at an activity concentration of 15 pCi/g. Potassium-40 is a naturally occurring radiological isotope in the environment and background activity concentrations in the TBCs range from 3 to 20 pCi/g in soil. This outlier falls within the background range for potassium-40 in soil. Potassium-40 is not a nuclide of potential concern. Radiological isotopes detected in surface soil samples at Building 517 were below their respective TBCs, except for thorium-232 in one sample detected at an activity concentration of 0.96 pCi/g. Thorium-232 background activity concentrations in the TBCs range from 0.10 to 3.4 pCi/g in soil. This outlier falls within the background range for thorium-232 in soil.

All radiological isotopes detected in soil samples at Buildings 509 and 517 were at background activity concentrations. All soil analytical results for Buildings 509 and 517 are presented in Table E1-1 at the end of this attachment.

Asphalt

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in the asphalt core sample collected at Building 509. The following table summarizes the analytical results, listing the number of samples and the activity concentrations.

BUILDING 509 ASPHALT ANALYTICAL RESULTS

Isotope	Number of Samples	Activity Concentration (pCi/g)
Building 509		
Cesium-137	1	< MDA (0.01)
Potassium-40	1	3.87 ±0.41
Radium-226	1	0.23 ±0.05
Thorium-228	1	0.33 ±0.03
Thorium-232	1	0.3 ±0.1

Notes:

MDA Minimum detectable activity

pCi/g picoCuries per gram

< Less than

± Plus or minus

Radiological isotopes detected in the asphalt core sample at Building 509 were detected at activity concentrations within the normal range expected for TBCs of soil in the U.S. (EPA 1995; Eisenbud 1987). Radium concentrations in the sample are consistent with naturally occurring radium activity supported by uranium-238, the long-lived parent of primordial activity.

All asphalt analytical results for Building 509 are presented in Table E1-2 at the end of this attachment.

3.2.4 Former Buildings 510 and 510A in IR-11/14/15

The Phase III radiation investigation at former NRDL Buildings 510 and 510A consisted of the following:

1. A radiological survey of the surface soil within and surrounding former Buildings 510 and 510A was conducted to identify areas exhibiting elevated gamma count rates. One-minute gamma count rates would be performed at 10-foot by 10-foot grid intersects using a 2-inch by 2-inch NaI detector. The grid was established in the field prior to the survey and sampling activities. All soils that exhibit elevated activity were delineated, recorded, and sampled.
2. Six surface soil sampling locations at Building 510 and two surface soil sampling locations at Building 510A were identified to be sampled for gamma-emitting radionuclides (gamma spectroscopy) remaining at the site above background. All sample and gamma activity counts were identified in the field using a GPS.

Buildings 510 and 510A were surveyed on the same 10-foot by 10-foot grid due to their proximity to each other. A GPS was used to identify soil sampling and gamma count grid node locations. Four out of four surface soil samples were sampled at Building 510, and two out of two surface soil samples were sampled at Building 510A for gamma-emitting radionuclides remaining at the site above background. Section 3.2.4.2 discusses the soil analytical results for Buildings 510 and 510A.

3.2.4.1 Gamma Survey Using GPS

Figure E1-9 presents the approximate 10-foot by 10-foot grid system used for taking fixed 1-minute grid node gamma measurements at former NRDL Buildings 510 and 510A. Figure E1-10 indicates the grid node locations, corresponding gamma 1-minute measurements, and the contours resulting from the data.

Several 1-minute gamma count measurements exceeded the L_c of 6,500 cpm at Buildings 510 and 510A. At a few locations, the gamma measurements exceeded the background L_c values, but they could not be associated with an anomaly and may be attributed to variances in background activity. Table E1-4 lists the gamma measurements exceeding 6,500 cpm and their associated surface coverings.

No anomalous areas of elevated activity were found. No residual radiological activity was detected above background at this site.

3.2.4.2 Soil Sampling

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in surface soil samples taken at Buildings 510 and 510A. The following table summarizes the analytical results of soil sampling, listing the number of samples, and the maximum, average, and standard deviation of activity concentrations.

BUILDINGS 510 AND 510A SOIL ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 510				
Cesium-137	6	0.05 ±0.03	0.03	0.01
Potassium-40	6	10.0 ±0.83	7.44	1.41
Radium-226	6	0.29 ±0.06	0.27	0.03
Thorium-228	6	0.38 ±0.05	0.26	0.06
Thorium-232	6	0.36 ±0.11	0.29	0.05
Building 510A				
Cesium-137	2	< MDA (0.02)	0.02	0.004
Potassium-40	2	11.0 ±0.81	8.25	2.75
Radium-226	2	0.29 ±0.06	0.27	0.02
Thorium-228	2	0.31 ±0.04	0.28	0.03
Thorium-232	2	0.41 ±0.15	0.37	0.04

Notes:

MDA Minimum detectable activity

pCi/g picoCuries per gram

< Less than

± Plus or minus

The following table summarizes the number of soil samples exceeding the screening criteria for TBCs for soil activity in the U.S. for the above-mentioned isotopes.

BUILDINGS 510 AND 510A SOIL RESULTS VERSUS TBCs

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 510				
Cesium-137	6	0.05 ±0.03	0.7	0
Potassium-40	6	10.0 ±0.83	10.0	0
Radium-226	6	0.29 ±0.06	1.0	0
Thorium-228	6	0.38 ±0.05	0.87	0
Thorium-232	6	0.36 ±0.11	0.87	0
Building 510A				
Cesium-137	2	< MDA (0.02)	0.7	0
Potassium-40	2	11.0 ±0.81	10.0	1
Radium-226	2	0.29 ±0.06	1.0	0
Thorium-228	2	0.31 ±0.04	0.87	0
Thorium-232	2	0.41 ±0.15	0.87	0

Notes:

- MDA Minimum detectable activity
- pCi/g picoCuries per gram
- TBC U.S. typical background concentration

- < Less than
- ± Plus or minus

None of the six surface soil samples exceeded their respective TBCs for Building 510. All radiological isotopes detected in the soil at Building 510 were at background activity concentrations. Radiological isotopes detected in surface soil samples at Building 510A were below their respective TBCs, except for potassium-40 in one sample detected at an activity concentration of 11 pCi/g. Potassium-40 is a naturally occurring radiological isotope in the environment and background activity concentration in the TBCs range from 3 to 20 pCi/g in soil. This outlier falls within the activity background range for potassium-40 in soil. Potassium-40 is not a nuclide of potential concern. All radiological isotopes detected in soil samples at Buildings 510 and 510A were at background activity concentrations.

All soil analytical results for Buildings 510 and 510A are presented in Table E1-1 at the end of this attachment.

3.2.5 Building 707 Concrete Drum Storage Pad in IR-39

The Phase III radiation investigation at the former NRDL Building 707 concrete drum storage pad consisted of the following:

1. A radiological survey of the surface soil within and surrounding the Building 707 concrete pad was conducted to identify areas exhibiting elevated gamma count rates. A 100 percent confirmation surface scan of the concrete pad was performed using a 2-inch by 2-inch NaI detector.
2. Swipes were taken at the pad on a 5-meter grid system and were analyzed for gross alpha and gross beta activity.
3. One-minute gamma count rates were performed at 10-foot by 10-foot grid intersects using a 2-inch by 2-inch NaI detector. The grid was established in the field prior to the survey and sampling activities. All soils that exhibited elevated activity were delineated, recorded, and sampled.
4. Twenty-seven surface soil sampling locations at the Building 707 concrete pad were identified to be measured for gamma-emitting radionuclides (gamma spectroscopy) remaining at the site. All samples and gamma measurement locations were identified in the field using a GPS.

A GPS was used to identify soil sampling and gamma count grid node locations. An independent 5-meter by 5-meter grid was established on the concrete pad and swipes were taken for gross alpha and gross beta analyses. A total of 52 swipes were taken. Section 3.2.5.3 discusses the swipe results for the Building 707 concrete pad.

Thirteen of 27 surface soil sampling locations were located on asphalt at the Building 707 concrete pad (B707SS04 through B707SS16). At these locations, asphalt cores were taken and sent to the off-site laboratory for analysis. When possible at these locations, soil under the asphalt was also sampled. Soil under two of the 13 asphalt sampling locations was sampled (B707SS04 and B707SS14). All soil and asphalt samples were analyzed for gamma-emitting radionuclides. Section 3.2.5.4 discusses the soil analytical results for the Building 707 concrete pad.

3.2.5.1 Gamma Survey Using GPS

Figure E1-11 presents the 10-foot by 10-foot grid system used for taking fixed 1-minute grid node gamma measurements at the Building 707 concrete pad. Figure E1-12 indicates the grid node locations, corresponding 1-minute gamma measurements, and the contours resulting from the data.

Many 1-minute gamma count measurements exceeded the L_c of 6,500 cpm at Buildings 506 and 529. However, most of the gamma counts that exceeded the L_c of 6,500 cpm were in fact taken on asphalt or concrete and did not exceed the L_c of 7,600 for asphalt cover. For the situations at Building 707 where both L_c s were exceeded, and an anomaly was not identified clearly, the elevated values may be associated with (1) statistical variability of the individual count, (2) variations in the natural activity, or (3) indication of trace residual contamination which may not require further action. Table E1-5 lists the gamma measurements exceeding 6,500 cpm and their associated surface coverings.

Only two anomalies were detected southeast of the concrete pad on asphalt near "J" Street, which exceeded the dose rate criteria. The two hot spots were approximately 20 feet apart with gamma count rates of 32,300 cpm and 17,300 cpm, respectively. Asphalt core samples were taken at both anomalies (sampling locations 2857070A1 and 2857070A2) and analyzed for gamma-emitting radionuclides (gamma spectroscopy). Section 3.2.5.5 summarizes the analytical results of the anomaly.

3.2.5.2 Gamma Scan Survey

A 100 percent gamma scan was performed on the Building 707 concrete pad using the 5-meter by 5-meter grid established for swipe sampling. A NaI detector was used to scan the pad. The scan activity for the concrete pad ranged from 4,000 to 7,000 cpm. The average background rate at the pad was $5,800 \pm 930$ cpm.

During the scan, two anomalies were discovered on the concrete pad. The two hot spots were approximately 10 feet apart with gamma count rates of 18,640 and 21,115 cpm, respectively. The anomaly with the greater count rate of the two spots was sampled (sampling location 2857070A3) for gamma-emitting radionuclides (gamma spectroscopy). Section 3.2.5.5 summarizes the analytical results of the anomaly.

3.2.5.3 Gross Alpha and Beta Swipes

This section summarizes swipe sample analytical results. The screening criteria used for evaluation of wipe results were NRC's Regulatory Guide 1.86 (1974) criteria for acceptable surface contamination (NRC 1974). Analytical results of swipes, numbers of swipes, maximum activity (pCi/100 cm²), average activity (pCi/100 cm²), and standard deviation (pCi/100 cm²) are summarized in following the table.

BUILDING 707 CONCRETE PAD SWIPE RESULTS

Analyte	Number of Swipes	Maximum Activity (pCi/100 cm ²)	Average Activity (pCi/100 cm ²)	Standard Deviation of Activity (pCi/100 cm ²)
Gross alpha	52	0.5 ±0.21	0.14	0.09
Gross beta	52	1.0 ±0.42	0.46	0.21

Notes:

pCi/100 cm² picoCuries per 100 square centimeters

± Plus or minus

Analytes of swipes, maximum activity (dpm/100 cm²), removable ASA (dpm/100 cm²), and number of swipes exceeding the removable ASA are summarized in the following table.

BUILDING 707 CONCRETE PAD SWIPE RESULTS

Analyte	Maximum Activity (dpm/100 cm ²)	ASA (dpm/100 cm ²)	Number of Samples Exceeding ASA
Gross alpha	1.11 ±0.47	20	0
Gross beta	2.22 ±0.93	1,000	0

Notes:

ASA Acceptable surface activity

dpm/100 cm² Disintegrations per minute per 100 square centimeters

± Plus or minus

Gross alpha and gross beta were not detected on any wipes above their removable acceptable surface activities. All swipe analytical results for the Building 707 concrete pad are presented in Table E1-3 at the end of this attachment.

3.2.5.4 Soil and Asphalt Sampling

Soil

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in surface soil samples taken at the Building 707 concrete pad. The following table summarizes the analytical soil results, listing the number of samples, and the maximum, average, and standard deviation of activity concentrations.

BUILDING 707 CONCRETE PAD SOIL ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 707 Concrete Pad				
Cesium-137	16	0.2 ±0.07	0.08	0.05
Potassium-40	16	16.0 ±1.20	8.32	2.51
Radium-226	16	0.4 ±0.12	0.23	0.06
Thorium-228	16	0.54 ±0.07	0.26	0.08
Thorium-232	16	0.46 ±0.19	0.28	0.08

Notes:

pCi/g picoCuries per gram

± Plus or minus

The following table summarizes the number of soil samples exceeding the screening criteria for TBCs for soil activity in the U.S. for the above-mentioned isotopes.

BUILDING 707 CONCRETE PAD SOIL RESULTS VERSES TBCs

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	TBC (pCi/g)	Number of Samples Exceeding TBC
Building 707 Concrete Pad				
Cesium-137	16	0.2 ±0.07	0.7	0
Potassium-40	16	16.0 ±1.20	10.0	1
Radium-226	16	0.4 ±0.12	1.0	0
Thorium-228	16	0.54 ±0.07	0.87	0
Thorium-232	16	0.46 ±0.19	0.87	0

Notes:

pCi/g picoCuries per gram

TBC U.S. typical background concentration

± Plus or minus

None of the 16 surface soil samples exceeded their respective TBCs for the Building 707 concrete pad, except for potassium-40 in one sample detected at an activity concentration of 16 pCi/g. Potassium-40 is a naturally occurring radiological isotope in the environment and background activity concentrations in the TBCs range from 3 to 20 pCi/g in soil. This outlier falls within the background range for potassium-40 in soil. Potassium-40 is not a nuclide of potential concern.

All soil analytical results for the Building 707 concrete pad are presented in Table E1-1 at the end of this attachment.

Asphalt

Cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 were detected in the 13 asphalt core samples collected along side of the Building 707 concrete pad.

The following table summarizes the analytical results, listing the number of samples, and the maximum, average, and standard deviation of activity concentrations. Activity concentrations were averaged over the entire asphalt core sample. On average, samples had a diameter and height of 3 inches, and weighed about 1,250 grams.

BUILDING 707 CONCRETE PAD ASPHALT ANALYTICAL RESULTS

Isotope	Number of Samples	Maximum Activity Concentration (pCi/g)	Average Activity Concentration (pCi/g)	Standard Deviation of Activity Concentration (pCi/g)
Building 707 Concrete Pad				
Cesium-137	13	1.45 ±0.12	0.22	0.41
Potassium-40	13	13.01 ±1.15	7.86	2.49
Radium-226	13	0.67 ±0.17	0.41	0.16
Thorium-228	13	0.89 ±0.13	0.56	0.21
Thorium-232	13	0.88 ±0.25	0.50	0.22

Notes:

pCi/g picoCuries per gram

± Plus or minus

Cesium-137 was detected at low concentrations in six of 13 asphalt samples. The laboratory counted the asphalt cores on their top and bottom surfaces. Activity was detected on the surfaces but not the bottoms, indicating that the activity was not uniformly distributed. The maximum concentration of cesium-137 detected in an asphalt sample was 1.45 pCi/g. When the activity was assumed to be concentrated at the surface, the surface activity was 4,024 dpm/100 cm². The cesium-137 concentrations at the Building 707 concrete pad were slightly elevated but within the average ASA criterion for cesium-137 of 5,000 dpm/100 cm².

All asphalt analytical results for the Building 707 concrete pad are presented in Table E1-8 at the end of this attachment.

3.2.5.5 Building 707 Concrete Pad Anomalies

Only three of the four anomalies were sampled at the Building 707 concrete pad due to the close proximity of two of the anomalies (see Figure E1-11).

The elevated activities on and off the concrete pad appear to be fixed surface activities on asphalt and concrete. The isotopic constituents of each anomaly are summarized in the following table, along with the activity concentration.

BUILDING 707 CONCRETE PAD ANOMALY ANALYTICAL RESULTS

Isotope	Activity Concentration (pCi/g)
Anomaly 1 - 2857070A1	
Cesium-137	4,300 ±55
Cobalt-60	22 ±9.9
Europium-152	130 ±36
Radium-226	51 ±25
Thorium-228	120 ±21
Thorium-232	52 ±42
Anomaly 2 - 2857070A2	
Cesium-137	4,800 ±60
Cobalt-60	< MDA (12)
Radium-226	61 ±24
Thorium-228	70 ±19
Thorium-232	87 ±42
Anomaly 3 - 2857070A3	
Cesium-137	7,000 ±67
Cobalt-60	< MDA (9.2)
Radium-226	54 ±30
Thorium-228	38 ±24
Thorium-232	81 ±36
Background Sample - 2857070B1	
Cesium-137	6.3 ±4.7
Cobalt-60	< MDA (6.4)
Radium-226	70 ±13
Thorium-228	79 ±7
Thorium-232	< MDA (38)

**BUILDING 707 CONCRETE PAD ANOMALY ANALYTICAL RESULTS
(Continued)**

Isotope	Activity Concentration (pCi/g)
Background Sample - 2857070B2	
Cesium-137	< MDA (11)
Cobalt-60	< MDA (7.8)
Radium-226	55 ±13
Thorium-228	< MDA (15)
Thorium-232	< MDA (49)

Notes:

MDA Minimum detectable activity
pCi/g picoCuries per gram
< Less than
± Plus or minus

Cesium-137, cobalt-60, europium-152, radium-226, thorium-228, and thorium-232 were detected in anomaly 1 (2857070A1). Cesium-137, radium-226, thorium-228, and thorium-232 were detected in anomaly 2 (2857070A2). Cesium-137, radium-226, thorium-228, and thorium-232 were detected in anomaly 3 (2857070A3). Thorium-228 and thorium-232 are usually naturally occurring, but indicated abnormal activity concentrations in these samples.

These samples exceeded the criteria for asphalt. Anomalies 1, 2, and 3 exceeded the Navy's criterion for cesium-137 of 100 pCi/g for hot spots and the Navy's criterion for radium-226 of 5 pCi/g at the surface. Europium was detected in anomaly 1. Europium is a fission product and its use at HPS is unknown.

The sample activity concentrations were intended to be compared against the two background samples (2857070B1 and 2857070B2) taken at the Building 707 concrete pad site; however, radium-226 was detected above background concentrations. The samples were deemed inappropriate for comparison to anomalous samples. The background sampling locations were rescanned on November 5, 1997 using a 2-inch by 2-inch NaI detector and fixed counts were performed to try to detect the elevated gamma radiation from the anomalous concentrations of radium and thorium detected in the background samples.

Based on the results of the scanning and fixed counts performed with the NaI detector, the area associated with the anomalous samples were indistinguishable from other areas on the pad or adjacent roadway.

All anomalous analytical results for the Building 707 concrete pad are presented in Table E1-10 at the end of this attachment. Background sample analytical results for the Building 707 concrete pad are presented in Table E1-6 at the end of this attachment.

3.2.6 Conclusions and Recommendations

Based on the results of the Phase III radiation investigation in Parcel E, TtEMI's recommendations follow for these sites: (1) former NRDL Buildings 506 and 529 in IR-11/14/15; (2) former NRDL Buildings 507 and 508 in IR-38; (3) former NRDL Buildings 509 and 517 in IR-11/14/15; (4) former NRDL Buildings 510 and 510A in IR-11/14/15; and (5) Building 707 concrete drum storage pad in IR-39.

Buildings 506 and 529

1. One-minute gamma count measurements exceeding the background limits for both soil and asphalt, and not associated with a known anomaly, may be areas of natural increased activity.
2. All radiological isotopes detected in soil samples were detected at background activity concentrations or was within TBC ranges.
3. The potential buried point source behind Building 529 should be excavated and recovered.

Buildings 507 and 508

1. Based on the criteria, no residual activity was present above background.
2. All radiological isotopes detected in soil samples were detected at background activity concentrations.
3. Based on the established criteria of this Phase III radiation investigation, this site may be considered for release by the Navy for unrestricted public use.

Buildings 509 and 517

1. One-minute gamma count measurements exceeding the background limits for both soil and asphalt, and not associated with a known anomaly, may be areas of natural increased activity.

2. All radiological isotopes detected in soil samples were detected at background activity concentrations or were within TBC ranges.
3. The area around the anomalous count rate measurements of 9,000 cpm, measured during the gamma count survey, should be assessed for potential removal.

Buildings 510 and 510A

1. Based on the criteria, no residual activity is present above background.
2. All radiological isotopes detected in soil samples were detected at background activity concentrations.
3. Based on the established criteria of this Phase III radiation investigation, this site may be considered for release by the Navy for unrestricted public use.

Building 707 Concrete Drum Storage Pad

1. One-minute gamma count measurements exceeding the background limits for both soil and asphalt, and not associated with a known anomaly, may be areas of natural increased activity.
2. The three anomalies investigation at the Building 707 concrete drum storage pad did not meet acceptable levels for cesium-137, radium-226, thorium-228, and thorium-232. The contaminated asphalt and concrete should be removed, the soil sampled below these anomalies, and the area rescanned for surface activity above background.
3. Any asphalt or concrete on the pad and area surrounding the pad exhibiting elevated surface activity should be removed and the areas rescanned.
4. Additional investigation should be conducted to determine the nature and extent of the elevated radium-226, thorium-228, and thorium-232 concentrations, and to determine if removal is necessary.

Buildings 507, 508, 510, and 510A may be considered for release by the Navy for unrestricted public use. Buildings 506, 529, 509, and 517 are not available for immediate release and further minor remediation is recommended. For Building 707 concrete pad, further study is recommended.

4.0 CONCLUSIONS AND RECOMMENDATIONS

TtEMI recommends considering the following building sites for free release and that EFA West forward this recommendation to RASO for approval so the Navy may release these sites for unrestricted public use:

- Building 351A in Parcel D
- Buildings 507 and 508 in Parcel E
- Buildings 510 and 510A in Parcel E

The following sites do not qualify for free release and further remediation is recommended based on the findings of the Phase III radiation investigation:

- Building 364, low-level radioactive waste storage tank vault site in Parcel D because cesium-137 and strontium-90 were detected at the site above established NRC acceptable surface activity criteria
- Buildings 506 and 529 in Parcel E because of a possible point source buried behind Building 529
- Buildings 509 and 517 in Parcel E because of anomalous count rate measurement near the upper northeast end of Building 517.
- Building 707 concrete drum storage pad in Parcel E because cesium-137 and radium-226, were detected at the site above established Navy and EPA criteria.

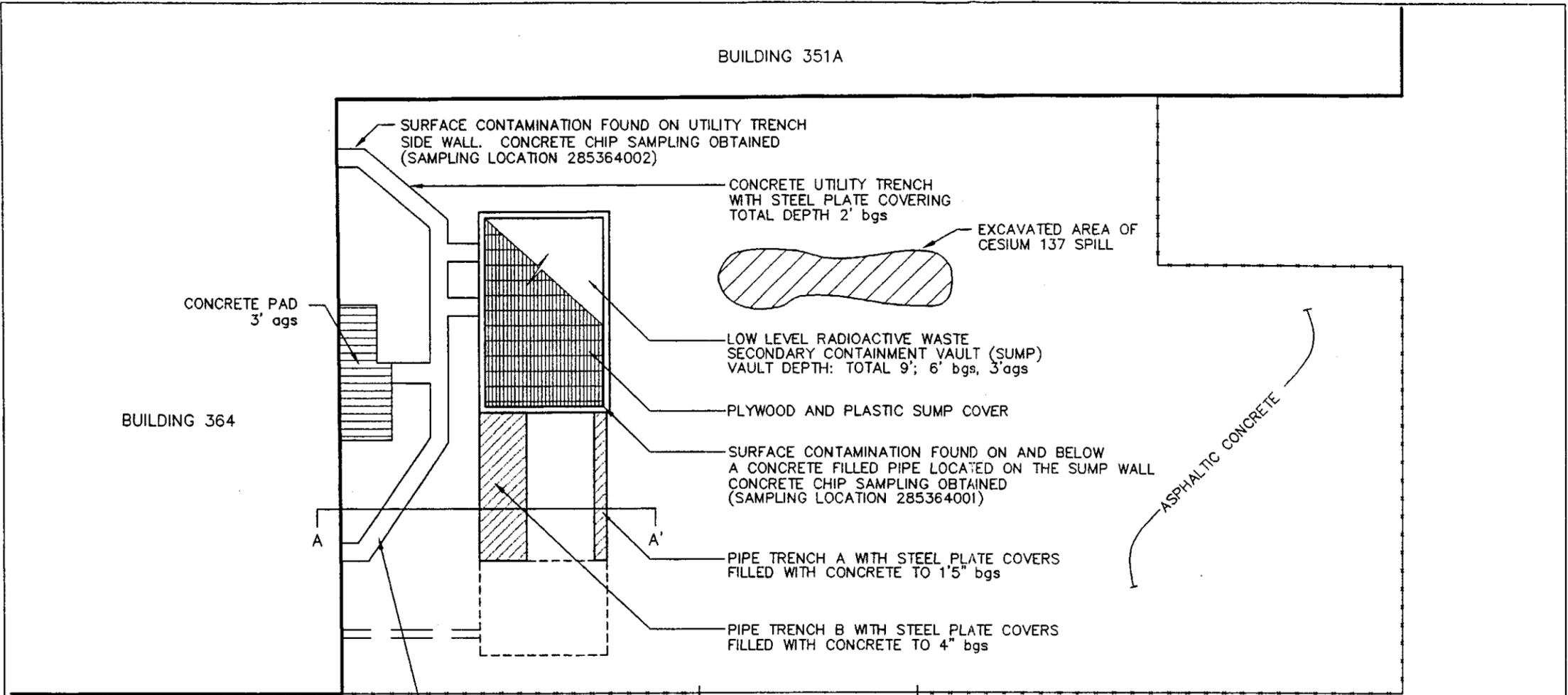
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FIGURES



BUILDING 364

CONCRETE PAD
3' ags

BUILDING 351A

SURFACE CONTAMINATION FOUND ON UTILITY TRENCH SIDE WALL. CONCRETE CHIP SAMPLING OBTAINED (SAMPLING LOCATION 285364002)

CONCRETE UTILITY TRENCH WITH STEEL PLATE COVERING TOTAL DEPTH 2' bgs

EXCAVATED AREA OF CESIUM 137 SPILL

LOW LEVEL RADIOACTIVE WASTE SECONDARY CONTAINMENT VAULT (SUMP) VAULT DEPTH: TOTAL 9'; 6' bgs, 3' ags

PLYWOOD AND PLASTIC SUMP COVER

SURFACE CONTAMINATION FOUND ON AND BELOW A CONCRETE FILLED PIPE LOCATED ON THE SUMP WALL CONCRETE CHIP SAMPLING OBTAINED (SAMPLING LOCATION 285364001)

PIPE TRENCH A WITH STEEL PLATE COVERS FILLED WITH CONCRETE TO 1'5" bgs

PIPE TRENCH B WITH STEEL PLATE COVERS FILLED WITH CONCRETE TO 4" bgs

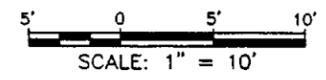
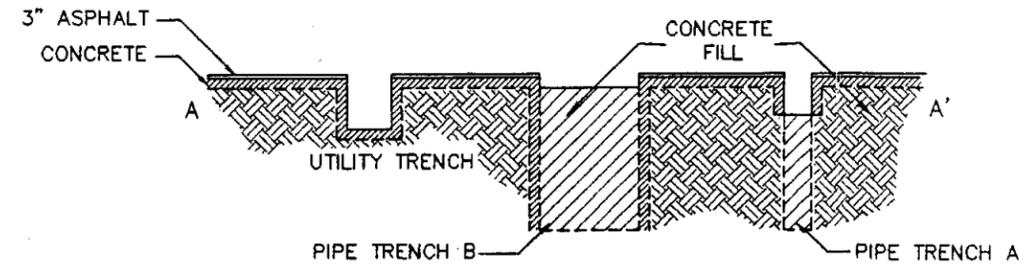
ASPHALTIC CONCRETE

CONCRETE UTILITY TRENCH WITH STEEL PLATE COVERING BOTTOM OF VAULT 2' bgs

LEGEND

- ags ABOVE GROUND SURFACE
- bgs BELOW GROUND SURFACE
- FENCE
- ▨ CONCRETE
- ▩ SOIL

CROSS SECTION A - A'
(Not to scale)



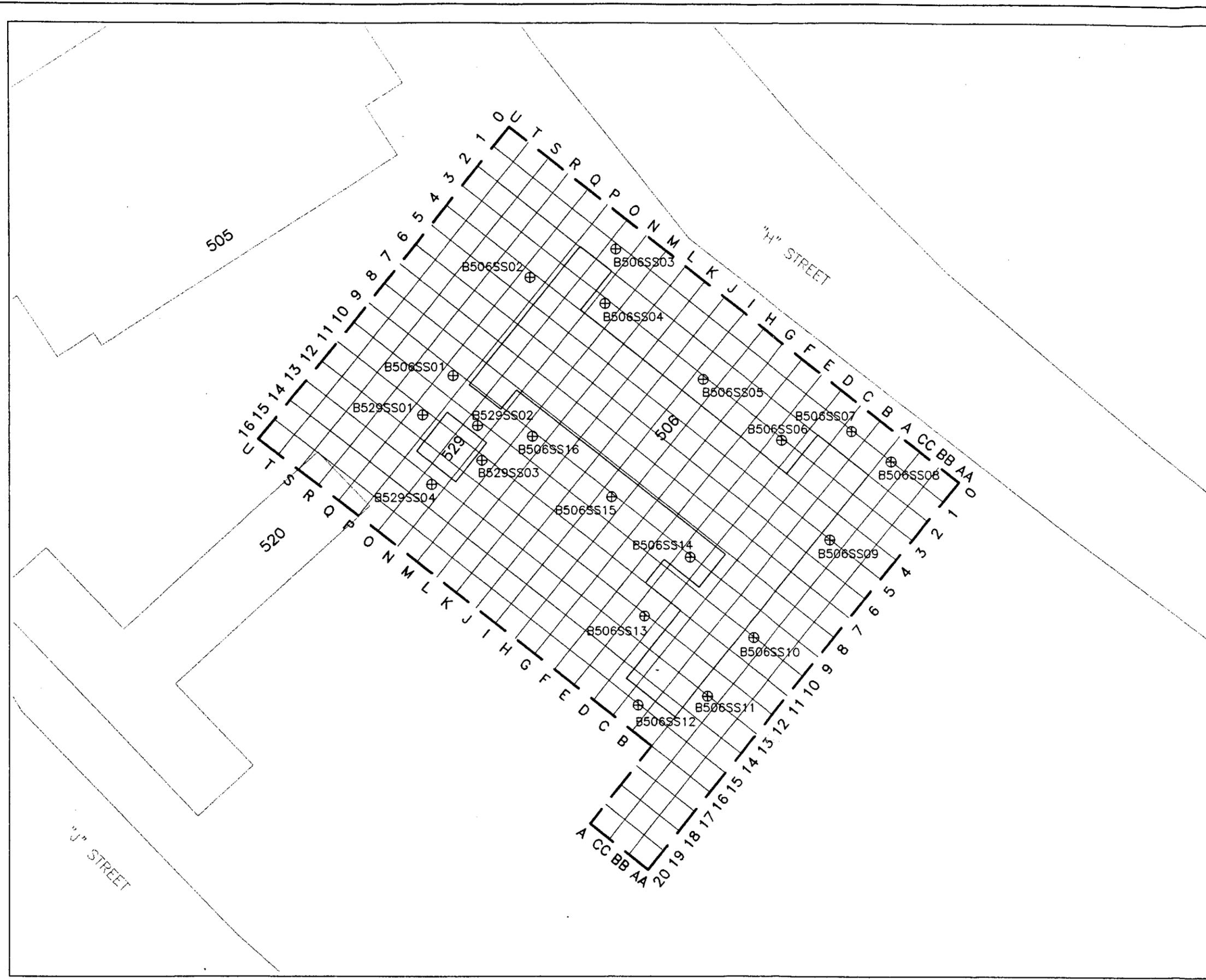
HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

FIGURE E1-2
FORMER NRDL SITE
BUILDING 364 SUMP
LOW-LEVEL
RADIOACTIVE WASTE STORAGE
TANK VAULT AND UTILITY TRENCHES

PRC ENVIRONMENTAL MANAGEMENT, INC.

