Plum Brook Reactor Facility

Final Status Survey Report

Attachment 13

Revision 1

Primary Pump House
(Building 1134)

FINAL STATUS SURVEY REPORT
ROUTING AND APPROVAL SHEET

Document Title: Final Status Survey Report,
Attachment 13
Primary Pump House (Building 1134)

Revision Number: 1

ROUTING

	SIGNATURE	DATE
Prepared By	B. Mann	1/4/12
Prepared By	N/A	
REVIEW & CONCURRENCE		
Independent Technical Reviewer	R. Case	1/4/12
Other Reviewer, QA Manager	J. Thomas	1/4/12
Other Reviewer	N/A	
FSS/Characterization Manager	W. Stoner	1/4/12
NASA Project Radiation Safety Officer	W. Stoner	1/4/12

<table>
<tr><th colspan="3">NASA PBRF DECOMMISSIONING PROJECT
CHANGE/CANCELLATION RECORD</th></tr>
<tr><td>DOCUMENT TITLE: Final Status Survey Report, Attachment 13, Primary Pump House (Building 1134)</td><td>DOCUMENT NO: N/A</td><td>REVISION NO: 1</td></tr>
<tr><td colspan="3"><u>Revision 0</u>: Initial issue of Report</td></tr>
<tr><td colspan="3"><u>Revision 1</u>: Page 27 of the text is revised to correct a typographical error in the 4^{th} bullet of paragraph 2.</td></tr>
</table>

Form
AD-01/3
Rev 1

LIST OF EFFECTIVE PAGES

DOCUMENT NO: N/A **REVISION NO: 1**

Page No.	Revision Level	Page No.	Revision Level	Page No.	Revision Level
Cover Page	1				
Routing & Approval Sheet	1				
Change/Cancellation Record	1				
LOEP	1				
TOC	0				
List of Tables & List of Figures	0				
List of Acronyms & Symbols, 2 pages	0				
Text, pages 1 through 26	0				
Text, page 27	1				
Text, pages 28 through 35	0				
Appendix A 22 pages	0				
Appendix B 45 pages	0				

Form
AD-01/5
Rev 2

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS & SYMBOLS

α	alpha; denotes alpha radiation, also type I error probability in hypothesis testing
AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
AF	Area Factor
β	beta; denotes beta radiation, also type II error probability in hypothesis testing
b_i	background counts in observation interval
B_R	Background count rate
BPL	Byproduct License
CFR	Code of Federal Regulations
cm	centimeters
cm^2	square centimeters
cpm	counts per Minute
CV	Containment Vessel, the large steel shell surrounding the reactor vessel and adjacent equipment rooms
Δ	delta, $DCGL_W$ – LBGR
d'	Scan surveyor sensitivity index
DCGL	Derived Concentration Guideline Level
$DCGL_{EMC}$	DCGL for small areas of elevated activity, used with the Elevated Measurement Comparison test (EMC)
$DCGL_W$	DCGL for average concentrations over a survey unit, used with statistical tests. (the "W" suffix denotes "Wilcoxon")
dpm	disintegrations per minute
E_i	Detector, or instrument efficiency
E_s	Surface efficiency
E_t	Total efficiency
EMC	Elevated Measurement Comparison
EPA	US Environmental Protection Agency
FSS	Final Status Survey
FSSP	Final Status Survey Plan
FSSR	Final Status Survey Report
γ	gamma; denotes gamma radiation
g	gram
gpm	gallons per minute
HTD	Hard To Detect
hr	hour
HSOO	Health Safety Operations Office
i	observation counting interval during scan surveys
in.	inch
LMI	Ludlum Measurements, Inc.
LBGR	Lower Bound of the Gray Region
m^2	square meters
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration

LIST OF ACRONYMS & SYMBOLS, Continued

MDC_{scan}	Minimum Detectable Concentration for scanning surveys
MDC_{static}	Minimum Detectable Concentration for static surface activity measurements
MDCR	Minimum Detectable Count Rate
mrem	millirem
MOTA	MOTA Corporation, now a subsidiary of Seimplekamp
MW	Megawatt
MWH	Montgomery Watson Harza, Inc.
NASA	National Aeronautics and Space Administration
N	Number of FSS measurements or samples established in a survey design
N/A	Not Applicable
NRC	US Nuclear Regulatory Commission
PCW	Primary Cooling Water
PBRF	Plum Brook Reactor Facility
PNL	Pacific Northwest Laboratory
PPH	Primary Pump House (Building 1134)
Φ	Standard normal distribution function
p	surveyor efficiency for scan surveys
pCi/g	picocuries per gram
%	percent
QC	Quality Control
RAMS	Remote Area Monitoring System
RESRAD	RESidual RADioactive – a pathway analysis computer code developed by Argonne National Laboratory for assessment of radiation doses. It is used to derive cleanup guideline values for soils contaminated with radioactive materials
RESRAD-BUILD	A companion code to RESRAD for evaluating indoor building contamination and developing site-specific DCGLs
ROLB	Reactor Office and Laboratory Building, Building 1141
s	seconds
σ	generic symbol for standard deviation of a population
SAIC	Science Applications International Corporation
SCW	Secondary Cooling Water
SEMS	Stack Effluent Monitoring System
SNL	Sandia National Laboratory
SR	Survey Request
t_b	background count time
t_s	sample count time
TBD	Technical Basis Document
μ	Mean activity concentration
UCM	Unusual Condition Measurement
UL	Upper limit of the confidence interval about the mean
VSP	Visual Sample Plan
$Z_{1-\alpha}$	Proportion of standard normal distribution values less than $1-\alpha$
$Z_{1-\beta}$	Proportion of standard normal distribution values less than $1-\beta$
∞	Mathematical symbol for infinity

1.0 Introduction

This report presents the results of the final status radiological survey of the Plum Brook Reactor Facility (PBRF) Primary Pump House (PPH, Building 1134). It is Attachment 13 of the PBRF Final Status Survey Report (FSSR). [1] This attachment describes the PPH, its operational history and final condition for the final status survey (FSS). It describes the methods used in the FSS and presents the results of the survey measurements.

As stated in the PBRF Final Status Survey Plan (FSSP) [NASA 2007], the goal of the decommissioning project is to release the facility for unrestricted use in compliance with the requirements of US NRC 10CFR20 Subpart E. The principal requirement is that the dose to future site occupants will be less than 25 mrem/y. Subpart E also requires that residual contamination be reduced to levels as low as reasonably achievable (ALARA). A Derived Concentration Guideline Level (DCGL) for residual surface contamination has been established for the PPH. Considering the radionuclide mixtures established for the PPH, the gross activity DCGL is 26,348 dpm/100-cm^2.[2]

The survey measurement results and supporting information presented herein demonstrate that residual contamination levels in each survey unit of the PPH are well below the DCGL. Additionally, it is shown that residual contamination has been reduced to levels that are consistent with the ALARA requirement. Therefore, the PPH meets the criteria for unrestricted release.

Section 2.0 of the report provides a description of the PPH. This includes the building layout, its relation to other PBRF buildings and facilities, design and materials of construction, building contents and use, systems and services, building modifications, final configuration for the FSS and scope of the FSS for this building.

A brief history of operations is presented in Section 3.0. A chronology of significant milestones is followed by history of operations with radioactive materials. Post shutdown and decommissioning activities are summarized.

Section 4.0 presents the FSS design for the PPH. This section includes applicable FSS Plan requirements, breakdown into survey units and assignment of MARSSIM classification to each, the survey design approach, instrumentation used for the FSS and measurement sensitivities.

Survey results are presented in Section 5.0. This section includes a summary of the FSS measurements performed in the PPH survey units, comparison to the DCGL, tests performed and an evaluation of residual contamination levels relative to the ALARA criterion.

Supporting information is contained in Appendices. Appendix A contains photos and schematics to supplement the text. Survey design maps, tables of coordinates and total surface beta measurement results for each survey unit are provided in Appendix B.

---

[1] The PBRF Final Status Survey Report comprises the report main body and several attachments. The attachments present survey results for individual buildings and open land areas. The entire final report will provide the basis for requesting termination of NRC Licenses TR-3 and R-93 in accordance with 10CFR50.82 (b) (6).

[2] As discussed in Section 4.0, in accordance with PBRF-TBD-07-001 [PBRF 2007] the gross activity DCGL is 26,348 dpm/100-cm^2 for all the PPH areas except Room 4, which due to the unique radionuclide mix, was assigned a DCGL of 11,186 dpm/100-cm^2. Also, one soil survey unit was established in the PPH. The DCGL for this survey unit is 6.23 pCi/g.

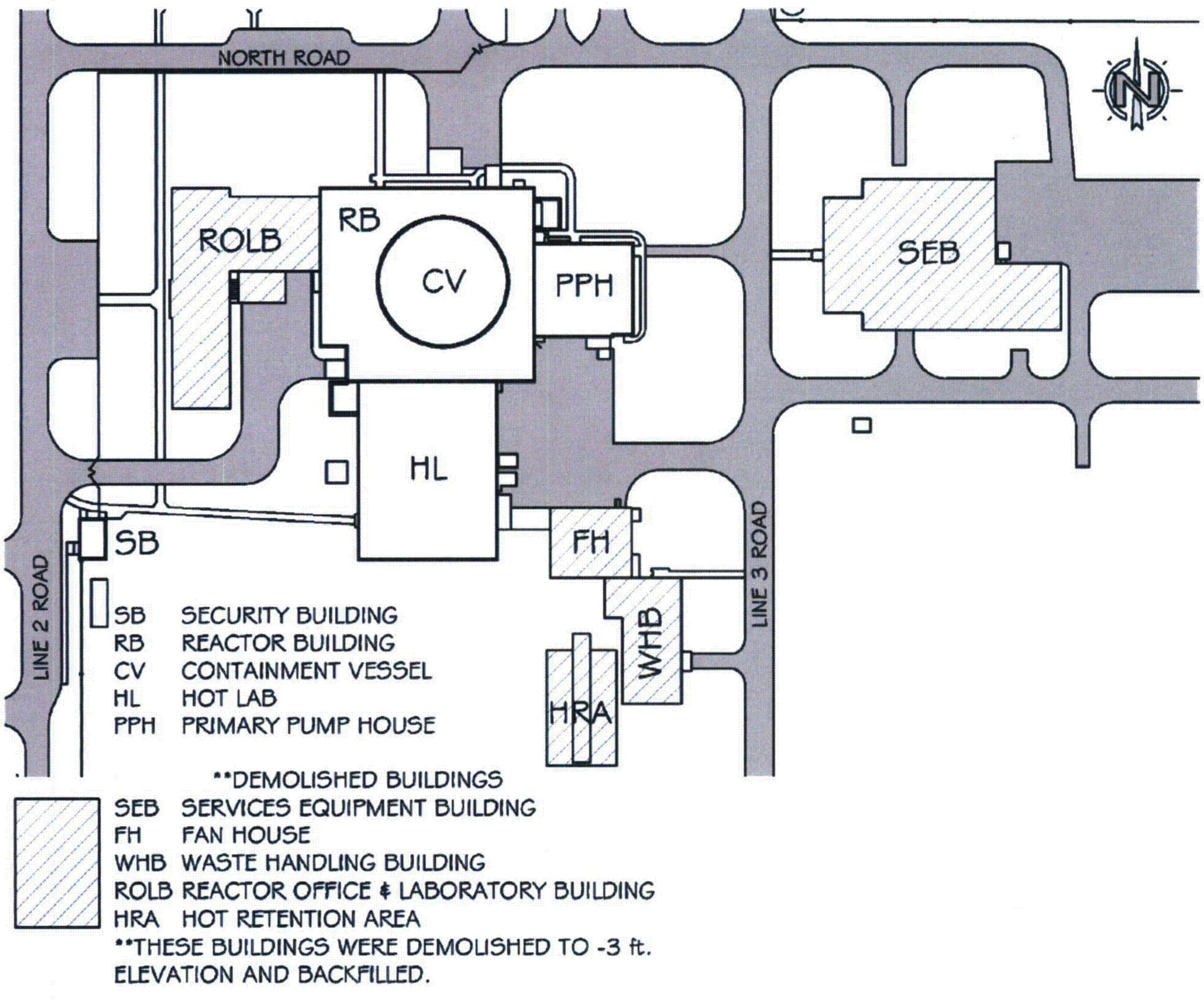
2.0 Primary Pump House Description

The Primary Pump House is located adjacent to and shares a common wall on the east side of the Reactor Building. It housed the major components of the reactor primary cooling water system. This included primary coolant pumps (three 8650 gpm pumps), two large heat exchangers, flow measuring and coolant monitoring equipment, a cleanup system and a fuel element test rig.

2.1 Building Layout and Construction

Figure 1, a map of the PBRF main facility area shows the Reactor Building and adjacent support buildings, the Primary Pump House and Hot Lab. Views of the PPH exterior are shown in Exhibit 1 of Appendix A. The PPH is of concrete construction with walls and roof designed to provide shielding from gamma radiation originating in the primary coolant and contaminated process equipment. The south and east walls contain sections with removable concrete blocks to provide access for large equipment replacement (heat exchangers, pumps, etc).

Figure 1, PBRF NW Area Showing Reactor Building, PPH and Hot Lab



The principal primary cooling water (PCW) system components are located on the main floor (at the PBRF 0 ft. elevation) of the PPH in heavily shielded rooms. The PPH main floor layout is shown in Figure 2. The three main coolant pumps were housed in individual pump rooms (Rooms 1 through 3) located adjacent to the main equipment galley, or Heat Exchanger Room (Room 4). The pumps were located on elevated platforms at the 7ft. 3 in. mezzanine level in each pump room. In addition to the two primary cooling system heat exchangers, Room 4 contained a venturi flow meter, a large strainer, associated PCW and secondary cooling water (SCW) supply and return and vent/relief piping and valves. It also contained PCW connections to the PCW by-pass cleanup system, and the PCW supply head tank (emergency and regular fill lines), and instrumentation (PCW differential pressure for flow, N-16 detector, PCW pressure, etc.).

