Plum Brook Reactor Facility

Final Status Survey Report

Attachment 15

Revision 0

Miscellaneous Structures and Pads

FINAL STATUS SURVEY REPORT
ROUTING AND APPROVAL SHEET

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Page No.	Revision Level	Page No.	Revision Level	Page No.	Revision Level
Cover Page	0				
Routing & Approval Sheet	0				
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TOC	0				
List of Tables & List of Figures	0				
List of Acronyms & Symbols, 3 pages	0				
Text, 37 pages	0				
Appendix A 27 pages	0				
Appendix B 48 pages	0				
Appendix C 14 pages	0				

Form
AD-01/5
Rev 2

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS & SYMBOLS

α	alpha; denotes alpha radiation, also type I error probability in hypothesis testing
AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
AF	Area Factor
β	beta; denotes beta radiation, also type II error probability in hypothesis testing
b_i	background counts in observation interval
B_R	Background count rate
BPL	Byproduct License
CFR	Code of Federal Regulations
cm	centimeters
cm^2	square Centimeters
cpm	counts per Minute
CRB	Cold Retention Basins (Building 1154)
CTB	Cooling Tower Basin (Building 1152)
Δ	delta, $DCGL_W$ – LBGR
d'	Scan surveyor sensitivity index
DCGL	Derived Concentration Guideline Level
$DCGL_{EMC}$	DCGL for small areas of elevated activity, used with the Elevated Measurement Comparison test (EMC)
$DCGL_W$	DCGL for average concentrations over a survey unit, used with statistical tests. (the "W" suffix denotes "Wilcoxon")
dpm	disintegrations per minute
E_i	Detector, or instrument efficiency
E_s	Surface efficiency
E_t	Total efficiency
EMC	Elevated Measurement Comparison
EMT	Elevated Measurement Test
EPA	US Environmental Protection Agency
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, denotes gamma radiation
g	gram
gpm	gallons per minute
HL	Hot Laboratory (Building 1112)
HP	Horse Power
HRA	Hot Retention Area/Basins (Building 1155)
HTD	Hard To Detect
i	observation counting interval during scan surveys
in.	inch
KVA	electrical system power rating in units of 1000 volt-amperes
LBGR	Lower Bound of the Gray Region

LIST OF ACRONYMS & SYMBOLS, Continued

LMI	Ludlum Measurements, Inc.
m^2	square meters
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
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
MSP	Miscellaneous Structures and Pads
MOU	Memorandum of Understanding
mrem	millirem
MW	Megawatt
MWH	Montgomery Watson Harza, Inc.
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
N	Number of FSS measurements or samples established in a survey design
N/A	Not Applicable
NRC	US Nuclear Regulatory Commission
PBOW	Plum Brook Ordinance Works
PBRF	Plum Brook Reactor Facility
PBS	Plum Brook Station
PNL	Pacific Northwest Laboratory
PPH	Primary Pump House (Building 1134)
PSB	Precipitator Sludge Basins (Building 1153)
Φ	Standard normal distribution function
p	surveyor efficiency for scan surveys
pCi/g	picocuries per gram
%	percent
QC	Quality Control
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)
s	seconds
σ	generic symbol for standard deviation of a population
SAIC	Science Applications International Corporation
SEB	Service Equipment Building (Building 1131)
SMTA	Surface Measurement Test Area
SNL	Sandia National Laboratory
SR	Survey Request
t_b	background count time
t_s	sample count time

TBD	Technical Basis Document

LIST OF ACRONYMS & SYMBOLS, Continued

μ	Mean activity concentration
UCM	Unusual Condition Measurement
UL	Upper limit of the confidence interval about the mean
VSP	Visual Sample Plan
WEMS	Water Effluent Monitoring System (Building 1192)
$Z_{1-\alpha}$	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 report presents the results of the final status radiological survey of Miscellaneous Structures and Pads (MSP) at the Plum Brook Reactor Facility (PBRF). These include the Water Effluent Monitoring System (WEMS), Cooling Tower and Precipitator Sludge basins, power system substation transformer vaults and pads, the Assembly and Test Storage (ATS) Building Tunnel and other miscellaneous pads. It is Attachment 15 of the PBRF Final Status Survey Report (FSSR) [1]. This attachment describes the structures, their operational history and final condition for the final status survey (FSS). It describes the methods used in the FSS and presents the results.

As stated in the PBRF Final Status Survey Plan (FSSP) [NASA 2007], the goal of the decommissioning project is to release the facility for unrestricted use in compliance with the requirements of US NRC 10CFR20 Subpart E. The principal requirement is that the dose to future site occupants will be less than 25 mrem/y. Subpart E also requires that residual contamination be reduced to levels as low as reasonably achievable (ALARA). The default Derived Concentration Guideline Level (DCGL) for PBRF structures, 20,831 dpm/100-cm^2 has been applied to the structures reported in this report, with the exception of the ATS Tunnel and the WEMS. The DCGL established for the ATS Tunnel is 36,450 dpm/100-cm^2, and for the WEMS is 30,306 dpm/100-cm^2.[2]

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

Section 2.0 of the report provides a description of the MSP. This includes their location, layout, relation to other PBRF buildings and facilities, design and materials of construction, use, modifications and final configuration for the FSS.

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

Section 4.0 presents the FSS design for the MSP. This section includes applicable FSS Plan requirements, breakdown into survey units and assignment of MARSSIM classifications. The survey design approach, instrumentation and measurement sensitivities are described.

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

[2] The DCGLs listed in this paragraph are the gross activity DCGLs for the radionuclide mixtures assigned to the specified areas with adjustments to account for the dose contribution from deselected radionuclides. Also it is noted that the values listed above are modified from the values originally used, to correct a calculation error in the Technical Basis Document TBD-07-001 [PBRF 2007].

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

Supporting information is contained in Appendices. Appendix A contains photos to supplement the text. Survey design maps, tables of coordinates and FSS measurement results for each survey unit are provided in Appendix B. Appendix C presents an evaluation of the impacts of DCGLs that were revised to correct errors noted in the original Technical Basis Document, PBRF-TBD-07-001 [PBRF 2007].

2.0 PBRF Site Description and History

A description of the PBRF site is provided and the history of facility operations summarized to provide background for identification and descriptions of the individual structures which comprise the scope of this FSS report. This is followed by descriptions of the individual structures. This FSS Report covers the following structures and areas:

- Assembly Test Storage Building Tunnel (ATS, Building 1121),
- Cooling Tower Basin (CTB, Building 1152),
- Water Effluent Monitoring System (WEMS, Building 1192),
- Precipitator Sludge-Settling Basins (PSB, Building 1153),
- Miscellaneous pads, foundations and sidewalks, including transformer substation pads and
- Reactor Security and Control Building (Building 1191).

2.1 PBRF Site Description

The PBRF site is located near the northern edge of the 6400 acre Plum Brook Station (PBS). The site, as described in the NRC license that controls decommissioning activities, comprises 27 acres which contain the Reactor Building and support buildings and facilities.[3] 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 a boundary fence. The southwest corner of the site, the intersection of Line 2 and Pentolite Roads is used as a reference location.[4] The coordinates are 41° 23' 03.73" North Latitude and 82° 41' 05.80" West Longitude.[5] Figure 1, a map of the PBRF site

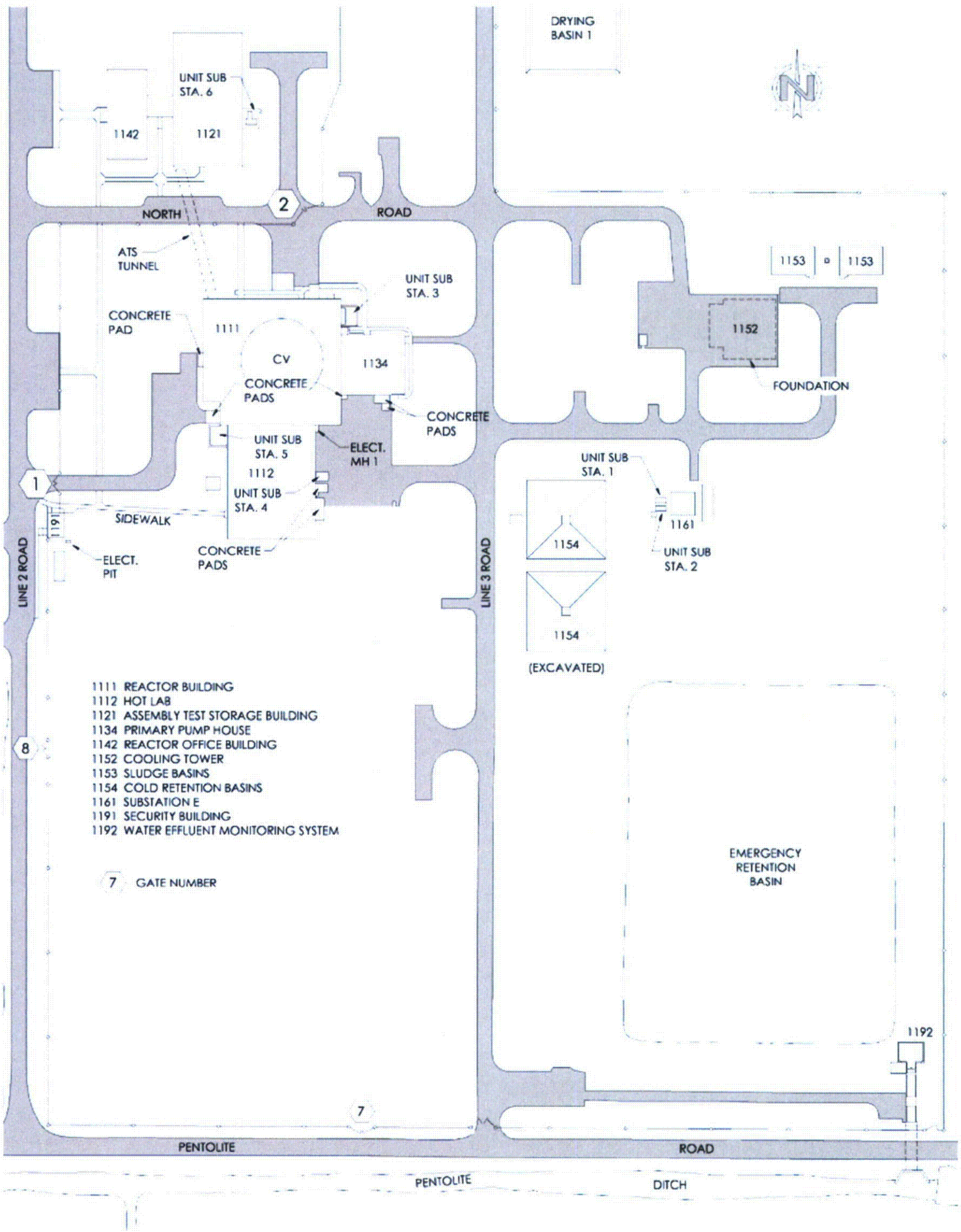
[3] See Technical Specifications for the License No. TR-3 (Amendment 13) and License No. R-93 (Amendment 9) [NASA 2007].