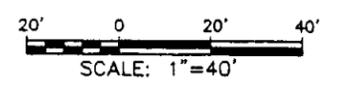
LESCF06364.DWG - 04/25/97 - PLOT 1-1 - REV002 - MSVIEW: 105SCALE
R:\PACKAGE\HP\5364.DWG PLOT FILE: SURVEY.PCP

LE547.dwg - 028552.dwg - 04/25/97 - REV001 - MSVIEW30SCALE
R:\PACKAGE\NPS\502.dwg PLOT FILE SURVEY.PCP



LEGEND
 ——— APPROXIMATE LIMIT OF SURVEY
 ⊕ B506SS01 SURFACE SOIL SAMPLING LOCATION

NOTE:
 GRIDS ARE APPROXIMATELY
 10 FEET BY 10 FEET SQUARE

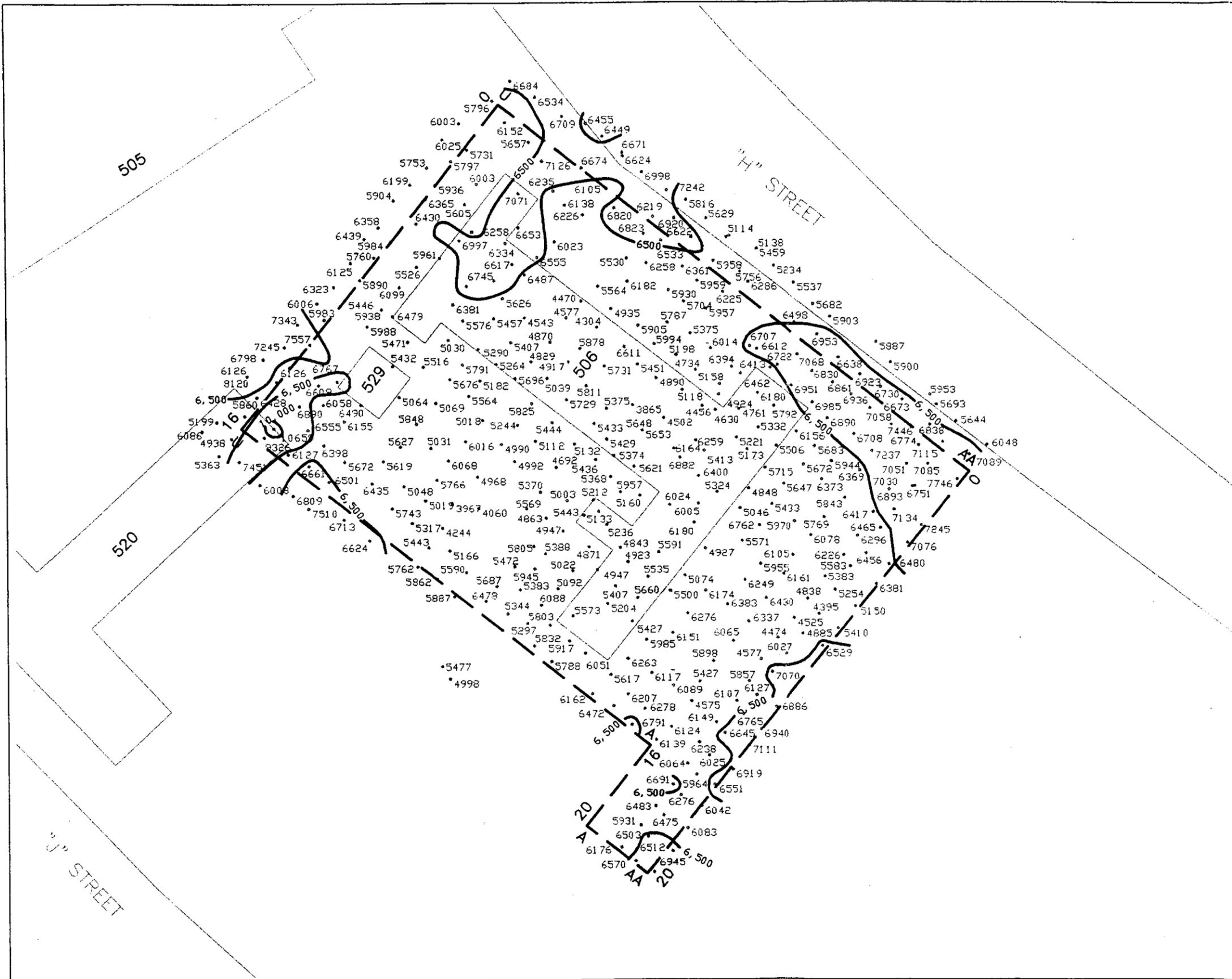


HUNTERS POINT SHIPYARD
 SAN FRANCISCO, CALIFORNIA

FIGURE E1-3
 FORMER NRDL SITE
 BUILDINGS 506 AND 529
 SURVEY GRID AND
 SOIL SAMPLING LOCATIONS

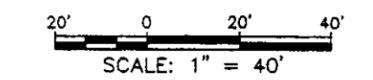
PRC ENVIRONMENTAL MANAGEMENT, INC.

LE56F0044-0285R006.DWG -04/25/97- REV001 MEVIEW305SCALE PLOT 1-1
K:\PACKAGE\HP\NR06.DWG PLOT FILE\RAD.PCP



LEGEND:

- 6.500 RADIATION CONTOUR (CONTOUR INTERVALS ARE 6.500, 10.000.)
- *5482 GAMMA COUNT LOCATION (1 MINUTE COUNT TIME) COUNTS PER MINUTE
- 529 BUILDING

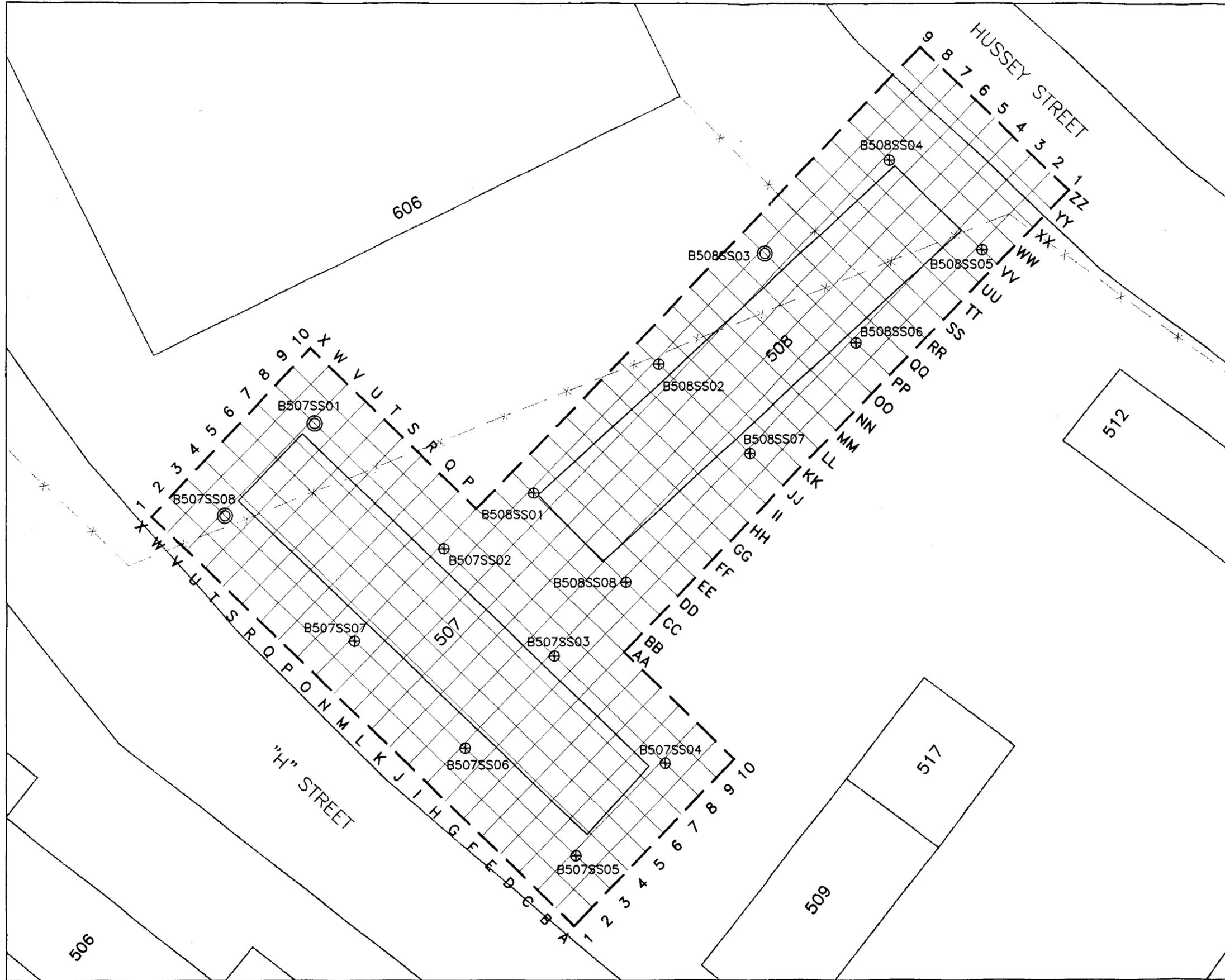


HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

FIGURE E1-4
FORMER NRDL SITE
BUILDINGS 506 AND 529
GAMMA COUNT AND CONTOUR MAP

PRC ENVIRONMENTAL MANAGEMENT, INC.

KCH (SFD) (06R-005) 5508.DWG -10/13/97- REV. 002 MSVIEW=OSCALE PLOT 1-1
X:\PACKAGE\NP\5508.DWG PLOT FILE SURVET.PCP

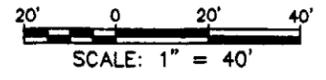


LEGEND

- APPROXIMATE LIMIT OF SURVEY
- ⊕ B507SS01 SURFACE SOIL SAMPLING LOCATION
- ⊙ B507SS01 SOIL SAMPLING LOCATION NOT SAMPLED
- X-X- FENCE

NOTE:

GRIDS ARE APPROXIMATELY 10 FEET BY 10 FEET SQUARE



HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

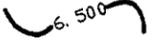
FIGURE E1-5
FORMER NRDL SITE
BUILDINGS 507 AND 508
SURVEY GRID AND
SOIL SAMPLING LOCATIONS

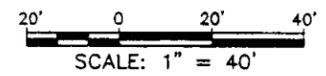
PRC ENVIRONMENTAL MANAGEMENT, INC.

LE56F044-02853.R507-H.DWG -04/25/97 REV001.MSVIEW40SCALE PLOT 1-1
R:\PACKAGE\NR507-H.DWG PLOT FILE: RAD.PCP



LEGEND:

-  6.500 RADIATION CONTOUR (CONTOUR INTERVALS IS 6.500)
-  5482 GAMMA COUNT LOCATION (1 MINUTE COUNT TIME) COUNTS PER MINUTE
-  529 BUILDING

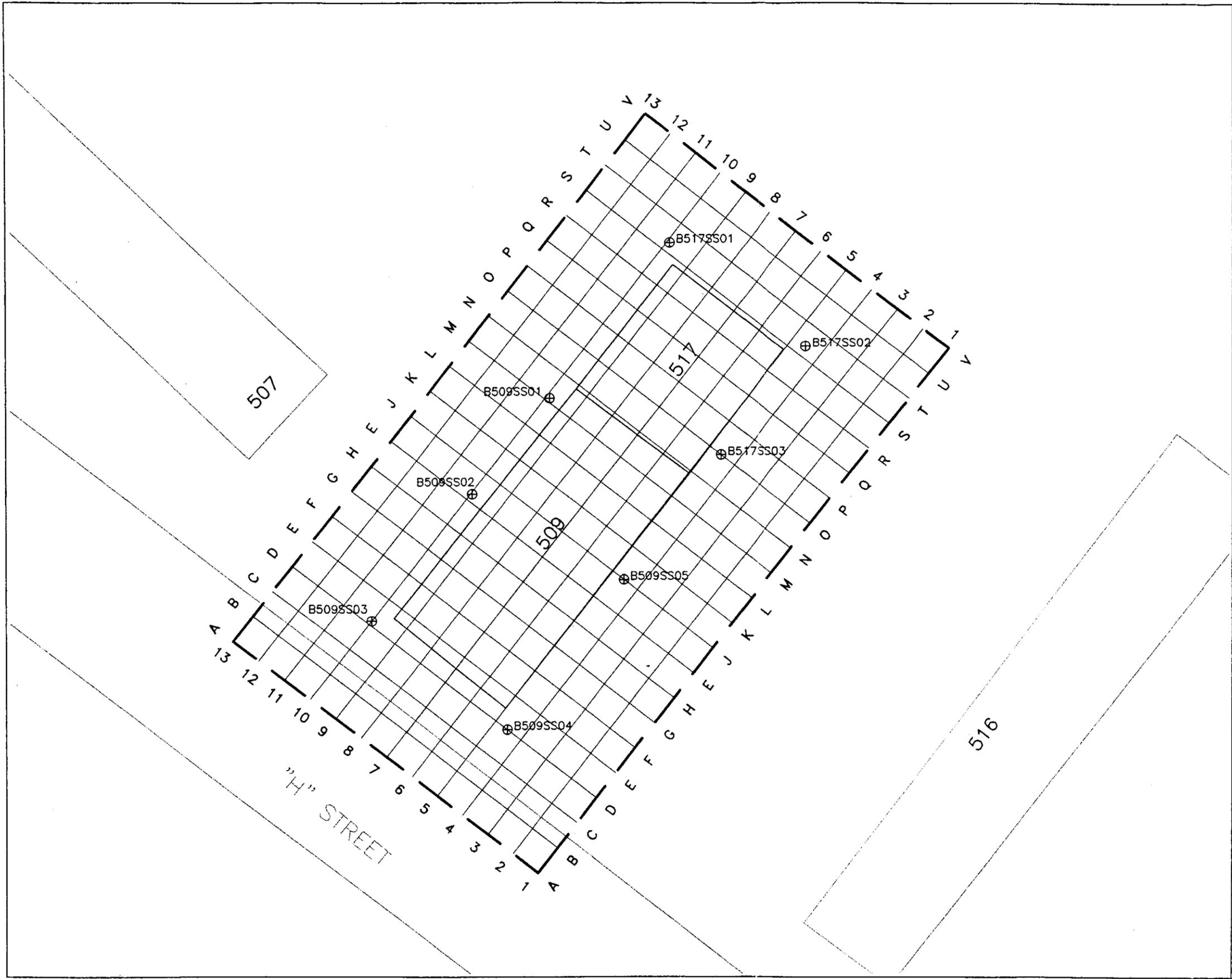


HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

FIGURE E1-6
FORMER NRD SITE
BUILDINGS 507 AND 508
GAMMA COUNT AND CONTOUR MAP

PRC ENVIRONMENTAL MANAGEMENT, INC.

LE565F\K044-0280\5509.DWG -04/21/97- REV001.MSVIEW.30SCALE
PACKAGE\N\5509.DWG PLOT TLE SURVEY.PCP

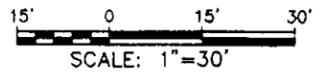


LEGEND

- APPROXIMATE LIMIT OF SURVEY
- ⊕ B509SS01 SURFACE SOIL SAMPLING LOCATION

NOTE:

GRIDS ARE APPROXIMATELY 10 FEET BY 10 FEET SQUARE



HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

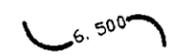
FIGURE E1-7
FORMER NRDL SITE
BUILDINGS 509 AND 517
SURVEY GRID AND
SOIL SAMPLING LOCATIONS

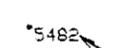
PRC ENVIRONMENTAL MANAGEMENT, INC.

LESCF1044-02853 RESOR.DWG -04/21/97- REV. 001 MSVIEW:30SCALE PLOT 1=1
R:\PACKAGE\NH\RESOR.DWG PLOT FILE: RAD.PCF

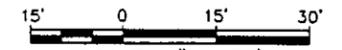


LEGEND:

 6,500 RADIATION CONTOUR
(CONTOUR INTERVALS ARE 6,500,
9,000)

 5482 GAMMA COUNT LOCATION
(1 MINUTE COUNT TIME)
COUNTS PER MINUTE

 529 BUILDING

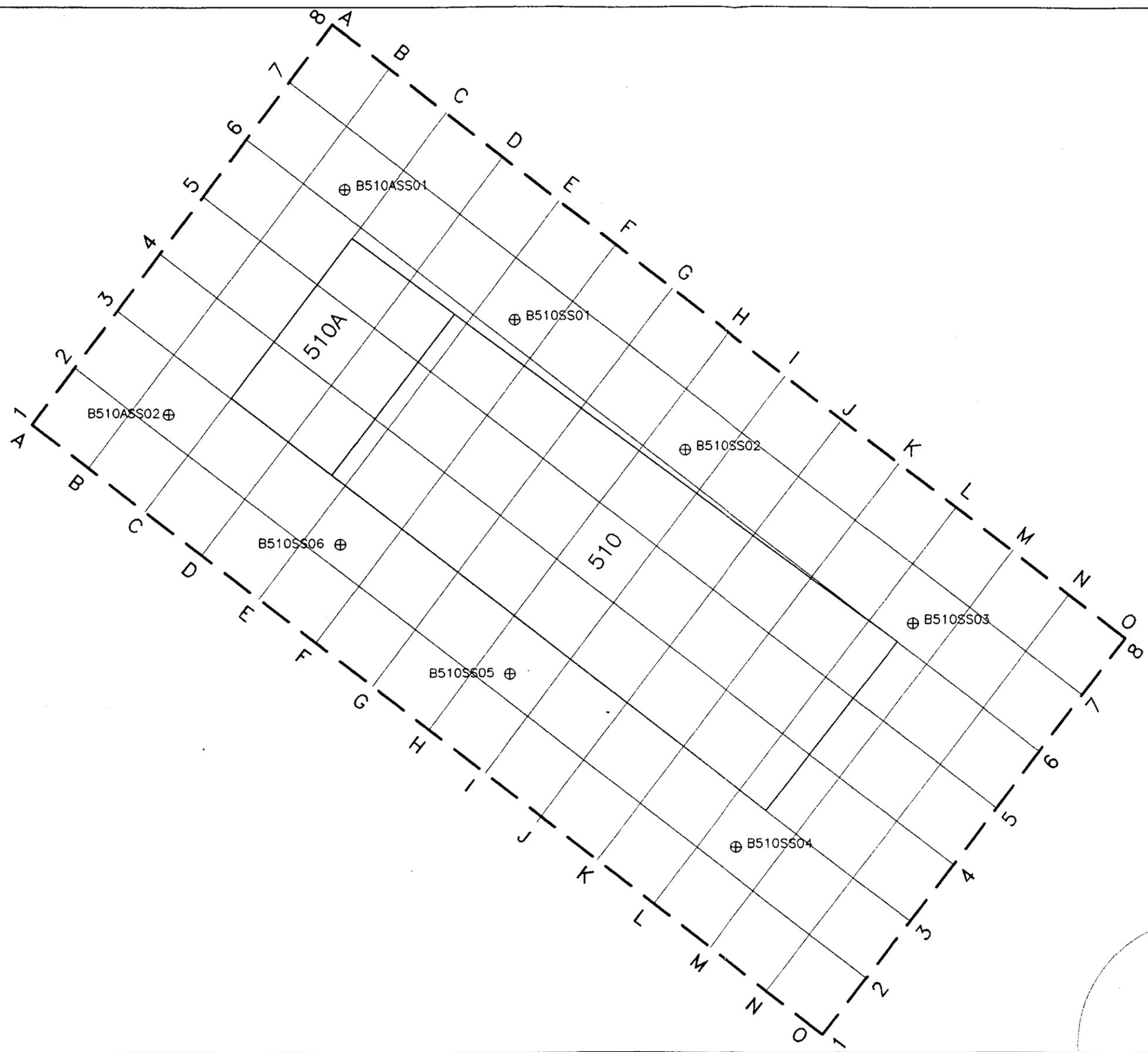

SCALE: 1" = 30'

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

FIGURE E1-8
FORMER NRDL SITE
BUILDINGS 509 AND 517
GAMMA COUNT AND CONTOUR MAP

PRC ENVIRONMENTAL MANAGEMENT, INC.

LES: GSF2044-02855510.DWG -04/25/97- REV:002 MSVIEW:SCALE
PACKAGE:HF:5510.DWG PLOT FILE SURVEY.PCF

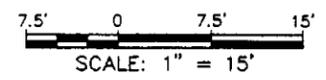


LEGEND

- — — APPROXIMATE LIMIT OF SURVEY
- ⊕ B510SS01 SURFACE SOIL SAMPLING LOCATION

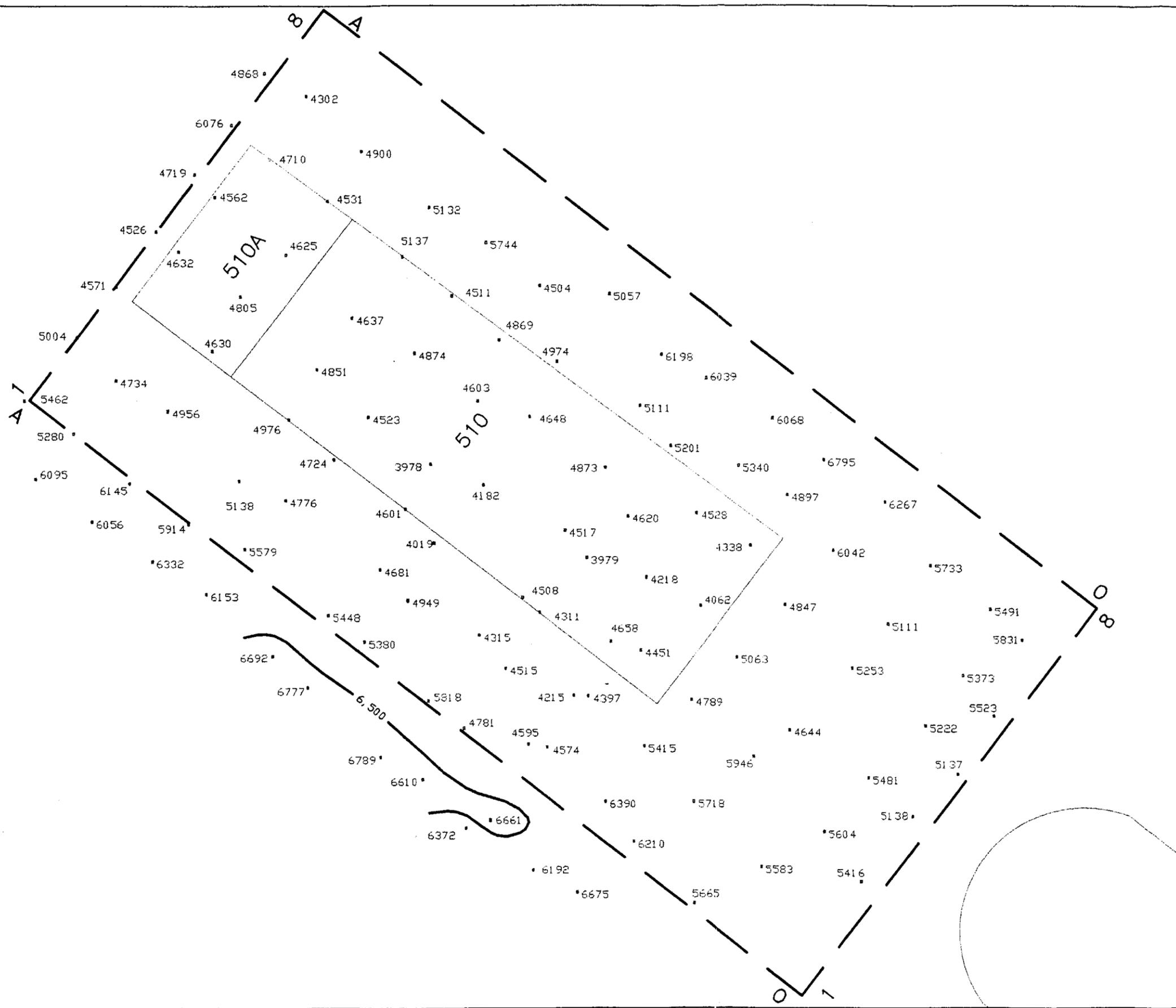
NOTE:

GRIDS ARE APPROXIMATELY
10 FEET BY 10 FEET SQUARE



HUNTERS POINT SHIPYARD SAN FRANCISCO, CALIFORNIA
FIGURE E1-9 FORMER NRDL SITE BUILDINGS 510 AND 510A SURVEY GRID AND SOIL SAMPLING LOCATIONS
PRC ENVIRONMENTAL MANAGEMENT, INC.

LESCF\044-02853_R51D-HDWG -04/25/97- REV001 HSNWARSSCALE PLOT 1-1
R:\PACKAGE\NPVRS10-HDWG PLOT FILE: RADPCF



LEGEND:
6,500 RADIATION CONTOUR
(CONTOUR INTERVALS IS 6,500)

5482 GAMMA COUNT LOCATION
(1 MINUTE COUNT TIME)
COUNTS PER MINUTE

529 BUILDING

7.5' 0 7.5' 15'
SCALE: 1" = 15'

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
FIGURE E1-10
FORMER NRDL SITE
BUILDINGS 510 AND 510A
GAMMA COUNT AND CONTOUR MAP

PRC ENVIRONMENTAL MANAGEMENT, INC.

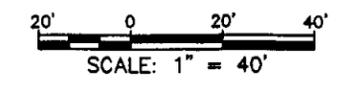


LEGEND

- — — — — APPROXIMATE LIMIT OF SURVEY
- ⊕ SURFACE SOIL SAMPLING LOCATION
- - - - - FENCE

NOTE:

GRIDS ARE APPROXIMATELY 10 FEET BY 10 FEET SQUARE



HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

FIGURE E1-11
FORMER NRDL SITE BUILDING 707
CONCRETE DRUM STORAGE PAD
SURVEY GRID AND
SOIL SAMPLING LOCATIONS

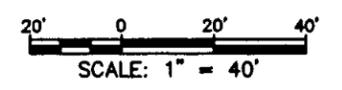
PMC ENVIRONMENTAL MANAGEMENT, INC.

KCH (SFP) 5707.DWG -10/13/97- PLOT 1-1 - REV. 002 - NSVIEW40SCALE
R:\PACKAGE\HP\5707.DWG PLOT FILE SURVEY.PCP



LEGEND:

- 6,500 RADIATION CONTOUR (CONTOUR INTERVALS ARE 6,500, 10,000, 20,000, 30,000)
- *5482 GAMMA COUNT LOCATION (1 MINUTE COUNT TIME) COUNTS PER MINUTE
- 529 BUILDING
- APPROXIMATE LIMIT OF SURVEY
- FENCE



HUNTERS POINT SHIPYARD
 SAN FRANCISCO, CALIFORNIA

FIGURE E1-12
 FORMER NRDL SITE
 BUILDING 707
 CONCRETE DRUM STORAGE PAD
 GAMMA COUNT AND CONTOUR MAP
 ENVIRONMENTAL MANAGEMENT, INC

TABLES

ANALYTICAL RESULT TABLES

TABLE E1-1

**SURFACE COVERINGS FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDINGS 506 AND 529
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
506/529	A0	6586	Asphalt
506/529	A01	7446	Asphalt
506/529	A02	7237	Asphalt
506/529	AA0	7089	Grass
506/529	AA2	7746	Asphalt
506/529	AA2	7552	Asphalt
506/529	AA3	7245	Asphalt
506/529	AA4	7076	Asphalt
506/529	AA9	6529	Asphalt - mound
506/529	AA10	6673	Asphalt
506/529	AA11	8372	Asphalt
506/529	AA12	6886	Asphalt - mound/rubble pile
506/529	AA13	6940	Asphalt
506/529	AA14	7111	Asphalt
506/529	AA15	6919	Asphalt
506/529	AA16	6551	Asphalt
506/529	AA19	6512	Asphalt - hollow
506/529	AA20	6945	Asphalt
506/529	B0	6673	Asphalt
506/529	B01	7058	Asphalt
506/529	B02	6708	Asphalt
506/529	B16	6791	Asphalt
506/529	BB0	7115	Asphalt
506/529	BB1	7085	Asphalt
506/529	BB2	6751	Asphalt
506/529	BB2	7030	Asphalt
506/529	BB3	7134	Asphalt
506/529	BB11	7070	Asphalt
506/529	BB13	6765	Asphalt
506/529	BB14	6645	Asphalt

TABLE E1-1 (Continued)

**SURFACE COVERINGS FOR GRID NODES GREATER THAN 6500 CPM
FOR BUILDINGS 506 AND 529
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
506/529	BB19	6503	Grass
506/529	BB20	6570	Asphalt
506/529	C0	6730	Asphalt
506/529	C01	6936	Gravel
506/529	C02	6890	Gravel
506/529	C07	6762	Gravel
506/529	C19	7254	Grass
506/529	CC0	6838	Asphalt
506/529	CC1	7051	Asphalt
506/529	CC3	6893	Asphalt
506/529	CC17	6691	Asphalt
506/529	D0	6923	Asphalt
506/529	D01	6861	Gravel
506/529	D02	6985	Gravel
506/529	D12	7557	Grass
506/529	D13	6798	Grass
506/529	D14	8120	Gravel
506/529	D19	7144	Grass
506/529	D20	6845	Grass
506/529	E0	6638	Asphalt
506/529	E01	6830	Gravel
506/529	E02	6951	Gravel
506/529	E16	7133	Grass
506/529	E19	6603	Concrete
506/529	F0	6953	Concrete - mound
506/529	F01	7068	Asphalt
506/529	F02	6722	Asphalt
506/529	F08	6921	Grass
506/529	F20	6666	Grass
506/529	G02	6612	Asphalt

TABLE E1-1 (Continued)

**SURFACE COVERINGS FOR GRID NODES GREATER THAN 6500 CPM
FOR BUILDINGS 506 AND 529
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
506/529	G07	6882	Grass
506/529	G20	6988	Grass
506/529	H08	7302	Grass
506/529	H2	6707	Grass
506/529	I2	6882	Grass
506/529	I19	7401	Grass
506/529	L0	6622	Gravel
506/529	L5	6611	Grass
506/529	M0	6920	Asphalt
506/529	M1	6533	Gravel
506/529	N00	7242	Asphalt - mound
506/529	N1	6823	Asphalt
506/529	O0	6820	Grass
506/529	O00	6998	Asphalt
506/529	O4	6884	Grass
506/529	O5	6722	Grass
506/529	O16	6624	Grass
506/529	P00	6624	Gravel
506/529	P4	6555	Grass
506/529	P16	6713	Grass
506/529	Q0	6864	Grass
506/529	Q00	6671	Gravel
506/529	Q1A	7835	Grass
506/529	Q4	6617	Grass
506/529	Q5	6745	Grass
506/529	Q12	7666	Grass
506/529	Q15	6501	Grass
506/529	Q16	7510	Asphalt
506/529	R0	6574	Grass
506/529	R0	6674	Grass - hollow

TABLE E1-1 (Continued)

**SURFACE COVERINGS FOR GRID NODES GREATER THAN 6500 CPM
FOR BUILDINGS 506 AND 529
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
506/529	R1	7126	Gravel
506/529	R2	7235	Gravel
506/529	R3	7049	Grass
506/529	R5	7078	Grass
506/529	R8	6744	Asphalt
506/529	R11	6994	Soil
506/529	R12	6767	Soil
506/529	R15	6661	Asphalt
506/529	R16	6809	Asphalt
506/529	S00	6709	Asphalt
506/529	S11	6802	Grass
506/529	S12	6609	Grass
506/529	S13	6890	Grass
506/529	S14	10659	Grass
506/529	S15	9323	Grass
506/529	S16	7451	Asphalt
506/529	T00	6534	Asphalt
506/529	T11	7245	Grass
506/529	U00	6684	Asphalt - hollow

Notes:

cpm Counts per minute

ID Identification

TABLE E1-2

**SURFACE COVERING FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDINGS 507 AND 508
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
507/508	A01	7188	Asphalt
507/508	C01	6589	Grass
507/508	JJ08	6553	Asphalt
507/508	KK09	6597	Asphalt
507/508	L01	6591	Grass
507/508	MM08	6516	Asphalt
507/508	OO05	6693	Asphalt
507/508	PP08	6516	Asphalt
507/508	PP09	6771	Asphalt
507/508	W05	6506	Asphalt
507/508	X01	6704	Asphalt
507/508	X02	6560	Asphalt
507/508	X03	6590	Asphalt - on 2 ft. thick steel
507/508	X06	6596	Asphalt
507/508	X07	6634	Asphalt
507/508	X08	6507	Asphalt
507/508	X09	6544	Asphalt
507/508	X10	6616	Asphalt

Notes:

cpm Counts per minute
ft. Feet
ID Identification

TABLE E1-3

**SURFACE COVERING FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDINGS 509 AND 517
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
509/517	A01	7370	Asphalt
509/517	A02	7325	Asphalt
509/517	A03	7348	Asphalt
509/517	A03	7912	Asphalt
509/517	A04	7272	Asphalt
509/517	A05	7208	Asphalt
509/517	A06	7387	Asphalt
509/517	A07	7319	Asphalt
509/517	A09	7095	Asphalt
509/517	A10	7209	Asphalt
509/517	A11	7353	Asphalt
509/517	A12	7351	Asphalt
509/517	A13	7460	Asphalt
509/517	A14	7519	Asphalt
509/517	A15	7365	Asphalt
509/517	D04	6590	Grass
509/517	D07	6632	Grass
509/517	D08	7132	Grass
509/517	E03	6780	Grass
509/517	F01	6582	Grass
509/517	G01	6523	Grass
509/517	G02	6682	Grass
509/517	H02	6840	Grass
509/517	J01	6565	Grass
509/517	J02	6745	Grass
509/517	J03	6719	Grass
509/517	J04	6871	Grass
509/517	K02	6719	Grass
509/517	K04	6958	Grass
509/517	K04	6978	Grass

TABLE E1-3 (Continued)

**SURFACE COVERING FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDINGS 509 AND 517
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
509/517	L01	6530	Grass
509/517	L02	6962	Grass
509/517	L03	7019	Gravel
509/517	L04	6568	Grass
509/517	M01	7533	Grass
509/517	M02	8073	Grass
509/517	M03	7564	Grass
509/517	N01	8113	Grass
509/517	O01	8109	Grass
509/517	O02	7760	Grass
509/517	P01	8198	Grass
509/517	P02	7688	Grass
509/517	Q01	7043	Grass
509/517	Q02	6990	Grass
509/517	S04	9374	Grass
509/517	T03	6912	Grass