Figure 2, PPH Main Floor Layout

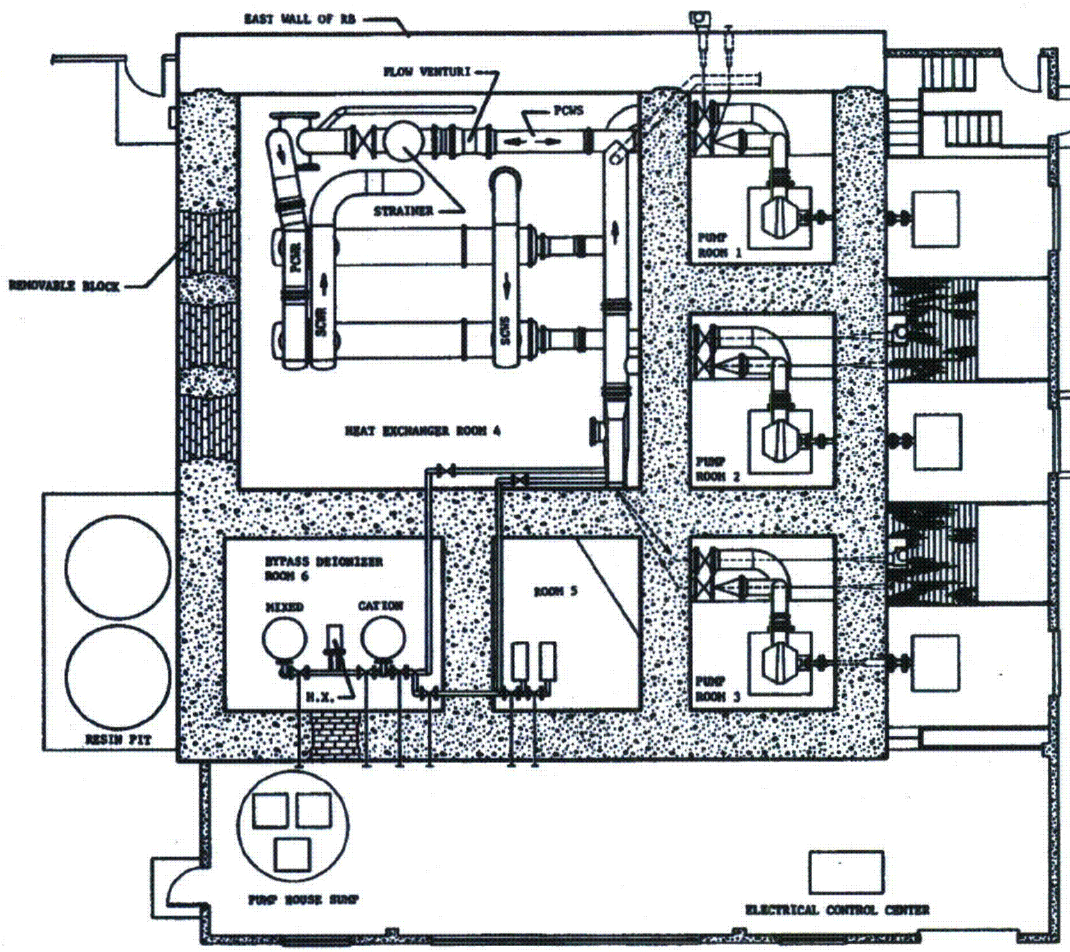


Figure 2 Note: The Resin Pit has been removed (demolished and excavated - 2010).

Rooms 5 and 6 housed PCW liquid and gaseous radioactive waste treatment equipment. Room 5 contained the PCW degassifier system including a degassifier, recirculation pump, steam generator, superheater, recombiner, condenser, vacuum pump, moisture separator, water cooled compressor, gas storage tank and condensate tank with associated piping and instrumentation. Room 6 housed two mixed-bed de-ionizers, two pumps, a filter and one heat exchanger for the by-pass cleanup system, plus associated piping, instrumentation and connections to the waste sump located in Room 8 and the adjacent resin pit.

Room 7, which ran the length of the PPH on the north side of the Pump Rooms at the -4 ft. elevation, included a mezzanine. This was located above and to the north of the Pump Rooms at the 7 ft. 3 in. elevation. This level, housed the three 600 HP PCW pump motors. The main floor of Room 7 served as an operating area. It contained pump motor control centers (the main PCW pump controls were located in the Reactor Control Room) and valve operating extensions. It also contained the fuel element test rig (used to test the mechanical integrity of new reactor fuel elements received from fuel fabrication contractors) on the lower level.

Room 8, on the 0 ft. elevation located on the east side of the PPH adjacent to Rooms 5 and 6 contained an electrical control center, valve extensions, a resin discharge sump, a sampling hood and a monorail crane for removing the PPH waste sump shield plug. A deionizer waste resin pit that was located outside below grade near the southeast corner of the building was connected to the waste resin discharge sump.

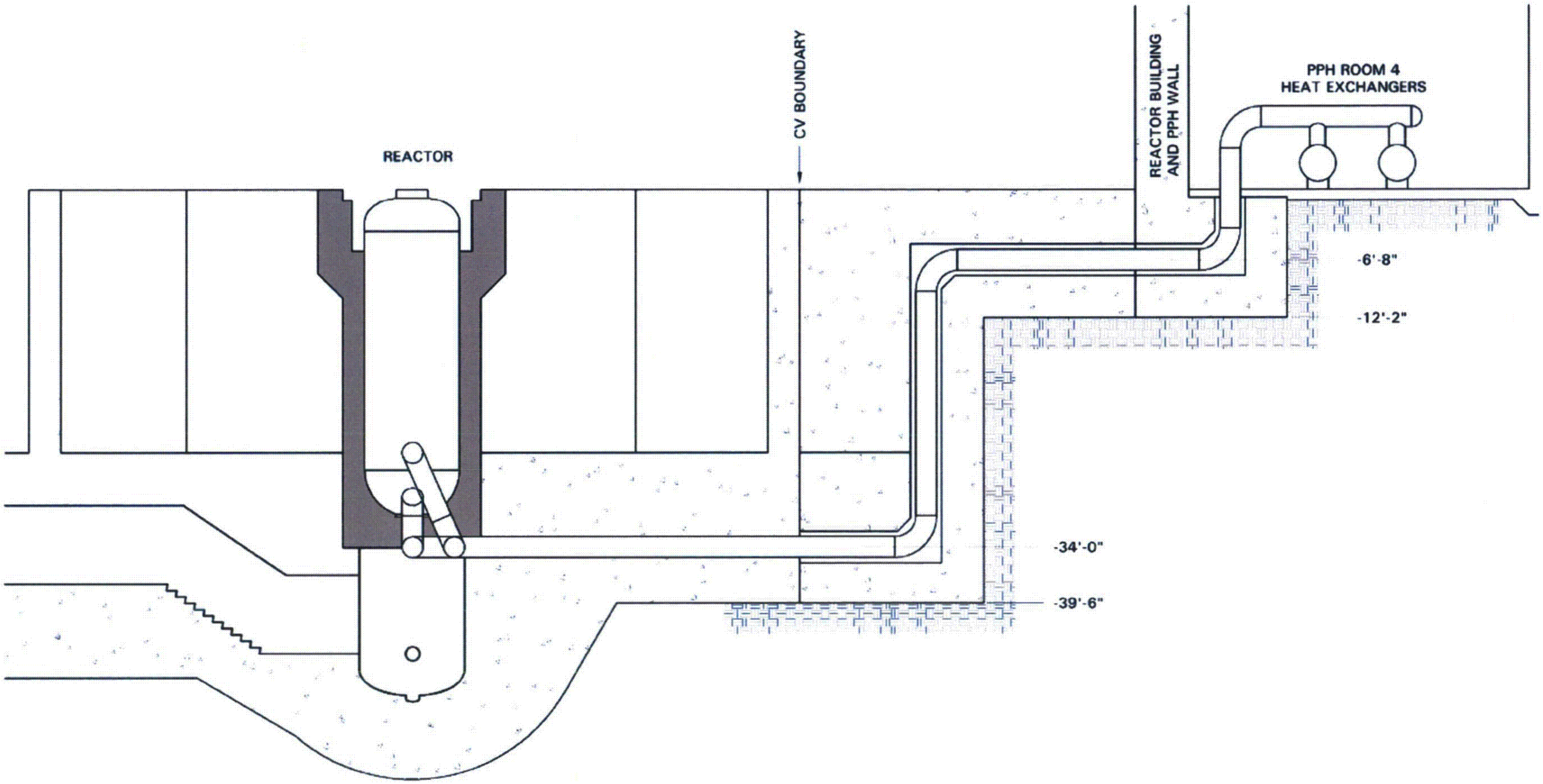
The five ft. thick PPH west wall (common wall with the Reactor Building) extends to the -15 elevation. The south end of the below grade portion of this wall is part of a concrete enclosure surrounding the 24 in. main PCW supply and return piping where it emerges from the PPH. This structure extends from beneath PPH Room 4 to the outer radius of the Reactor Bioshield, a linear distance of approximately 110 ft. From the PPH, the PCW piping runs underneath the Reactor Building and connects to the Reactor Vessel at the – 34 ft. elevation. A schematic of the PCW piping between the PPH and the Reactor Containment Vessel (CV) is shown in Figure 3. The Cold Pipe Tunnel (CPT) passed beneath Room 7, but was not connected to the PPH.[3]

The PPH roof was constructed of three-ft. thick concrete covered with 1" rigid insulation board topped with a built -up 4-ply bitumen and gravel finish. Access to the interior of Rooms 1 to 6 was provided through roof openings (hatchways and manholes) that were normally closed with shield plugs; these shielding plugs were removable using gantry type cranes located at various positions on PPH roof pads. The roof also contained vents and roof drains. The roof perimeter was bordered with safety hand-rails.

The PPH was not continuously occupied during PBRF operations. The PPH equipment required only periodic checks to ensure proper performance. During routine operations, personnel periodically entered Rooms 7 and 8 to monitor equipment, take primary water samples and collect operational data. The equipment rooms (Rooms 1 through 6) were primarily accessed only for equipment repair, maintenance or modification. These rooms were generally "high radiation areas" during reactor operations. Routine personnel access to the PPH was provided through a door on the west side connecting Room 7 directly to the Reactor Building. Personnel doors on the south and north sides provided access from outside at grade level. A ladder mounted on the south exterior provided personnel access to the roof area. A large truck door was located on the east side of the building.

[3] The FSS of the CPT is reported as part of the Service Equipment Building in Attachment 2 of the PBRF FSS Report.

Figure 3, Schematic Showing Main PCW Piping Between PPH and Reactor Building



2.2 Building Systems and Services

In addition to the PCW and process systems described above, the PPH was connected to most of the PBRF common building services and utilities. These included station electric power, high and low pressure steam for process system and space heating, domestic water, fire protection, secondary cooling water and building ventilation. No sanitary sewer connections were provided to the PPH. Of special note are radioactive process waste handling and monitoring systems. These include the PPH ventilating air system, the hot drain system and the Remote Area Monitoring System (RAMS).

The PPH ventilating system was designed to maintain negative air pressure in the building interior by pulling outside air through roof plug and wall penetration interfaces, valve stems, pipes and conduits. Contaminated air was collected by vent risers in the Heat Exchanger Room, the three pump rooms, the degassifier room (Room 5), the bypass deionizer cleanup room (Room 6), and the PPH sump (which collected contaminated air from the resin pit and the sump tank). A 6 in. fresh air inlet line provided a continuous purge of the sump. There were also vent relief valves located on the primary pumps, the primary pump inlet header and the PCW strainer and PCW line shutoff valves. These vented air and primary coolant to the floor drains. The eight vent risers drew air from the aforementioned vents, valve stem seals, roof plugs, pipe and conduit seals and the discharge from the PCW degassifier gas storage tank in a manner that induced uncontaminated air inflow from outside the PPH to the contaminated spaces inside the building. The vent risers exhausted to the eight inch PPH ventilating air line which connected to the Fan House via the underground ventilation exhaust header. Exhaust air from the PPH and other PBRF buildings was filtered and monitored prior to release to the Fan House Stack.

Contaminated water from PPH equipment drains and floor drains was collected in the main PPH sump located below grade in the south end of Room 8. This sump connected to underground Hot Drain System collection piping that fed contaminated waste water to the Hot Retention Area tanks for storage and processing as described in Attachment 5 of the FSS Report.

The RAMS provided essential information on PPH conditions, as the building was not routinely occupied. The system provided continuous radiation monitoring information to the Health Safety Operations Office (HSOO) in the Reactor Office and Laboratory Building (ROLB) and to a panel in the Reactor Control Room (in the Reactor Building). The RAMS had the capacity to receive information from up to 100 field monitoring units located throughout the PBRF. Field units included radiation detection instruments for monitoring airborne activity (particulate and radioiodine), activity in process water and direct radiation levels. The base units (containing receiver channels, recorders and alarm annunciators) were located in the HSOO. Detectors for airborne particulate activity and direct radiation were located in PPH Room 7 on the mezzanine level (12 ft. elevation) and in Room 8 near the south door.[4]

2.3 Building Modifications

The PPH was operated as designed and built, with only minor modifications after initial startup. The external ladder to the roof was removed and a stair case added in the 1960s to provide a safer means for personnel access to the roof. A PCW sampling hood was added to Room 8 and the fission product monitoring system removed in about 1969. The roof was modified sometime in the 1980-90 time period, with the addition of a foam sealant layer to minimize rainwater leakage into the building. Also, the roof was repaired during decommissioning (circa 2006) to mitigate rainwater in-leakage.

2.4 Final Configuration and Scope

Configuration of the PPH for the FSS and the period until license termination is controlled by PBRF decommissioning and FSS procedures. The structure was intact for the FSS except for the following:

- the floor concrete of Room 3 was removed (a soil survey unit was added to cover the exposed soil beneath),
- the concrete roof plugs were removed[5] and
- the Resin Pit formerly located adjacent to the south wall has been removed by excavation.[6]

For the FSS, the PPH was essentially stripped of equipment and fixtures (see Section 3.5 for a summary of equipment removal and preparation of surfaces). Utilities and services are limited to temporary lighting and power. The scope of the FSS includes the basic building structure interior surfaces and exterior walls and roof. Primary Pump House conditions at the time of the FSS are illustrated by photos in Appendix A (see Exhibit 1 and Exhibits 4 through 20).

3.0 History of Operations

A chronology of major PBRF milestones which include the PPH is given below. This is followed by a discussion of building operations, post-shutdown and decommissioning activities. Emphasis is on

[4] Descriptions of the RAMS are provided in the PBRF Operations Procedures Manual, system Procedure OSY-7617 located in PBRF Records Management Files Box #23, Remote Area Monitoring System. Also, PBRF Training Manual, Section 8.4, Remote Area Monitoring System.

[5] Materials removed from PBRF facilities prior to FSS are evaluated for disposition under PBRF Radiological Control Procedures, primarily RP-008, *Radiological Release of Equipment, Material and Vehicles*.

[6] The FSS of the excavated area formerly occupied by the Resin Pit is reported in Attachment 16 of the PBRF FSS Report.

operations with radioactive materials that could affect the final building condition and final status survey.[7]

3.1 Chronology

Major PBRF and PPH milestones are listed below:

1956 – September, groundbreaking for PBRF.

1957 – PPH construction initiated.

1959 – PPH structure completed.[8]

1961 – June, 60 MW Test Reactor critical.

1963 – Full Power 60 MW Test Reactor Operations begin.

1973 - January 5th, Reactor shutdown (after 152 "cycles").

1973 – June 30, PBRF facilities placed in "standby condition".

1985 – Initial radiological characterization, Teledyne Isotopes Inc.

1989 – Follow-up radiological characterization, GTS-Duratek.

2002 – Decommissioning Plan approved; initial equipment removal and building decontamination.

2006- 2010 - Remediation of PPH contaminated areas and preparation for FSS.

2011 – FSS measurements completed.