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

[5] 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].

layout, shows the principal PBRF buildings and many of the miscellaneous structures and pads.

Figure 1, PBRF Site Map Showing Miscellaneous Structures and Pads



The site is generally level and graded to promote surface water drainage to the WEMS, located at the south east corner of the site [USACE 2004]. The site reference grade level at the Reactor Building is 631 ft. above mean sea level [NACA 1956].[6]

The PBRF 27 acre site contained several multi-story buildings and multiple support structures. Below-grade structures and utilities extended throughout the site. These include 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 site was occupied by buildings, water processing structures (Cooling Tower Basin, WEMS, Sludge Basins, Cold Retention Basins, etc) paved roadways, parking areas, sidewalks and equipment pads. The remainder of the site surface was open land soil areas.

Areas adjacent to the PBRF on the north (north of North Rd.) contained utilities and support facilities for PBRF operations. These included the ATS Building, the former Reactor Office Building (ROB), an electric substation and a deionized water storage tank. These facilities and the surrounding land area were cleared of licensed radioactive materials and released from the NRC licenses prior to decommissioning of the PBRF.[7]

The present attachment to the PBRF Final Status Survey Report covers those items listed at the beginning of this section. These represent only a portion of the various structures, foundations and pads not included in the main PBRF building reports. Many of the other miscellaneous pads, foundations and small structures were removed during decommissioning and the materials disposed of in accordance with PBRF work control and radiological control procedures.[8]

The FSS of areas where major outdoor commodities, systems and structures were removed are covered in other FSS Report attachments, specifically:

- Attachment 7 includes FSS results of excavated areas where many outdoor systems and structures were removed. These include storm drains, storm drain catch basins, the Cold Retention Basins, Fan House Evaporator Pit, PPH resin pits, the Emergency Retention Basin (ERB) sump, drain and fill lines and sanitary sewer lines.
- Attachment 10 reports the FSS of the excavated ERB footprint.

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[6] 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.

[7] License Number TR-3, Amendment No. 6, approved by NRC letter dated Dec. 17, 1976.

[8] Removal of approximately 40 miscellaneous structures, foundations and pads was performed under the PBRF Work Execution Package, PBRF-WEP-09-015, *Miscellaneous Foundation Removal*, Approved, 10/13/09 and closed 12/8/10. The principal procedure for control of materials at the PBRF is RP-008, *Radiological Release of Equipment, Materials and Vehicles*.

2.2 History of PBRF Construction and Operation

Plum Brook Station was formerly a World War II era explosives manufacturing facility and prior to that was occupied by family farms and orchards [Bowles 2006]. Construction of the Plum Brook Ordinance Works (PBOW) in 1941-42, involved razing of existing farms, residences and small commercial buildings and construction of explosives manufacturing facilities. After World War II, the PBOW lay dormant for 10 years. In 1955 the Department of the Army transferred 500 acres in the northern portion of the former Ordinance Works to the National Advisory Committee on Aeronautics (NACA), the NASA predecessor, for construction of the Plum Brook test reactor facility.

Planning and design for the PBRF construction was initiated in 1955. Principal milestones are listed below: [9]

1956 – September, groundbreaking for PBRF.

1956 – Reactor Building construction initiated.

1959 – 1960 Major building construction completed.

1961 – June, 60 MW Test Reactor critical.

1961 – 1962 - Preoperational Testing

1963 – Full power 60 MW Test Reactor operations begin.

1973 - January 5th, Reactor shutdown (after 152 operating cycles). [10]

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

1985 – Initial radiological characterization, Teledyne Isotopes Inc.

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

2002 – Decommissioning Plan approved.

2003 – 2004 – Equipment removal and initial building decontamination.

2006 - 2011 – Remediation of contaminated areas and preparation for FSS.

2011 – FSS measurements completed.

It is noted that the Reactor Building and principal supporting facilities were completed during 1956 - 1960, but modifications to the PBRF occurred throughout the operations period. Major modifications included installation of cathodic protection wells (1961-62), construction of the Waste Handling Building (1962-64), construction of the ATS Building and utility and

[9] Information sources for the site history include construction drawings and photos, PBRF operating cycle reports, PBRF annual reports, memoranda and other historical files maintained by PBRF Document Control.

[10] 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.

personnel passage tunnel to the Reactor Building (1964-65), WEMS modifications (several times during 1961 – 1973) and modification of storm drains (1968).

2.3 ATS Tunnel Description

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 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. These facilities improved the 60 MW Test Reactor on-line performance as non-critical work could be conducted in an environment where radiological controls were not required. 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. 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 [PBRF 2010].

The ATS Tunnel is constructed of reinforced poured concrete, with 12 in. floor and 10 in. wall and ceiling thickness. The tunnel is 152 ft. long with an interior cross section 10 ft. wide and 8 ft. in height. To construct the tunnel, the area between the NW corner of the Reactor Building and the SW corner of the ATS Building at the -15 ft. elevation was excavated. The floor of the tunnel is at elevation -14.5 ft. and the top of the tunnel is at the -5.5 ft. elevation. The finish grade above the tunnel is at 632.5 ft. above sea level. A 6 in. perforated drain was installed along both sides of the tunnel footer; these drains tie into RB and ATS Building cold sumps. Floor drain trenches covered with grating were constructed across the floor at each end of the tunnel. These were 10 ft. long and 1 x 1 ft. in cross section. These trenches also drained to cold sumps in the respective buildings [PBRF 2010].

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 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. The entire length of the tunnel, from the RB to the block wall at the ATS Building is accessible from the RB. The Tunnel is included in the PBRF Decommissioning Plan [NASA 2007a] and is included in the FSS plan [NASA 2007].

2.4 Cooling Tower Basin Description

The Cooling Tower was located east of the Service Equipment Bldg (SEB) and the N/S section of the Cold Pipe Tunnel. The tower, a wooden (cedar) structure was mounted on a reinforced concrete pad at the 0 ft. elevation with a large reinforced concrete water basin and sump below. The basin floor was below grade and the walls on the north, east and south sides extended 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. The Cooling Tower basin was of dimensions approximately 62 x71 ft. The north-south dimension was the larger dimension.

Nine secondary cooling water pumps, three large main cooling water pumps, two auxiliary cooling water pumps, two shutdown cooling water pumps and two test loop cooling water pumps were mounted on the sump roof. The 200 HP main cooling water pumps could supply 10,800 gpm of secondary cooling water, through a 16 in. discharge pipe to the primary heat exchanger located in Primary Pump House (PPH) Room 4. The 125 HP auxiliary pumps could supply 2700 gpm of secondary cooling water, through a 14 in. supply header, to the Reactor Building and subsequently to all other buildings on site. This water cooled various equipment throughout the facility such as air compressors, diesel generators, air conditioning systems, chillers and test rigs. The 30 HP test loop pumps could supply 400 gpm of secondary cooling water, through a 6 in. supply line, to the Reactor Bldg. for cooling experiment equipment. The 40 HP shutdown pumps could supply 1000 gpm of secondary cooling water, through an 8 in. pipe, to the reactor core shutdown heat exchangers [PBRF 2010a].

2.5 WEMS Description

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 trench containing metal gates and a series of three Parshall flumes. It also contained measurement and sampling systems for monitoring water radioactivity levels. All PBRF liquid effluent flowed through the flumes where the flow rate was recorded, radioactivity levels monitored and then discharged to Pentolite Ditch outside the fenced area. The WEMS was designed to automatically close the gates when radioactivity levels exceeded pre-set limits. These limits were set to prevent radioactivity level releases that would exceed the Federal licensing limits [PBRF 2009].

The reinforced concrete WEMS structure consisted of 1 ft. thick floors, walls and roof slabs covering parts of the trench to protect the flume monitoring equipment from the weather elements (ice). The canal way/trench was 10 ft. wide by 70 ft. long. Five motor driven gates; three gates downstream (south end) and two upstream (north end) isolated the effluent flow if radioactivity levels exceeded preset limits. The gates also could be hand-operated from above. A metal grating covered an area south of the trash screens to protect the flow metering area from damage by debris; the screens were north of the two gates.

The electrical and electronic components of the radioactivity monitoring and flow measuring equipment were housed in a Butler type building located over the trench. The three Parshall flumes (3, 12 and 24 in.) were capable of measuring flows in the range of 0 to 200, 0 to 1200 and 0 to 10,000 gpm. These were connected to twenty-four hour chart recorders to provide a permanent record of effluent flow rates [PBRF 2009].

The radioactivity level of the effluent water was monitored originally by:

- Continuous measurements by a cluster of five GM tubes, located in a shielded "pot" coupled to a count rate meter and 24 hour chart recorder. This monitoring system initiated automatic gate closures at water gross beta-gamma activity of $1x10^{-5}$ µCi/ml.
- Sampling of effluent water by accumulation of effluent water in a storage-catch tank during a 24-hour period using proportional pumps. A 2-liter sample was taken from the catch tank each 24 hours for radiometric analysis. The data obtained in terms of µCi/ml was applied to the total volume of liquid discharged during the collection period and the total amount of activity discharged was calculated [PBRF 2009].

Because of a large number of unnecessary gate closures due to defective GM tubes, contamination of detectors, and electronics failures, the WEMS system was upgraded in 1967 (See Facility Change no. 67-027). A more reliable system, a beta-gamma scintillation detector with three independent photo-multipliers, was installed to replace the original equipment. The sample vessel was a 30-inch diameter hemisphere which incorporated shielding to reduce detector background. The count rate from each channel was displayed at the WEMS station and in the Health Safety Operations Office in the Reactor Building. A diode circuit selected the highest count rate from the three channels and feed the information to a recorder as a permanent record. The count rate and flow rate information were also used to initiate automatic closure of the WEMS gates.