Notes:

cpm Counts per minute
ID Identification

TABLE E1-4

**SURFACE COVERING FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDINGS 510 AND 510A
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
510/510A	F01	6692	Grass
510/510A	G01	6777	Grass
510/510A	H01	6789	Grass
510/510A	I01	6610	Grass
510/510A	J01	6661	Grass
510/510A	K08	6795	Grass
510/510A	M01	6675	Grass

Notes:

cpm Counts per minute

ID Identification

TABLE E1-5

**SURFACE COVERINGS FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDING 707 CONCRETE PAD
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
707	A02	6868	Asphalt
707	A03	6906	Asphalt
707	A07	7164	Asphalt
707	A08	6693	Asphalt
707	A13	6831	Asphalt
707	A16	6931	Asphalt
707	A17	7010	Asphalt
707	A18	7028	Asphalt
707	A19	7045	Asphalt
707	A20	6964	Asphalt
707	A21	6867	Asphalt
707	A22	7053	Asphalt
707	A23	6860	Asphalt
707	A25	6565	Asphalt
707	A26	6966	Asphalt
707	B01	6922	Asphalt
707	B02	6887	Asphalt
707	B03	6959	Asphalt
707	B04	7012	Asphalt
707	B05	6870	Asphalt
707	B06	6944	Asphalt
707	B07	6850	Asphalt
707	B08	6996	Asphalt
707	B09	6992	Asphalt
707	B10	7202	Asphalt
707	B11	7096	Asphalt
707	B12	7046	Asphalt
707	B13	7075	Asphalt
707	B14	6836	Asphalt
707	B15	6983	Asphalt

TABLE E1-5 (Continued)

**SURFACE COVERINGS FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDING 707 CONCRETE PAD
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
707	B16	6925	Asphalt
707	B17	7000	Asphalt
707	B18	6966	Asphalt
707	B19	7064	Asphalt
707	B21	6779	Asphalt
707	B22	6885	Asphalt
707	B23	6543	Asphalt
707	B25	6872	Asphalt
707	C01	6692	Asphalt
707	C01	6773	Asphalt
707	C02	7008	Asphalt
707	C03	7141	Asphalt
707	C04	6873	Asphalt
707	C05	6891	Asphalt
707	C06	6752	Asphalt
707	C07	6729	Asphalt
707	C08	6898	Asphalt
707	C09	6849	Asphalt
707	C10	6952	Asphalt
707	C11	6806	Asphalt
707	C12	6635	Asphalt
707	C13	6972	Asphalt
707	C15	6716	Asphalt
707	C16	6711	Asphalt
707	C17	6776	Asphalt
707	C18	6535	Asphalt
707	C18	6799	Asphalt
707	C20	6698	Asphalt
707	C22	6528	Asphalt
707	C23	6734	Asphalt

TABLE E1-5 (Continued)

**SURFACE COVERINGS FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDING 707 CONCRETE PAD
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
707	C24	6683	Asphalt
707	C26	7095	Asphalt
707	D01	7240	Asphalt
707	D02	8129	Asphalt
707	D03	23773	Asphalt
707	D04	32261	Gravel
707	D05	6873	Asphalt
707	D17	6705	Concrete
707	D18	6875	Asphalt
707	D19	6796	Asphalt
707	D21	6722	Asphalt
707	D22	6692	Asphalt
707	D23	6771	Asphalt
707	D24	6693	Asphalt
707	E01	6570	Asphalt
707	E02	6773	Asphalt
707	E03	7651	Asphalt
707	E04	7856	Asphalt
707	E05	6688	Asphalt
707	E15	6664	Asphalt
707	E18	6525	Asphalt
707	F01	6604	Asphalt
707	F02	6551	Asphalt
707	F03	6990	Asphalt
707	F05	7013	Asphalt
707	F06	6907	Asphalt
707	F16	6933	Asphalt
707	F17	6728	Asphalt
707	F18	6862	Asphalt
707	G03	15899	Asphalt

TABLE E1-5 (Continued)

**SURFACE COVERINGS FOR GRID NODES
GREATER THAN 6500 CPM FOR BUILDING 707 CONCRETE PAD
PARCEL E REMEDIAL INVESTIGATION, HUNTERS POINT SHIPYARD**

Building No.	Grid ID	Count Rate	Surface Cover
707	G04	7034	Asphalt
707	G04	17336	Asphalt
707	G05	7152	Asphalt
707	G15	12007	Asphalt
707	G17	6503	Asphalt
707	G18	6674	Asphalt
707	H04	6827	Asphalt
707	H05	6892	Asphalt
707	H18	6542	Asphalt
707	I05	6918	Asphalt

Notes:

cpm Counts per minute
ID Identification

ATTACHMENT E1-1
SUMMARY OF DETECTOR INFORMATION

TABLE E1-1-1

**DETECTORS USED IN THE PHASE III RADIATION INVESTIGATION
HUNTERS POINT SHIPYARD**

Detector Number	Detector Type	Detector Model/ Serial Number	Radiation Detected	Area (cm²)	Efficiency^{a,b} (%)		Background (cpm)	Activity Conversion Factor		L_D^c (dpm/100 cm²)
D-001	Large Scintillation	43-90 / 129383	alpha	100	10.6		0.5	9.43		25
D-004	Gas Proportional	43-37 / 128616	beta-gamma	400	40.9		790	0.61		250
D-005	Gas Proportional	43-20 / 117366	beta-gamma	100	42.8		250	2.34		250
D-006	NaI Scintillation	44-10 / 102678	gamma	NA	NA		5,400	NA		NA
D-007	Geiger-Muller	V190 / 977	alpha-beta		13.6	17.1	40	7.33	5.86	NA

Notes:

- cpm Counts per minute
- cm² Centimeters squared
- dpm/100 cm² Disintegrations per minute per 100 centimeters squared
- NA Not applicable
- NaI Sodium Iodide

- a This value will vary depending on geometry and calibration isotope energy
- b Values are for 4π steradian geometry
- c Values are 25% of the NRC Regulatory Guidance free release criteria

ATTACHMENT E1-2
WORK PLAN VARIATIONS

WORK PLAN VARIATIONS

The following six variations were made in the work plan:

- Variation:** The steel plates were scanned with a pancake probe and spot-checked with an alpha scintillation detector.

Work Plan: The work plan called for a 100 percent scan of the steel plates using a 2-inch by 2-inch NaI detector, alpha scintillation detector, and a pancake probe.

Reason for Variation: The possibility of the steel plates being contaminated is considered low. The only feasible way the plates could have been contaminated is if the pipes in the utility and pipe trenches burst during NRDL operations in Building 364. If this had happened, extensive contamination in the utility and pipe vaults would be evident. Only one area of elevated activity was found in the utility and pipe trenches. The corresponding steel plate laid over this area was rescanned with both the alpha scintillation detector for alpha activity and the gas proportional detector for beta activity. The activity on the steel plate corresponded to background activity.
- Variation:** Fixed grid node counts for alpha and beta activity were added for characterization of the Building 364 sump site.

Work Plan: The work plan called for only a 100 percent scan of the affected area at the Building 364 sump site.

Reason for Variation: Fixed counts in an affected area are part of a radiological close-out survey procedure according to NUREG 5849.
- Variation:** Swipes in affected areas at the Building 364 sump site were analyzed for carbon-14 and tritium.

Work Plan: The work plan called for swipes to be analyzed for gross alpha and gross beta activity only.

Reason for Variation: Swipes were analyzed for carbon 14 and tritium because a full list of radioisotopes used at Building 364 sump site was unavailable and the radiation equipment used in this survey was not sensitive to these isotopes.
- Variation:** The Building 707 concrete pad was swiped for gross alpha and gross beta activity.

Work Plan: The work plan in the test did not mention if the concrete pad should be swiped, but it was listed on the survey summary table in the work plan.

Reason for Variation: The most conservative approach to conducting the survey was performed.
- Variation:** GPS was used to perform the survey in open areas without reliance on a pre-established fixed grid system.

Work Plan: A fixed grid system would be established at each building site prior to survey.

Reason for Variation: The approach used was more efficient and provided the same degree of coverage as specified in the work plan.

ATTACHMENT E1-3
QUALITY ASSURANCE

QUALITY ASSURANCE

All work for this Phase III radiation investigation was performed in accordance with PRC's CLEAN Quality Control Management Plan (PRC 1995). Specific provisions related to radiological measurements are discussed in the following sections. Data quality objectives (DQO), data recording, and data validation are described in the following sections.

DATA QUALITY OBJECTIVES

Data quality for this survey was achieved by meeting the DQOs described in the following sections. All supporting documentation for the following sections is available upon request.

Precision

Precision is a measure of mutual agreement among individual measurement of the same property, usually under prescribed similar conditions. To evaluate precision, duplicate radiation measurements of the same sample or location were taken or measured. Duplicate samples were taken at frequency of one in 20 soil samples. Duplicate fixed count measurements at the Building 364 sump site were taken at a frequency of one in 10 counts. No duplicate measurements were taken on the 10-foot by 10-foot grid systems due to the copious number of fixed gamma count readings taken at each former NRDL building sites.

The work plan (PRC 1996a) specified that overall measurement repeatability at any field location would be demonstrable within 50 percent of the detection limit, when positioning error, other field error factors, and instrument precision were considered.

Accuracy

Accuracy is a measure of agreement between any observed or measured value and the true value as determined by a primary physical standard, standard reference material, or a secondary traceable standard. The accuracy of field radiological measurements was determined by measuring a secondary standard prepared by a commercial vendor as a calibration standard. The secondary standards are traceable to the NIST with certifications of source emissions on record.

Each instrument was calibrated at the start of the project. After initial calibration, each detector was checked daily to confirm that the measurement system was maintained within acceptable control parameters as determined by a control chart, or the instrument was recalibrated. The control measurement of background and source activity was made using a fixed jig or template, providing the same geometry as the source measurement. The background measurement was made so it would be free of surface activity influence. At the same time that the detector control measurement was made (establishing detector efficiency), a second measurement was made as a working check source.

The mean value and standard deviation were determined from a series of 20 measurements for the same time interval as the field measurement. Drifting outside the calculated 95th percentile control limits (or two sigma boundary) calculated from this series is a cause for concern and requires evaluation and explanation. Any measurement made by an instrument that drifted outside the two sigma control value would be considered for rejection and the measurement process repeated.

The Phase III radiation investigation plotted control chart values demonstrate that the detectors were within control limits with some exceptions. The exceptions occurred when control parameters were exceeded. In several cases, the detector response factor, determined on a daily basis, increased beyond what would be expected. This increase would result in an overestimated activity and, therefore, a conservative and acceptable variation that did not affect the conclusions of the Phase III radiation investigation. Higher readings may occur if the surveyor holds the detector closer to the source than the distance established during the initial calibration setup. This is the most likely cause for the variation of efficiency.

Completeness

Completeness is a measure of how well the final survey meets the initial survey design after data validation, in terms of required measurement and samples collected.

Measurements that are properly recorded, made by a properly calibrated instrument, and acceptable after verification of a second independent measurement are considered valid, as described in the section on data validation.

The completeness criterion for each section of the survey design is 95 percent for each of the former building areas identified in the work plan (PRC 1996a) or approximately 90 percent for the total survey (the product of completeness for each individual portion).

Sensitivity

Sensitivity is evaluated by confirming that required sensitivities or detection limits are in fact achieved. As described in Section 2.5.2 of the report, the detection limits are within the NRC's Regulatory Guide 1.86 (1974). Activity criteria met the specification criteria established in the work plan (PRC 1996a).

DATA RECORDING

All field survey measurements where the GPS was not used were recorded on standard field collection forms and managed in accordance with PRC's Navy CLEAN contract standard operating procedures and Quality Control Management Plan (PRC 1995). All daily source checks, control charts, calibration records, and related records were maintained as project records.

Field survey measurements using the GPS were recorded in an electronic format which could be down-loaded into a GIS, Excel, or database format. PRC verified that instrument data were recorded and transferred from the data logger to the computer to the GIS without error. PRC confirmed the accuracy of the position of the data by comparing GPS readings to U.S. Geological Survey benchmarks and known locations recorded on Navy engineering drawings (see Figure E1-1).

All supporting documentation is available upon request.

DATA VALIDATION

The following sections describe the procedures used to ensure the quality and validity of data collected during the Phase III radiation investigation.

Independent Surveyor Results of Building 364 Sump

An independent survey of at least 5 percent of all fixed survey point locations was conducted at the Building 364 sump site. The independent surveyor used the same instrumentation and calibration sources; however, all calculations, measurements, and calibrations were independent.

In addition, the independent surveyor performed a 100 percent beta-gamma scan of 1 percent of the total surface area, using judgmental selection of areas considered most likely to retain residual contamination. The independent surveyor used the same instrument as used in the individual surveys. Anomalies identified were compared with results from partial coverage scans to assess the representativeness of the scanning survey technique.

The independent surveyor found no hot spots not previously identified at the Building 364 sump site.

All supporting documentation from the independent survey is available upon request.

Validation of Analytical Data

Data validation is a systematic process for reviewing and qualifying data against a set of criteria to ensure that the laboratory-analyzed data are adequate for their intended use. Data are validated by reviewing and evaluating precision, accuracy, representativeness, completeness, and comparability characteristics of the data sets. The analytical data generated during the Phase III radiation investigation were validated according to the procedures and quality assurance criteria outlined in the Functional Guidelines for Radiation Validation (Westinghouse Hanford Company 1993), *Radiochemistry Data Validation* (Karnofsky 1993), and radiological EPA methods.

Data were validated in two stages: a cursory review of the analytical reports that evaluated the most critical QA/QC information, and a full review that evaluated additional QA/QC criteria and checked calculations and analyte identification against the raw sample data. At each stage of validation, qualifiers were assigned to the results in an electronic database according to the criteria, protocols, and definitions set forth in the established PRC quality assurance project plan (PRC 1996b).

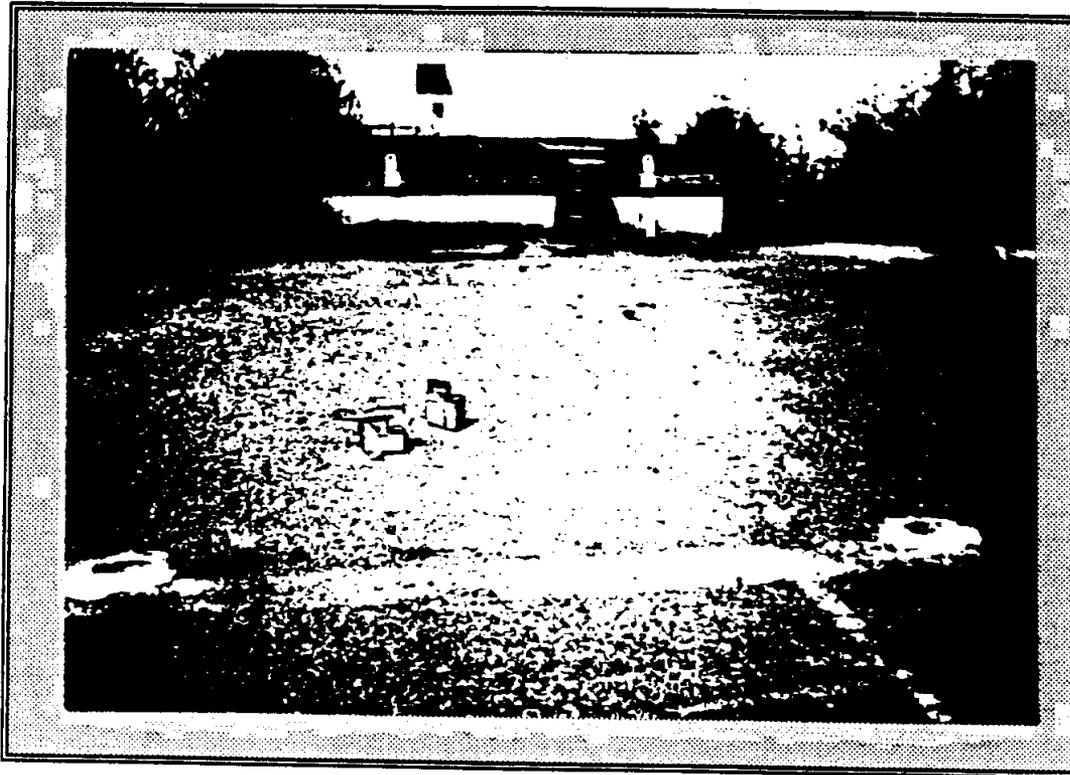
The data quality is consistent with the existing guidelines for definite data, and the data are suitable for site characterization. In considering the sampling program, QA/QC, and data validation results, PRC concludes that the precision, accuracy, representativeness, completeness, and comparability characteristics of the data are acceptable.

All supporting documentation, including laboratory results and cursory and full data validation reports, is available upon request.

ATTACHMENT E1-4
FINAL REPORT
HUNTERS POINT ANNEX CESIUM REMEDIATION

FINAL REPORT

**Hunter's Point Cesium Remediation
San Francisco, California**



Prepared by:

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1.0 INTRODUCTION

Allied Technology Group, Inc. (ATG) was contracted by the Industrial Operations Command (IOC), Radioactive Waste Disposal Office for the remediation of a site contaminated with Cesium-137 at the Hunter's Point Annex, San Francisco, California. The remediation was to include the packaging and shipment for disposal of the resulting waste. ATG has prepared this report and the attached supporting documentation in accordance with Delivery Order Number: DAAA09-95-G-0007, Project Number: USN 95-007 to summarize all on site activities pursuant to this delivery order.

The IOC Point of contact for this project was a Mr. Dave Horton. The Radiological Affairs Support Office, RASO point of contact was LCDR Lino Fragosso. The facility representative POC (EFA WEST) was Mr. Dave Song. Project Director for ATG was Mr. William Haney. The project manager was Mr. Darren W. Smith and project supervisor was Mr. Neal Whatley.

All work plans and site specific governing procedures were reviewed and approved by TOC in conjunction with ATG's project management.

2.0 SITE DESCRIPTION

- 2.1 A Cesium-137 asphalt contaminated site was discovered by a Navy's contractor during environmental investigation. The site is located at Hunter's Point in San Francisco, California between Buildings 364 and 351 of Parcel D. It is believed that a spill from past operations occurred at this causing a peanut-shaped area with a dimension of 20' x 8'. Prior to ATG's presence on site an independent party surveyed the site and the elevated readings were outlined. A sample was taken from within the elevated readings and revealed Cesium-137 contamination with a level of 232 pCi/gram. ATG's scope of work was to remediate this peanut shaped area to background levels.

3.0 DESCRIPTION OF WORK

3.1 General

Industrial Operations Command, Radioactive Waste Disposal Division requested the following work to be completed per their Scope of Work dated 12/13/95.

- 3.1.1 Perform all work under ATG's NRC license with the State of Washington. This included the preparation of the Work Plan (Appendix A), a Quality Assurance Project Plan (Appendix B), and a Health and Safety Plan (Appendix C) for the State of Washington's review and approval.
- 3.1.2 Provide the remediation, packaging, and shipment of the contaminated asphalt from Hunter's Point Annex.
- 3.1.3 Preparation of a Final Report detailing all on site activities.

3.2 Health and Safety

- 3.2.1 A Site Specific Health and Safety Plan was developed for the activities specified in Section 4.0 of this report. In general, the primary health hazard associated with the activities conducted on site was exposure to Cs-137. Personnel working in extreme high winds was the secondary health concern.
- 3.2.2 The principle isotope of concern was Cesium-137. Radiological controls consisted of, but were not limited to, contamination surveys, air sample surveys, posted boundaries, all personnel involved wearing dosimetry, and all personnel performing work under the direction of a Radiation Work Permit (RWP).
- 3.2.3 Daily safety meetings were conducted with all ATG personnel. Emphasis was placed each day on radiological and physical hazards.
- 3.2.4 All personnel involved in handling radioactive materials were issued TLDs (Thermoluminescent dosimeters) for the purpose of measuring the dose equivalent received while conducting project activities. Results are shown in Appendix D of this report.

3.3 Site Preparation

- 3.3.1. A Radiation Work Permit (RWP) was issued by the Health Physics Supervisor and approved by the RSO Manager prior to the start of work providing guidelines specifying appropriate protective measures addressing the existing radiological conditions, work scope limitations, radiological limitations, specific protective requirements, ALARA considerations, and instructions to Health Physics Technicians. The RWP outlined the requirements for equipment, monitoring frequencies, safety considerations, etc. that the individual(s) involved in handling radioactive materials must

must comply with while working at Hunter's Point in order to perform his/her job function in a safe manner. A copy of the RWP is provided as Appendix E.

- 3.3.2. Personal radiation dosimeters (TLC's) were issued to all individuals involved with handling radioactive material, or entering the exclusion zone work area.
- 3.3.3. The major area of concern at the site was established through initial radiological surveys to be the outlined peanut shaped CS-137 spill area.
- 3.3.4. The spill area was isolated from general access with yellow and black caution tape posted at 25' around the site perimeter. This posting also established the outer support zone perimeter. The fence surrounding the site was kept locked during non-work hours.
- 3.3.5. The peanut shaped CS-137 spill site was surveyed to assess the radiological conditions of the area. Survey results are provided in Appendix F.
- 3.3.6. Contamination control was established by conspicuously posting the spill outline with yellow and magenta ribbon/Radioactive Material placards to designate the exclusion zone.
- 3.3.7. The contamination reduction zone was established between the Exclusion zone and Support zone. A "STEP OFF PAD" was placed at the boundary of the exclusion zone and the contamination reduction zone to aid with donning and removal of protective clothing and personnel equipment access.
- 3.3.8. All loose gravel and debris was removed from the work area prior to remediation.
- 3.3.9. An air sampler unit was set up in the exclusion zone in preparation for continuous air sampling during remediation.
- 3.3.10. A clean laydown area was established in preparation for receipt and loading of (4) 55 gallon drums.

4.0 SAMPLING/SURVEYING

- 4.1 Basic initial site radiological surveys were done on Friday, February 23, 1996. This survey was performed in the peripheral area of the site.

Results of these surveys indicated some areas of elevated radioactivity within the outlined area. These surveys are provided in Appendix F of this report.

- 4.2** Low volume air samples were obtained in worker breathing zones during the entire removal process. No detectable airborne activity and/or above 10% of the DAC value listed in 10 CFR 20 for Cs-137 were detected on any of these samples. Air filters were counted with a Ludlum Model-2929 Dual Alpha Beta/Gamma Scaler equipped with a Model 43-10-1 scintillation probe.

The results of these samples are included in Appendix G of this report.

- 4.3** Radiation and contamination surveys were performed utilizing the following instrumentation:

Ludlum Model -12s Micro-R Meter (scintillation detector)
Ludlum Model Survey Meter with model 440 probe.
Ludlum Model 929 Dual Alpha Beta/Gamma Scaler
Ludlum Model-12 Survey Meter with model 44-09-GM Dectector.

- 4.4** All smear survey sample papers were counted on a Ludlum Model-2929 Dual Alpha, Beta/Gamma Scaler with a scintillation probe.

- 4.5** Soil Samples

A total of twenty (20) confirmatory samples were obtained from the removal area and analyzed by Analytical Technology, Inc. for Isotopic Cesium-137 with a one week turnaround. The results of these analysis and survey have been provided in Appendix H.

5.0 PROJECT REMEDIATION ACTIVITIES

- 5.1** Pre-surveys, establishment of the Radiation Work Permit (RWP), and establishment of the exclusion zone were done prior to any removal activities. The area was cleaned of all debris and four 55 gallon 7A drums were placed at the east end of the exclusion zone. A frisking station and air monitoring equipment were set up at the north side of the exclusion zone.
- 5.2** The peanut-shaped area was removed approximately four inches below surface. The material was placed into the 55 gallon containers and surveyed for release from the area. A total of 30 cubic feet was removed from the site.

- 5.3 The four containers were surveyed for both smearable activity and dose rate. No detectable smearable activity was found. The containers were manifested and shipped to the appropriate disposal site per ATG's scope of work. A copy of the manifest is provided as Appendix I.
- 5.4 The area was then surveyed and sampled for free release. The surveys for release were performed with the following instruments: Ludlum Model 12, with a 44-09 probe; Ludlum Model 12s; and Ludlum Model 3, with a 44-10 probe.
- 5.5 A centerline was marked through the area. Samples were obtained on both sides of the centerline at a rate of every three feet. Two random samples (Samples SS0026C & SS0027C) were obtained in the vicinity of the highest reading from the pre-surveys. Six samples were obtained in the area adjacent to the removed area. They were samples SS008C-SS013C. Confirmatory sample results are provided in Appendix H. A total of twenty (20) confirmatory samples were obtained.
- 5.6 All tools, equipment, etc. utilized during removal were surveyed prior to unrestricted release. No detectable activity above background levels were detected. Release surveys of equipment have been provided in Appendix F.
- 5.7 The exclusion zone and postings were removed from the site.
- 5.8 All on site activities were directly supervised by Mr. Dave Horton, Industrial Operations Command, Department of the Army.

6.0 SITE RELEASE

- 6.1 Twenty confirmatory samples were obtained in the removed area and/or its adjacent area. The sample results range between 0 to 1.2 pCi/gram with an average of .341 pCi/gram. The table below illustrates the sample results. These results satisfy the NUREG1500 limits for Cesium-137 [2.14 pCi/g at the 3 mrem/yr level for the most restrictive scenario (residential)] and that at these levels, human health is protected.

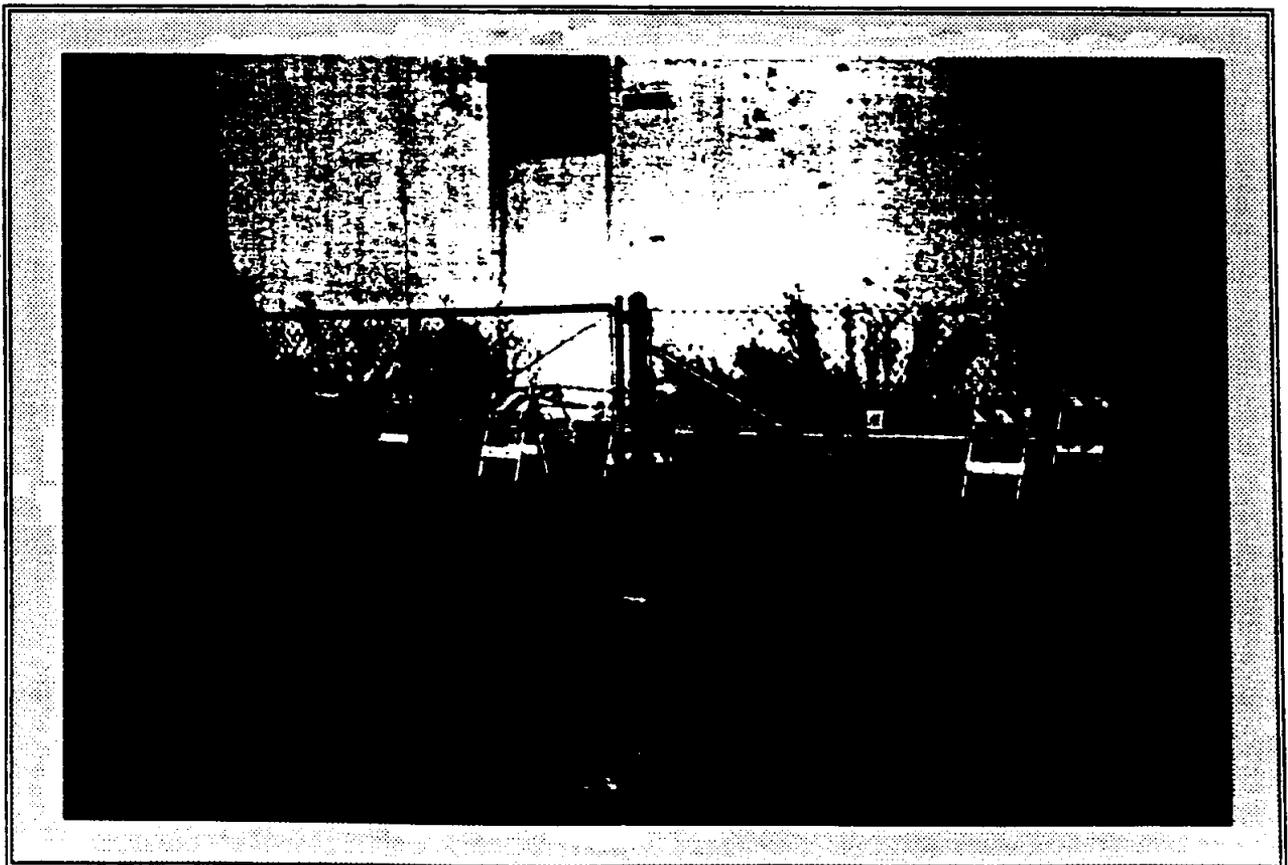
TABLE 6.1 Confirmatory Sample Results

Sample ID	Activity	(+/-)	Analysis
SS008C	0.913	0.103	DRY
SS009C	0.494	0.070	DRY
SS010C	1.170	0.113	DRY
SS011C	0.339	0.055	DRY
SS012C	1.160	0.109	DRY
SS013C	0.152	0.042	DRY
SS014C	0.197	0.047	DRY
SS015C	0.528	0.051	DRY
SS016C	0.029	0.025	DRY
SS017C	0.379	0.050	DRY
SS018C	0.295	0.047	DRY
SS019C	0.097	0.041	DRY
SS020C	0.096	0.029	DRY
SS021C	0.000	0.029	DRY
SS022C	0.068	0.034	DRY
SS023C	0.086	0.041	DRY
SS024C	0.220	0.049	DRY
SS025C	0.295	0.060	DRY
SS026C	0.236	0.042	DRY
SS027C	0.072	0.025	DRY

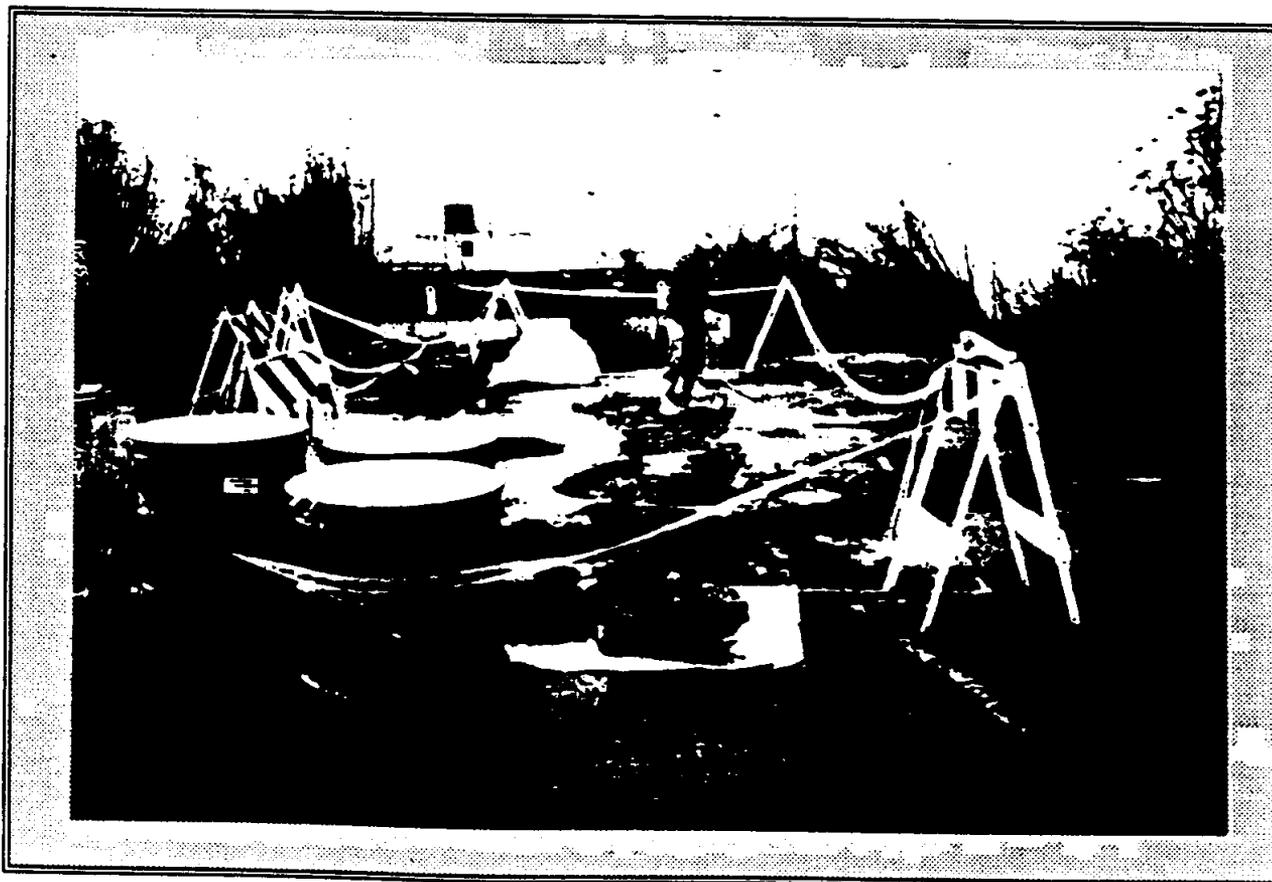
Confirmatory Results Average 0.341 pCi/gram

- 6.2 The area was 100 % surveyed to release the site. The release surveys were performed for Beta-gamma activity and showed no sign of elevated activity above background levels. A copy of the survey is supplied in Appendix F.
- 6.3 All rental equipment and tools were surveyed, data confirmed no radiation levels above limits of Regulatory Guide 1.86.