3.2 Startup and Operations

Construction of the PPH was mostly completed in the 1959-1960 timeframe. The PPH was an integral part of reactor operations and it was utilized throughout the reactor operations period and during preparation for reactor standby status in 1973. The PPH systems were first utilized in 1960 for hydraulic testing of the primary cooling water system before reactor criticality in June 1961 and subsequently for low power testing. The PPH building was utilized from 1960 through the period of PBRF 60MW test reactor operations from June 1961 to January 1973,

---

[7] Information sources for the history and pre-decommissioning period include, construction photos, construction drawings, PBRF operating cycle reports, Radiochemistry periodic reports, PBRF Annual Reports, Unusual Occurrence Files, memoranda and other historical files maintained by PBRF Document Control.

[8] Construction photos show that PPH construction was underway in 1957 and the structure completed in 1959 [PBRF 2009].

and then for a short period post shutdown to clean the system and prepare it for standby condition.

3.3 Radioactive Materials in the PPH

The US Atomic Energy Commission (AEC) authorized operations and use of radioactive materials at the PBRF under several licenses.[9] License No.TR-3 (Docket 50-30) authorized the 60 MW test reactor. The 100 KW mock-up reactor was licensed under License No. R-93. A broad byproduct license (BPL) No. 34-06706-03, authorized possession and use of radioactive materials (byproduct material) produced by the Plum Brook 60MW and Mockup reactors and other radioactive materials [PBRF 2009].

The main source of radiation fields and radioactive materials in the PPH was the primary cooling water which carried activation and fission products from the reactor core where they were deposited throughout the PCW piping and components. Radioactive materials were removed from the coolant by the by-pass cleanup and degassifier systems. In addition to the primary circuit piping and components and cleanup systems, the resin disposal system, hot drains and sumps, ventilation systems and sample collection points were contaminated.

Radioactive materials (primary cooling water, resins and other samples) were routinely transported from the PPH to the radiochemistry and metallurgy laboratories in the ROLB. For example, primary reactor coolant samples were routinely carried from Room 8 in lead casks or other shielded containers for counting and analysis in the radiochemistry labs. This process occasionally led to minor spills. In addition, contamination occurred in various locations from PCW valve leakage, PCW main and auxiliary pump seal leakage or failure, and maintenance activities such as PCW strainer cleanout and pump replacement. The PPH was designed and operated to confine and control leaks and spills from potential sources (PCW water leakage, ventilating air, spent resins, etc.). They were contained and directed to hot storage facilities and systems where they were sampled, monitored and treated to ensure compliance with the AEC regulations prior to release to the environment. However a number of incidents and spills occurred which resulted in contamination of PPH structures.

Unplanned incidents in PBRF facilities, including the PPH, were documented in PBRF Health Safety Operations Office Operations Cycle Reports. Table 1 summarizes the unusual incident reports for PPH related activities.

[9] Authority for the PBRF reactor and radioactive materials licenses was assumed by the US Nuclear Regulatory Commission in 1975.

Table 1, Unusual Incident Reports Involving the PPH (1960-1973)

Report Cycle No.	Date	Description
10	12/26/1963	Contaminated primary cooling water from the Tungsten-185 sampling resin column drained from the Room 8 floor drain to the cold sump at the Reactor Building -15 ft. elevation. It was determined that the Room 8 floor drain was required to be a "hot drain".
11	2/4/1964	Radiation levels of up to 500 mrad/hr were measured on the PCW sampling hood drain line in Room 8. A PCW leak discovered in the rear of the sampling hood had spilled onto the floor. The line was repaired and the floor decontaminated.
12	2/8/1964	Pieces of spiro-helic gasket reading 1.5 Rad/hr were found in the PCW strainer.
15	3/26/1964	Radiation levels of up to 400 mR/hr were measured on the PCW sampling hood drain line. The area was posted and the drain line shielded.
15	4/4/1964	Radiation levels of up to 6.5 rad/hr were measured on piping and valves associated with the PH meter in Room 8. The area was appropriately zoned and posted.
23	9/21/1964	Radiation levels of up to 25 Rad/hr were measured at the fission product monitor cabinet door in Room 8. This was attributed to high PCW activity - probably from minor fuel leaks. Shielding was added.
27	11/8/1964	One gallon of PCW was spilled in Room 8. It drained to a cold floor drain near the PCW sampling hood. The cold floor drain was converted to a hot drain line.
68	10/28/1967	Primary cooling water was discovered to be leaking from the fission product monitor in Room 8. The leak was repaired and the area decontaminated.
80	9/23/1968	While back-flushing the PCW cleanup loop filters, high activity was recorded on the PBRF Stack Effluent Monitoring System (SEMS). A radiation survey of the filter housing recorded 60 mR/hr.
84	12/3/1968	A fan belt failure in the PCW sampling hood caused a buildup of airborne activity from off gassing of a PCW sampling line that was left on slow purge. Airborne activity of 7×10^{-9} μCi/ml beta-gamma was measured in the vicinity. The fan was repaired and air activity was reduced to normal levels.
127	5/21/1971	RAMS #27 indicated high airborne activity on the mezzanine Level near 10P01 pump shaft opening (2×10^{-7} μCi/ml beta-gamma). The opening was calked. During this investigation a small PCW leak (3×10^{-2} μCi/ml) was noted in the PPH-Reactor Building wall. The area was established as a controlled area and a commercial absorbent applied (Zorb-all). The open valve was closed.
136	11/27/1971	Primary cooling water leaking through an open isolation valve and a leaking check valve in PPH Room 8 contaminated the deionized water line in the CPT and the SEB lab. A sample of the contaminated water measured 3×10^{-3} μCi/ml (beta-gamma). The affected lines were purged to the hot drains.
139	2/24/1972	A deionized water sample taken in the PPH Room 8 sink measured 1.2×10^{-4} μCi/ml (beta-gamma). It was suspected that PCW had leaked through the pH meter lines contaminating the truck fill line in Room 8.
148	9/17/1972	A gasket blew out of the north by-pass cleanup deionizer in PPH Room 6 causing an 80-90 gpm PCW leak and resin spill. Three inches of water and resin were found on the floor creating a direct radiation field of 2.5 Rem/hr at three feet. The area was cleaned up and the waste packaged in radwaste drums. Radiation levels of up to 10 R/hr at the drum surfaces and work area fields of up to 5 R/hr were measured.

3.4 Post-Shutdown Materials Disposition and Characterization

In the period following termination of reactor operations in January 1973 and June 30th of 1973, layup of PPH systems was performed in accordance with the PPH "end-condition statement". The PBRF end condition statements governed the status of each system for the protected safe shutdown mode. The end condition statement required flushing, decontaminating the PCW and associated systems and components. Layup efforts included installation of a continuous nitrogen purge system to keep the PCW system dry. Following shutdown, activities were controlled under modified NRC licenses TR-3, R-93 and Byproduct Material License No. 34-06706-03. Selected materials, equipment and waste (both low level radioactive and non-radioactive) were removed to other locations or disposed of. A brief summary of post-shutdown activities is provided in the NASA PBRF Decommissioning Plan, Revision 6 [NASA 2008]. [10]

The radiological status of the PPH has been investigated on several occasions since the PBRF was shutdown in January 1973. The initial post shutdown survey was performed in 1973 by Teledyne Isotopes Inc., the NASA radiological support contractor. The 1973 PPH surveys reported high direct radiation levels in contact with equipment of up to 5 R/hr (West Heat Exchanger – south end) and general area dose rates in equipment rooms of about 5 mR/hr. A summary of the 1973 survey results was provided in the 1987 Teledyne report [TELE 1987].

A comprehensive decommissioning planning and evaluation study was performed by Teledyne Isotopes, Inc. during 1984-86. This study included radiological surveys of most of the PBRF facility [TELE 1987]. The Teledyne Isotopes study reported that all the PPH pumps, other equipment and piping were contaminated and would require removal and disposal as contaminated waste. Piping and equipment residues in the PPH contained primarily Co-60, Sr-90 and Cs-137. Removable surface contamination levels measured on equipment external surfaces ranged up to 26,000 dpm/100-cm^2 beta and 44 dpm/100-cm^2 alpha [TELE 1987].

At the time of the 1984-86 Teledyne study, direct radiation levels in the PPH equipment rooms ranged from < 1 mR/hr up to 75 mR/hr (in the vicinity of the heat exchangers). Removable surface contamination levels on PPH structure surfaces reported in the Teledyne study were low, with maximum smear sample results of 30 dpm/100-cm^2 (both for beta and alpha). It was concluded in the Teledyne report that "the Building 1134 structure has but minimal contamination" [TELE 1987].[11] The PPH was not covered in the 1998 Plum Brook Confirmatory Survey performed by GTS-Duratek [GTS 1998].

3.5 Decommissioning

In October of 2003, the decommissioning contractor performed comprehensive surveys in PPH Rooms 1 through 6 [PBRF 2005]. High levels of total and removable surface contamination were found, with the highest readings summarized in Table 2.

[10] See PBRF Decommissioning Plan, Section 1.2.1 Historical Overview.

[11] In contrast to the Teledyne conclusion that the PPH structure was minimally contaminated, characterization surveys performed during 2003 – 2009 showed extensive contamination of the structure.

Table 2, PPH Pre-decommissioning Survey Results

		Total Surface Activity		Removable Surface Activity	
PPH Room	Equipment or Structure Surface	Beta (1)	Alpha (1)	Beta (1)	Alpha (1)
1	Equipment	980k (2)	389	2k	-
	Struct. Surface	1.3M (3)	502	7k	-
2	Equipment	2.3M	175	370	-
	Struct. Surface	5.3M	267	15k	-
3	Equipment	2.0M	470	2k	-
	Struct. Surface	3.4M	312	20k	-
4	Equipment	1.6M	597	320	103
	Struct. Surface	1.3M	490	2k	21
5	Equipment	550k	239	7k	13
	Struct. Surface	160k	224	120	8
6	Equipment	240k	221	172	42
	Struct. Surface	1.5M	383	145	-

Table 2 Notes:

1. Units are dpm/100-cm^2.
2. k represents kilo or multiplier of 1000.
3. M represents a multiplier of one million.

All equipment housed in the PPH was removed and disposed of as contaminated waste or recyclable materials during 2004 and 2005. All tanks, piping, fans, electrical cabinets, instrument and control panels, metal gratings, etc. were shipped for disposal.

After removal of equipment and piping from the rooms, sub-floor drain and process piping was decontaminated during 2006 and 2007. Following decontamination, the piping was surveyed for FSS using structural DCGL values. Results of the PPH piping FSS are reported in Attachments 9 (Embedded Piping) and 17 (Buried and Miscellaneous Piping) of the PBRF Final Survey Report. The 24 inch PCW piping (including the remnants that entered Room 4) was decontaminated and surveyed to meet FSS Plan embedded piping DCGL values. The piping above 3 ft. below grade was cut off and disposed of. The remaining piping (below 3 ft. below grade) was grouted in place.

Also, during 2006 and 2007, the decommissioning contractor remediated the surfaces of PPH rooms by sponge blasting the walls and ceilings. Floor shaving was performed in rooms 4, 7 and 8. Local areas required aggressive remediation by scabbling and related mechanical means. Core bores were used to remove contaminated concrete around penetrations and to remove local areas of concrete contaminated to depth. Extensive areas of the Room 3 floor were determined to have volumetric contamination above DCGL values and the floor was removed in 2009. See Exhibits 4 through 18 for illustration of the extensive remediation performed in the PPH.[12]

[12] The summary of PPH decommissioning activities is adapted from Survey Design No. 47, Section 2.0, History.

Radiological surveys performed in support of the PPH decommissioning activities are summarized above. The objective of final post-remediation surveys was to ensure that the PPH could satisfy the release criteria with a high probability of success. Surveys were performed in 2006 by the decommissioning contractor in 2006 (MOTA) and by Science Applications International Corporation (SAIC) in 2009 in support of remediation and preparation for FSS.[13]

The radionuclide mixture for development of the PPH gross activity DCGL for the FSS was reported in TBD-07-001 [PBRF 2007]. The information used to develop the radionuclide profile was obtained from characterization samples collected in the PPH in 2003 and other PBRF buildings in 2005.

4.0 Survey Design and Implementation for the PPH

This section describes the method for determination of the number of fixed measurements and samples for the FSS of the PPH. Applicable requirements of the FSS Plan are summarized. These include the $DCGL_W$[14], the gross activity DCGL, scan survey coverage and action-investigation levels, classification of areas and breakdown of the survey units. Radiological instrumentation used in the FSS of the PPH and their detection sensitivities are discussed.

4.1 FSS Plan Requirements

The DCGLs for individual radionuclides were obtained for PBRF structures considering exposure to future site occupants from two potential pathways. Single radionuclide DCGLs were calculated using RESRAD-BUILD Version 3.22 for a building reuse scenario. Single radionuclide volumetric DCGLs were calculated for subsurface structures using RESRAD Version 6.21 for a resident farmer scenario.[15] The volumetric DCGLs (in pCi/g) were converted to "effective surface" DCGLs (in dpm/100-cm^2) using surface-to-volume ratios for the assumed volume of contaminated subsurface concrete. The DCGL calculations are described in the FSSP, Attachment B. To obtain the DCGLs for PBRF structures, the smaller of the two DCGLs calculated for each of the radionuclides of concern were selected.

A gross activity DCGL is used for structural surfaces in the PBRF, where multiple radionuclides are potentially present in residual contamination. The gross activity DCGL accounts for the presence of multiple radionuclides, including beta-gamma and alpha emitters. The gross activity DCGL can also account for so-called hard-to-detect (HTD) radionuclides. The latter are not detected, or detected with very low efficiency, by the beta detectors selected for the FSS of structures.

[13] Final PPH post remediation surveys were performed under Survey Request SR-118.

[14] The convention used in the MARSSIM is to identify the DCGL used as the benchmark for evaluating survey unit measurement results, as the $DCGL_W$. The "W" subscript denotes "Wilcoxon", regardless of the particular test used (Wilcoxon Rank Sum Test, or Sign Test).

[15] Potential exposure to future occupants from subsurface structures could occur from contaminated concrete rubble placed as fill and from contaminated intact structures such as the below-grade portion of the Reactor Bioshield.

The gross activity DCGL for the PPH is calculated using equations in the FSSP for gross beta, gross alpha and surrogate DCGLs, based on the radionuclide mixture in residual contamination. Activity fractions and the gross activity DCGLs for the PPH are shown in Table 3.

Table 3, PPH Radionuclide Activity Fractions and Gross Activity DCGLs

Location	Radionuclides								$DCGL_W$ (dpm/100-cm^2)
	H-3	Co-60	Sr-90	I-129	Cs-137	Eu-154	U-234	U-235	
	Activity Fractions Assigned to PPH (1)								
Room 4 (2)	0.4291	0.0956	0.0256	0.2255	0.1892	0	0.0334	0.0016	11,186
All Other Rooms	0.5422	0.0866	0.0939	0	0.1881	0	0.0805	0.0087	26,348
Exterior Surfaces (3)	0.2707	0.0965	0.0788	0.0142	0.4671	0.0012	0.0698	0.0017	27,166

Table 3 Notes:

1. Activity profiles and gross activity DCGLs for structures are reported in the Technical Basis Document PBRF-TBD-07-001 [PBRF 2007].
2. The DCGL for PPH Room 4 was established in TBD-07-001 as 11,186 dpm/100-cm^2. This was due to the unique radionuclide composition obtained from Room 4 characterization samples whereby I-129 and Co-60 (both with relatively low DCGLs, 14,900 and 11,000 dpm/100-cm^2, respectively) constituted over 1/3rd of the activity.
3. The default radionuclide mixture and DCGL for PBRF structures reported in TBD-07-001 was applied to PPH exterior surfaces.