2.6 Precipitator Sludge-Settling Basins Description

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 drainage main lateral where it could impact WEMS operations, the sludge was sent directly 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. Once cleared for release, it was pumped to sludge drying basins just north of the PBRF site. When the drying basins were full, the resultant dried lime-alum mixture was removed and trucked to a PBS dumpsite [PBRF 2010a].

The two concrete sludge-settling basins were constructed prior to reactor startup in the 1961-1963 time frame. Each 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.[11]

Associated with the settling basins were Distribution Pits numbers 1, 2, and 3 and a drain sump and check valve pit. Distribution Pits 1 and 2 are concrete sump pits (an integral part of each settling basin). Distribution Pit 3 was a steel grating covered separate concrete pit located west of the settling basins. It was used to direct sludge flow to either one or both settling basins. Pits 1 and 2 were 6 x 6 x 8 ft. deep and Pit 3 was 4 x 5 ½ x 4 ½ ft. deep. A drain sump was located between the two settling basins for pumping out ground water collected by drain tile under and around the settling basins. The drain sump was 5 ft. square x 15 ft. deep [PBRF 2010a].

2.7 Miscellaneous Structures Description

This group of survey units for FSS includes the following miscellaneous concrete structures:

- 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 the 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.

Most of these miscellaneous structures did not house active systems; the main exceptions are the electrical substation and transformer pads. The electrical distribution system is described below.

Commercial power was supplied to PBRF from two incoming 138 KV, 3 phase - 60 cycle transmission lines energized from separate sources. One from the Greenfield Substation in Southwest Sandusky (North line) and one from Brownhelm Junction (South line). At PBS Substation A, the power is reduced to 34.5 KV and sent to PBRF over two lines. At PBRF, the power is stepped down to 4160 volts through two 5000/6250 KVA, 34,500/4160 volt, three phase, 60 cycle, Delta-Wye (Grounded neutral) step down transformers and distributed to 6 unit substations [PBRF 2010a].

Two of the substations (Main and Substation 4) have concrete vaults under the transformer for power line distribution; the remaining four have concrete slabs with underground conduit for distribution lines. There are also three electrical manholes that were used to distribute power lines underground and several areas where buried concrete electrical ductwork was used.

[11] See PBRF drawings PF-06135 thru 06138 for construction details of the sludge settling basins, drying basins and associated piping.

The Main Substation transformers and associated switchgear were located on a 1 ft. thick, concrete pad of about 26 x 28 ft. The concrete vault, beneath the pad, had outside dimensions of roughly 8 ft. deep x 11 ft. long (east to west) x 28 ft. wide (north to south). The unit one and unit two 750 KVA, 4160/480 volt transformers and associated switchgear were located on separate 1 ½ ft. thick x 6 x 11 ft. concrete pads west of the main slab. Two storage buildings were also located southwest of main substation on separate pads 11 x 12 ft. x 1 ft. thick. Also, there were five smaller pads for power line support structures and fuses east of the main substation.

During 1999, another transformer, called T6 (4160/480 volt, 225 KVA), was added to provide standby power. A pad 6 x 5 ft. by roughly 1 ft. thick was used. Both main transformers, T1 and T2, were permanently removed from service.

Electrical manhole #1 was an electrical pit 6 x 4 ft. x 3 ½ft. deep and located outside the northeast corner of the Hot Laboratory adjacent to the Reactor Building. Electrical manhole #2 was an 8 x10 ft. x 7 ft. deep vault under substation #4 outside the east side of the Hot Lab. Electrical manhole #3 was an underground electrical pit located northwest of the main substation (30 ft. north of Cold Retention Basin #1, south of the SEB); the pit was roughly 8 ft. deep x 9 ½ ft. x 11 ½ ft. The pit is accessible by round metal cover in the yard.

Dimensions for the remaining transformer pads are:

- Unit substation # 4 – 10 x 13 ft. x 1 ft. thick (north of hot laboratory east truck door)
- Unit substation # 5 – 16 x 18 ft. x 1 ft. thick (northwest corner of hot laboratory, south of west reactor building truck door)
- Unit substation # 6 – outside PBRF site fence on east side of the ATS Building [PBRF 2010a].

The concrete pads and structures in the group are located within the 27 acre controlled access area of the PBRF with some exceptions. The sidewalk and curb west of the Reactor Security Building on the east side of Line 2 Road are located outside the controlled area. Also, the sluice gate structures associated with the former sludge drying basins are located north of North Road and the WEMS outfall wing-wall is located just south of Pentolite Road below the location of the former WEMS.

2.8 Reactor Security Building Description

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

2.9 Final Configuration and Scope of FSS

The final condition of the ATS Tunnel for FSS is essentially bare concrete floor, walls and ceiling [PBRF 2010]. The tunnel interior surfaces were divided into six Class 1 survey units for the FSS. See Exhibit 1 in Appendix A for photos which show the condition of the tunnel at the time of the FSS.

The Cooling Tower basin, sump and pad were prepared for the FSS by removal of any remaining soil, sludge and debris to expose the concrete floor and wall surfaces. The Cooling Tower structures were divided into 15 Class 1 survey units for the FSS. See Exhibits 2 and 3 of Appendix A for photos showing conditions at the time of the FSS.

To prepare the WEMS for FSS, the Butler building and all equipment were removed. Accumulated soil, sediment and standing water were also removed. The surfaces of the remaining WEMS concrete structure were divided into 7 Class1 survey units for the FSS. See Exhibits 4 through 6 for photos showing the condition of the WEMS at the time of the FSS.

The precipitator sludge settling basins were prepared for the FSS by removal of pumps, piping, other equipment and any remaining sludge and debris to expose the concrete floor and wall surfaces. The structures were divided into 9 Class 1 survey units for the FSS. See Exhibits 7 through 9 of Appendix A for photos showing conditions at the time of the FSS.

Most of the miscellaneous pads, foundations and walkways are bare concrete. They have been cleared of equipment, soil, surface dust, mud and debris as necessary for FSS measurements. An exception is Unit Substation 5, which remained active to supply power to a sump pump in the Reactor Building at the time of the FSS. The miscellaneous pads, foundations and walkways were divided into six survey units (one Class 1 and five Class 2) for the FSS. See Exhibits 10 through 20 of Appendix A for photos illustrating the condition of the miscellaneous foundations, pads and walkways for the FSS.

For the FSS, the security building was covered by a single Class 2 survey unit. It continued to serve as the main PBRF access control point with all personnel-portal monitors operating. See Exhibits 21 and 22 of Appendix A for views of the Reactor Security Building at the time of the FSS.

3.0 Operations with Radioactive Materials

Operations with radioactive materials at the PBRF were controlled by procedures established to comply with requirements of US Atomic Energy Commission (AEC) licenses.[12] 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

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

and use of radioactive materials (byproduct material) produced by the Plum Brook 60 MW and Mockup reactors and other radioactive materials. Radioactive materials of PBRF origin that could have contaminated MSP structures originated from PBRF tests and experiments and process system wastes. This section addresses handling and disposition of radioactive materials during startup and facility operations, after facility shutdown in 1973, site characterization and decommissioning.

3.1 Startup and Operations

The ATS Tunnel was a passive structure without any active or radioactive systems. Thus it had no active role in operations with radioactive materials. However, contaminated materials were occasionally transported through the tunnel.

The Cooling Tower was an integral part of PBRF operations because it was the principal method of dissipating the 60 MW of heat produced by the reactor. It operated continuously, except for periods of maintenance. Due to the need for cooling of the Reactor and auxiliary equipment, it was required to be operating by license whenever the 60 MW test reactor was operating at power. Cooling tower water was chemically treated with corrosion inhibitors and a blow-down system (a controlled drain on the east end of the basin) was used to prevent an accumulation of solids in the cooling water. The fans used during reactor power operations resulted in significant water evaporation to the environment. Because of the high volume of air passing through the tower, the basin and sump water was contaminated with fallout radionuclides during atmospheric nuclear weapons testing in the 1960's (see Table 1, Activities Covered in Unusual Incident Reports).

Following completion of the WEMS construction in or about 1961, the system was tested for conformance to the original design and operating specifications. During the PB reactor operations period of 1961 through early 1973, the WEMS system was operated continuously. The WEMS was not staffed continuously, but was monitored by the Health Safety staff daily, usually once per shift. It also received periodic and special maintenance necessary to keep it operational per license technical specifications. If the WEMS was not operating properly, the WEMS gates were closed until the system was restored to operational status. All WEMS operations were controlled by PBRF procedures.

The WEMS collected effluent water from PBRF facilities including Cooling Tower blowdown, ground water collected in building sumps, building clean sump outputs and HRA, CRB and ERB discharges. It also received excess lake water softened by the precipitator and surface water runoff collected by the storm drain system. One exception was the sanitary sewer system which discharged separately to the PBS sanitary waste treatment plant. Inputs to the WEMS included both clean and radioactively contaminated waste water. Sources of contaminated water were primarily HRA, CRB and ERB discharges and accidental spills. Occasionally, cross contamination of normally clean system discharges occurred, for example, primary water leakage into the deionized water system that ended up in clean sumps. Gross beta-gamma water activity levels measured in the various systems ranged from about $1x10^{-6}$ μCi/ml to $1x10^{-2}$ μCi/ml. The highest-level contaminated waters occurred during periods of reactor operations with leaking reactor fuel elements.

Generally, controlled releases were made from the areas where radioactively contaminated waters were retained, such as the HRA, CRB and ERB. During controlled releases, dilution waters were directed to the WEMS inlet ditch to allow mixing prior to release off-site through the WEMS (after monitoring to ensure that release limits were met). There were two heavy rain falls (in 1966 and in 1969) that exceeded 9 inches per day. These caused a major buildup of sludge (sand, mud and silt) in the HRA tanks from flood waters pumped from building basements and sumps including the hot waste sumps. Pump out of the HRA, including tank bottoms from periodic clean-outs, often led to discharges of silt and sludge which impacted the WEMS. Reactor operating cycle reports of unusual conditions involving radioactivity in the WEMS are summarized in Table 1.

The sludge settling basins were operable during the startup phase of 60 MW reactor operations. Plum Brook Reactor Facility operating procedures required that the sludge be pumped from the settling basins when the prescribed "full level" was reached. The sludge was required to be sampled (OSY-2802-R1, Sludge Settling Basins) and analyzed to ensure that it was within regulatory chemical and radioactivity limits (RDS-0-004-R5, Water Quality Requirements for Process Systems) prior to pumping to the drying basins. After drying, the sludge was trucked to a PBS dump site. The potential for radioactive contamination of the precipitator sludge and settling basins was very low because of their location and lack of direct connection to radioactive materials of PBRF origin. No reported incidents of contamination of the sludge settling basins were found in the Health Safety Operations Office reports of unplanned incidents in the PBRF Operations Cycle Reports.

