National Aeronautics and
Space Administration
John H. Glenn Research Center
Lewis Field
Plum Brook Station
Sandusky, OH 44870

September 18, 2012

Reply to Attn of: QD

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Final Status Survey Report, Main Body of Report, Revision 1, for the Plum Brook Reactor Facility, Licenses Nos. TR-3, Docket No. 50-30 and R-93, Docket No, 50-185

Enclosed for your review is the Main Body of the Final Status Survey Report, Revision 1, to support termination of the licenses for the Plum Brook Reactor Facility.

The complete Final Status Survey Report consists of a series of eighteen Attachments, each addressing an individual survey area or group of survey areas or environmental areas as described in our NRC approved Final Status Survey Plan. This final submission is the Main Body of the Final Report and consolidates and summarizes the details presented in the Attachments. In addition, it evaluates the site ground water well monitoring data and provides a comparison to EPA MCLs. It also summarizes the dose modeling results that demonstrate that the dose to any member of the public from exposure to residual activity in sediments in Plum Brook is well below the release for unrestricted use criteria of 10CFR20.1402. This report supports our conclusion that radiological remediation of all areas of the Plum Brook reactor Facility have been completed and the facility meets the criteria for unrestricted release specified in 10 CFR 20.1402.

Accordingly, any areas potentially affected radiologically by demolition and waste management activities were subjected to radiological surveys to confirm that the conditions and conclusions documented in the Final Status Survey Report have not been altered.

FSME20

Should you have any questions or need additional information, please contact me a NASA Plum Brook Station, 6100 Columbus Avenue, Sandusky, Ohio 44870, or by telephone at (419) 621-3242.

Peter C. Kolb
NASA Decommissioning Program Manager

Enclosure
Final Status Survey Report, Main Body of Report, Revision 1, dated September 17, 2012.

cc:
USNRC/C. J. Glenn (FSME)
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National Aeronautics and Space Administration

Glenn Research Center

Plum Brook Reactor Facility

Final Status Survey Report

Revision 1

FINAL STATUS SURVEY REPORT ROUTING AND APPROVAL SHEET

Document Title: Final Status Survey Report

Revision Number: 1

ROUTING

	SIGNATURE	DATE
Prepared By	Roderick Case	9/17/12
Prepared By	N/A	
REVIEW & CONCURRENCE		
Independent Technical Reviewer	William Stoner	9/17/12
Other Reviewer, QA Manager	N/A	
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NASA Project Radiation Safety Officer	William Stoner	9/17/12

NASA PBRF DECOMMISSIONING PROJECT CHANGE/CANCELLATION RECORD		
DOCUMENT TITLE: Final Status Survey Report	**DOCUMENT NO: NA**	**REVISION NO: 1**
Revision 0: Initial issue of Report		
Revision 1: The following changes were made in response to the NRC comments: Added brief discussion on the Plum Brook project to section 1.0; Updated section 2.0 to reflect final status of the site; Modified Section 2.3, Plum Brook, by removing "release of offsite areas for unrestricted use"; In Section 3.4, clarified "action level" and added RAL to List of Acronyms & Symbols; Updated Tables 1 & 2 to reflect final waste shipment data; Clarified dose goal selection in Section 4.1; Clarified use of most limiting $DCGL_{sur}$ for excavated soils; Modified Section 5.1 to provide more clarity to the discussion on scan action level exceedances; Corrected $DCGL_w$ values in Table 26; Section 5.3 was revised to reflect changes made to Attachment 17 and added reference to TBD-12-002; Corrected maximum values in Table 31; Revised description of MP throughout Report to be consistent with Attachment 17; Modified Section 5.4 to include discussion of on-site laboratory analysis for environmental samples and clarify radionuclide evaluation of off-site analysis. Added reference to TBD-12-001; Section 6.0 was revised to incorporate conclusions that resulted from revision of Attachment 17; Updated LOEP; Corrected building nomenclature to be consistent throughout document; Removed the discussion of un-numbered buildings; Corrected text in Section 4.1 to refer to Table 5 not Table 3; Corrected various spelling and typographical errors in text; Modified Cover Page to show "before" and "after" site photographs.		

Form AD-01/3 Rev 1

LIST OF EFFECTIVE PAGES

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LIST OF ACRONYMS & SYMBOLS

α	alpha; denotes alpha radiation, also type I error probability in hypothesis testing
A	Area, also detector open area
A_{EMC}	Area corresponding to the area factor calculated using the scan MDC
AEC	Atomic Energy Commission
ALARA	As Low as Reasonably Achievable
AF	Area Factor
ATS	Assembly Test Storage, Building 1121
β	beta; denotes beta radiation, also type II error probability in hypothesis testing
b_i	background counts in observation interval
BP	Buried Piping
B_R	Background count rate
BPL	Byproduct License
BSFR	Bulk Survey for Release
CFR	Code of Federal Regulations
CPT	Cold Pipe Tunnel
CRB	Cold Retention Basins, Building 1154
CsI	Cesium Iodide
CV	Reactor Containment Vessel
cm	centimeters
cm^2	square Centimeters
cpm	counts per Minute
Δ	delta, $DCGL_W$ – LBGR
d'	Scan surveyor sensitivity index
DAW	Dry Active Waste
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)"
DCS	Diversion Control Setpoint
dpm	disintegrations per minute
DQO	Data Quality Objective
E_i	Detector, or instrument efficiency
E_s	Surface efficiency
E_t	Total efficiency
EMC	Elevated Measurement Comparison
EMT	Elevated Measurement Test
EPA	US Environmental Protection Agency
EP	Embedded Piping
ERB	Emergency Retention Basin
FH	Fan House, Building 1132
FSS	Final Status Survey
FSSP	Final Status Survey Plan
FSSR	Final Status Survey Report
γ	gamma

LIST OF ACRONYMS & SYMBOLS, Continued

g	gram
GRC	Glenn Research Center
H_A	Alternate Hypothesis
H_O	Null Hypothesis
HP	Horsepower
HPGe	High Purity Germanium
HPT	Hot Pipe Tunnel
HRA	Hot Retention Area
HTD	Hard To Detect
HL	Hot Laboratory, Building 1112
h/y	Hours per year
i	observation counting interval during scan surveys
in.	inch
kev	kilo-electron volt
LBGR	Lower Bound of the Gray Region
LLC	Limited Liability Corporation
LMI	Ludlum Measurements, Inc.
LSA	Low Specific Activity
m^2	square meters
mCi	milliCurie
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MAPEP	Mixed Analyte Performance Evaluation Program
MCL	Maximum Contaminant Level
MDC	Minimum Detectable Concentration
MDC_{scan}	Minimum Detectable Concentration for scanning surveys
MDC_{static}	Minimum Detectable Concentration for static surface activity measurements
MDCR	Minimum Detectable Count Rate
MP	Miscellaneous Piping
mrem	millirem
mrem/y	millirem per year
MW	Megawatt
MWD	Megawatt-Days
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
NaI	Sodium Iodide
NRC	US Nuclear Regulatory Commission
O/S	Outside of
PBRF	Plum Brook Reactor Facility
PCW	Primary Cooling Water
PNL	Pacific Northwest Laboratory
PPP	Process Piping Pump (Room)
Φ	Standard normal distribution function
p	surveyor efficiency for scan surveys

LIST OF ACRONYMS & SYMBOLS, Continued

pCi/g	picocuries per gram
%	percent
QC	Quality Control
RAL	Remediation Action Level, ~50% DCGL
RB	Reactor Building, sometimes abbreviated as RX Bldg.
RCP	Rigid corrugated piping
RCRA	Resource Conservation and Recovery Act
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
ROB	Reactor Office Building, Building 1142
ROLB	Reactor Office and Laboratory Building, Building 1141
s	seconds
σ	generic symbol for standard deviation of a population
S^+	Sign Test statistic
SEB	Reactor Service Equipment Building, Building 1131
SNM	Special Nuclear Materials
SNL	Sandia National Laboratory
SMTA	Surface Measurement Test Area
t_s	background count time
t_b	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
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VOC	Volatile Organic Compound
VSP	Visual Sample Plan
WEMS	Water Effluent Metering Station, Building 1192, also identified as Water Effluent Monitoring System
WEP	Work Execution Package
WHB	Waste Handling Building, Building 1133
$Z_{1-\alpha}$	Proportion of standard normal distribution values less than 1-α
$Z_{1-\beta}$	Proportion of standard normal distribution values less than 1-β
∞	Mathematical symbol for infinity

1.0 Introduction

This is the main body of the final status survey report (FSSR) of the National Aeronautics and Space Administration (NASA) Plum Brook Reactor Facility (PBRF). The PBRF Final Status Survey (FSS) Report comprises 19 volumes: this volume and 18 attachments. The attachments contain detailed descriptions of the individual buildings and environmental areas. They describe the FSS methodology and present survey results for each. The purpose of this volume is to provide an overview of the FSS of the PBRF and environs and to summarize the survey results presented in the 18 attachments. It also provides an overview of the characterization, surveying, and cleanup activities of the Plum Brook. These activities were previously reviewed and evaluated by the NRC. In that evaluation, NASA demonstrated that the dose to a member of the critical group from residual radioactivity in sediments from Plum Brook is well below the dose criterion for unrestricted use in 10 CFR 20.1402. The entire final report provides the basis for requesting termination of NRC Licenses TR-3 and R-93 in accordance with 10CFR50.82 (b) (6).

The goal of NASA is to release the facility for unrestricted use in compliance with the criteria in the US NRC 10CFR20 Subpart E regulation. The principal criterion 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). As described in the FSS Plan, the 25 mrem/y criterion is satisfied by collection of measurements to show that residual contamination levels are below Derived Concentration Guideline Levels (DCGLs). The DCGLs for residual contamination in soil and on structure surfaces have been established in accordance with the PBRF Final Status Survey Plan [NASA 2007].

The survey measurement results and supporting information are summarized herein and presented in detail in the attachments. They demonstrate that residual contamination levels in each of the survey units established for FSS of PBRF structures and environmental areas are well below the appropriate DCGLs. Additionally, it is shown that residual contamination has been reduced to levels that are consistent with the ALARA requirement.

Section 2.0 of the report provides a description of the PBRF and the surrounding environmental areas covered in the FSS. This includes a description of the facility layout, major buildings, and environmental areas, modifications, and final configuration for the FSS.

A brief history of the PBRF 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 also summarized.

Section 4.0 presents an overview of the FSS methodology for the facility as described in the FSS Plan. This section summarizes FSS Plan requirements, identifies applicable implementation procedures and provides a summary description of each procedure. The DCGLs are identified for each structure and environmental area. The breakdown of the structures and environmental areas into survey units and their MARSSIM classification are summarized. The survey design approach, instrumentation used for the FSS, measurement sensitivities and action-investigation levels are described.

Survey results are presented in Section 5.0. This section includes a summary of the FSS measurements performed in the PBRF structures and environmental areas. Results of scan surveys, static measurements, removable surface activity measurements and soil samples are presented with reference to the Appendices in this volume and the 18 FSS Report Attachments. The results include comparison to the DCGLs, tests performed and a summary of residual contamination levels relative to the ALARA criterion and to the EPA Trigger levels.

2.0 Site Description

The PBRF site is located near the northern edge of the 6400 acre Plum Brook Station. The site, as described in the NRC license that controls decommissioning activities, comprises 27 acres, identified as the Restricted Area, which contained the major buildings and support facilities.[1] The controlled-access site is bounded on the south by Pentolite Rd., on the west by Line 2 Rd. and on the north and east by the boundary fence. The southwest corner of the site, the intersection of Line 2 and Pentolite Roads is used as a reference location.[2] The coordinates are 41° 23' 03.73" North Latitude and 82° 41' 05.80" West Longitude.[3]

The PBRF Restricted Area is generally level and graded to promote surface water drainage to the Water Effluent Metering Station (WEMS) located at the south east corner of the site [USACE 2004]. The site reference grade level at the location of the Reactor Building is 631 ft. above mean sea level [NACA 1956].[4]

The PBRF site contained several multi-story buildings and numerous support structures. Below-grade structures and utilities extended throughout the site. These included underground pipe and utility tunnels, storm drains, catch basins, sanitary sewers, water and gas supply lines, cathodic protection wells and ground water monitoring wells. Prior to decommissioning, about 25% of the Restricted Area was occupied by buildings, water processing structures and sludge basins, paved roadways, parking areas, sidewalks and equipment pads. The remainder of the site surface was open land. Figure 1, shows the main site layout from Pentolite Rd. on the south to North Rd. on the north. By July 2012, all the PBRF buildings were demolished and excavated to 3 ft. below grade and backfilled. The only structure remaining is the Reactor Security Control Building (RSCB) which will remain intact for future use. It is noted that the Restricted Area includes about 2 acres located north of North Rd. This area is shown in Figure 2.

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[1] See Technical Specifications for the License No. TR-3 (Amendment 13) and License No. R-93 (Amendment 9) [NASA 2007a].

[2] Prior to decommissioning, the Reactor Vessel center was typically used as a local reference location for the PBRF.

[3] Note that the coordinate grid system used for construction of the PBRF was a local coordinate system established by the Army Corps of Engineers in the 1940's for construction of the Plum Brook Ordinance Works. This local grid system has been balanced (tied in) to the Ohio regional state plane coordinate system by NASA to align Glenn Research Center and Plum Brook Station geographic references with modern high-accuracy geo-reference systems. This provides the ability to reference locations specified on historical drawings to global latitude and longitude [Hagelin 2010].

[4] The finished floor elevation of the Reactor Building first floor is designated as the 0 ft. elevation for major PBRF buildings. This is one ft. above grade level at the Reactor Building location.

Figure 1, PBRF Site Layout

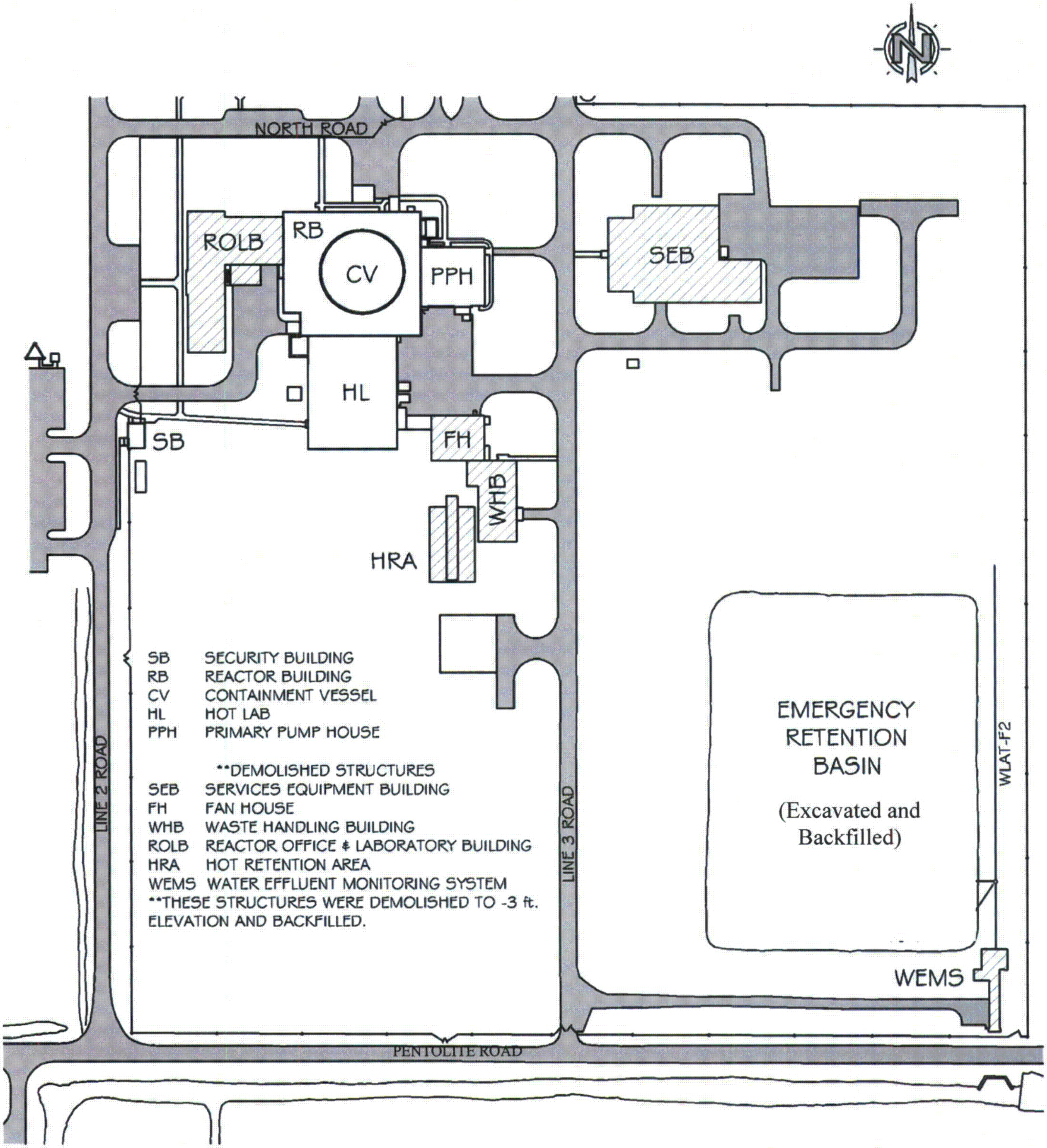
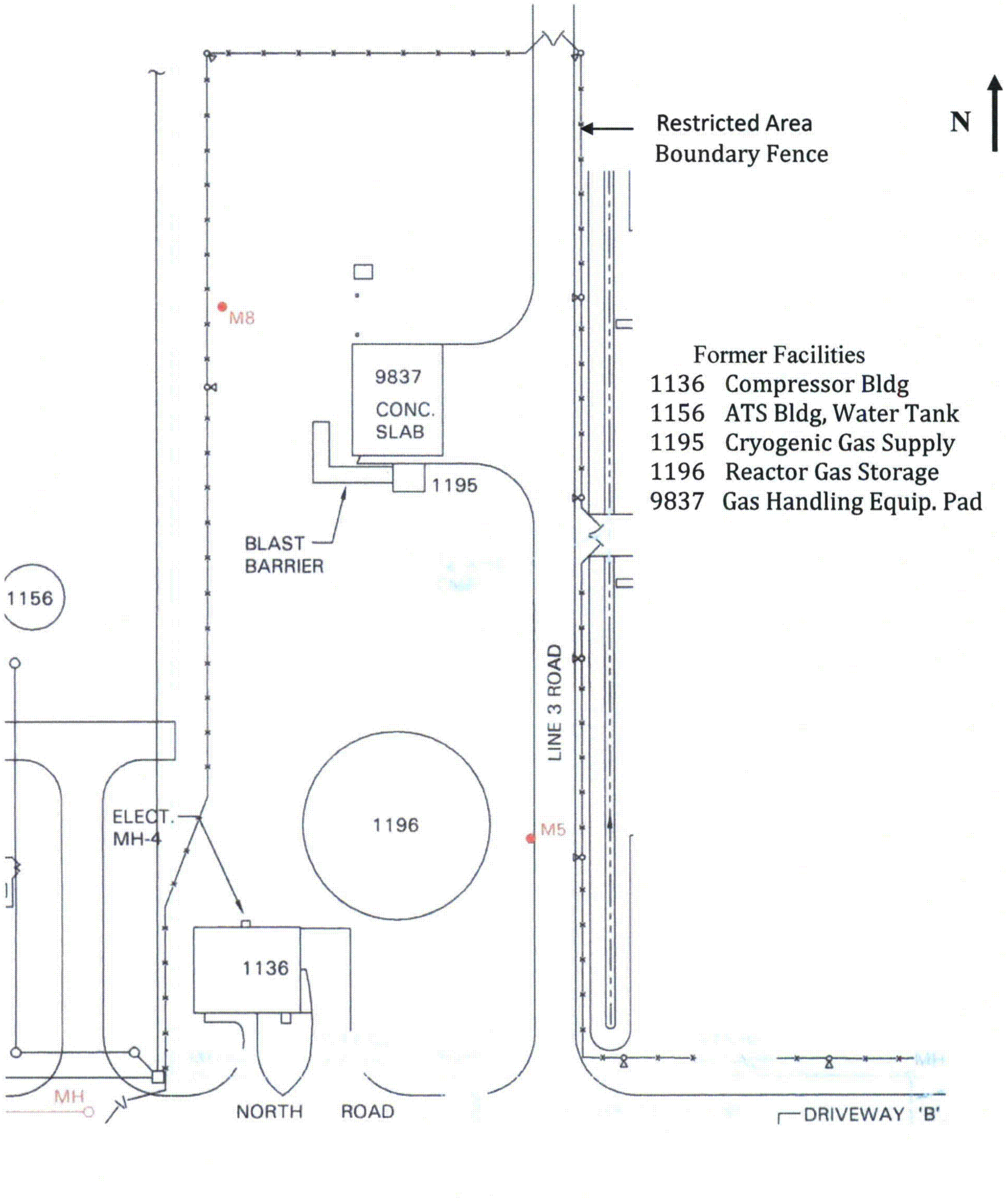


Figure 2, Northern Portion of Restricted Area



2.1 Major Buildings

The major PBRF buildings are shown in Figure 3 midway through decommissioning. A summary description of each of the major buildings is provided below:

Reactor Building (Building 1111)

The Reactor Building (RB) was a large, 41,000 $ft.^2$ (floor area) four story structure which housed the Plum Brook 60 MW Test Reactor, the 100 kW Mockup Reactor (MUR) and associated experimental and test facilities.[5] It was 162 ft. (E-W) by 149 ft. (N-S) at grade level There were two levels below grade (-15 ft. and -25 ft.), the main floor at grade level and a mezzanine floor at 12 ft. The Reactor Building was the center of a four-building complex which comprised the heart of the PBRF. It was connected to three major buildings; the Hot Laboratory (HL), Primary Pump House (PPH) and Reactor Office and Laboratory Building (ROLB). The Reactor Building construction included the Containment Vessel (CV), a large cylindrical steel structure which contained the 60 MW Test Reactor. The CV was 100 ft. in diameter, 111 ft. in height at the center and extended from 56 ft. below grade to 55 ft. above grade. It surrounds the Reactor Tank (Pressure Vessel), Bioshield and experiment-test areas. The MUR was located outside the CV in Canal H in the southeast corner of the RB. For the purposes of FSS, the CV and the RB are reported separately. Detailed descriptions of the CV and the Reactor Building are provided in Attachments 11 and 12, respectively.

Hot Laboratory (Building 1112)

The Hot Laboratory (HL) was a 15,000 $ft.^2$ (floor area), three story building located adjacent to the south side of the Reactor Building. The HL was designed to handle and analyze highly radioactive materials. Chemical, radiochemical and metallurgical analyses of irradiated experiment specimens such as moon rocks, various nuclear fuel materials and nuclear rocket components were performed in the HL. Activities conducted in the HL also included inspection, disassembly, and modification of reactor core components such as fuel elements, beryllium reflectors (sections and plates), the upper grid assembly and irradiated test hardware. The HL contained extensive concrete shielding in walls, floors and ceilings, including high density concrete in the front and side walls of the seven hot cells. Through-wall mechanical manipulators, periscopes, microscopes and other remotely controlled analytical equipment were used to limit personnel exposure to radiation. A detailed description of the Hot Laboratory is provided in Attachment 8.

Primary Pump House (Building 1134)

The Primary Pump House (PPH), a 4,200 $ft.^2$ (floor area, including a mezzanine) building housed major components of the reactor primary cooling water system. These components 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. The PPH shared a common wall with the Reactor Building east side and was of thick-walled concrete construction. The walls and roof were designed to provide shielding from gamma

[5] The combined floor area of the Reactor Building and CV was 41,324 ft^2. The Reactor Building floor area exclusive of the CV was 30,200 ft^2 and the CV floor area was 11,100 ft^2.

radiation originating in the primary coolant and contaminated process equipment. The south and east walls contained sections with removable concrete blocks to provide access for large equipment replacement (heat exchangers, pumps, etc). A detailed description of the PPH is provided in Attachment 13.

Reactor Office and Laboratory Building (Building 1141)

The Reactor Office and Laboratory Building (ROLB) was a three story, 27,000 ft^2 (floor area) structure located immediately west of the Reactor Building. It contained offices, a conference room, a classroom, a library, repair shops, health physics offices, a first aid facility, instrument calibration shop, new fuel vault, equipment calibration facility, and radiochemistry laboratories. The east wall of the ROLB abutted the west wall of the Reactor Building. The buildings were structurally independent. The elevation of the ROLB first floor was at grade level, corresponding to Reactor Building 0 ft. elevation (631 ft. above mean sea level). Other major elevations were: basement, -15 ft.; second floor, 12 ft. and roof, 24 ft. 3 in. The ROLB connected to the Reactor Building through doorways at the basement, first and second floor levels. A detailed description of the ROLB is provided in Attachment 1.

Service Equipment Building (Building 1131)

The Service Equipment Building (SEB), a three-story 25,000 ft^2 (floor area) structure, provided deionized high-purity cooling water for the 60 MW Test Reactor and process (secondary cooling) water for Reactor systems. It also provided service air and instrument air, emergency electric power, heating and process steam and other utilities to the PBRF complex. The SEB housed water processing equipment, air compressors, electrical control equipment, diesel generators for emergency electrical power, and a backup control console with capability to safely shutdown the 60 MW Test Reactor. It also housed personnel offices, an environmental radiological counting laboratory and a chemical test laboratory for water treatment analysis. There were a number of ancillary facilities connected to the SEB. These included the main electrical substation, the water treatment precipitator, two utility air intakes, two diesel fuel oil tanks, a waste oil tank, and the Cold Pipe Tunnel. A detailed description of the SEB is provided in Attachment 2.

Fan House (Building 1132)

The Fan House (FH) was a two level, 6,400 ft^2 (floor area) structure located about 40 meters southeast of the Reactor Building and 10 meters east of the Hot Laboratory (HL). The Fan House first floor elevation is at grade level, corresponding to Reactor Building 0 ft. elevation.

Primary Fan House functions were collection and processing of exhaust air and contaminated water from the Reactor Building and other PBRF buildings. The FH received air from the Reactor Building, the CV, reactor experiments, HL, ROLB basement, PPH, Waste Handling Building (WHB), Hot Retention Area (HRA) and the Hot Pipe Tunnel (HPT). The incoming air was filtered, monitored, compressed and stored for decay as required, then exhausted through the monitored PBRF Stack located adjacent to the east side of the FH.

All radioactively contaminated water from PBRF was processed in the Fan House. This included the reactor primary coolant system, the HRA, Cold Retention Basins (CRBs), experiment cooling water systems, the Quadrant and Canal systems, hot sumps and contaminated laundry. Processed waste water was either recycled or stored for decay, but was eventually disposed of as effluent waste water through the Water Effluent Metering Station (WEMS). A detailed description of the Fan House is provided in Attachment 3.