Survey designs incorporate requirements for scan coverage and investigation levels derived from the MARSSIM classification of survey units. The values applicable to the PPH are shown in Table 4.

Table 4, Class-Based Survey Scan Coverage and Action Level Requirements

Classification	Scan Survey Coverage	Scan Investigation Levels	Static Measurement or Sample Result Investigation Levels
Class 1	100%	$> DCGL_{EMC}$	$> DCGL_{EMC}$
Class 2	10 to 100%	$> DCGL_W$ or $> MDC_{scan}$ if MDC_{scan} is $> DCGL_W$	$> DCGL_W$
Class 3	Minimum of 10%	$> DCGL_W$ or $> MDC_{scan}$ if MDC_{scan} is $> DCGL_W$	$\geq$ 50% of the $DCGL_W$

4.2 Area Classification and Survey Unit Breakdown

The PPH was divided into 12 survey areas, all classified as MARSSIM Class 1, as shown in Table 2-1 of the FSS Plan. As part of the FSS implementation process, individual survey units were identified and their final MARSSIM classification established. The PPH building interior was divided into 30 survey units and the building exterior into 12 survey units, all Class 1, for the FSS. These are identified in Table 5. Table 5 also identifies the Survey Design and Survey Request associated with each survey unit. Table 6 summarizes the survey unit breakdown by major elevation (building interior and exterior).[16]

Table 5, PPH Survey Units for FSS

Survey Unit (1)	Class	Area (m^2)	Survey Design	SR #	Description	Class in FSSP (2)
PH-1-1	1	64.5	27	323/339	Room 1 – Floor, Ceiling, Platform,	1
PH-1-2	1	84.4	27	323/339	Room 1 – Walls	1
PH-1-3	1	64.6	27	323/339	Room 2 – Floor, Ceiling, Platform,	1
PH-1-4	1	84.1	27	323/339	Room 2 – Walls	1
PH-1-5	1	58.7	27	323/339	Room 3 – Floor, Ceiling, Platform,	1
PH-1-6	1	86.9	27	323/339	Room 3 – Walls	1
PH-1-7	1	72.3	27	322/339	Room 4 – Floor Section 1	1
PH-1-8	1	53.1	27	322/339	Room 4 – Floor Section 2	1
PH-1-9	1	99.0	27	322/339	Room 4 – West & North Walls	1
PH-1-10	1	93.8	27	322/339	Room 4 – East & South Walls & Wall penetrations	1
PH-1-11	1	56.4	27	322/339	Room 4 – W Ceiling & Hatchway	1
PH-1-12	1	52.9	27	322/339	Room 4 – E Ceiling & Hatchway	1
PH-1-13	1	40.3	27	323/339	Room 5 – Floor, Ceiling, & Hatchway	1
PH-1-14	1	75.5	27	323/339	Room 5 – Walls	1
PH-1-15	1	51.9	27	323/339	Room 6 – Floor, Ceiling, & Hatchway	1
PH-1-16	1	98.4	27	323/339	Room 6 – Walls	1
PH-1-17	1	69.3	26	132	Room 7 & 8 – Floor Section 1	1
PH-1-18	1	45.2	26	132	Room 7 & 8 – Floor Section 2	1
PH-1-19	1	42.6	26	132	Room 7 & 8 – Floor Section 3	1
PH-1-20	1	56.6	26	132	Room 8 Sump	1
PH-1-21	1	84.1	26	133	Room 7 & 8 – Wall Section 1 & West Stairs	1
PH-1-22	1	95.2	26	133	Room 7 & 8 – Wall Section 2	1
PH-1-23	1	89.2	26	133	Room 7 & 8 – Wall Section 3 & East Stairs	1
PH-1-24	1	71.3	26	133	Room 7 & 8 – Wall Section 4	1
PH-1-25	1	93.7	26	133	Room 7 & 8 – Wall Section 5	1
PH-1-26	1	99.2	26	133	Room 7 & 8 – Wall Section 6	1
PH-1-27	1	94.4	26	133	Room 7 & 8 – Platforms	1
PH-1-28	1	94.1	26	134	Room 7 & 8 – Ceiling Section 1	1
PH-1-29	1	87.1	26	134	Room 7 & 8 – Ceiling Section 2	1
PH-1-30	1	11.4	47	342	Room 3 soil.	1
PH-2-1	1	98.0	68	347/350	Roof Section #1	1

[16] The calculations performed in preparation of this report are documented in a memorandum to the PBRF Decommissioning Project File [PBRF 2011].

Table 5, PPH Survey Units for FSS

Survey Unit (1)	Class	Area (m^2)	Survey Design	SR #	Description	Class in FSSP (2)
PH-2-2	1	98.3	68	347/350	Roof Section #2	1
PH-2-3	1	70.5	68	347/350	Roof Section #3	1
PH-2-4	1	67.0	68	347/350	Roof Section #4	1
PH-2-5	1	93.6	68	347/350	Roof Section #5	1
PH-2-6	1	90.4	68	347/350	Roof Section #6	1
PH-2-7	1	53.0	68	347/350	South Wall - Lower	1
PH-2-8	1	94.2	68	347/350	South Wall – Upper	1
PH-2-9	1	45.6	68	347/350	East Wall - Lower	1
PH-2-10	1	88.0	68	347/350	East Wall - Upper	1
PH-2-11	1	56.8	68	347/350	North Wall - Lower	1
PH-2-12	1	91.5	68	347/350	North Wall - Upper	1

Table 5 Notes:

1. The FSSP Table 2-1 identified 12 PPH survey areas. For the FSS, this was divided into 42 survey units to meet FSS Plan classification-based size limits.
2. The FSS Plan classification was based on area history and available characterization data.

Table 6, PPH Survey Unit Breakdown

Major Elevation	No. of Survey Units	Surface Area (m^2)	% of Survey Units	% of Surface Area
Building Interior	30	2170.2	71	70
Outside Walls & Roof	12	946.9	29	30
Total	42	3117.1	100	100

4.3 Number of Measurements and Samples

The number of measurements and samples for each survey unit was determined using the MARSSIM statistical hypothesis testing framework as outlined in the FSS Plan. The Sign Test is selected because background count rates of instruments to be used are equivalent to a small fraction of the applicable $DCGL_W$.[17] Decision error probabilities for the Sign Test are set at $\alpha = 0.05$ (Type I error) and $\beta = 0.10$ (Type II error) in accordance with the FSSP.

The Visual Sample Plan (VSP) software was used to determine the number of FSS measurements in the PPH. [18] When the Sign Test is selected, the VSP software uses

[17] Background count rates for the LMI 44-116 detector, the instrument of choice for FSS surface beta activity measurements on structures, are in the range of 300 cpm or less for most materials. This is equivalent to about 2500 dpm/100-cm^2 (this assumes a detection efficiency of ~ 12%).

[18] The FSS Plan (Section 5.2.4) states that a qualified software product, such as Visual Sample Plan© [PNL 2010], may be used in the survey design process.

MARSSIM Equation 5-2 to calculate the number of measurements. Equation 5-2 is shown below:

$$N = 1.2 \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4\left[\Phi\left(\frac{\Delta}{\sigma}\right) - 0.5\right]^2}, \qquad \textbf{(Equation 1)}$$

where:

1.2 = adjustment factor to add 20% to the calculated number of samples, per a MARSSIM requirement to provide a margin for measurement sufficiency,
N = Number of measurements or samples,
α = the type I error probability,
β = the type II error probability,
$Z_{1-\alpha}$ = proportion of standard normal distribution < $1 - \alpha$ (1.6449 for σ = 0.05),
$Z_{1-\beta}$ = proportion of standard normal distribution < $1 - \beta$ (1.2816 for β = 0.1),
Φ (Δ/σ) = value of cumulative standard normal distribution over the interval $-\infty$, Δ/σ,
Δ = the "relative shift", defined as the DCGL – the Lower Bound of the Gray Region (LBGR) and
σ = the standard deviation of residual contamination in the area to be surveyed (or a similar area). This may include the variation in measured "ambient" background plus the material background (for total surface beta measurements).

The MARSSIM module of VSP requires user inputs for the following parameters: α, β, LBGR, the $DCGL_W$ and σ. The numbers of measurements were calculated for PPH survey units using the parameters established in five survey designs. Table 7 summarizes the PPH survey design calculations and lists the values of the key VSP input parameters.

Table 7, PPH Survey Design Summary

Design No. (1)	Survey Units	Class	DCGL (2)	LBGR (2)	Δ (2)	σ (2)	Δ/σ	N
26	PH-1-17 through 1-29	1	23,713 (3)	22,807	906	302	3.0	11
27	PH-1-1 through 1-7 & PH-1-13 through 1-16	1	23,713 (3)	19,081	4,632	1,544	3.0	11
27	PH-1-8 through 1-12 (Room 4)	1	10,067 (4)	5,435	4,362	1,544	3.0	11
47	PH-1-30, Room 3 soil	1	6.23 (5)	3.11	3.12	1.25	2.5	11
68	Building Exterior	1	24,449 (6)	12,225	12,225	4,890	2.5	11

Table 7 Notes:

1. The data reported in this table is taken from the Survey Design reports listed. They are maintained in the PBRF Document Control System.
2. Units are dpm/100-cm^2, except for Design 47, where the units are pCi/g.
3. For these designs, the $DCGL_W$ for the survey design calculations, 23,713 dpm/100-cm^2, was obtained by adjusting the DCGL of 26,348 dpm/100-cm^2 published in TBD-07-001, by a factor of 22.5/25 to account for the allocation of 2.5 mrem for "insignificant" radionuclides.
4. The $DCGL_W$ for the survey design calculations, 10,067 dpm/100-cm^2, was obtained by adjusting the DCGL of 11,186 dpm/100-cm^2 published in TBD-07-001, by a factor of 22.5/25 to account for the allocation of 2.5 mrem for "insignificant" radionuclides. See Table 3 notes for an explanation of the relatively low DCGL value for the Room 4 survey units.
5. The DCGL for soil sampling design, per Design 47 DCGL used the radionuclide mixture from PPH structure residual contamination reported in TBD-07-001 [PBRF 2007].
6. The $DCGL_W$ for the survey design calculations, 24,449 dpm/100-cm^2, was obtained by adjusting the DCGL of 27,166 dpm/100-cm^2 published in TBD-07-001, by a factor of 22.5/25 to account for the allocation of 2.5 mrem for "insignificant" radionuclides.

Selection of design input parameters followed guidance in the FSS Plan. The Plan states that "the LBGR is initially set at 0.5 times the $DCGL_W$, but may be adjusted to obtain a value for the relative shift (Δ/σ) between 1 and 3." It is seen in Table 7 that relative shift values of 2.5 and 3.0 were used in the final calculations for determining N.

The VSP software automatically performs an analysis to examine the sensitivity of N, the number of samples, to critical input parameter values. The following is an example obtained from the VSP report for survey unit PH-1-1. The sensitivity of N was explored by varying the following parameters: standard deviation, lower bound of gray region (as % of DCGL), beta, probability of mistakenly concluding that the survey unit mean concentration (μ) is greater than the DCGL and alpha, probability of mistakenly concluding that the survey unit mean concentration is less than the DCGL. Table 8 summarizes this analysis. The region of interest is for $\alpha = 0.05$ (required to be fixed), $\beta = 0.10$ (may be adjusted) and the LBGR at 70% to 90% of the DCGL. With the LBGR set to 90%, doubling σ increases N from 14 to 34. With the LBGR set to 80%, doubling σ increases N slightly (from 11 to 14). The sensitivity of N to an incorrect conclusion that the survey unit will pass (regulator's risk) is quite low; increasing α from 0.05 to 0.10 and 0.15 while holding β constant at 0.10 and σ constant at 1544 dpm/100-cm^2, shows that the number of measurements is 11 or fewer in all cases (when the LBGR is between 80 to 90% of the DCGL). These results show that N = 11 represents a conservative design.

Table 8, Sensitivity Analysis for PPH FSS Design

Number of Samples							
DCGL = 23,713 (1)		$\alpha = 0.05$ (2)		$\alpha = 0.10$		$\alpha = 0.15$	
		$\sigma = 3088$ (1) (3)	$\sigma = 1544$	$\sigma = 3088$	$\sigma = 1544$	$\sigma = 3088$	$\sigma = 1544$
LBGR = 90% (1) (4)	$\beta = 0.05$ (5)	42	17	34	14	28	12
	$\beta = 0.10$	34	14	26	11	21	9
	$\beta = 0.15$	28	12	21	9	17	7
LBGR = 80%	$\beta = 0.05$	17	14	14	11	12	9
	$\beta = 0.10$	14	11	11	8	9	7
	$\beta = 0.15$	12	9	9	7	7	6
LBGR = 70%	$\beta = 0.05$	14	13	11	11	10	9
	$\beta = 0.10$	11	11	9	8	7	7
	$\beta = 0.15$	10	9	7	7	6	6

Table 8 Notes:
1. Units of DCGL, σ and LBGR are dpm/100-cm^2.
2. α = alpha, probability of mistakenly concluding that μ < DCGL.
3. σ = Standard Deviation.
4. LBGR = Lower Bound of Gray Region (as % of DCGL).
5. β = beta, probability of mistakenly concluding that μ > DCGL.

Visual Sample Plan was also used to determine the grid size, the random starting location coordinates and to display the measurement locations on survey unit maps drawn to scale. Refer to Appendix B for location coordinate tables and scale VSP maps showing measurement locations for each PPH survey unit.

The survey designs also specify scan survey coverage and action levels based on the MARSSIM classification listed in Table 4. If the scan sensitivity of the detectors used in Class 1 survey units is below the $DCGL_W$, the number of measurements in each survey unit is determined solely by the Sign Test. If the scan sensitivity is not below the $DCGL_W$, the number of measurements is increased as determined by the Elevated Measurement Comparison (EMC). As discussed in the next section, the scan sensitivities of instruments used in the FSS of the PPH are below the $DCGL_W$, and no increase in the number of measurements above the value calculated using the Sign Test was required.

4.4 Instrumentation and Measurement Sensitivity

Instruments to be used in the FSS of each survey unit are selected in each survey design. Their detection sensitivities must be sufficient to meet the required action levels for the MARSSIM class of each survey unit. Minimum detection sensitivities for direct surface activity static and scan (alpha and beta) measurements are calculated using equations from Section 6.4 of the FSS Plan [NASA 2007]. The static MDC equation is:

$$MDC_{static} = \frac{3 + 3.29\sqrt{B_R t_s (1 + \frac{t_s}{t_b})}}{t_s E_{tot} \frac{A}{100}}, \qquad \textbf{(Equation 2)}$$

where:

MDC_{static} = Minimum Detectable Concentration (dpm/100-cm^2),

B_R = Background Count Rate (cpm),

t_b = Background Count Time (min),

t_s = Sample Count Time (min),

A = Detector Open Area (cm^2) and

E_{tot} = Total Detection Efficiency (counts per disintegration). The total efficiency equals the product of Detector Efficiency, E_i and Surface Efficiency, E_s.