As with the sludge settling basins, the remaining structures, walkways and pads in the MSP were not routinely in direct contact with radioactive materials, so their contamination potential was generally quite low. However, many of these surfaces were potentially in contact with radioactive material from spills and from removal and transport of excavated soil and demolition debris across most portions of the site during decommissioning. None of these areas was involved in recorded Unusual Incident Reports summarized in Table 1. The Table identifies only the Cooling Tower (one incident) and the WEMS as the subject of reportable incidents involving radioactive materials. As the WEMS was involved in many incidents, only a representative number are summarized in the table to illustrate typical incidents.

Table 1, Activities Covered in Unusual Incident Reports (1960-1973)

Report Cycle No.	Date	Description
3	8/21/63	During Cycle 3, the Cooling Tower water reached a level of $2x10^{-6}$ μCi/ml due to scrubbing of radioactive fallout from weapons testing.
4	9/25/63	The WEMS gates closed as a result of a slug of silt being released from HRA #2 during a controlled release. Grab samples between the gates and upstream of the gates indicated gross beta-gamma levels of $2x10^{-4}$ and $5x10^{-6}$ μCi/ml respectively that supported the slug versus continuous discharge supposition. Results of further sampling downstream indicated low levels; isotopic analysis indicated Silver-110 and Tungsten-187 were the major isotopes. On September 6^{th}, another slug of silt during a planned controlled release caused automatic WEMS gate closure. These incidents indicated a need for a better method of HRA tank discharge, cleanout of the tank bottoms and better dilution or mixing prior to passing through the WEMS. When averaged over several days as permitted by regulations, no release limits were exceeded.
7	10/20/63	Health-Safety personnel noted a count rate increase on the WEMS recorder. During the investigation that found a valve in the waste cleanup discharge was open with a flow of 5 gpm of contaminated water to the effluent ditch, a WEMS gate closure occurred. Dilution water was added and the water pumped into the Emergency Retention Basin. Later, it was released under a controlled release.
14	3/11/64	The WEMS gates closed near the end of the pump out of an HRA tank (4% tank level). Investigation showed that radioactive solids at the bottom of the tank were pumped out as a slug. This has occurred several times in the past for similar reasons.
32	4/7/65	A routine check of the WEMS revealed that the count-rate system was not responding properly and the count rate was zero counts per minute. The gates were manually closed, a faulty detector cable was replaced and the system placed back in service after testing.
48	7/4/66	A 3.5 inch rainfall occurred in a 4 hour period causing WEMS gate closure and flooding in the RB, FH and SEB basements. Radiological contamination was cleaned up and normal operations resumed on July 6^{th}. Subsequently on July 12^{th} a total of 11.5 inches of rain fell within a 14-hour period and the WEMS gates closed. Extensive flooding occurred in basement areas and the effluent ditches overflowed. The WEMS gates were reopened and cleanup was initiated. The maximum contamination level was $1x10^{-6}$ μCi/ml gross beta-gamma at the minus 15 foot level in the Reactor Building. The areas were returned to normal on July 13^{th}. Floodwater from the hot sumps was pumped to the HRA.

Table 1, Activities Covered in Unusual Incident Reports (1960-1973)

Report Cycle No.	Date	Description
multiple	6 – 9/66	False WEMS gate closures were occurring almost every other day. A study revealed seventy-seven per cent were due to defective G.M. tubes, contamination of the detector assembly or electronics failures. Based on this data the WEMS monitoring system was upgraded as described in Facility Change 67-027.
107	4/10/70	During a controlled release from an HRA tank the WEMS gates closed on high radiation level (one sample indicated 7.54×10^{-6} μCi/ml gross beta-gamma). Sludge from the bottom of the HRA tank was apparently pumped out to the ditch. The release was terminated and additional dilution water was added to flush the ditch. The daily regulatory limit average concentration was not exceeded.
151	12/1/72	The WEMS gates closed on high activity during a controlled release of HRA tank 3. The occurrence was caused by residual high activity sludge in the disposal lines from the previous pump out of the high solids HRA tank 7. On 12/14, another WEMS gate closure occurred due to a ruptured filter in the Waste Cleanup System which permitted high activity sludge to enter the plant effluent. Water in HRA tank 1 was being disposed under controlled conditions at the time.

3.2 Disposition of Materials in the Post-Shutdown Period

In the period between termination of reactor operations in January 1973 and June 30th of 1973, equipment on the MSP was placed in standby status as was the entire PBRF. End condition statements were prepared which governed the status of each system and structure for the protected safe shutdown mode.

Notification was received on January 5, 1973 that due to budget constraints, NASA was terminating all nuclear related research operations at PBRF. The Test Reactor, Mock-up Reactor, Hot Laboratory and all associated operations were shutdown and placed in a standby condition and the reactor staff terminated by June 30, 1973. Following notification, the 60MW test reactor was immediately shutdown. A Master Plan was developed to address activities associated with terminating the operating licenses for PBRF and placing the facility in a standby status. Plum Brook Reactor Facility End Condition Statements for Protected Safe Storage Mode detailed the facility final condition status goals for mid-1973; including the systems reported under Miscellaneous Structures and Pads: the Cooling Tower, Precipitator Sludge Basins, the WEMS, the electric power distribution system, etc. The Cooling Tower and Sludge Basins were initially placed on standby and subsequently deactivated when it was determined that the PBRF would not be reactivated. Only the WEMS and portions of the electrical distribution system remained active after June 1973.

During the period between 1973 and the start of decommissioning, activities at PBRF were controlled in accordance with the modified AEC and NRC licenses: TR-3, R-93 and BPL No. 34-06706-03. These licenses authorized possession only of the remaining radioactive materials on site, i.e., no facility operations were permitted. During this period, selected equipment, materials, and waste (both low-level radioactive and non-radioactive) were removed to other locations or disposed of as the projected long-term considerations for the facility changed from possible restart to standby to decommissioning. In 1982, the NRC terminated BPL 34-06706-03 based on NASA's request. A Decommissioning and Dismantling amendment to Licenses TR-3 and R-93 transferred any existing licensed radioactive materials to those licenses. 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 termination of PBRF operations on January 5, 1973 and until June 30th of 1973, the WEMS remained active and was to be maintained in that condition until there was no radiological release hazard. The final end condition was that the WEMS was deactivated and the gates left open to the Pentolite ditch. Prior to deactivation, however, the following conditions were met:

- No liquid radioactive waste discharges had occurred for two months
- A rainfall of 1 inch in 24 hours and an accumulated rainfall of 2 inches had occurred and
- The liquid effluent radioactively level had not exceeded $1x10^{-7}$ µCi/ml beta-gamma and $3x10^{-8}$ µCi/ml alpha since the beginning of the two month period.

Subsequent to July 1st 1973, the WEMS was controlled according to Nuclear Regulatory Commission Licenses TR-3, R-93 and Broad By-Product Material License BPL No. 34-06706-03. Periodic effluent sampling for radioactivity was conducted as part of the PBRF facility and environmental program to demonstrate compliance with the federal regulations. The annual reports to the NRC provide the details of significant events or changes in status during the period between 1973 and the approval of the PBRF Decommissioning Plan in 2001.

Prior to permanent deactivation of the WEMS in the fall of 1973, the PBRF trenches, catch basins, settling basins and the WEMS inlet basin were flushed to remove silt and sand. Unnecessary loose equipment was removed from the WEMS Butler Building, as were scrap materials inside and outside. Electrical heaters and other equipment were shutdown after a WEMS functional test and the building closed and locked.

3.3 Site Characterization

The ATS Tunnel was not covered in the 1985 Teledyne Isotopes characterization survey [Tele 1987] or the 1998 GTS Duratek confirmatory survey [GTS 1998]. However, it was surveyed several times in the 2003 – 2005 period by the decommissioning contractor. These surveys included a 100 % beta scan survey and 112 total surface beta and removable surface beta and alpha activity measurements (selected on a systematic grid with random starting location). The scan survey showed no measurements above an action level equivalent to 90% of a proposed gross activity DCGL of 29,329 dpm/100-cm^2. The total surface beta measurement results ranged from 167 to 1035 dpm/100-cm^2. All removable surface beta and alpha activity measurements were less than the counting instrument MDA, 16.93 and 12.94 dpm/100-cm^2, for beta and alpha activity, respectively.[13]

The Cooling Tower basin and the sludge settling basins were also not covered in the 1985 Teledyne Isotopes characterization survey or the 1998 GTS Duratek confirmatory survey. The Teledyne Isotopes characterization survey included measurements obtained in the WEMS (direct radiation and removable surface contamination measurements in the WEMS canal). The maximum direct reading was 40 µR/hr (in the WEMS canal directly beneath the Butler Building) and maximum smear reading was 48 dpm/100-cm^2 beta-gamma in the trench below the control building [Tele 1987].

The 1998 Duratek conformation survey also reported measurements in the WEMS. Direct surface beta measurements were taken at 13 locations on the WEMS walls and floor. The measured activities ranged from non-detectable to a maximum of 19,000 dpm/100-cm^2. Three sludge/soil samples taken from the WEMS showed Co-60 and Cs-137 as the major contaminants. Maximum concentrations measured in the samples were 3.75 and 11.2 pCi/gm respectively [GTS 1998].

In 2003 the decommissioning contractor collected samples of sludge as part of a characterization survey of the settling basins. The samples were analyzed by gamma spectroscopy and results of the sample analysis were < MDA for Co-60 (2.47E-02 pCi/g) and Cs-137 (1.65E-02 pCi/g), principal gamma-emitting PBRF contaminants in soil.[14]

The 1998 Duratek survey also covered pads and paved areas on the PBRF site. Results from five areas which are on or in close proximity to survey units established for the MSP are summarized in Table 2.

[13] The 2005 ATS Tunnel survey results reported here are from three survey packages: C2111 101C1 (March 2005), C2111 101F1 (April 2005) and C2111 102F1 (April 2005). The latter two packages were developed and implemented as FSS packages, but the contract of the then-decommissioning contractor was terminated in September of 2005 and NASA decided not to report these results as FSS results, pending selection of a new contractor and revising the FSS Plan.

[14] Characterization Package C1153 301 C1, October 2003.