7.0 PICTORIAL



7.0 PICTORIAL



7.0 PICTORIAL



**COMPREHENSIVE LONG TERM ENVIRONMENTAL ACTION NAVY (CLEAN II)
Northern and Central California, Nevada, and Utah
Contract No. N62474-94-D-7609**

Contract Task Order No. 005

Prepared for

**U.S. DEPARTMENT OF THE NAVY
Naval Facilities Engineering Command
Engineering Field Activity West
San Bruno, California**

**PARCEL E REMEDIAL INVESTIGATION
DRAFT FINAL REPORT
HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA**

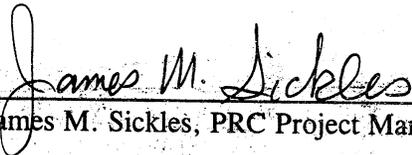
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APPENDIX P

RADIATION RISK ASSESSMENT

(67 Pages)

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ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	Below ground surface
Cal/EPA	California Environmental Protection Agency
CCSF	City and County of San Francisco
cm ³ /ft ³	Cubic centimeters per cubic foot
COPC	Chemical of potential concern
CSM	Conceptual site model
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
ELCR	Excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	Exposure point concentration
ft ²	Square foot
ft ³	Cubic foot
FUDS	Formerly used defense sites
g/day	Grams per day
HEAST	Health Effects Assessment Summary Tables
HHRA	Human health risk assessment
HLA	Harding Lawson Associates
HPS	Hunters Point Shipyard
IAS	Initial assessment study
IR	Installation restoration
IRP	Installation Restoration Program
k _d	Radium distribution coefficients
kg	Kilogram
kg/yr	Kilograms per year
LTD	Lifetime total dose
m	Meter
m ²	Square meter

ABBREVIATIONS AND ACRONYMS (Continued)

m ³	Cubic meter
mCi	milliCurie
mg	Milligram
NAREL	National Air and Radiation Environmental Laboratory
Navy	U.S. Department of the Navy
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NORM	Naturally occurring radioactive materials
NRC	Nuclear Regulatory Commission
NRDL	Naval Radiological Defense Laboratory
pCi	picoCurie
pCi/m ²	picoCuries per square meter
pound/ft ²	Pound per square foot
PRC	PRC Environmental Management, Inc.
PRG	Preliminary remediation goal
RAGS	Risk Assessment Guidance for Superfund
RI	Remedial investigation
RME	Reasonable maximum exposure
RSS	Radiological Safety Section
SCRS	Surface confirmation radiation survey
SF	Slope factor
SFRA	San Francisco Redevelopment Agency
Triple A	Triple A Machine Shop
USDA	U.S. Department of Agriculture
VDG	Van de Graaf
μCi	microCurie
μg	Microgram

FIGURES

Figure

- P-1 HUMAN HEALTH RISK ASSESSMENT EXPOSURE AREAS
- P-2 RADIUM DAUGHTER DECAY CHAIN AND PRIMARY RADIOACTIVE DECAY EMISSIONS
- P-3 RADIATION SURVEY GRID AND GAMMA ANOMALIES
- P-4 CONCEPTUAL SITE MODEL
- P-5 HUMAN HEALTH RISK ASSESSMENT EXPOSURE AREAS AND RADIATION SURVEY GRID
- P-6 CARCINOGENIC RISK FROM RADIONUCLIDES OF POTENTIAL CONCERN, FUTURE RESIDENTIAL EXPOSURE SCENARIO
- P-7 CARCINOGENIC RISK FROM RADIONUCLIDES OF POTENTIAL CONCERN, FUTURE INDUSTRIAL EXPOSURE SCENARIO

1.0 INTRODUCTION

This appendix presents the radiation risk assessment for Parcel E of Hunters Point Shipyard (HPS) located in San Francisco, California. This assessment is based on the site characterization and sampling data presented in Appendix E of the Parcel E remedial investigation (RI) report. Information on the history, geology, and hydrogeology of HPS and more detailed descriptions of Parcel E Installation Restoration Program sites are also provided in the RI report.

HPS consists of six geographic parcels, Parcels A through F. Parcel E occupies approximately 135 acres and includes the following installation restoration (IR) sites which are considered to contain potential contaminant sources in this radiation risk assessment (see Figure P-1):

- IR-01/21: Industrial Landfill (Triple A Machine Shop [Triple A] Sites 1 and 16)
- IR-02 Northwest: Bay Fill Area (Triple A Sites 2 and 14)
- IR-02 Central: Bay Fill Area (Triple A Sites 18 and 19) and Building 600, Bachelor Enlisted Men's Quarters
- IR-02 Southeast: Bay Fill Area (Triple A Site 13) and Former Tank S-505 and Burn Disposal Area
- IR-11/14/15: Oily Waste Ponds; Oily Liquid Waste Disposal Area; Incineration Tank (Triple A Sites 6, 7, 12, and 13); and Building 521, Power Plant

The radiation risk assessment objective, radiation risk assessment technical approach, and overall organization of the radiation risk assessment report are discussed below.

1.1 RADIATION RISK ASSESSMENT OBJECTIVE

The objective of this radiation risk assessment is to evaluate the potential risks associated with human exposure to radionuclides of potential concern detected at Parcel E, under the future land-use scenarios. This radiation risk assessment evaluates exposures and risks to human health under the future residential and industrial land-use scenarios for Parcel E. Current land-use scenarios are not evaluated in the radiation risk assessment because IR-01/21, IR-02 Northwest, IR-02 Central, IR-02 Southeast, and IR-11/14/15 are currently not used for any purposes and much of Parcel E is fenced off from the

rest of HPS. Portions of Parcel E having acceptable risk levels under the future industrial land-use scenario would also have acceptable risk levels under the current industrial land-use scenario.

1.2 TECHNICAL APPROACH

The radiation risk assessment was prepared in accordance with EPA's "Risk Assessment Guidance for Superfund: Volume I -- Human Health Evaluation Manual, Part A" (EPA 1989); EPA's "Superfund Standard Default Exposure Factors for Central Tendency and Reasonable Maximum Exposures" (EPA 1993); and other EPA and California Protection Agency (Cal/EPA) guidance as appropriate. As described in EPA guidance (1989), a risk assessment is typically prepared in four basic steps: (1) data evaluation and the identification of radionuclides of potential concern, (2) the exposure assessment, (3) the toxicity assessment, and (4) risk characterization. These four steps are briefly summarized below and are discussed in more detail in Sections 2.0 through 4.0 of this radiation risk assessment report.

The first step is data evaluation and identification of radionuclides of potential concern. Based on data collected during the radiological investigations (see Section 2.3), radium-226 and its radioactive daughters are radionuclides of potential concern for evaluation in this risk assessment.

The second step of the risk assessment is the exposure assessment. During the exposure assessment, conceptual site models are developed to describe each complete, probable, or actual exposure pathway at each IR site. A complete exposure pathway considers sources of contaminants, possible mechanisms of contaminant release, and the environmental fate and transport of these contaminants. Exposure point concentrations (EPC), the concentrations at which human receptors would be exposed to radionuclides of potential concern, are derived from survey data collected from Phase I radiation and other investigations as appropriate. EPCs are calculated for each exposure area where receptors may be exposed to radionuclides of potential concern. Finally, pathway-specific intakes are calculated for both the reasonable maximum exposure (RME) and average exposure cases. This radiation risk assessment evaluates risks under the following land-use scenarios: (1) future residential land-use scenario, based on 2,500-square-foot (ft²) exposure areas; and (2) future industrial land-use scenario, based on 0.5-acre exposure areas.

Table P-1 lists the IR sites and associated industrial exposure areas (0.5-acre) and associated residential exposure areas (2,500-ft² exposure areas). Exposure areas are associated with IR sites if they are completely in, are partially in, or border the site boundary. Figure P-1 shows the 2,500-ft² and 0.5-acre exposure areas and identifies these areas by number.

The third step of a risk assessment is the toxicity assessment. The toxicity assessment consists of an evaluation of available toxicity information for radionuclides of potential concern identified at Parcel E. Potential adverse health effects associated with exposure to radionuclides of potential concern are then assessed. Toxicity values for radionuclides of potential concern (slope factors [SF]) were obtained from Health Effects Assessment Tables (HEAST) (EPA 1995a).

The fourth step of a risk assessment is risk characterization. This step quantitatively and qualitatively characterizes the carcinogenic risks associated with the results of the exposure assessment and toxicity assessment for each exposure area. Excess lifetime cancer risks (ELCR) are estimated for the radionuclides of potential concern for each exposure area. Risks are also characterized for each IR site by evaluating the ELCRs associated with each exposure area that falls completely or partially within the IR site or that touches the site boundaries. Radionuclides of potential concern contributing a total ELCR equal to or exceeding 1×10^{-6} are then identified.

Information from data evaluation, exposure assessment, and toxicity assessment were compiled and used in U.S. Department of Energy's (DOE) RESRAD computer code (DOE 1997) to model risks at radiation sites (see Attachments P1 and P2). RESRAD is a multimedia model that incorporates a number of media-specific submodels, all of which were chosen for reliability and general health protectiveness (EPA 1994a). RESRAD models a time-dependent source term that accounts for radioactive ingrowth, decay, and also leaching and erosion in the contaminated zone and considers site-specific geologic and hydrogeologic parameters (see Section 3.1.1.1) (DOE 1993). Using the same data compiled from data evaluation, exposure assessment, and toxicity assessment for RESRAD, EPA's RISKCALC computer code (EPA 1994b) was used to estimate risk for comparative purposes with RESRAD (see Attachment P3). RISKCALC is a model that estimates risk using the soil exposure pathway equations referenced in EPA's "Risk Assessment Guidance for Superfund, Part A" (EPA 1989). RISKCALC does not calculate a time-dependent source term that accounts for radioactive

ingrowth, decay, leaching, and erosion in the contaminated zone and does not consider site-specific geologic and hydrogeologic parameters. The contaminated zone in the RISKCALC model is assumed to be a constant, non-depleting source of radioactivity for the calculations. Therefore, it provides an upper bound estimate of exposure to radionuclides in soil.

1.3 REPORT ORGANIZATION

This HHRA report includes four sections in addition to this introduction. Section 2.0 discusses previous investigations, data evaluation, and identification of radionuclides of potential concern; Section 3.0 presents the exposure and toxicity assessment for Parcel E; Section 4.0 discusses the risk characterizations for each IR site; and Section 5.0 presents the conclusion of the radiation risk assessment. Attachments P1 through P5 present supporting information, including estimating carcinogenic risks using RESRAD, estimating carcinogenic risks due to exposure to radon, estimating carcinogenic risks using RISKCALC, calculation of carcinogenic risks from isotropic point sources of radium, and a sensitivity analysis of RESRAD.

2.0 IDENTIFICATION OF RADIONUCLIDES OF POTENTIAL CONCERN

The process by which radium-226 and its radioactive daughters were identified as radionuclides of potential concern to human health at Parcel E is described in this section. Section 2.1 summarizes the historical background of radioactive materials at Parcel E. Section 2.2 discusses the physical and radiological properties of radium-226 and its radioactive daughters. Section 2.3 summarizes radiological investigations conducted at Parcel E to determine the extent of radium-226. Section 2.4 presents an evaluation of the data produced from radiological investigations. Section 2.5 discusses uncertainties related to the identification of radionuclides of potential concern.

2.1 HISTORICAL BACKGROUND

HPS was a center of shipbuilding and ship repair during World War II. Pure and applied radiological research performed by the Naval Radiological Defense Laboratory (NRDL) also played a major role in HPS history. These activities at HPS resulted in the routine use, storage, and disposal of radioactive materials. Two radiological concerns exist at HPS: (1) disposal of radium-containing devices

generated during ship repair and maintenance activities, and (2) residual radioactive contamination resulting from former NRDL activities. Section 2.1.1 presents a history of the disposal of radium-containing ship devices at Parcel E. Section 2.1.2 presents a history of NRDL activities at HPS.

2.1.1 History of Radium-Containing Devices at HPS

Historical accounts indicate that during routine maintenance operations on Navy ships and submarines, unserviceable radium-containing devices were removed and disposed of at Parcel E (PRC 1996a). These devices included luminescent instrument dials, gauges, deck markers, and other electronic equipment components. Prior to the 1970s, most radium-containing devices used by the military contained radium-226 mixed into a phosphorescent paint base. The paint, which was applied to numerals and markers on ship equipment, produced a dull glow that made it easy to read instruments at night without additional lighting. Until the late 1960s, it was common industrial practice to dispose of unserviceable radium-containing devices by shallow land burial (PRC 1996b).

Radium-containing devices were disposed or may have been inadvertently deposited during the movement of fill material at the Industrial Landfill (IR-01/21), the northwestern portion of the Bay Fill Area (IR-02 Northwest), the central portion of the Bay Fill Area (IR-02 Central), the southeastern portion of the Bay Fill Area (IR-02 Southeast), and IR-11/14/15. The U.S. Department of the Navy (Navy) created these land areas by filling in the Bay margin with quarried materials consisting primarily of serpentinite bedrock from the HPS peninsula and other materials such as sands, gravel, construction debris, industrial debris, and sandblast waste (PRC 1996b). In addition, IR-01/21 and IR-02 Northwest have been extensively filled with waste generated during HPS industrial activities (PRC 1996a). Because the land areas of IR-01/21 and the IR-02 sites were created with Artificial Fill, they are often referred to as "landfill" areas in historical documents; the ambiguity of this term has led to confusion in historical documents between the Industrial Landfill and the Bay Fill Area.

The initial assessment study (IAS) performed at HPS in 1984 consisted of a visual site inspection and review of Navy and historical documents. The IAS report stated that 6,000 pounds of radium-containing devices were removed from ships during repair and maintenance activities and disposed of at the Industrial Landfill (IR-01/21) (WESTEC 1984). This finding was based on Navy records that

indicated disposal of the devices in the "landfill" area at Parcel E. However, subsequent studies reveal that radium-containing devices were buried at a "disposal dump area" in the Bay Fill Area at IR-02 Northwest, rather than at the Industrial Landfill; the disposal dump area at IR-02 Northwest was used by the Navy as a disposal site for industrial waste (PRC 1996c).

During site reconnaissance activities conducted in 1988, a preliminary surface radiation survey was performed at Parcel E to determine if elevated levels of radiation were present that would pose an exposure risk to field workers (HLA 1990). Localized elevated gamma radiation readings were observed at IR-02 Northwest; this suggested the presence of discrete point sources of radioactivity such as buried radium-containing devices (HLA 1990).

In 1991, buried slag-like materials exhibiting alpha and gamma activity were discovered during RI trenching activities at Parcel E (PRC 1992). These slag-like materials may be present due to the decomposition of radium-containing devices. Field gamma spectroscopic analysis performed by DOE radiological specialists from the Lawrence Livermore Laboratory determined that radium-226 was the source of radioactivity in these slag-like materials (PRC 1992). This initial identification of radium-226 was subsequently confirmed by laboratory analysis of several radium-containing devices found at the site (PRC 1992).

As a result of these findings, radium-226 was identified as a radionuclide of potential concern to human health at Parcel E. The Phase I and Phase II radiological investigations were conducted to determine the nature and extent of radium-226 at Parcel E. These radiological investigations are summarized in Section 2.3.

2.1.2 History of NRDL at HPS

In 1946, the Radiological Safety Section (RSS), a part of the San Francisco Naval Shipyard Industrial Laboratory, originated at HPS (PRC 1996b). One mission of this organization was to identify methods to decontaminate ships that had returned from nuclear weapons test near Bikini Atoll in the Marshall Islands. In 1948, the RSS became known as the NRDL. Its mission was to study the effects of nuclear weapons and to develop effective countermeasures against radiation. NRDL activities required the use of a cyclotron, a Van de Graaff (VDG) generator, X-ray machines, radiological laboratories, support

offices, and kennels for animals used in radiological studies (PRC 1996b). In 1950, the NRDL became a separate Navy command. Until 1955, NRDL laboratory operations were conducted at various buildings and sites throughout HPS. All radioactive waste generated by the NRDL at HPS was reportedly disposed of off site in compliance with regulatory requirements (WESTEC 1984).

On April 25, 1969, the Navy announced the disestablishment of NRDL with a projected closure date of December 31, 1969. Part of the disestablishment of the NRDL was the termination of radioactive material licenses that had been issued to the Navy by the Atomic Energy Commission (AEC), which was the original agency responsible for authorizing the use of radioactive material, and later by the Nuclear Regulatory Commission (NRC). All licenses issued to the NRDL by the AEC and NRC have been terminated (PRC 1996b).

In 1997, the Phase III radiation investigation was conducted to determine whether residual radioactive contamination associated with former NRDL activities was present at Parcel E. Parcel E and the adjacent formerly used defense sites (FUDS) contain 14 former NRDL sites. The Phase III investigation included sites where residual contamination was suspected or where radiation surveys had not been performed as part of the termination process for a radiological material license. This radiological investigation is summarized in Section 2.3.3.

2.2 PHYSICAL AND RADIOLOGICAL PROPERTIES OF RADIUM-226 AND ITS RADIOACTIVE DAUGHTERS

The physical form of devices containing radium-226 is discussed in Section 2.2.1. The radiological properties of radium-226 and its radioactive daughters are summarized in Section 2.2.2.

2.2.1 Radium-Containing Devices

Several types of radium-containing devices have been found in the disposal dump area during field investigations at Parcel E. The most common device is a radium illuminator commonly used on submarines and below decks of large ships to mark equipment and emergency exit locations. The radium illuminator is about 18 millimeters in diameter and contains about 1 microcurie (μCi) of radium-226 sealed in a glass bead. Another commonly found radium-containing device is a disk-shaped, metal dial about the size and thickness of a silver dollar. Radium-226 associated with these

dials is present mainly in paint applied to the metal surface of the dial. In addition, deck markers and other electronic parts with radium-containing paint may be present in the disposal dump area; these devices range from nickel-sized to quarter-sized.

Many of the radium-containing devices present in the disposal dump area are completely intact. Radium-226 present in intact glass beads and paint that has not decomposed is isolated from the environment; therefore, transfer of radium-226 to the environment is limited while the device remains intact. However, some of the devices have decomposed or broken and are no longer in their original manufactured form. Fine-grained materials from crushed glass beads and oxidation products from weathered dials are mixed with soils in the disposal dump area. Over time, radium-containing devices will continue to weather and decompose; radioactive material released from decomposing devices will be available for movement through the environment.

2.2.2 Radiological Properties

Radium-226 is a naturally occurring radioactive element formed from the disintegration of uranium-238. Low levels of radium-226 from the decay of naturally occurring uranium-238 can be detected in soil, water, rocks, coal, plants, and food. Radium-226 is part of the uranium-238 decay chain. Uranium-238 has a half-life of 4,500,000,000 years and decays to thorium-234, protactinium-234, uranium-234, and thorium-230 prior to the formation of radium-226.

Radium-226 has a half-life of 1,600 years and emits primarily alpha radiation and low-energy gamma radiation upon decay. The radium-226 decay scheme consists of sequential transformation to radon-222, polonium-218, lead-214, bismuth-214, polonium-214, lead-210, bismuth-210, and polonium-210; the decay scheme ends with stable isotope lead-206 (see Figure P-2). The only daughter of radium-226 with an appreciable half-life is lead-210, which has a half-life of about 22 years. All other radium-226 daughters have half-lives of less than 6 months.

Because of the low energy and infrequent occurrence of its gamma emissions, radium-226 cannot be directly identified using gamma spectroscopy. Instead, the presence of radium-226 is inferred by detecting radiation from its gamma-emitting daughters. These daughters will not migrate substantially from the source and therefore emit gamma radiation in the vicinity of the source. The daughters

lead-214 and bismuth-214 are the primary indicators of radium-226 because they emit relatively high-intensity gamma energies compared with other daughters. Buried radium-containing devices are commonly located using gamma spectroscopy to detect gamma radiation emitted by these daughters. A device containing 1 μCi of radium-226 can usually be detected to depths of 1 to 1.5 feet below ground surface (bgs) using gamma spectroscopy.

Decay of a radium-226 atom produces radon-222, an alpha-emitting radioactive gas with a half-life of 3.8 days. Radon-222 is a noble gas and is therefore chemically inert. Radon-222 is a radioisotope of particular concern when radium-226 is present because it provides an additional pathway for human exposure to radiation. The gaseous physical state of radon-222 and its nonreactive chemical properties allow it to readily diffuse from the source. Radon-222 produced by a buried radium-containing device may diffuse through soil to the ground surface and into the atmosphere, where it undergoes further radioactive decay.

2.3 RADIOLOGICAL INVESTIGATIONS

Data from radiological investigations were used to identify radium-226 and its radioactive daughters as radionuclides of potential concern to human health at Parcel E. These investigations are summarized in this section. The Phase I investigation, a surface confirmation radiation survey (SCRS), is summarized in Section 2.3.1. The Phase II investigation, a subsurface evaluation of radium-containing devices at Parcel E, is summarized in Section 2.3.2. The Phase III investigation, a survey of former NRDL sites, is summarized in Section 2.3.3. The groundwater investigation is summarized in Section 2.3.4. A proposed treatability study is summarized in Section 2.3.5. Conclusions of these investigations are summarized in Section 2.3.6. A complete discussion of the methodology, results, and conclusions of these radiological investigations is presented in Appendix E of this RI report.

2.3.1 Phase I Investigation

The Phase I radiation investigation was initiated in 1991 to determine the nature and surficial extent of radium-containing devices in the disposal dump area at IR-02 Northwest. Although elevated gamma radiation readings were detected only at IR-02 Northwest during the 1988 survey, IR-01/21, IR-02

Central, IR-02 Southeast, IR-03, and IR-11/14/15 were surveyed during the Phase I investigation due to their proximity to the disposal dump area.

A comprehensive surface gamma walkover survey was performed to establish the nature and surficial extent of radium-containing devices discovered at IR-02 Northwest in 1988. During the Phase I investigation, gamma readings exceeding two times the background level were considered radioactive anomalies associated with buried radium-containing devices (PRC 1992). Gamma activity was mapped on a grid coordinate system consisting of 30-foot by 30-foot subgrids; the number of gamma anomalies found in each subgrid was documented. During the surface walkover survey, over 300 gamma anomalies considered to be associated with buried radium-containing devices were observed in a central area at IR-02 Northwest that extended about 50 feet across the site boundary into IR-02 Central; this area corresponds to the location of the disposal dump area used by the Navy for disposal of industrial waste (PRC 1992). The area of gamma anomalies was about 600 feet by 600 feet. In addition to the gamma anomalies detected in this large area, a few gamma anomalies were observed at scattered locations at IR-01/21, IR-02 Central, and IR-02 Southeast. Figure P-3 presents the locations where anomalies were detected during the Phase I investigation.

Soil samples were collected to identify radioisotopes present at Parcel E and to determine whether radium-226 from radium-containing devices had migrated to soil. Soil samples were collected from random locations throughout Parcel E at a frequency of one sample per 2 acres and at locations where elevated gamma readings were observed. Radiochemical analysis of these samples demonstrated that other than radium-226 associated with radium-containing devices and radium-226 daughters, all radioisotopes present in these soil samples were within expected background levels (PRC 1992). Elevated concentrations of radium-226 were observed in 13 soil samples collected from the disposal dump area at IR-02 Northwest, one soil sample collected from IR-01/21, and two soil samples collected from IR-02 Southeast (see Appendix E of this RI report, Section 2.1.2).

Radon flux testing was performed to assess the presence of radon at selected locations at and around areas where gamma anomalies were observed. Increased radon concentrations may indicate the presence of subsurface radium-containing devices. Elevated levels of radon gas were only observed at locations where canisters were placed directly on top of radium-containing devices present at the

ground surface; radon gas was not detected at locations where radium-containing devices were not visible (PRC 1992).

Air sampling for gross alpha and gross beta radioactivity was performed to establish the concentration of airborne radioactive particulates at Parcel E. Elevated gross alpha or gross beta radioactivity was not detected in the air samples collected in and surrounding Parcel E (PRC 1992).

Groundwater was sampled and analyzed for gross alpha and gross beta radioactivity to determine if the presence of radium-containing devices in soil was impacting groundwater in the vicinity (PRC 1992). However, because the presence of dissolved and suspended solids in groundwater interfered with the analysis, the results were inconclusive (PRC 1992). In 1993, groundwater samples were analyzed for radionuclides by the U.S. Environmental Protection Agency (EPA) National Air and Radiation Environmental Laboratory (NAREL) and were not found to contain radium-226 above background; these results are presented in Section 2.3.3.

The Phase I investigation concluded that the radioisotopes of concern at Parcel E are radium-226 and its daughters from buried radium-containing devices disposed of during shipyard activities. These radium-containing devices were identified in (1) surface soil at scattered locations at IR-01/21 and IR-02, and (2) a central disposal dump area at IR-02 Northwest extending into IR-02 Central. Limited radium-226 contamination was observed in soil collected from IR-01/21, IR-02 Northwest, and IR-02 Southeast. In addition, the Phase I investigation concluded that radium-containing devices may be present in the subsurface environment of these areas.

2.3.2 Phase II Investigation

In 1993, the Phase II radiation investigation was conducted at Parcel E to delineate the subsurface distribution of radium-containing devices at IR-01/21, IR-02 Northwest, and IR-02 Central.

Thirty-four test pits and three trenches were excavated at IR-02 Northwest and locations at IR-02 Central along the site boundary. Six test pits were excavated at IR-01/21. The trenches and test pits were excavated until Bay Mud or groundwater was encountered. The walls of each excavation were scanned every 2 feet to detect gamma-emitting radioactive material below the surface. Gamma

readings exceeding one and one-half times the background level were considered radioactive anomalies associated with buried radium-containing devices (PRC 1996a).

Excavation activities at the disposal dump area at IR-02 Northwest and IR-02 Central detected approximately 111 discrete gamma anomalies (PRC 1996a). The subsurface distribution of radium-containing devices associated with these gamma anomalies was confined to an area of approximately 400 feet by 250 feet to a maximum depth of 9 feet bgs (PRC 1996a). The eastern portion of this area extended about 50 feet into IR-02 Central, where a few radium-containing devices were observed in the uppermost 1 foot of soil. Ninety percent of the radium-containing devices found at the disposal dump area during excavation activities were located in the uppermost 6.5 feet of soil; no devices were located below the Bay Mud (PRC 1996a). Soils in the disposal dump area include many soil types, are often mixed with industrial and construction debris, and are indicative of disposal practices such as dumping and burying. Abundant debris was deposited in several pits in the area where most radium-containing devices were detected during the Phase I investigation (PRC 1996a). Based on field observations, the radium-containing devices detected at IR-02 Northwest appear to be associated with the disposal of industrial debris (PRC 1996c).

Statistical analysis and computer modeling calculated the volume of affected soil at the disposal dump area at IR-02 Northwest and IR-02 Central to be 5,500 cubic yards (PRC 1996a). During the Phase II investigation, the average distribution of radium-containing devices was found to be one source for every 2 cubic yards of excavated soil; therefore, the total affected soil volume was calculated to contain approximately 2,750 radium-containing devices (PRC 1996a). Based on historical knowledge of the types of radium-containing devices present at the disposal dump area, each device was assumed to contain about 1 μCi of radium-226. Therefore, the estimated aggregate radium-226 activity for the total volume of affected soil at the disposal dump area was calculated to be 2.8 millicuries (mCi) (PRC 1996a).

Radium-containing devices and elevated concentrations of radium-226 were not detected in subsurface soils at IR-01/21 (PRC 1996a). These results confirm that the primary disposal site for radium-containing devices was the disposal dump area at IR-02 Northwest, rather than the Industrial Landfill (IR-01/21) as reported in the IAS.

Subsurface soil samples collected from excavation locations exhibiting elevated gamma activity at IR-02 Northwest contained elevated concentrations of radium-226 and its daughters. Radium-226 contamination migrated no more than 12 to 18 inches from any radium-containing device, even if the device had decomposed (PRC 1996a). Radioisotopes other than radium-226 were not detected above background levels. Because elevated radium-226 concentrations in soil were not observed more than 18 inches from any radium-containing device, radium-226 contamination in soil has apparently not migrated appreciably and is limited to the disposal dump area at IR-02 Northwest and IR-02 Central (PRC 1996a).

The Phase II radiation investigation concluded that the disposal dump area at IR-02 Northwest and IR-02 Central was the primary disposal area for all radium-containing devices generated at HPS as a result of ship repair and maintenance activities (PRC 1996a). Radium-containing devices were detected when a significant percentage (at times more than 50 percent) of the volume of excavated material was industrial debris, indicating that radium-containing devices were disposed of along with other industrial debris in the disposal dump area (PRC 1996a). Radium-containing devices were disposed of in the uppermost 9 feet of soil at the disposal dump area (PRC 1996a).

The few radium-containing devices found at other Parcel E locations may have been inadvertently transported from the disposal dump area in IR-02 Northwest as a result of ongoing soil excavation, redistribution, and dumping activities at the site (PRC 1996c). In addition, Triple A excavation and disposal activities may have unearthed radium-containing devices at IR-02 Northwest. As various construction and industrial materials and debris were stored, transported, and disposed of, the first few inches of soil from the disposal dump area may have been excavated and placed in other areas of Parcel E (PRC 1996c).

2.3.3 Phase III Investigation

In 1997, the Phase III radiation investigation was conducted at former NRDL sites to determine whether residual radioactive contamination was present. A comprehensive surface gamma walkover survey was conducted at eight sites at Parcel E during the Phase III investigation. Gamma readings

exceeding two times the background level were considered radioactive anomalies and were further investigated through soil sampling and excavation.

One gamma reading more than two times background was observed at IR-11/14/15 between former Buildings 520 and 529; this anomaly may be due to the presence of a buried radium-containing device. The location of this anomaly was excavated to a depth of 12 inches bgs; gamma activity increased with depth but no source was found. Radionuclide concentrations in soil samples collected from this location did not exceed background. The elevated gamma reading may be the result of a radium-containing device buried more than 12 inches bgs. This location at IR-11/14/15 is included in this risk assessment and is shown in Figure P-3.

Residual radioactive contamination unrelated to the disposal of radium-containing devices was detected on and near a concrete pad adjacent to Building 707. The concrete pad was used by the NRDL to store drums of radioactive waste prior to off-site disposal. During the Phase III investigation, two areas on the concrete pad and two asphalt areas near the pad exhibited levels of cesium-137, radium-26, thorium-228, and thorium-232, exceeding their respective screening criteria. Rather than include additional radioisotopes in this risk assessment, the risk to human health was assumed to be unacceptable and an interim removal action is planned for this site.

One gamma reading slightly above background was observed near the northeast corner of Building 517 at IR-11/14/15. Because the gamma activity at this location did not exceed two times the background activity, this anomaly was not considered indicative of a buried radium-containing device and soil in this area was not collected for analysis. This location will be assessed for removal during the proposed interim removal action for contamination present on the concrete pad adjacent to Building 707.

The methodology, results, and conclusions of the Phase III radiation investigation are presented in Appendix E of this RI report.

2.3.4 Groundwater Investigation

In 1993, 25 groundwater samples were collected from monitoring wells at IR-02 sites for analysis by EPA NAREL. These samples were analyzed for radium-226 by a coprecipitation method.

These samples did not indicate concentrations of radium-226 above background levels (PRC 1995). Radium-226 contamination in Parcel E soils has apparently not migrated to groundwater.

2.3.5 Treatability Study

In 1994, EPA conducted soil sampling at Parcel E as part of a proposed treatability study for a remediation technology to address radium contamination in soil. Soil samples were analyzed by NAREL for particle size and radium-226 distribution (EPA 1994c). The results indicated that most soil at Parcel E contained background concentrations of radium-226 and that limited soil contamination was associated with the presence of radium-containing devices (EPA 1994c). Selective removal of soil in the vicinity of identifiable sources and removal of the sources by particle-size separation was identified as a potential remedial alternative (EPA 1994c).

2.3.6 Conclusions

All radium-containing devices generated at HPS during ship repair and maintenance activities were apparently disposed of in a centralized disposal dump area at IR-02 Northwest that extends into IR-02 Central. Radium-containing devices were disposed of along with industrial debris in an area of approximately 400 feet by 250 feet to a maximum depth of 9 feet bgs. The few radium-containing devices found at other Parcel E locations (such as IR-01/21, IR-02 Southeast, and IR-11/14/15) may have been inadvertently transported from the disposal dump area at IR-02 Northwest during soil excavation, redistribution, and dumping activities at the site.

Radium-226 and its daughters were the only radionuclides detected above background levels in soil samples collected throughout Parcel E during the Phase I and Phase II investigations. Elevated concentrations of radium-226 and its daughters were not observed more than 18 inches from any radium-containing device.

2.4 DATA EVALUATION

The identification of radium-226 and its radioactive daughters as radionuclides of potential concern for evaluation in this risk assessment is based on data collected during the radiological investigations

summarized in Section 2.3. During these investigations, all laboratory and field activities were conducted in accordance with quality assurance and quality control procedures specified in relevant planning documents and the quality assurance project plan for HPS (HLA 1988). The data set for each radiological investigation was reviewed at the conclusion of the investigation to verify that the quality of the data was acceptable for its intended use; data review procedures are specified in the respective reports for each radiological investigation. All data collected during the radiological investigations at Parcel E were considered to be of acceptable quality to characterize the nature and extent of radionuclides present at Parcel E sites.

2.5 IDENTIFICATION UNCERTAINTIES

Uncertainties associated with the data from the radiological investigations are summarized in the following sections.

2.5.1 Uncertainties Associated with Assumptions

Uncertainties associated with assumptions made during the radiological investigations are summarized in the following subsections.