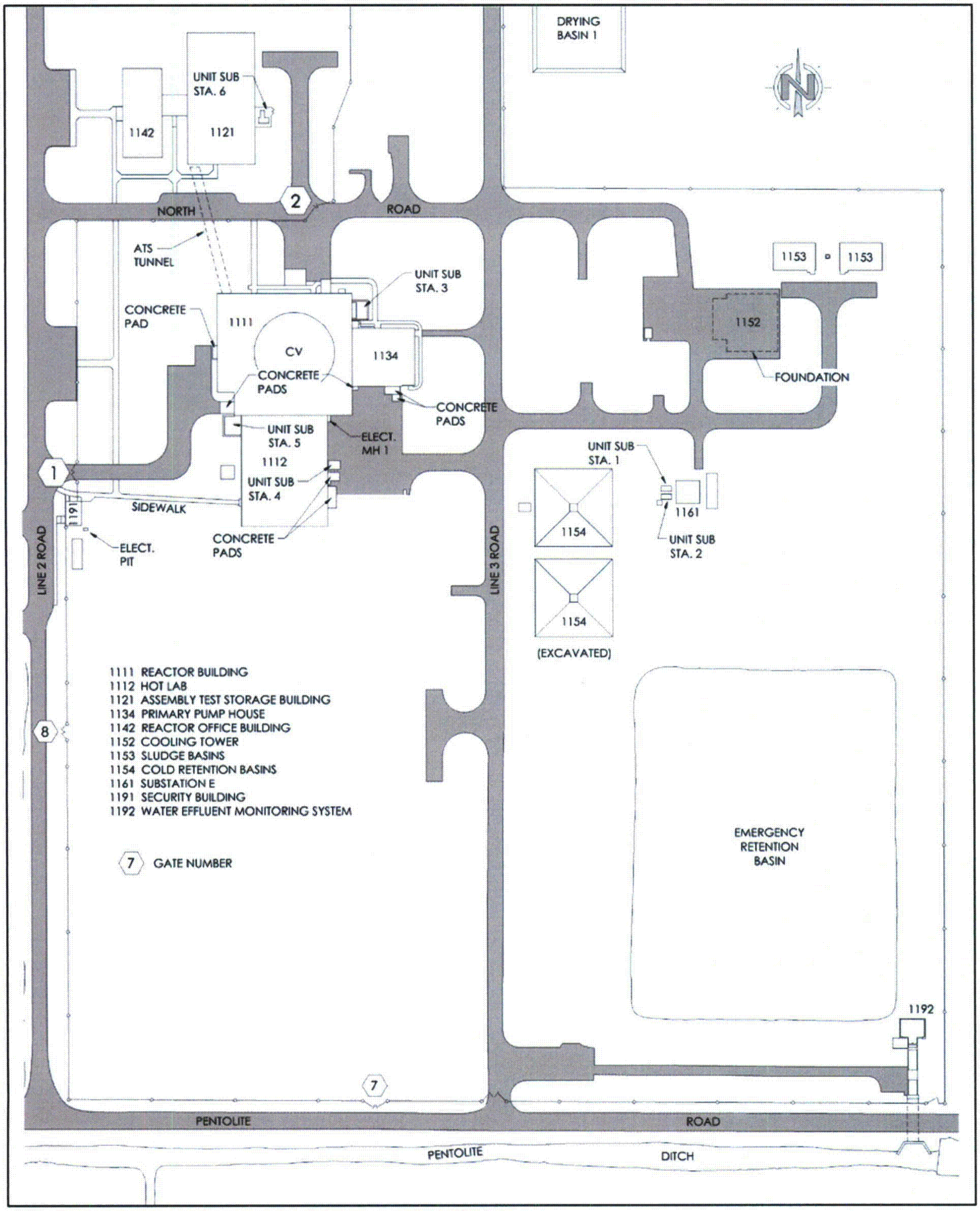
Waste Handling Building (Building 1133)

The Waste Handling Building (WHB), with a floor area of 6,750 ft.^{2}, was designed for handling and processing radioactive material. It was located immediately south of and directly connected to the Fan House. The building contained equipment for processing contaminated water, protective clothing, miscellaneous contaminated trash, or dry active waste (DAW) and equipment and experiment hardware. Waste processing activities included decontamination, waste shipment and recycling. The WHB included laundry facilities for decontaminating protective clothing. It contained operating areas for processing and packaging radioactive waste for offsite shipment. It also contained an evaporator facility for processing high-solids contaminated waste water and work areas for decontaminating reusable equipment and for packaging radioactive waste for storage and shipment. The WHB was designed for operation in close conjunction with the FH and HRA for processing PBRF radioactive wastes. A detailed description of the WHB is provided in Attachment 6.

Hot Retention Area (Building 1155)

The Hot Retention Area (HRA) was designed to provide holding capacity for large volumes of radioactively contaminated water generated in PBRF operations. It functioned as a tank farm for storage, holdup and decay of water from the PBRF Hot Drain system. Eight 60,000 gallon tanks were housed in the HRA reinforced concrete vault-structure located south of the Fan House and adjacent to the west side of the Waste Handling Building. It was 45 ft. wide (east-west) and 90 ft. long (north-south) with the vault floor 25 ft. below grade. The vault roof, or top surface was at grade level, corresponding to the Reactor Building 0 ft. elevation. The main HRA vault however, was covered with a four ft. thick earthen berm to provide shielding from gamma radiation emanating from contaminated water in the tanks. A detailed description of the HRA is provided in Attachment 5.

Figure 3, Portion of PBRF Site Showing Major Buildings



2.2 Process Systems and Structures

Process systems and structures are described which are included in the scope of the FSS. Those that are summarized below were either contaminated or potentially contaminated based on characterization survey results and operating history. These include process systems and structures which were remediated during decommissioning and for which any portions remaining were included in the FSS. The following descriptions are not based on design and function; they are descriptive of their final condition and grouping for the FSS.

Embedded Piping Systems

Embedded piping (EP) is any piping situated below the minus three foot elevation that is totally encased in concrete or piping directly beneath building floors that may not be totally encased in concrete, but contained within the structural foundation of the building. Additionally, EP is grouted after FSS of the piping in compliance with FSS Plan Section 7.5 [NASA 2007]. Detailed descriptions of the EP are provided in Attachment 9. The EP has been divided into four groups for the FSS. They are:

Group 1- Primary Cooling Water Piping

The remnants of this piping system include several hundred linear feet of piping, about 15 separate runs, most of which is embedded in concrete. The most significant portion is the 24-inch primary cooling water (PCW) piping, about 280 feet in length. The PCW piping also includes the embedded remnants of the: By-pass Cleanup, Instrument Cooling and Shutdown loops and drain lines. The PCW piping is stainless steel and it is the only embedded piping system that operated significantly above ambient temperature and pressure and under controlled chemistry conditions. In addition to the primary cooling water piping itself, piping whose main source of water is from the PCW system have been included in Group 1.

Group 2- Quadrant and Canal Piping

This piping totaled over 2000 ft. in length and comprised about 45 runs of stainless and carbon steel piping ranging from 2 to 10 inches in diameter. This piping included drain and supply piping for the Quads and Canals (mostly low temperature water). It comprised the Quad and Canal Recirculation and Pump-out systems.

Group 3- Hot Drain Piping

This was a large and diverse group of piping, with some 50 or more runs totaling several thousand feet in length. This piping typically ranged from one to 4 in. in diameter. These drain lines received water from the Reactor Building, ROLB laboratory drains, process buildings (Primary Pump House, Waste Handling Building and Fan House) and the Hot Cells. In addition to drains from the aforementioned buildings, it includes Hot Pipe Tunnel piping and drains.

Group 4 - Cold Drain System Piping

This was a group of long-run piping with approximately 25 piping runs totaling several thousand feet in length. It included a portion of the Cold Pipe Tunnel piping and floor drains and the ROLB and SEB basement cold drains and other process system piping. This piping ranged from approximately one to 4 in. in diameter and was comprised mostly of carbon steel.

Buried and Miscellaneous Piping

Buried Piping (BP) is defined as any pipe buried in soil and situated outside the structural foundation of a building. The buried piping totals about 1100 linear ft. of piping with diameters ranging from 2 to 14 in. Miscellaneous Piping (MP) is any piping, conduit or similar system which does not meet the definition of Buried Piping or Embedded Piping as defined in the PBRF FSSP, but will remain in the structure. The MP comprises about 8,400 linear ft. of piping with diameters ranging from one to 20 in. It is comprised mostly of piping embedded in concrete walls above 3 ft. below grade. The BP and MP are divided into survey units based primarily on location relative to the structures these piping run survey units are associated with. This protocol is consistent with the requirements and guidance in the PBRF FSSP, Sections 3.4 and 7.5 [NASA 2007]. Detailed descriptions of the BP and MP are provided in Attachment 17.

Storm Drains

The storm drain system at PBRF included 9200 ft. of underground piping, mostly rigid corrugated piping (RCP) and 56 catch basins. The piping diameter ranged from 2 in to 36 in. Most of the storm drains were removed and the overburden and underlying soil was excavated. The storm drain system is described in detail in Attachment 7.

Cold Retention Basins

The CRBs were designed as a holding area for quadrant and canal water associated with the 60 MW Test Reactor and Mock-up Reactor operations. The north basin was identified as CRB-1 and the south as CRB-2. The basins were mostly below grade with a roof section that was about 1-2 feet above grade. They were constructed as two inverted-truncated prism shaped concrete basins with a capacity of about 500,000 gallons each. The basins were 94 feet square at the top, 22 feet square at the bottom and 18 feet deep. A 25 HP vertical shaft pump in each basin returned stored water to the Quadrant and Canal system. This water could also be pumped to the effluent trench (lateral D of the WEMS system) or transferred between basins. The CRBs were demolished and the surrounding gravel and soil excavated. The CRBs are described Attachment 7.

Emergency Retention Basin

The ERB, a three-acre, above ground earthen water storage basin, was located in the southeast corner of the PBRF site. It provided emergency storage for radioactively contaminated water that exceeded liquid effluent discharge criteria. It also provided temporary storage of water from flood events. The ERB had an effective storage capacity of 5,000,000 gallons. It was constructed of clay/soil with dimensions of approximately 200 x 300 ft. at the floor and about 250 x 350 ft. at the top of the surrounding 10 ft. high berm. The water management system was designed to divert effluent water from the WEMS to the ERB when radioactivity levels exceeded pre-set release limits. The ERB was removed (excavated) during decommissioning. The ERB is described in detail in Attachment 10.

Water Effluent Metering Station

The WEMS was designed to record the flow rate and the associated radioactivity levels of wastewater released from the PBRF. It was located in the southeast corner of the reactor site adjacent to and inside the PBRF fence. The WEMS consisted of a large catch basin, a metal building mounted on top of a large concrete trench containing metal gates and a series of three Parshall flumes. The building contained measurement and sampling systems for monitoring radioactivity levels in the effluent water. All PBRF liquid effluent flowed through the flumes where the flow rate was recorded and radioactivity levels were monitored prior to discharge to the Pentolite Ditch. The WEMS was designed to automatically close the gates when radioactivity levels exceeded limits set to prevent radioactivity level releases that would exceed the limits specified in the PBRF AEC/NRC licenses. A detailed description of the WEMS is provided in Attachment 15.

Miscellaneous Structures and Pads

In addition to the WEMS, remnants of several water processing structures and other PBRF structures and pads are contained in the FSS group identified as Miscellaneous Structures and Pads. Detailed descriptions are provided in Attachment 15. Summary descriptions are provided below:

1. Assembly Test Storage (ATS) Building Tunnel

   The tunnel connecting the Reactor Building and the ATS Building was constructed in 1964-65 as part of the Reactor Office Building (ROB) and ATS Building additions to the PBRF. This facility expansion accommodated the growth of personnel and equipment related to new experimental programs. It also enabled the assembly of test experiment hardware prior to installation in the Reactor Building experimental areas. The ATS Tunnel connecting the two buildings facilitated the use of common utilities such as steam, communications, raw water, deionized water, cooling water and experimental air. The 152 ft. long tunnel was constructed of reinforced poured concrete, with 12 in. floor and 10 in. wall and ceiling thickness. The interior cross section was 10 ft. wide and 8 ft. in height. Following permanent shutdown of the PBRF in 1973, the ROB and ATS Buildings were removed from the PBRF licenses in 1976. These buildings were segregated from the PBRF restricted area by relocation of the boundary fence to align with North Road just north of the Reactor Building. All tunnel utilities were severed and the tunnel was isolated by installation of a concrete block wall at the ATS Building end to prevent personnel access from outside the restricted area.

2. Cooling Tower Basin

   The Cooling Tower and the underlying basin were located east of the Service Equipment Bldg and the N/S section of the Cold Pipe Tunnel. The tower, a wooden (cedar) structure, was mounted on the walls of a large reinforced concrete water basin. The basin included a raised concrete pump pad attached to the west side of the main basin with a separate sump located below. The main basin floor was below grade and the walls on the north, east and south sides extended upward to the 5 ft. elevation. The sump west wall was a common wall with the Cold Pipe Tunnel. The cooling tower sump had a footprint of approximately 57 x 28 ft. The sump was approximately 5 ft. deep on the east side, increasing to a depth to 15 ft. on the west side. The sump was separated from the Cooling Tower basin by a 1 ft. thick reinforced concrete wall. Four aluminum grating trash screens of approximately 5 x 7 ft. in the wall permitted water flow from the basin. The roof of the sump was 1 ft. thick reinforced concrete, on which nine secondary cooling water pumps were mounted. The Cooling Tower basin was of dimensions approximately 62 x71 ft. The north-south dimension was the larger dimension.

3. Precipitator Sludge-Settling Basin

   Two precipitator sludge-settling basins (identified as Building 1153) were located northeast of the cooling tower water basin and east of the precipitator. These two basins received the blow down materials, called sludge or blanket material, from the water treatment precipitator (Building 1157) located north of the SEB. The precipitator and sludge settling basins were part of the system for treating raw Lake Erie water, the source of process water for the PBRF. As an integral part of precipitator operation, a controlled portion of the precipitator blanket, a suspension of lime and alum for softening the incoming raw lake water, was continuously blown down. To preclude sending the sludge directly into the storm drain main lateral where it could impact WEMS operations, the sludge was sent to two settling basins. When the sludge reached a prescribed fill level (thickness and depth) in the settling basins, it was sampled and analyzed for radioactivity in accordance with PBRF operating procedures and pumped to sludge drying basins just north of the PBRF restricted area. Each settling basin was rectangular, 32 x 49 ft., with a sloping floor 8 ft. deep at one end and 10 ft. deep at the other. The walls and wall footers were roughly 1 ft. thick; the flooring was 4 inches thick. Each basin was equipped with a pump for moving sludge to the drying basins. The metal mesh covered sludge-settling basins had internal sections to facilitate sludge removal.

4. Other Miscellaneous Structures

   This group of small-miscellaneous structures includes the following:

   - Reactor electrical substation pads,
   - Pads and foundations west of the Reactor Building,

- Pads and foundations east of the Hot Lab and Reactor Building,
- Substation 4 pad and equipment ramp east of the Hot Lab rollup door.
- The sidewalk connecting the Hot Lab and Reactor Buildings to the Reactor Security Building,
- Pads for decommissioning work crew and equipment trailers formerly located west of the Hot Lab,
- The WEMS outfall wing wall south of Pentolite Road and
- Sludge drying basin sluice gates, located north of the northern restricted area boundary fence.

Most of these miscellaneous structures did not house active process systems.

5. Reactor Security Building

The Reactor Security Building was a 20 x 32.5 ft. single story wood frame building with exterior plywood sheeting covered with vinyl siding. The roof was constructed of 1 x 8 in. oak planks with multiple-ply built-up paper and bitumen covering. The building was located just inside the PBRF restricted area boundary fence directly west of the Hot Lab. The building served as the access control facility since the PBRF began operations in 1961.

2.3 Environmental Areas

The PBRF environmental areas comprise outdoor areas included in the FSS. Most of these are identified in the FSS Plan Table 2-2. Summary descriptions of these areas are provided below. The FSSR Report attachments are identified where detailed descriptions and FSS results are presented.

<u>Pentolite Ditch</u>

The Pentolite Ditch was constructed in the 1958-61 timeframe as part of PBRF site water management infrastructure. A 1958 vintage site map shows a small unnamed surface stream running west to east just south of Pentolite Road. During PBRF construction, the Pentolite Ditch was created by straightening and extending the stream channel to run parallel to Pentolite Road from Garage Road on the west to the Plum Brook on the east, a distance of approximately 2750 ft. In about 1958, the ditch was excavated from a 4 foot bottom to a "V" profile, roughly 12-15 feet wide and 6 feet deep during the reactor construction period. The Ditch was designed to receive surface runoff from Plum Brook Station areas south of Pentolite Road, to drain the Pentolite Road right of way and to receive liquid effluents from the PBRF. Liquid effluents from PBRF operations, from storm drains, processed Lake Erie dilution water and surface runoff were released in a controlled manner to the ditch via the WEMS. The ditch was designed to accommodate maximum expected WEMS outflow and surface runoff from the 100-year rainfall event. The Pentolite Ditch and environs are described in detail in Attachment 4.

Excavated Areas within the Restricted Area

Excavated areas within and immediately adjacent to the Restricted Area are described in Attachment 7 of this report. This attachment includes the FSS of excavated footprints of the storm drains and catch basins, the Cold Retention Basins, sanitary sewers, the ERB sump and drain lines, the HRA underground storage tanks, seven localized areas identified as "spill areas" and an area identified as the RCRA soil area located immediately south of the former SEB. The excavated areas also included areas where miscellaneous underground utilities were located plus portions of the WHB foundation (evaporator pit) and the Fan House (resin pit). Altogether, the excavated areas reported in Attachment 7 comprised a surface area of about 25,000 m^2 (6.2 acres).

Open Land Areas

Open land areas within the PBRF Restricted Area, plus adjacent buffer areas are described in detail in Attachment 16. The ERB is not included in the open land areas described here; it is described in Attachment 10. The open land areas addressed in these attachments include the land surface exclusive of paved areas (roadways, parking lots and pads). They include all the excavated areas identified above – after they were backfilled with clean fill to grade level. The description of and FSS of excavated and backfill material are provided in Attachment 18.

Transport Roadways and Parking Lots

The Transport Roadways and Parking Lots include all paved roadways, parking lots and other paved areas within the PBRF and the PBS where licensed radioactive materials were stored and over which they were transported. These areas are described in detail in Attachment 14. They include:

- All remaining sections of roadways and paved areas within the Restricted Area fence,
- The PBRF paved parking lot between Line 1 Road and Line 2 Road,
- The staging/storage area west of the PBS warehouses on Pentolite Rd. west of the PBRF, commonly referred to as the "bone yard",
- Line 1, Line 2 and Line 3 Roads,
- The parking lot and connecting roadways in the vicinity of the ATS facility,
- Pentolite Road beginning at the confluence of Plum Brook and Pentolite Ditch then heading west to the western boundary of the "bone yard" identified above,
- Garage Road beginning at the intersection with Pentolite Road and extending south for 0.10 miles and

- Transport routes for radwaste shipments from the PBRF to the PBS exit gates not listed above.

Plum Brook

Plum Brook, from the Pentolite Ditch to its terminus at Sandusky Bay, a distance of approximately four miles, was determined to contain sediments contaminated with radionuclides of PBRF origin at concentrations above the single radionuclide DCGLs for soil established in the FSS Plan. The impacted stream course was extensively characterized and local areas with concentrations of Cs-137 above the DCGL were remediated by excavation. From discussions with the NRC and the Ohio Department of Health, it was agreed that the 25 mrem/y dose criterion approved for the PBRF would also apply to the Plum Brook and environs. In accordance with this agreement, NASA demonstrated through dose modeling calculations that the dose to a member of the critical group from residual radioactivity in sediments from Plum Brook is well below the dose criterion for unrestricted use in 10 CFR 20.1402. Characterization survey results were used to develop source terms for dose assessments which showed that the dose to an average member of the public is well below the 25 mrem/y dose criterion. This approach was adopted in lieu of performing an FSS of the entire stream course. The results of this evaluation are summarized in this report with references for detailed descriptions of the Plum Brook, the Plum Brook Characterization and the dose assessment in PBRF Technical Basis Documents.

2.4 Site Modifications

There were many modifications to the PBRF after initial criticality of the 60 MW Test Reactor in 1961 continuing until shutdown in 1973. Many of these modifications involved radioactive systems and equipment and areas where radioactive materials were handled and stored. Some changes to the facility occurred after shutdown of the reactors in 1973, including protective maintenance of the major buildings. Modifications to the major buildings and site facilities are summarized below:

Reactor Building and Containment Vessel

Modifications to the 60 MW Test Reactor and experimental facilities and to the Reactor Building occurred throughout the period 1961 to 1973. Modifications to the 60 MW Test Reactor and experiment facilities, mostly inside the CV, included:

- beryllium reflector plate replacement in the 60 MW Test Reactor,
- addition of insertion tables for Reactor experiments in Quadrants A, C and D,
- an underwater beam room was installed on the floor of Quadrant D,
- hot cells were installed on the east and north sides of the Dry Annulus at the – 25 ft. elevation (these were small hot cells, generally referred to as the Hot Caves),
- neutron radiography capability was added to Quadrant A,

- an experimental air lock was added to the CV shell on the southwest area of the 0 ft. elevation
- concrete partitions were installed on the Quadrant B thermal column,
- a balcony was added to Quadrant B,
- acoustic panels were added to the CV dome ceiling, and
- the traveling bridge was relocated above Quadrant C.

Many modifications were also made to the Reactor Building outside of the CV. These included:

- Addition of a decontamination room with an emergency shower to the area outside the east airlock on the 0 ft. elevation (1969).
- Partitions were installed on the mezzanine level to convert a shop area to offices to house shift support staff (Rooms 1 through 4).
- Modifications to the Experiment Control Room were made to centralize the operation of experiments and to upgrade the computerized data logging system. This included modification and expansion of Rooms 102 – 103 to serve as the Experiment Control Room annex.
- A fenced-locked controlled area was added to the – 15 ft. elevation, northwest side for storing radioactive sources and miscellaneous small shielded and unshielded radioactive material items.
- A recycle cleanup system for Canal H was added to the -15 ft. elevation south of the east stairwell.
- Spent fuel storage capacity was expanded by the installation of additional cadmium-lined spent fuel storage racks in Canal G.
- A major modification involved installation of the cathodic protection system in 1961. Twenty anode stations were installed around the perimeter of the CV approximately 18 degrees apart. The stations, or wells, were installed on the 0 ft. -15 ft. and -25 ft. elevations. The anode stations were constructed of 6 in. pipe casing extending down to bedrock at depths between the –35 ft. 6 in. and –50 ft. 6 in. elevations.[6]

In addition, support services were added for the expanded experimental facilities. These included: cooling water and cryogenic cooling, service air, electrical power and instrumentation.

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[6] The FSS of RB cathodic protection wells is covered in the Final Report Attachment 17, Buried and Miscellaneous Piping.

Hot Laboratory

The Hot Laboratory was operated mostly as designed and built, with only minor modifications during the PBRF operating period. Stainless steel liners were installed in the hot cells circa 1962, to facilitate decontamination. In the 1980s and 1990s, the roofing material was removed and foamed material installed to limit rainwater leakage into the building.

Primary Pump House

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 staircase added in the 1960s to improve personnel safety for 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.

Reactor Office and Laboratory Building

The ROLB was constructed as a multipurpose office and laboratory building and modifications occurred throughout the 1960-1973 period. New equipment was added in response to new or revised mission requirements. For example, a radiation detector/instrumentation calibration facility was added outside the northwest corner of the basement in the 1961 timeframe. Upgrades of existing laboratory equipment occurred and new analytical equipment was installed in the second floor radiochemistry laboratories. These included a mass spectrometer, spectro-photometer, and infrared analyzer in the late 1960s. Other modifications were made to improve safety and efficiency of laboratory operations. These included addition of filter housings, cabinets, fume hoods and shielded glove boxes. Emergency showers and eye wash stations were installed in 1963-64. Some office areas were modified; primarily wall partition rearrangements during the operations phase to facilitate organizational changes. Room rearrangements in the electronics shops, health physics and radiochemistry laboratories areas were also made in this period.

Service Equipment Building

Modifications to the SEB facility occurred several times to improve operations such as the addition of a 2,200 square foot Annex in the 1964-1965 time frame, replacement of four small diesels generators with two larger units, and remodeling to create a separate radioactivity counting room.

Fan House

Several modifications were made to the Fan House after initial construction. These included removal of the contaminated laundry equipment when this function was transferred to the WHB in 1964. Other modifications included addition of instrumentation and controls for various Fan House processing systems and improvements to the air and water cleanup systems. The air handling system was expanded to include WHB exhaust air processing. The Fan House Roof was repaired and upgraded in 1986 and again in 1998.

Waste Handling Building

The WHB was constructed in 1962-64, after initial criticality of the 60 MW Test Reactor in 1961. It was operated as designed and built, with only minor modifications after initial startup. The contaminated laundry operation was moved from the Fan House and installed in the WHB in 1964.

Hot Retention Area

The HRA was operated as designed and built, with minor modifications. During early reactor full power operations, soaps from laundry operations and decontamination activities fouled the ion exchange resins in the waste cleanup system. Subsequently, to improve water processing, the four underground holdup tanks were used exclusively for laundry and decontamination waste. The high-solids waste water was processed through an evaporator located in the WHB. Modifications were also made to control water intrusion into the vault and pipe chase after the PBRF was shutdown. A pump system was added in 1985 to control groundwater levels in the vault. In 1986, the HRA valve handle extensions were removed and the pipe chase roof sealed to prevent rain water intrusion into the pipe chase.

Assembly Test Storage Building

The Assembly Test Storage Building was constructed in 1964-65 as part of the Reactor Office Building (ROB) and ATS Building addition to the PBRF site. This facility expansion was made to accommodate the growth of personnel and equipment related to new experimental programs. It also enabled the assembly of test experiment hardware prior to installation in the Reactor Building experimental areas. As part of the ATS building construction, a tunnel, called the ATS Tunnel, was constructed connecting the two buildings. It facilitated the use of common utilities such as steam, communications, raw water, deionized water, cooling water and experimental air. Utility piping was suspended by racks on the east side of the tunnel and power and communications cables were carried in cable trays on the west side. The tunnel also served as a personnel passageway between the two buildings. Following shutdown of the PBRF operating facilities in 1973, the ATS Tunnel was isolated by installation of a concrete block wall at the north end of the tunnel to prevent personnel access from the ATS Building.

Storm Drains

The Storm Drain System was originally constructed in the 1959 to 1963 time frame. Major modifications were made to the system several times to improve performance such as adding a hydro-mat liner to the open ditches, reshaping the flow path, and subsequently adding concrete piping and covering the ditches

Water Effluent Metering Station

The WEMS effluent radiation monitoring and gate control system was upgraded in 1967 to reduce the frequency of unnecessary gate closures due to defective detectors (GM tubes) in the water monitoring and gate control system. A more reliable system, using a beta-gamma scintillation detector with three independent photo-multipliers, was installed to replace the original equipment. As part of this modification, a new sampling mechanism was installed, which included a 30-inch diameter hemisphere which incorporated shielding to reduce detector background.