Table 2, Summary of GTS-Duratek Survey Results in or near MSP Areas

Survey ID Code	Area Description	No. of Measurements	Total Surface Beta (net dpm/100-cm^2)	
			Minimum	Maximum
01F01	Pads and Pavement Adjacent to RB North Side	5	476	1020
07F01	Pads and Pavement Adjacent to Precipitator North of SEB	5	181	4649
08F01	Roadway Immediately North of Main Substation (Bldg 1161)	6	215	748
09F01	Pads and Pavement West of RB	5	ND (1)	41,570 (2)
10F01	Pads and Pavement East of RB and HL	5	2256	965,200 (3)

Table 2 Notes:
1. ND means non-detect (0 net counts).
2. Maximum measured value on RB West Rollup Door Entrance Pad).
3. Maximum measured value from Equipment Pad-Hot Pipe Tunnel Access Cover area.

3.4 Decommissioning

The ATS Tunnel was isolated in 1981 by construction of a concrete block wall at the north end and from that time forward was only accessible from the Reactor Building -15 ft. elevation. During decommissioning, it was stripped of all piping, cable trays, conduit and hangars in the 2003 – 2004 time frame. Since there was minimal contamination present, no remediation of the concrete surface was required. Preparation for FSS constituted housekeeping-cleaning to remove dust, paint shards and surface debris to enable surface activity measurements. Water accumulation in the floor trenches required pumping and drying. Final Status Survey Measurements were completed in March 2008.

The Cooling Tower wooden structure was demolished in 1983 and the sidewalls of the basin were also partially removed. During decommissioning, the basin floor was uncovered again. A characterization survey was performed in 2008 which revealed surface contamination levels of up to 103,000 dpm/100-cm^2. The concrete surfaces were cleaned, decontaminated and resurveyed to prepare for FSS [PBRF 2010a]. The FSS was completed in September 2010.

The WEMS remained essentially intact from deactivation in 1973 until 2006 when work was initiated to prepare for FSS. The WEMS was dewatered and a temporary system installed to divert incoming water to the Pentolite Ditch well downstream of the WEMS. The accumulated sludge and debris was removed and transported to a lay down area for FSS.[15] The WEMS concrete surfaces were then power-washed. The Butler Building, fixed mechanical equipment, pumps and exposed piping were removed in the summer of 2010. The FSS was completed in September 2010. The WEMS concrete structure was demolished to three feet below grade and backfilled to grade level in November 2010.

[15] The FSS of excavated soil, sludge and temporary fill material is reported in Attachment 18 of the PBRF FSS Report.

In the fall of 2010, the decommissioning contractor prepared the sludge settling basins for the FSS. The basins were de-watered and sludge removed. The remaining piping and gratings were removed, the remaining concrete was cleaned and post-remediation surveys were performed. The FSS was completed in October 2010.

Misc pads, foundations required little preparation for FSS, other than removal of surface debris and soil as necessary to perform measurements. The FSS measurements were completed in October 2011. Similarly, the Reactor Security Building required little preparation. The FSS of the Reactor Security Building was completed in November 2011.

4.0 Survey Design and Implementation

This section describes the method for determination of the number of fixed measurements and samples for the FSS of the Miscellaneous Structures and Pads. Applicable requirements of the FSS Plan are summarized. These include the $DCGL_W$[16], the gross activity DCGL, scan survey coverage and action-investigation levels, classification of areas and breakdown of the survey units. The radiological instrumentation and their detection sensitivities are discussed.

4.1 FSS Plan Requirements

The DCGLs for individual radionuclides were obtained for PBRF structures considering exposure to future site occupants from two potential pathways. Single radionuclide DCGLs were calculated using RESRAD-BUILD Version 3.22 for a building reuse scenario. Single radionuclide volumetric DCGLs were calculated for subsurface structures using RESRAD Version 6.21 for a resident farmer scenario.[17] The volumetric DCGLs (in pCi/g) were converted to "effective surface" DCGLs (in dpm/100-cm^2) using surface-to-volume ratios for the assumed volume of contaminated subsurface concrete. The DCGL calculations are described in the FSSP, Attachment B. To obtain the DCGLs for PBRF structures, the smaller of the two DCGLs calculated for each of the radionuclides of concern were selected.

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

The gross activity DCGL for the MSP is calculated using equations in the FSSP for gross beta, gross alpha and surrogate DCGLs, based on the radionuclide mixture in residual

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

[17] 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.

contamination. Activity fractions and the gross activity DCGLs for the MSP are shown in Table 3.

Table 3, Radionuclide Activity Fractions and Gross Activity DCGLs

Location	Radionuclides								$DCGL_W$ (dpm/100-cm²) (2) (3)
	H-3	Co-60	Sr-90	I-129	Cs-137	Eu-154	U-234	U-235	
	Activity Fractions Assigned to MSP (%) (1)								
ATS Tunnel	0.0	0.0	0.0	0.0	48.4	0.0	51.6	0.0	35,296
WEMS	0.0	7.56	0.0	0.0	92.44	0.0	0.0	0.0	33,834
All other MSP areas (4)	27.07	9.65	7.88	1.42	46.71	0.12	6.98	0.17	27,166

Table 3 Notes:

1. Activity profiles assigned to the various PBRF structures are reported in the Technical Basis Document PBRF-TBD-07-001 [PBRF 2007].
2. In MSP Survey Designs, the DCGL values are adjusted to account for dose contributions from "insignificant radionuclides" and embedded piping (see Table 6).
3. The gross activity DCGLs shown in this table are those reported in TBD-07-001. As discussed in Appendix C, the gross activity DCGLs have been revised to correct an error discovered in TBD-07-001.
4. The default radionuclide mixture and the associated DCGL were assigned to the Reactor Cooling Tower Basin, Sludge Basins, other miscellaneous pads and walkways and the Reactor Security building.

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

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

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

4.2 Area Classification and Survey Unit Breakdown

At the time the FSS Plan was prepared, not all the MSP were identified and assigned MARSSIM classifications. Several were included in the environmental areas listed in Table 2-2 of the Plan. For example, the Sludge Basins and the Precipitator were included in two environmental survey areas and listed as Class 1/2/3. The Reactor Security Building was listed in Table 2-1 and classified as a Class 3 area. As part of the FSS implementation process, individual survey units were established and their final MARSSIM classification assigned.

The MSP were divided into 44 survey units for the FSS (38 Class 1 and 6 Class 2). These are identified in Table 5.

Table 5, Miscellaneous Structures and Pads Survey Units for FSS

Survey Unit	Class	Area (m^2)	Survey Design	SR	Description
MA-1-1	1	74.72	22	101	ATS Tunnel –South Floor
MA-1-2	1	73.89	22	101	ATS Tunnel – North Floor
MA-1-3	1	98.40	22	101	ATS Tunnel – East Wall - South End
MA-1-4	1	98.40	22	101	ATS Tunnel – West Wall - South End
MA-1-5	1	99.12	22	101	ATS Tunnel – Ceiling - South End
MA-1-6	1	92.72	22	101	ATS Tunnel – N & S Walls, E & W Walls North End, & Ceiling North End
MA-2-1	1	66.10	50	267	Cooling Tower Basin – Sump Floor
MA-2-2	1	99.21	50	267	Cooling Tower Basin – Sump Ceiling
MA-2-3	1	97.53	50	267	Cooling Tower Basin- Sump Ceiling
MA-2-4	1	88.68	50	267	Cooling Tower Basin – Sump Walls
MA-2-5	1	69.36	50	267	Cooling Tower Basin – Sump Floor and Walls
MA-2-6	1	61.81	50	268	Cooling Tower Basin – Floor, Section # 1
MA-2-7	1	67.89	50	268	Cooling Tower Basin- Floor, Section # 2
MA-2-8	1	68.28	50	268	Cooling Tower Basin- Floor, Section # 3
MA-2-9	1	68.28	50	268	Cooling Tower Basin- Floor, Section # 4
MA-2-10	1	67.62	50	268	Cooling Tower Basin – Floor, Section # 5
MA-2-11	1	55.22	50	268	Cooling Tower Basin- Floor, Section #6
MA-2-12	1	72.15	50	268	Cooling Tower Sump – Exterior Walls
MA-2-13	1	92.13	50	268	Cooling Tower Basin – Exterior Walls and Roof, South End
MA-2-14	1	100	50	268	Cooling Tower Sump - Exterior Walls and Roof, North End
MA-2-15	1	18.85	50	267	Cooling Tower Sump – Steel Pipes
MA-3-1	1	59.0	52	274	Water Effluent Monitoring Station (WEMS) Sump Floor
MA-3-2	1	99.0	52	274	WEMS - Sump Walls and Ledges
MA-3-3	1	92.4	52	274	WEMS - Pump Slab Walls and Miscellaneous Sections
MA-3-4	1	100.0	52	274	WEMS - Walls
MA-3-5	1	45.8	52	274	WEMS - Flumes and Gates
MA-3-6	1	44.6	52	274	WEMS - Trash Screen Walls, Ceiling & Floor
MA-3-7	1	47.2	52	274	WEMS - Floor
MA-4-1	1	69.7	53	275	West Sludge Basin - Floor Section #1
MA-4-2	1	73.4	53	275	West Sludge Basin - Floor Section #2
MA-4-3	1	91.9	53	275	West Sludge Basin - N, W & S Walls
MA-4-4	1	86.4	53	275	West Sludge Basin - E Wall, Short Wall, Valve Pit & West Valve Pit
MA-4-5	1	69.7	53	275	East Sludge Basin - Floor Section #1

Table 5, Miscellaneous Structures and Pads Survey Units for FSS

Survey Unit	Class	Area (m^2)	Survey Design	SR	Description
MA-4-6	1	73.4	53	275	East Sludge Basin - Floor Section #2
MA-4-7	1	91.8	53	275	East Sludge Basin - N, E & S Walls
MA-4-8	1	76.7	53	275	East Sludge Basin - W Wall, Short Wall & Valve Pit
MA-4-9	1	59.6	53	275	East & West Basins top ledge, exterior walls & Sump
MA-5-1	2	191.0	71	353	Reactor Substation (Building 1161)
MA-5-2	2	130.1	71	353	Pads & Foundations west of the Reactor Building.
MA-5-3	2	80.0	71	353	Pads & Foundations east of the Hot Lab & Reactor Building
MA-5-4	1	108	71	353	Substation 4 & Equip. Ramp at east HL Roll-up Door
MA-5-5	2	96.7	71	353	RSCB sidewalks & Misc. Pads
MA-5-6	2	86.8	71	353	WEMS Outfall Wing Wall & Drying Basin Sluice Gates
RS-1-1	2	417	72	364	Reactor Security Building

4.3 Number of Measurements and Samples

The number of measurements and samples for each survey unit was determined using the MARSSIM statistical hypothesis testing framework as outlined in the FSS Plan. The Sign Test is selected because background count rates of instruments to be used are equivalent to a small fraction of the applicable $DCGL_W$.[18] Decision error probabilities for the Sign Test are set at $\alpha = 0.05$ (Type I error) and $\beta = 0.10$ (Type II error) in accordance with the FSSP.