2.5.1.1 Activity of Radium-Containing Devices

During the radiation investigations, each radium-containing device present at Parcel E was assumed to contain 1 μCi of radium-226. During the Phase I and Phase III investigations, devices with this activity present in the uppermost 1 foot of soil were detected with the survey instrumentation. During the Phase II investigation, devices with this activity present within 1 foot of the trench walls could be detected with the survey instrumentation. Using this assumption, the number of radium-containing devices present in the near-surface at Parcel E could be determined and the number of devices in the subsurface at the disposal dump area could be estimated.

This assumption introduces uncertainty which may underestimate the number of radium-containing devices present in both the near-surface and subsurface at Parcel E. Radium-containing devices may contain less than 1 μCi of radium-226 because of their design or because they have partially

decomposed. Devices containing less than 1 μCi may not have been detected during field gamma surveys. Therefore, the number of radium-containing devices found in the near-surface and subsurface at Parcel E during the radiation investigations may be biased low. Because most radium-containing devices found in the disposal dump area were intact and contained about 1 μCi of radium-226, the significance of this uncertainty is expected to be minor.

2.5.1.2 Survey Instrumentation

During the radiation investigations, it was assumed that survey instrumentation would detect all devices containing 1 μCi of radium-226 at distances of at least 1 foot from the instrument. This assumption introduces uncertainty which may over- or underestimate the number of radium-containing devices present in the near-surface and subsurface at Parcel E. Because of the heterogeneous nature of the fill material and the variability of soil compaction and ground shielding factors, survey instrumentation may detect radium-containing devices at distances greater than 1 foot; in this case, the number of buried devices found during the investigation may be biased high. Conversely, survey instrumentation may not detect radium-containing devices to distances of 1 foot; in this case, the number of buried devices found during the investigation may be biased low. Because standard survey instrumentation and survey protocols were used in the investigations, the significance of this uncertainty is expected to be minor.

2.5.1.3 Gamma Activity Screening Criteria

During the Phase I and Phase III investigations, a location with an elevated gamma reading exceeding two times the background gamma activity of the site was assumed to be the location of a buried radium-containing device. During the Phase II investigation, a location with an elevated gamma reading exceeding one and one-half times the background gamma activity of the site was assumed to be the location of a buried radium-containing device. These screening criteria introduce uncertainty which may over- or underestimate the number of buried radium-containing devices at Parcel E. The screening criteria of one and one-half times or two times background activity may be biased high or low. Where the criteria are biased low, naturally occurring radioactive materials (NORM) found in sands and granite at HPS may be mistakenly identified as buried devices. Where the criteria are biased

high, gamma activity from buried radium-containing devices may be misidentified as background levels of gamma radiation. Because standard methods of determining gamma activity screening criteria were used, the significance of this uncertainty is expected to be minor.

2.5.1.4 Modeling Assumptions

During the statistical analysis and computer modeling conducted during the Phase II investigation, the average number of radium-containing devices found in each cubic yard of soil excavated during the Phase II investigation was assumed to be representative of the entire disposal dump area. Uncertainty is associated with the use of an average number of devices per cubic yard of soil as well as with the representativeness of the area. Additionally, each point source was assumed to contain 1 μCi of radium-226. These assumptions introduce uncertainty which may over- or underestimate the number of subsurface radium-containing devices present in the disposal dump area and which may over- or underestimate the radium-226 activity calculated for the total volume of soil in the disposal dump area. However, error associated with these assumptions is not a source of uncertainty in the risk assessment because data from the Phase II investigation were not used for quantitative purposes.

2.5.2 Background Determination

During the Phase I and Phase III investigations, gamma activity screening criteria were developed to determine the locations of buried radium-containing devices; these screening criteria were based on background gamma activity at the site. The determination of background activity introduces uncertainty which may over- or underestimate the number of buried radium-containing devices at Parcel E.

Background measurements in the field at HPS are variable for many reasons, such as the extremely heterogeneous nature of the fill material. Variations in background gamma activity of 30 percent or more from subgrid to subgrid were observed during the Phase I investigation. The method used to determine background gamma activity during the radiation investigations was a conservative, subgrid-specific method designed to compensate for these variable background measurements. However, in some subgrids, the background measurement may be biased high or low and the number

of buried radium-containing devices actually present in a subgrid may be more or less than was measured during the field investigations.

In some subgrids, the background activity may be biased low; this may result in NORM found in sands and granite at HPS mistakenly identified as buried devices. In addition, low background levels of anthropogenic radionuclides present at the earth's surface due to fallout from atmospheric testing of nuclear weapons may have been mistakenly identified as buried devices. In subgrids where the background level may be biased high, some buried radium-containing devices may not have been identified. However, the significance of this uncertainty is expected to be minor because background gamma activity was determined on a subgrid-specific basis.

2.5.3 Number of Samples Collected

The total number of soil samples collected in areas where gamma anomalies were observed is quite large; however, in areas where gamma anomalies were not observed, soil samples were collected at a frequency of one sample per 2 acres. Therefore, the small number of samples collected in some areas introduces uncertainty which may over- or underestimate the types and amounts of radioisotopes present in soil. However, this factor is not a source of uncertainty in this risk assessment because soil data were not used for quantitative purposes.

In addition, the small number of groundwater samples collected at IR-02 introduces uncertainty which may underestimate the amount of radium-226 present in groundwater. However, since groundwater samples were collected in the most contaminated area and no evidence was found of radium-226 migration to groundwater, the uncertainty is expected to be minor. Groundwater data were not used for quantitative purposes in this risk assessment.

2.5.4 Trenching Location Selection

During the Phase II investigation, the locations chosen for excavating trenches and test pits were assumed to be representative of conditions throughout the disposal dump area. However, because of the extremely heterogeneous subsurface conditions at the disposal dump area, some uncertainty may be introduced which may over- or underestimate the number of subsurface radium-containing devices

present at the disposal dump area. The uncertainty is expected to be minor because many trenches and test pits were excavated throughout the disposal dump area at apparently representative locations. Data from the Phase II investigation were not used for quantitative purposes in this risk assessment.

2.5.5 Radon Uncertainty

Several uncertainties are associated with the radon data collected during the Phase I investigation. In general, the radon-222 data collected during this investigation are not considered conclusive for characterization or risk assessment purposes; these data were not used for quantitative purposes in this risk assessment.

One uncertainty associated with the radon data is related to the availability of radon for release. Radium-containing devices must have partially or totally decomposed to release radon to the environment. The number of radium-containing devices buried at the disposal dump area which have decomposed is unknown. Most devices encountered during the radiation investigations appeared to be intact. Additionally, the rate at which these devices are decomposing is unknown. Therefore, uncertainty associated with the physical state of the radium-containing devices may affect current and future estimates of the amount of radon and radium-226 present in the disposal dump area.

Another uncertainty associated with the radon data is related to representativeness of radon testing locations at the ground surface. It is possible that radon was not detected at the ground surface because the testing was not performed in locations where radium-containing devices were buried. Additionally, the heterogeneous nature of the fill material and the variability of soil compaction may have inhibited the migration of radon to the ground surface before the expiration of its short half-life.

2.5.6 Analytical Uncertainty

Uncertainty inherent in all analytical procedures may result in the over- or underestimation of the types and amounts of radioisotopes present in soil, groundwater, and air samples collected during the radiological investigations. However, since standard analytical protocols were used, this potential error is expected to be minor. Soil, groundwater, and air data were not used for quantitative purposes in this risk assessment.

3.0 EXPOSURE AND TOXICITY ASSESSMENT

This section presents methods used to estimate the types and magnitude of human exposure to radionuclides of potential concern present at or migrating from HPS Parcel E, specifically IR-01/21, IR-02 Northwest, IR-02 Central, IR-02 Southeast, and IR-11/14/15. This section also identifies the basis for the toxicity values used and the specific values used to quantify potential adverse effects associated with the radionuclides of potential concern and uncertainties associated with the exposure assessment and toxicity assessment. For consistency, the exposure and toxicity assessments in this radiation risk assessment report use the same general values as the chemical risk assessment presented in Appendix N of the Parcel E RI report.

3.1 EXPOSURE ASSESSMENT

This exposure assessment consists of three fundamental steps: (1) exposure setting characterization; (2) exposure pathway identification; and (3) exposure quantification. These steps are discussed briefly below and are presented in greater detail in Appendix N of the RI report (chemical human health risk assessment). Specifically, Section 3.1.1 characterizes the exposure setting with respect to the general physical characteristics of Parcel E and the characteristics of the human receptors at or near Parcel E. Much of this information is discussed in detail elsewhere in the RI report; therefore, Section 3.1.1 summarizes available information and refers the reader to appropriate sections of the RI report for more detail. Section 3.1.2 identifies and discusses the exposure pathways associated with Parcel E. Section 3.1.3 discusses the methods used to quantify exposures and presents the equations used to estimate intake associated with each complete exposure pathway.

3.1.1 Exposure Setting Characterization

The exposure setting consists of the physical setting of Parcel E and the populations which may reside in the future at or near Parcel E. Section 3.0 and Appendix N of the RI report describe the physical setting of Parcel E in detail, including climate, topography and surface water drainage, ecology, soils, geology and hydrogeology, and groundwater use and potential development at Parcel E. Rather than repeating this information, Section 3.1.1.1 focuses on the specific aspects of the current physical setting considered in the exposure assessment. Section 3.1.1.2 discusses exposure populations at or near

Parcel E under the future land-use scenarios. Section 3.1.1.3 discusses exposure areas related to this radiation risk assessment.

3.1.1.1 Physical Properties

As discussed in Section 1.3 of the RI report, HPS is situated on a long promontory located in the southeastern part of San Francisco, extending eastward into San Francisco Bay. The promontory is bounded on the north and east by San Francisco Bay and on the south and west by the Bayview Hunters Point district of San Francisco. Fences and locked gates surround HPS. Entrance to HPS is limited to the main gate. The on-base property at HPS consists of 493.47 acres of land, 135 acres of which make up Parcel E. Parcel E on-base property is bounded on the north by Parcel A, on the west and southwest by San Francisco Bay, and on the east by Parcel D.

Several physical properties associated with the radionuclide-contaminated area must be determined or assumed to perform the risk assessment using the RESRAD model, including contaminated zone parameters; cover and contaminated zone hydrogeologic data; and saturated zone hydrogeologic data (see Table P-2) (DOE 1993). For purposes of calculating exposure factors, to the extent practicable site-specific values of hydrogeologic and other parameters were used. Otherwise, RESRAD standard default values were adopted. For hydrogeologic parameters where site-specific data were unavailable, a model sensitivity analysis was performed and a health protective parameter was selected (see Attachment P5). For more information regarding Parcel E's geologic and hydrogeologic properties, see Section 3.0 of the RI report.

Contaminated zone parameters include area, thickness, and length parallel to aquifer flow of the contaminated zone and the amount of time since the radionuclides have been placed. As discussed in Section 2.3.2, the primary area of concern is the disposal dump area, which is approximately 250 feet by 400 feet (100,000 ft² or 9,290-square-meters [m²]) (PRC 1996a). For purposes of this radiation risk assessment, the contaminated zone used in the RESRAD was 1,000,000 m², the maximum value RESRAD allows and essentially assumes an infinite areal extent of contamination. Also discussed in Section 2.3.2, the subsurface distribution of radium-containing devices associated with these gamma anomalies was determined to be confined to a maximum depth of 9 feet bgs or 2.7 meters bgs

(PRC 1996a). For purposes of this radiation risk assessment, the thickness of the contaminated zone used was 10 feet bgs or 3 meters bgs to be consistent with the chemical human health risk assessment (see Appendix N). The length of contaminated zone parallel to aquifer flow used was 1,000 meters. The underlying aquifer was assumed to be a homogeneous horizontal aquifer the length of one side of the contaminated area of 1,000,000 m². As discussed in Section 2.1.1, historic records indicate that radium-containing devices were buried between 1960 and the early 1970s; therefore, the radionuclide placement parameter was assumed to be 30 years prior.

Cover and contaminant zone hydrogeologic parameters used are listed in Table P-2. The parameters that do not use RESRAD standard default values are discussed in this paragraph. The typical soil type at HPS varies from clay to gravel. Therefore, a default soil type of sandy loam that is intermediate in grain size between clay and gravel was assumed for the contaminated area. The RESRAD recommended values were used based on sandy loam type soil for soil density, zone B parameter, and runoff coefficient (DOE 1993). The total porosity, effective porosity, and evapotranspiration rate for the contaminated area of 0.34 (unitless), 0.3 (unitless), and 0.75 (unitless) were obtained from a HPS facility-wide hydrogeologic investigation (PRC 1994). A hydraulic conductivity of 1,450 meters/year is the 50th percentile of the 67 available Bouwer and Rice slug test results (PRC 1997). The annual precipitation rate in San Francisco is 0.547 meters/year (NWS 1997). Based on the future land uses at HPS (see Section 3.1.1.2), the likelihood of irrigation at Parcel E is unlikely; therefore, irrigation was assumed to be 0 meters/year. The maximum value allowed to be entered into the RESRAD model of 1,000,000 m² for the watershed area for a nearby water was assumed because of Parcel E's proximity to the San Francisco Bay.

Because radionuclides were not detected above background concentrations in groundwater at IR-02 sites (see Section 2.3.4), no contamination was assumed in the saturated zone. Nevertheless, as a health protective measure, the saturated zone is assumed to be present in the contaminated zone, and the parameters used for the cover and contaminated zone also were assumed for the saturated zone parameters. A well pumping rate of 0 cubic meters (m³)/year was assumed because it is unlikely that groundwater will be used as a drinking or irrigation water source (see Appendix N of the RI report). The nondispersion model was selected to be used for water/soil concentration calculations because mass

balance model is not recommended for contaminated zones with an area greater than 1,000 m² (DOE 1993).

Distribution coefficients and leach rate constants used are listed in Table P-2. The contaminated zone distribution coefficients for radium-226 and lead-210 used were based on the default soil type of sandy loam. No contamination in the saturated zone is assumed; therefore, distribution coefficients of radium-226 and lead-210 were assumed to be 0. The leach rate and solubilities for radium-226 and lead-210 are calculated based on the distribution coefficients for the contaminated zone (DOE 1993).

3.1.1.2 Exposure Populations

Current land-use scenarios are not evaluated in the radiation risk assessment because IR-01/21, IR-02 Northwest, IR-02 Central, IR-02 Southeast, and IR-11/14/15 are currently not used for any purposes and these areas and much of Parcel E is fenced off from the rest of HPS. Portions of Parcel E with acceptable risk levels under the future industrial land-use scenario would have acceptable risk levels under the current industrial land-use scenario.

Potentially exposed populations under the future land-use scenarios are identified as those considered in the proposed draft reuse plan. The proposed draft reuse plan as of November 26, 1996 for IR-01/21, IR-02 Northwest, IR-02 Central, IR-02 Southeast, and IR-11/14/15 of Parcel E include the following future land-use scenarios: open space, business park and research and development, industrial, and maritime activities (SFRA 1996).

At this time, it is uncertain whether the SFRA reuse plan will be implemented as proposed. This radiation risk assessment therefore evaluates exposures only under the future residential and industrial land-use scenarios. The evaluation of exposures and risks to child and adult residents is health-protective because the residential land-use scenario assumes unrestricted land use. Unrestricted land-use scenario assumes that the resident is in frequent, repeated contact with the contaminated media and generally results in an unlikely maximum potential exposure to radionuclides.

Portions of Parcel E having acceptable risk levels under the residential land-use scenario would probably have acceptable risk levels under more restricted land-use due to lower exposure duration and

unlikelihood of visitors and recreationalists consuming homegrown produce at the rate assumed in this risk assessment. The light industrial land-use scenario represents a reasonable future scenario associated with less exposure to radionuclides than residential land use. Evaluating both the residential and light industrial land-use scenarios will therefore provide risk managers with a range of potential exposure cases and should allow a qualitative evaluation of risks associated with other potential land uses.

3.1.1.3 Exposure Areas

For the purposes of this radiation risk assessment, Parcel E is divided into approximately 0.5-acre exposure areas measuring 150 feet by 150 feet for the industrial land-use scenario and is divided into 2,500-ft² exposure areas measuring 50 feet by 50 feet for the residential land-use scenario. For the radiation risk assessment, a grid composed of 0.5-acre exposure area cells was placed over all of Parcel E regardless of IR site status or other boundaries resulting from previous environmental investigations. Each 0.5-acre cell is further divided into nine cells to represent the 2,500-ft² exposure areas. These exposure areas match the exposure areas used to evaluate the human health risk assessment conducted for chemical contaminants. Potential soil-specific EPCs within each exposure area were used to represent exposure concentrations to the radionuclides of potential concern present throughout the exposure area.

As discussed in Appendix N, an exposure area of 2,500 ft² under the residential land-use scenario was used because this area is the minimum residential lot size for a single-family home in San Francisco, California (CCSF 1995). The 0.5-acre cell size is a reasonable estimate of the size of a light industrial business lot located in the San Francisco Bay area.

3.1.2 Exposure Pathways

A conceptual site model (CSM) was developed to describe probable or actual exposure pathways of radionuclides from Parcel E sources to exposure points (see Figure P-4). An exposure pathway can be characterized by four fundamental steps: (1) identifying a source and mechanism of radionuclide release, (2) identifying an affected medium and probable contaminant migration process, (3) identifying an exposure point, and (4) determining an EPC. These steps are discussed in the following sections.

3.1.2.1 Sources and Mechanism of Release

The sources and mechanism of radionuclide release to the environment at Parcel E are discussed in detail in Section 2.0 of this radiation risk assessment. The following paragraphs briefly summarize the sources of release of the radionuclides.

IR-01/21

During the Phase I radiation investigation, a cluster of elevated gamma readings was observed in the southwestern portion of the site. In addition, elevated gamma readings were observed at two scattered locations in the western portion of IR-01/21 just north of the cluster. Three radium-containing devices were removed from surface soil collected during the Phase I investigation. Only one of 26 surface soil samples collected at IR-01/21 contained radium-226 at a concentration above background; this sample was collected near the cluster of elevated gamma readings. Radon-222 testing was performed at 158 locations at IR-01/21; radon-222 was not detected above background levels except at two locations directly above visible radium-containing devices.

During the Phase II radiation investigation, elevated gamma readings were not observed in any of the six test pits excavated at IR-01/21 and radium-containing devices were not encountered in subsurface soil at IR-01/21.

IR-02 Northwest

During the Phase I radiation investigation, more than 300 elevated gamma readings were observed in an area at IR-02 Northwest that extended about 50 feet across the site boundary into IR-02 Central. This area was about 600 feet by 600 feet and corresponded to the location of the former Navy disposal dump area. Radium-containing devices were removed from many surface soil samples collected during the Phase I investigation. Thirteen of 46 soil samples collected at IR-02 Northwest contained radium-226 at concentrations above background; these samples were collected from the area where elevated gamma readings were detected. Radon-222 testing was performed at 91 locations at IR-02 Northwest; radon-222 was not detected above background levels except at locations directly above visible radium-containing devices.

During the Phase II radiation investigation, approximately 111 elevated gamma readings were observed in the subsurface at the disposal dump area at IR-02 Northwest. The subsurface distribution of radium-containing devices associated with these elevated gamma readings was confined to an area of approximately 250 feet by 400 feet to a maximum depth of 9 feet bgs. The eastern portion of this area extended about 50 feet into IR-02 Central. Ninety percent of the point sources found at the disposal dump area during the Phase II investigation were located in the uppermost 6.5 feet of soil; no sources were located below the Artificial Fill/Bay Mud surface contact.

IR-02 Central

During the Phase I radiation investigation, a cluster of elevated gamma readings were observed along the southwestern boundary of the site near IR-02 Northwest. In addition, one elevated gamma reading was observed at the northwest corner of the Building 600 parking lot and one elevated gamma reading was observed in the eastern portion of the site near the boundary of IR-03. Seventeen surface soil samples were collected at IR-02 Central; none of these samples contained radium-226 at a concentration above background. Radon-222 testing was performed at eight locations at IR-02 Central; radon-222 was not detected above background levels.

During the Phase II radiation investigation, elevated gamma readings were observed in the uppermost 1 foot of soil in seven test pits and a portion of a trench excavated at IR-02 Central. The subsurface locations of radium-containing devices associated with these elevated gamma readings comprise the eastern boundary of the disposal dump area located primarily in IR-02 Northwest.

IR-02 Southeast

During the Phase I radiation investigation, elevated gamma readings were observed at one location in the former burn area and at five locations near Berth 36. Radium-containing devices were not found at IR-02 Southeast. Two of six soil samples collected at IR-02 Southeast contained radium-226 at concentrations above background; these samples were collected from the area near Berth 36 where elevated gamma readings were detected. Radon-222 testing was not performed within the extended site boundaries of IR-02 Southeast. Radium-containing soil may have been inadvertently transported to

IR-02 Southeast from the disposal dump area in IR-02 Northwest during the movement of construction and industrial materials around Parcel E.

IR-11/14/15

During the Phase III radiation investigation, one elevated gamma reading was observed between Buildings 520 and 529. The location of this anomaly was excavated to a depth of 1 foot bgs; gamma activity increased with depth. These findings indicate the possible presence of a buried radium-containing device.

3.1.2.2 Affected Media and Probable Migration Process

As determined through review of analytical data, the radionuclides were primarily released into Parcel E surface and subsurface soil at the disposal dump area. Analytical results do not indicate that radionuclides are present in groundwater at levels above background.

Probable migration processes of radionuclides are discussed based on site characterization information and knowledge of the chemical and physical properties of both the environmental media and radionuclides identified at Parcel E. These probable migration processes are summarized below (DOE 1993).

- Radionuclides in soil emit gamma radiation
- Radionuclides in soil migrate to air through resuspension
- Radionuclides decay and may migrate through air as radon gas
- Plants roots may uptake radionuclides present in soil

The fate and transport processes of the radionuclides of potential concern (radium-226, lead-210, and radon-222) are discussed in the following paragraphs.

Radium-226

The small amount of radium-226 naturally present in soils is the result of radioactive decay of uranium-238 of primordial origin in soil. Radium is geochemically similar to the other alkaline-earth

elements, with a +2 oxidation state over the normal soil pH range (4 to 8). Radium-226 has a half-life of 1,602 years.

In association with particulate matter, radium-226 may be transported in the atmosphere. Readily absorbed by sediments and soils, radium-226 is not a readily mobile constituent in the environment (Benes and Others 1986). The solubility of radium salts in water increases with increased pH levels (Langmuir and Riese 1985). However, radium-226 exists primarily as a stable divalent ion in water, and its concentration is usually controlled by adsorption-desorption mechanisms at solid liquid interfaces and by the solubility of radium-containing devices (ATSDR 1990). Radium distribution coefficients (k_d) range from 467 to 214 milliliters per gram indicating that it is fairly soluble in water and, therefore, mobile in infiltrating precipitation. Radium-226 does not hydrolyze, nor is it significantly influenced by oxidation-reduction reactions (Ames and Rai 1978). Radium shows little tendency to form complex species and would be expected to substitute for other divalent cations during replacement or precipitation reactions. Leaching studies with different types of competing cations suggest that an important reaction mechanism for radium adsorption is cation exchange. Radium could be expected to migrate slowly into the soil column by leaching. As a result, radium-226 is not expected to migrate significantly from its point of origin since its potential release between 1960 and early 1970's.

Lead-210

Lead is present in various igneous and sedimentary rocks. Lead-210 results from decay of radium-226 and has a half-life of 22.6 years. It is the only naturally occurring radioactive lead isotope that is stable for periods longer than minutes or hours.

Lead is a heavy metal that exists in one of three oxidation states, 0, +2, or +4. Neither metallic lead nor the common lead minerals is soluble in water. Therefore, natural compounds of lead are not usually mobile in normal soil or groundwater because the lead becomes sorbed by ferric hydroxide or manganese oxides, or tends to combine with carbonate or sulfate ions to form insoluble compounds.

Radon-222

At atmospheric pressures and temperatures, radon exists as gas. Radon is often found in groundwater because as a gas it is quite soluble in water. Radon dissolves into groundwater as it is formed by radioactive decay. The variability of radon content in groundwater may be related to residence time in the rock, distance from source, and characteristics of the rock (for example, porosity and grain size).

Radon is a water-soluble noble (inert) gas that does not participate in any physiochemical reactions with geologic media. Radon has a solubility in water of about 0.5 grams per liter at standard temperature and pressure.

3.1.2.3 Exposure Points

An exposure point is defined as a location where receptors may potentially be exposed to radionuclides in a particular medium or media. A location is an exposure point if a human receptor might, in the present or future, be exposed to radionuclides from an environmental medium or media. Exposure pathways are potentially complete where exposure points are located as identified in the CSM (see Figure P-4). Exposure points and exposure routes under the future residential and industrial land-use scenarios at Parcel E are discussed in the following paragraphs.

Under the future residential land-use scenario, adult and child residents are assumed to be exposed to radionuclides in soil through the following:

- Direct external exposure to penetrating radiation from radionuclides in soil
- Internal exposure through inhalation of airborne radionuclides
- Internal exposure through inhalation of radon (emanating from radium in soil) and radon decay products
- Internal exposure through ingestion of homegrown produce (fruits and vegetables) contaminated by radionuclides in the soil
- Internal exposure through incidental ingestion of radionuclides in soil

Under the future residential land-use scenario, individuals are assumed to live on site and be exposed chronically to residual concentrations of radionuclides through the above-mentioned exposure pathways. The exposure points and exposure routes evaluated under the future residential scenario are conservative or health-protective because they assume exposure pathways similar to those of single family homes; however, SFRA's proposed draft reuse plan for Parcel E indicates that any residential housing will likely be located above businesses as lofts. The exposure points and routes in this radiation risk assessment assume contact with and ingestion of shallow and deep soil and ingestion of produce grown in site soils. Although produce is not currently grown at HPS, future homegrown produce can become contaminated through (1) uptake of radionuclides of potential concern in soil through plant root systems, (2) absorption of radionuclides of potential concern through the deposition of fugitive dust on exposed plant surfaces, and (3) absorption of radionuclides of potential concern through exposed surfaces and root systems as a result of irrigation with water containing radionuclides of potential concern. However, despite the low likelihood of growing produce in Parcel E, ingestion of homegrown produce by future residents is evaluated in the radiation risk assessment (see Appendix N for a complete discussion).

Under the future industrial land-use scenario, adult workers are assumed to be exposed to radionuclides in soil through the following:

- Direct external exposure to penetrating radiation from radionuclides in soil
- Internal exposure through inhalation of airborne radionuclides
- Internal exposure through inhalation of radon and radon decay products emanating from radium in soil
- Internal exposure through incidental ingestion of radionuclides in soil

The future industrial scenario addresses long-term exposure and risks to workers exposed daily to residual levels of radionuclides in soil during an average 8-hour workday, on site, both indoors and outdoors.

Exposure to radionuclides can also occur through secondary sources from locations other than the disposal dump area, such as runoff from nearby sources, or windblown deposition. In general, the

radiation dose resulting from these secondary sources is negligibly small compared with the dose resulting from direct exposure to the primary source through external exposure, inhalation, or ingestion (DOE 1993). Air sampling for gross alpha and gross beta radioactivity was performed to establish the concentration of airborne radioactive particulates at Parcel E. Elevated gross alpha or gross beta radioactivity were not detected in the air samples collected within and surrounding Parcel E (PRC 1992); however, this pathway is evaluated in the radiation risk assessment. In addition, radionuclides were not detected in groundwater at concentrations above background at Parcel E and, as discussed in Appendix N of the RI report, groundwater beneath Parcel E is not currently used as a source of potable drinking water or for any industrial purposes and is unlikely to be in the future. Therefore, these secondary sources are not evaluated in this radiation risk assessment.

Radon flux testing was performed at selected locations at and around areas where gamma anomalies were observed to assess the presence of radon gas. Elevated levels of radon gas were observed at locations where canisters were placed directly over radium-containing devices present at the ground surface; radon gas was not detected at locations where radium-containing devices were not visible (PRC 1992). It is likely that structures built in the areas of concern would use design and construction features that mitigate exposures to indoor radon; therefore, exposure to radon through inhalation of radon buildup in indoor air is evaluated separately from the internal and external exposure pathways discussed above.

3.1.2.4 Exposure Point Concentrations

The EPC is defined as the concentration of a radionuclide that a human receptor is exposed to at an exposure point. A review of existing data and information indicate that almost all of the radium-226 contamination is associated with discrete point sources found in the disposal dump area. EPCs in soil under the RME and average exposure cases were estimated from data pertaining to the distribution and frequency of anomalies identified during the Phase I and Phase III radiation investigations.

EPCs in Soil

Radionuclides at Parcel E are associated with the radium-containing devices and, due to the low mobility of the radionuclides because of the source form and geochemical properties of radium-226, are

likely to be located either within the source or near the source depending on source construction and other physical characteristics such as damage and weathering. In general, random soil sampling in Parcel E detected only background levels of radium-226. Data from biased sampling were not used because they would likely overestimate overall soil concentrations. Therefore, the radionuclide concentration in soil was estimated from 30-foot by 30-foot subgrids mapped during the Phase I investigation and data collected from Phase III investigation at IR-11/14/15; the number of gamma anomalies found in each subgrid was documented. For purposes of estimating risk for future land-use scenarios, determination of EPCs involves two primary steps: (1) quantifying the number of anomalies for each residential and industrial exposure area observed during the Phase I and III radiation investigations, and (2) converting the number of anomalies in each exposure area to uniform soil concentrations of radium-226. EPCs are expressed as activity per unit mass or specific activity (EPA 1989).

The first step in determining the EPC was to quantify the relative number of anomalies for each exposure area. The number of anomalies is based on results of the Phase I and III investigations that evaluated radioactive anomalies associated with buried radium-containing devices. Navy data indicate that anomalies have a range of activity, but the activity level of specific anomalies was not determined. Therefore, a nominal activity level of 1 μCi or 1×10^6 picoCuries (pCi) was used. A μCi is equivalent to the decay rate of 1 microgram (μg) of radium-226 (EPA 1989). During the Phase I investigation, the instrumentation used for the surface walkover survey generally detected activity levels of at least 1 μCi to a depth of 1.5 feet bgs. As a conservative assumption, all anomalies detected were assumed to exist in the top 1 foot of soil, rather than the top 1.5 feet.

Under the future residential land-use scenario, all anomalies detected during the Phase I and Phase III investigation in each 30-foot by 30-foot subgrid were transcribed to the 2,500-ft² residential exposure areas (see Figure P-5). Under the future residential scenario, RME case, all anomalies identified in all 30-foot by 30-foot subgrids found totally, or partially, within the 2,500-ft² residential exposure area are assumed to contribute to the estimated EPCs. Under the future residential scenario, average exposure case, EPCs are based on the fraction of each 30-foot by 30-foot subgrid that is within the 2,500-ft² exposure area. For example, residential exposure area 056109 encompasses one whole 30-foot by 30-foot Phase I subgrid (containing six sources) and eight portions of other 30-foot by 30-foot Phase I

subgrids (containing one, one, two, two, two, three, four, and five sources). For the RME case, the number of anomalies is based on all the point sources within the nine affected subgrids for a total of 26 sources. The number of anomalies in an average exposure case is based on the number of anomalies found within the one full Phase I subgrid (containing six sources), and the percentage of area multiplied by the number of anomalies found within the remaining eight exposure areas (for example, 32 percent of the area of a subgrid containing one anomaly would equal 0.32 of an anomaly; 37 percent of the area of a subgrid containing five anomalies would equal 1.87 anomalies) for a grand total of 9.9 anomalies for exposure area 056109 under the average exposure case. This approach is health protective because the RME case results in some double-counting where the subgrids contact more than one residential exposure area. The number of anomalies for each residential exposure area under the RME and average exposure cases are listed in Table P-3. The number of anomalies listed in Table P-3 is assumed for the top 1 foot and each 1 foot interval to a depth of 10 feet bgs.

Under the future industrial land-use scenario, the 30-foot by 30-foot subgrids were transcribed to the 0.5-acre (or 22,500-ft²) exposure areas (see Figure P-5). The methodology used under the future residential land-use scenario described above is also applied to the industrial scenario, with the exception of a 0.5-acre exposure area that was used instead of the 2,500-ft² exposure area. The source term for each industrial exposure area is listed in Table P-4.

The second step in determining the EPC involved converting the number of anomalies per exposure area into soil concentrations of radium-226. The following assumptions were used in the conversion:

- All anomalies identified in the Phase I investigation were assumed to be radium-226 anomalies with an activity level of 1 μCi .
- Soil density is assumed to be 1.44 grams per cubic centimeter (g/cm^3) which is the RESRAD standard default value for a soil type of sandy loam.

The following equation was used to convert the number of anomalies to the EPC:

$$EPC_{\text{soil}} = \frac{N_{\text{anomaly}} \times C_{\text{anomaly}}}{V_{\text{soil}} \times SD \times CF} \quad (\text{Equation 3-1})$$

where

EPC_{soil}	=	Exposure point concentration in soil (pCi/g)
N_{anomaly}	=	Number of anomalies (unitless)
C_{anomaly}	=	Concentration per anomaly (1 μ Ci or 1×10^6 pCi)
V_{soil}	=	Volume of soil (residential - 2,500 ft ³ ; industrial - 22,500 ft ³)
SD	=	Soil density (1.44 g/cm ³)
CF	=	Conversion factor (2.83×10^4 cm ³ /ft ³)

The EPCs for one anomaly for the future residential and industrial land-use scenarios were calculated to be 0.0098 and 0.0011 pCi/g, respectively. To simplify extrapolations of EPC, values of 0.01 and 0.001 pCi/g were used for future residential and industrial land-use scenarios, respectively.