Emergency Retention Basin

The ERB was operated as constructed from facility startup until 1968, when the water inlet and drain systems were modified. Effluent water from the WEMS was originally pumped from the main WEMS lateral to the ERB by a gasoline motor-driven pump. The inlet system was modified by replacement of the gasoline motor pump with two electric motor-driven 1500 gpm pumps. The increased pumping capacity was added to handle potential storm drain overflow from unusually heavy rainfall. The gasoline motor driven pump was retained as a backup.

As initially constructed, the ERB was drained via a siphon system. However, the siphon drain proved to be ineffective during freezing weather. Also, air in-leakage through the siphon gate valves reduced the efficiency. In 1968, a drain line was connected to the sump to improve control and metering of the ERB discharge. It included 4 in. schedule 40 black steel pipe from the ERB sump to a below grade valve pit containing two valves in series (a plug valve and a butterfly valve for fine control). The ERB drain water then discharged through a weir box to a catch basin (18A) on the main WEMS storm and effluent drain lateral located directly east of the ERB.

Cold Retention Basins

During facility operations, it was suspected that the Cold Retention Basins leaked so a plastic liner was installed in 1969. Both basins were pumped dry during the 1985 characterization study, and some silt had accumulated both on the liner and in the bottoms of the basins. The concrete structures and underlying soil could also be contaminated [NASA 2007a].

Pentolite Ditch

On several occasions since initial construction, the Pentolite Ditch bed was dredged to remove accumulated sediment and debris and the banks graded to remove vegetation growth. Soil and sediment removed by these activities were spread on nearby land areas south of the ditch.

2.5 Final Configuration for FSS

The final configuration for FSS refers to the configuration at the time of the FSS of the PBRF buildings, remaining portions of systems and environmental areas. This is to distinguish from the so-called end state condition of the facility. For the end-state condition, it is NASA's intention to remove all remaining above-grade structures and paved areas to create a natural-area wetlands. The final configuration for the FSS of the PBRF is summarized:

- The major building structures were intact with interior surface coverings removed that could have covered legacy contamination. All furnishings were removed and all accessible equipment was removed including pumps and accessible piping.
- Equipment associated with miscellaneous outdoor structures and pads was removed, for example, the water tower, precipitator and precipitator basin equipment, electrical substation equipment and transformers, etc.
- Excavated areas were cleared of all piping, equipment and non-soil materials.
- Open land soil areas, including excavated areas that had been subjected to FSS and backfilled, were cleared of all remaining debris from decommissioning. Water was drained as necessary from low areas.
- Transport Roadways and Parking Lots were cleaned to remove residue from decommissioning operations, mostly mud and gravel.
- Embedded piping was cleared of obstructions, dried, access openings provided as necessary and decontaminated for the FSS.
- Similarly to embedded piping, buried and miscellaneous piping was cleared and decontaminated as necessary, with pipe ends made accessible for FSS detectors.

Detailed descriptions and photographs which illustrate the condition of the various buildings and environmental areas for the FSS, are provided in the attachments to this report.

3.0 Site History

A chronology of PBRF milestones is given below. This is followed by a discussion of facility operations, post-shutdown and decommissioning activities. Emphasis is on operations with radioactive materials that could have affected the final site condition and Final Status Survey.[7]

3.1 Chronology

Planning and design activities for the PBRF were initiated in 1955 with ground breaking in 1956. The Plum Brook 60 MW Test Reactor began full power operations in 1963. It operated for a total of 98,000 megawatt days (MWD - thermal power) in support of fuel and material testing for the Nuclear Aircraft, Space Nuclear Rocket and other NASA programs [NASA 2007a, Bowles 2006]. Major PBRF milestones are listed below:

1956 – September, groundbreaking for PBRF.

[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.

1957 – Reactor Building construction initiated.

1959 – Initial site occupancy.

1961 – June, 60 Mw Test Reactor critical.

1963 – full power operations begin.

1973 - January 5th, Reactor shutdown (after 152 operating cycles).[8]

1973 – June 30, All fuel removed and PBRF facilities placed in standby condition.

1985 – Initial site radiological characterization, Teledyne Isotopes Inc. [Tele 1987].

1989 – Follow-up radiological characterization, GTS-Duratek [GTS 1998].

2002 – Decommissioning Plan approved. Equipment removal and decontamination of buildings initiated.

2002 - 2010 - Remediation of contaminated buildings and environmental areas.

2011 – FSS measurements completed.

2012 - Building demolition completed.

3.2 Operations with Radioactive Materials

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. This license also covered Hot Laboratory operations and related analytical activities in the radiochemistry laboratories. Special Nuclear Materials license SNM 605 covered the right to possess and irradiate limited quantities of source and special nuclear materials.

Controls for radioactive materials included inventory records of radioactive materials at the PBRF. These recorded receipts, storage, transfer and disposition of individual radioactive material items. Radionuclides recorded on inventory sheets included tritium, C-14, Na-22, P-32, Sc-46, Cr-51, Mn-54, Fe-55, Fe-59, Co-60, Ni-63, Zn-65, Kr-85, Sr-90, Ru-106, Cd-109,

[8] The length of an operating cycle was determined by fuel burn-up in the 60 MW Test Reactor. Loss of reactivity, usually driven by xenon poisoning, dictated when the reactor was shut down and refueled. The typical cycle duration was two weeks; three days for refueling and 11 days of operating time. Some shutdown periods extended longer than three days, for example for experiment installation, reactor modifications and maintenance.

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

Ag-110m, Cd-115, Ba-133, Ce-144, Cs-137, Nd-147, Pm-147, Eu-152, Eu-154, Ta-182, W-185, Hg-203, Tl-204, Po-210, mixed fission products, Radium, Uranium (natural, depleted and enriched), Am-Be neutron sources and Np-237. Most of the source inventory was disposed as radioactive waste during operations (1961-73) and during the transition to "mothball" status in 1973. The remainder was transferred to other licensees, returned to the AEC, or stored on-site for potential future use under "possession only" AEC/NRC licenses.

Routine reactor operations resulted in production of radioactive materials and contamination of various systems and areas within the PBRF. The following summary of routine operations leading to contamination of PBRF structures and environmental areas is excerpted from the Decommissioning Plan [NASA 2007a]:

- During reactor operations, irradiated fuel specimens were processed in the Hot Laboratory; so fission products were expected to be present in the hot cells, hot drains, hot sumps, etc. Characterization sampling showed that Cs-137 and Sr-90 were present in the hot cell drains and sumps.

- Portions of the biological shield nearest the reactor tank were contaminated by neutron activation.

- Operational tasks performed in the seven hot cells resulted in radioactive contamination in the Hot Laboratory air handling and liquid drain systems as well as on various equipment and building surfaces.

- There were many options for routing quadrant and canal water to and from the Hot Retention Area and Cold Retention Basins, which resulted in low levels of contamination in these piping systems.

- The hot drain system collected water from all radioactively contaminated areas and was contaminated.

- During reactor operations, tritium was produced in the various beryllium components of the reactor core. Sampling confirmed that tritium was off-gassing inside the reactor tank.

- Contamination in the primary cooling water piping consisted of an activated corrosion product film deposit in the piping and loose crud and debris in components such as the PCW strainer, pumps, valves, etc. This type of contamination was also expected to be present inside the reactor tank, as well as the by-pass cleanup piping, components, pumps, tanks, resin pits etc., in the Primary Pump House.

- Characterization sampling showed that Cs-134, Cs-137, and Sr-90 were present in the quadrant and canal drains, all hot sumps, resin pits, Hot Retention Area, and in the soil at the Emergency Retention Basin. This fission product contamination resulted from small fuel cladding failures, routine operations and maintenance of reactor systems or recycling of contaminated water from hot drain systems.

- During facility operations, it was suspected that the Cold Retention Basins leaked so a plastic liner was installed in 1969. Both basins were pumped dry during the 1985 characterization study, and some silt had accumulated both on the liner and in the bottoms of the basins. The concrete structures and underlying soil were also suspected to be contaminated.

- During operations, the Emergency Retention Basin was used for emergency storage of radioactively contaminated water, and the stored water could evaporate, percolate into the soil, decay off and be discharged, or be diluted and discharged. Therefore, soil contamination in the Emergency Retention Basin was expected. Characterization surveys showed that the clay liner slowed or prevented penetration of contamination to the deeper underlying soil.

- Low-level contaminated water was discharged to the storm drain system (drain pipes and catch basins), traveled through the WEMS trench, and then discharged to the Pentolite Ditch. Radioactively contaminated silt collected in these areas.

Activities within PBRF facilities involving radioactive material handling were documented in PBRF cycle reports, radiochemistry periodic and special reports, PBRF annual reports, and experiment results reports. On occasion, incidents involving loss of control of radioactive materials were reported. These were recorded in Operations Cycle reports. Spills and other events leading to contamination of facility areas included:

- The PBRF 60 MW Test reactor poison injection safety system was designed to inject gadolinium nitrate solution into the core. This system was accidentally triggered on three occasions during operations; at least one of these occurred during criticality while neutron fluxes were present. The primary cooling water piping was promptly flushed and cleaned out.

- A low-level radioactivity spill occurred during spent resin pumping near the Primary Pump House resin pits, resulting in a small area of contaminated soil.

- A spill occurred adjacent to the Waste Handling Building concrete pad, resulting in contamination of the pavement and underlying soil.

- Flood events in 1966 caused the storm drain lateral which fed waste water to the WEMS to overflow. This caused contamination of the soil area east of the WEMS.

- During the 1985 characterization study, the polyethylene hot cell drain line in the Hot Pipe Tunnel (HPT) was found to be broken, leaking contamination onto the floor of the tunnel [Tele 1987]. The cause of failure was believed to be the expansion/contraction due to temperature difference together with possible failure due to radiation damage. The fracture was repaired and a strippable coating formulated to remove contamination from concrete surfaces was applied to the contaminated area. It was partially successful at removing the contamination.

- Spills occurred in a small location on the floors of Room 212 and 214 in the Reactor Office and Laboratory Building that penetrated the cracks between the floor tiles.

3.3 Disposition of Materials in the Post-Shutdown Period

Notification was received at the PBRF on January 5, 1973 that NASA top management had directed that all nuclear related operations at PBRF was to be terminated due to budget constraints. The test reactor, mock-up reactor, hot laboratory and all associated operations were to be placed in standby condition by June 30, 1973. This included termination of the reactor facility operations staff.

Following notification, the 60 MW Test Reactor was immediately shutdown on January 5th. A Master Plan was developed to address the activities associated with terminating the operating licenses for PBRF and placing the facility in a standby status. End condition statements were developed. These specified the final conditions for all buildings, structures and equipment on the PBRF site as of June 30, 1973. Both the initial Master Plan and the End Condition Statements were subject to revision as activities progressed or conditions changed.

All source material (natural uranium) and special nuclear material were to be removed from the facility; except for calibration sources covered by general licenses per 10CFR70 and 10CFR40. Materials removed included fuel elements (new and spent, MTR-type 93 per cent enriched uranium-aluminum alloy), fission chambers, plutonium-beryllium neutron sources for MUR startup and neutron calibration. Also removed were sealed and unsealed byproduct sources (such as a polonium-beryllium neutron source), Ce-144, Au-198, Cs-137, Co-60 and others. The items for removal were identified and either disposed of as radioactive waste, transferred to other licensed facilities, returned to the AEC for credit or stored for calibration of radiation monitoring equipment.

Between January and June 1973, all source and special nuclear materials were removed from the site. The various foils, pins, fission chambers and sources used in operations and experiments were transferred to other licensees, returned to the AEC or disposed of as radioactive waste. All irradiated fuel elements from the 60 MW Test Reactor and the MUR were shipped to the AEC (the Savannah River Laboratory) for reprocessing between March and May 1973 via 15 shipments. The PBRF inventory of un-irradiated fuel elements (118 standard and 26 control elements) were shipped to the AEC Oak Ridge Laboratory for use in the Oak Ridge Reactor. The PBRF fuel fabrication contract with Gulf-United Nuclear Corp. was terminated. All finished fuel elements, useable unfinished fuel element parts and other SNM in the supply line were returned to the AEC or sent to other licensees per provisions in the contract termination letter.

Highly radioactive items that could possibly be used for restart of the 60 MW Test Reactor were placed in the Hot Dry Storage area of the Hot Lab. These included beryllium plates, seven irradiated control rods (containing mostly cadmium and stainless steel) and irradiated experiment equipment.

Beginning in mid-1973, activities at PBRF were controlled according to modified AEC/NRC possession only licenses TR-3, R-93 and BPL No. 34-060706-03. The by-product license No.

34-060706-03 was terminated in May, 1982. Licenses TR-3 and R-93 controlled and authorized possession only of the remaining radioactive materials on-site, i.e., no facility operations were permitted until decommissioning was authorized in 2002. During 1973 to 2002, selected equipment, materials, and waste (both low-level radioactive and non-radioactive) were removed to other locations or discarded as the projected long-term considerations for the facility changed from possible restart to standby to decommissioning. For a brief history of the activities during this period, see the NASA PBRF Decommissioning Plan, Section 1.2.1 Decommissioning Historical Overview [NASA 2007a].

Following permanent shutdown of the PBRF operating facilities in 1973, the ROB and ATS Buildings were removed from the PBRF licenses in 1976. These buildings were segregated from the PBRF secured area by relocation of the boundary fence to align with North Road just north of the Reactor Building. All ATS tunnel utilities were severed and the tunnel was isolated by installation of a concrete block wall at the ATS Building end of the tunnel. The relocation of the boundary fence removed all the area north of North Rd. from the Restricted Area, except an area bounded on the south by North Rd. extending north for about 600 ft. and bounded on the east by Line 3 Rd (shown in Figure 2). This approximately two acre parcel and the site area shown in Figure 1 comprise the 27 acre Restricted Area described in the current NRC License.

3.4 Decommissioning

The PBRF Decommissioning Plan identified major decommissioning tasks to achieve termination of the NRC licenses [NASA 2007a]. They were:

- Characterize facility systems, structures and environmental areas,
- Remove friable asbestos and lead paint,
- Remove 60 MW Test Reactor internals and tank,
- Remove the activated material stored in the Hot Laboratory Hot Dry Storage Area,
- Remove loose equipment, fixed equipment and components, and piping in buildings and underground areas where necessary,
- Remove activated portions of the concrete biological shield and other areas of contaminated concrete inside and outside of buildings,
- Remove embedded piping (i.e., piping embedded in concrete) where necessary,
- Remove contaminated soil and either leveling or backfilling the areas,
- Conducting final status surveys of all affected areas after decontamination to verify that radioactive material has been removed to below the license termination criteria,

- Demolish the above grade portions of decontaminated buildings and other structures (either before or after license termination) and

- Backfill the below grade portions of decontaminated buildings and in-ground structures.

As it transpired, the decommissioning scope expanded to include removal of storm drains, catch basins, sanitary sewers and underground utilities and excavation of contaminated areas under and adjacent to building foundations. Also, site support and service structures and above ground utilities were removed. Packaging and shipment of radioactive waste constituted a major decommissioning task. Decommissioning work tasks were performed under PBRF work control procedures which included Work Execution Packages (WEPs), Radiation Work Permits (RWPs) and other applicable safety procedures and permits (confined space entry, hot work, elevated work, etc). Decommissioning activities are summarized below for the major contaminated buildings and the environmental areas.[10]

When decommissioning was initiated in 2002, the majority of highly radioactive material was located in two locations on site:

- The 60 MW Test Reactor Tank (pressure vessel) and attached experiment irradiation facilities. This included, experiment horizontal through tubes (2), horizontal beam tubes (3), vertical test tubes and core supports. The reactor core area included, reactor core fuel boxes, beryllium reflector and beryllium side plates, in-core experiment facilities and control rod drives.

- The aforementioned items stored in the Hot Dry Storage Area of the Hot Lab.

<u>Reactor Building and CV</u>

Decommissioning of the RB and CV (and the other buildings) proceeded in phases. In the initial phase, from 2002 through approximately 2006, the principal focus was on removing free-standing and fixed equipment, including exposed valves, piping and supporting equipment. The RB and CV were cleared of removable items such as piping, pumps, valve extensions and handles, electrical boxes, cable trays, ventilation systems, electronic instrumentation (including control room panels and equipment), experiment hardware, etc. This included waste disposal of radioactively contaminated items. Recyclable items were segregated where possible.

Following removal of fixed equipment, asbestos abatement was performed. Asbestos abatement work in the Reactor Building, CV and other buildings was initiated in late 2007 and continued in 2008. Asbestos containing materials included mastic-sealant on water-filled area surfaces, floor tiles and thermal system insulation and gasket material that remained after fixed equipment removal. Techniques for removal of asbestos-containing material included

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[10] Sources of information for the summary of decommissioning activities include on-going work summaries, personnel recollections, memorandums to files, Work Execution Package documents and Decommissioning Newsletters. The latter were published approximately quarterly from 2004 through 2011 to provide information on decommissioning progress to the public and to the local Community Work Group (a citizens advisory group).

sponge-jet blasting, wall and floor shaving and scabbling using "box scabbling" equipment and hand tools.[11] It is noted that asbestos abatement in effect was the first stage of decontamination of building surfaces because much of the asbestos-containing material was contaminated or in close contact with contaminated piping and equipment remnants.

The Reactor Tank and associated support structures were cut out in sections and shipped off-site for disposal. The region of the biological shielding surrounding the Reactor core area was removed (3 to 4 ft. above and below the core center-line) and disposed of as radioactive waste. The Thermal Column and surrounding concrete were removed. Beam tubes and through tubes, were also cut out and disposed of.

The Subpile Room, access hallway, stairway and connected piping systems and thimbles were grouted up to the -25-ft. elevation. The lead shield-donut and the control rod drive housing below the Reactor Tank were also grouted in place after completion of the FSS. The CV airlocks were removed. The lift-gate doors (and frames) connecting the quads and canals were also removed.

Three of the four quadrants (A, C and D) and Canals E, F and G were filled with water during Reactor operations and the surfaces of these structures were exposed to contaminated water for extended periods. The Process Piping Pump (PPP) Room and the -25 ft. elevation sub-basement floors and trenches were also exposed to contaminated water for extended periods. After removal of attached external piping and equipment, detailed characterization surveys performed in 2005 and 2006 determined that most of the contamination was in areas where the painted/mastic surface coating had failed, and at wall/floor joints, unistruts, seams, bolt/anchor holes, around penetrations and in the "bathtub rings".

A variety of techniques were used to prepare the Reactor Building and CV surfaces for FSS. Surface wall coatings of water-filled quads, canals and trenches were removed by sponge jet blasting and the underlying concrete was shaved or scabbled. Pipe stubs, equipment mounting brackets and bolts, door frames and other protuberances were removed by flame cutting. Areas where elevated activity was measured and where contamination had penetrated to depths were remediated by over-coring and with impact-tools.

Prior to the FSS of the structures, embedded piping and other wall and floor penetrations were remediated and surveyed to meet the appropriate release criteria. The remediated embedded and buried piping for floor drains, quadrant and canal drains and recirculation lines, plus primary cooling lines left in place and select other lines were grouted to meet FSS Plan requirements.

Hot Laboratory

It was recognized early-on in the decommissioning that contamination in the HL structure was widespread and significant remediation would be required. Extensive radiological surveys were performed to guide remediation efforts. A summary of characterization survey results

[11] PBRF Work Execution Package, PBRF-WEP-06-004, *Asbestos Abatement in Main PBRF Buildings*, approved 9/14/07, closed 7/10/08.

from the 2003-2004 time period is provided to illustrate contamination levels in the HL prior to remediation of the structure surfaces:

- Total surface beta contamination levels in the Hot Cells up to 1.2E+07 dpm/100-cm^2 and removable surface beta activity levels of up to 7.0E+03 dpm/100-cm^2 were measured. Total surface alpha activity of up to 900 dpm/100-cm^2 was measured in the hot cells.

- In the Hot Work Area, Decontamination Room and equipment repair areas, total surface beta activity levels of up to 1.7 E+06 dpm/100-cm^2 and removable activity of up to 2.5 E+03 dpm/100-cm^2 were measured.

- Surveys of the Locker Room, Lavatory and Manipulator Repair Area reported total surface beta activity levels of up to 7.8 E+04 dpm/100-cm^2 and removable surface beta activity of up to 2.5 E+03 dpm/100-cm^2. Direct surface alpha activity of up to 150 dpm/100-cm^2 was reported (in addition, 37 smears were collected in these areas and counted for alpha activity - all were < MDA). [12]

The irradiated control rods that were stored in the Hot Dry Storage Area were classified as Class C mixed waste due to the cadmium content (a hazardous waste). They were packaged in a steel-lined concrete shipping cask and moved to a temporary secured storage area on the PBS for storage (until off-site disposal in 2008). Other activated and contaminated equipment that was placed for storage in the Hot Dry Storage area after PBRF shutdown in 1973 was removed and shipped as radioactive waste to Barnwell South Carolina in 2004.

Also during 2004, the equipment, piping and pipe hangers, ventilation ductwork, and other interferences were removed from the Cold Work Area/Manipulator Repair Shop, making a large portion of the floor, walls, and ceiling accessible to survey. During this time, the interior partition walls, piping and fixtures in the lavatory and locker room areas were also removed. Additional remediation was performed in these areas in 2006 through early 2008. Approximately ⅛ in. of the floor surface was removed using a floor shaver. The paint on the walls, ceiling, and steel beams was removed using a sponge blaster. Post remediation surveys were performed after the completion of these activities.

The floor of the Hot Dry Storage Area at -25 ft. elevation was shaved to remove surface activity, and the top 6 ft. of the walls were shaved to remove the paint/mastic layer so that asbestos would not be a concern during building demolition. Trenches were cut in the floor concrete of the Interim Storage Pit and the Hot Dry Storage Area to remove volumetric contamination. Trenches were 100% scanned and static measurements taken. Cracks and boreholes were investigated and remediated as necessary.

Contamination from leaking pipes and valves in the Hot Pipe Tunnel required an aggressive decontamination effort. All exposed surfaces were surface-cleaned and decontaminated. Floors and a small section of several lower wall areas were decontaminated by use of

[12] Contamination levels in the Hot Cells and support areas on the 0 ft. elevation prior to structure remediation are from the 2004 Supplemental Characterization Report, prepared by Montgomery Watson Harza [NASA 2004].

hydraulic hammers, concrete shavers and/or scabbing to a depth greater than 5 centimeters. The majority of the remaining wall and other surface areas were cleaned by sponge/grit blasting. A section of the main floor slab was removed and then re-poured after performing FSS of the exposed concrete edge and sub-floor surface soil. During 2006-2008, embedded piping and other wall and floor penetrations were surveyed and remediated to meet FSS criteria. Floor drains and other process lines that could not be remediated were removed. Remediated floor drains that were left in place and select other lines were grouted (after FSS measurements were completed) to meet FSS Plan requirements.

In 2007 and 2008, the decommissioning contractor performed the following tasks in the Hot Cells:

- removed periscopes and manipulator arms, removed concrete blocks, screw gears and viewing windows,
- removed the crane in Hot Cells 1 and 2,
- removed highly radioactive material from the shielded storage container in Hot Cell 1,
- removed the hot cell door shield-plug rails,
- performed remediation, removal and release of the hot cell ceiling plugs,
- sponge blasted, scabbled and hammer drilled walls and floor,
- removed steel liners from hot cell walls and floor and
- performed spot remediation by scabbling areas above the Remediation Action Level (RAL).[13]

In 2010, the rolling assembly and hoist mechanism were removed from the overhead crane in the Hot Handling Room.

<u>Other Buildings</u>

The sequence of decommissioning tasks in the other buildings was similar to the major buildings described above. In general, the extent of contaminated surfaces requiring remediation was much less, but the remediation techniques were similar. After completion of FSS of the buildings, the ROLB, SEB, WHB, Fan House and HRA were demolished to 3 ft. below grade and then backfilled to grade level. Demolition of the WHB and the Fan House included excavation of contaminated sub-surface structures (WHB Evaporator Pit and Fan House Resin Pit). In addition to removal of the concrete pit structures, potentially contaminated soil adjacent to and beneath the pits was removed. Also, overburden soil was excavated from above the Cold Pipe Tunnel (CPT) as part of the SEB demolition and from

[13] Remediation Action Levels were typically set at 50% of the applicable DCGL.

the underground Calibration Facility as part of the ROLB demolition. The FSS of excavated areas adjacent to the buildings identified above is reported in Attachment 7 of the FSS Report.

Emergency Retention Basin

During 2005, approximately 3,400 tons of soil were excavated from the ERB and shipped for disposal as radwaste by the decommissioning contractor. In late 2009, demolition of the ERB was completed under PBRF-WEP-09-025 (*Emergency Retention Basin Demolition*, Oct. 2009). This consisted of removal of standing water, removal of cover and miscellaneous debris, removal of temporary concrete block walls (installed for temporary repairs during decommissioning) and excavation of potentially contaminated soils. This included excavation of approximately 6 in. of soil from the basin floor and excavation of the entire surrounding berm. The FSS of the ERB is reported in Attachment 10 of the PBRF Final Status Survey Report.

Cold Retention Basins

The Cold Retention Basins were removed in 2009 under PBRF-WEP-09-006 (*Cold Retention Basin Dismantlement*, April 2009). After the CRB structures and concrete basins were demolished and removed, potentially contaminated gravel and soil was removed from the basin cavities and perimeters. The FSS of the CRB is reported in Attachment 18 of the PBRF Final Status Survey Report.

Storm Drains and Catch Basins

In 2010 and early 2011, potentially contaminated soil was excavated while removing approximately 7700 feet of contaminated storm sewer piping and the associated catch basins. Most of his work was performed under PBRF-WEP-09-020 (*Storm Drain System Dismantlement*, Jan. 2010). A detailed description of this work and the FSS of the excavated storm drains and catch basins are provided in Attachment 7 of the FSS Report.

HRA Underground Storage Tanks

The HRA main vault structure was demolished and the adjacent underground storage tanks were removed in 2010. Potentially contaminated soil required to remove the underground storage tanks was excavated. This work was performed under PBRF Work Execution Package, PBRF-WEP-09-010 (*Underground Storage Tank and Contaminated Soil Removal*, April 2010). The FSS of the HRA is reported in Attachment 5 of the PBRF Final Status Survey Report.

Spill Areas

Remediation of the designated spill areas was performed under several Work Execution Packages. Spill Areas No. 1 and No. 3 and the WEMS Spill Area were excavated under PBRF-WEP-09-009 (*Spill Area Excavation*, Nov. 2009). Spill Area No. 2 was remediated in 2005. Any remnants of this spill area were excavated in 2009-2010 as part of the storm drain system dismantlement under PBRF-WEP-09-020. Spill Area No. 4 was also excavated as part of the Storm Drain system dismantlement. A contaminated soil area located just south of the south CRB identified as Spill Area 5 was excavated as part of the CRB excavation under PBRF-WEP-09-006. The FSS of the spill areas after excavation is reported in Attachment 7 of the FSS Report.