The scan MDC equation is:

$$MDC_{scan} = \frac{d' \sqrt{b_i} \frac{60}{i}}{E_i E_s \sqrt{p} \frac{A}{100}}, \qquad \textbf{(Equation 3)}$$

where:

MDC_{scan} = Minimum Detectable Concentration (dpm/100-cm^2),

d' = Index of sensitivity related to the detection decision error rate of the surveyor, from Table 6.5 of MARSSIM [USNRC 2000],

i = observation counting interval, detector width (cm) / scan speed (s),

b_i = background counts per observation interval,

E_i = Detector Efficiency (counts per disintegration),

Es = Surface Efficiency, typically 25% for alpha and 50% for beta per ISO 7503-1, Table 2 [ISO 1988],

p = Surveyor efficiency (typically 50%) and

A = Detector Open Area (cm^2).

A summary of the a priori detection sensitivities of instruments used in the FSS of the PPH is provided in Table 9.

Table 9, Typical Detection Sensitivities of Field Instruments

Detector Model	Detector Efficiency (c/d) (1)	MDC_{scan} (dpm/100-cm^2) (2) (3)	Net cpm Equivalent to $DCGL_W$	MDC_{static} (dpm/100-cm^2) (2)
LMI 44-116 (4) (5)	0.140	2,587	2,772	589
LMI 44-9 (6)	0.125	11,268	356	3,668

Table 9 Notes:

1. The detector efficiencies listed are total efficiency, i. e., $E_t = E_i + E_s$.
2. A priori scan sensitivities are calculated using Equation 3 and static sensitivities are calculated using Equation 2.
3. The scan MDC for the LMI 44-116 is reported in Design No. 27 for background count rate = 200 cpm; scan speed =15 cm/s and E_s = 0.5. An efficiency correction factor = 0.8349 is applied to compensate for concrete roughness (the detector-to-surface distance is 0.5 in.).
4. The static MDC for the LMI 44-116 detector is reported in Design No. 27 for background count rate = 200 cpm, E_s = 0.5 and the detector-to-surface distance = 0.5 in. (one minute count times are assumed for both the background and sample counts).
5. The scan MDC for the LMI 44-9 is obtained from Survey Design No. 27. The background count rate is 125 cpm with a scan speed of 4.4 cm/s and the detector in contact with the surface. Note that the scan speed is reduced to 2.2 cm/s when the 44-9 is used in Room 4 (PH-1-8 through Ph-1-12) to achieve the necessary sensitivity (MDC_{scan} = 7967 dpm/100-cm^2); as the $DCGL_W$ is only 10,067 dpm/100-cm^2.

6. The static MDC for the LMI 44-9 listed in Table 9 is obtained from Survey Design No. 27. The background count rate is 125 cpm and the detector in contact with the surface (one minute count times are assumed for both the background and sample counts).

The scan investigation level for Class 1 survey units listed in Table 4 is the $DCGL_{EMC}$, as specified in the FSS Plan Section 8.1. However, the scan investigation level is typically set at an instrument count rate corresponding to the $DCGL_W$ established in the survey design for each structure survey unit. For example, as seen in Table 9 above, the 44-116 detector count rate that corresponds to the $DCGL_W$ is 2772 net cpm. In practice, this is rounded downward to 2700 gcpm in typical PPH survey instructions.[19] This practice was established early in the FSS of PBRF structures and has been continued.

It is also noted the FSS Plan states that technicians are to respond to indications of increased count rates even though scan count rates may not be above the investigation level specified in survey instructions.[20]

Scan sensitivities for detectors used for gamma scan surveys of soil are determined using the method referenced in the PBRF FSS Plan and described in NUREG-1507 [USNRC 1998]. Scan sensitivities for the Ludlum Model 44-10 NaI detectors used in FSS of soils at PBRF were developed in a technical basis document [PBRF 2009a]. The method is summarized and the key equations presented. The scan MDC is calculated using the following equations adapted from NUREG-1507 [USNRC 1998] for walkover gamma scanning with NaI detectors:

$$MDCR_{SURV} = \frac{d' \sqrt{bi}}{\sqrt{p}} \left(\frac{60}{i} \right)$$ **(Equation 4)**

$$MDC_{scan} = \frac{MDCR_{surv}}{Conv * MS_O}$$ **(Equation 5)**

where:

MDC_{SURV} = the minimum detectable count rate in cpm that can be reliably detected by the "surveyor",

d' = index of sensitivity, unitless (MARSSIM default value of 1.38 is assigned),

b_i = background counts observed in the interval i,

[19] Note that for the scan survey of PH Room 4 (PH-1-8 through PH-1-12) the scan investigation level for the 44-116 detector is reduced to 1177 ncpm to correspond with the lower DCGL (10,067 dpm/100-cm^2) for these survey units.

[20] From FSS Plan Section 7.1.1: "Technicians will respond to indications of elevated areas while surveying. Upon detecting an increase in visual or audible response, the technician will reduce the scan speed or pause and attempt to isolate the elevated area. If the elevated activity is verified to exceed the established investigation level, the area is bounded (e.g., marked and measured to obtain an estimated affected surface area). Representative static measurements are obtained as determined by the FSS/Characterization Engineer. The collected data is documented on a Radiological Survey Form."

i = observation interval (s),

p = surveyor efficiency, unitless (MARSSIM default value of 0.5 for walkover scans is assigned),

MDC_{scan} = the scan MDC, here in units of pCi/g,

Conv = instrument response conversion factor, units of cpm per μR/hr and

MS_o = instrument response in units of μR/hr per pCi/g (determined empirically or with a shielding algorithm).

Site-specific parameter values for the MDC_{scan} equation are obtained from the technical basis document [PBRF 2009a]. The instrument response factor for Cs-137 is 0.139 μR/hr per pCi/g, calculated using the MicroShield code. The most conservative instrument response conversion factor measured for detectors in the PBRF LMI 44-10 inventory is 232.39 cpm per μR/hr for Cs-137.

Using these values, typical detection sensitivities of the instruments used in the FSS of soil survey units are provided in Table 10. Minimum detectable count rates and MDC_{scan} values for 44-10 detectors operated in the Cs-137 window vs. background count rates are shown in the table.

Table 10, Typical Detection Sensitivities of Field Instruments used for Soil Scans

LMI 44-10 with Cs-137 Window (1)		
Background (cpm) (2)	MDCR (ncpm) (3)	MDC_{scan} (pCi/g)
100	50	1.54
150	60	1.87
200	70	2.14
220 (3)	72	2.24

Table 10 Notes:

1. Ludlum Model 44-10 NaI detector with Model 2350-1 data logging scaler-rate meter setup to count in Cs-137 energy window. Data from Survey Design No. 47. Scan speed = 0.5 m/s, detector to soil surface = 10 cm.
2. Specified as average background count rate.
3. The scan action level for soil scan surveys in PH-1-30 was set at 109 ncpm in Survey Design No. 47, for background count rates of 220 cpm (or less).

Survey instructions include directions to account for unusual measurement conditions. Modified detection sensitivities may be applied taking into account adjustments in detector efficiency. Scan speeds may be reduced to ensure that required scan sensitivities are achieved. The bases for adjustments due to non-standard conditions are provided in PBRF Technical

Basis Documents.[21] Examples of areas or locations in PPH survey units where special measurement conditions apply are shown in Exhibits 16 through 20 of Appendix A.

5.0 PPH Survey Results

Results of the PPH FSS are presented in this section. This includes scan survey results for each survey unit and investigations prompted by scan surveys. Systematic-fixed measurement results for each survey unit and the results of comparison tests of survey unit maximum and average values with the $DCGL_W$ are reported. As discussed below, no statistical tests were required. Static measurements initiated by scan investigations, removable surface activity measurement results and QC measurements are presented. It is shown that levels of residual contamination have been reduced to levels that are ALARA. This section closes with a summary which concludes that applicable criteria for release of the PPH for unrestricted use are satisfied and all FSS Plan requirements are met.

5.1 Scan Surveys

Scan survey results were reviewed to confirm that the scan coverage requirement (as % of survey unit area) was satisfied for all survey units. The results of QC replicate scan surveys were also reviewed to confirm that the minimum coverage requirement of 5% was satisfied. Results of the PPH scan surveys are compiled in Table 11. The table shows that scan coverage requirements were satisfied for all survey units. The table also shows that investigations were performed in seven survey units (all PPH survey units are Class 1).

Table 11, Scan Survey Results

Survey Unit	Class	Scan Survey Coverage (%) (1)	Survey Request No.	Investigation Performed	QC Replicate Scan Coverage (%) (1) (2) (3)
PH-1-1	1	100	323/339	Yes	7.5%
PH -1-2	1	100	323/339	No	7.5%
PH -1-3	1	100	323/339	No	7.5%
PH -1-4	1	100	323/339	No	7.5%
PH -1-5	1	100	323/339	No	7.5%
PH -1-6	1	100	323/339	No	7.5%
PH -1-7	1	100	323/339	Yes	6.7%
PH -1-8	1	100	323/339	No	6.7%
PH -1-9	1	100	323/339	No	6.7%
PH -1-10	1	100	323/339	Yes	6.7%
PH -1-11	1	100	323/339	No	6.7%
PH -1-12	1	100	323/339	No	6.7%
PH -1-13	1	100	323/339	No	7.5%
PH -1-14	1	100	323/339	No	7.5%
PH -1-15	1	100	323/339	Yes	7.5%
PH -1-16	1	100	323/339	Yes	7.5%

[21] The PBRF-TBD-07-004 [PBRF 2007a] presents efficiency correction factors developed for the LMI 44-116 detector. The correction factors are presented as a function of detector-to-surface distance. Application of the factors requires empirical measurements of the effective detector-to-surface distance for areas with non-standard surface conditions as part of the survey unit inspection process.

Table 11, Scan Survey Results

Survey Unit	Class	Scan Survey Coverage (%) (1)	Survey Request No.	Investigation Performed	QC Replicate Scan Coverage (%) (1) (2) (3)
PH -1-17	1	100	132	No	6.4%
PH -1-18 (4)	1	100	132	No	6.4%
PH -1-19	1	100	132	No	6.4%
PH -1-20	1	100	132	Yes	6.4%
PH -1-21	1	100	133	Yes	5.4%
PH -1-22	1	100	133	No	5.4%
PH -1-23	1	100	133	No	5.4%
PH -1-24 (4)	1	100	133	No	5.4%
PH -1-25	1	100	133	No	5.4%
PH -1-26	1	100	133	No	5.4%
PH -1-27 (4)	1	100	133	No	5.4%
PH -1-28	1	100	134	No	6.3%
PH -1-29	1	100	134	No	6.3%
PH-1-30	1	100	342	No	8.8%
PH-2-1	1	100	347/350	No	5.6%
PH-2-2	1	100	347/350	No	5.6%
PH-2-3	1	100	347/350	No	5.6%
PH-2-4	1	100	347/350	No	5.6%
PH-2-5	1	100	347/350	No	5.6%
PH-2-6	1	100	347/350	No	5.6%
PH-2-7	1	100	347/350	No	5.6%
PH-2-8	1	100	347/350	No	5.6%
PH-2-9	1	100	347/350	No	5.6%
PH-2-10	1	100	347/350	No	5.6%
PH-2-11	1	100	347/350	No	5.6%
PH-2-12	1	100	347/350	No	5.6%

Table 11 Notes:

1. Calculated scan % coverage values are rounded to the nearest 1/10th per cent. Values reported with the first decimal as 5, e. g., 5.5, are rounded downward.
2. The % scan coverage is given as the % of the area scanned in the initial survey.
3. Replicate QC scan results are reported for multiple survey units in most Survey Requests. The QC scan percentages are reported as % of the scanned area of the survey units combined. So the same % coverage value is assigned to all of the survey units reported in a Survey Request.
4. One hundred percent of the accessible surface area was scanned. A fraction of the surface area of the survey unit is inaccessible for scanning. In most such survey units, it is less than a few percent of the total surface area.

5.2 Fixed Measurements and Tests

Results of the assessment of PPH FSS total surface beta measurements are presented in Table 12 (individual measurements in each survey unit are reported in Appendix B). The table presents the number of measurements, maximum, average and standard deviation for each survey unit. It compares the maximum activity measured in each survey unit to the $DCGL_W$.[22] It is demonstrated that all measured activity values are less than the $DCGL_W$, thus all survey units meet the 25 mrem/y release criterion. The mean activity of each survey unit is also compared to the $DCGL_W$, and as expected, are all less than the $DCGL_W$. The average of 454 total surface beta measurements reported in the PPH release records is: 775 ± 568 dpm/100-cm^2 (one standard deviation) [PBRF 2011]. [23]

Table 12, PPH Total Surface Beta Activity Measurement Summary and Test Results

Survey Unit ID	No. of Measurements	Maximum (1)	Test Result: Maximum < $DCGL_W$	Average (1)	Standard Deviation (1) (2)	Test Result: Average < $DCGL_W$
PH-1-1	11	1487	Yes	859	319	Yes
PH -1-2	11	1342	Yes	829	242	Yes
PH -1-3	11	1895	Yes	1134	405	Yes
PH -1-4	11	1217	Yes	946	152	Yes
PH -1-5	11	3622	Yes	1307	908	Yes
PH -1-6	11	4849	Yes	1925	1052	Yes
PH -1-7	11	1118	Yes	661	360	Yes
PH -1-8	12	1072	Yes	819	174	Yes
PH -1-9	11	1797	Yes	917	353	Yes
PH -1-10	11	972	Yes	724	126	Yes
PH -1-11	11	928	Yes	687	168	Yes
PH -1-12	11	1469	Yes	756	296	Yes
PH -1-13	11	937	Yes	644	237	Yes
PH -1-14	11	1190	Yes	835	189	Yes
PH -1-15	11	1570	Yes	931	291	Yes
PH -1-16	11	8100	Yes	1943	2065	Yes
PH -1-17	11	627	Yes	378	173	Yes
PH -1-18	11	789	Yes	606	127	Yes
PH -1-19	11	1013	Yes	665	274	Yes
PH -1-20	11	1183	Yes	778	289	Yes
PH -1-21	11	1010	Yes	674	321	Yes
PH -1-22	11	1050	Yes	590	299	Yes
PH -1-23	11	861	Yes	521	270	Yes
PH -1-24	11	975	Yes	729	156	Yes
PH -1-25	11	972	Yes	700	133	Yes
PH -1-26	12	1040	Yes	692	167	Yes
PH -1-27	11	1070	Yes	685	252	Yes
PH -1-28	11	1220	Yes	834	212	Yes
PH -1-29	11	868	Yes	548	157	Yes
PH-2-1	11	948	Yes	530	310	Yes
PH-2-2	11	1301	Yes	469	434	Yes

[22] For comparison of survey unit maximum and average values to the $DCGL_W$, the most restrictive PPH $DCGL_W$, value, 10,067 dpm/100-cm^2, was used.