Radionuclide EPCs in soil for RME and average exposure cases are presented in Tables P-3 and P-4 for the future residential and industrial land-use scenarios, respectively.

EPCs in Homegrown Produce

Direct measurements of radionuclide concentrations in homegrown produce or other types of vegetation are unavailable for Parcel E because produce is currently not grown at HPS. As discussed in Section 3.1.2.3, homegrown produce can become contaminated through a variety of mechanisms. This radiation risk assessment assumes that the uptake of radionuclides of potential concern from soil to homegrown produce is the primary mechanism by which radionuclides of potential concern in soil may migrate into produce growing at Parcel E; therefore, EPCs for homegrown produce are derived based on radionuclide concentrations in soil and soil-to-plant uptake factors. The mechanism of uptake addressed in this assessment is root uptake of radionuclides from soil and translocation of contaminants to edible plant parts. This uptake is modeled using the following equation:

$$EPC_{\text{produce}i} = C_{\text{soil}i} \times UF_i \quad (\text{Equation 3-2})$$

where

- $EPC_{\text{produce}i}$ = EPC of contaminant in produce
(pCi of radionuclide per g of plant wet weight)
- $C_{\text{soil}i}$ = Concentration of contaminant in soil
(mg of contaminant per kg of plant dry weight)
- UF_i = Uptake factor for contaminant from soil into plants
([mg of contaminant per kg of plant wet weight] \times [mg of contaminant per kg of soil dry weight]⁻¹); a conversion factor of 0.174 is used to convert from plant dry weight to plant wet weight

The soil-to-plant concentration factors were converted from a dry weight to a wet-weight basis by multiplying soil-to-plant concentration factor by a conversion factor reflecting the ratio of the dry weight of produce to the wet weight of the same produce. The DOE presents conversion factors for a variety of different fruits and vegetables (DOE 1984). Produce (including apples, sweet peppers, squash, and tomatoes) with edible surfaces exposed to the atmosphere has an average dry weight-to-wet weight ratio of 0.126. Protected produce, including carrots, oranges, potatoes, and watermelons, with edible surfaces that either develop below ground or are protected by coverings, have an average dry weight-to-wet weight ratio of 0.222. Because residents at Parcel E may grow both exposed and protected produce in their gardens, a conversion factor was calculated as the average of the factors for exposed and protected produce, or 0.174. Soil-to-plant concentration factors reported by NRC (NRC 1993) were multiplied by 0.174 to convert them to a wet-weight basis. The table below presents the converted uptake factors used to calculate the concentration of each metal in homegrown produce.

Radionuclide	Soil-to-Plant Concentration Factors (pCi/g wet weight per pCi/g Soil)		
	Leafy Vegetables	Nonleafy Vegetables	Fruit
Radium-226	1.3×10^{-2}	5.6×10^{-4}	1.1×10^{-3}
Lead-210	1.0×10^{-3}	5.6×10^{-4}	1.6×10^{-3}

Notes:

pCi picoCurie
g Gram

Radionuclide uptake from soil is a complex process only partially described by the equations above. Factors affecting this process include the site-specific geochemistry of the soil, the type of plant and its metabolic requirements, and the plant part ingested (radionuclides are not typically distributed uniformly throughout the plant). For purposes of this radiation risk assessment, geologic and hydrogeologic parameters affecting the ingestion of homegrown produce pathway of exposure are presented in Table P-2. Other parameters required by the RESRAD model are presented in the following table.

Parameter	Value
Depth of Roots (m)	0.15 ^a
Storage times/use of fruits and vegetables (day)	1 ^a

Notes:

m Meters

a RESRAD standard default value

Preparation and cooking methods may significantly alter radionuclide concentrations in cooked produce compared to concentrations in uncooked produce. Soil amendment, such as addition of topsoil or use of imported soil, is also not considered in deriving the EPC. For these reasons, the uncertainty associated with the estimated EPCs in produce is very high; however, in the absence of site-specific data, the model discussed above provides a crude estimate of EPCs in produce that can then be used to provide some indication of the potential health effects associated with the ingestion of homegrown produce grown in Parcel E soil. For these reasons, the radiation risk assessment for the ingestion of homegrown produce is considered conservative or health-protective.

3.1.3 Exposure Quantification

Exposure intake equations consider contact rate and frequency and duration of exposure to estimate the intake of each radionuclide to the receptor. Exposure intakes were calculated for the RME case, which is the highest exposure reasonably expected to occur, and for the average exposure case, which is the most likely (average) exposure expected to occur.

An exposure can occur over a period of time. Exposures quantified in this radiation risk assessment for inhalation, ingestion of radionuclides in soil, and ingestion of radionuclides in homegrown produce are presented in units of pCi, and are termed "intakes". Exposures quantified in this radiation risk assessment for the external gamma radiation are presented in pCi/m². Equation 3-2 presents a generic equation for calculating chemical intake as follows (EPA 1989):

$$I = C \times CR \times EF \times ED \quad \text{(Equation 3-2)}$$

where

- I = Intake for inhalation and ingestion: the amount of radionuclides at the exchange boundary; to evaluate exposure to carcinogenic radionuclides, the intake is referred to as lifetime total dose (LTD). Intake for external exposure is evaluated slightly different (see Table P-5).
- C = Radionuclide concentration: the average concentration (EPC) contacted over the exposure period (for example, pCi/g for soil)
- CR = Contact rate: the amount of contaminated medium contacted per unit of time or event (for example, pCi/day for soil)
- EF = Exposure frequency: how often the exposure occurs (days/year)
- ED = Exposure duration: how long the exposure occurs (years)

Variations of Equation 3-2 used to calculate pathway-specific exposures to radionuclides of potential concern are presented in Tables P-5 through P-8. However, because RESRAD varies the EPC_{soil} based on modeling of geologic and hydrogeologic parameters, and radioactive ingrowth and decay, the results of RESRAD cannot be exactly reproduced using the equations presented in Tables P-5 through P-8. The exposure dose equations for non-produce and produce are discussed in the following subsection.

3.1.3.1 Non-Produce Exposure Dose Equation

Exposures were evaluated under both RME and average exposure cases. The exposure parameter values for the RME case are the same as those used to derive the EPA Region IX PRGs (EPA 1995b). The exposure parameter values for the average exposure case were obtained from EPA's "Superfund Standard Default Exposure Factors for Central Tendency and Reasonable Maximum Exposures" (EPA 1993); "Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous

Waste Sites and Permitted Facilities" (DTSC 1992); or the "Exposure Factors Handbook" (EPA 1995c). The RME values from EPA Region IX PRGs are generally consistent with DTSC and EPA guidance. Using the adult and child parameters, age-adjusted exposure parameters for the residential land-use scenario were derived (see Tables P-5 through P-7).

3.1.3.2 Produce Exposure Dose Equation

Exposure through ingestion of homegrown produce is not addressed in the equations for deriving the EPA Region IX PRGs (EPA 1995b). The produce consumption rates, which are unique to this pathway, are based on EPA guidance as discussed in the following paragraphs.

EPA recommendations on consumption rates for homegrown fruits and vegetables are based on two sources: "Foods Commonly Eaten by Individuals: Amount Per Day and Per Eating Occasion" (Pao and Others 1982) and "Food Consumption: Households in the United States, Seasons and Years 1977 - 1978" (USDA 1983). Based on information provided in these sources, EPA estimates that for adults, the average consumption rate of vegetables is 200 g/day, with homegrown vegetables accounting for approximately 25 percent of the total consumption (50 g/day). The average daily homegrown fruit consumption rate is 140 g/day, with homegrown fruits accounting for approximately 20 percent of the total consumption (28 g/day). Under the RME case, EPA suggests using 40 percent of the total intake for homegrown vegetable consumption and using 30 percent of the total intake for homegrown fruit consumption. Further, the NRC estimates that 17.7 percent and 82.3 percent of the total vegetable intake are leafy and nonleafy vegetable consumption rates, respectively (NRC 1993). These recommendations are summarized in Table P-8.

Recommendations of homegrown fruit and vegetable consumption rates for children cannot be estimated based on EPA guidance; however, average fruit and vegetable consumption rates for children 5 years of age and under are provided in EPA's Exposure Factors Handbook (EPA 1995c). This age group most closely corresponds to the age group addressed in this radiation risk assessment for the child resident (0 to 6 years of age). The total daily consumption rates for this group are 157 g/day for fruits and 81 g/day for vegetables. The daily homegrown consumption rates can be estimated by assuming the same homegrown fractions as for adults. The recommendations for the ratio of leafy and

nonleafy vegetable intake rate applied to the adult residential land-use scenario were also applied to the child residential land-use scenario. The homegrown produce rates for the residential child under the RME and average exposure cases are shown in Table P-8. Using the adult and child parameters, age-adjusted exposure parameters for the residential land-use scenario were derived (see Table P-8).

3.2 TOXICITY ASSESSMENT

This section identifies the toxicity values quantifying potential adverse effects to human health associated with exposure to the radionuclides of potential concern at Parcel E. The adverse health effects of any radionuclide depend on where the nuclide is located when it decays and on the type and energy of the radiation emitted. The distribution of an ingested nuclide within the body depends on its chemistry, which is essentially identical to nonradioactive isotopes of the same element. The decay pattern is a property of the radionuclide itself. EPA assigns weight-of-evidence designations to indicate the likelihood that a chemical or physical agent is a carcinogen in humans (EPA 1989). All radionuclides are considered Group "A" carcinogens (proven human carcinogens), based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of radiogenic cancers in humans (EPA 1995a). Effects of radiation doses at environmental concentrations are considered stochastic (the probability of effect is proportional to dose).

For almost all radionuclides, the only significant adverse effect from chronic exposure is the increased risk of induction of radiogenic cancer by the emitted ionizing radiation. A few radionuclides, such as uranium-238, the predominant isotope in natural uranium, also have significant chronic noncarcinogenic toxicities as chemical effects of the radionuclides. The toxicity values for assessing carcinogenic risk are presented in Section 3.2.1. Section 3.2.2 discusses the toxicity profiles for radionuclides of potential concern at Parcel E.

3.2.1 Toxicity Values for Assessing Carcinogenic Risk

The toxicity values used to convert intake to carcinogenic risk are SFs. When combined with site-specific media concentration data and appropriate exposure assumptions discussed in Section 3.1, ELCRs can be calculated as the product of SF and intake. Radionuclide SFs are central tendency

estimates in a linear model of the age-averaged, attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested for uniform exposure over a lifetime, expressed as risk/pCi. External exposure SFs are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/year per pCi/gram of soil (EPA 1995a).

SFs are specific to a radionuclide and route of exposure and are generally available for external exposure, inhalation, and ingestion. SFs for radionuclides of potential concern were obtained from Health Effects Assessment Summary Tables (EPA 1995a).

Radionuclide^a	External Gamma Slope Factor (risk/year per pCi/g)	Inhalation Slope Factor (risk/pCi)	Oral Slope Factor (risk/pCi)
Radium-226 +D	6.7E-06	2.8E-09	3.0E-10
Lead-210 +D	1.5E-10	3.9E-09	1.0E-09
Radon-222 +D	--	7.6E-12	--

Notes:

g gram

pCi picoCurie

a Radionuclides with the suffix "+D" indicate that cancer risk estimates for these radionuclides include contributions from their short-lived decay products, assuming equal activity concentrations (that is, secular equilibrium) with the parent nuclide in the environment (EPA 1995a).

-- Not applicable

3.2.2 Toxicity Profiles

Radionuclides are isotopes whose nuclei undergo a spontaneous reaction to form another isotope. That daughter isotope may also be radioactive and react further, continuing the process until a stable (nonradioactive) nuclide is reached. This transmutation process, called radioactive decay (or decay chain in the case of a series of decays), releases extremely large amounts (by chemical reaction standards) of energy, which appear as ionizing radiation. When that radiation interacts with matter, including tissue, it produces many ions and may alter or destroy the molecules with which it reacts and

produce toxic reaction products. The adverse effects of different types of ionizing radiation on a given tissue depend on the energy, dose rate, and spatial rate of energy transfer.

There are three important types of ionizing radiation: alpha, beta, and gamma. Alpha radiation is a particulate consisting of helium nuclei and originates from decay of uranium, thorium, radium, and other metals with high atomic number nuclei. Generally, alpha particles only travel very short distances; however, it can only travel only a few micrometers through solid matter. Alpha particles may cause severe disruption of the matter. Beta particles are electrons and can travel as much as one centimeter through typical solid matter. Since their energy is transferred through a much greater amount of matter, the damage is less intensive. Gamma rays are massless photons; once emitted, they are indistinguishable from X-rays, which originate in the electron shells of atoms rather than in the nuclei. Gamma rays have still greater penetration and therefore cause still less intensive, but more extensive, damage to matter. The nuclear decay processes at this site do not release neutrons. The following section discusses the toxicity profiles of radium-226, lead-210, and radon-222.

3.2.2.1 Radium-226

Radium-226, a daughter of uranium-238, is the most common radium isotope (Eisenbud 1987; Budavari 1996). It is found in all uranium deposits and has been used in treatment of certain cancers; most commonly, "needles" containing radium-226 or other isotopes are inserted in the target area and the radiation released by the isotope and its short-lived daughters (radon-222 and its daughters; see Section 3.2.2.3 for radon's toxicity profile) destroys the adjacent tissue. It has been also used as a source of gamma rays to substitute for X-rays in materials testing. Former uses include as a quack medicine and as an energy source in luminous paints for clocks, instruments, and similar items. Studies of workers who applied radium paint (and often licked the brush to get a better point) have provided much knowledge of the adverse effects of radium-226 and its daughters.

Commercial radium-226 is chemically pure or, more commonly, mixed with barium as a carrier. Radium-226 decays with a half-life of 1602 years to radon-222. Since radon-222 has a half-life of only 3.8 days, "in-growth" of its daughters is completed rapidly. By 3 years after the original purification, an undisturbed sample of radium-226 will contain all daughters through lead-210 in essentially identical

activities (in terms of curies per mass), a situation called "secular equilibrium". While the risk from radium-226 itself is essentially limited to ingestion because of the very short range of the alpha particle, environmental sources will present significant direct exposure risks due to gamma rays from such daughters as lead-214 and thallium-210.

The chemistry of radium is almost identical to that of barium, and therefore similar to that of calcium. Therefore, ingested or inhaled radium is deposited in the bones. Bone-associated cancers, including leukemia originating in bone marrow as well as bone tumors like osteogenic sarcomas, are the principal adverse effects of radium-226. Much of the daughter radon-222 is exhaled before it decays, but some remains inside the body (see Section 3.2.2.3 for radon-222 toxicity profile)

3.2.2.2 Lead-210

Lead-210 is the last relatively long-lived daughter of uranium-238, with a half-life of 22 years (Eisenbud 1987; Budavari 1996) and decays to stable lead-206. Lead-210 is used as a beta source for a few therapeutic applications, primarily in ophthalmology.

Ingested (or inhaled) lead-210 will be deposited in bone, where its primary toxic effect will be radiation-induced, bone-associated cancers. The gamma rays produced in small amounts by lead-210 and some of its daughters mean that environmental exposures also present a small external exposure risk.

3.2.2.3 Radon-222

Radon-222, the daughter of radium-226, is the longest-lived radon isotope, with a half-life of 3.82 days (Eisenbud 1987; Budavari 1996). It has been used as a radiation source for cancer therapy and in a number of chemical and physical applications.

Because it is an inert, noble gas, radon-222 is highly mobile. Exposure to radon-222 involves exposure to all daughters through lead-210, which include alpha, beta, and gamma emitters. Exposure to old sources of radon-222 also involve significant exposure to the daughters of lead-210 as discussed in Section 3.2.2.2. While exposure to purified radon-222 would present solely an inhalation risk,

exposure to environmental radon-222 also involves significant ingestion and external exposure risks from the daughters.

3.3 EXPOSURE AND TOXICITY ASSESSMENT UNCERTAINTIES

Uncertainties in the exposure assessment result from (1) the selection of exposure pathways, (2) the selection of exposure parameters used to estimate chemical intake, (3) the assumption of no soil amendment, and (4) the modeling assumptions and modeling process. The degree of uncertainty generally depends on the amount of site-specific data available. Uncertainties exist in the toxicity assessment as a result of the methodology used to quantify various toxicological effects and difficulties encountered in identifying the toxicological effects of radionuclides of potential concern. In some instances, these uncertainties may result in overestimation of risk, and in others, risk may be underestimated. Sources of uncertainty are discussed in the following sections.

3.3.1 Selection of Exposure Pathways

Exposure pathways for this radiation risk assessment were identified based on observed and assumed activity patterns of future Parcel E receptors. To the degree that actual activity patterns are not represented by the patterns observed and assumed, uncertainty is introduced into this radiation risk assessment.

Uncertainty is associated with the future land-use scenario because the activity patterns of future child and adult residents are estimated based on future land-use assumptions. Future land-use assumptions present the biggest area of uncertainty because deed restrictions or remediation prior to future development may be imposed; thus, exposure estimates developed under the future land-use scenario may not be consistent with actual future land use. Furthermore, the possibility that all of Parcel E will be developed for residential purposes is extremely remote. Certain areas that may become residential developments are likely to be preferentially located in areas known to be uncontaminated. Also, existing development patterns for similar real estate in the HPS area indicate multifamily housing with minimal space for growing produce in housing lots. Risk estimates developed considering residential exposures, including those resulting from ingestion of homegrown produce, are therefore expected to represent the high end of the risk ranges.

3.3.2 Selection of Exposure Parameters

Standard exposure parameter assumptions for population characteristics, such as period of exposure, and assumptions for exposure characteristics, such as frequency, duration, contact rate, and degree of absorption or soil adherence, may not represent actual exposure conditions.

The impact of population characteristic differences are probably insignificant when considering the entire potentially exposed population because population characteristics used in the radiation risk assessment are based on national averages or large sample populations. However, these characteristics may not accurately represent individuals who are or would be exposed at HPS; therefore, actual exposure may be over- or underestimated.

Uncertainties are inherent in most exposure characteristics to various degrees; therefore, exposure doses based on the selected exposure parameters may over- or underestimate actual exposure doses. This radiation risk assessment is generally based on RME parameters, which assume a residential lot size of 0.5-acre (EPA 1994d). The homegrown produce consumption rate used for calculating the consumption of homegrown produce is based on EPA default factors developed by considering a residential lot size of 0.5-acre. It is uncertain whether assumptions based on a 0.5-acre residential lot size are valid for application to residential lots based on a 2,500-ft² size assumed in this radiation risk assessment. For example, it is assumed that 40 percent of residential vegetable intake and 30 percent of residential fruit intake would consist of homegrown produce. This assumption leads to an intake of 122 g/day of homegrown produce by adults and of 79 g/day by children, for a total of 402 g/day for a family of four (two adults and two children). These figures amount to almost 150 kg/year. EPA includes a productivity figure of 0.9 pound/ft² for home gardens (EPA 1995c), which indicates that an area of 360 ft² would be required to produce the amount of fruits and vegetables assumed in the radiation risk assessment. The standard San Francisco design for a residential house has two stories of about 1,000 ft² of living space above a garage/utility story. Allowing for stairs, walls, driveway, fences, sidewalks or public ways, and other built-up areas, at least 1,500 ft² of soil would be covered and unavailable for gardening. Close to half of the remaining portion of the 2,500 ft² lot would be required for the garden, with relatively little soil area remaining for lawns, flowers, recreation, and

other activities; therefore, the exposure parameters for homegrown produce ingestion used in this radiation risk assessment appear to be unreasonably high.

Food intake parameters developed for the nation are also generally higher than those applicable to potential future residential lots at HPS. The primary sources of all food intake parameters are the decennial "National Food Consumption Surveys" of the U.S. Department of Agriculture, whose results were published in 1987 and 1988, and surveys by the National Gardening Association from the same period (EPA 1995c). These surveys detail the consumption of hundreds of different foodstuffs, the source of the food (market, restaurant, homegrown, and others), and other information. Some of the broader data are broken down by demographic factors, including the region of the country and the size of the community (city, suburb, small town, and rural). One inherent variable in determining consumption rates for homegrown produce is the percentage of households with gardens and, therefore, sources for homegrown produce. The national figure for vegetable gardens is 38 percent, which leads to the exposure factors used in this radiation risk assessment; however, the figure for the Pacific states is 32 percent and for cities is only 26 percent. Therefore, it is expected that only 26 percent of the residents of San Francisco have a home garden. This assumption would produce a corresponding reduction in the intake of homegrown produce, indicating that this radiation risk assessment may overestimate risks and hazards associated with ingestion of homegrown produce.

3.3.3 Assumption of No Soil Amendment

For the exposure pathway involving consumption of homegrown produce, soil amendment is another factor expected to reduce EPCs in soil. The EPCs reflect the radionuclide concentration in soil as it was placed approximately 30 years ago. In actuality, the soil present in a garden would be significantly diluted by imported, presumably uncontaminated materials. Several inches to 1 foot of topsoil may be imported and mixed with existing soil. In an extreme case, the entire root zone for annual plants (such as vegetables) would be replaced with imported soil. Even without the one-time addition of topsoil, regular addition once or more a year of organic matter such as peat moss, mulch, green manure, compost, and fertilizers would be added to the garden site. In general, the assumption of no soil amendment probably results in overestimation of radionuclide concentrations and exposure doses.

3.3.4 Modeling of Slope Factors

External exposure SFs are derived assuming external radiation from photon-emitting radionuclides are distributed uniformly in a thick layer of soil. This may overestimate the true health effects associated with exposure to a given radionuclide because radionuclide concentrations may not be uniformly distributed (see Sections 2.5.1.4 and 3.3.3).

4.0 RISK CHARACTERIZATION

This section characterizes the carcinogenic risks associated with the exposure pathways identified in Section 3.0 of this radiation risk assessment report. Risks are characterized for radionuclides of potential concern for each exposure pathway and for exposure attributable to multiple exposure pathways. Section 4.1 presents the methodology used to characterize carcinogenic risks. Section 4.2 characterizes carcinogenic risks associated with radium-226 in soil under the future residential and industrial land-use scenarios. Section 4.3 characterizes carcinogenic risks associated with the inhalation of radon-222 under the future residential and industrial land-use scenarios. Section 4.4 discusses uncertainties associated with the risk characterization results.

4.1 RISK CHARACTERIZATION METHODOLOGY

This section presents the methods used to quantify carcinogenic risks for radionuclides at Parcel E. Section 4.1.1 discusses the method used to quantify carcinogenic risks for radium-226 and its daughters, with the exception of radon-222. Section 4.1.2 discusses the method used to quantify carcinogenic risks associated with the inhalation of radon-222 gas that may be released from the radioactive decay of radium-226; the rationale for assessing this radionuclide separately is also discussed in this section. Section 4.1.3 discusses other risk characterization methodologies.

4.1.1 Carcinogenic Risks for Radium-226

Risk estimates represent the incremental probability that an individual will develop cancer over a lifetime as a result of exposure to a carcinogenic radionuclide. These risks, or ELCRs, are calculated as follows:

$$\text{ELCR (Risk)} = \text{LTD} \times \text{SF}$$

where

LTD = Lifetime total dose (pCi for the inhalation and ingestion exposure pathways and pCi-years/gram for the external exposure pathway)

SF = Slope factor (risk/pCi for the inhalation and ingestion exposure pathways and risk/year per pCi/g for the external exposure pathway)

This equation does not account for radioactive ingrowth, decay, leaching, and erosion in the contaminated zone and does not consider site-specific geologic and hydrogeologic parameters. Therefore, for this radiation risk assessment, risk was calculated using the RESRAD model, which includes a time-dependent source term that accounts for these factors while generally following the equation shown above.

Risk is expressed as probability. For example, an ELCR of 1×10^{-6} translates to one additional case of cancer in an exposed population of 1 million. According to the revised National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (EPA 1990c), EPA has established an “acceptable” risk range for carcinogenic risk from exposure at a Superfund site of 1×10^{-6} (one case of cancer in an exposed population of 1 million) to 1×10^{-4} (one case of cancer in an exposed population of 10,000). In general, a potential ELCR of 1×10^{-6} is used by EPA as a point of departure for determining remediation goals.

Within a given exposure pathway, receptors may be exposed to more than one radionuclide. Specifically, for radium-226, risk within a given exposure pathway is considered to be the sum of the risk associated with the radium-226 subchain, which includes radium-226 and all sequential daughters to lead-210, as well as the lead-210 subchain, which includes lead-210 and all sequential daughters to the stable isotope lead-206. The total upper-bound ELCR associated with exposure to radium-226 through a single exposure pathway is estimated as follows:

$$\text{Risk (EP)} = \text{Risk (radium-226 subchain)} + \text{Risk (lead-210 subchain)}$$

where

$$\text{Risk (EP)} = \text{Total ELCR for a given exposure pathway}$$

This approach is consistent with federal radiation protection guidance, which states that the total carcinogenic risk from exposure to multiple radionuclides can be estimated as the sum of the carcinogenic risk posed by individual radionuclides (EPA 1987).

At particular exposure points, receptors may be exposed to radium-226 and its daughters through a number of exposure pathways, including external radiation, particulate inhalation, homegrown produce ingestion, and soil ingestion. At each particular exposure point, the total exposure for a receptor equals the sum of the exposures through the various exposure pathways to which the receptor is exposed. Under each land-use scenario, exposure pathway combinations were developed for both future residents and future workers. The total ELCRs posed to a future resident and future worker through a combination of exposure pathways were calculated for each exposure area as follows:

$$\text{Total ELCR(future resident)} = \text{Risk (ground)} + \text{Risk (inhalation)} + \text{Risk (plant)} + \text{Risk (soil)}$$

$$\text{Total ELCR(future worker)} = \text{Risk (ground)} + \text{Risk (inhalation)} + \text{Risk (soil)}$$

where

Total ELCR	=	Risk resulting from multiple exposure pathways
Risk (ground)	=	Risk resulting from direct external exposure to penetrating radiation from radionuclides in soil
Risk (inhalation)	=	Risk resulting from the particulate inhalation pathway
Risk (plant)	=	Risk resulting from the homegrown produce ingestion pathway
Risk (soil)	=	Risk resulting from the soil ingestion pathway

The RESRAD model calculated the total ELCR under each future land-use scenario using the EPCs developed in Section 3.1.2 for the case of exposure through multiple pathways to a single gamma anomaly (see Table P-9). The total ELCR for a given exposure area was calculated by multiplying the total ELCR for the single anomaly case by the number of anomalies found in that exposure area during the Phase I and Phase III radiation investigations.

4.1.2 Carcinogenic Risks from Radon-222

Radon-222 may be released from the radioactive decay of radium-226, migrate through the soil to the ground surface, and enter current and future on-site buildings through cracks in the walls or foundations. Because risk associated with the inhalation of radon gas is only relevant if buildings are constructed in the contaminated zone, this risk was assessed separately and was not added to the total risk values for radium-226.

The methodology used to assess radon-222 inhalation risk is similar to the methodology discussed in Section 4.1.1. However, the risk is based solely on the exposure to radon-222 through the inhalation pathway, rather than exposure to multiple radionuclides through multiple pathways. The RESRAD model calculated the radon-222 ELCR under each future land-use scenario using the EPC developed in Section 3.1.2 for the case of exposure to a single gamma anomaly. The radon-222 ELCR for a given exposure area was calculated by multiplying the radon-222 ELCR for the single anomaly case by the number of anomalies found in that exposure area during the Phase I and Phase III investigations.

Radon flux testing performed during the Phase I radiation investigation did not detect radon gas above background levels at the ground surface of the disposal dump area at IR-02 Northwest, which is the primary area of contamination. During the Phase I investigation, radon-222 gas was detected only where radium-containing devices were present at the ground surface. No evidence exists that high concentrations of radon gas are present at the ground surface or will be present at the ground surface in the future. In addition, risk associated with radon-222 inhalation is only relevant if buildings are constructed in the contaminated zone. Therefore, risk calculated for the radon-222 inhalation pathway is assessed separately and is not added to the total risk.

4.1.3 Other Risk Characterization Methodologies

For this radiation risk assessment, risk was calculated by the RESRAD model, which makes corrections for radioactive ingrowth and decay, leaching and erosion in the contaminated zone, and site-specific geology and hydrogeology. These results are presented in Sections 4.2 and 4.3.

Risk was also calculated using the RISKCALC model, which estimates risk using the soil exposure pathway equations presented in Section 4.1.1 and in EPA's "Risk Assessment Guidance for Superfund, Part A" (EPA 1989). Attachment P3 presents the RISKCALC results for the single anomaly case under the future land-use scenarios. A comparison of risk calculated by the RISKCALC and RESRAD methods is also presented in Attachment P3.

Risk calculated for this risk assessment using the RESRAD and RISKCALC models is based on a homogeneous distribution of radium-226 in soil. However, since many of the radium-containing devices at Parcel E were observed to be intact, risk was also calculated for exposure to an isotropic radium-containing point source. Attachment P4 presents the risk results for the isotropic point source case and compares this risk with risk calculated by the RESRAD and RISKCALC models.

4.2 RISK CHARACTERIZATION FOR RADIUM-226

This section discusses risks associated with radium-226 in soil under the future land-use scenarios at Parcel E. Specifically, this section discusses the total ELCRs associated with each of the complete exposure pathways, with the exception of radon inhalation. For radium-226, risk within a given exposure pathway is considered to be the sum of the risk associated with the radium-226 subchain and the lead-210 subchain. Section 4.2.1 presents risk characterization results for radium-226 under the future residential land-use scenario. Section 4.2.2 presents risk characterization results for radium-226 under the future industrial land-use scenario. Within each land-use discussion, risks associated with soil under the RME case are discussed first, followed by risks associated with the average exposure case.

4.2.1 Residential Land-Use Scenario

This section presents the risk characterization results for radium-226 in soil under the future residential land-use scenario at Parcel E. Specifically, this section discusses the total ELCRs associated with the external radiation, particulate inhalation, homegrown produce ingestion, and soil ingestion exposure pathways. Risks associated with potential future resident exposure to radionuclides in soil for the RME case are discussed in Section 4.2.1.1. Risks associated with potential future resident exposure to

radionuclides in soil for the average exposure case are discussed in Section 4.2.1.2. Total ELCR results for each exposure area under the residential land-use scenario are summarized in Table P-10.

4.2.1.1 RME Case

Of the 147 residential exposure areas for which total ELCRs were calculated, the following breakdown was observed under the RME case:

Total ELCR Range	Number of Exposure Areas
1×10^{-5} to 1×10^{-4}	57
1×10^{-6} to 1×10^{-5}	90

Note:

ELCR Excess lifetime cancer risk

Figure P-6 presents the total ELCRs associated with each exposure area. Of the residential exposure areas with the highest total ELCR range, two are in IR-02 Central and 55 are in IR-02 Northwest. External exposure to radiation is the dominant exposure pathway and contributes about 76 percent of the total ELCRs. Ingestion of homegrown produce contributes about 21 percent and ingestion of soil contributes about 2 percent of the total ELCRs. Inhalation of particulates contributes negligibly to the total ELCRs.

4.2.1.2 Average Exposure Case

Of the 147 residential exposure areas for which total ELCRs were calculated, the following breakdown was observed under the average exposure case:

Total ELCR Range	Number of Exposure Areas
1 × 10 ⁻⁶ to 1 × 10 ⁻⁵	52
< 1 × 10 ⁻⁶	95

Note:

ELCR Excess lifetime cancer risk

Figure P-6 presents exposure areas with total ELCRs equal to or exceeding 1 × 10⁻⁶. Of the residential exposure areas in the highest total ELCR range, one is in IR-01/21, one is in IR-02 Central, and the rest are in IR-02 Northwest. External exposure to radiation is the dominant exposure pathway and contributes about 84 percent of the total ELCRs. Ingestion of homegrown produce contributes about 15 percent and ingestion of soil contributes about 1 percent of the total ELCRs. Inhalation of particulates contributes negligibly to the total ELCRs.

4.2.2 Future Industrial Risk Characterization

This section presents the risk characterization results for radium-226 in soil under the future industrial land-use scenario at Parcel E. Specifically, this section discusses the total ELCRs associated with the external radiation, particulate inhalation, and soil ingestion pathways. Risks associated with potential future exposure of industrial workers to radionuclides in soil for the RME case are discussed in Section 4.2.2.1. Risks associated with potential future exposure of industrial workers to radionuclides in soil for the average exposure case are discussed in Section 4.2.2.2. Total ELCR results for each exposure area under the industrial land-use scenario are summarized in Table P-11.

4.2.2.1 RME Case

Of the 35 industrial exposure areas for which total ELCRs were calculated, the following breakdown was observed under the RME case:

Total ELCR Range	Number of Exposure Areas
1×10^{-6} to 1×10^{-5}	9
$< 1 \times 10^{-6}$	26

Note:

ELCR Excess lifetime cancer risk

Figure P-7 presents the total ELCRs associated with each exposure area. All of the industrial exposure areas in the highest total ELCR range are in IR-02 Northwest. External exposure to radiation is the dominant exposure pathway and contributes about 99 percent of the total ELCRs. Ingestion of soil contributes about 1 percent and inhalation of particulates contributes negligibly to the total ELCRs.

4.2.2.2 Average Exposure Case

Of the 35 industrial exposure areas for which total ELCRs were calculated, all ELCRs were less than 1×10^{-6} . External exposure to radiation is the dominant exposure pathway and contributes about 99 percent of the total ELCRs. Ingestion of soil contributes about 1 percent and inhalation of particulates contributes negligibly to the total ELCRs.