Miscellaneous Structures and Pads (including the WEMS)

Approximately 50 miscellaneous structures (foundations, basins, pits and trenches) and equipment pads were removed during PBRF decommissioning. These included equipment pads, sidewalks, building roll-up truck door aprons, pipe trenches, and large structures such as the WEMS. A detailed listing is provided in WEP-09-015 (*Miscellaneous Foundation Removal*, October 14, 2009), which covered removal of most of these items. Some of these structures were removed or demolished under WEP-09-020. Pads on grade were removed and concrete structures that extended below grade were removed to at least 3 ft. below grade. Many of these structures and pads were either confirmed to be contaminated or were identified as potentially impacted by radiological contamination. The soil adjacent to and underneath these structures and pads was excavated for evaluation and FSS. The FSS of excavated areas associated with the Miscellaneous Structures and Pads is reported in Attachment 7 of the FSS Report.

Impacted Utilities

Several underground utilities that traversed impacted soil areas were removed during 2009 and 2010. This included:

- excavation and removal of approximately 1300 ft. of sanitary sewer piping,
- removal of underground process piping from the CRB Valve Pit to the Fan House (including the HRA pump-out line),
- removal of resin/valve pit adjacent to (south of) the Primary Pump House (PPH) and associated drain lines and
- removal of approximately 630 ft of miscellaneous piping in the vicinity of, and between the Fan House and the PPH. This work was performed under PBRF-WEP-09-007 (*Impacted Utility Excavation*, Oct. 2009).

Pentolite Ditch

In 2005, 1600 tons of soil were excavated from the Pentolite Ditch and surrounding areas and shipped as radwaste. Remediation of the Pentolite Ditch and adjacent areas were completed in 2009. This work was performed under PBRF Work Execution Package WEP-09-003 (*Pentolite Ditch Excavation*, July 2009). The final remediation campaign included the following tasks:

- Brush, trees and debris were removed from the Class 1 and Class 2 survey units.
- A bypass piping system for the Pentolite Ditch was installed, dams were installed in the ditch and temporary storage tanks staged to control excavation water.

- Batched water was processed, sampled and discharged.
- Areas were remediated by excavation based on contamination levels.

The total estimated amount of soil removed from the Pentolite Ditch area in the 2009 campaign was 35,472 tons. The FSS of the Pentolite Ditch is reported in Attachment 4 of the PBRF Final Status Survey Report.

RCRA Soil Area

Soil potentially contaminated with volatile organic compounds (VOCs) was excavated during removal of approximately 60 ft. of storm drains, two catch basins and an abandoned water monitoring well located immediately south of the former SEB. This action was performed in accordance with the NASA Plum Brook groundwater remediation plan [SAIC 2010]. The plan called for removal of the subject storm drain piping, catch basins, former monitoring well and associated overburden and impacted soil as potential sources of groundwater contamination. This work was controlled under PBRF-WEP-09-027 (*Removal of Storm Sewer South of Building 1132 Excavation*, July 2010). Approximately 2000 tons of soil were excavated and evaluated for radioactivity and VOCs. The soil was surveyed for radioactivity and found to be acceptable for free release under PBRF Radiation Protection Procedure, RP-08 (no detectable activity). Seven 55-gallon drums of VOC contaminated liquid/sludge were removed from the catch basins, sampled and evaluated. They were classified as hazardous waste and shipped offsite for disposal at a licensed disposal facility [SAIC 2010].

Plum Brook

As described in Section 2.3, radioactive material of PBRF origin, mostly Cs-137 and lesser concentrations of Co-60 were measured in the Plum Brook downstream of the Pentolite Ditch in 2005. Comprehensive characterization surveys of the Plum Brook were subsequently performed. These surveys identified scattered localized areas of contamination in excess of the PBRF site Cs-137 soil DCGL (14.7 pCi/g) in the stream bed and banks [PBRF 2009c, PBRF 2010]. Most of these occurrences were found between the Pentolite Ditch and the Plum Brook Country Club, a distance of about 2 miles. Approximately 20 localized areas where concentrations above the Cs-137 DCGL were measured were remediated by hand excavation under PBRF-WEP-10-007 (*Plum Brook Remediation*, July 2010). Approximately 15 tons of sediment and soil were removed in 2010 and transported in 55 gallon drums to the PBRF for disposal as radwaste.

Other Site Systems and Structures

Removal of the myriad site infrastructure components was completed in phases. The initial phase, 2003-2005, included removal of the main water tower and associated equipment.

During the final phase, completed in 2009 under WEP-09-015, the remaining items were removed. These included removal of several impacted structures after completion of FSS: the precipitator foundation, cooling tower foundation and sludge basins. A large number of other items were also removed: These included:

- Compressor Building foundation
- Gas Handling Building Foundation
- Cryogenic Pipe Trench
- Electric Substation Foundation and Vault, Building 1161
- Reactor Gas Storage Structure, Building 1196 circular foundation
- Pipe Trench north of SEB
- Helium Gas Trailer pad
- Weather Tower foundation
- Reactor Gas Services Building, Building 1135, support piers and gas bottle storage pads
- Waste Handling Building gantry crane apron and sand hopper
- Natural gas valve pits
- Utility poles
- Sidewalks and
- Rollup door aprons, air intake pits and personnel door pads to various PBRF buildings.

Handling and Processing of Excavated Materials

Approximately 5,000 tons of soil excavated from the Pentolite Ditch and the ERB in 2004-2005 was shipped for offsite disposal as radioactive waste. No FSS of excavated soil was performed. In 2008-2011, when most of the soil excavation occurred during the PBRF decommissioning, excavated soil and other materials were processed on-site to determine the final disposition.

Management of excavated soil and materials was implemented via a system of stockpiles. This was a key element of the overall material handling and survey process. This material was controlled under PBRF Radiological Control and FSS procedures to control contaminated stockpiles as radioactive material and to prevent contamination of designated clean stockpiles.

Typically, the first step in the process was to perform a walkover Gamma scan survey of the designated area prior to excavation. From the results of the pre-excavation scan surveys, material disposition was as follows:

1. Overburden Stockpile - soil layered over tanks, piping systems, or structures requiring remediation. Overburden Stockpile soils are not expected to exceed 50% of the DCGL as confirmed through surveying and/or sampling during the excavation process.[14]

2. Contaminated Stockpile - excavated soil exceeding 50% of the DCGL but < DCGL as confirmed through characterization and/or job coverage surveying and/or sampling.

3. Direct Off-Site Disposal Stockpile - excavated soil known to exceed the DCGL as confirmed through characterization and/or job coverage surveying and/or sampling.

All material in the overburden and contaminated stockpiles was designated as feed material for FSS. The Direct Off-site Disposal Stockpile soil was packaged and shipped to an off-site radiological waste disposal facility. Two principal methods were used for performing FSS of excavated soil. Most of the excavated soil material generated during 2008-2009 was processed and surveyed using a conveyor survey-sorting system. This system is identified as the "Orion ScanSort" System. A detailed description of this system is provided in Attachment 18. After the ScanSort system was demobilized in August 2010, excavated soil and gravel was placed on standard "lifts", 6 inches thick and surveyed by manual walkover scan survey and sampling. The FSS of excavated soil in lifts is also described in Attachment 18.

Structural steel, other building materials and piping removed from buildings during decommissioning were segregated for radiological release surveys. This material was surveyed by qualified technicians under PBRF Procedure RP-008, *Radiological Release of Equipment, Material and Vehicles*. Under this procedure, material with detectable activity was segregated and staged for either decontamination or disposal as radioactive waste. Most, if not all of this material was staged for disposal as radioactive waste. Material with no detectable radioactivity was either recycled or disposed of as non-radioactive industrial waste.

<u>Radioactive Waste Shipping and Disposal</u>

Throughout the Decommissioning Project duration, radioactive waste was accumulated and periodically shipped off site for disposal at facilities properly licensed for receipt, processing, transfer, and disposal of licensed material.

The first shipment occurred in August of 2001. The waste was generated by pre-decommissioning work that included removal of equipment and material stored in the Hot Cells. The shipment consisted of three 98-cubic foot containers of Class A Dry Activated Waste (DAW) and one Seal Land Container with about 300 $ft.^3$ of Class A material constituting a Type A quantity of material. The material was shipped via ALARON Corporation, located in Wampum, Pennsylvania for disposal at the EnviroCare facility in Clive, Utah.

No shipping of Radioactive Waste occurred in 2002.

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[14] In the pre-excavation surveys, the action level for determining off-site disposal was set at the most conservative DCGL. In most areas, scan walkover surveys were performed with 2x2 in. NaI detectors with scaler-rate meters set to record counts in an energy window corresponding to the Cs-137 (Ba-137) 0.661 Mev gamma. For this setup, the default, most conservative surrogate DCGL for Cs-137, 10.3 pCi/g corresponds to 700 net cpm (RWP No. PB-10-005, 12/22/09).

A total of fifty three shipments occurred in 2003. Fifty-two shipments were disposed as Class A Waste at the EnviroCare Facility in Clive, Utah. The majority of this material was shipped to ALARON Corporation for trans-shipment by rail to Utah. One shipment consisting of irradiated components and beryllium material was shipped in a shielded cask to Barnwell, South Carolina for disposal as Class B Waste.

In 2004, 197 shipments were disposed of as Class A Waste at EnviroCare. Nine shipments of "mixed waste" containing lead, mercury, or cadmium were processed and disposed of at EnviroCare Clive Utah facility. Five shipments containing irradiated reactor components were transported in NRC Licensed shielded casks to the Barnwell facility for disposal as Class C Waste.

In 2005, remediation of Pentolite Ditch and the surrounding environmental areas and the ERB was initiated. This soil exceeded the DCGLs and required disposal as licensed material at a licensed disposal facility. The soil was packaged in "Super Sacks", transported by truck to a rail facility near Willard, Ohio, where it was transferred to rail cars and shipped to the EnviroCare Facility Clive, Utah for disposal. A total of 519 sacks were shipped in 269 truck shipments. The material consisted of about 10.1 million pounds and 101,206 cubic feet (3750 cubic yards) of soil. The average activity of this soil was 69 pCi/g. This material was shipped as an "Exempt Quantity of Material" under DOT Classification regulations and was disposed as Class A Waste.

In late 2006, two shipments of Class A DAW were shipped under a brokerage arrangement to EnviroCare for disposal.

No shipping of radioactive waste occurred in Calendar Year 2007.

In 2008, a shipping campaign was mounted to remove the risk associated with stored waste material at the site. The first shipment of the year was a brokered shipment made through arrangements with the US Department of Energy. It consisted of the irradiated cadmium and stainless steel control rods and associated material that was stored on the PBS site in a dry cask. The material was shipped in a shielded shipping cask as a Low Specific Activity Material (LSA) for disposal as Class A Waste at the DOE Nevada Test Site facility. It required special processing due to its cadmium content.

One additional special shipment, consisting of sealed sources from Plum Brook and from Glenn Research Center (GRC) were combined and shipped under the GRC Materials License to the Bear Creek Facility (Owned now by Energy Solutions) for disposal or reuse as appropriate. In addition, six mixed waste shipments consisting of contaminated lead and 28 DAW shipments were disposed at the Energy Solutions (formerly EnviroCare) facility in Clive, Utah.

During 2009, 18 shipments of DAW and one mixed waste shipment were sent directly to Energy Solutions in Clive, Utah. In addition, decommissioning activities during 2009 generated a significant volume of soil, concrete rubble, excavated pipe debris, and macadam debris. A contractual arrangement was made where this material was shipped in bulk using Inter-Modal type containers to the ALARON Corporation facility in Wampum, Pennsylvania.

There, the material was consolidated into gondola rail cars owned by Energy Solutions, and shipped by rail for disposal in Clive, Utah. Forty-five containers of this bulk debris were consolidated into nine railroad gondola cars, shipped as "Limited Quantity of Radioactive Material", and disposed of as Class A Waste. In early 2010, an additional five containers, consolidated into one additional gondola car were shipped.

Shipping continued in 2010 with bulk soil, debris, and soil-like material for disposal in the State of Tennessee under the Agreement State Licensed program referred to as Bulk Survey for Release (BSFR) This program allows disposal of very low levels of contaminated material that constitutes "Licensed Material" under NRC Regulations that would otherwise require disposal at a 10CFR61 type disposal site. This material is buried under stringent State of Tennessee requirements in a commercial municipal waste landfill under a license granted by the State. There were restrictions on the quantity of material disposed as it relates to the total quantity of municipal waste taken in by the facility, the radiation dose rates from the containers, the activity concentration, and the radionuclides present. In addition, the material could contain no material meeting any other hazard class. The material was bulk packaged at the site and hauled by truck to Impact Services, LLC. Upon receipt, Impact Services confirmed the acceptability of the material by both survey and sampling and then manifested the load to the Chestnut Ridge Landfill in Heiskill, TN. Most of the material was from final remediation of Pentolite Ditch and excavation of the site storm drains. In late 2010 and early 2011, a total of 298 truck loads containing 12,298,560 lb. (5673 cu. yd.) of material with about 88 mCi of activity (average concentration was about 15 pCi/g) was shipped for disposal. Additional shipments of DAW were sent in 2010 to ALARON Corporation for consolidation and rail shipment to the Energy Solutions Clive, Utah facility for disposal. Waste oil was disposed via the PERMAFIX facility and the Energy Solutions Bear Creek Facility, both in Oak Ridge, Tennessee.

Additional bulk shipments of soil and debris were conducted between August 2010 and January 2011. These shipments consisted of soil, concrete rubble, demolition debris, and other collections of bulk material that did not meet the Waste Acceptance Criteria for Impact Services. A total of 371 shipments, all "exempt quantities of material", were shipped to ALARON Corporation for consolidation in gondola cars and rail shipment to Energy Solutions in Clive, Utah. This material included 14,446,510 lb. of material (6023 cu. yd.). It contained 93 mCi of activity with an average concentration of 14.2 pCi/g.

In January 2011, preparations were made to demobilize the PBRF Decommissioning Project prime contractor. An additional 46 bulk shipments were sent to Impact Services. Fourteen bulk shipments of soil and rubble and 1 shipment of DAW were sent to the Energy Solutions Clive, Utah facility via ALARON Corporation. In December 2011, an additional sixteen shipments were sent for disposal at Energy Solutions. Two were direct shipped, the remaining were shipped via ALARON Corporation.

In September 2012, a final shipment of all the remaining DAW, mixed waste, sealed sources, and demolition debris was made to Energy Solutions. The sealed sources were sent to the Bear Creek Operations Facility in Oak Ridge, Tennessee. The remaining waste material was sent directly to the Energy Solutions facility in Clive, Utah for disposal.

A summary of all shipments by calendar year is shown in Table 1. Table 2 shows a summary of shipments by type of shipment.

Table 1, PBRF Decommissioning Project Waste Shipments by Calendar Year

Calendar Year	Number of Shipments	Weight of Waste (lb)	Disposal Volume (ft.^{3})	Activity Disposed (mCi)
2001	1	9,850	588	1.08E+02
2002	0	0	0	0.00E+00
2003	52	1,349,294	46,778	1.13E+06
2004	211	4,887,254	204,589	1.00E+07
2005	361	12,205,137	174,343	1.25E+04
2006	2	19,980	5,120	5.41E+01
2007	0	0	0	0.00E+00
2008	36	1,030,887	32,455	5.75E+04
2009	64	2,073,290	35,485	1.01E+03
2010	621	25,483,605	270,297	1.42E+02
2011	77	2,475,057	68,014	2.69E+01
2012	5	44,842	1,122	5.46E+02
Totals	1,430	49,579,196	838,791	1.12E+07

Table 2, PBRF Decommissioning Project Waste Shipments by Type of Waste

Shipment Type/Disposal Site	Number of Shipments	Volume of Waste (ft.^{3})	Weight of Waste (lb.)	Activity (mCi)
DAW Shipments to Clive, Utah	393	373,399	9,199,585	1.13E+06
Mixed Waste Shipments to Clive, Utah	26 (1)	11,096	654,182	1.55E+03
Class B and C Waste to Barnwell, SC	6 (2)	667	21,274	1.00E+07
Waste Water Shipments to Duratek or Bear Creek	9	4,887	291,434	2.93E+02
Soil & Debris in "Super Sacks" - to Clive, Utah	269	101,226	10,122,550	3.17E+02
Bulk Soil and Debris Shipments to Clive, Utah	424	193,106	16,346,820	1.10E+02
Bulk Soil and Debris Shipments to Tennessee under BSFR Program	298	154,107	12,928,560	8.78E+01
Other (includes sources)	5	303	14,790	5.62E+04
Totals	1,430	838,791	49,579,196	1.12E+07

Table 2 Notes:

1. The total number of 26 includes one shipment of "mixed waste" that contained irradiated control rods. This shipment was sent to a DOE facility at Nevada Test Site and was disposed as Class A Waste.
2. Five of these shipments were disposed as Class C Waste and one was disposed as Class B Waste. All other waste was Class A and the project produced no *"Greater Than Class C"* Waste.

4.0 Final Status Survey Methodology

The FSS Plan is based on NRC guidance; primarily the "Multi-Agency Radiation Survey and Site Investigation Manual" (MARSSIM), NUREG-1575, [USNRC 2000] and "Consolidated NMSS Decommissioning Guidance, NUREG 1757" [USNRC 2006]. The graded approach described in the MARSSIM is followed to ensure that survey efforts are focused on those areas having the greatest potential for residual contamination. The FSSP, Revision 1 replaces the description of the final status survey in the Decommissioning Plan, and provides a description of the planned final radiation surveys as required by 10CFR50.82(b)(4)(iii). Revision 1 of the FSSP was approved by the NRC in 2008.[15]

This section describes the methods for implementation of the PBRF Final Status Survey Plan. Principal requirements of the Plan are presented. These include release criteria and site-specific DCGLs, classification of areas and establishment of survey units for the FSS. Implementing procedures are identified. The approach to survey design, radiological instrumentation, survey methods, investigation levels, data collection and processing, data assessment and compliance, reporting, and quality control are described.

4.1 FSS Plan Requirements

The FSS Plan specifies that the objective of the PBRF decommissioning project is to meet the requirements of 10CFR20 Subpart E for release of the facility for unrestricted use. These include the 25 mrem/y dose criterion and reduction of residual contamination to ALARA levels.

Derived concentration guideline levels (DCGLs) were obtained for PBRF structures in consideration of exposure to future site occupants from residual surface contamination on structures and from volumetric contamination associated with subsurface structures[16]. Single radionuclide DCGLs were calculated for structures 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. Volumetric DCGLs (pCi/g) were converted to "effective surface" DCGLs (dpm/100-cm^2) using surface-to–volume ratios for the assumed volume of contaminated subsurface concrete. The

[15] The FSSP Rev. 1 was approved by the NRC by issuance of amendments to the possession only licenses for the 60 MW Test Reactor (License TR-3) and the 100 kw Mockup Reactor (License R-93). The amendment approvals were issued by NRC letter dated March 24, 2008.

[16] 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.

assumptions and details of the DCGL calculations are described in the FSSP, Attachment B. To obtain the DCGLs for PBRF structures, the smaller (more conservative) of the DCGLs calculated for the building reuse scenario and the effective surface DCGLs calculated using the resident farmer scenario were selected for each of the radionuclides of concern. The DCGL values for the radionuclides of concern in PBRF structures are shown in Table 3.

Table 3, DCGL Values for PBRF Structures

Radionuclide	DCGL (dpm/100 cm^2)
Co-60	11,000
Sr-90	33,100
Cs-137	40,500
Eu-154	4,500
H-3	9.1E+06
I-129	14,900
U-234	31,500
U-235	27,100
U-236	33,200

The DCGLs for individual radionuclides in soil were calculated using RESRAD Version 6.21 for a resident farmer occupancy scenario. The DCGL calculations are described in the FSSP, Attachment B. The DCGL values from the FSSP for the three significant PBRF soil radionuclides are given in Table 4. These DCGL values are also applied to subsurface soil and to soil-like excavated materials such as sediment and soil-sand-gravel mixtures.

Table 4, DCGL Values for Soil

Radionuclide	DCGL (pCi/g)
Co-60	3.8
Sr-90	5.4
Cs-137	14.7

As described in Section 2.2, Embedded Pipe is any pipe situated below the -3 ft. elevation that is totally encased in concrete or piping directly beneath building floors that may not be totally encased in concrete, but contained within the structural foundation of the building. The EP DCGL values represent piping interior surface activity concentrations that correspond to an annual dose of 1 mrem/y to a future building occupant. They are listed in Table 5. They are calculated as described in Attachment C of the FSS Plan. In order to utilize the EP DCGL values, piping must be grouted prior to license termination.[17]

Table 5, DCGL Values for Embedded Piping

Radionuclide	DCGL (dpm/100 cm^2 per mrem/y)
Co-60	2.408E+05
Eu-154	5.325E+05
Eu-152	7.352E+05
Nb-94	9.082E+05
Ag-108m	1.312E+06
Cs-137	3.785E+06

Buried Piping and Miscellaneous Piping are also described in Section 2.2. The DCGL values for structures listed in Table 3 are applied to Buried and Miscellaneous Piping.

For structural surfaces in the PBRF, where multiple radionuclides are potentially present in residual contamination, the DCGL for FSS design and implementation is a gross activity DCGL that represents the unrestricted use criterion of 25 mrem/y. The gross activity DCGL accounts for the presence of multiple radionuclides, each with their individual-single radionuclide DCGL. This approach enables field measurements of gross activity rather than the determination of individual radionuclide concentrations. As described below, FSS measurements of structures are performed using beta detectors since beta and beta-gamma emitters comprise a significant fraction of the surface activity measured in characterization surveys of PBRF structures.

In other situations, individual radionuclide activity concentrations are measured directly and gross activity DCGLs do not apply. These include FSS measurements of radionuclides in soil samples by gamma spectroscopy and by radiochemical separation and counting for alpha emitters. The FSS of much of the embedded piping involved the use of NaI detectors set up to measure individual gamma emitting radionuclides (Cs-137 or Co-60). In both gross activity counting and in specific radionuclide analysis, the situation is encountered where some radionuclides of concern are not detected or are detected with a very low efficiency. These may include weak (low energy) gamma and weak beta emitters and alpha emitting radionuclides. In these situations a surrogate DCGL is used whereby the DCGL of a readily detected radionuclide is adjusted to account for the presence of so-called hard-to-detect (HTD) radionuclides.

[17] The FSSP, Section 3.3 states "The PBRF dose goal for EP is 1 mrem/y. However, at the discretion of PBRF, different dose goals could be applied in different areas as long as the residual contamination on the structure surface in the survey unit containing the given EP is sufficiently low to allow for the selected dose goal. For example, if the FSS results indicate that the residual contamination level in Hot Dry Storage is 0.5 times the DCGL, the dose from the two drains in this survey unit could be as high as 12.5 mrem/y."

The general process for calculating these DCGLs is summarized:

1. Perform a surrogate calculation to account for radionuclides that cannot readily be measured and, if necessary

2. Perform a gross beta activity DCGL calculation using the surrogate radionuclide DCGL value and the DCGLs of other detectable beta-emitting radionuclides determined to be present in significant fractions.

The surrogate DCGL is computed based on the activity ratios of the hard-to-detect radionuclides and the easy-to-detect radionuclides. Where HTD radionuclides, e. g., weak beta emitters such as H-3 or I-129, are present, a surrogate radionuclide is used to account for the effect of their DCGLs. For PBRF structures, Cs-137 is typically used as the surrogate radionuclide. The surrogate DCGL is calculated using the following equation: [18]

$$DCGL_{Sur} = \frac{1}{\left[\left(\frac{1}{DCGL_1}\right)+\left(\frac{R_2}{DCGL_2}\right)+\left(\frac{R_3}{DCGL_3}\right)+....+\left(\frac{R_n}{DCGL_n}\right)\right]} \quad \textbf{(Equation 1)}$$

Where: $DCGL_{Sur}$ = Surrogate radionuclide DCGL,
$DCGL_1$ = DCGL for the radionuclide to be used as the surrogate for the other radionuclides,
$DCGL_2$, $DCGL_3$,... $DCGL_n$, = DCGL for each radionuclide to be represented by the surrogate and
R_2 ....R_n = Ratio of concentration (or nuclide mixture fraction) of radionuclides 2 through n to the surrogate radionuclide concentration.

Where multiple beta-emitting radionuclides are present, a gross beta DCGL can be developed. This approach enables field measurements of gross beta activity rather than a determination of individual radionuclide activities for comparison to radionuclide-specific DCGLs. The gross beta DCGL is calculated using the following equation: [19]

$$DCGL_{GB} = \frac{1}{\frac{f_1}{DCGL_1}+\frac{f_2}{DCGL_2}+\frac{f_3}{DCGL_3}+....+\frac{f_n}{DCGL_n}} \quad \textbf{(Equation 2)}$$

Where: $DCGL_{GB}$ = gross beta activity DCGL
f_1, f_2, f_3 ...f_n = mixture fraction of radionuclides 1, 2, 3.... "n" and
$DCGL_1$, $DCGL_2$, $DCGL_3$, ...$DCGL_n$ = DCGLs of radionuclides 1, 2, 3... "n".

[18] Surrogate DCGL equation from Section 3.6.1 of the FSS Plan.

[19] Gross beta activity DCGL equation from Section 3.6.2 of the FSS Plan.

Note 1: The gross beta equation may also be used to calculate a gross alpha DCGL for application in areas where DCGL values are established for alpha emitters and where alpha detectors are used.

Note 2: If a surrogate radionuclide is used, the "f_n" in Equation 2 is set equal to the surrogate radionuclide activity fraction (and the surrogate DCGL is inserted in the denominator of the term).

Note 3: The value of 1 in the numerator is replaced by the actual fraction of detectable beta (or alpha) emitters if less than 100% of the mixture.

The FSSP contains provisions to accounting for dose contributions from sources not accounted for in the basic DCGL derivation. These include:

- Radionuclides considered to be present in residual surface contamination, but in "insignificant quantities"[20] and
- Contributions from sources in embedded piping that remains in or adjacent to a structural survey unit.

If these conditions apply, this accounting may be done by adjusting the DCGL downward in the design phase. Alternatively, in the post-survey data review, FSS measurement results are reviewed to ensure that there is sufficient margin below the structure survey unit DCGL to account for contributions from these sources. The "adjusted" DCGLs are then used in the survey design calculations. They are identified as the $DCGL_W$, where the "W" subscript denotes Wilcoxon, for the Wilcoxon test (regardless of whether the Wilcoxon test or the Sign test is actually used). The $DCGL_W$ values are also used for evaluation of FSS measurement results to demonstrate that the 25 mrem/y dose criterion is satisfied.