[23] It is noted that in converting total surface activity measurements in cpm to dpm/100-cm^2, the detector background response from surface materials is not subtracted. As a result, the total surface activity measurement results are biased high.

Table 12, PPH Total Surface Beta Activity Measurement Summary and Test Results

Survey Unit ID	No. of Measurements	Maximum (1)	Test Result: Maximum < $DCGL_W$	Average (1)	Standard Deviation (1) (2)	Test Result: Average < $DCGL_W$
PH-2-3	11	1842	Yes	894	418	Yes
PH-2-4	11	2862	Yes	974	673	Yes
PH-2-5	11	895	Yes	449	346	Yes
PH-2-6	11	1170	Yes	809	218	Yes
PH-2-7	11	2784	Yes	796	724	Yes
PH-2-8	11	1125	Yes	593	229	Yes
PH-2-9	11	732	Yes	360	164	Yes
PH-2-10	12	809	Yes	471	335	Yes
PH-2-11	11	948	Yes	509	316	Yes
PH-2-12	11	1270	Yes	650	342	Yes

Table 12 Notes:

1. The units for: maximum, average and standard deviation are dpm/100-cm^2.
2. Standard deviations of the measurements in each survey unit are reported for comparison to the values used in the survey design. In most PPH structural survey units, values of σ obtained from the FSS measurements are much less than values used in the survey designs, as reported in Table 7. This confirms that the survey designs for the PPH were conservative.
3. In the FSS design calculation for survey units developed using VSP; "extra" fixed measurement locations are sometimes added when "fitting" the calculated grid size onto the survey unit layout.

5.3 Additional Measurements

Additional measurements were performed as a result of investigations initiated during scan surveys of the PPH survey units. The investigations and the results of the investigative static measurements are summarized in Table 13 (investigative measurements are designated as IM-x). It is noted that most of the investigations were initiated when technicians observed increased count rates during scans as opposed to observing count rates above action levels (scan survey action levels in survey instructions are discussed in Section 4.0). As shown in the table, scan investigation-action levels were exceeded in some cases. Also, in one case an investigative static measurement exceed the $DCGL_W$.

Table 13, PPH Investigative Static Measurements

Survey Unit	SR	Static Measurement (dpm/100-cm^2)	Size of Elevated Area (cm^2)	Measurement ID	$DCGL_W$
PH-1-1	323	13,300	100	IM-1	23,713
PH-1-1	323	15,000	100	IM-2	23,713
PH-1-1	323	21,100	100	IM-3	23,713
PH-1-7	322	7,400	100	IM-1	23,713
PH-1-7	322	7,990	100	IM-2	23,713
PH-1-10	322	1,707	100	IM-1	10,067
PH-1-10	322	2,473	100	IM-2	10,067
PH-1-15	133	20,700	100	IM-1	23,713
PH-1-16	133	13,100	100	IM-1	23,713
PH-1-16	133	25,000	100	IM-2	23,713

Table 13, PPH Investigative Static Measurements

PH-1-20	132	16,294	800	IM-1	23,713
PH-1-21	133	5,520	12 (1)	IM-1	23,713

Table 13 Note:
1. Measurement taken with LMI 44-9 detector.

As a result of the investigative static measurement in Survey Unit PH-1-16 which exceeded the DCGL, the elevated measurement comparison (EMC) and elevated measurement test (EMT) were performed. In accordance with the FSS Plan, Section 8.3, the $DCGL_{EMC}$ is calculated as the product of the Area Factor (AF) and the $DCGL_W$. The EMT is defined by the following unity rule equation:

$$\frac{\delta}{DCGL_W} + \frac{(average\ concentration\ in\ elevated\ area) - \delta}{(AF)\ (DCGL_W)} \leq 1.0 \qquad \textbf{[Equation 6]}$$

Where: δ is the average residual activity concentration in the survey unit.

If more than one elevated area is found in a survey unit, the second term in Equation 6 is calculated for each and summed with the first term to perform the unity rule calculation for the EMT. Results of the $DCGL_{EMC}$ and EMT calculations are summarized:

- From Table 13, the size of the elevated area is 100 cm^2; per the FSS Plan Table 3-5, the area factor for elevated areas of size ≤ 0.25 m^2 is 40.2.
- From Table 12, the average residual activity concentration, δ, in Survey Unit PH-1-16 is 1943 dpm/100-cm^2.
- From Table 7, the applicable $DCGL_W$ is 23,713 dpm/100-cm^2.
- The $DCGL_{EMC}$ is calculated to be 9.53E+05 dpm/100-cm^2 (40.2 x 23,713 dpm/100-cm^2); this is much greater than 25,000 dpm/100-cm^2, the measured activity in the elevated area. Thus the elevated measurement comparison is easily satisfied.
- Calculating the unity value using Equation 6 yields:

$$\frac{1943}{23{,}713} + \frac{(25{,}000 - 1943)}{(40.2)(23{,}713)} = 0.11, \text{ which is much less than 1.0.}$$

Removable surface activity measurements were taken at each systematic measurement and investigative measurement location in structural survey units. The Plan requires that removable surface activity in each survey unit be less than 10% of the $DCGL_W$. Removable surface activity is measured by counting 100 cm^2 smear samples for beta and alpha activity.[24] Smear results were below 10% of the $DCGL_W$ in all PPH survey units and less than counting

[24] Smears are counted in the PBRF Counting Laboratory on automated sample changer proportional counters. Two such counters are available for this purpose: Tennelec Model LB-5100 and Tennelec Model 5X-LB.

instrument MDA in all except one PPH survey unit. The measurement results in excess of MDA are shown in Table 14.

Table 14, Removable Surface Activity Measurements

Survey Unit ID	Measurement ID	Beta Activity (1) (3) (4)	Alpha Activity (1) (3) (4)
PH-1-16	IM-1 (2)	25.97	< MDA
PH-1-16	IM-2 (2)	60.09	< MDA

Table 14 Notes:

1. Units are dpm/100-cm^2.
2. IM denotes investigative measurement.
3. Maximum removable surface activity measured in the survey unit.
4. The beta MDA for these measurements was 16.55 dpm. The alpha MDA for these measurements was 8.33 dpm.

5.4 Soil Survey Unit Results

One soil survey unit was established for the PPH FSS: Survey Unit PH-1-30 Room 3 Soil. It was established to cover soil exposed by removal of the contaminated concrete floor of Room 3, one of the three PPH pump rooms. As shown in Table 11, Scan Survey Results, 100 % of the exposed soil area was scanned (by NaI detectors set up to count in the Cs-137 energy window). No elevated areas were observed and no investigations were performed. Surface soil samples were collected from the survey unit and analyzed by gamma spectroscopy by the PBRF laboratory. The results are summarized in Table 15. All results are < MDA.

Table 15, PPH Soil Survey Unit Sample Results

Survey Unit ID	Survey Design	No. of Samples (1)	Maximum Concentration (pCi/g) (2)		
			Cs-137	Co-60	Sr-90
PH-1-30	47	11	< MDA	< MDA	See Note (3)

Table 15 Notes:

1. The No. of samples is systematic measurements (samples) per survey design.
2. The maximum concentrations shown are from systematic samples. No investigative samples were collected.
3. Sr-90 concentrations are inferred from measured Cs-137 activity concentration. The Sr-90: Cs-137 activity ratio is 0.499 assuming the same mix as in the PPH Room 3 structure per TBD-07-001 [PBRF 2007]. Hence the maximum Sr-90 concentration is < 1/2 the maximum Cs-137 MDA of 7.71E-02 pCi/g.

5.5 QC Measurements

Per FSS Plan requirements, QC replicate measurements were taken for at least 5% of the PPH measurements. This included scan surveys, systematic total surface activity measurements and soil samples. Scan QC survey results are shown in Table 11 wherein the 5% scan QC coverage is confirmed. These surveys confirmed the results of the original scan surveys of the areas covered. No QC scan surveys identified areas of elevated activity.

Replicate total surface activity measurements were performed at selected measurement locations including systematic and investigative measurements. The 5 % requirement is satisfied in that 31 QC measurements were reported; this represents 6.7 % of 466 systematic and investigative measurements. The measurement results for the 31 surface activity original and QC replicate measurement data pairs are shown in Table 16.

Table 16, PPH Total Surface Activity QC Measurements

Survey Unit	Measurement Location No.	Net Activity (dpm/100 cm^2) (1)	QC Replicate (dpm/100 cm^2)	RPD (%)
PH-1-11	SM-7	362	566	43.97
PH-1-29	SM-5	493	362	30.64
PH-1-11	SM-5	566	650	13.82
PH-1-17	SM-6	627	968	42.76
PH-1-22	SM-2	646	550	16.05
PH-1-11	SM-9	651	923	34.56
PH-1-11	SM-8	658	748	12.80
PH-1-24	SM-2	671	732	8.70
PH-2-4	SM-2	678	902	28.35
PH-1-23	SM-5	759	530	35.53
PH-1-18	SM-7	789	601	27.05
PH-1-11	SM-6	809	713	12.61
PH-1-14	SM-4	895	804	10.71
PH-2-4	SM-6	914	915	0.11
PH-1-19	SM-5	915	1066	15.24
PH-2-4	SM-4	974	810	18.39
PH-2-4	SM-1	980	1418	36.53
PH-1-28	SM-3	987	812	19.46
PH-2-4	SM-5	1020	784	26.16
PH-1-26	SM-10	1040	966	7.38
PH-2-4	SM-7	1145	1216	6.01
PH-1-14	SM-5	1190	1220	2.49
PH-1-16	SM-1	1520	1410	7.51
PH-1-16	SM-2	1980	2020	2.00
PH-2-4	SM-3	2862	2190	26.60
PH-1-21	IM-1	5520	4680	16.47
PH-1-7	IM-2	7,990	9,224	14.34
PH-1-1	IM-1	13,300	12,340	7.49
PH-1-20	IM-1	16,294	17,283	5.89
PH-1-15	IM-1	20,700	20,600	0.48
PH-1-16	IM-2	25,000	24,200	3.25

Table 16 Notes:

1. Table data is sorted by increasing net activity.
2. RPD is calculated as: absolute value [(original – QC)/{(original + QC)/2}].

The FSS Plan (Section 12.7) specifies that the relative percent difference (RPD) between original and replicate measurements must be within 20% [NASA 2007]. Ten of the 31 measurement pairs were above the 20% criterion. Each measurement pair failing to meet the 20% criterion was individually investigated and resolved in accordance with FSS Plan requirements and implementing procedures.[25]

It is found that all the measurements which failed the 20% criterion were low activity measurements (below 1000 dpm/100-cm^2). Results of the replicate QC measurement evaluation are summarized in Table 17. The table shows that the average RPD is inversely proportional to the magnitude of residual surface contamination levels.

Table 17, RPD Evaluation of Replicate QC Surface Activity Measurements

Activity Range (1)(2)	No. of Measurement Pairs	Average Original Activity (1)	Average QC Rep. Activity (1)	Average RPD (%) (3)
< 1000	18	743	782	22.6
1000 to 10000	9	2696	2634	12.1
> 10,000	4	18824	18606	4.3

Table 17 Notes:
1. Units are 100 dpm/100-cm^2.
2. The activity range is specified for the original measurements.
3. Calculated as the average of individual RPD values within the stated activity ranges.

A replicate QC sample was collected from the PPH soil survey unit (PH-1-30) and analyzed. Results for all analytes in both the original and QC samples are <MDA. The PH-1-30 Release Record reported that the results were evaluated in accordance with Section 12.7.2 of the FSS Plan and that positive agreement the original and QC sample was indicated.

5.6 ALARA Evaluation

It is shown that residual contamination in the PPH has been reduced to levels that are ALARA, using a method acceptable to the NRC. The NRC guidance on determining that residual contamination levels are ALARA includes the following:

> "In light of the conservatism in the building surface and surface soil generic screening levels developed by the NRC, NRC staff presumes, absent information to the contrary, that licensees who remediate building surfaces or soil to the generic screening levels do not need to provide analyses to demonstrate that these screening levels are

[25] When the acceptance criterion is not met, an investigation is performed to determine the cause and corrective actions. The investigation may include repetition of the replicate QC measurement or other actions determined by the FSS/Characterization Supervisor. If upon repetition, the RPD criterion is still not satisfied, the result may be accepted if the original and QC replicate measurement are in agreement that both are below the $DCGL_W$ for the survey unit, the FSS/Characterization Supervisor reviews the investigation and concurs that the measurement is acceptable and the results of the investigation are documented in the Survey Request Summary and Close-out (Procedure CS-01, *Survey Methodology to Support PBRF License Termination*).

ALARA. In addition, if residual radioactivity cannot be detected, it may be presumed that it had been reduced to levels that are ALARA. Therefore the licensee may not need to conduct an explicit analysis to meet the ALARA requirement."[26]

Screening level values published by the NRC for the mix of radionuclides in structural surface residual contamination potentially present in the PPH are shown in Table 18. Since individual radionuclide activity concentrations are not measured in the FSS of structures, a direct comparison of residual contamination levels to individual radionuclide screening level values is not possible. A comparison can be made by converting the nuclide-specific screening level values to an appropriate gross activity DCGL. This is accomplished using activity fractions used in development of the PPH gross activity DCGL for Room 4, the PPH Heat Exchanger Room. A screening level value that is equivalent to the gross activity DCGL was calculated using the equations in Section 3.6 of the FSS Plan.[27] The activity fractions listed in Table 3 (also shown in Table 18) were used in the calculation. The screening level equivalent DCGL for the PPH Room 4 is calculated to be 2103 dpm/100-cm^2.

The average total surface beta activity measured in the FSS of the PPH is 775 ± 568 dpm/100-cm^2 (one standard deviation). The upper limit of the 95th % confidence interval of this mean value is 828 dpm/100-cm^2.[28] This value is below the screening level gross activity DCGL of 2103 dpm/100-cm^2. From this comparison, it is concluded that the ALARA criterion is satisfied.

Table 18, Screening Level Values for PPH and Radionuclide Activity Fractions

Radionuclide	Screening Level Value (dpm/100-cm^2)	PPH Activity Fraction (%) [(1)]
H-3	1.2 E+08 [(2)]	42.91
Co-60	7.1E+03 [(2)]	9.56
Sr-90	8.7E+03 [(2)]	2.56
I-129	3.5E+04[(2)]	22.55
Cs-137	2.8E+04 [(2)]	18.92
Eu-154	1.2E+04[(3)]	0
U-234	9.1E+01 [(3)]	3.34
U-235	9.8E+01[(3)]	0.16

Table 18 Notes.

1. Activity fractions used to develop the $DCGL_W$ for PPH Room 4.
2. Values from NUREG-1757 Vol. 2, Table H.1 [USNRC 2006].
3. Values from NUREG/CR-5512, Vol. 3, Table 5.19 [SNL 1999]. These are 90th percentile values of residual surface activity corresponding to 25 mrem/y to a future building occupant.