The Visual Sample Plan (VSP) software was used to determine the number of FSS measurements in the MSP.[19] When the Sign Test is selected, the VSP software uses MARSSIM Equation 5-2 to calculate the number of measurements. Equation 5-2 is shown below:

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

(Equation 1)

[18] 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; less than 10% of PBRF structure DCGLs (this assumes a detection efficiency of ~ 12%).

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

where:

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

The MARSSIM module of VSP requires user inputs for the following parameters: α, β, LBGR, the $DCGL_W$ and σ. The numbers of measurements were calculated for the MSP survey units using the parameters established in 6 survey designs. Table 6 summarizes the survey design parameters, including values of key VSP input parameters used to calculate N, the number of measurements.

Table 6, Survey Design Summary

Design No. (1)	Survey Units	Class	DCGL (2)	LBGR (2)	Δ (2)	σ (2)	Δ/σ	N
22	MA-1-1 through 1-6, ATS Tunnel	1	35,296 (3)	34,497	799	266	3.0	11
50	MA-2-1 through 2-15, Cooling Tower Basin	1	26,079 (4)	23,471	2,608	598	4.4	11
52	MA-3-1 through 3-7, WEMS	1	30,451 (5)	15,225	15,226	6090	2.5	11
53	MA-4-1 through 4-9, Sludge Basins	1	24,449 (6)	12,224	12,225	4890	2.5	11
71	MA-5-1 through MA-5-6 Misc Pads	1/2	24,449 (6)	12,224	12,225	4890	2.5	11
72	RS-1-1	2	24,449 (6)	12,224	12,225	4890	2.5	11

Table 6 Notes:

1. The data reported in this table is obtained from the Survey Design reports listed where the DCGLs published in TBD-07-001 were used to calculate the number of measurements. The effect of the revised DCGLs published in TBD-11-002 on the calculated number of measurements is evaluated in Appendix C.
2. Units are dpm/100-cm^2.

3. The DCGL is obtained from PBRF TBD-07-001, Table 5-3 [PBRF 2007]. This DCGL is the same as that of the Reactor Building -15 ft. elevation, which connected to the ATS Tunnel. No adjustment was made in the Design 22 for insignificant radionuclides.
4. The DCGL in Design 50 is obtained from PBRF-TBD-07-001, Table 5-3. It is the default DCGL, with adjustment to account for the potential dose contribution from insignificant radionuclides. Added note: the adjustment to account for insignificant radionuclides was incorrectly calculated in Design 50. It should be 27,166 - 27,166 x 2.5/25, or 24,449 dpm/100-cm^2.
5. The initial DCGL in Design 52, obtained from TBD-07-001, Table 5-3, is 33,834 dpm/100-cm^2. It is adjusted by a factor of 2.5/25 to account for insignificant radionuclides. This yields the value 30,451 dpm/100-cm^2 used in the design to determine the number of measurements.
6. The DCGL in Designs 53, 71 and 72, is obtained from PBRF-TBD-07-001, Table 5-3. It is the default DCGL, 27,166 dpm/100-cm^2, adjusted by a factor of 2.5/25 to account for the potential dose contribution from insignificant radionuclides.

Selection of design input parameters followed guidance in the FSS Plan. The Plan states that "the LBGR is initially set at 0.5 times the $DCGL_W$, but may be adjusted to obtain a value for the relative shift (Δ/σ) between 1 and 3". The VSP software automatically performs an analysis to examine the sensitivity of N, the number of samples, to critical input parameter values. The following is an example obtained from the VSP report for survey unit MA-1-1. The sensitivity of N was explored by varying the following parameters: standard deviation, lower bound of gray region (as % of DCGL), beta, probability of mistakenly concluding that the survey unit mean concentration, μ, is greater than the DCGL and alpha, probability of mistakenly concluding that the survey unit mean concentration, μ, is less than the DCGL. Table 7 summarizes this analysis. The region of interest is for $\alpha = 0.05$ (required to be fixed), $\beta = 0.10$ (may be adjusted) and the LBGR at 70% to 90% of the DCGL. In this region, doubling σ causes no increase in N (for $\beta = 10$). The sensitivity of N to an incorrect conclusion that the survey unit will pass (regulator's risk) is quite low; increasing α from 0.05 to 0.10 and 0.15 and holding σ constant at 266.3 dpm/100-cm^2, shows that the number of measurements is 11 or fewer in all cases. These results show that N = 11 represents a conservative design.

Table 7, Sensitivity Analysis for FSS Design

Number of Samples							
$DCGL_W$ = 35,296 (1)		$\alpha = 0.05$ (2)		$\sigma = 0.10$		$\alpha = 0.15$	
		σ = 532.6 (1) (3)	σ = 266.3	σ = 532.6	σ = 266.3	σ = 532.6	σ = 266.3
LBGR = 90% (1) (4)	$\beta = 0.05$ (5)	14	14	11	11	10	10
	$\beta = 0.10$	11	11	9	9	8	8
	$\beta = 0.15$	10	10	8	8	6	6
LBGR = 80%	$\beta = 0.05$	14	14	11	11	10	10
	$\beta = 0.10$	11	11	9	9	8	8
	$\beta = 0.15$	10	10	8	8	6	6
LBGR = 70%	$\beta = 0.05$	14	14	11	11	10	10
	$\beta = 0.10$	11	11	9	9	8	8
	$\beta = 0.15$	10	10	8	8	6	6

Table 7 Notes:

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

Visual Sample Plan was also used to determine the grid size, the random starting location coordinates (for Class 1 and 2 survey units) and to display the measurement locations on survey unit maps drawn to scale. Refer to Appendix B for location coordinate tables and scale VSP maps showing measurement locations for each MSP survey unit.

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

4.4 Instrumentation and Measurement Sensitivity

Instruments to be used in the FSS of each survey unit are selected in each survey design. Their detection sensitivities must be sufficient to meet the required action levels for the MARSSIM class of each survey unit. Minimum detection sensitivities for static alpha and beta measurements are calculated using the following equation:

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

where:

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

B_R = Background Count Rate (cpm),

t_b = Background Count Time (min),

t_s = Sample Count Time (min),

A = Detector Open Area (cm^2) and

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

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

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

Where:

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

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

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

b_i = background counts per observation interval,

E_i = Detector Efficiency (counts per disintegration),

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

p = Surveyor efficiency (typically 50%) and

A = Detector Open Area (cm^2).

A summary of representative a priori detection sensitivities of instruments used in the FSS of the Miscellaneous Structures and Pads is provided in Table 8. Note that these parameter values are those published in the survey designs based on the DCGLs in TBD-07-001. In Appendix C, it is shown that where the DCGLs were reduced, scan sensitivities were still sufficient to meet the investigation level requirements in Table 4.

Table 8, Typical Detection Sensitivities of Field Instruments

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

Table 8 Notes:

1. The detector efficiencies listed are total efficiency, i. e., $E_t = E_i + E_s$.
2. A' priori scan sensitivities are calculated using Equation 3 and static sensitivities are calculated using Equation 2.
3. The scan MDC for the LMI 44-116 is reported in Design No. 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.).
4. 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).
5. 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.
6. 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.
7. 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).

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.[20] Examples of areas or locations in MSP survey units where special measurement conditions apply are shown in Exhibits 23 through 25 of Appendix A.

5.0 Survey Results

Results of the FSS of the MSP are presented in this section. This includes scan survey frequencies (% of areas covered) for each survey unit and occurrence of events where scan investigation levels were exceeded. Investigations performed and the results are summarized. Fixed measurement results for each survey unit and the results of comparison tests of survey unit maximum and average values with the $DCGL_W$ are reported. As discussed below, no statistical tests were required. It is shown that levels of residual contamination have been reduced to levels that are ALARA. This section closes with a summary which concludes that applicable criteria for release of the Miscellaneous Structures and Pads for unrestricted use are satisfied and all FSS Plan requirements are met.

5.1 Scan Surveys

Scan survey results were reviewed to confirm that the scan coverage requirement (as % of survey unit area) was satisfied for all survey units. The results of QC replicate scan surveys were also reviewed to confirm that the minimum coverage requirement of 5% was satisfied. Results of the scan surveys are compiled in Table 9. The table shows that scan coverage requirements were satisfied for all survey units. The table also shows that no investigations were performed in the 44 MSP survey units. No scan investigation-action levels were exceeded in the original scan surveys or the QC scan surveys.