4.3 RADON-222 RISK CHARACTERIZATION

This section discusses risks associated with the inhalation of radon-222 under the future land-use scenarios at Parcel E. Specifically, this section discusses the ELCRs associated with this exposure pathway. The radon-222 ELCRs for the single anomaly case are presented in the following table.

Land-Use Scenario	ELCR
Residential RME Case	5.5×10^{-6}
Residential Average Exposure Case	1.1×10^{-6}

(Continued)

Land-Use Scenario	ELCR
Industrial RME Case	2.2×10^{-7}
Industrial Average Exposure Case	2.1×10^{-8}

Notes:

ELCR Excess lifetime cancer risk
RME Reasonable maximum exposure

Section 4.3.1 presents risk characterization results for radon-222 inhalation under the future residential land-use scenario. Section 4.3.2 presents risk characterization results for radon-222 inhalation under the future industrial land-use scenario. Within each land-use discussion, risks associated with radon-222 under the RME case are discussed first, followed by risks associated with the average exposure case.

4.3.1 Residential Land-Use Scenario

This section presents the risk characterization results for radon-222 under the future residential land-use scenario. Specifically, this section discusses the ELCRs associated with the radon-222 inhalation exposure pathway. Risks associated with potential future resident exposure to radon-222 for the RME case are discussed in Section 4.3.1.1. Risks associated with potential future resident exposure to radon-222 for the average exposure case are discussed in Section 4.3.1.2. Radon-222 ELCR results for each exposure area under the residential land-use scenario are summarized in Table P-12.

4.3.1.1 RME Case

Of the 147 residential exposure areas for which radon-222 ELCRs were calculated, the following breakdown was observed under the RME case:

Total ELCR Range	Number of Exposure Areas
1×10^{-4} to 1×10^{-3}	21
1×10^{-5} to 1×10^{-4}	83
1×10^{-6} to 1×10^{-5}	43

Note:

ELCR Excess lifetime cancer risk

All of the residential exposure areas in the highest radon-222 ELCR range are in IR-02 Northwest.

4.3.1.2 Average Exposure Case

Of the 147 residential exposure areas for which radon-222 ELCRs were calculated, the following breakdown was observed under the average exposure case:

Total ELCR Range	Number of Exposure Areas
1×10^{-5} to 1×10^{-4}	13
1×10^{-6} to 1×10^{-5}	75
$< 1 \times 10^{-6}$	59

Note:

ELCR Excess lifetime cancer risk

All of the residential exposure areas in the highest radon-222 ELCR range are in IR-02 Northwest.

4.3.2 Future Industrial Risk Characterization

This section presents the risk characterization results for radon-222 under the future industrial land-use scenario at Parcel E. Specifically, this section discusses the ELCRs associated with the radon-222 inhalation pathway. Risks associated with potential future exposure of industrial workers to radon-222 for the RME case are discussed in Section 4.3.2.1. Risks associated with potential future exposure of industrial workers to radon-222 for the average exposure case are discussed in Section 4.3.2.2. Radon-

222 ELCR results for each exposure area under the industrial land-use scenario are summarized in Table P-13.

4.3.2.1 RME Case

Of the 35 industrial exposure areas for which radon-222 ELCRs were calculated, the following breakdown was observed under the RME case:

Total ELCR Range	Number of Exposure Areas
1×10^{-5} to 1×10^{-4}	6
1×10^{-6} to 1×10^{-5}	10
$< 1 \times 10^{-6}$	19

Note:

ELCR Excess lifetime cancer risk

All of the industrial exposure areas in the highest radon-222 ELCR range are in IR-02 Northwest.

4.3.2.2 Average Exposure Case

Of the 35 industrial exposure areas for which radon-222 ELCRs were calculated, the following breakdown was observed under the average exposure case:

Total ELCR Range	Number of Exposure Areas
1×10^{-6} to 1×10^{-5}	2
$< 1 \times 10^{-6}$	33

Note:

ELCR Excess lifetime cancer risk

All of the residential exposure areas in the highest radon-222 ELCR range are in IR-02 Northwest.

4.4 RISK CHARACTERIZATION UNCERTAINTIES

The accuracy of risk results derived from the RESRAD model depends on the accuracy of the input parameters; therefore, risk results derived from RESRAD contain inherent uncertainties based on the assumptions used in choosing input parameters. The results of the RESRAD model are based on complex, usually non-linear, mathematical relationships among several dozen input parameters. Because of the complexity of the RESRAD model, it is difficult to predict how an individual input parameter will affect the overall risk results obtained from RESRAD. Therefore, the effect of the input parameters used in this radiation risk assessment on the overall risk results underwent a sensitivity analysis to identify which input parameters most influence the results. The results of the sensitivity analysis are presented in Attachment P5 and are summarized in the following paragraphs.

The sensitivity analysis demonstrated that, overall, the RESRAD model was most sensitive to the following input parameters: (1) cover depth, (2) distribution coefficient, and (3) erosion rate. The RESRAD model was also sensitive to some exposure pathway-specific input parameters such as fruit, vegetable, and grain consumption rate; mass loading for foliar deposition; shielding factors; produce factors; fraction of time spent indoors on site; and fraction of time spent outdoors on site. During the Parcel E radiation risk assessment, RESRAD input parameter values were selected to limit uncertainty introduced into the risk characterization process due to model sensitivity.

During the Parcel E radiation risk assessment, values for highly sensitive input parameters were selected based on conceptual site model assumptions, EPA guidance, recommendations in the RESRAD data collection handbook, or RESRAD defaults; these sources generally provide conservative and health-protective values. Although accurate site-specific data for several input parameters (such as soil erosion rate and distribution coefficient) may increase the accuracy of the total risk results, obtaining this type of data is not feasible. Therefore, selection of conservative and health-protective input parameter values used in the Parcel E radiation risk assessment will produce health-protective risk results using the RESRAD program.

5.0 SUMMARY AND CONCLUSIONS

This section summarizes the results of the radiation risk assessment and provides conclusions about risks for HPS Parcel E. Parcel E occupies approximately 135 acres and includes five sites which are evaluated in this radiation risk assessment: IR-01/21, IR-02 Northwest, IR-02 Central, IR-02 Southeast, and IR-11/14/15. The objective of the radiation risk assessment is to evaluate potential risks to future residents and workers from exposure to radionuclides of potential concern identified at the site. The radiation risk assessment was prepared in accordance with EPA guidance. Identification of radionuclides of potential concern, the exposure assessment, the toxicity assessment, the risk characterization, uncertainties related to the radiation risk assessment, and conclusions are presented in the following sections.

5.1 IDENTIFICATION OF RADIONUCLIDES OF POTENTIAL CONCERN

Based on data collected during the radiological investigations at Parcel E, radium-226 and its radioactive daughters were identified as radionuclides of potential concern. The sources of these radionuclides are radium-containing devices from ship repair and maintenance activities that were apparently disposed of in the disposal dump area at IR-02 Northwest that extends into IR-02 Central. Some of these radium-containing devices may have been inadvertently transported from the disposal dump area to IR-01/21, IR-02 Southeast, and IR-11/14/15 during soil excavation, redistribution, and dumping activities.

5.2 EXPOSURE ASSESSMENT

The exposure assessment identified potential receptors that may be exposed to radionuclides. Under the future land-use scenarios, potential receptors are adult and child residents and adult workers. Current land-use scenarios were not evaluated in the radiation risk assessment because IR-01/21, IR-02 Northwest, IR-02 Central, IR-02-Southeast, and IR-11/14/15 are currently not used for any purposes, because future exposure assumptions are more conservative than current exposure assumptions, and because portions of Parcel E with acceptable risks under the future industrial land-use scenario would also have acceptable risk under the current land-use scenario.

The exposure areas used for the radiation risk assessment match the exposure areas used for the human health risk assessment conducted for chemical contaminants (see Appendix N). Parcel E was divided into approximately 0.5-acre exposure areas for the industrial land-use scenario and was divided into 2,500-ft² exposure areas for the residential land-use scenario. The 0.5-acre exposure area is a reasonable estimate of the size of a light industrial business lot in the San Francisco Bay area. The 2,500-ft² exposure area is the minimum residential lot size for a single-family home in San Francisco.

The exposure pathways of radionuclides of potential concern from sources to exposure points were then identified. Radionuclides were primarily released into Parcel E surface and subsurface soil in the disposal dump area. Radionuclides in soil emit gamma radiation, may be taken up in plant roots, and decay and may migrate through air as radon gas. Under the future residential land-use scenario, adult and child residents were assumed to be exposed to radionuclides in soil through the following exposure pathways:

- Externally from direct, penetrating radiation from radionuclides in soil
- Internally through inhalation of airborne radionuclides
- Internally through inhalation of radon and radon decay products emanating from radium-226 in soil
- Internally through ingestion of homegrown produce (fruits and vegetables) contaminated by radionuclides in the soil
- Internally through incidental ingestion of radionuclides in soil

Under the future industrial land-use scenario, adult workers were assumed to be exposed to radionuclides in soil through the following exposure pathways:

- Externally from direct, penetrating radiation from radionuclides in soil
- Internally through inhalation of airborne radionuclides
- Internally through inhalation of radon and radon decay products emanating from radium-226 in soil
- Internally through incidental ingestion of radionuclides in soil

EPCs were then derived for each exposure area where receptors may be exposed to radionuclides of potential concern. Based on data collected from the Phase I and Phase III radiation investigations, the number of gamma anomalies in each exposure area was quantified. The number of anomalies per exposure area was then converted into soil concentrations of radium-226, based on the assumption that each anomaly represented a radium-containing device with an activity of 1 μCi . Radionuclide EPCs in soil were calculated for the RME and average exposure cases.

5.3 TOXICITY ASSESSMENT

The toxicity assessment identifies the toxicity values, or SFs, used to quantify potential adverse health effects associated with exposure to radionuclides of potential concern. The SFs used in this radiation risk assessment were obtained from HEAST (EPA 1995a).

5.4 RISK CHARACTERIZATION

Information from the identification of radionuclides of potential concern, the exposure assessment, and the toxicity assessment were used to quantify the carcinogenic risks for each exposure area using the RESRAD computer model developed by DOE. Risks were quantified for exposure to radium-226 in soil through multiple exposure pathways. Significant risks associated with potential exposure to radium-226 in soil are summarized in Section 5.4.1. Significant risks associated with potential exposure to radon-222 in indoor air are summarized in Section 5.4.2. Because the radon-222 risk is relevant only if buildings are constructed in the contaminated areas, this risk was assessed separately.

5.4.1 Radium-226 Risk Characterization

Risk characterizations for radium-226 in soil under the future land-use scenarios are summarized in the following paragraphs.

Future Residential Land-Use Scenario

Under the RME case, all of the 147 residential exposure areas have total ELCRs greater than 1×10^{-6} but less than 1×10^{-4} . Under the average exposure case, only 51 exposure areas have total ELCRs

greater than 1×10^{-6} and no exposure areas have total ELCRs greater than 1×10^{-5} . Direct external exposure to radiation is the dominant exposure pathway and contributes 76 percent of the total ELCR under the RME case and 84 percent of the total ELCR under the average exposure case.

Future Industrial Land-Use Scenario

Under the RME case, nine exposure areas in IR-02 Northwest have total ELCRs greater than 1×10^{-6} but less than 1×10^{-5} . Under the average exposure case, no industrial exposure areas have total ELCRs greater than 1×10^{-6} . Direct external exposure to radiation is the dominant exposure pathway and contributes 99 percent of the total ELCR under the RME case.

5.4.2 Radon-222 Risk Characterization

Risk characterizations for the inhalation of radon-222 gas under the future land-use scenarios are summarized in the following paragraphs. This risk is relevant only if buildings are constructed in the contaminated areas.

Future Residential Land-Use Scenario

Under the RME case, all of the 147 residential exposure areas have radon-222 ELCRs greater than 1×10^{-6} but less than 1×10^{-3} ; eighteen residential exposure areas have radon-222 ELCRs between 1×10^{-4} to 1×10^{-3} . Under the average exposure case, 88 exposure areas have radon-222 ELCRs greater than 1×10^{-6} and no exposure areas have radon-222 ELCRs greater than 1×10^{-4} .

Future Industrial Land-Use Scenario

Under the RME case, 16 exposure areas have radon-222 ELCRs greater than 1×10^{-6} but less than 1×10^{-4} . Under the average exposure case, only two industrial exposure areas have radon-222 ELCRs greater than 1×10^{-6} .

5.5 CONCLUSIONS

Risks calculated in this radiation risk assessment are subject to uncertainty from a variety of sources. Uncertainties associated with field investigation data, the exposure and toxicity assessments, and the RESRAD model are compounded in the risk characterization step. These uncertainties are managed by making conservative assumptions during data interpretation and by selecting conservative values for the exposure and toxicity variables. Use of these conservative assumptions and values during the risk characterization step will result in a risk estimate that is likely to be biased high and therefore health-protective. Actual risks are unlikely to exceed the risk values estimated in this radiation risk assessment. For example, EPCs were likely overestimated since they were based on the assumption that all radium-226 from buried devices had migrated to and was uniformly distributed throughout the uppermost 1 foot of soil. In actuality, soil analysis demonstrated limited concentrations of radium-226 near buried devices.

The most significant areas of uncertainty in this radiation risk assessment involve (1) the assumption of residential development throughout Parcel E, and (2) possible construction of buildings in the contaminated areas at Parcel E. Residential development is not planned for Parcel E. Some industrial and business park development is expected at Parcel E. However, most of the contaminated areas at Parcel E lie along the shoreline and are expected to be used for recreational areas, parks, and maritime activities.

The sites included in this radiation risk assessment will be evaluated in the Parcel E FS for remedial action.

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TABLE P-1

**IR SITES AND ASSOCIATED INDUSTRIAL AND RESIDENTIAL EXPOSURE AREAS^a
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

IR Site	Industrial Exposure Area (0.5-Acre)	Residential Exposure Area (2,500-Square-Foot)
IR-01/21	AA35	016101 and 016102
	AB39	019114 and 019115
	AC35	020102, 020103, 021102, and 021103
	AC39	020115
	AC40	020116 and 021116
IR-02 Northwest	AK37	045109
	AK38	045110, 046110, and 046111
	AL37	047109, 048108, 048109, and 049108
	AL38	047110, 047111, 048110, 048111, 048112, 049111, and 049112
	AL39	049113
	AM37	050109, 051108, 051109, 052108, and 052109
	AM38	050112, 051110, 051111, 051112, 052110, 052111, and 052112
	AM39	050113, 050114, 051113, 051114, 051115, 052113, 052114, and 052115
	AN35	055103
	AN36	055104, 055105, and 055106
	AN37	053108, 053109, 054107, 054108, 054109, 055107, 055108, and 055109
	AN38	053110, 053111, 053112, 054110, 054111, 054112, 055110, 055111, and 055112
	AN39	053113, 053114, 053115, 054113, 054114, 055113, and 055114
	AO36	056105, 056106, 057106,
	AO37	056107, 056108, 056109, 057107, 057108, 057109, 058107, 058108, and 58109

TABLE P-1 (Continued)

**IR SITES AND ASSOCIATED INDUSTRIAL AND RESIDENTIAL EXPOSURE AREAS*
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

IR Site	Industrial Exposure Area (0.5-Acre)	Residential Exposure Area (2,500-Square-Foot)
IR-02 Northwest (Continued)	AO38	056110, 056111, 056112, 057110, 057111, 057112, 058110, 058111, and 058112
	AO39	056113, 056114, 057113, 057114, 057115, 058113, and 058114
	AP37	059108, 059109, 060108, and 060109
	AP38	059110, 059111, 059112, 060110, 060111, 060112, 061111, and 061112
	AP39	059113, 059114, 060113, 060114, 061113, and 061114
	AP40	061116 and 061117
IR-02 Central	AQ39	062113, 062114, 062115, 062114, and 062115
	AQ40	063116
	AR38	066111 and 067111
	AV36	078105, 079104, and 079105
IR-02 Southeast	BH35	113103 and 114103
	BH36	113104 and 114104
	BI34	117100, 118099, and 118100
	BJ34	120098, 120099, 120100, 121098, and 121099
IR-11/14/15	BA33	092096

Notes:

IR Installation restoration

a Only exposure areas detecting radioactive anomalies during Hunters Point Shipyard Parcel E radiological investigations are listed

TABLE P-2

**GEOLOGIC AND HYDROGEOLOGIC PROPERTIES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Parameters	Value	Pathways ^a
Contaminated Zone Parameters		
Area of Contaminated Zone (m ²)	1,000,000 ^b	E, Inh, Ing, P, R
Thickness of Contaminated Zone (m)	3 ^b	E, Inh, Ing, P, R
Length Parallel to Aquifer Flow (m)	1,000 ^b	P, R
Time Since Material Placement (year)	30 ^c	E, Inh, Ing, P, R
Cover and Contaminated Zone Hydrogeologic Data		
Cover Depth (m)	0 ^b	E, Inh, Ing, P, R
Contaminated Zone Erosion Rate (m/year)	0.001 ^d	E, Inh, Ing, P, R
Soil type: clay to gravel	Sandy loam ^e	E, Inh, Ing, P, R
Density of Contaminated Zone Soil (g/cm ³)	1.44 ^f	E, Inh, Ing, P, R
Contaminated Zone B Parameter (m/year)	4.9 ^f	E, Inh, Ing, P, R
Runoff coefficient	0.4 ^f	E, Inh, Ing, P, R
Contaminated Zone Total Porosity (unitless)	0.34 ^c	E, Inh, Ing, P, R
Contaminated Zone Effective Porosity (unitless)	0.3 ^c	E, Inh, P, R
Evapotranspiration Coefficient (unitless)	0.75 ^c	E, Inh, Ing, P, R
Contaminated Zone Hydraulic Conductivity (m/year)	1,450 ^g	E, Inh, Ing, P, R
Precipitation (m/year)	0.547 ^h	E, Inh, Ing, P, R
Irrigation (m/year)	0 ^b	E, Inh, Ing, P, R
Irrigation mode	-- ^b	E, Inh, Ing, P, R
Watershed Area for Nearby Water Body (m ²)	1,000,000 ^b	P, R
Accuracy for Water/Soil Computations	0.001 ^d	P, R
Saturated Zone Hydrogeologic Data		
Soil type: clay to gravel	Sandy loam ^e	E, Inh, Ing, P, R
Density of Contaminated Zone Soil (g/cm ³)	1.44 ^f	Ing, P, R

TABLE P-2 (Continued)

**GEOLOGIC AND HYDROGEOLOGIC PROPERTIES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Parameters	Value	Pathways ^a
Saturated Zone Hydrogeologic Data (Continued)		
Saturated Zone B Parameter (m/year)	4.9 ^f	Ing, P, R
Saturated Zone Total Porosity (unitless)	0.34 ^d	Ing, P, R
Saturated Zone Effective Porosity (unitless)	0.3 ^d	Ing, P, R
Saturated Zone Hydraulic Conductivity (m/year)	1,450 ^g	Ing, P, R
Saturated Zone Hydraulic Gradient (unitless)	0.02 ⁱ	Ing, P, R
Water Table Drop Rate (m/year)	0.001 ^{b, c}	Ing, P, R
Well Pump Intake Depth (m below water table)	0.00001 ^{b, c}	Ing, P, R
Nondispersion or Mass-Balance	Nondispersion ^b	E, Inh, Ing, P, R
Well Pumping Rate (m ³ /year)	0 ^b	Ing, P, R
Distribution Coefficients and Leach Rate Constants		
Contaminated Zone Distribution Coefficient	Radium-226: 36,000 ^f Lead-210: 16,000 ^f	
Saturated Zone Distribution Coefficient	Radium-226: 0 ^b Lead-210: 0 ^b	
Leach Rates	Radium-226: 0 ^b Lead-210: 0 ^b	
Solubility (mol/L)	Radium-226: 0 ^b	

Notes:

cm ³	Cubic centimeter	m ³	Cubic meter
g	Gram	mrem	Millirem
m	Meter	Pb-210	Lead-210
m ²	Square meter	Ra-226	Radium-226

a Pathways affected by the geologic and hydrogeologic properties in the RESRAD model include:

- E - External gamma radiation exposure
- Inh - Inhalation of fugitive dust and radon
- Ing - Incidental ingestion of soil
- P - Ingestion of homegrown produce (future residential land-use scenario only)
- R - Radon

b Based on professional judgment, see Section 3.1.1 for explanation

TABLE P-2 (Continued)

**GEOLOGIC AND HYDROGEOLOGIC PROPERTIES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Notes (Continued):

- c Hunters Point Shipyard site-specific value (PRC 1994)
- d RESRAD standard default value (DOE 1993)
- e Sandy loam is a type of soil between clay and gravel; Hunters Point Shipyard soil varies from clay to gravel
- f RESRAD standard default value based on soil type (DOE 1993)
- g Based on the 50th percentile of 67 Bouwer and Rice slug test results at 13 feet/day (PRC 1997)
- h San Francisco annual precipitation rate is 21.52 inches/year (NWS 1997)
- i RESRAD standard default value is based on land layout
- Not applicable

TABLE P-3

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-01/21				
016101	1	0.01	0.5	0.005
016102	1	0.01	0.5	0.005
019114	4	0.04	0.1	0.001
019115	4	0.04	3.9	0.039
020102	1	0.01	0.2	0.002
020103	1	0.01	0.4	0.004
020115	5	0.05	1.0	0.010
020116	2	0.02	0.4	0.004
021102	1	0.01	0.1	0.001
021103	1	0.01	0.3	0.003
021116	2	0.02	1.6	0.016
IR-02 Northwest				
045109	1	0.01	0.3	0.003
045110	1	0.01	0.7	0.007
046110	1	0.01	0.02	0.0002
046111	1	0.01	0.1	0.001
047109	1	0.01	0.04	0.0004
047110	2	0.02	0.9	0.009
047111	2	0.02	1.0	0.010
048108	2	0.02	1.5	0.015
048109	2	0.02	1.1	0.011

TABLE P-3 (Continued)

**NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
048110	3	0.03	0.6	0.006
048111	2	0.02	1.1	0.011
048112	1	0.01	0.2	0.002
049108	1	0.01	0.3	0.003
049111	1	0.01	0.3	0.003
049112	2	0.02	1.1	0.011
049113	2	0.02	0.3	0.003
050109	1	0.01	0.04	0.0004
050112	2	0.02	0.7	0.007
050113	4	0.04	0.9	0.009
050114	1	0.01	0.4	0.004
051108	1	0.01	0.04	0.0004
051109	12	0.12	4.0	0.040
051110	18	0.18	7.8	0.078
051111	19	0.19	3.1	0.031
051112	4	0.04	0.9	0.009
051113	6	0.06	2.8	0.028
051114	9	0.09	3.1	0.031
051115	2	0.02	0.2	0.002
052108	2	0.02	1.8	0.018
052109	13	0.13	5.5	0.055

TABLE P-3 (Continued)

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
052110	34	0.34	12	0.12
052111	26	0.26	11	0.11
052112	7	0.07	1.6	0.016
052113	4	0.04	0.9	0.009
052114	9	0.09	4.2	0.042
052115	1	0.01	0.4	0.004
053108	4	0.04	1.5	0.015
053109	9	0.09	2.2	0.022
053110	16	0.16	4.6	0.046
053111	22	0.22	11	0.11
053112	16	0.16	2.2	0.022
053113	5	0.05	1.5	0.015
053114	8	0.08	4.5	0.045
053115	1	0.01	0.05	0.0005
054107	2	0.02	0.6	0.006
054108	11	0.11	5.3	0.053
054109	11	0.11	2.8	0.028
054110	25	0.25	9.7	0.097
054111	46	0.46	16	0.16
054112	23	0.23	7.1	0.071
054113	14	0.14	2.3	0.023

TABLE P-3 (Continued)

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
054114	9	0.09	3.7	0.037
055103	1	0.01	0.1	0.001
055104	1	0.01	0.9	0.009
055105	2	0.02	0.2	0.002
055106	4	0.04	1.4	0.014
055107	3	0.03	2.3	0.023
055108	10	0.10	2.9	0.029
055109	24	0.24	5.3	0.053
055110	29	0.29	17	0.17
055111	37	0.37	19	0.19
055112	23	0.23	126	0.12
055113	10	0.10	2.0	0.020
055114	10	0.10	3.3	0.033
056105	2	0.02	0.5	0.005
056106	4	0.04	1.0	0.01
056107	6	0.06	2.1	0.021
056108	14	0.14	6.5	0.065
056109	26	0.26	9.9	0.099
056110	28	0.28	11	0.11
056111	24	0.24	9.0	0.090
056112	15	0.15	2.9	0.029

TABLE P-3 (Continued)

**NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
056113	10	0.10	4.7	0.047
056114	11	0.11	5.4	0.054
057106	1	0.01	0.9	0.009
057107	3	0.03	0.1	0.001
057108	7	0.07	0.9	0.009
057109	15	0.15	3.5	0.035
057110	32	0.32	13	0.13
057111	12	0.12	4.5	0.045
057112	2	0.02	0.2	0.002
057113	14	0.14	3.9	0.039
057114	13	0.13	5.7	0.057
057115	1	0.01	0.2	0.002
058107	1	0.01	0.3	0.003
058108	9	0.09	2.5	0.025
058109	13	0.13	4.9	0.049
058110	24	0.24	5.2	0.052
058111	15	0.15	5.1	0.051
058112	3	0.03	0.6	0.006
058113	6	0.06	2.5	0.025
058114	5	0.05	1.8	0.018
059108	9	0.09	4.1	0.041
059109	18	0.18	7.0	0.070

TABLE P-3 (Continued)

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
059110	24	0.24	12	0.12
059111	18	0.18	4.2	0.042
059112	9	0.09	4.4	0.044
059113	6	0.06	1.6	0.016
059114	2	0.02	1.2	0.012
060108	1	0.01	0.05	0.005
060109	3	0.03	0.4	0.004
060110	13	0.13	3.5	0.035
060111	20	0.20	6.1	0.061
060112	12	0.12	4.6	0.046
060113	8	0.08	2.9	0.029
060114	9	0.09	0.7	0.007
061111	1	0.01	0.3	0.003
061112	3	0.03	0.3	0.003
061113	9	0.09	3.7	0.037
061114	10	0.10	3.2	0.032
061116	1	0.01	0.3	0.003
061117	1	0.01	0.7	0.007
IR-02 Central				
062113	2	0.02	0.3	0.003
062114	3	0.03	0.9	0.009

TABLE P-3 (Continued)

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Central (Continued)				
062115	8	0.08	1.0	0.010
063114	1	0.01	0.04	0.0004
063115	8	0.08	6.7	0.067
063116	7	0.07	0.3	0.003
066111	1	0.01	0.7	0.007
067111	1	0.01	0.3	0.003
078105	1	0.01	0.002	0.00002
079104	1	0.01	0.2	0.002
079105	1	0.01	0.8	0.008
IR-02 Southeast				
113103	1	0.01	0.1	0.001
113104	1	0.01	0.7	0.007
114103	1	0.01	0.005	0.00005
114104	1	0.01	0.2	0.002
117100	1	0.01	0.005	0.00005
118099	1	0.01	0.2	0.002
118100	1	0.01	0.7	0.007
120098	2	0.02	0.5	0.005
120099	4	0.04	2.1	0.021
120100	2	0.02	0.1	0.001
121098	1	0.01	0.5	0.005
121099	3	0.03	0.9	0.009

TABLE P-3 (Continued)

NUMBER OF RADIUM-226 ANOMALIES PER RESIDENTIAL EXPOSURE AREAS^a
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-11/14/15				
092096	1	0.01	1	0.01

Notes:

EPC_{soil} Exposure point concentration in soil

g Gram

RME Residential maximum exposure

pCi picoCurie

a See Section 3.1.2.4 for method to determine number of anomalies and EPC_{soil}

TABLE P-4

**NUMBER OF RADIUM-226 ANOMALIES PER INDUSTRIAL EXPOSURE AREAS^a
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-01/21				
AA35	1	0.001	1.0	0.0010
AB39	4	0.004	4.0	0.0040
AC35	1	0.001	1.0	0.0010
AC39	1	0.001	1.0	0.0010
AC40	2	0.002	2.0	0.0020
IR-02 Northwest				
AK37	1	0.001	0.3	0.0003
AK38	2	0.002	0.9	0.0009
AL37	3	0.003	3.0	0.0030
AL38	7	0.007	5.2	0.0052
AL39	2	0.002	0.3	0.0003
AM37	22	0.022	12	0.012
AM38	55	0.055	38	0.038
AM39	18	0.018	13	0.013
AN35	1	0.001	0.1	0.0001
AN36	5	0.005	2.7	0.0027
AN37	47	0.047	23	0.023
AN38	125	0.130	97	0.097
AN39	32	0.032	17	0.017
AO36	3	0.003	2.3	0.0023
AO37	51	0.051	31	0.031
AO38	82	0.082	52	0.052

TABLE P-4 (Continued)

**NUMBER OF RADIUM-226 ANOMALIES PER INDUSTRIAL EXPOSURE AREAS^a
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	EPC _{soil} (pCi/g)	Number of Anomalies	EPC _{soil} (pCi/g)
IR-02 Northwest (Continued)				
AO39	27	0.027	24	0.024
AP37	17	0.017	11	0.011
AP38	46	0.046	35	0.035
AP39	17	0.017	13	0.013
AP40	1	0.001	1.0	0.0010
IR-02 Central				
AQ39	10	0.01	8.7	0.0087
AQ40	7	0.007	0.3	0.0003
AR38	1	0.001	1.0	0.0010
AV36	1	0.001	1.0	0.0010
IR-02 Southeast				
BH35	1	0.001	0.1	0.0001
BH36	1	0.001	0.9	0.0009
BI34	1	0.001	1.0	0.0010
BJ34	4	0.004	4.0	0.0040
IR-11/14/15				
BA33	1	0.001	1.0	0.001

Notes:

EPC_{soil} Exposure point concentration in soil
g Gram
pCi picoCurie
RME Residential maximum exposure

a See Section 3.1.2.4 for method to determine number of anomalies and EPC_{soil}

TABLE P-5

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
EXTERNAL GAMMA RADIATION, RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

$$LTD \text{ (pCi-years/g)} = EPC_{soil} \times Te \times ED \times (1-Se)$$

Parameter	Resident Adult		Resident Child		Resident Age-Adjusted		Adult Worker	
	RME	Average	RME	Average	RME	Average	RME	Average
Exposure Point Concentration in Soil (EPC_{soil}) (pCi/g)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Gamma indoor exposure time factor (Te) (unitless)	--	--	--	--	0.623 (c)	0.628 (c)	0.228 (d)	0.228 (d)
Exposure duration (ED) (years)	24 (e)	7 (f)	6 (e)	2 (f)	30 (e)	9 (f)	25 (e)	4.5
Gamma shielding Factor (1- Se) (unitless)	0.8 (g)	0.8 (g)	0.8 (g)	0.8 (g)	0.8 (g)	0.8 (g)	0.8 (g)	0.8 (g)

Notes:

- Average Exposure m^2 Square meter
- cm^3 Cubic centimeter m^3 Cubic meter
- g Gram pCi picoCurie
- LTD Lifetime total dose RME Reasonable maximum exposure
- m Meter

a Total number of anomalies in all 30-foot by 30-foot Phase I subgrid in or bordering an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)

b Relative number of 1 μ Ci anomalies in an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)

c $Te = \text{age adjusted gamma exposure time factor} \left(\frac{ET_{adult}}{ET} \times \frac{EF_{adult}}{EF} \times \frac{ED_{adult}}{ED} \right) + \left(\frac{ET_{child}}{ET} \times \frac{EF_{child}}{EF} \times \frac{ED_{child}}{ED} \right)$

Where:

Parameter	Resident Adult		Resident Child	
	RME	Average	RME	Average
Exposure Time (ET) (hours/day)	15 (h)	15 (h)	18 (h)	18 (h)
Exposure Frequency (EF)(days/year)	350 (e)	350 (f)	350 (e)	350 (f)
Exposure Duration (ED) (years)	24 (e)	7 (f)	6 (e)	2 (f)

TABLE P-5 (Continued)

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
EXTERNAL GAMMA RADIATION, RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Notes (Continued)

d $T_e = \text{gamma exposure time factor} \left(\frac{ET_{worker}}{ET} \times \frac{EF_{worker}}{EF} \right)$

Where:

Parameter	Adult Worker	
	RME	Average
Exposure Time (ET) (hours/day)	8 (i)	8 (i)
Exposure Frequency (EF)(days/year)	250 (e)	250

e EPA 1995b

f EPA 1993

g EPA 1989; Se = 0.2

h EPA 1990a

i Professional judgment based on a standard work day

-- Not applicable

TABLE P-6

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
 INHALATION OF PARTICULATES, RME AND AVERAGE EXPOSURE CASES
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION**

$$\text{LTD (pCi)} = \text{EPC}_{\text{soil}} \times \text{IR} \times \text{ML} \times \text{EF} \times \text{ED} \times \text{CF}$$

Parameter	Resident Adult		Resident Child		Resident Age-Adjusted		Adult Worker	
	RME	Average	RME	Average	RME	Average	RME	Average
Exposure Point Concentration in Soil (EPC _{soil}) (pCi/g)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Inhalation Rate (IR) (m ³ /day)	20 (c)	13.3 (d)	10 (c)	8.7 (d)	18 (e)	12.28 (e)	20 (c)	10.4 (d)
Mass Loading (g/cm ³)	4 × 10 ⁻⁵ (f)							
Exposure Frequency (EF) (days/year)	350 (c)	350 (g)	350 (c)	350 (g)	350 (c)	350 (g)	250 (c)	250
Exposure Duration (ED) (years)	24 (c)	7 (g)	6 (c)	2 (g)	30 (c)	9 (g)	25 (c)	4.5 (h)
Conversion Factor (CF) (cm ³ / m ³)	10 ⁶							

Notes:

- | | | | |
|-----------------|---------------------|----------------|-----------------------------|
| Average | Average Exposure | m ³ | Cubic meter |
| cm ³ | Cubic centimeter | pCi | picoCurie |
| g | Gram | RME | Reasonable maximum exposure |
| LTD | Lifetime total dose | | |

a Total number of anomalies in all 30-foot by 30-foot Phase I subgrid in or bordering an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)

b Relative number of anomalies in an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)

c EPA 1995b

d EPA 1995c

e
$$\text{IR}_{\text{Adj}} = \text{age adjusted inhalation rate} \left(\text{IR}_{\text{adult}} \times \frac{\text{ED}_{\text{adult}}}{\text{ED}} \right) + \left(\text{IR}_{\text{child}} \times \frac{\text{ED}_{\text{child}}}{\text{ED}} \right)$$

Where:

IR_{adult} = adult inhalation rate (m³/day)

IR_{child} = child inhalation rate (m³/day)

TABLE P-6 (Continued)

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
INHALATION OF PARTICULATES, RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Notes (Continued):

- f The minimum mass loading value allowed by RESRAD code which is for a future farm scenario (DOE 1993)
- g EPA 1993
- h U.S. Department of Commerce 1994

TABLE P-8

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
INGESTION OF HOMEGROWN PRODUCE^a, RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

$$LTD (pCi) = \left[\sum [F_i \times CR_i \times UF_i] \right] \times EPC_{soil} \times EF \times ED \times MCF$$

Parameter	Resident Adult		Resident Child		Resident Age-Adjusted	
	RME	Average	RME	Average	RME	Average
Fraction Ingested (F _i) (unitless)	(b)	(b)	(b)	(b)	(b)	(b)
Consumption Rate (CR) (g/wet weight/day)	lveg: 14.2 nlveg: 65.8 fr: 42 (c)	lveg: 8.9 nlveg: 41.1 fr: 28 (c)	lveg: 5.7 nlveg: 26.3 fr: 47 (c)	lveg: 3.5 nlveg: 16.5 fr: 31 (c)	lveg: 12.5 nlveg: 57.9 fr: 43 (c,d)	lveg: 7.7 nlveg: 35.6 fr: 28.7 (c,d)
Uptake Factor (UF) (pCi radionuclide/g-plant wet weight) × (pCi radionuclide/g-soil) ⁻¹	(b)	(b)	(b)	(b)	(b)	(b)
Exposure Point Concentration in Soil (EPC _{soil}) (pCi/g)	(e)	(f)	(e)	(f)	(e)	(f)
Exposure Frequency (EF) (days/year)	350 (g)	350 (h)	350 (g)	350 (h)	350 (g)	350 (h)
Exposure Duration (ED) (years)	24 (g)	7 (h)	6 (g)	2 (h)	30 (g)	9 (h)
Conversion Factor (CF) (g/kg)	10 ⁻³	10 ⁻³	10 ⁻³	10 ⁻³	10 ⁻³	10 ⁻³

Notes:

Average	Average Exposure	lveg	Leafy vegetable
fr	Fruit	mg	Milligram
g	Gram	nlveg	nonleafy vegetable
kg	Kilogram	pCi	picoCurie
LTD	Lifetime total dose	RME	Reasonable maximum exposure

^a Ingestion of homegrown produce is only evaluated under the future residential land-use scenario. Homegrown produce are those fruits and vegetables grown in soils at each residence; homegrown produce represents only a fraction of the total amount of produce consumed by each residence.