The FSSP provides for situations where local areas of "elevated activity" are detected during the FSS. These are small areas containing residual activity greater than the applicable DCGL for a survey unit. The size of an area of elevated activity that may be allowed to remain in a survey unit and still satisfy the 25 mrem/y dose criterion is determined by applying an "area factor" (AF). The AF is the multiple of the DCGL that is permitted for an area of elevated activity that may remain without requiring remediation. The AF is also used in the survey design process as discussed in Section 4.4. Area factors for PBRF structures are shown in Table 6. The area factors for soil areas are shown in Table 7 and for embedded piping in Table 8.

[20] The FSSP, in accordance with NRC guidance, contains provisions to account for radionuclides that constitute a small fraction of residual activity levels such that in the aggregate, they contribute less than 10% of the total dose to a future site occupant (Building Reuse occupant or Resident Farmer as the case may be).

Table 6, Area Factors for Structures

Elevated Area (m^2)	0.25	0.50	1	2	4	6	8	10	15	25	50	75
Area Factor	40.2	20.8	11.1	6.2	3.6	2.8	2.4	2.1	1.7	1.4	1.1	1

Table 7, Surface Soil Area Factors

Elevated Area (m^2)	1	2	3	5	10	15	25	100	250	2,000
Area Factor	10.4	6.2	4.7	3.4	2.3	1.9	1.6	1.2	1.1	1

Table 8, Embedded Pipe Area Factors

Pipe Length (ft)	Area Factor
1	5.9
2	3.0
5	1.5
10	1.2

When areas of elevated activity are identified in a Class 1 survey unit during the FSS, a test called the elevated measurement comparison (EMC) test is used to determine if the survey unit meets the release criterion, or if remediation is required. The test is applied to all occasions where investigation levels are exceeded, either by the systematic fixed measurements, or by measurements taken to investigate locations "flagged" by scan surveys.

The $DCGL_{EMC}$ is calculated as follows:

$$DCGL_{EMC} = AF \times DCGL_W$$ [21] **(Equation 3)**

Structures at the PBRF were evaluated as part of site characterization activities to identify all areas potentially impacted by PBRF operations with radioactive materials. Areas with some potential for residual contamination are identified as impacted areas. Areas with no reasonable probability of residual contamination are classified as non-impacted. The major buildings

[21] For the initial $DCGL_{EMC}$ determination in the survey design phase, the AF multiplier for the $DCGL_W$ is usually calculated as the survey unit area divided by the number of fixed measurements.

were identified as impacted areas and were subdivided into "areas" for assignment of initial "classification" as Class 1, 2 or 3 per MARSSIM guidance as summarized below:

- Class 1 Areas - Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiation surveys) above the $DCGL_W$. Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material and high specific activity.

- Class 2 Areas - Areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the $DCGL_W$. To justify changing the classification from Class 1 to Class 2, there should be measurement data that provides a high degree of confidence that no individual measurement would exceed the $DCGL_W$. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form, 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of buildings or rooms subjected to airborne radioactivity, 5) areas handling low concentrations of radioactive materials, and 6) areas on the perimeter of former contamination control areas.

- Class 3 Areas - Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the $DCGL_W$, based on site operating history and previous radiation surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Several requirements derive from the MARSSIM classification. Size limits for structure and open land survey units are shown in Table 9. The FSS Plan also establishes coverage requirements and action levels for surveys of structures and open land areas based on their classification. These are shown in Table 10.

Table 9, Survey Unit Area Limits for MARSSIM Classes

Class	Structures	Land
1	up to 75 m^2 (1)	up to 2000 m^2
2	up to 1000 m^2	up to 10,000 m^2
3	up to 10,000 m^2	up to 100,000 m^2

Table 9 Note:

1. The size limit for Class 1 structures is 75 m^2 for floors only. The total surface area of a Class 1 survey unit may be up to 100 m^2.

Table 10, Class-Based Survey Scan Coverage and Action Level Requirements

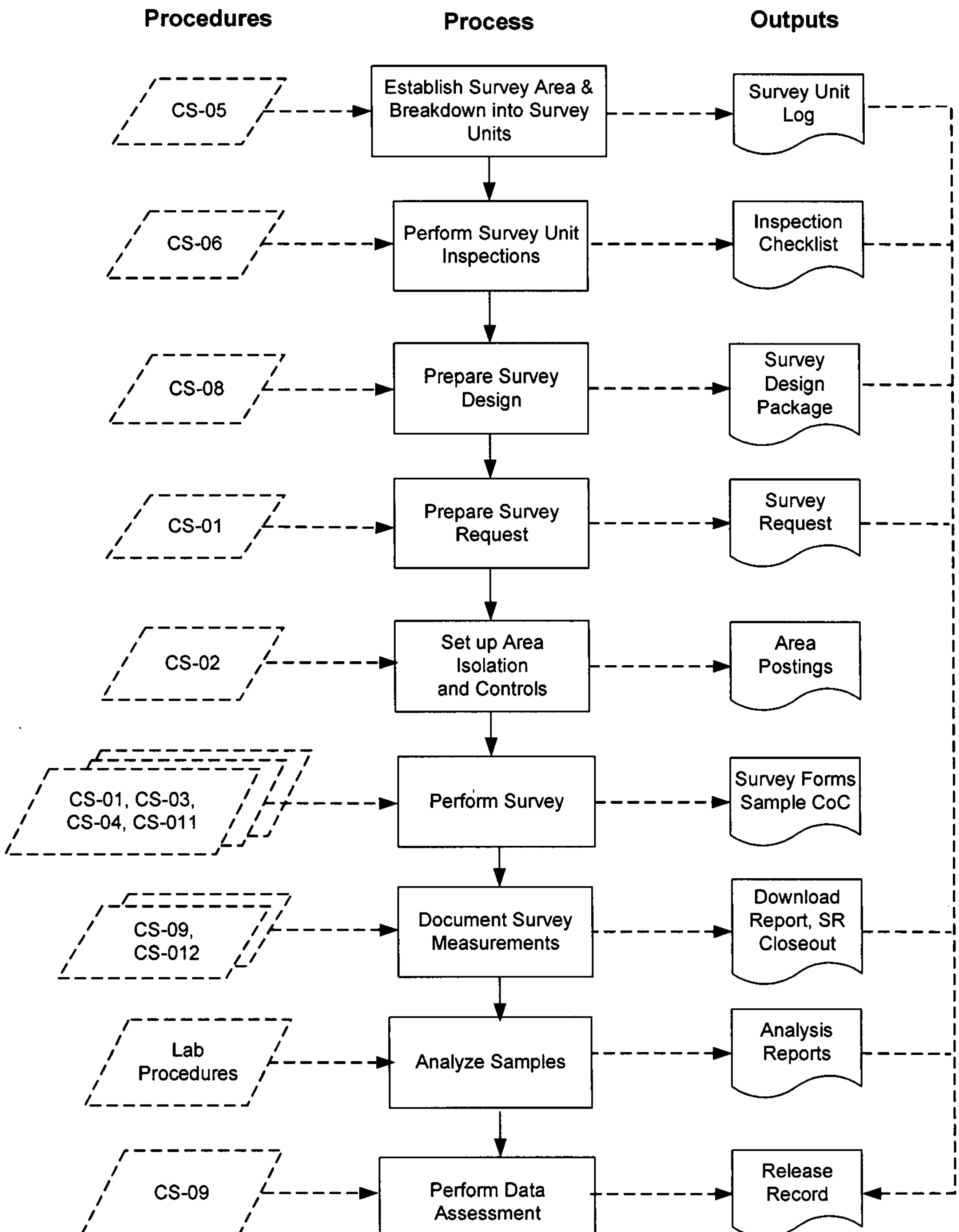
Classification	Scan Survey Coverage	Scan Investigation Levels	Static Measurement or Sample Result Investigation Levels
Class 1	100%	$>DCGL_{EMC}$	$>DCGL_{EMC}$
Class 2	10 to 100%	$>DCGL_W$ or $>MDC_{scan}$ if MDC_{scan} is $>DCGL_W$	$>DCGL_W$
Class 3	Minimum of 10%	$>DCGL_W$ or $>MDC_{scan}$ if MDC_{scan}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

The FSS Plan also requires that removable surface contamination levels be no greater than 10% of the applicable DCGL in each survey unit.

4.2 FSS Plan Implementation

The FSS Plan has been implemented via a standardized process, with critical tasks controlled by approved procedures. Figure 4 shows the principal FSS process steps, their outputs and identifies the controlling procedures.

Figure 4, FSS Process Diagram



The FSS procedures are identified in Table 11.

Table 11, FSS Procedures

Procedure Number	Title
CS-01	Survey Methodology to Support PBRF License Termination
CS-02	FSS Area Isolation and Control
CS-03	Sample Chain of Custody Controls
CS-04	Laboratory Sample Preparation
CS-05	Final Status Survey Area Classification
CS-06	Survey Unit Inspection to Support FSS Design
CS-07	Issue, Control and Accountability of FSS/Characterization Portable Radiological Instrumentation
CS-08	Final Status Survey Design
CS-09	Final Status Survey Data Quality Assessment
CS-011	Operation of Ludlum Model 2350-1 Data Logger Survey Instrument
CS-012	Documentation of FSS/Characterization Surveys

Supporting functions for the FSS are also controlled by procedures. These include operation, calibration, performance checking and calibration of field instruments and operation and control of on-site laboratory instruments. Key supporting procedures are listed in Table 12.

Table 12, Key FSS Supporting Procedures

Procedure Number	Title	FSS-Related Functions
RP-010	Portable Instrument Procedure	Daily instrument performance checks.
RP-015	Measurement of Gross Alpha and Beta Particles	Operation, calibration and performance checks for automatic sample changing counters (FSS smear sample counting).
RP-020	Operation and Calibration of ORTEC Gamma Spectroscopy System	Operation, calibration and performance checks for gamma spectroscopy system (FSS soil sample counting)
RP-060	PBRF Radiological Laboratory Quality Assurance/Quality Control Program	QA & QC for FSS soil sample analysis.
RP-008	Radiological Release of Equipment, Material and Vehicles	Survey and disposition of materials removed in demolition activities and survey of vehicles, tools and equipment leaving the Restricted Area.
QA-03	Audits and Corrective Actions	Self-assessment of FSS and corrective actions.

4.3 Survey Unit Breakdown and Classification

The breakdown and classification of the PBRF survey units are summarized for structures, open land-soil areas and piping in Tables 13, 14 and 15. Descriptions of the individual survey units are provided in the FSS Report Attachments listed in the tables.

Table 13, Summary of PBRF Structure Survey Unit Breakdown for FSS

Description	Total No. of Survey Units	Class 1	Class 2	Class 3	ID of Survey Units Included	FSS Report Attachment	Type (1)
Reactor Office and Laboratory Building (2)	59	42	10	7	RO-1-1 thru RO-1-12; RO-2-1 thru RO-2-23; RO-3-1 thru RO-3-28A; RO-4-1 & RO-4-2	1	1
Service Equipment Building	52	40	7	5	SE-1-1 thru SE-1-12; SE-2-1 thru SE-2-4; SE-3-1 thru SE-3-34; SE-4-1 & SE-4-2	2	1
Fan House	38	38	0	0	FH-1-1 thru FH-1-20: FH-2-1 thru FH-2-17; FH-4-1	3	1
Hot Retention Area	34	34	0	0	HR-1-1 thru HR-1-34	5	1
Waste Handling Building (3)	28	28	0	0	WH-1-1 thru WH-1-12; WH-2-1 thru WH-2-3; WH-3-2 thru WH-3-13; WH-4-1	6	1
Hot Laboratory Building (4)	138	135	2	1	HL-1-1 thru HL-1-90; HL-2-1 thru HL-2-4; HL-3-1 thru HL-3-19; HL-3-21; HL-4-1 thru HL-4-21; HL-5-1 thru HL-5-3	8	1
Reactor Containment Vessel	87	85	2	0	CV-1-1 thru CV-1-37; CV-3-1 thru CV-3-48; CV-4-1 & CV-4-2	11	1
Reactor Building (5)	129	115	13	1	RB-1-1 thru RB-1-43; RB-2-1 & RB-2-2; RB-3-1; RB-3-3 thru RB-3-39; RB-4-1 thru RB-4-43; RB-5-1 thru RB-5-3	12	1
Primary Pump House (6)	41	41	0	0	PH-1-1 thru PH-1-29; PH-2-1 thru 2-12	13	1

Table 13, Summary of PBRF Structure Survey Unit Breakdown for FSS

Description	Total No. of Survey Units	Class 1	Class 2	Class 3	ID of Survey Units Included	FSS Report Attachment	Type (1)
Roadways and Parking Lots	15	11	4	0	TR-1-1 thru TR-1-11; TR-2-1 thru TR-2-4	14	2
Misc Structures and Pads	44	38	6	0	MA-1-1 thru MA-1-6; MA-2-1 thru MA-2-15; MA-3-1 thru MA-3-7; MA-4-1 thru MA-4-9; MA-5-1 thru MA-5-6; RS-1-1	15	2
Totals	665	607	44	14			

Table 13 Notes:

1. Type 1 = building surfaces, Type 2 = outdoor paved surfaces.
2. The ROLB contains one soil survey unit (RO-3-28B) not included in the total count of structure survey units.
3. The WHB contains one soil survey unit (WH-3-1) not included in the total count of structure survey units.
4. The Hot Lab contains two soil survey units (HL-1-91 & HL-3-20)) not included in the total count of structure survey units.
5. The Reactor Building contains one soil survey unit (RB-3-2) not included in the total count of structure survey units.
6. The PPH contains one soil survey unit (PH-1-30) not included in the total count of structure survey units.
7. Miscellaneous structures and pads contain two structures that are not outdoor paved surfaces. They are the ATS Tunnel (six survey units) and the Reactor Security Building (one survey unit).

Table 14, Summary of PBRF Soil Survey Unit Breakdown for FSS

Description	Total No. of Survey Units	Class 1	Class 2	Class 3	ID of Survey Units Included	FSS Report Attachment	Type
Open Land Areas within Restricted Area and Outside Buffer Zone	59	52	7	0	OL-1-46 thru OL-1-98; OL-2-1 thru OL-2-6	16	1
Emergency Retention Basin	7	7	0	0	OL-1-26 thru OL-1-32	10	1
Soil Lifts and Staging Area	41	41	0	0	OL-5-1 thru OL-5-45	18	3
Soil Processed by ScanSort Conveyor	211	211	0	0	Batch 1 thru Batch 211	18	3
Pentolite Ditch	36	36	0	0	OL-3-1 thru OL-3-42	4	2
Storm Drains, Pipe Trenches and Other Sub-surface Excavations	39	39	0	0	OL-1-1 thru OL-1-26; OL-1-33 thru OL-1-45	7	2
Hot Lab sub-foundation	2	2	0	0	HL-1-91: HL-3-20	8	4
PPH sub-foundation	1	1	0	0	PH-1-30	13	4
Reactor Building sub-foundation	1	1	0	0	RB-3-2	12	4
ROLB sub-foundation	1	0	0	1	RO-3-28B	1	4
WHB sub-foundation	1	1	0	0	WH-3-1	6	4
Totals	399	391	7	1			

Table 14 Notes:

1. Type 1 = open land areas.
2. Type 2 = excavated areas.
3. Type 3 = excavated soil.
4. Type 4 = soil under structures.

Table 15, Summary of PBRF Piping Survey Unit Breakdown for FSS

Description	Total No. of Survey Units (pipe runs) (1)	Total Linear ft.	Description of Survey Units included	FSS Report Attachment
Embedded Piping	196	7,238 (2) (3)	Primary Cooling Water, Quadrant and Canal, Hot Drain and Cold Drain piping.	9
Buried Piping	4	801	Sanitary sewers, Pentolite Ditch crossovers and WEMS outfall piping under Pent. Rd.	17
Miscellaneous Piping	31	8,560	Equipment and floor drains in HL, RB, CV, WHB, PPH, FH, HRA & CPT. Conduits in Hot Cells & RB. Penetrations in Quads & Canal E, ROLB & PPH.	17
Totals	231	16,828 (3)		

Table 15 Notes:

1. A survey unit was established for each "pipe run". All EP and most BP/ MP survey units are Class 1.
2. Length of piping that was reported in Embedded Piping Release Records.
3. Reported piping length totals vary somewhat among the different tabulations that were performed.

4.4 Survey Design Process

The survey design process as outlined in the FSSP follows the Data Quality Objectives (DQO) approach outlined in the MARSSIM. The product of the survey design process is a design package, or document called the "survey design". The survey design addresses the following key elements:

- Action levels for investigation
- Scan survey coverage and sensitivities
- Instrument sensitivities for fixed measurements
- Tests to determine the number of samples or fixed measurements
- Reference coordinate system, grid size and spacing for fixed measurement and sample locations
- Adjustments to measurement techniques to account for special conditions.

A survey design may cover multiple survey units of the same MARSSIM classification, usually contiguous and of the same characteristics. Inputs for the survey design include survey unit inspection checklists, historical information and characterization data.

As discussed in Section 4.1, scan survey coverage is based on the MARSSIM classification. The percent of survey unit surfaces covered is 100% for Class 1 structures, between 10 and 50% for Class 2 structures and a minimum of 10% for Class 3 structures. If the scan sensitivity of the detectors used is below the $DCGL_W$, the number of measurements in each survey unit is determined solely by a statistical test as described below. If the scan sensitivity is not below the $DCGL_W$, the number of measurements is increased as determined by the Elevated Measurement Test, also discussed below.

A statistical hypothesis decision framework is used to determine if the average residual contamination level (surface activity in structure survey units and soil concentration in soil survey units) is less than the gross activity $DCGL_W$. The null hypothesis is stated as H_O: "The mean concentration of residual activity above background in each survey unit exceeds the $DCGL_W$". The design goal is to obtain sufficient information to reject the null hypothesis and accept the alternate hypothesis H_A: "The mean concentration of residual surface activity is below the $DCGL_W$." The Sign Test is used for determining the number of FSS measurements in PBRF structures and soil areas. In accordance with the FSSP, the sign test is selected because background levels are equivalent to a small fraction of the applicable $DCGL_W$. [22] 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 number of samples or measurements is a function of the decision error probabilities, α and β, and a quantity, Δ/σ, called the relative shift, which is equivalent to the measurement "signal to noise" ratio.

First, the relative shift is calculated as follows:

$$\frac{\Delta}{\sigma} = \frac{(DCGL_W - LGBR)}{\sigma} \qquad \textbf{(Equation 4)}$$

Where:

LBGR = the lower bound of the gray region between the DCGL and background and

σ = standard deviation of the residual contamination levels.

The LBGR is initially set at 50% of the DCGL and adjusted if necessary to obtain a value of the relative shift between 1 and 3. Given that post-remediation values of σ are usually small relative to the $DCGL_W$, an iterative process is used to establish a value of the relative shift within the target range.

The variability of residual activity measurements has two principal components; the variability of residual contamination levels and the variability of the detector background. For surface activity measurements the detector background also has two principal components, counts from ambient radiation and counts from naturally occurring radioactivity in the material being surveyed. The background contribution from ambient radiation is accounted

[22] 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 or less than 10% of most PBRF structure DCGLs (this assumes a detection efficiency of ~ 12%). Similarly, the background concentrations of PBRF principal radionuclides of concern in soil (Cs-137, Sr-90 and Co-60) are typically less than 10% of the single radionuclide DCGLs for soil.

for by the use of paired unshielded and shielded surface activity measurements. The total σ of surface contamination measurements can be estimated as follows:

$$\sigma_t = \sqrt{\sigma_n^2 + \sigma_b^2}$$ **(Equation 5)**

Where:

σ_t = total estimated uncertainty

σ_n = standard deviation of net activity measurements

σ_b = standard deviation of material background measurements.

Estimates of σ_n and σ_b are obtained from PBRF characterization surveys and material background studies, respectively. For typical structure survey designs, values of σ_t in the range of approximately 400 to 700 dpm/100-cm^2 are used. For soil areas, estimates of individual radionuclide concentration σ values are obtained from characterization survey results. In the absence of sufficient background measurement data to support an estimate of σ, a value of 20% of the DCGL was typically assumed.

The FSS Plan indicates that if the Sign Test applies, Table 5-5 in the MARSSIM is used to determine the number of measurements or samples in a survey unit (if the Wilcoxon Rank Sum Test applies, MARSSIM Table 5-3 is used). Note that the number of measurements obtained using the MARSSIM tables includes an upward adjustment of 20% to ensure sufficient power of the statistical tests and to allow for possible data losses. The FSS Plan also states that a qualified software product, such as Visual Sample Plan (VSP©) may be used in the survey design process.

Visual Sample Plan was used to determine the number of measurements in PBRF survey units. When the Sign Test is selected, the VSP software uses MARSSIM, Equation 5-2 to calculate the number of measurements (the 20% adjustment is included in the calculation). The formula based on MARSSIM, Equation 5-2 is shown below:

$$N = 1.2\frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4\left[\Phi\left(\frac{\Delta}{\sigma_t}\right) - 0.5\right]^2}$$ **(Equation 6)**

Where:

1.2 = factor that increases the calculated number of measurements by 20%,
N = Number of measurements,
$Z_{1-\alpha}$ = proportion of standard normal distribution < 1 – α (1.6449 for σ = 0.05),
$Z_{1-\beta}$ = proportion of standard normal distribution < 1 - β (1.2816 for β = 0.1) and
Φ (Δ/σ_t) = value of cumulative standard normal distribution over the interval -∞, Δ/σ.

An additional adjustment to the sample size (or number of measurements) is made in Class 1 survey units if the scan MDC is greater than the $DCGL_W$. The sample size is calculated as follows:

$$N_{EMC} = \frac{A}{A_{EMC}} \qquad \textbf{(Equation 7)}$$

Where:

N_{EMC} = elevated area comparison size,
A = survey unit area and
A_{EMC} = area corresponding to the area factor calculated using the scan MDC.

If N_{EMC} exceeds the sample size (N) as determined using the Sign Test, N is replaced by N_{EMC}

The area factor is calculated as follows:

$$AreaFactor = \frac{MDCscan}{DCGL_W} \qquad \textbf{(Equation 8)}$$

For Class 1 and 2 survey units, the measurements are located on the nodes of a standardized grid pattern placed on the survey unit at a randomly selected starting location. Grid dimensions, the distance between sample or measurement locations, (L) is determined for a triangular grid by:

$$L = \sqrt{\frac{A}{0.866N}} \qquad \textbf{(Equation 9)}$$

A reference location, or origin, for the coordinate-grid system is established using a standard convention, typically the SW corner of the survey unit. A random number generator may be used to generate starting location coordinates for the grid system. For class 3 survey units, measurement or sample locations are selected randomly over the survey unit without grid spacing.

4.5 Number of Measurements and Samples

In lieu of the manual calculations described above, VSP was used to prepare survey designs, including calculating the number of measurement (and sample) locations, establishing grid size and laying out measurement locations on scale drawings of the survey units. In total, 102 survey designs were prepared for the FSS of the PBRF. A summary of the designs is provided in Table 16. The table lists the designs by structure or environmental area, the number of designs for each and identifies the individual designs and the MARSSIM classification of the survey units covered by each design. The table also shows the number of samples or measurements "N" calculated by VSP for the designs. For the majority of designs, N = 11, but in a few instances N was as high as 15. For most of these cases the samples in excess of 11 are due to additional grid points required to fit a triangular grid onto the survey unit layout.

Table 16, Survey Design Summary

Building or Area	Number of Designs (1)	Identification of Designs and MARSSIM Class	Number of Measurements or Samples
Reactor Building Structure	13	Class 1: 43, 59, 60A, 60B, 61A, 61B, 61C, 66, 70A, 70C. Class 2: 65, 69B. Class 3: 69A	11 (12 designs) 15 (one design)
CV Structure	12	Class 1: 19, 43, 45A, 45B, 48A, 48B, 48C, 48D, 62, 63, 64. Class 2: 58.	11 (all designs)
Hot Laboratory Structure	19	Class 1: 24A, 24B, 25, 38A, 38B, 40A, 40B, 40C, 40D, 40E, 40F, 40G, 40H, 41A, 41B, 42A, 42B, 42C. Class2/3: 67.	11(17 designs) 12 (one design) 14 (one design)
Primary Pump House Structure	3	Class 1: 26, 27, 68	11 (all designs)
ROLB Structure	10	Class 1: 1, 4, 7. Class 2: 2, 5, 8. Class 2/3: 34. Class 3: 3, 6, 9.	11 (all designs)
SEB Structure	11	Class 1: 11, 10, 14, 21. Class 2: 12, 15, 17. Class 2/3: 36. Class 3: 13, 16, 18.	11 (all designs)
Fan House Structure	2	Class 1: 23, 29A	11 (all designs)
HRA Structure	2	Class 1: 28, 31	11 (all designs)
WHB Structure	5	Class 1: 29A, 29B, 29C, 49A, 49B.	11 (all designs)
Miscellaneous Structures and Pads	6	Class 1: 22, 50, 52, 53. Class 1/2: 71. Class 2: 72.	11 (all designs)
Transport Roadways and Parking Lots	1	Class 1/2: 73	11
Soil Areas under Buildings	6	Class 1: 70B (RB), 24B, 40I (HL), 47 (PPH), 29B (WHB). Class 3: 9 (ROLB)	11 (5 designs) 14 (one design)
Open Land Areas	5	Class 1: 32 (Pent Ditch), 46 (ERB), 51 (OLA). Class 2: 35 (Pent Ditch), 54 (OLA).	11 (all designs)
Excavated Areas	6	Class 1: 30, 33, 37, 39, 44, 46.	11 (all designs)
Excavated Soil	2	Class 1: 55, 57.	11 (all designs)
Total	103 (2)		

Table 16 Notes:

1. The designs listed do not include designs for survey of embedded, buried and miscellaneous piping.
2. The total number of designs in the table listing includes double counting of one design. Design No. 9 (ROLB Basement Crawl Space) was used for both the structure and the adjacent soil area.

For the survey design of PBRF structures, gross beta DCGLs were developed using radionuclide activity fractions established for distinct radionuclide mixtures in 19 areas in the PBRF. In addition, a default mixture was established for areas where insufficient characterization data was available. The radionuclide activity fractions and associated DCGLs were obtained from the Technical Basis Document TBD-07-001 [PBRF 2007].

For the FSS of soil, surrogate DCGLs are used to determine scan sensitivities, action levels, sample analysis MDA requirements and to determine $DCGL_W$ values for survey designs. They are calculated from the single nuclide soil DCGLs using radionuclide mixtures established for the various outdoor land areas. These are obtained from the Technical Basis Document on radionuclide distributions and DCGLs for site soils, TBD-09-001 [PBRF 2009c]. The surrogate DCGLs for FSS scans and the $DCGL_W$ values for various soil survey areas are shown in Table 17. Excavated soils from various locations were stockpiled prior to FSS as described in Attachment 18. For the FSS of the excavated soil, the most restrictive $DCGL_{SUR}$ values were used as the basis for scan survey investigation and action levels (10.31 pCi/g Cs-137; 3.28 pCi/g Co-60) since the soil from different areas was occasionally comingled and the exact location of soil origin could not be assured.