Table 9, Scan Survey Results for Miscellaneous Structures and Pads

Survey Unit	Class	Scan Survey Coverage (%) (1) (2)	Survey Request No.	Investigation Performed	QC Replicate Scan Coverage (%) (3) 4)
MA-1-1	1	100	101	No	6.5%
MA-1-2	1	100	101	No	6.5%
MA-1-3	1	100	101	No	6.5%
MA-1-4	1	100	101	No	6.5%
MA-1-5	1	100	101	No	6.5%
MA-1-6	1	100	101	No	6.5%
MA-2-1	1	100	267	No	5.6%
MA-2-2	1	100	267	No	5.6%

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

Table 9, Scan Survey Results for Miscellaneous Structures and Pads

Survey Unit	Class	Scan Survey Coverage (%) (1) (2)	Survey Request No.	Investigation Performed	QC Replicate Scan Coverage (%) (3) 4)
MA-2-3	1	100	267	No	5.6%
MA-2-4	1	100	267	No	5.6%
MA-2-5	1	100	267	No	5.6%
MA-2-6	1	100	268	No	5.5%
MA-2-7	1	100	268	No	5.5%
MA-2-8	1	100	268	No	5.5%
MA-2-9	1	100 (5)	268	No	5.5%
MA-2-10	1	100 (5)	268	No	5.5%
MA-2-11	1	100 (5)	268	No	5.5%
MA-2-12	1	100	268	No	5.5%
MA-2-13	1	100	268	No	5.5%
MA-2-14	1	100	267	No	5.5%
MA-2-15	1	100	274	No	5.6%
MA-3-1	1	100	274	No	6.0%
MA-3-2	1	100	274	No	6.0%
MA-3-3	1	100	274	No	6.0%
MA-3-4	1	100	274	No	6.0%
MA-3-5	1	100	274	No	6.0%
MA-3-6	1	100	274	No	6.0%
MA-3-7	1	100	274	No	6.0%
MA-4-1	1	100	275	No	5.7%
MA-4-2	1	100	275	No	5.7%
MA-4-3	1	100	275	No	5.7%
MA-4-4	1	100 (6)	275	No	5.7%
MA-4-5	1	100	275	No	5.7%
MA-4-6	1	100	275	No	5.7%
MA-4-7	1	100	275	No	5.7%
MA-4-8	1	100	275	No	5.7%
MA-4-9	1	100	275	No	5.7%
MA-5-1	2	58	353	No	5.7%
MA-5-2	2	56	353	No	18.1%
MA-5-3	2	49	353	No	18.1%
MA-5-4	1	100	353	No	18.1%
MA-5-5	2	40	353	No	18.1%
MA-5-6	2	38	353	No	18.1%
RS-1-1	2	35	364	No	18.1%

Table 9 Notes:

1. Scan % coverage values are rounded to the nearest whole per cent.
2. One hundred percent of the accessible surface area of Class 1 survey units was scanned. In some cases, a small fraction of a survey unit surface area is inaccessible for scanning. In most such survey units, it is less than a few percent of the total surface area. In all cases it is less than 10%. See Notes 5 and 6 below.
3. QC scan % coverage values are reported to the nearest one tenth %. The % QC scan coverage is given as the % of the area scanned in the initial survey.

4. Replicate QC scan results are reported for multiple survey units in some Survey Requests. For these, the QC scan percentages are reported as % of the scanned area of the survey units combined. So the same % coverage value is assigned to all of the survey units reported in a Survey Request.
5. Small portions of the concrete in the Cooling Tower Basin floor had been removed during Cooling Tower demolition and thus a small portion of the structure surface was unavailable for scanning (about 11 m^2 of a total floor surface area of 653 m^2).
6. A valve pit bottom in the Sludge Basin Survey Unit MA-4-4 was soil and not scanned during the FSS. The affected area was 1.2 m^2, out of a total survey unit surface area of 86.4 m^2. The exposed surface soil of this valve pit and two other valve pits adjacent to the Sludge Basins were subjected to 100 % scans with NaI detectors and a soil sample was collected from each in a post-remediation characterization survey under SR-266 in October 2010. The scan investigation level was not exceeded and all three sample analysis results were < MDA for Cs-137 and Co-60.

5.2 Fixed Measurements and Tests

Results of the assessment of FSS total surface beta measurements are presented in Table 10 (individual measurements in each survey unit are reported in Appendix B). The table presents the number of measurements, maximum, average and standard deviation for each survey unit and compares the maximum activity measured in each survey unit to the $DCGL_W$. It is demonstrated that all measured activity values are less than the $DCGL_W$, thus all survey units meet the 25 mrem/y release criterion. The mean activity of each survey unit is also compared to the $DCGL_W$, and as expected, are all less than the $DCGL_W$.[21] The average of 490 total surface beta measurements reported in the MSP release records is: 679 ± 324 dpm/100-cm^2 (one standard deviation). [22]

Removable surface activity measurements were also performed at each fixed activity measurement location and counted for gross alpha and gross beta activity. A review of the release records was conducted to ensure that all smear counting results were less than 10% of the gross activity DCGL. The requirement for PBRF laboratory smear counting instruments is that the MDAs be < 10% of the applicable gross activity DCGL[23]. Gross beta and gross alpha counts for all FSS smears collected in the MSP were less than MDA.

[21] In Appendix C it is shown that when the fixed measurement results are evaluated against the revised DCGLs published in TBD-11-002, the 25 mrem/y dose criterion is still satisfied.

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

[23] Typical MDAs for PBRF low background smear counting instruments are 14 dpm for alpha and 18 dpm for beta. Smears cover 100 cm^2, so these MDA values are equivalent to dpm/100-cm^2.

Table 10, Total Surface Beta Activity Measurement Summary and Test Results

Survey Unit ID	No. of Measurements	Maximum (1)	Test Result: Maximum < $DCGL_W$ (2)	Average (1)	Standard Deviation (1) (3)	Test Result: Average < $DCGL_W$ (2)
MA-1-1	16 (4)	1,126	Yes	819	203	Yes
MA-1-2	11	1,210	Yes	861	211	Yes
MA-1-3	11	1,000	Yes	706	243	Yes
MA-1-4	11	1,080	Yes	739	185	Yes
MA-1-5	11	708	Yes	530	101	Yes
MA-1-6	11	1,009	Yes	615	263	Yes
MA-2-1	11	889	Yes	537	189	Yes
MA-2-2	11	987	Yes	790	142	Yes
MA-2-3	11	956	Yes	486	264	Yes
MA-2-4	11	726	Yes	560	92	Yes
MA-2-5	11	911	Yes	601	159	Yes
MA-2-6	11	949	Yes	650	185	Yes
MA-2-7	11	898	Yes	678	141	Yes
MA-2-8	11	771	Yes	597	109	Yes
MA-2-9	11	1,220	Yes	822	317	Yes
MA-2-10	11	1,410	Yes	816	309	Yes
MA-2-11	12 (4)	696	Yes	506	167	Yes
MA-2-12	11	834	Yes	487	224	Yes
MA-2-13	11	1,380	Yes	1008	345	Yes
MA-2-14	11	1,310	Yes	968	224	Yes
MA-2-15	11	388	Yes	12	206	Yes
MA-3-1	11	1,180	Yes	615	234	Yes
MA-3-2	11	674	Yes	432	166	Yes
MA-3-3	11	1,140	Yes	877	121	Yes
MA-3-4	11	1,160	Yes	782	270	Yes
MA-3-5	11	1,800	Yes	1264	396	Yes
MA-3-6	11	1,330	Yes	683	321	Yes
MA-3-7	11	1,100	Yes	785	208	Yes
MA-4-1	11	895	Yes	642	131	Yes
MA-4-2	11	889	Yes	516	195	Yes
MA-4-3	11	771	Yes	477	174	Yes
MA-4-4	11	647	Yes	407	141	Yes
MA-4-5	11	1,037	Yes	701	177	Yes
MA-4-6	11	1,100	Yes	718	185	Yes
MA-4-7	11	868	Yes	564	153	Yes
MA-4-8	11	949	Yes	689	192	Yes
MA-4-9	11	2,190	Yes	1275	720	Yes
MA-5-1	10 (5)	967	Yes	641	215	Yes
MA-5-2	11	1,315	Yes	921	214	Yes
MA-5-3	11	1,135	Yes	679	263	Yes
MA-5-4	11	1,173	Yes	709	228	Yes
MA-5-5	11	1,284	Yes	833	272	Yes
MA-5-6	12 (4)	845	Yes	744	76	Yes
RS-1-1	11	288	Yes	71	145	Yes

Table 10 Notes:

1. The units for: maximum, average and standard deviation are dpm/100-cm^2.
2. The survey unit maximum and average activities were compared to the lowest $DCGL_W$ value for the MSP, 24,449 dpm/100 cm^2 (in Appendix C they are compared to the revised lowest DCGL, 20,831 dpm/100-cm^2).
3. Standard deviations of the measurements in each survey unit are reported for comparison to the values used in the survey design. In all 44 MSP survey units, values of σ obtained from the FSS measurements are less than values used in the survey designs (see Table 5). This confirms that the survey designs for the MSP were conservative.
4. In the FSS design calculation for survey units developed using VSP, "extra" fixed measurement locations are sometimes added when fitting the calculated grid size onto the survey unit layout.
5. In survey unit MA-5-1, the electrical substation pit west of the Reactor Building, the systematic measurement for location SM-6 was not taken due to standing water.

5.3 Removable Surface Activity Measurements

The FSS Plan requires that removable surface activity in each survey unit be less than 10% of the $DCGL_W$. In accordance with the FSS Plan, removable surface activity measurements were taken at each systematic measurement location in MSP survey units. Removable surface activity is measured by counting 100 cm^2 smear samples for beta and alpha activity.[24] Results were below counting instrument MDA values in all but one survey unit. Removable surface beta activity measurements in excess of counting instrument MDA values were measured at two locations in survey unit MA-5-1 (alpha activity was < MDA). These beta activity results were 22.31 dpm/100-cm^2 at location SM-2 and 19.55 dpm/100-cm^2 at location SM-10. Removable surface activity measurement results are less than 10% of the applicable survey unit $DCGL_W$ for all MSP survey units.

5.4 QC Measurements

Per FSS Plan requirements, QC replicate measurements were taken for at least 5% of the MSP FSS measurements. This included scan surveys and total surface activity measurements. Scan QC survey results are shown in Table 9 wherein the 5% scan QC coverage is confirmed. No QC scan surveys identified areas of elevated activity – these surveys confirmed the results of the original scan surveys of the areas covered.

Replicate total surface activity measurements were performed at selected systematic measurement locations. The 5 % requirement is satisfied in that 31 replicate QC measurements were reported; this represents 6.3 % of the 490 systematic measurements taken in the FSS of the MSP. The measurement results for the 31 total surface activity original and QC replicate measurement pairs are shown in Table 11.

[24] Smears are counted in the PBRF Counting Laboratory on automated sample changer proportional counters. Two such counters are available for this purpose: Tennelec Model LB-5100 and Tennelec Model 5X-LB. Typical MDAs for these counters are 10 to 16 dpm beta and 8 to 12 dpm alpha.