TABLE P-8 (Continued)

**EXPOSURE DOSE EQUATION AND PARAMETER VALUES FOR
INGESTION OF HOMEGROWN PRODUCE^a, RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Notes (Continued):

- b Values of the parameters F and UF are discussed in Section 3.1.2.4.
- c Homegrown produce ingestion rates under the RME case were estimated by assuming that homegrown vegetables represent 40 percent of the total vegetable intake and homegrown fruits represent 30 percent of the total fruit intake (EPA 1995c). Homegrown produce ingestion rates under the average exposure case were estimated by assuming that homegrown vegetables represent 25 percent of the total vegetable intake and homegrown fruits represent 20 percent of the total fruit intake (EPA 1995c).

Receptor	Produce Type	Total Produce Ingestion Rate (g/day)	RME Homegrown Produce Ingestion Rate (g/day)	Average Exposure Homegrown Produce Ingestion Rate (g/day)
Resident Adult	Vegetables	200 (EPA 1990a)	80	50
	Fruits	140 (EPA 1990a)	42	28
Resident Child	Vegetables	81 (EPA 1995c)	32	20
	Fruits	157 (EPA 1995c)	47	31

Vegetable consumption rates are further separated into leafy and nonleafy vegetables according to the Nuclear Regulatory commission NUREG/CR-5512 for which leafy vegetable represent 17.7 percent of total vegetable intake and nonleafy vegetable represent 82.3 percent of total vegetable intake (NRC 1993).

d $CR_{LAdj} = \text{age adjusted vegetable ingestion rate} \left(CR_{adult} \times \frac{ED_{adult}}{ED} \right) + \left(CR_{child} \times \frac{ED_{child}}{ED} \right)$

Where:

- CR_{adult} = adult consumption rate (g/d)
- CR_{child} = child consumption rate (g/d)

- e Total number of anomalies in all 30 foot by 30 foot Phase I subgrid in or bordering an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)
- f Relative number of anomalies in an exposure area (see Table P-3 for residential land-use scenario and Table P-4 for industrial land-use scenario)

TABLE P-9

**TOTAL ELCRs FOR RADIUM-226 FOR THE SINGLE ANOMALY CASE,
RME AND AVERAGE EXPOSURE CASES
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Total ELCR (residential) = Risk (ground) + Risk (inhalation) + Risk (plant) + Risk (soil)

Total ELCR (industrial) = Risk (ground) + Risk (inhalation) + Risk (soil)

where

Risk (pathway i) = Risk (radium-226 subchain) + Risk (lead-210 subchain)

Exposure Pathway	Radionuclide	Residential ELCRs		Industrial ELCRs	
		RME	Average	RME	Average
Ground	Radium-226	9.9×10^{-7}	3.0×10^{-7}	4.8×10^{-8}	8.7×10^{-9}
	Lead-210	2.2×10^{-11}	6.7×10^{-12}	1.1×10^{-12}	2.0×10^{-13}
Inhalation	Radium-226	2.1×10^{-10}	4.3×10^{-11}	1.9×10^{-11}	1.8×10^{-12}
	Lead-210	3.1×10^{-10}	6.2×10^{-11}	2.8×10^{-11}	2.6×10^{-12}
Plant	Radium-226	1.5×10^{-7}	2.8×10^{-8}	NA	NA
	Lead-210	1.2×10^{-7}	2.4×10^{-8}	NA	NA
Soil	Radium-226	3.9×10^{-9}	6.7×10^{-10}	1.4×10^{-10}	2.4×10^{-11}
	Lead-210	1.3×10^{-8}	2.3×10^{-9}	4.5×10^{-10}	8.2×10^{-11}
Total ELCRs		1×10^{-6}	4×10^{-7}	5×10^{-8}	9×10^{-9}

Notes:

ELCR Excess lifetime cancer risk

NA Not applicable

RME Reasonable maximum exposure

TABLE P-10

**TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-01/21				
016101	1	1×10^{-6}	0.5	2×10^{-7}
016102	1	1×10^{-6}	0.5	2×10^{-7}
019114	4	5×10^{-6}	0.1	4×10^{-8}
019115	4	5×10^{-6}	3.9	1×10^{-6}
020102	1	1×10^{-6}	0.2	7×10^{-8}
020103	1	1×10^{-6}	0.4	1×10^{-7}
020115	5	6×10^{-6}	1.0	4×10^{-7}
020116	2	3×10^{-6}	0.4	1×10^{-7}
021102	1	1×10^{-6}	0.1	5×10^{-8}
021103	1	1×10^{-6}	0.3	1×10^{-7}
021116	2	3×10^{-6}	1.6	6×10^{-7}
IR-02 Northwest				
045109	1	1×10^{-6}	0.3	9×10^{-8}
045110	1	1×10^{-6}	0.7	3×10^{-7}
046110	1	1×10^{-6}	0.02	7×10^{-9}
046111	1	1×10^{-6}	0.1	4×10^{-8}
047109	1	1×10^{-6}	0.04	1×10^{-8}
047110	2	3×10^{-6}	0.9	3×10^{-7}
047111	2	3×10^{-6}	1.0	3×10^{-7}
048108	2	3×10^{-6}	1.5	5×10^{-7}

TABLE P-10 (Continued)

**TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
048109	2	3×10^{-6}	1.1	4×10^{-7}
048110	3	4×10^{-6}	0.6	2×10^{-7}
048111	2	3×10^{-6}	1.1	4×10^{-7}
048112	1	1×10^{-6}	0.2	8×10^{-8}
049108	1	1×10^{-6}	0.3	1×10^{-7}
049111	1	1×10^{-6}	0.3	1×10^{-7}
049112	2	3×10^{-6}	1.1	4×10^{-7}
049113	2	3×10^{-6}	0.3	9×10^{-8}
050109	1	1×10^{-6}	0.04	1×10^{-8}
050112	2	3×10^{-6}	0.7	3×10^{-7}
050113	4	5×10^{-6}	0.9	3×10^{-7}
050114	1	1×10^{-6}	0.4	1×10^{-7}
051108	1	1×10^{-6}	0.04	1×10^{-8}
051109	12	2×10^{-5}	4.0	1×10^{-6}
051110	18	2×10^{-5}	7.8	3×10^{-6}
051111	19	2×10^{-5}	3.1	1×10^{-6}
051112	4	5×10^{-6}	0.9	3×10^{-7}
051113	6	8×10^{-6}	2.8	1×10^{-6}
051114	9	1×10^{-5}	3.1	1×10^{-6}
051115	2	3×10^{-6}	0.2	6×10^{-8}

TABLE P-10 (Continued)

TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
052108	2	3×10^{-6}	1.8	6×10^{-7}
052109	13	2×10^{-5}	5.5	2×10^{-6}
052110	34	4×10^{-5}	12.0	4×10^{-6}
052111	26	3×10^{-5}	11.4	4×10^{-6}
052112	7	9×10^{-6}	1.6	6×10^{-7}
052113	4	5×10^{-6}	0.9	3×10^{-7}
052114	9	1×10^{-5}	4.2	1×10^{-6}
052115	1	1×10^{-6}	0.4	1×10^{-7}
053108	4	5×10^{-6}	1.5	5×10^{-7}
053109	9	1×10^{-5}	2.2	8×10^{-7}
053110	16	2×10^{-5}	4.6	2×10^{-6}
053111	22	3×10^{-5}	10.5	4×10^{-6}
053112	16	2×10^{-5}	2.2	8×10^{-7}
053113	5	6×10^{-6}	1.5	5×10^{-7}
053114	8	1×10^{-5}	4.5	2×10^{-6}
053115	1	1×10^{-6}	0.05	2×10^{-8}
054107	2	3×10^{-6}	0.6	2×10^{-7}
054108	11	1×10^{-5}	5.3	2×10^{-6}
054109	11	1×10^{-5}	2.8	1×10^{-6}
054110	25	3×10^{-5}	9.7	3×10^{-6}
054111	46	6×10^{-5}	16.1	6×10^{-6}

TABLE P-10 (Continued)

TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
054112	23	3×10^{-5}	7.1	2×10^{-6}
054113	14	2×10^{-5}	2.3	8×10^{-7}
054114	9	1×10^{-5}	3.7	1×10^{-6}
055103	1	1×10^{-6}	0.1	2×10^{-8}
055104	1	1×10^{-6}	0.9	3×10^{-7}
055105	2	3×10^{-6}	0.2	7×10^{-8}
055106	4	5×10^{-6}	1.4	5×10^{-7}
055107	3	4×10^{-6}	2.3	8×10^{-7}
055108	10	1×10^{-5}	2.9	1×10^{-6}
055109	24	3×10^{-5}	5.3	2×10^{-6}
055110	29	4×10^{-5}	17.2	6×10^{-6}
055111	37	5×10^{-5}	18.5	6×10^{-6}
055112	23	3×10^{-5}	11.6	4×10^{-6}
055113	10	1×10^{-5}	2.0	7×10^{-7}
055114	10	1×10^{-5}	3.3	1×10^{-6}
056105	2	3×10^{-6}	0.5	2×10^{-7}
056106	4	5×10^{-6}	1.0	3×10^{-7}
056107	6	8×10^{-6}	2.1	7×10^{-7}
056108	14	2×10^{-5}	6.5	2×10^{-6}
056109	26	3×10^{-5}	9.9	3×10^{-6}
056110	28	4×10^{-5}	11.2	4×10^{-6}

TABLE P-10 (Continued)

TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
056111	24	3×10^{-5}	9.0	3×10^{-6}
056112	15	2×10^{-5}	2.9	1×10^{-6}
056113	10	1×10^{-5}	4.7	2×10^{-6}
056114	11	1×10^{-5}	5.4	2×10^{-6}
057106	1	1×10^{-6}	0.9	3×10^{-7}
057107	3	4×10^{-6}	0.1	4×10^{-8}
057108	7	9×10^{-6}	0.9	3×10^{-7}
057109	15	2×10^{-5}	3.5	1×10^{-6}
057110	32	4×10^{-5}	13.3	5×10^{-6}
057111	12	2×10^{-5}	4.5	2×10^{-6}
057112	2	3×10^{-6}	0.2	8×10^{-8}
057113	14	2×10^{-5}	3.9	1×10^{-6}
057114	13	2×10^{-5}	5.7	2×10^{-6}
057115	1	1×10^{-6}	0.2	7×10^{-8}
058107	1	1×10^{-6}	0.3	9×10^{-8}
058108	9	1×10^{-5}	2.5	9×10^{-7}
058109	13	2×10^{-5}	4.9	2×10^{-6}
058110	24	3×10^{-5}	5.2	2×10^{-6}
058111	15	2×10^{-5}	5.1	2×10^{-6}
058112	3	4×10^{-6}	0.6	2×10^{-7}
058113	6	8×10^{-6}	2.5	9×10^{-7}

TABLE P-10 (Continued)

TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
058114	5	6×10^{-6}	1.8	6×10^{-7}
059108	9	1×10^{-5}	4.1	1×10^{-6}
059109	18	2×10^{-5}	7.0	2×10^{-6}
059110	24	3×10^{-5}	12.4	4×10^{-6}
059111	18	2×10^{-5}	4.2	1×10^{-6}
059112	9	1×10^{-5}	4.4	2×10^{-6}
059113	6	8×10^{-6}	1.6	6×10^{-7}
059114	2	3×10^{-6}	1.2	4×10^{-7}
060108	1	1×10^{-6}	0.05	2×10^{-8}
060109	3	4×10^{-6}	0.4	1×10^{-7}
060110	13	2×10^{-5}	3.5	1×10^{-6}
060111	20	3×10^{-5}	6.1	2×10^{-6}
060112	12	2×10^{-5}	4.6	2×10^{-6}
060113	8	1×10^{-5}	2.9	1×10^{-6}
060114	9	1×10^{-5}	0.7	2×10^{-7}
061111	1	1×10^{-6}	0.3	1×10^{-7}
061112	3	4×10^{-6}	0.3	1×10^{-7}
061113	9	1×10^{-5}	3.7	1×10^{-6}
061114	10	1×10^{-5}	3.2	1×10^{-6}
061116	1	1×10^{-6}	0.3	9×10^{-8}
061117	1	1×10^{-6}	0.7	3×10^{-7}

TABLE P-10 (Continued)

TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Central				
062113	2	3×10^{-6}	0.3	1×10^{-7}
062114	3	4×10^{-6}	0.9	3×10^{-7}
062115	8	1×10^{-5}	1.0	3×10^{-7}
063114	1	1×10^{-6}	0.04	1×10^{-8}
063115	8	1×10^{-5}	6.7	2×10^{-6}
063116	7	9×10^{-6}	0.3	9×10^{-8}
066111	1	1×10^{-6}	0.7	2×10^{-7}
067111	1	1×10^{-6}	0.3	1×10^{-7}
078105	1	1×10^{-6}	0.002	6×10^{-10}
079104	1	1×10^{-6}	0.2	6×10^{-8}
079105	1	1×10^{-6}	0.8	3×10^{-7}
IR-02 Southeast				
113103	1	1×10^{-6}	0.1	4×10^{-8}
113104	1	1×10^{-6}	0.7	2×10^{-7}
114103	1	1×10^{-6}	0.01	2×10^{-9}
114104	1	1×10^{-6}	0.2	7×10^{-8}
117100	1	1×10^{-6}	0.05	2×10^{-8}
118099	1	1×10^{-6}	0.2	7×10^{-8}
118100	1	1×10^{-6}	0.7	3×10^{-7}
120098	2	3×10^{-6}	0.5	2×10^{-7}
120099	4	5×10^{-6}	2.1	8×10^{-7}

TABLE P-10 (Continued)

**TOTAL ELCRs FOR RADIUM-226 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Southeast (Continued)				
120100	2	3×10^{-6}	0.1	2×10^{-8}
121098	1	1×10^{-6}	0.5	2×10^{-7}
121099	3	4×10^{-6}	0.9	3×10^{-7}
IR-11/14/15				
092096	1	1×10^{-6}	1.0	4×10^{-7}

Notes:

- ELCR Excess lifetime cancer risk
- RME Residential maximum exposure

TABLE P-11

TOTAL ELCRs FOR RADIUM-226 PER INDUSTRIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-01/21				
AA35	1	5×10^{-8}	1.0	9×10^{-9}
AB39	4	2×10^{-7}	4.0	4×10^{-8}
AC35	1	5×10^{-8}	1.0	9×10^{-9}
AC39	1	5×10^{-8}	1.0	9×10^{-9}
AC40	2	1×10^{-7}	2.0	2×10^{-8}
IR-02 Northwest				
AK37	1	5×10^{-8}	0.3	2×10^{-9}
AK38	2	1×10^{-7}	0.9	8×10^{-9}
AL37	3	1×10^{-7}	3.0	3×10^{-8}
AL38	7	3×10^{-7}	5.2	5×10^{-8}
AL39	2	1×10^{-7}	0.3	3×10^{-9}
AM37	22	1×10^{-6}	11.6	1×10^{-7}
AM38	55	3×10^{-6}	38.4	3×10^{-7}
AM39	18	9×10^{-7}	13.1	1×10^{-7}
AN35	1	5×10^{-8}	0.1	6×10^{-10}
AN36	5	2×10^{-7}	2.7	2×10^{-8}
AN37	47	2×10^{-6}	22.8	2×10^{-7}
AN38	125	6×10^{-6}	97.4	9×10^{-7}
AN39	32	2×10^{-6}	17.4	2×10^{-7}
AO36	3	1×10^{-7}	2.3	2×10^{-8}
AO37	51	2×10^{-6}	30.9	3×10^{-7}

TABLE P-11 (Continued)

**TOTAL ELCRs FOR RADIUM-226 PER INDUSTRIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
AO38	82	4×10^{-6}	51.9	5×10^{-7}
AO39	27	1×10^{-6}	24.0	2×10^{-7}
AP37	17	8×10^{-7}	11.1	1×10^{-7}
AP38	46	2×10^{-6}	35.4	3×10^{-7}
AP39	17	8×10^{-7}	13.4	1×10^{-7}
AP40	1	5×10^{-8}	1.0	9×10^{-9}
IR-02 Central				
AQ39	10	5×10^{-7}	8.7	8×10^{-8}
AQ40	7	3×10^{-7}	0.3	2×10^{-9}
AR38	1	5×10^{-8}	1.0	9×10^{-9}
AV36	1	5×10^{-8}	1.0	9×10^{-9}
IR-02 Southeast				
BH35	1	5×10^{-8}	0.1	1×10^{-9}
BH36	1	5×10^{-8}	0.9	8×10^{-9}
BI34	1	5×10^{-8}	1.0	9×10^{-9}
BJ34	4	2×10^{-7}	4.0	4×10^{-8}
IR-11/14/15				
BA33	1	5×10^{-8}	1.0	9×10^{-9}

Notes:

- ELCR Excess lifetime cancer risk
- RME Residential maximum exposure

TABLE P-12

TOTAL ELCRs RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-01/21				
016101	1	6×10^{-6}	0.5	6×10^{-7}
016102	1	6×10^{-6}	0.5	5×10^{-7}
019114	4	2×10^{-5}	0.1	1×10^{-7}
019115	4	2×10^{-5}	3.9	4×10^{-6}
020102	1	6×10^{-6}	0.2	2×10^{-7}
020103	1	6×10^{-6}	0.4	4×10^{-7}
020115	5	3×10^{-5}	1.0	1×10^{-6}
020116	2	1×10^{-5}	0.4	4×10^{-7}
021102	1	6×10^{-6}	0.1	2×10^{-7}
021103	1	6×10^{-6}	0.3	3×10^{-7}
021116	2	1×10^{-5}	1.6	2×10^{-6}
IR-02 Northwest				
045109	1	6×10^{-6}	0.3	3×10^{-7}
045110	1	6×10^{-6}	0.7	8×10^{-7}
046110	1	6×10^{-6}	0.02	2×10^{-8}
046111	1	6×10^{-6}	0.1	1×10^{-7}
047109	1	6×10^{-6}	0.04	5×10^{-8}
047110	2	1×10^{-5}	0.9	1×10^{-6}
047111	2	1×10^{-5}	1.0	1×10^{-6}
048108	2	1×10^{-5}	1.5	2×10^{-6}
048109	2	1×10^{-5}	1.1	1×10^{-6}

TABLE P-12 (Continued)

**TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
048110	3	2×10^{-5}	0.6	7×10^{-7}
048111	2	1×10^{-5}	1.1	1×10^{-6}
048112	1	6×10^{-6}	0.2	3×10^{-7}
049108	1	6×10^{-6}	0.3	3×10^{-7}
049111	1	6×10^{-6}	0.3	3×10^{-7}
049112	2	1×10^{-5}	1.1	1×10^{-6}
049113	2	1×10^{-5}	0.3	3×10^{-7}
050109	1	6×10^{-6}	0.04	5×10^{-8}
050112	2	1×10^{-5}	0.7	8×10^{-7}
050113	4	2×10^{-5}	0.9	1×10^{-6}
050114	1	6×10^{-6}	0.4	4×10^{-7}
051108	1	6×10^{-6}	0.04	5×10^{-8}
051109	12	7×10^{-5}	4.0	5×10^{-6}
051110	18	1×10^{-4}	7.8	9×10^{-6}
051111	19	1×10^{-4}	3.1	3×10^{-6}
051112	4	2×10^{-5}	0.9	1×10^{-6}
051113	6	3×10^{-5}	2.8	3×10^{-6}
051114	9	5×10^{-5}	3.1	4×10^{-6}
051115	2	1×10^{-5}	0.2	2×10^{-7}
052108	2	1×10^{-5}	1.8	2×10^{-6}

TABLE P-12 (Continued)

**TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION**

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
052109	13	7×10^{-5}	5.5	6×10^{-6}
052110	34	2×10^{-4}	12.0	1×10^{-5}
052111	26	1×10^{-4}	11.4	1×10^{-5}
052112	7	4×10^{-5}	1.6	2×10^{-6}
052113	4	2×10^{-5}	0.9	1×10^{-6}
052114	9	5×10^{-5}	4.2	5×10^{-6}
052115	1	6×10^{-6}	0.4	4×10^{-7}
053108	4	2×10^{-5}	1.5	2×10^{-6}
053109	9	5×10^{-5}	2.2	2×10^{-6}
053110	16	9×10^{-5}	4.6	5×10^{-6}
053111	22	1×10^{-4}	10.5	1×10^{-5}
053112	16	9×10^{-5}	2.2	3×10^{-6}
053113	5	3×10^{-5}	1.5	2×10^{-6}
053114	8	4×10^{-5}	4.5	5×10^{-6}
053115	1	6×10^{-6}	0.05	5×10^{-8}
054107	2	1×10^{-5}	0.6	6×10^{-7}
054108	11	6×10^{-5}	5.3	6×10^{-6}
054109	11	6×10^{-5}	2.8	3×10^{-6}
054110	25	1×10^{-4}	9.7	1×10^{-5}
054111	46	3×10^{-4}	16.1	2×10^{-5}
054112	23	1×10^{-4}	7.1	8×10^{-6}

TABLE P-12 (Continued)

TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
054113	14	8×10^{-5}	2.3	3×10^{-6}
054114	9	5×10^{-5}	3.7	4×10^{-6}
055103	1	6×10^{-6}	0.1	7×10^{-8}
055104	1	6×10^{-6}	0.9	1×10^{-6}
055105	2	1×10^{-5}	0.2	2×10^{-7}
055106	4	2×10^{-5}	1.4	2×10^{-6}
055107	3	2×10^{-5}	2.3	3×10^{-6}
055108	10	6×10^{-5}	2.9	3×10^{-6}
055109	24	1×10^{-4}	5.3	6×10^{-6}
055110	29	2×10^{-4}	17.2	2×10^{-5}
055111	37	2×10^{-4}	18.5	2×10^{-5}
055112	23	1×10^{-4}	11.6	1×10^{-5}
055113	10	6×10^{-5}	2.0	2×10^{-6}
055114	10	6×10^{-5}	3.3	4×10^{-6}
056105	2	1×10^{-5}	0.5	6×10^{-7}
056106	4	2×10^{-5}	1.0	1×10^{-6}
056107	6	3×10^{-5}	2.1	2×10^{-6}
056108	14	8×10^{-5}	6.5	7×10^{-6}
056109	26	1×10^{-4}	9.9	1×10^{-5}
056110	28	2×10^{-4}	11.2	1×10^{-5}
056111	24	1×10^{-4}	9.0	1×10^{-5}

TABLE P-12 (Continued)

TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
056112	15	8×10^{-5}	2.9	3×10^{-6}
056113	10	6×10^{-5}	4.7	5×10^{-6}
056114	11	6×10^{-5}	5.4	6×10^{-6}
057106	1	6×10^{-6}	0.9	1×10^{-6}
057107	3	2×10^{-5}	0.1	1×10^{-7}
057108	7	4×10^{-5}	0.9	1×10^{-6}
057109	15	8×10^{-5}	3.5	4×10^{-6}
057110	32	2×10^{-4}	13.3	1×10^{-5}
057111	12	7×10^{-5}	4.5	5×10^{-6}
057112	2	1×10^{-5}	0.2	2×10^{-7}
057113	14	8×10^{-5}	3.9	4×10^{-6}
057114	13	7×10^{-5}	5.7	6×10^{-6}
057115	1	6×10^{-6}	0.2	2×10^{-7}
058107	1	6×10^{-6}	0.3	3×10^{-7}
058108	9	5×10^{-5}	2.5	3×10^{-6}
058109	13	7×10^{-5}	4.9	6×10^{-6}
058110	24	1×10^{-4}	5.2	6×10^{-6}
058111	15	8×10^{-5}	5.1	6×10^{-6}
058112	3	2×10^{-5}	0.6	7×10^{-7}
058113	6	3×10^{-5}	2.5	3×10^{-6}

TABLE P-12 (Continued)

TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
058114	5	3×10^{-5}	1.8	2×10^{-6}
059108	9	5×10^{-5}	4.1	5×10^{-6}
059109	18	1×10^{-4}	7.0	8×10^{-6}
059110	24	1×10^{-4}	12.4	1×10^{-5}
059111	18	1×10^{-4}	4.2	5×10^{-6}
059112	9	5×10^{-5}	4.4	5×10^{-6}
059113	6	3×10^{-5}	1.6	2×10^{-6}
059114	2	1×10^{-5}	1.2	1×10^{-6}
060108	1	6×10^{-6}	0.05	6×10^{-8}
060109	3	2×10^{-5}	0.4	5×10^{-7}
060110	13	7×10^{-5}	3.5	4×10^{-6}
060111	20	1×10^{-4}	6.1	7×10^{-6}
060112	12	7×10^{-5}	4.6	5×10^{-6}
060113	8	4×10^{-5}	2.9	3×10^{-6}
060114	9	5×10^{-5}	0.7	7×10^{-7}
061111	1	6×10^{-6}	0.3	3×10^{-7}
061112	3	2×10^{-5}	0.3	4×10^{-7}
061113	9	5×10^{-5}	3.7	4×10^{-6}
061114	10	6×10^{-5}	3.2	4×10^{-6}
061116	1	6×10^{-6}	0.3	3×10^{-7}
061117	1	6×10^{-6}	0.7	8×10^{-7}

TABLE P-12 (Continued)

TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
 HUNTERS POINT SHIPYARD
 PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Central				
062113	2	1×10^{-5}	0.3	3×10^{-7}
062114	3	2×10^{-5}	0.9	1×10^{-6}
062115	8	4×10^{-5}	1.0	1×10^{-6}
063114	1	6×10^{-6}	0.04	5×10^{-8}
063115	8	4×10^{-5}	6.7	8×10^{-6}
063116	7	4×10^{-5}	0.3	3×10^{-7}
066111	1	6×10^{-6}	0.7	8×10^{-7}
067111	1	6×10^{-6}	0.3	3×10^{-7}
078105	1	6×10^{-6}	0.002	2×10^{-9}
079104	1	6×10^{-6}	0.2	2×10^{-7}
079105	1	6×10^{-6}	0.8	9×10^{-7}
IR-02 Southeast				
113103	1	6×10^{-6}	0.1	1×10^{-7}
113104	1	6×10^{-6}	0.7	8×10^{-7}
114103	1	6×10^{-6}	0.01	6×10^{-9}
114104	1	6×10^{-6}	0.2	2×10^{-7}
117100	1	6×10^{-6}	0.05	5×10^{-8}
118099	1	6×10^{-6}	0.2	2×10^{-7}
118100	1	6×10^{-6}	0.7	8×10^{-7}
120098	2	1×10^{-5}	0.5	5×10^{-7}
120099	4	2×10^{-5}	2.1	2×10^{-6}

TABLE P-12 (Continued)

TOTAL ELCRs FOR RADON-222 PER RESIDENTIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Residential Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Southeast (Continued)				
120100	2	1×10^{-5}	0.1	6×10^{-8}
121098	1	6×10^{-6}	0.5	6×10^{-7}
121099	3	2×10^{-5}	0.9	1×10^{-6}
IR-11/14/15				
092096	1	6×10^{-6}	1.0	1×10^{-6}

Notes:

ELCR Excess lifetime cancer risk
RME Residential maximum exposure

TABLE P-13

TOTAL ELCRs FOR RADON-222 PER INDUSTRIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-01/21				
AA35	1	2×10^{-7}	1.0	2×10^{-8}
AB39	4	9×10^{-7}	4.0	8×10^{-8}
AC35	1	2×10^{-7}	1.0	2×10^{-8}
AC39	1	2×10^{-7}	1.0	2×10^{-8}
AC40	2	4×10^{-7}	2.0	4×10^{-8}
IR-02 Northwest				
AK37	1	2×10^{-7}	0.3	5×10^{-9}
AK38	2	4×10^{-7}	0.9	2×10^{-8}
AL37	3	7×10^{-7}	3.0	6×10^{-8}
AL38	7	2×10^{-6}	5.2	1×10^{-7}
AL39	2	4×10^{-7}	0.3	6×10^{-9}
AM37	22	5×10^{-6}	11.6	2×10^{-7}
AM38	55	1×10^{-5}	38.4	8×10^{-7}
AM39	18	4×10^{-6}	13.1	3×10^{-7}
AN35	1	2×10^{-7}	0.1	1×10^{-9}
AN36	5	1×10^{-6}	2.7	6×10^{-8}
AN37	47	1×10^{-5}	22.8	5×10^{-7}
AN38	125	3×10^{-5}	97.4	2×10^{-6}
AN39	32	7×10^{-6}	17.4	4×10^{-7}
AO36	3	7×10^{-7}	2.3	5×10^{-8}

TABLE P-13 (Continued)

TOTAL ELCRs FOR RADON-222 PER INDUSTRIAL EXPOSURE AREA
HUNTERS POINT SHIPYARD
PARCEL E REMEDIAL INVESTIGATION

Industrial Exposure Area	RME		Average Exposure	
	Number of Anomalies	ELCR	Number of Anomalies	ELCR
IR-02 Northwest (Continued)				
AO37	51	1×10^{-5}	30.9	6×10^{-7}
AO38	82	2×10^{-5}	51.9	1×10^{-6}
AO39	27	6×10^{-6}	24.0	5×10^{-7}
AP37	17	4×10^{-6}	11.1	2×10^{-7}
AP38	46	1×10^{-5}	35.4	7×10^{-7}
AP39	17	4×10^{-6}	13.4	3×10^{-7}
AP40	1	2×10^{-7}	1.0	2×10^{-8}
IR-02 Central				
AQ39	10	2×10^{-6}	8.7	2×10^{-7}
AQ40	7	2×10^{-6}	0.3	6×10^{-9}
AR38	1	2×10^{-7}	1.0	2×10^{-8}
AV36	1	2×10^{-7}	1.0	2×10^{-8}
IR-02 Southeast				
BH35	1	2×10^{-7}	0.1	2×10^{-9}
BH36	1	2×10^{-7}	0.9	2×10^{-8}
BI34	1	2×10^{-7}	1.0	2×10^{-8}
BJ34	4	9×10^{-7}	4.0	8×10^{-8}
IR-11/14/15				
BA33	1	2×10^{-7}	1.0	2×10^{-8}

Notes:

ELCR Excess lifetime cancer risk
RME Residential maximum exposure