Table 17, Activity Fractions and Typical DCGLs for FSS of PBRF Soil

Location	Activity Fractions			Predominant (surrogate) Radionuclide	Scan $DCGL_{SUR}$	$DCGL_W$ for Survey Design
	Cs-137	Co-60	Sr-90		(pCi/g)	
Default for PBRF site and Spill Areas 4, 5 & 6.	0.912	0.007	0.081	Cs-137	11.55 (1)	11.4 (2)
Spill Areas 1, 2 & 3	0.201	0.714	0.085	Co-60	3.28 (3)	3.0 (4)
ERB & Environs Outside Perimeter Fence	0.878	0.037	0.085	Cs-137	10.31 (1)	11.1 (2)
Pentolite Ditch and Environs	0.969	0.014	0.017	Cs-137	13.34 (1)	13.5 (2)

Table 17 Notes:

1. Cs-137 is the surrogate for both Co-60 and Sr-90 in scan surveys.
2. For sample analysis, Cs-137 is the surrogate for Sr-90 as Co-60 is measured directly. These values have been reduced to account for 0.5 mrem/y contribution for insignificant radionuclides.
3. Co-60 is the surrogate for both Cs-137 and Sr-90 in scan surveys.
4. For sample analysis, Co-60 is the surrogate for Sr-90 as Cs-137 is measured directly.

The design approach for FSS of piping (EP, BP & MP) was based on the objective of achieving to the extent practicable, 100 percent "coverage" of the piping interior surfaces. Since controlled scan surveys of most piping runs were not possible with the available equipment, static survey measurement locations were spaced along the pipe runs to achieve 100% coverage. The number of static measurements was determined by determining the pipe length within the field of view of the detector (typically about 1 ft.) and dividing this into the total pipe run length.

To illustrate details of the calculations for determining the number of measurements (samples) for structures and soil areas, key parameter values used in the VSP calculations for representative survey designs are shown in Table 18. The table includes two designs for structures and two for soil areas.

Table 18, Key Parameter Values for Representative Survey Design Calculations

Description	$DCGL_W$	LBGR	$\frac{LBGR}{DCGL_W}$	Δ	σ	Δ/σ	N
Design 43, Reactor Building Canals F, G & H, structure survey units RB-4-1 thru RB-4-11, all Class 1 (1)	27,271 (2)	24,166 (2)	0.87	3,105 (2)	1,035 (2)	3.0	11
Design 10, SEB Cold Pipe Tunnel, structure survey units SE-3-31 thru SE-3-32, all Class 1 (3)	11,000 (2)	7,660 (2)	0.70	3,340 (2)	1,113 (2)	3.0	11
Design 55, Excavated soil surveyed in lifts, (4)	11.4 (5)(6)	5.7 (5)	0.50	5.7 (5)	2.28 (5)	2.5	11
Design 40I, Hot Lab, Hot Work Area Soil, survey unit HL-1-91, Class 1(7)	9.7 (5)(6)	4.85 (5)	0.50	4.85 (5)	1.9 (5)	2.55	11

Table 18 Notes:

1. From Attachment 12, Table 7.
2. Units are dpm/100-cm^2.
3. From Attachment 2, Table 7.
4. From Attachment 18, Table 7.
5. Units are pCi/g.
6. Surrogate DCGL (Cs-137) to account for Cs-137 and Sr-90 using PBRF soil area default radionuclide activity ratios.
7. From Attachment 8, Table 6.

In 2011, errors were identified in several of the gross activity values in TBD-07-001 that were used in designs for PBRF structures. [23] As a result, a new Technical Basis Document, TBD-11-002, was prepared to correct the DCGL values and to re-evaluate the radionuclide mixtures and activity fractions used to calculate the DCGLs [PBRF 2012]. It is noted that in the process of revising the DCGLs, the radionuclide mixtures assigned to the areas were also re-evaluated. The radionuclide activity fractions assigned to several of the areas were revised when it was determined that uranium activity concentrations in core samples used to obtain activity fractions were not significantly different from background. Thus, U-234 and U-235 were removed from all areas where core samples were the basis for determining radionuclide mixtures. The revised radionuclide mixtures and activity fractions are also included in TBD-11-002. Evaluations were performed to assess the impact of changes in the DCGL values on the FSS which was largely completed by the time that the impact of the DCGL errors was evaluated (in late 2011 and early 2012).

It was found that most of the changes in DCGLs were small, less than 2%. Three DCGLs are changed by more than 10%, however. These are: ROLB New Fuel Vault (decreased by 62.8%), Default Areas (decreased by 14.8%) and RB – 15 ft. (increased by 14.7%). Of most concern, are those cases where the DCGL is decreased in value. A number of design calculations were re-performed using VSP to determine the effect of the revised DCGLs on the calculated number of measurements, N. The effect of the revised DCGLs on the Reactor

[23] A detailed problem description was prepared under the PBRF QA Procedure, QA-03, *Audits and Corrective Actions* [PBRF 2011]. The evaluation of the effects of the DCGL errors on the FSS, including survey designs and instrument sensitivities is documented in the C/A-5 Close-out report [PBRF 2012a].

Building design calculations are reported in Attachment 12 (Appendix D) and on Miscellaneous Structures and Pads in Attachment 15 (Appendix C). To illustrate the effect of the revised DCGLs on survey design calculations for PBRF structures, calculations for representative designs with DCGL decreases are summarized in Table 19. The purpose of this table is to demonstrate that the FSS survey design parameters are not significantly affected by the changes in the DCGLs calculated in PBRF-TBD-11-002 [PBRF 2012].

Table 19, Summary of Survey Design Calculations with Revised DCGLs

Design No. (% change)	Area	$DCGL_W$ (1)	LBGR (1)	LBGR / $DCGL_W$	Δ (1)	σ (1)	Δ/σ	N
60A (-1.5)	-25 ft. Floor & Trenches (2)	12,556	6,278	0.5	6,278	2,260	2.8	11
	-25 ft. Floor & Trenches, Revised (2)	12,369	6,184	0.5	6,184	2,260	2.7	11
43 (-3.1)	RB Canals F, G, H (2)	27,271	24,166	0.89	3,105	1,035	3.0	11
	RB Canals F, G, H, Revised (2)	26,431	23,422	0.89	3,009	1,035	2.9	11
59 (-3.5)	RB Area 11 Mezzanine (3)	26,154	25,077	0.96	359	359	3.0	15
	RB Area 11 Mezzanine, Revised (3)	25,236	24,197	0.96	359	359	2.9	15
27 (-5.3)	PPH Room 4 (3)	10,067	5,435	0.54	4,362	1,544	3.0	11
	PPH Room 4, Revised (3)	9,529	5,146	0.54	4,383	1,544	2.84	11
26 (-9.2)	PPH, All Other Rooms (3)	23,713	22,807	0.98	906	302	3.0	11
	PPH, All Other Rooms, Revised (3)	21,522	21,092	0.98	430	302	1.42	15
13 (-14.8)	SEB Areas O/S Pipe Tunnel (default) (4)	27,166	26,054	0.96	1,112	371	3.0	11
	SEB Areas O/S Pipe Tunnel (default), Revised (4)	23,146	22,223	0.96	923	371	2.5	11
7 (-62.8)	ROLB New Fuel Vault (4)	27,166	11,261	0.41	15,905	5,302	3.0	11
	ROLB New Fuel Vault, Revised (4)	11,475	4,704	0.41	6,771	5,302	1.27	17

Table 19 Notes:

1. Units are dpm/100-cm^2.
2. In Designs 60A and 43, the $DCGL_W$ values in TBD-07-001, were adjusted to account for 2.5 mrem/y for insignificant radionuclides and 1 mrem/y for EP to obtain the $DCGL_W$ values. The TBD-11-002 revised DCGLs, were adjusted similarly to obtain the $DCGL_W$ values.

3. In Designs 59, 27 and 26, the $DCGL_W$ values in TBD-07-001, were adjusted to account for 2.5 mrem/y for insignificant radionuclides to obtain the $DCGL_W$ values. The TBD-11-002 revised DCGLs, were adjusted similarly to obtain the $DCGL_W$ value. No adjustment was made for embedded piping.

4. In Design 13, the gross activity DCGL value from TBD-07-001 was not adjusted at the design stage – the gross activity value was used in the VSP design calculations. Similarly, the revised gross activity value from TBD-11-002 was not adjusted.

5. In Design 7, the default DCGL for structures 27,166 dpm/100-cm^2, without adjustment, was used in the design even though TBD-07-001 had assigned a gross activity of 30,831 dpm/100-cm^2. This decision was made to add conservatism and to provide consistency with the remainder of the ROLB survey designs. The revised DCGL from TBD-11-002, 11,475 dpm/100-cm^2, was also used without adjustment.

It is seen from examination of Table 19, that the revised-reduced DCGLs changed the design calculation result in two of the seven designs shown in the table. In both cases the revised DCGL "relative shifts" (Δ/σ) were significantly reduced causing increases in N from 11 to 15 in Design 26 and from 11 to 17 in Design 7. Examination of the actual FSS measurements for the survey units covered under these designs reveals that the standard deviations were much less than estimated in the design process. For Design 26, survey unit PH-1-17 (Rooms 7 & 8), the actual value of σ was equal to 173 dpm/100-cm^2, whereas 302 dpm/100-cm^2 was assumed in the design calculation. For Design 7, ROLB New Fuel Vault, the actual values of σ obtained from survey results were much less than the value assumed in the design calculation, 5,302 dpm/100-cm^2. For survey unit RO-3-4, σ was equal to 170 dpm/100-cm^2, RO-3-7 was 339 dpm/100-cm^2 and RO-3-11 was 474 dpm/100-cm^2. This retrospective evaluation demonstrates that the 11 measurements used in the FSS of these survey units provided sufficient statistical power to demonstrate that the average residual activity concentration is well below the DCGL.

In the survey design process, adjustments may be required to account for unusual conditions identified in survey unit inspections. Conditions may exist in structures and open land areas where standard measurements may be inaccurate. Detection efficiencies obtained under standard calibration geometries may not apply and detection sensitivities (scan and static) are impacted. These conditions include surface roughness, isolated cracks, pits or protrusions that create non-standard measurement geometries. In the scan survey of open land areas, soil may be wet or partially covered by water. The survey designs specify adjustments in detection efficiency and survey technique to accommodate these conditions.

4.6 Instrumentation

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 static alpha and beta measurements are calculated using the following equation:

$$MDC_{static} = \frac{3 + 3.29\sqrt{B_R * t_s * (1 + \frac{t_s}{t_b})}}{t_s * E_{tot} * \frac{A}{100}}, \qquad \textbf{(Equation 10)}$$

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.

Scan sensitivities for detectors which measure alpha and beta surface activity are determined using the following equation:

$$MDC_{scan} = \frac{d' * \sqrt{b_i} * \frac{60}{i}}{E_i * E_s * \sqrt{p} * \frac{A}{100}}, \qquad \textbf{(Equation 11)}$$

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 (ISO 7503-1, Table 2 [ISO 1988],

p = Surveyor efficiency (typically 50%) and

A = Detector Open Area (cm^2).

A summary of typical a priori detection sensitivities of instruments used in the FSS of structures is provided in Table 20.

Table 20, Typical Detection Sensitivities of Beta Detectors

Detector Model	Detector Efficiency (c/d) (1)	MDC_{scan} (dpm/100-cm^2) (2)	Net scan cpm Equivalent to $DCGL_W$ (3)	MDC_{static} (dpm/100-cm^2) (2)
LMI 44-116	0.140	2,587 (4)	2,858	589 (5)
LMI 43-37	0.150	741 (6)	3,667	NA
LMI 44-9	0.125	11,268 (7)	367	3,668 (8)

Table 20 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 11 and static sensitivities are calculated using Equation 10.

3. The $DCGL_W$ value used in Design 71 is derived from the default value for structures published in TBD-07-001 (27,166 dpm/100-cm^2). It is adjusted to account for the dose contribution from insignificant radionuclides to obtain the $DCGL_W$ value, 24,449 dpm/100-cm^2.

4. The scan MDC for the LMI 44-116 is reported in Design No. 71 for background count rate = 200 cpm; scan speed =15.2 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.).

5. The static MDC for the LMI 44-116 detector is reported in Design No. 71 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).

6. The scan MDC for the LMI 43-37 is from Survey Design No. 71. The background count rate is 500 cpm; the scan speed is 27 cm/s, E_s = 0.5 and the detector-to-surface distance is 0.5 in.

7. The scan MDC for the LMI 44-9 is obtained from Survey Design No. 71. The background count rate is 125 cpm with a scan speed of 4.4 cm/s and the detector in contact with the surface.

8. The static MDC for the LMI 44-9 is obtained from Survey Design No. 71. 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).

An evaluation was conducted to determine the effect of the revised DCGLs on the scan sensitivity requirements in the FSS Plan. The surveys that had been completed prior to the issuance of TBD-11-002 were evaluated. This was to determine if instrument sensitivities were adequate to meet FSS Plan requirements for scan investigation levels where the revised DCGLs published in TBD-11-002 resulted in a decrease in the applicable $DCGL_W$. In other words, were the scan sensitivities of the instruments used adequate to detect contamination levels equal to the $DCGL_{EMC}$ in Class 1 survey units and the $DCGL_W$ in Class 2 and 3 survey units?

For Class 1 survey units, the smallest Area Factor was calculated, based on the largest survey unit size (100 m^2), and the smallest number of samples calculated by VSP (11 samples). This Area Factor is 2.1. When this Area Factor was applied to the revised-reduced DCGLs, the revised $DCGL_{EMC}$ was greater than the scan investigation level, set at the original DCGL value used in the Survey Designs. Thus, the FSS Plan requirement that in Class 1 survey units, the instrumentation used in scan surveys be sensitive enough to detect activity equivalent to the $DCGL_{EMC}$ is satisfied. Although the surveys performed did not meet the Scan Investigation Levels and Action Levels specified in the Survey Designs, because of the conservatisms applied in the designs, the surveys met the requirements of the FSSP. This result was obtained in all areas except the ROLB New Fuel Vault.

For the New Fuel Vault, the $DCGL_{EMC}$ was calculated using the revised $DCGL_W$ from TBD-11-002 (11,475 dpm/100cm^2). This DCGL was corrected for the dose contribution from deselected nuclides and embedded pipe (9,869 dpm/100cm^2). The Area Factor was calculated for each of the 3 survey units in the New Fuel Vault, and the smallest was used to calculate the $DCGL_{EMC}$. This Area Factor, 2.27, times the corrected DCGL results in 22,402 dpm/100cm^2. The 9 surveys that were performed in these 3 survey units were then evaluated to determine the dpm/100cm^2 activity that would have been detected using the instrument efficiency, background, and investigation level used for each survey. For each survey, the corresponding dpm/100cm^2 value was less than the calculated $DCGL_{EMC}$ using the revised DCGL from TBD-11-002. Due to the conservatisms used in FSS process, these surveys met the scan sensitivity requirements of the FSSP.

For Class 2 and 3 areas, a similar approach was used to compare the results of the individual surveys to see if the surveys were capable of detecting activity at the revised DCGL for Class 2 areas, and at 50% of the revised DCGL in the Class 3 survey units. The results of these calculations show that the surveys in these areas also meet the requirements of the FSSP. The details of these evaluations are documented in the C/A-5 Issue 0421 Corrective Action Response Report [PBRF 2012a].

Modifications to survey instructions are adjusted 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.[24]

Scan sensitivities for detectors used for walkover gamma scans of soil are determined using the method referenced in the PBRF FSS Plan and described in NUREG-1507 [NRC 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 2009]. The method is summarized and the key equations presented. The scan MDC is calculated using the following equations adapted from NUREG-1507 for walkover gamma scanning with NaI detectors:

$$MDCR_{surv} = \frac{d'\sqrt{bi}}{\sqrt{p}}\left(\frac{60}{i}\right)$$ **(Equation 12)**

$$MDC_{scan} = \frac{MDCR_{surv}}{Conv * MS_O}$$ **(Equation 13)**

[24] 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. The PBRF-TBD-09-002 [PBRF 2009] calculates LMI 44-10, NaI detector scan MDC values for various survey conditions, including non-standard sized areas of elevated activity. The PBRF-TBD-09-006 [PBRF 2009a] evaluates the LMI 44-10 response when performing soil scans in water covered areas. It is shown that the effect of water covering the soil scan area can be compensated for by modifying the scan survey technique, primarily by decreasing the detector-to-surface distance.

where:

$MDCR_{surv}$ = 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,

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/h and

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

Site-specific parameter values for the MDC_{scan} calculation for the LMI 44-10 detector are obtained from the technical basis document TBD-09-002 [PBRF 2009]. Instrument response factors for Cs-137 and Co-60 respectively are 0.138 and 0.667 µR/h per pCi/g as calculated using the MicroShield code. The most conservative instrument response conversion factors measured for detectors in the PBRF LMI 44-10 inventory are 232.39 and 262.21 cpm per µR/h for Cs-137 and Co-60, respectively.

Using these values, typical detection sensitivities of the instruments used in the FSS of soil survey units are provided in Table 21. Minimum detectable count rates and MDC_{scan} values for 44-10 detectors operated in Co-60 and Cs-137 windows vs. background count rates are shown in the table.

Table 21, Typical Detection Sensitivities of Field Instruments used for Soil Scans

LMI 44-10 with Co-60 Window (1)			LMI 44-10 with Cs-137 Window (2)		
Background (cpm)	$MDCR_{surveyor}$ (ncpm)	MDC_{scan} (pCi/g)	Background (cpm)	$MDCR_{surveyor}$ (ncpm)	MDC_{scan} (pCi/g)
25	36	1.06	50	101	3.13
50	50	1.50	100	142	4.43
100	71	2.13	150	174	5.42
150	87	2.61	200	201	6.26
200	101	3.01	250	225	7.0

Table 21 Notes:

1. Ludlum Model 44-10 NaI detector with Model 2350-1 data logging scaler-rate meter setup to count in Co-60 energy window. Data from Survey Design No. 57. Scan speed = 0.25 m/s, detector to soil surface = 10 cm.

2. 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. 55. Scan speed = 0.5 m/s, detector to soil surface = 10 cm.

The scan investigation level for Class 1 survey units listed in Table 10 is the $DCGL_{EMC}$ as specified in the FSS Plan, Section 8.1. However, the scan investigation level for the FSS of soil survey units is typically set at a fraction of the $DCGL_W$ established in the survey design to ensure that areas in excess of the DCGL are identified and investigated. It is also noted that 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. [25] Accordingly, the scan investigation level for soil survey units where Co-60 predominates was set at 3 pCi/g, about 90% of the 3.28 pCi/g DCGL for Co-60. In survey units where Cs-137 predominates, it was set at 7.7 pCi/g, or 75% of most restrictive soil DCGL for Cs-137, 10.3 pCi/g

A variety of detectors were used for FSS measurements in embedded, buried piping and miscellaneous piping. The majority were cylindrical-solid scintillation detectors (NaI, CsI). The detectors were mounted in specially fabricated holders or "sleds" for insertion into the piping. The sled mounted detectors were deployed using fiberglass push-rods and pull tapes with distance encoders to determine the position of the detector within the pipe run when measurements were taken. The detector efficiencies were determined using vendor-fabricated NIST traceable Cs-137 and Co-60 sources. On these sources, the source activity was deposited on flexible polyvinyl sheets with protective mylar coverings. The flexible sources of various sizes were designed for placement into pipes to "conform" with the pipe inside circumferential surface to simulate uniformly deposited surface activity. Detector efficiencies were determined using pipe mockups of various diameters in which the conformal sources were mounted. The detectors were inserted into the various pipe diameter mockups for the counts to determine efficiencies. The detector efficiencies were determined with cable lengths to be used for each application in the field (typically 25 to 75 ft.). The detectors were coupled to LMI 2350-1 data-logging rate meters and were set up to count within gamma energy windows corresponding to Cs-137 or Co-60 gamma emissions depending on which radionuclide was predominant.

Table 22 lists detectors, their detection efficiencies, minimum detectable count rates and MDCs for static counts for representative gamma detector and pipe size combinations. When deployed into piping for FSS measurements, one minute counts were typically used. In some cases, two minute counts were used to improve the counting statistics when the detection efficiency was low.

[25] 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."

Table 22, Detection Sensitivities of Gamma Detectors used for EP, BP and MP

Detector Model	Nuclide	Pipe Size	Detector Efficiency (c/d) (1)	MDCR (ncpm)	MDC_{static} (dpm/100-cm^2)
Ludlum 44-159	Co-60	1.5"	0.00047	9.0	5233
		3"	0.00030	9.0	4099
		4"	0.00020	9.0	4613
		8"	0.00010	9.0	4613
	Cs-137	1.5"	0.00071	10.7	4135
		3"	0.00028	10.7	5243
		4"	0.00083	10.7	1327
		8"	0.00077	10.7	715
Ludlum 44-62	Co-60	1.5"	0.00028	7.9	7710
		3"	0.00013	7.9	8303
	Cs-137	1.5"	0.00019	11.5	16514
		3"	0.00032	11.5	4902
Bicron 1MG1	Co-60	4"	0.00039	9.0	2563
		8"	0.00029	9.0	1591
	Cs-137	4"	0.00055	14.4	2699
		8"	0.00030	14.4	2474
Bicron G3	Co-60	8"	0.0037	40.8	567
		12"	0.0041	40.8	318
	Cs-137	8"	0.0086	61.6	368
		12"	0.0060	61.6	383
Bicron FO/1.5L-X	Co-60	0.75"	0.00069	12.4	9864
		1.5"	0.00049	12.4	8315
	Cs-137	0.75"	0.000745	13.9	10260
		1.5"	0.00052	13.9	7330
Ludlum 44-10	Cs-137	31"	0.00041	29	940

Table 22 Notes:

1. The background count rates used in the MDC static determinations were selected from the efficiency determination worksheets for the each instrument.
2. All readings obtained with these detectors were static measurements; scans were not performed with these detectors.
3. *A priori* static measurement sensitivities for the detectors are calculated using Equation 10.

In some instances, beta detectors were used for FSS measurements in Buried and Miscellaneous piping. Table 23 lists the detector and typical detection sensitivities for these detectors.

Table 23, Typical Detection Sensitivities of BP/MP Beta Detectors

Detector Model	Detector Efficiency (c/d)	MDC_{scan} ($dpm/100cm^2$)	Net cpm Equivalent to $DCGL_W$	MDC_{static} ($dpm/100cm^2$)
LMI 44-116	0.280	3,176	2000	723
LMI 44-9	0.146	3,140	200	3,808

Table 23 Notes:

1. Static count time of 1 minute.
2. 44-116 background count rate of 200 cpm.
3. 44-9 background count rate of 125.

In support of the FSS, analysis of soil and other bulk samples, and smear counting was performed at the PBRF on-site counting laboratory. The laboratory consisted of three high resolution gamma spectroscopy units, one liquid scintillation counter, and two gas flow proportional alpha/beta counters. These counting systems are identified and their performance characteristics summarized in Table 24.

Table 24, PBRF On-site Counting Laboratory Instrumentation

Description and Purpose	Manufacturer and Model	Detector Type	MDA (typical)	Calibration
Gamma Spectroscopy Analysis of Soil and other Bulk Samples	Ortec GMX-45P-A-S (1) Ortec GMX-45P4-A (1) Ortec GMX-40P4 (1)	High Purity Germanium (HPGe) (2)	Cs-137, 0.1 pCi/g (3) Co-60, 0.1 pCi/g (3)	Annual calibration using custom mixed radionuclide NIST-traceable sources in several geometries (4)
Alpha/Beta Counters for Smear Counting (5)	Tennelec LB5100 Tennelec S5XLB	Gas Flow Proportional Counter	Alpha, 12 dpm (6) Beta, 20 dpm	Annual calibration using NIST-traceable 47 mm electroplated disk sources (Tc-99 & Th-230)
Liquid Scintillation Counter for Analysis of Tritium in Water	Packard Tri-Carb 2900TR	Liquid Scintillation	1200 pCi/l	Annual calibration using NIST-traceable liquid H-3 and C-14 reference source vials

Table 24 Notes:

1. Ortec GammaVision™ - 32 operating software, Version 6.08
2. Three HPGe detectors with 50% nominal efficiencies for Co-60.
3. 5 minute count time for typical MDAs for soil and concrete.
4. Principal calibration source geometries include 1-liter water, 250 & 100 ml soil/sediment, smear, & 3 in. diameter x ½ in. thick concrete core disk. All geometries contained Am-241, Co-57, Ce-139, Sn-113, Cs-137, Co-60 and Y-88.
5. Automatic sample changer with 100 sample capacity.
6. Typical MDAs for 1 minute count times.

4.7 Quality Assurance

Quality assurance for the FSS is addressed in the NASA PBRF Decommissioning Project QA Plan [NASA 2006]. Quality Assurance program elements for the FSS were established to ensure that survey measurement data were sufficient in number and of the quality required to unequivocally demonstrate that the release criteria are satisfied. Key elements are:

1. The FSS Plan is implemented in accordance with approved procedures,
2. Surveys are conducted by trained personnel using calibrated instruments,
3. All documents produced in survey design and implementation are independently reviewed,
4. Continuous management oversight of FSS operations is provided,
5. Discrepancies identified through routine operations and self-assessments are documented and remedied through a corrective actions procedure,
6. On-site sample analysis laboratory QA procedure,
7. Procurement of qualified vendor laboratory services and
8. Quality control measures for FSS field measurements.

Quality control measures are applied to FSS field measurements and laboratory samples. Data quality objectives are established for the measurements in each survey unit. These are checked as part of the data evaluation process and confirmed using a DQA check sheet. Field instruments are given source and background checks before and after FSS measurements are collected each day. To evaluate measurement precision, replicate fixed measurements are performed at least 5% of the measurement locations, and replicate scan surveys performed on at least 5% of the surface area in each survey unit.

The PBRF Radiological Laboratory is designed to support the analytical requirements of decommissioning work activities, environmental program, and Final Status Survey. The laboratory is operated by qualified personnel with documented training on all of the laboratory equipment. Sample processing and analysis is performed in accordance with site procedures and chain of custody is maintained for all samples. The PBRF laboratory participates in the United States Department of Energy Mixed Analyte Performance Evaluation Program (MAPEP) and the Eckert & Zeigler Analytics cross check programs. The laboratory also routinely counts sample blanks, split samples and replicate QC samples with each batch of FSS soil or other media samples.