[26] This guidance was initially published in Draft Regulatory Guide DG-4006, but has been reissued in NUREG-1757 Volume 2, Appendix N.

[27] The equivalent screening level gross activity DCGL is calculated using an EXCEL template [PBRF 2011]. This template incorporates the equations in section 5.3 of the FSS Plan [NASA 2007].

[28] The upper limit of the confidence interval, 95th percentile value, is calculated as: UL = mean + 1.96 $\sigma/\sqrt{n}$, where n = 454 measurements.

Table 19, NRC Soil Screening Level ALARA Comparison

Radionuclide	NRC Screening Level (pCi/g) (1)	Maximum Measured Concentration (pCi/g)
Co-60	3.8	< MDA(2)
Cs-137	11	< MDA (3)
Sr-90	1.7	See Note (4)

Table 19 Notes:

1. Values from NUREG-1757 Vol. 2, Table H.2 [USNRC 2006].
2. The average Co-60 MDA is 0.066 ± 0.011 and the maximum is 0.090 pCi/g.
3. The average Cs-137 MDA is 0.058 ± 0.010 and the maximum is 0.077 pCi/g.
4. Maximum Sr-90 concentration inferred from the maximum Cs-137 MDA and Sr-90: Cs-137 activity ratio of 0.499. The maximum inferred Sr-90 concentration so obtained is < 0.045 pCi/g.

5.7 Comparison with EPA Trigger Levels

The PBRF license termination process includes a review of residual contamination levels in groundwater and soil, as applicable, in accordance with the October 2002 Memorandum of Understanding (MOU) between the US NRC and the US Environmental Protection Agency (EPA) [USEPA 2002]. Concentrations of individual radionuclides, identified as "trigger levels" for further review and consultation between the agencies, are published in the MOU.

This comparison is shown in Table 20. The table shows that the measured soil activity concentrations are well below EPA trigger levels. It is noted that groundwater is not within the scope of the PPH FSS.

Table 20, Comparison of Soil Sample Results with EPA Trigger Levels

Radionuclide	EPA Trigger Level (pCi/g)	Maximum Measured Concentration (pCi/g)
Co-60	4	< MDA(1)
Cs-137 (4)	6	< MDA (2)
Sr-90 (4)	23	See Note (3)

Table 20 Notes:

1. The maximum Co-60 MDA in PPH soil samples is 0.090 pCi/g.
2. The maximum Cs-137 MDA in PPH soil samples is 0.077 pCi/g.
3. Maximum Sr-90 concentration is < 0.045 pCi/g; inferred from the maximum Cs-137 MDA and SR-90: Cs-137 activity ratio of 0.499.
4. Specified in the MOU as including daughter activity [USEPA 2002].

5.8 Conclusions

The results presented above demonstrate that the PPH satisfies all FSS Plan commitments and meets the release criteria in 10CFR20 Subpart E. The principal conclusions are:

- Scan surveys were performed in 100 % of the accessible surfaces of all 42 PPH survey units – all were Class 1.
- Residual surface contamination levels requiring investigation were observed in seven survey units. A localized area with activity above the $DCGL_W$ was measured in one survey unit. The EMC and EMT were performed and were successful.
- All randomly selected (systematic with random start) fixed total surface activity measurements are less than the applicable $DCGL_W$.
- All survey unit mean fixed measurement results (total surface beta activity) are below the $DCGL_W$, hence no statistical tests were required.
- All removable surface activity measurements are less than 10% of the $DCGL_W$.
- Residual surface and soil activity concentration measurement results are shown to be less than NRC screening level values - demonstrating that the ALARA criterion is satisfied.
- Only minor changes from what was proposed in the FSS Plan were made – the PPH was divided into 42 survey units, whereas the FSS Plan had not shown a survey unit breakdown.
- There was one change from initial assumptions (in the FSS Plan) regarding the extent of residual activity in the PPH. One area of potentially contaminated soil was identified underneath the PPH in Room 3; this was not identified in the FSS Plan. No reclassification of survey units was required as a result of FSS measurements and investigations.

6.0 References

GTS 1989 GTS Duratek Radiological Engineering and Field Services, Kingston, TN, *Plum Brook Confirmatory Survey*, November 1998.

ISO 1988 International Organization for Standardization, *Evaluation of Surface Contamination, Part 1: Beta Emitters and Alpha Emitters,* ISO-7503-1, 1988.

MWH 2003 MWH Constructors, Inc., *Characterization Package C1134- 201C1 Primary Pump House Structure,* Prepared for US Army Corps of Engineers Under Contract DACW-27-97-0015, October 2003.

NASA 2006 NASA Safety and Mission Assurance Directorate, Plum Brook Reactor Facility, *Decommissioning Project Quality Assurance Plan,* QA-01, Revision 2, February 2006.

NASA 2007 NASA Safety and Mission Assurance Directorate, *Final Status Survey Plan for the Plum Brook Reactor Facility,* Revision 1, February 2007.

NASA 2008	NASA Safety and Mission Assurance Directorate, *Decommissioning Plan for the Plum Brook Reactor Facility*, Revision 6, July 2008.
PBRF 2005	Plum Brook Reactor Facility, MWH Constructors, Inc. *Survey Package C1134 201C1, Primary Pump House (1134) Structural Surfaces Rooms 1-6,* August 2005.
PBRF 2007	Plum Brook Reactor Facility Technical Basis Document, *Adjusted Gross DCGLs for Structural Surfaces,* PBRF-TBD-07-001, June 2007.
PBRF 2007a	Plum Brook Reactor Facility Technical Basis Document, *Efficiency Correction Factor,* PBRF-TBD-07-004, November 2007.
PBRF 2009	Plum Brook Reactor Facility, Memorandum to Project File, J. L. Crooks, Don Young, *Final FSS Report Background –NASA Plum Brook Reactor Facility Primary Pump House (1134),* December 08, 2009.
PBRF 2009a	Plum Brook Reactor Facility Technical Basis Document, *44-10 NaI Detector MDCscan Values for Various Survey Conditions,* PBRF-TBD-09-002, June 2009.
PBRF 2011	Plum Brook Reactor Facility Decommissioning Project Office, Memorandum to Project File, *Engineering Record for Final Status Survey Report Calculation – PPH Update.* August 4, 2011.
PNL 2010	Battelle Pacific Northwest Laboratories (PNL), *Visual sample Plan*, Version 5.9, 2010.
SNL 1999	Sandia National Laboratories (SNL), for US Nuclear Regulatory Commission, *Residual Radioactive Contamination From Decommissioning, Parameter Analysis,* NUREG/CR-5512, Vol.3, Oct. 1999.
TELE 1987	Teledyne Isotopes, *An Evaluation of the Plum Brook Reactor Facility and Documentation of Existing Conditions*, Prepared for NASA Lewis Research Center, December 1987.
USEPA 2002	Memorandum of Understanding, US Environmental Protection Agency and US Nuclear Regulatory Commission, *Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites*, October 9, 2002.
USNRC 1998	US Nuclear Regulatory Commission, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions,* NUREG-1507, Rev.1, June 1998.
USNRC 2000	US Nuclear Regulatory Commission, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, NUREG-1575, Rev.1, August 2000.
USNRC 2006	US Nuclear Regulatory Commission, *Consolidated Decommissioning Guidance, Characterization, Survey and Determination of Radiological Criteria*, NUREG 1757, Vol. 2, Rev.1, September 2006.

7.0 Appendices

Appendix A – Exhibits

Appendix B – Survey Unit Maps and Tables Showing Measurement Locations and Results

Final Status Survey Report

Attachment 13

Primary Pump House
(Building 1134)

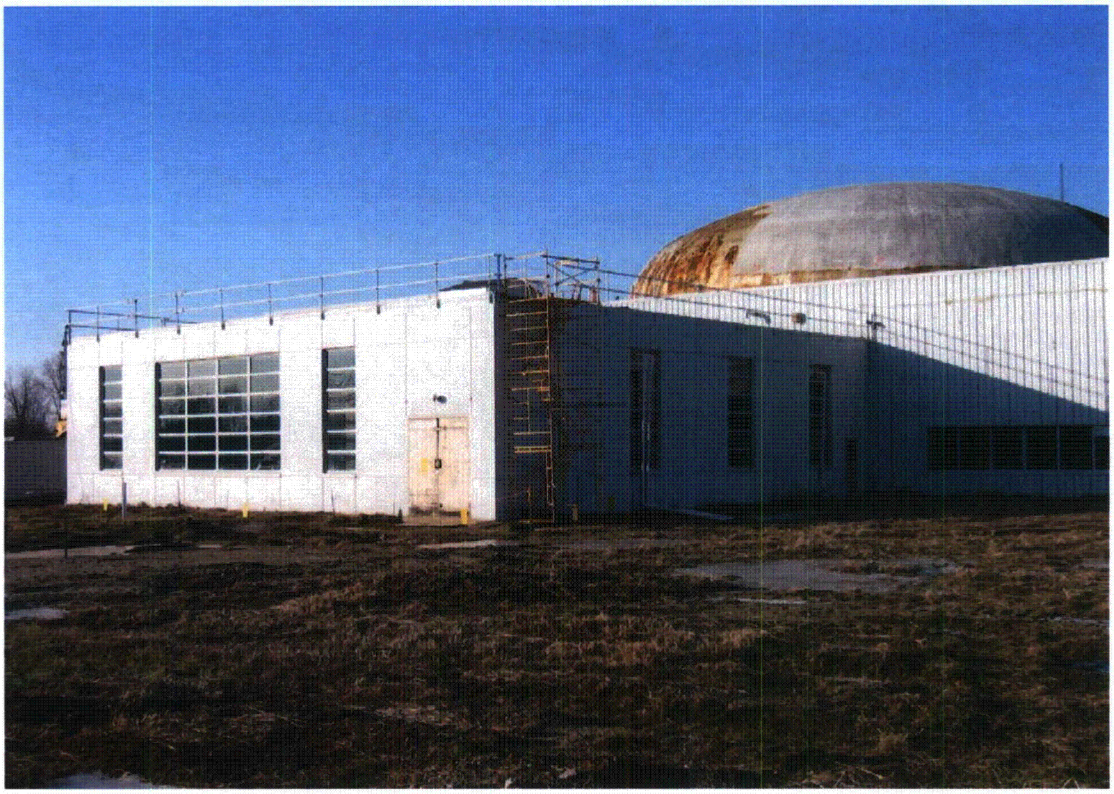
Revision 0

Appendix A

Exhibits

List of Exhibits

Exhibit 1, Current Views of PPH Exterior
(view from northeast)



(view from south)

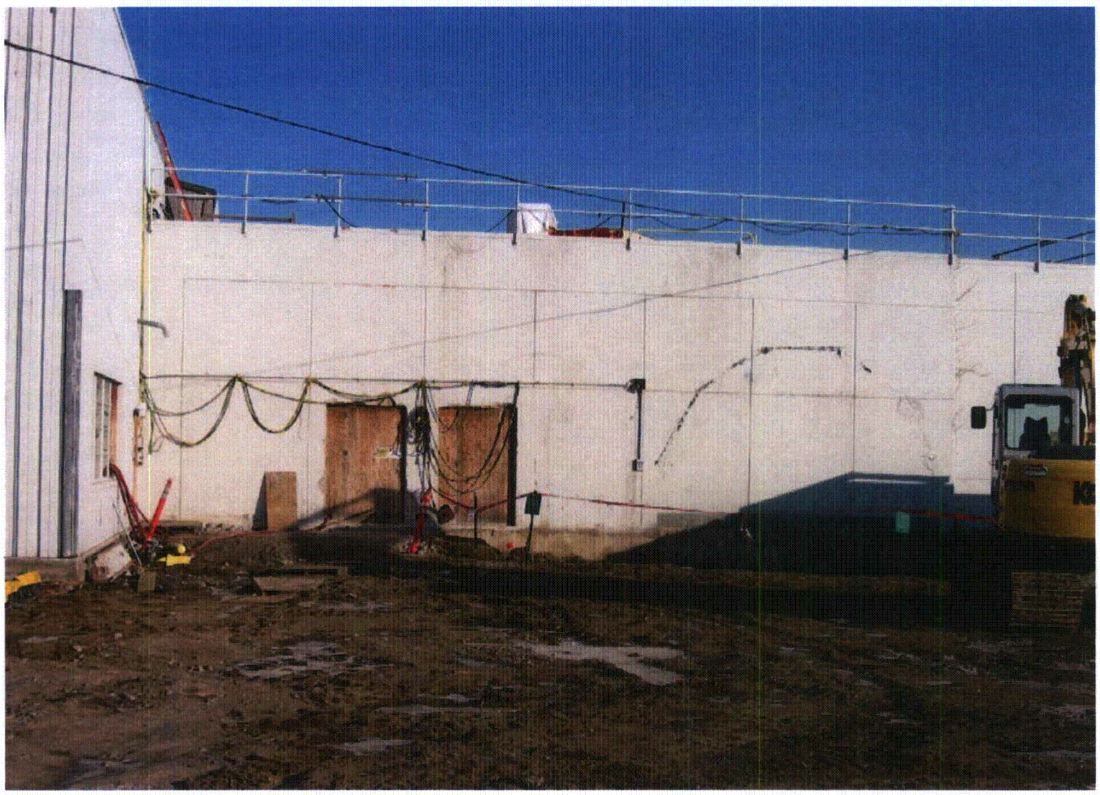


Exhibit 2, PPH Construction Photo
(Grade Level View Looking Southwest)