4.8 Data Assessment

Data assessment is performed for individual survey units. The product of this process is a release record, wherein the survey measurements and results of the data assessment are documented. Upon completion of FSS measurements and sample collection, the measurement and sample analysis results are assembled. The survey documentation is initially reviewed to determine if all the requirements of the survey design (and instructions) have been met. A checklist is used to guide and document the data quality assessment process. The review is conducted to determine if all applicable requirements are met. These include:

- Compliance with survey instructions as specified in the survey design package.
- The instrumentation MDC for structure static measurements was below the $DCGL_W$ for Class 1 and 2 survey units or below 50% $DCGL_W$ for Class 3 survey units.
- The instrumentation MDC for structure scan measurements was below the $DCGL_W$, or, if not, the need for additional static measurements was addressed in the survey design.
- The instrumentation MDC for volumetric measurements and smear analysis was below 10% of the $DCGL_W$.
- The MDCs and assumptions used to develop them were appropriate for the instruments and techniques used to perform the survey.
- The survey methods used to collect data were proper for the types of radiation involved and for the media being surveyed.
- "Special methods" for data collection were properly applied for the survey unit under review.
- The data set is comprised of qualified measurement results collected in accordance with the survey design, which accurately reflects the radiological status of the facility.

If the checklist items are satisfied, the survey measurements are acceptable for evaluation. If the checklist is not satisfied, the surveys are returned to the field supervisor for investigation and corrections as needed.

Scan survey information is evaluated to ensure that the required scan coverage was achieved; and if scan action levels were exceeded, investigations were performed and properly documented. For structure survey units, smear counting results are evaluated to ensure that no removable surface activity measurement was greater than 10% of the $DCGL_W$. Fixed measurements results for structures, converted to dpm/100-cm^2 are tabulated and the summary statistics: mean, median and standard deviation are calculated. The maximum value is also tabulated. For open land survey units, soil sample results, in units in pCi/g, are also tabulated and summary statistics calculated.

Before the data analysis, including statistical tests, is performed, a review is conducted to determine if the $DCGL_W$ requires adjustment. The $DCGL_W$ may require adjustment to account for the presence of embedded pipe or "insignificant" radionuclides in the survey unit. Note that this adjustment may have been made in the survey design.

The data analysis and statistical testing then proceeds as follows:

1. If all samples and measurements are below the $DCGL_W$ (Class 1 and 2), or below $0.5xDCGL_W$ (Class 3), the survey unit "passes." If not, proceed with the tests below.

2. If elevated areas have been identified (by scans, fixed measurements or samples), and the average activity in each elevated area is below the $DCGL_{EMC}$ (Class 1), below the $DCGL_W$ (Class 2) or below $0.5xDCGL_W$ (Class 3), the survey unit passes. Then proceed with the tests below. If not true, the survey unit fails.

3. If the result of the elevated measurements unity rule test is less than 1.0, the survey unit passes. Then proceed with the tests below. If not true, the survey unit fails.

4. If the mean of the soil sample activity concentrations or fixed surface activity measurement data is below the $DCGL_W$, the survey unit passes. If not true, proceed to the test below.

5. If the results of the statistical test (S+ for Sign Test, or W for the WRS test) $\geq$ the critical value, the survey unit passes. If not true, the survey unit fails and further remediation and resurvey are required.

5.0 Survey Results

Results of the FSS measurements and evaluations are summarized in this section. It is noted that the individual measurements in each PBRF survey unit and the evaluations to demonstrate that each survey unit satisfies the release criteria are presented in the attachments to this report. Presented here are summaries of the measurements for individual structures, remaining piping and environmental areas. Results of scan surveys, fixed measurements and soil samples are summarized, as are results of investigative measurements. Fixed measurement results for each survey unit and the results of comparisons of survey unit maximum values with the $DCGL_W$ are reported. As discussed below, these are all below the applicable DCGLs and no statistical tests were required. It is shown that levels of residual contamination have been reduced to levels that are ALARA. Results of groundwater sampling and dose assessment are presented. Soil activity and groundwater concentrations are compared to EPA trigger levels in accordance with the 2002 Memorandum of Understanding between the NRC and EPA [USEPA 2002]. The Plum Brook characterization and dose assessment results are also presented.

5.1 Structures

The FSS results for PBRF structures include scan survey results, results of systematic measurements and the results of investigative measurements and tests. Scan survey results are summarized in Table 25. The table shows that scan coverage requirements in each structure are satisfied and that the 5% QC scan coverage requirement is also satisfied. It also identifies those structures in which the scan investigation level was exceeded in one or more survey units. Investigation levels are provided in each Survey Design Package and are typically set at a fraction of the DCGL. The scan action level was exceeded and investigative measurements performed in 76, or 11%, of the 665 PBRF structure survey units. Locations identified by scan or static measurements that exceed an investigation level are marked, verified, and additional measurements are collected. The results of these investigations are shown in Table 27. In all these cases, the measurements were below the $DCGL_{EMC}$ and the EMT unity rule sum was < 1.0. It is noted that most localized areas of elevated activity were quite small, typically about 100 cm^2 or less and an area factor of 40.2 applied. Thus, in no case was the 25 mrem dose criterion exceeded by the added contribution from localized areas with concentrations in excess of the DCGL.

Table 26 summarizes the systematic total surface beta measurements. It shows that the maximum measurement result is less than the lowest DCGL for each structure, considering both the original DCGLs based on TBD-07-001 and the revised DCGLs in TBD-11-002. In all cases, the maximum measurement result is less than the $DCGL_W$ value and no further evaluations or tests were required. From the data used to compile Table 26, it is calculated that the mean of 7459 systematic total surface beta activity measurements taken in the FSS of the PBRF structures is 547 ± 479 dpm/100cm^2 (one standard deviation).

Table 25, Summary of FSS Scan Surveys of PBRF Structures

Description	Scan Survey Coverage	Scan Action Level Exceeded	No. of Investigative Measurements	QC Scan (% coverage)
ROLB	100% in Class 1, 51 to 65% in Class2, 11 to 14% in Class 3	Yes (in 2 SUS)	2	6 to 30%
SEB	100% in Class 1, 51 to 57% in Class2, 10 to 13% in Class 3	Yes (in 2 SUS)	4	5 to 12%
Fan House	100% (all Class1)	Yes (in 3 SUs)	3	5 to 9%
HRA	100% (all Class1)	Yes (in 3 SUs)	5	5 to 18%
WHB	100% (all Class1)	Yes (in 3 SUs)	6	5 to 15%
Hot Lab	100% in Class 1, 30 to 41% in Class 2, 10 to 11% in Class 3	Yes (in 37 SUs)	95	5 to 10%
CV	100% in Class 1, 40 to 54% in Class 2	Yes (in 4 SUs)	5	5 to 12%
Reactor Bldg.	100% in Class 1, 39 to 63% in Class 2, 10% in Class 3	Yes (in 11 SUs)	31	5 to 29%
PPH	100% (all Class1)	Yes (in 11 SUs)	12	5 to 7%
Roadways & Parking Lots	100% in Class 1, 32 to 48% in Class 2	No	None	8 to 11%
Misc. Structures & Pads	100% in Class 1, 35 to 56% in Class 2	No	None	5 to 18%

A summary of the investigative measurements in structures is provided in Table 27. One hundred sixty three investigative measurements were reported, and of these 27 were greater than the applicable DCGL. In all these cases, the measurements were below the $DCGL_{EMC}$ and the EMT unity rule sum was < 1.0. It is noted that most localized areas of elevated activity were quite small, typically about 100 cm^2 or less and an area factor of 40.2 applied. Thus, in no case was the 25 mrem dose criterion exceeded by the added contribution from localized areas with concentrations in excess of the DCGL. It is noted that a review of the Table 27 conclusions was performed in view of the revised-reduced DCGLs in TBD-11-002. It was found that the EMC and EMT results were not changed. The margin provided by the large Area Factors, typically 40.2 (most of the elevated areas were < 0.25 m^2) more than compensates for the reduced DCGL values.

Also, removable surface activity measurements were performed at each systematic measurement location and typically at each investigative measurement location and counted for alpha and beta activity at the PBRF on-site counting laboratory. The majority were less than smear counter MDA values, typically 12 dpm/100-cm^2 for alpha and 20 dpm/100 cm^2 for beta activity. The highest smear measurement results were reported for the Hot Laboratory, 162 dpm/100-cm^2 beta at an investigative measurement location. The majority of removable surface activity measurements were < MDA. Hence all removable surface activity measurements were < 10% of the applicable DCGLs.

Table 26, Systematic Total Surface Beta Activity Measurement Results for PBRF Structures

Building or Structure	No. of Survey Units (1)	Total No. of Measurements	Maximum	Average	Standard Deviation	$DCGL_W$ (2)
			dpm/100-cm^2			
ROLB	59	650	2,500	503	408	11,475
SEB	52	579	2,688	494	258	11,000
Fan House	38	431	8,000	538	592	36,857
HRA	34	381	4,149	844	521	34,213
WHB	28	316	1,290	548	320	40,051
Hot Lab	138	1574	8,690	587	620	34,404
CV	87	967	3,180	413	348	11,544
Reactor Bldg.	129	1441	5,458	451	480	14,382
PPH	41	454	8,100	775	568	10,588
Roadways & Parking Lots	15	176	14,108	483	1050	23,146
Misc. Structures & Pads	44	490	2,190	679	324	23,146

Table 26 Notes:

1. The number of survey units does not include survey units established for soil areas underneath several of the buildings. Refer to Table 13 for details.
2. The $DCGL_W$ values shown in the table for comparison to measurement results are the lowest of the $DCGL_W$ values given in Table 8 of TBD-11-002 for the survey units in each building or structure.

Table 27, Summary of PBRF Structure Investigative Measurements

Description	No. of Investigative Measurements	Maximum Measurement Result (dpm/100-cm^2)	Number Exceeding $DCGL_W$	EMC Result	EMT Unity Result
ROLB	2	54,447	1	< $DCGL_{EMC}$	< 1.0
SEB	4	21,574	1	< $DCGL_{EMC}$	< 1.0
Fan House	3	105,000	1	< $DCGL_{EMC}$	< 1.0
HRA	5	17,100	0	N/A	N/A
WHB	6	74,400	1	< $DCGL_{EMC}$	< 1.0
Hot Lab	95	48,100	9	< $DCGL_{EMC}$	< 1.0
CV	5	13,800	1	< $DCGL_{EMC}$	< 1.0
Reactor Bldg.	31	45,000	12	< $DCGL_{EMC}$	< 1.0
PPH	12	25,000	1	< $DCGL_{EMC}$	< 1.0
Roadways & Parking Lots	None	N/A	N/A	N/A	N/A
Misc. Structures & Pads	None	N/A	N/A	N/A	N/A

5.2 Land Areas and Soil

Results are presented for FSS of PBRF soil areas. This includes results for all the survey units identified in Table 14. A summary of scan survey results are presented in Table 28. The table shows that scan survey coverage requirements were satisfied in that 100% of the accessible areas in Class 1 survey units was covered, from 30 to 100 % in Class 2 and 13% in the single Class 3 survey unit. This meets or exceeds the FSS Plan requirements shown in Table 10. Scan investigation levels were exceeded and investigations were performed in 12 of the 399 PBRF soil survey units. A total of 36 investigative soil samples were reported. In only one survey unit did an investigative sample result exceed the applicable DCGL. The EMC and EMT were performed and the result was satisfactory, i.e., the $DCGL_{EMC}$ was not exceeded and the EMT unity test result was < 1.0. The table also shows that the 5% minimum QC scan coverage was satisfied in all soil survey units.

Table 28, FSS Scan Survey Results for PBRF Soil Survey Units

Description	Scan Surveys Performed	Scan Action Level Exceeded	No. of Investigative Samples Collected	Investigative Sample Results (pCi/g) (1)	QC Scan (% coverage)
Open Land Areas within Restricted Area and Outside Buffer Zone	100% in Class 1, 30 to 100 % in Class 2	Yes (in 5 SUs)	18	up to 6.39 pCi/g Cs-137 & 2 positive Co-60, max. 1.0 pCi/g	5.1 to 8.5%
Emergency Retention Basin	100% (all Class 1)	Yes (in 1 SU)	4	1.06 to 4.29 pCi/g, Cs-137	6.0%
Soil Lifts and Staging Area	100%	Yes (in 1 SU)	1	2.93 pCi/g Cs-137	5.3 to 11.3%
Soil Processed by ScanSort Conveyor	100 %	Yes (2)	N/A (2)	5.6 to 70.9 pCi/g, Cs-137 (2)	5%
Pentolite Ditch	100% in Class 1, 51 to 55% in Class 2	Yes (in 1 SU)	2	Both samples < DCGL	5%
Storm Drains, Pipe Trenches and Other Sub-surface Excavations	100% (all Class 1, 39 SUs)	Yes (in 3 SUs)	9	All < DCGL except in one area: Cs-137 24.9 & Co-60 4.9 pCi/g (3)	5%
Hot Lab sub-foundation	100% (two Class 1 SUs)	Yes (in 1 SU)	2	Max. 4.12 Cs-137, Co-60 < MDA	5%
PPH sub-foundation	100% (one Class 1 SU)	No	None	N/A	5%
Reactor Building sub-foundation	100% (one Class 1 SU)	No	None	N/A	5%
ROLB sub-foundation	13% (one Class 3 SU)	No	None	N/A	5%
WHB sub-foundation	100% (one Class 1 SU)	No	None	N/A	> 5%

Table 28 Notes:

1. Where Co-60 results are not listed, they were < MDA.
2. Under the ScanSort operating procedures, the diversion control set point (DCS, 5.2 pCi/g, Cs-137) is equivalent to a scan investigation-action level. The DCS was exceeded on nine occasions. In each of these events, about 175 lb. of soil was diverted to a contaminated soil stock pile for disposal as radwaste. The average concentration of Cs-137 measured in these diverted batches ranged from 5.6 to 70.9 pCi/g).
3. In survey unit OL-1-5, EMC and EMT were performed and results were satisfactory.

The FSS sample analysis results for systematic soil samples collected from the PBRF soil survey units are summarized in Table 29. The table lists the number of survey units for each area, the number of systematic soil samples collected, the maximum measured Cs-137 and Co-60 concentrations and the minimum DCGL values used in the survey designs of each area.

It is seen from examination of Table 29, that the maximum sample concentrations are less than the DCGL in all cases and no additional tests are required. On this basis, it can be concluded that all the soil survey units satisfy the 25 mrem/y release criterion.

Table 29, Soil Survey Unit FSS Systematic Sample Analysis Results

Description	No. of Survey Units	No. of Soil Samples	Max. Cs-137 Conc.	Cs-137 $DCGL_{SUR}$ (1)	Max. Co-60 Conc.	Co-60 $DCGL_{SUR}$ (1)
			pCi/g			
Open Land Areas within Restricted Area and Outside Buffer Zone	59	680	6.86	11.4	< MDA (2)	5.7
Emergency Retention Basin	7	74	2.73	11.4	< MDA (2)	5.7
Soil Lifts and Staging Area	41	536	0.77	11.4	< MDA (2)	3.5
Soil Processed by ScanSort Conveyor	211	3196	1.32	10.3	< MDA (2)	3.5
Pentolite Ditch	36	465	7.62	14.02	0.149	3.8
Storm Drains, Pipe Trenches and Other Sub-surface Excavations	39	431	0.88	10.3	1.0	3.5
Hot Lab sub-foundation	2	25	1.44	5.87	< MDA (2)	N/A (3)
PPH sub-foundation	1	11	< MDA (4)	6.23	< MDA (2)	N/A (3)
Reactor Building sub-foundation	1	11	0.16	5.77	< MDA (2)	N/A (3)
ROLB sub-foundation	1	11	0.12	11.7	< MDA (2)	3.8
WHB sub-foundation	1	11	0.57	12.9	< MDA (2)	3.8

Table 29 Notes:

1. The $DCGL_{SUR}$ values shown are the lowest value for the survey designs in each area.
2. Typical Co-60 MDA values are 0.1 pCi/g.
3. The $DCGL_W$ for Cs-137 is the surrogate DCGL under the assumption that Cs-137 is the surrogate for both Sr-90 and Co-60, thus no Co-60 DCGL was used.
4. The maximum Cs-137 MDA for the PPH soil samples was 0.08 pCi/g.

5.3 Piping

Embedded Piping

As described in Section 2.2 and in accordance with the FSS Plan, embedded piping is any piping situated below the minus three foot elevation that is totally encased in concrete or piping directly beneath building floors that may not be totally encased in concrete, but contained within the structural foundation of the building (within the building footprint).

Additionally, EP is grouted after FSS in compliance with FSS Plan Section 7.5 [NASA 2007]. The descriptions and results presented here were obtained from Attachment 9 of this report.

The EP remediation and survey campaign began in 2005 and continued through the decommissioning effort at PBRF. As a result of this remediation and survey campaign the EP was remediated, surveyed and grouted in compliance with the FSSP. Embedded piping DCGLs correspond to a dose contribution of 1 mrem/y to a future building occupant of the structural survey unit in which EP is located as described in the FSSP. The structural survey units for which the DCGL is adjusted for the dose contribution from embedded piping are identified in the Final Status Survey Report attachments for each structure that contains embedded piping. They are:

- ROLB – Attachment 1
- Service Equipment Building – Attachment 2
- Fan House – Attachment 3
- Waste Handling Building – Attachment 6
- CV – Attachment 11
- Reactor Building – Attachment 12.

The DCGLs for FSS of embedded piping were established using an exposure model where an individual occupies an area within the Reactor Building which contains a number of embedded pipes. The source term for this evaluation constitutes a uniform layer of contamination on the piping interior surfaces. The pipes are assumed to be filled with grout. The single radionuclide DCGLs are calculated as the concentration in dpm/100-cm^2 which results to a dose of 1 mrem/y to an individual who spends 2340 h/y in the vicinity of the embedded piping. The MicroShield® was used for the dose calculation. The resulting single nuclide DCGLs for the principal radionuclides in PBRF embedded piping are in dpm/100-cm^2:

- Co-60: 240,800 and
- Cs-137: 3,785,000.

Single radionuclide DCGLs were also calculated for other radionuclides which were measured at much lower concentrations than Co-60 or Cs-137. They ranged from 532,500 dpm/100-cm^2 for Eu-154, to 1,312,000 dpm/100-cm^2 for Ag-108m.

As described in Section 4.6, most of the FSS measurements in EP were performed using gamma scintillation detectors set up to count gamma radiation from either Co-60 or Cs-137. The detector setup for each piping run was determined by the predominant radionuclide. Static measurements were collected at one foot intervals along most pipe runs.

Using this method, field measurements in cpm were converted to total Co-60 or Cs-137 equivalent surface activity in dpm/100cm^2 through application of the detector efficiency and a geometry factor which depended on the pipe diameter. The total surface Co-60 or Cs-137 activity was then compared to the applicable surrogate DCGL. The surrogate DCGLs (equivalent to 1 mrem/y) were calculated using the activity fractions for the applicable piping group (described in Section 2.2). The resulting dose was obtained as the ratio of the total surface activity to the surrogate DCGL.

The EP FSS gamma measurement results are summarized in Table 30. The table shows that the maximum dose contribution from this piping was 0.346 mrem/y.

Table 30, Summary of Embedded Piping Gamma Survey Measurements and Results

Surrogate Radionuclide Used for Measurements	No. of Piping Runs	No. of Measurements	Maximum Activity	Average Activity	Maximum Dose (mrem/y)
			dpm/100-cm^2		
Co-60	173	4850	158,135	6190	0.346
Cs-137	21	950	365,886	22,190	0.277

The results summarized above apply to all of the embedded piping in the PBRF except the two 24 inch recirculation pipe runs, each 146 ft. in length. These were surveyed using a specially fabricated pipe counter assembly. The detector assembly used a single LMI 44-116 beta scintillation detector mounted in a pipe-centered jig which positioned the detector on the pipe surface. The detector could be positioned in any location around the pipe circumference at a given distance into the pipe run. It could be operated in either scan or static measurement mode. The piping activity measurements were converted to total surface beta activity under the conservative assumption that Co-60 was the only radionuclide present. A dose goal of 2 mrem/y was selected for the main coolant piping after repeated decontamination efforts resulted in no significant decrease in residual contamination. The measured activity was compared to the DCGL equivalent to this dose goal, 481,600 dpm/100-cm^2. From this comparison, it was determined that the maximum dose associated with these two piping runs was 1.37 mrem/y. For the 10 structural survey units associated with this piping, 1.37 mrem/y was added to the dose from the structure surface activity.

Buried and Miscellaneous Piping

Buried Piping (BP) is any pipe buried in soil and situated outside the structural foundation of a building, such as storm drains, footer drains, or sanitary lines. Miscellaneous Piping (MP) is any piping, conduit or similar system which does not meet the definition of Buried Piping or Embedded Piping as defined in the PBRF FSSP, but will remain in the structure. Examples of MP include various vents and drain lines, instrument tubing, conduits, and ventilation ducts. It also includes various penetrations in concrete walls and floors that once contained system pipes or valve operator shafts. All piping that was embedded in concrete structures above the -3' elevation was removed during building demolition and surveyed for release and recycled or disposed as radioactive waste.

Piping interior surfaces were surveyed after remediation using detectors mounted in engineered sleds. The detector is manipulated by technicians through the piping to perform the survey. A one minute static measurement was obtained for each foot of BP/MP for all survey units.[26] A summary of the FSS measurement results for the BP/MP piping is provided in Table 31. This summary is prepared from Table 6 in Attachment 17. For this summary, the BP and MP are divided into two groups: piping classified as Class 1 and Class 3 piping (there was no piping classified as Class 2). There are 23 Class 1 BP/MP piping survey units and one Class 3 survey unit.

Table 31, Summary of BP/MP FSS Measurements

Piping Group	No. of Pipe Runs (Survey Units)	No. of FSS Measurements	Maximum Activity (1)	Mean Activity (1) (2)	No. of Survey Units with Measurements > DCGL
Class 1	23	1493	146,830	8,369 ± 2,981	8
Class 3	1	40	2,452	1,328 ± 780	0

Table 31 Notes:

1. Units are dpm/100-cm^2.
2. Mean values of all measurement results reported ± one standard deviation.

Table 31 indicates that measurements above the assigned $DCGL_W$ values occurred in 8 survey units. In total, 29 individual measurements out of a total of 1533 measurements were above the $DCGL_W$. For these measurements the elevated measurement comparison tests (EMC and EMT) were performed. All measurements passed the tests. The EMT unity values ranged from 0.505 to 0.884. It should be noted that the Area Factors were underestimated in most cases since the average size of the elevated areas (0.17m^2) is much smaller than the area used in the FSSP (0.25m^2) to calculate the largest AF (40.2). Eighty percent of the elevated areas identified during the FSS of BP/MP were less than 0.25 m^2 in area. The Sign test was performed on each survey unit where the maximum activity of any single measurement exceeded the $DCGL_W$ and all passed the test.

A dose assessment was performed for the remaining MP and BP as a result of comments received from the NRC. Calculation methods and assumptions are documented in TBD-12-002 [PBRF 2012c] and are consistent with those used for embedded piping as described in the FSS Plan. The objective was to demonstrate that the dose is well below the 25 mrem/y dose criterion including the dose contribution from residual contamination measured in the structures or land areas in which the piping resides. Six survey units with the highest dose potential were selected for evaluation. They included four miscellaneous piping survey units and two buried piping survey units. The results for MP show that the calculated doses are quite low even for the cases with the largest number of pipes (pipe clusters). The eleven-pipe cluster in the Quad C wall contains the highest concentration of miscellaneous pipes found and it is assumed that the maximum measured concentration in the MP-10-5 survey unit, 31,132 dpm/100-cm^2 is uniformly distributed throughout the piping. The calculated dose from this configuration is 2.6E-03 mrem/y. This result represents the worst case upper bound on the dose to a future building occupant.

[26] The sanitary sewer system was an exception since the system was "live" during the survey. Only those portions of the system that could be accessed safely was surveyed.

The results for the BP are calculated for the Resident Farmer scenario and an Intruder scenario. The Resident Farmer results are obtained using MicroShield (2340 h/y occupancy) when a future site occupant occupies an area in the center of the Pentolite Ditch Crossover piping. Under these assumptions, the highest annual dose from is 4.66E-05 mrem/yr. Doses calculated under the Intruder scenario using RESRAD (100 h/y occupancy) assumes that an intruder or worker occupies an area in the center of the Pentolite Ditch Crossover where the contaminated soil was brought to the surface. Under these assumptions, the highest annual dose from BP is 1.72E-01 mrem/y (BP-2-1).

The results summarized above demonstrate that the BP/MP satisfy all FSS Plan commitments and meets the release criteria in 10CFR20 Subpart E. The principal conclusions are:

- Static radiation measurements were performed at 1 foot intervals on 100% of all remaining BP/MP Class 1 survey units. Direct surface measurements were made on accessible portions of Class 3 active sanitary sewer system piping.
- All survey unit mean fixed measurement results are below the $DCGL_W$.
- Investigations were performed following observation of elevated activity in 8 survey units. As a result of these investigations, elevated measurement comparisons and elevated measurement tests were performed and all were satisfactory. The Sign test was performed successfully on all survey units where elevated activity was observed.
- Although the classification of Miscellaneous Pipe (MP) is not specifically defined in the FSS Plan, the MP was surveyed using the same criteria as BP.
- Residual surface activity concentration measurement results are shown to be less than NRC screening level values - demonstrating that the ALARA criterion is satisfied.
- A majority of MP was removed from the associated structures during the decontamination phase of the project. All the MP situated above the -3ft elevation was removed and disposed of as radioactive waste or free released for recycling in accordance with NASA procedure RP-008 [NASA 2006a].

5.4 Groundwater

In accordance with a Memorandum of Understanding (MOU) between the US NRC and the US Environmental Protection Agency (EPA) [USEPA 2002], the PBRF license termination process includes a review of residual contamination levels in groundwater (and soil). Also, an NRC comment on the PBRF Final Status Survey Report requested that NASA identify any radionuclides of concern (associated with the PBRF site) in groundwater and provide information comparing groundwater sampling results for each well against the applicable Environmental Protection Agency maximum contaminant levels (MCL's) [NASA 2012].

A technical basis document, TBD-12-001, has been prepared to address these requirements [PBRF 2012b]. The evaluations and results of this TBD are summarized below.

Groundwater MCLs

The Maximum Contaminant Levels used in the evaluation of Plum Brook groundwater are the EPA MCLs for drinking water published in the National Primary Drinking Water Regulations, 40CFR Parts 9, 141 and 142 [USEPA 2000]. The MCLs that apply to Plum Brook groundwater are:

- Beta particle and photon emitting radionuclides – concentration of individual radionuclides not exceeding a dose limit of 4 mrem/y. Of most significance to Plum Brook groundwater is tritium concentration of 20,000 pCi per liter, which according to the EPA, is equivalent to 4 mrem/y to an individual who obtains all of his or her drinking water from the groundwater in question.

- Gross alpha emitters – 15 pCi per liter.

- Ra-226 and Ra-228 (combined) – 5 pCi per liter.

- Uranium – 30 micrograms (μg) per liter.