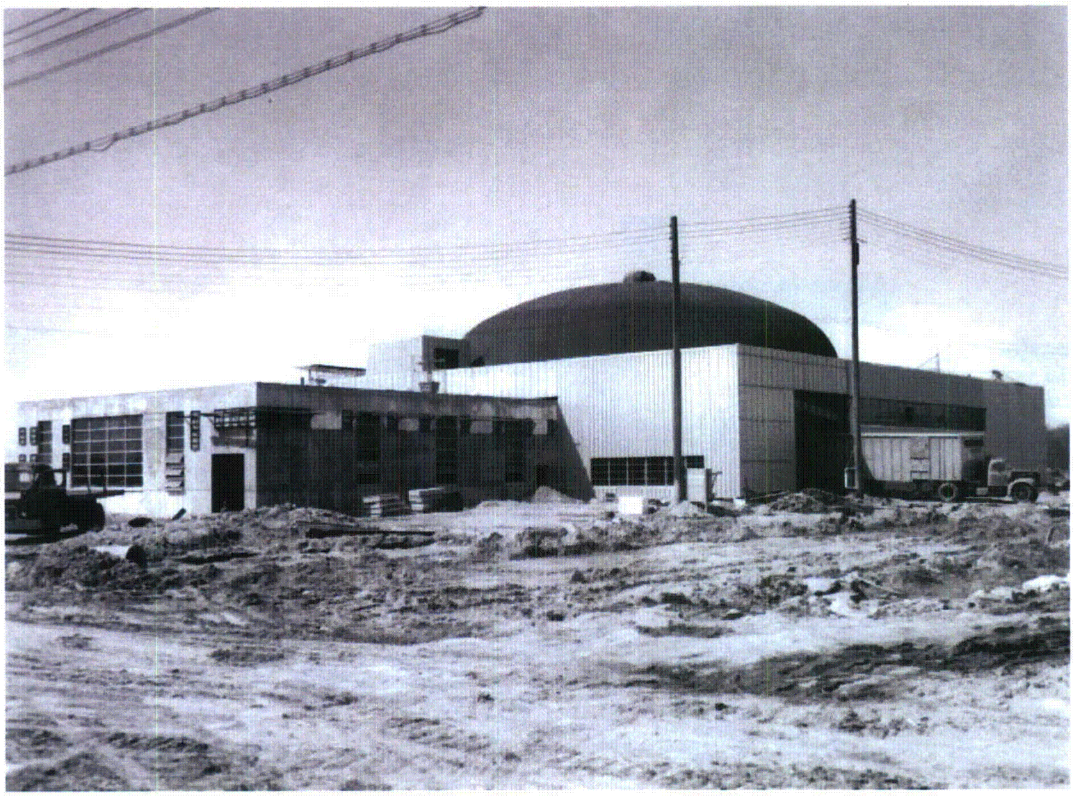
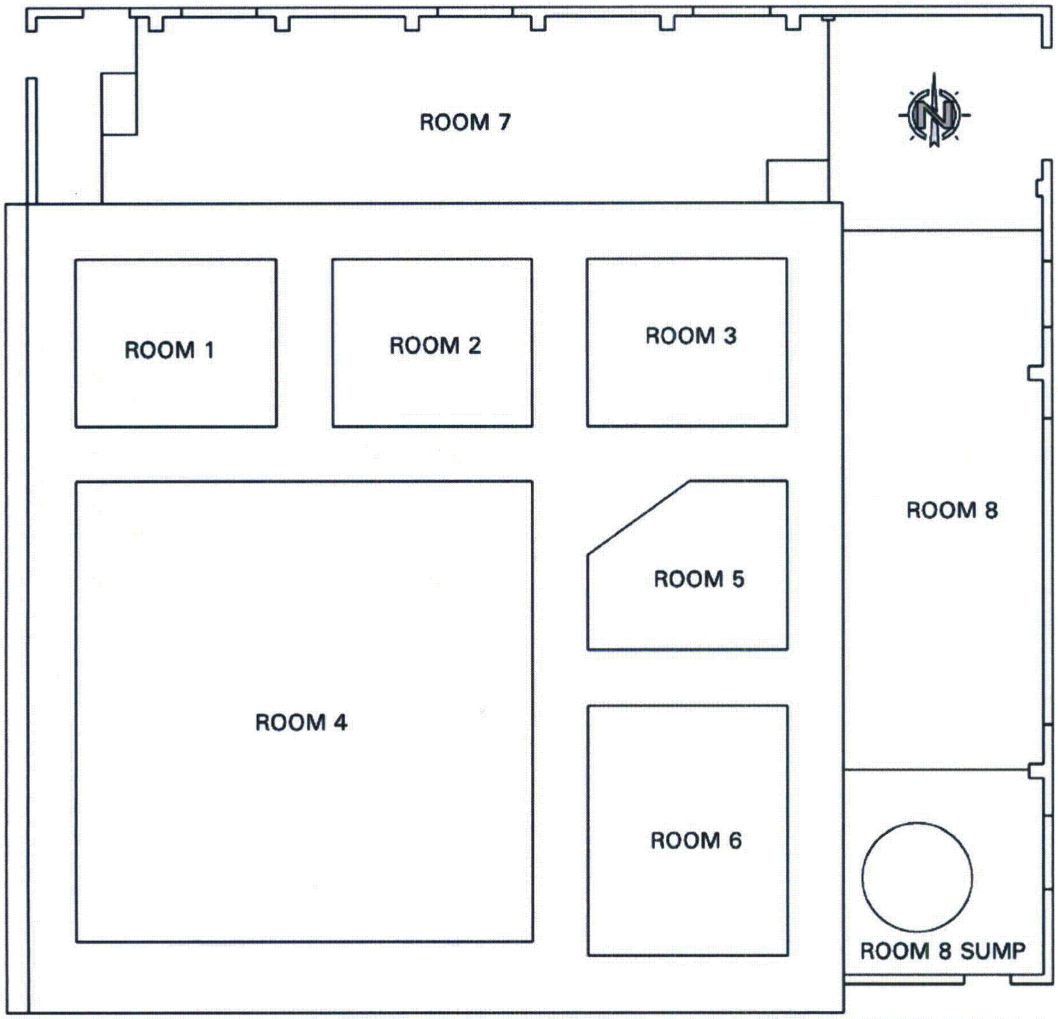


Exhibit 3, PPH First Floor Layout Showing Survey Units



Survey Unit	Description	Survey Unit	Description
PH-1-1	Room 1 – Floor, Ceiling, Platform, Hatchways	PH -1-16	Room 6 – Walls
PH -1-2	Room 1 – Walls	PH -1-17	Room 7 & 8 – Floor Section 1
PH -1-3	Room 2 – Floor, Ceiling, Platform, Hatchways	PH -1-18	Room 7 & 8 – Floor Section 2
PH -1-4	Room 2 – Walls	PH -1-19	Room 7 & 8 – Floor Section 3
PH -1-5	Room 3 – Floor, Ceiling, Platform, Hatchways	PH -1-20	Room 8 Sump
PH -1-6	Room 3 – Walls	PH -1-21	Room 7 & 8 – Wall Section 1 & West Stairs
PH -1-7	Room 4 – Floor Section 1	PH -1-22	Room 7 & 8 – Wall Section 2
PH -1-8	Room 4 – Floor Section 2	PH -1-23	Room 7 & 8 – Wall Section 3 & East Stairs
PH -1-9	Room 4 – West & North Walls	PH -1-24	Room 7 & 8 – Wall Section 4
PH -1-10	Room 4 – East & South Walls & Wall penetrations	PH -1-25	Room 7 & 8 – Wall Section 5
PH -1-11	Room 4 – West Ceiling & Hatchway	PH -1-26	Room 7 & 8 – Wall Section 6
PH -1-12	Room 4 – East Ceiling & Hatchway	PH -1-27	Room 7 & 8 – Platforms
PH -1-13	Room 5 – Floor, Ceiling, & Hatchway	PH -1-28	Room 7 & 8 – Ceiling Section 1
PH -1-14	Room 5 – Walls	PH -1-29	Room 7 & 8 – Ceiling Section 2
PH -1-15	Room 6 – Floor, Ceiling, & Hatchway	PH-1-30	Room 3 – Soil

Exhibit 4, Pump Room Views

(Room 1 floor looking east)

(Room 2 upper walls, showing valve pedestal)

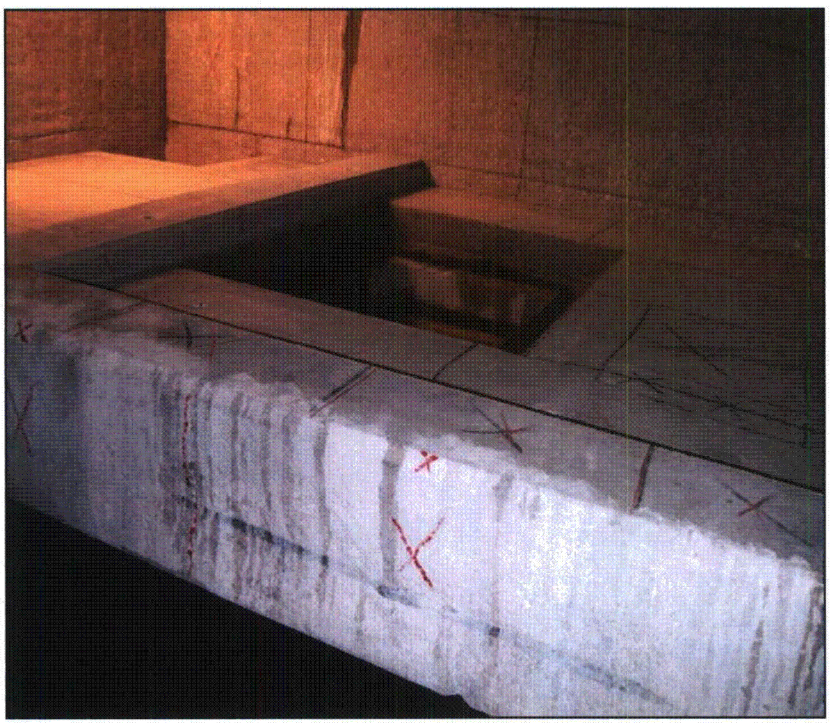


Exhibit 5, Pump Room Views, Continued

(Room 2 floor, showing cored areas)

(Room 2, wall and ceiling)

Exhibit 6, Room 3 and Soil Survey Unit

(walls and ceiling and floor remnant)

(close-up of soil surface beneath former floor)

Exhibit 7, Room 4 - Heat Exchanger Room

(Floor looking west to east)

(South Wall showing removable block openings)

Exhibit 8, Room 4 - Heat Exchanger Room, Continued

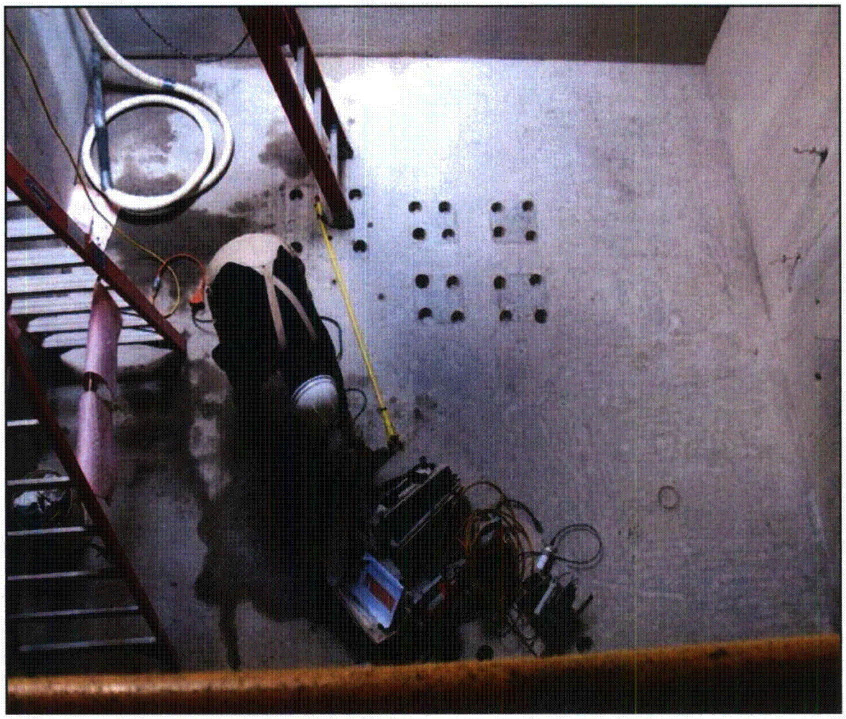
(Room 4 showing main PCW piping egress in southwest corner)

(grouted PCW piping entrance/exit from PPH inside sheath below Room 4 floor)

Exhibit 9, Room 5 – Degassifier Room
(View of Floor showing sump and floor corings)

(NW Wall showing pipe penetrations, remediated concrete and ledge)

Exhibit 10, Room 6 – Bypass Deionizer Room
(view of floor showing holes bored to remove anchors)



(West Wall showing concrete remediated around penetrations)

Exhibit 11, Room 7 Views

(Room 7 looking east)

(West entrance from Reactor Building and stairs to Pump Room motor platforms)

Exhibit 12, Room 7 Views, Continued

(pump motor platform galley above Room 7 looking east)

Exhibit 13, Room 8 Views

(Floor and lower walls looking south)

(PPH Sump access at south end of Room 8)

Exhibit 14, Room 8 Views, Continued

(ceiling central area looking south)

(Room 7/8 ceiling north east corner of PPH looking north)

Exhibit 15, PPH Sump Views

(View of Sump from Room 8 Floor)

(view from sump first level to the bottom)

Exhibit 16, Unusual Condition Measurement Areas (UCMs)

(Remediated area in Room 4 wall concrete showing rebar)

(through-wall penetrations from Room 7 to Pump Room)

Exhibit 17, Unusual Condition Measurement Areas (UCMs), Continued
(typical anchor plate)

(aggressively decontaminated concrete)

Exhibit 18, Surface Measurement Test Areas (SMTAs)
(Scabbled concrete in Room 7 floor)

Exhibit 19, Examples of Other Special Measurement Conditions

(grout-filled pipe in Room 4 floor)

(irregular surface from core drilling to remove contaminated pipe in Room 4 Wall)

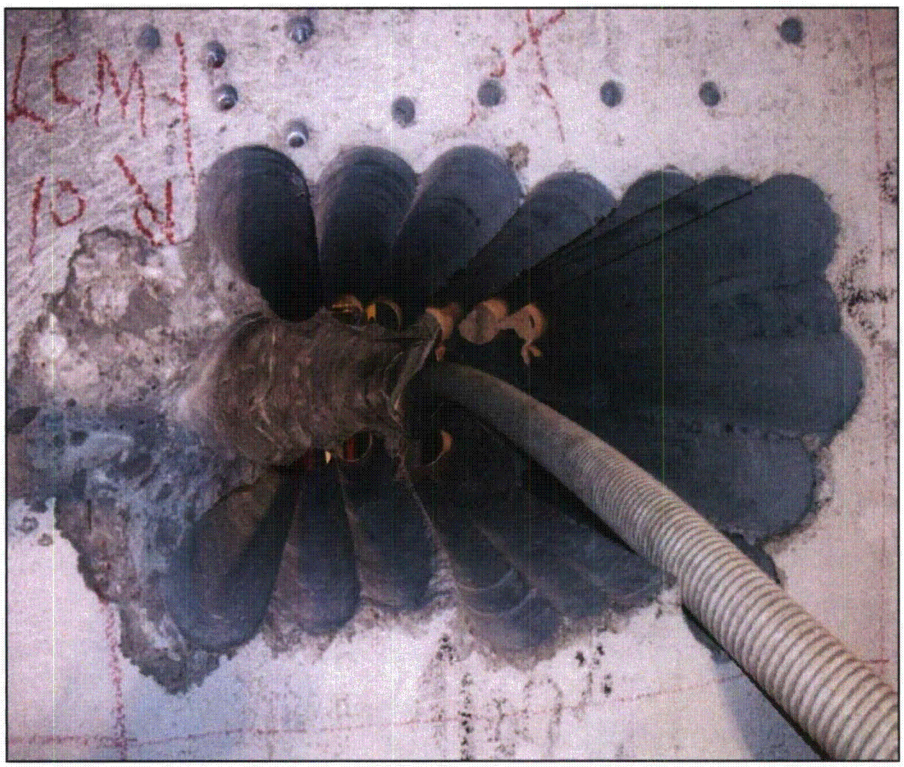


Exhibit 20, Examples of Other Special Measurement Conditions, Continued

(eight-inch core bores in Room 8 floor)

(penetration in Room 3 ceiling showing rough edges and rebar)