PBRF Water Monitoring Program

The water samples reported in this evaluation were collected from wells located on the PBRF site on established frequencies. The samples were analyzed for gross alpha and gross beta activity at a vendor laboratory. Analysis for tritium (by liquid scintillation counting) and for gamma emitting radionuclides by gamma spectroscopy was performed at the PBRF on-site counting laboratory. The monitoring wells include 7 deep wells and 11 shallow wells. The wells and sampling frequencies are described in Table 32. The PBRF has established Project Specific Action Levels (PSALs) for gross alpha activity (20 pCi/liter) and gross beta activity (500 pCi/liter). When PSALs are exceeded, specific radionuclide analysis is performed.

Table 32, PBRF Water Monitoring Wells

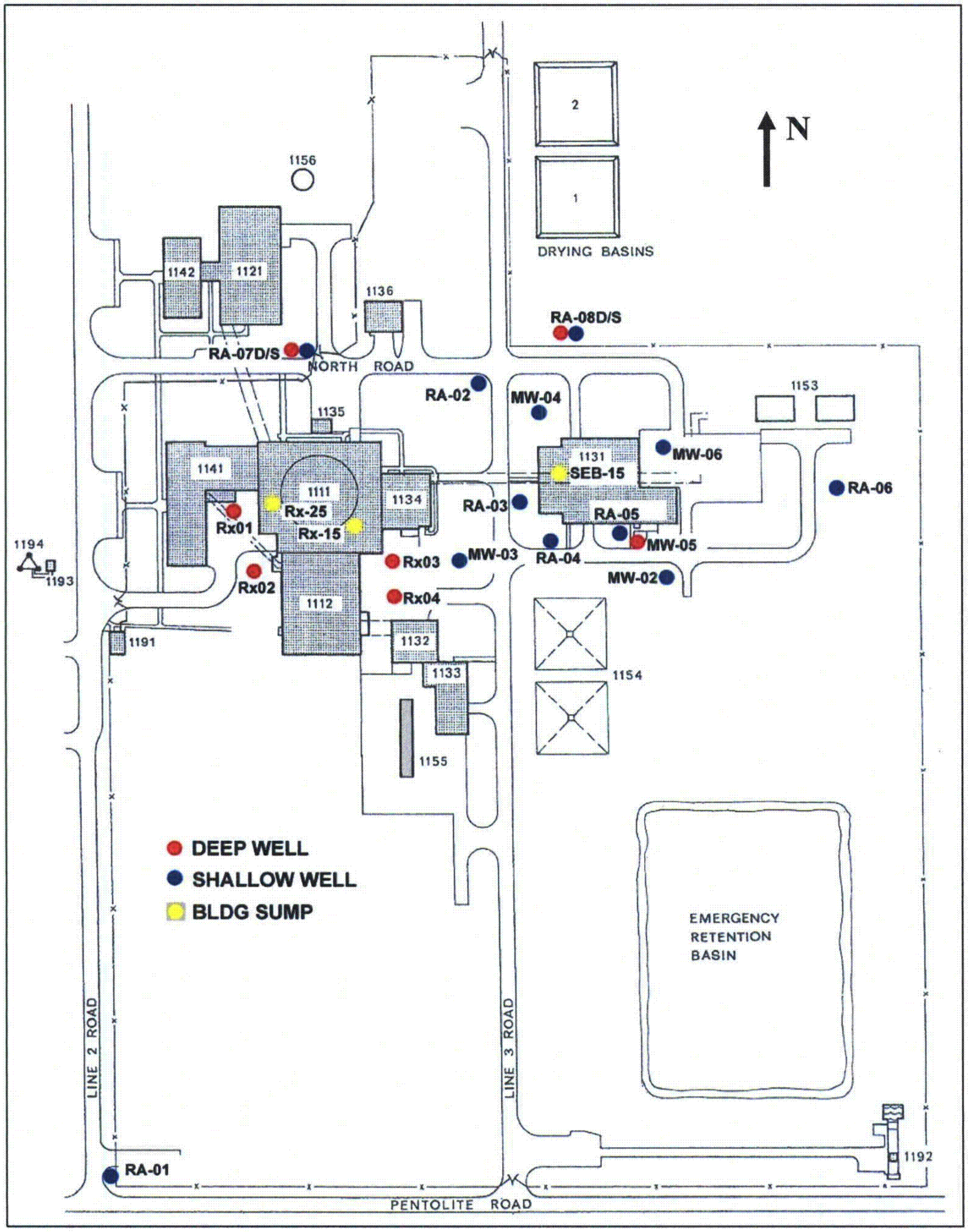
Well ID	Depth (ft)	Date Installed	Sampling Frequency
Deep Wells			
Rx-01	80	Jun-1960	Monthly
Rx-02	40	May-1960	Annual
Rx-03	40	May-1960	Monthly
Rx-04	40	May-1960	Annual
MW-05 (1)	49.5	Jun-1988	Monthly
RA-07D	55	Oct-2003	Monthly
RA-08D	55	Oct-2003	Intermittent
Shallow Wells (2)			
RA-01	16	Dec-1990	Monthly
RA-02	20	Dec-1990	Monthly
RA-03 (3)	22	Dec-1990	Annual
RA-04	10	Dec-1990	Annual
RA-05 (3)	10	Dec-1990	Annual
RA-06	10	Dec-1990	Annual
RA-07S	23.5	Oct-2003	Monthly
RA-08S	22	Oct-2003	Monthly
MW-02 (3)	24.5	June-1988	Monthly
MW-04	22.5	June-1988	Annual
MW-06	23.5	June-1988	Annual

Table 32 Notes:

1. Well removed in July 2010 (not replaced).
2. A shallow well shown on Figure 5 identified as MW-03, proved to be ineffective, as it had only low and intermittent yields. Sampling from this well was discontinued in 2011.
3. Wells removed in July 2010 and replaced in August 2010.

The well locations are shown in Figure 5. Groundwater (shallow and deep) and sump samples are collected monthly or annually, and are summarized in the NASA PBRF Decommissioning Project Environmental Media Sampling and Analysis annual reports.

Figure 5, PBRF Site Map Showing Monitoring Well Locations



Water Sample Results

All PBRF environmental water samples are analyzed by the on-site laboratory for gamma emitting radionuclides and tritium prior to being sent to an off-site laboratory for additional gross alpha and beta analysis. If gross activity results exceed a PSAL, additional radionuclide measurements are performed (e.g., Sr-90, Am-241, Cm-242, Pu-238, etc.). The results from over 600 water samples collected from the PBRF monitoring wells from 2007 through 2011 were reviewed in TBD-12-001 [PBRF 2012b] and compared against the EPA MCLs. The results of these comparisons show that gross alpha contamination has not exceeded more than about 43% of the EPA MCL, and gross beta results are no more than about 16% of the PSAL of 500 pCi/liter. A few samples have shown analysis results above the EPA MCL for gross alpha and the PBRF PSAL gross beta value. Additional analyses have shown that only natural occurring radioactive materials are present in these samples. No other sample wells/locations were above any action level.

It can be seen from this review that residual concentrations of radionuclides in groundwater at the PBRF site are well below the EPA drinking water limits. The maximum sampling result for tritium in PBRF well water, 4,000 pCi/liter, is far below the EPA drinking water MCL of 20,000 pCi/liter (only 19 positive tritium results were reported). The resulting dose to an individual corresponding to the EPA MCL for tritium would be 0.8 mrem/y. Using the water dependent pathway analysis features of the RESRAD computer code with PBRF site specific resident farmer scenario parameter values, the expected dose from the maximum observed concentration of tritium, 4000 pCi/liter, in PBRF well water is calculated to be 0.125 mrem/y falling to near zero after about two years.

5.5 Plum Brook

As discussed in Section 2.3, demonstration that the Plum Brook and near-stream environs meets the 25 mrem/y dose criterion is demonstrated by assessment of doses to individuals living in or occupying areas adjacent to the stream. This consists of three parts: 1) preparing exposure scenarios that are representative of land use along the stream, 2) development of source terms through extensive characterization surveys, and 3) calculating doses to individuals using the RESRAD code.

Exposure Scenarios

Four exposure scenarios were established for the dose assessment. They are: Suburban Gardener, Brook-side Resident, Country Club Maintenance Worker and Recreationist. Each scenario was developed by matching Plum Brook stream-environment characteristics with land use most representative of each section of the Plum Brook watershed. It should be noted that while the exposure scenarios are considerably more representative of possible exposure conditions than the generic resident farmer scenario, they still involve conservative assumptions. For example, in the absence of detailed information on human contact with contaminated Plum Brook sediments, occupancy factors from NRC studies of postulated scenarios for urban contaminated sites are used. The exposure scenarios are summarized in Table 33.

Table 33, Scenario Summary

Scenario Title	Plum Brook Stream Section	Dose Receptor	Source	Pathways
Suburban Gardener	Upper Stream	Resident	Vegetable garden located on flood backwater area or on soil supplemented with excavated stream bank-sediment.	Direct exposure, Inhalation, direct ingestion of sediment and consumption of vegetables from garden
Brook-side Resident	Lower Stream	Resident	Layer of sediment from flood event adjacent to and partially underneath house	Direct exposure, inhalation and direct ingestion of sediment
Country Club Maintenance Worker	Upper Flood Plain	Landscape Maintenance Worker	Soil and sediment from ponds used as fill on golf course walkway	Direct exposure, inhalation and direct ingestion of sediment
Natural Area Recreation Day User	Lower Flood Plain & River Mouth	Recreational user (seasonal use)	Stream bottom and adjacent alluvial deposits	Direct exposure, fish consumption, inhalation and direct ingestion of sediment

The Suburban Gardener scenario was suggested by the observation that several residences along the upper meandering stream section (between PBRF and Rt. 2) have gardens. It is assumed that the garden is located on flood backwater sediment deposits and soil that was supplemented by sediment excavated by the resident from the banks of Plum Brook. The garden is assumed to be 186 m^2 (about 45 x 45 ft.). The Suburban Gardener exposure pathways include direct exposure while working in the garden (123 hours per year), ingestion of Cs-137 from eating vegetables grown in the garden, direct soil ingestion and inhalation. Due to tilling, the contaminated sediment is mixed with soil (uncontaminated). A conservative assumption is that the contaminated soil-sediment mixture lies on the surface of the garden in a three inch thick layer.

The Brookside Resident scenario was suggested by the observation that some houses near the Plum Brook in the lower stream section were constructed after a severe flood event in 1969. These homes could have been constructed in areas impacted by flood backwaters such that they were constructed on land where contaminated sediments were deposited. In this scenario, it is assumed that a home is situated on an area of contaminated sediment that extends partially beneath the house. The house is assumed to have a 2000 ft^2 (186 m^2) footprint and the contaminated zone is an area of 45.6 m^2 in area. The exposure pathways are direct exposure to a resident inside the house (attenuated by the house-structure), direct exposure to contaminated sediments outside the house (lawn mowing and landscaping maintenance), ingestion of contaminated soil and inhalation of suspended sediment (dust). The resident is assumed to spend 1096 hours per year in the portion of the house located on contaminated sediment and 80 hours a year on the contaminated portion of the outdoor property.

The Country Club Maintenance worker exposure scenario is based on the observation that soil containing sediment from Plum Brook has been used as landscaping fill on the Plum Brook Country Club golf course. It is assumed that contaminated sediment was used to fill-in an area 3 meters wide on either side of a golf cart path that extends for 100 meters. The sediment is in a three-inch thick layer on the surface and the maintenance worker spends an average of 15 hours a week during the 30 week golfing season traveling along the path and performing landscape maintenance along the pathway.

The Recreationist scenario is placed on the Plum Brook estuary, located between US Rt.6 and the Sandusky Bay (also identified as the lower flood-plain stream mouth section). The Recreationist is assumed to be a fisherman who spends about 10 hours a week for 10 weeks each year in the stream. This individual is exposed from direct radiation, inhalation and direct ingestion of contaminated sediments while walking and standing on the contaminated stream bank and alluvial deposits in the adjacent wetlands. He or she consumes game fish caught in the Plum Brook stream mouth. The contaminated zone is assumed to be a band of sediment 1500 m^2 in area that underlies the stream bank in an area that is accessible to the public just north of the Rt. 6 overpass.

Source Term Development

In developing source terms for the dose assessment, results of the radiological characterization of Plum Brook sediments and the features of RESRAD were considered. Characterization survey results show that Cs-137 (and Co-60) contamination of PBRF origin are not distributed continuously along the Plum Brook but tend to be located in small areas or "pockets" on a horizontal scale of about one meter (or less) in the stream meander sections and in larger lens-shaped deposits in areas impacted by flood backwaters, the flood plain and estuary [PBRF 2009d, PRRF 2010]. Areas with detectable activity typically exhibit a vertical distribution as well. In some locations, the highest concentrations are found in subsurface layers.

The RESRAD code is designed to calculate doses from radioactive material distributed uniformly in a layer of soil called the "contaminated zone." This can be modeled as either a circular disk (cylinder) or a polygon. The thickness and area can be varied without practical limits, but the dimensions are constant for a given case. The contaminated zone can be modeled as a surface layer or a subsurface layer overlain by an uncontaminated covering soil layer of specified thickness [ANL 2001].

Given the non-uniform distribution of contaminated sediments in the Plum Brook, source term models are developed that are comprised of multiple components. Complex source terms are modeled as a combination of volume sources of uniform contaminant concentration. Each RESRAD case is limited to one source volume, but source terms with more than one source volume are implemented using multiple case runs. The operating assumption is that the doses are additive; the total scenario dose is obtained as the sum of the doses from the individual source term elements. Scenario-specific source term models are developed. The source term models for the four scenarios are summarized in Table 34.

Table 34, Exposure Scenario Source Models

Scenario	Principal Source	Localized Area of Elevated Activity
Suburban Gardener	Surface layer of soil-sediment mixture 186 m^2 in area & 3 in. thick.	Modeled as a cylindrical three-layer source of one meter radius. Each layer is 6 in. thick.
Brook-side Resident	Three-layer source 186 m^2 in area. Surface layer is 6 in. thick. Subsurface layers are 9 in. thick.	Modeled as cylindrical three-layer source of one meter radius. Each layer is 6 in. thick.
Country Club Maintenance Worker	Surface layer of soil-sediment mixture 600 m^2 in area & 3 in. thick.	Modeled as cylindrical three-layer source; three meter radius. Surface layer is 6 in. thick; subsurface layers are each 12 in. thick.
Natural Area Recreation Day User	Three-layer source 1500 m^2 in area. Surface layer is 6 in. thick. Subsurface layers are 12 in. thick	Modeled as cylindrical three-layer source; three meter radius. Surface layer is 6 in. thick; subsurface layers are each 12 in. thick.

As seen in Table 34, the source term model for each scenario consists of two principal source volumes: the principal contaminated zone source and a localized small area source of elevated activity. Depending on the scenario, the sources are composed of either single or multiple layers or strata. Direct pathway doses from multiple sources including multiple layer sources are obtained as the sum of the doses calculated by RESRAD for each source term component.

To illustrate the concentrations of Cs-137 and Co-60 used in the source term components for an exposure scenario dose calculation, the Suburban Gardner source term concentrations are shown in Table 35.

Table 35, Suburban Gardner Source Term Component Concentrations

Source Term Component	Cs-137 (pCi/g)		Co-60 (pCi/g)	
	Concentration	Uncertainty	Concentration	Uncertainty
Cont. Zone 3 in	1.20E+00	2.80E+00	1.30E-01	7.00E-02
Elev. local Area layer 1; 6 in	5.78E+01	2.26E+00	1.60E+00	2.10E-01
Elev. local Area layer 2; 6 in	7.24E+01	2.77E+00	6.53E-01	1.40E-01
Elev. local Area layer 3; 6 in	2.05E+01	1.10E+00	2.88E-01	9.00E-02

Dose Calculation Results

The dose calculation results are summarized in Table 36. It is seen that the calculated doses to individuals exposed in the four scenarios range from 0.65 to 1.17 mrem/y. The average of the doses to the four scenario receptors is 0.88 ± 0.22 mrem/y.

Table 36, Plum Brook Dose Assessment Results

Source Term Component and Dose Pathway	Cs-137 (mrem/y)		Co-60 (mrem/y)		Total (mrem/y)	
	Dose	Uncertainty	Dose	Uncertainty	Dose	Uncertainty
Suburban Gardner	7.18E-01	3.85E-01	7.80E-02	4.07E-02	7.96E-01	3.87E-01
Brookside Resident	7.33E-01	4.33E-01	1.86E-01	8.28E-02	9.19E-01	4.41E-01
Maintenance Worker	1.07E+00	5.83E-01	9.73E-02	9.03E-02	1.17E+00	5.90E-01
Recreationist	6.17E-01	3.35E-01	3.01E-02	2.14E-02	6.47E-01	3.37E-01

These results show that the dose to an individual is well below the 25 mrem/y dose criterion agreed as being acceptable for the Plum Brook areas impacted by contaminated sediments. It is noted that the source term concentrations used in the dose assessment calculations are from characterization surveys performed prior to the remediation of the areas of highest concentrations in 2010. If the dose calculations were performed for post-remediation conditions, it is expected that the calculated doses would be reduced from those reported above.

Perspective is also provided by comparison of the calculated doses with the dose to the public from Cs-137 that remains in the environment from atmospheric weapons testing. The annual average dose to individuals in the northern hemisphere from fallout Cs-137 is reported to be about 0.5 mrem/y (with an estimated uncertainty of ± 100%) [Bouv. 2002].[27] From this, it is seen that the calculated doses from Plum Brook sediments are indistinguishable from the "background" dose received from the fallout Cs-137 burden in the Plum Brook watershed.

5.6 ALARA Evaluation

It is shown that residual contamination in the PBRF 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

[27] Most published estimates of annual doses to individuals from fallout Cs-137 (and other radionuclides) are derived from data in reports published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the most recent of which was published in 2010 [UN 2010]. Estimates of the annual dose to individuals in the continental US derived from the UNSCEAR data may vary somewhat, depending on the assumptions used to convert the UNSCEAR data (committed effective population dose equivalent) to annual average dose to an individual.

need to provide analyses to demonstrate that these screening levels are 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."[28]

Screening level values published by the NRC for the radionuclides in structural surface residual contamination potentially present in PBRF structures are shown in Table 37. Since individual radionuclide activity concentrations are not measured in the FSS of structures, a direct comparison of residual contamination levels to 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 was accomplished using activity fractions used in development of gross activity DCGLs in PBRF structures. A screening level value that is equivalent to the gross activity DCGL for each structure was calculated using the equations in Section 3.4 of the FSS Plan. The radionuclide mixture in the area within a structure that resulted in the lowest screening level DCGL was typically used. This was compared to the upper 95th % confidence limit of the mean activity measured in the structure. These results are reported in the attachments to this report.

To calculate a screening level equivalent DCGL for the PBRF structures as a whole, the default radionuclide mixture for structures is used. The NRC screening level single radionuclide DCGLs and the PBRF default mixture activity fractions are shown in Table 37. The screening level equivalent DCGL for the revised default mixture is 14,124 dpm/100-cm^2. As reported in Section 5.1, the average total surface beta activity measured in the FSS of the PBRF structures is 547 ± 479 dpm/100-cm^2 (one standard deviation). This value is obtained as the mean of 7459 systematic total surface beta measurements. The upper limit of 95th % confidence interval about this mean value is 558 dpm/100-cm^2.[29] This value is well below the reference screening level gross activity DCGL of 14,124 dpm/100-cm^2.[30]

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

[29] The upper limit of the confidence interval, 95th percentile value, is calculated as: UL = mean + 1.96 $\sigma/\sqrt{n}$, where n = 7459 measurements.

[30] In fact, the UCL of the overall mean of the 7459 total surface beta activity measurements in PBRF structures is below the screening level equivalent DCGL of all the PBRF structure areas except one, the ROLB New Fuel Vault. The screening level equivalent DCGL for the New Fuel Vault is driven by the very low screening level values for uranium: 91 and 98 dpm/100-cm^2 for U-234 and U-235, respectively (the New Fuel Vault mixture contains 34% U-234). However the New Fuel Vault represents only three of 665 structure survey units.

Table 37, Screening Level Values for Radionuclide Activity Fractions

Radionuclide	Screening Level Value (dpm/100-cm^2)	Default Activity Fractions (%) (2)
H-3	1.2 E+08 (1)	26.5
Co-60	7.1E+03 (1)	17.8
Sr-90	8.7E+03 (1)	7.8
I-129	3.5E+04(1)	1.3
Cs-137	2.8E+04 (1)	46.5
Eu-154	1.2E+04(3)	0.13
U-234	9.1E+01 (3)	0
U-235	9.8E+01(3)	0

Table 37 Notes:

1. Values from NUREG-1757 Vol. 2, Table H.1 [USNRC 2006].
2. The revised default activity fractions are from TBD-11-002 [PBRF 2012].
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.

Applicable NRC surface soil screening values are: Cs-137, 11; Co-60, 3.8 and Sr-90, 1.7 (all in pCi/g). From Table 29, the maximum Cs-137 concentration measured in systematic soil samples is 7.62 pCi/g and the maximum Co-60 concentration is 1.0 pCi/g. The maximum Sr-90 concentration is inferred using the Sr-90/Cs-137 activity ratio of 0.089 (from Table 15, default soil mixture). This obtains a maximum Sr-90 concentration of 0.68 (0.089 x 7.62). From these comparisons, it is concluded that the ALARA criterion is satisfied.

5.7 Comparison with EPA Trigger Levels

The PBRF license termination process includes a review of residual contamination levels in soil and groundwater 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. The trigger levels applicable to the PBRF for residual soil concentrations of the radionuclides of concern are:

- Co-60, 4 pCi/g, in residential soil and 6 pCi/g in industrial/commercial soil
- Sr-90 (plus daughter activity), 23 pCi/g in residential soil and 1,070 pCi/g in industrial/commercial soil and
- Cs-137 (plus daughter activity), 6 pCi/g in residential soil and 11 pCi/g in industrial/commercial soil.

The MOU also specifies that the NRC will identify sites and consult with EPA where there is radioactivity contamination in groundwater in excess of EPA maximum contaminant levels (MCLs). As discussed in Section 5.4, the MCLs for specific radionuclides in water listed in the National Primary Drinking Water Regulations are:

- Beta particle and photon emitting radionuclides – concentration of individual radionuclides not exceeding a dose limit of 4 mrem/y. Of most significance to Plum Brook groundwater is tritium concentration of 20,000 pCi per liter, which according to the EPA, is equivalent to 4 mrem/y to an individual who obtains all of his or her drinking water from the groundwater in question.

- Gross alpha emitters – 15 pCi per liter.

- Ra-226 and Ra-228 (combined) – 5 pCi per liter.

- Uranium – 30 micrograms (µg) per liter.

For comparison with the EPA soil trigger values for soil, it is desirable here to compare the soil FSS results for the PBRF site as a whole. From the perspective of risk to future site occupants, average concentrations of contaminants are the most relevant. The best available estimates are the averages of the results of soil samples selected by survey designs. However for added conservatism, the average of the maximum values of the principal soil contaminant radionuclides measured in all samples selected by FSS designs are used. These values are listed below:

- Co-60; 0.57 pCi/g

- Sr-90; 0.2 pCi/g [31] and

- Cs-137; 2.25 pCi/g,

All are below the respective EPA trigger levels for residential soil. As also discussed in Section 5.4, the results of analyses of over 600 water samples collected from PBRF monitoring wells from 2007 through 2011 were evaluated. It was found that none of the EPA MCLs were exceeded. The highest measured concentration of tritium was 4,000 pCi/liter. From these results, it is concluded that residual contamination in PBRF soil and groundwater are below the applicable EPA trigger values.

6.0 Conclusions

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

- Scan surveys were performed in all survey units with scan coverage in excess of the percentage requirements for all three classes of survey units.

- Residual contamination above investigation levels was measured in 113 of 1064 survey units. Areas of elevated activity above the applicable $DCGL_W$ were measured in 40 survey units. The EMC test was conducted and was satisfied in all.

[31] The Sr-90 concentration, 0.2 pCi/g is obtained using the Sr-90/Cs-137 activity ratio of 0.089 from the data in Table 17, default soil mixture.

- All total surface activity measurements are less than the applicable $DCGL_W$, except as noted above.

- All soil sample radionuclide activity concentrations are below their respective $DCGL_W$ values.

- 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 $DCGL_W$.

- Radiation surveys were performed on 177 embedded pipe (EP) survey units. The highest EP dose is 1.366 mrem/yr from the 24 inch diameter PCW piping. All of the remaining EP survey units were <1.0 mrem/y.

- Residual surface activity and soil concentration measurement results are shown to be less than NRC screening level values - demonstrating that the ALARA criterion is satisfied.

- Residual activity concentrations measured in PBRF soil survey units were compared to, and found to be less than EPA trigger levels.

- Evaluation of over 600 water sample analysis results collected from PBRF monitoring wells from 2007 through 2011 showed that the results were less than the applicable EPA drinking water MCLs.

- A dose assessment was performed to evaluate the dose to members of the public from sediments contaminated from radionuclides of PBRF origin in the Plum Brook. The highest calculated dose to an individual was 1.17 mrem/y, far below the applicable dose criterion, 25 mrem/y.

- Several changes were made from what was proposed in the FSS Plan. They included addition of several areas for FSS that were not identified in the Plan. Several land area buffer area survey units were added, the Plum Brook was added and the transport roadways were expanded. No areas were assigned MARSSIM classifications reduced from what was established in the Plan. The MARSSIM classification of a number of open land survey units was increased above the classification levels indicated in the FSS Plan (Class 2 to Class 1, etc).

- There were minor changes from initial assumptions (in the FSS Plan) regarding the extent of residual activity in the facility. These included the extent of contamination in several building sub-foundation areas and environmental areas.

- Although the classification of Miscellaneous Pipe (MP) is not defined in the FSS Plan, the MP was surveyed using the same criteria as BP. A dose assessment was conducted to determine the maximum contribution from BP or MP. The rationale for this methodology is described in TBD-12-002 [PBRF 2012c] and Attachment 17 of this report. The maximum dose contribution from BP or MP is less than 0.2 mrem/y.

7.0 Attachments

Attachment 1 – Reactor Office and Laboratory Building (Building 1141)

Attachment 2 – Service and Equipment Building (Building 1131)

Attachment 3 – Fan House (Building 1132)

Attachment 4 – Pentolite Ditch (Environmental Area A2300)

Attachment 5 – Hot Retention Area (Building 1155)

Attachment 6 – Waste Handling Building (Building 1133)

Attachment 7 – Storm Drains, Pipe Trenches & Other Sub-surface Excavations

Attachment 8 – Hot Laboratory (Building 1112)

Attachment 9 – Embedded Piping

Attachment 10 – Emergency Retention Basin (ERB)

Attachment 11 – Reactor Containment Vessel

Attachment 12 – Reactor Building (Building 1111)

Attachment 13 – Primary Pump House (Building 1134)

Attachment 14 – Roadways and Parking Lots

Attachment 15 – Miscellaneous Structures and Pads

Attachment 16 – Open Land Areas within Restricted Area and Outside Buffer Area

Attachment 17 – Buried and Miscellaneous Piping

Attachment 18 – Excavated and Backfill Materials

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