Table 11, Replicate QC Measurements

Survey Unit	Measurement Location No.	Net Activity (dpm/100 cm^2)	QC Replicate (dpm/100 cm^2)	RPD (%)
MA-1-1	10	1126	894	23.0
MA-1-2	4	1210	1000	19.0
MA-1-3	9	1000	794	23.0
MA-1-4	5	1080	941	13.8
MA-1-5	1	708	978	32.0
MA-1-6	11	1009	985	2.4
MA-2-2	3	777	575	29.9
MA-2-3	7	849	596	35.0
MA-2-4	11	554	301	59.2
MA-2-9	2	904	1960	73.7
MA-2-9	3	1170	1090	7.1
MA-2-10	3	682	644	5.7
MA-2-13	3	1210	1380	13.1
MA-2-13	11	1380	1120	20.8
MA-2-15	1	-263	-809	101.9
MA-2-15	3	-302	192	898.2
MA-3-1	1	799	632	23.3
MA-3-1	3	820	542	40.8
MA-3-1	8	1,180	889	28.1
MA-3-6	2	1,330	410	105.7
MA-4-5	1	699	379	59.4
MA-4-5	3	1,037	876	16.8
MA-4-5	5	735	804	9.0
MA-4-6	1	618	621	0.5
MA-4-6	3	463	810	54.5
MA-4-6	5	566	601	6.0
MA-5-1	1	777	351	75.5
MA-5-2	8	1,274	1245	2.3
MA-5-3	5	689	957	32.6
MA-5-5	4	743	678	9.1
RS-1-1	8	29	0	200.0

The FSS Plan (Section 12.7) identifies a target criterion of 20% for the relative percent difference (RPD) between original and replicate measurements [NASA 2007]. Nineteen of the 31 measurement pairs exceeded the 20% criterion. Each measurement pair failing to meet the

20% criterion was individually investigated in accordance with FSS Plan requirements and implementing procedures, resolved and determined to be acceptable.[25]

It is found that all of the MSP FSS measurements subjected to QC replicates were low activity measurements (below 1400 dpm/100-cm^2). Experience and the theory of measurement errors have shown that low activity measurements such as these are subject to variation which is high relative to the measured activity.

5.5 ALARA Evaluation

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

> "In light of the conservatism in the building surface and surface soil generic screening levels developed by the NRC, NRC staff presumes, absent information to the contrary, that licensees who remediate building surfaces or soil to the generic screening levels do not need to provide analyses to demonstrate that these screening levels are ALARA. In addition, if residual radioactivity cannot be detected, it may be presumed that it had been reduced to levels that are ALARA. Therefore the licensee may not need to conduct an explicit analysis to meet the ALARA requirement."[26]

Screening level values published by the NRC for the mix of radionuclides in structural surface residual contamination potentially present in the MSP are shown in Table 12. Since individual radionuclide activity concentrations are not measured in the FSS of structures, a direct comparison of residual contamination levels to individual radionuclide screening level values is not possible. A comparison can be made to an appropriate gross activity DCGL. A screening level value that is equivalent to the gross activity DCGL was calculated using the equations in Section 3.6 of the FSS Plan.[27] The activity fractions listed in Table 2 (also shown in Table 12) were used in the calculation. The activity fractions used for this ALARA evaluation are the default mixture developed for the PBRF in TBD-07-001; a conservative assumption. The screening level equivalent DCGL for the MSP using this mixture is calculated to be 781 dpm/100-cm^2.

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

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

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

The average total surface beta activity measured in the FSS of the MSP surfaces is 679 ± 324 dpm/100-cm^2 (one standard deviation). The upper limit of the 95th % confidence interval of this mean value is 708 dpm/100-cm^2.[28] This value is below the screening level gross activity DCGL of 781 dpm/100-cm^2. [29]

Table 12, Screening Level Values and Radionuclide Activity Fractions

Radionuclide	Screening Level Value (dpm/100-cm^2)	Activity Fraction (%) (1)
H-3	1.2 E+08 (2)	27.07
Co-60	7.1E+03 (2)	9.65
Sr-90	8.7E+03 (2)	7.88
I-129	3.5E+04(2)	1.42
Cs-137	2.8E+04 (2)	46.71
Eu-154	1.2E+04(3)	0.12
U-234	9.1E+01 (3)	6.98
U-235	9.8E+01(3)	0.17

Table 12 Notes.

1. Activity fractions used to develop the $DCGL_W$ for MSP are from Design No. 72, the default radionuclide mixture.
2. Values from NUREG-1757 Vol. 2, Table H.1 [USNRC 2006].
3. Values from NUREG/CR-5512, Vol. 3, Table 5.19 [SNL 1999]. These are 90th percentile values of residual surface activity corresponding to 25 mrem/y to a future building occupant.

5.6 Comparison with EPA Trigger Levels

The PBRF license termination process includes a review of residual contamination levels in groundwater and soil, as applicable, in accordance with the October 2002 Memorandum of Understanding (MOU) between the US NRC and the US Environmental Protection Agency (EPA) [USEPA 2002]. Concentrations of individual radionuclides, identified as "trigger levels" for further review and consultation between the agencies, are published in the MOU. As the FSS of the MSP comprises no soil or groundwater measurements, the comparison with EPA trigger levels is not applicable.

[28] The upper limit of the confidence interval, 95th percentile value, is calculated as: UL = mean + 1.96 $\sigma/\sqrt{n}$, where n = 460 measurements.

[29] In Appendix C, the ALARA evaluation is revisited using revised default radionuclide activity fractions and DCGLs published in TBD-11-002. As a result of these changes, the screening level equivalent DCGL is changed from 781 to 14, 124 dpm/100-cm^2, because uranium is removed from the mixture; the ALARA requirement is well satisfied.

5.7 Conclusions

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

- Scan surveys were performed in 100 % of the accessible surfaces of all 38 Class 1 survey units and at least 35% of the six Class 2 survey units.
- In no survey units were the scan action-investigation level exceeded.
- All systematic (with random start) total surface activity measurements are less than the applicable $DCGL_W$.
- All survey unit mean fixed measurement results (total surface beta activity) are below the $DCGL_W$, hence no statistical tests were required.
- All removable surface activity measurements are less than 10% of the $DCGL_W$.
- Residual surface activity concentration measurement results are shown to be less than NRC screening level values - demonstrating that the ALARA criterion is satisfied.
- The only change from what was proposed in the FSS Plan was that the MSP was divided into 44 survey units, whereas the FSS Plan did not provide a detailed breakdown of miscellaneous structures and pads.
- There were no changes from initial assumptions (in the FSS Plan) regarding the extent of residual activity in the MSP. No reclassification of survey units was required as a result of FSS measurements.
- Errors in several of the DCGLs published in a supporting technical basis document were recently discovered and revised DCGLs were published in a new technical basis document. The potential impacts of revised-reduced DCGLs were evaluated and it is found that all FSS Plan requirements remain satisfied and the conclusion holds that the 25 mrem/y dose criterion is satisfied for all the MSP survey units.

6.0 References

Bowles 2006	Mark D. Bowles, *Science in Flux, NASA's Nuclear Program at Plum Brook Station 1955 – 2000*, NASA History Division, Washington DC, June 2006.
GTS 1998	GTS-Duratek, Inc., *NASA/Lewis Plum Brook Facility 1998 Confirmation Survey, Volume 1 - Survey Packages and Survey Results*, November 1998.
Hagelin 2010	Karl W. Hagelin, Bremba K. Jones and Associates, *NASA Plum Brook Reactor Facility Coordinates, Personal Communication*, December 20, 2010.
ISO 1988	International Organization for Standardization, *Evaluation of Surface Contamination, Part 1: Beta Emitters and Alpha Emitters,* ISO-7503-1, 1988.
NACA 1956	National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, *NACA Reactor Facility Hazards Summary*, October 1956.
NASA 2007	NASA Safety and Mission Assurance Directorate, *Final Status Survey Plan for the Plum Brook Reactor Facility,* Revision 1, February 2007.
NASA 2007a	NASA Safety and Mission Assurance Directorate, *Decommissioning Plan for the Plum Brook Reactor Facility*, Revision 6, July 2007.
ORISE 2011	Oak Ridge Institute for Science and Education, Independent Environmental Assessment and Verification Program, *Final – Independent Confirmatory Survey Report for the Reactor Building, Hot Laboratory, Primary Pump House, and Land Areas at the Plum Brook Reactor Facility, Sandusky, Ohio*, October 2011.
PBRF 2007	Plum Brook Reactor Facility Technical Basis Document, *Adjusted Gross DCGLs for Structural Surfaces,* PBRF-TBD-07-001, June 2007.
PBRF 2007a	Plum Brook Reactor Facility Technical Basis Document, *Efficiency Correction Factor,* PBRF-TBD-07-004, November 2007.
PBRF 2009	Plum Brook Reactor Facility, Memorandum to Project File, J. L. Crooks, Don Young, *Final FSS Report Background – Waste Effluent Monitoring Station/System,* December 15, 2009.
PBRF 2010	Plum Brook Reactor Facility, Memorandum to Project File, J. L. Crooks, Don Young, *Final FSS Report Background – Reactor Building/Assembly Test and Storage Building Utility Tunnel,* November 11, 2010.
PBRF 2010a	Plum Brook Reactor Facility, Memorandum to Project File, J. L. Crooks, Don Young, *Final FSS Report Background – Miscellaneous Foundations, Basins, Pits and Trenches,* August 31, 2010.

PBRF 2012 Plum Brook Reactor Facility Technical Basis Document, Re-evaluation of Structure DCGLs and Uranium Activity Fractions, PBRF-TBD-11-002, January 2012.

PNL 2010 Battelle Pacific Northwest Laboratories (PNL), *Visual sample Plan*, Version 5.9, 2010.

SNL 1999 Sandia National Laboratories (SNL), for US Nuclear Regulatory Commission, *Residual Radioactive Contamination From Decommissioning, Parameter Analysis,* NUREG/CR-5512, Vol.3, Oct. 1999.

TELE 1987 Teledyne Isotopes, *An Evaluation of the Plum Brook Reactor Facility and Documentation of Existing Conditions*, Prepared for NASA Lewis Research Center, December 1987.

USACE 2004 US Army Corps of Engineers Louisville District, *Hydrological Report Plum Brook Reactor Facility Sandusky, Ohio*, November 17, 2004.

USEPA 2002 Memorandum of Understanding, US Environmental Protection Agency and US Nuclear Regulatory Commission, *Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites*, October 9, 2002.

USNRC 2000 US Nuclear Regulatory Commission, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, NUREG-1575, Rev.1, August 2000.

USNRC 2006 US Nuclear Regulatory Commission, *Consolidated Decommissioning Guidance, Characterization, Survey and Determination of Radiological Criteria*, NUREG 1757, Vol. 2, Rev.1, September 2006.

7.0 Appendices

Appendix A – Exhibits

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

Appendix C – Evaluation of Revised DCGLs

Plum Brook Reactor Facility

Final Status Survey Report

Attachment 15

Miscellaneous Structures and Pads

Revision 0

Appendix A

Exhibits

List of Exhibits

Exhibit 1, ATS Tunnel

View of Tunnel Floor and Lower Walls – Looking North towards ATS Building

View of Tunnel Floor and Walls – Looking South towards Reactor Building

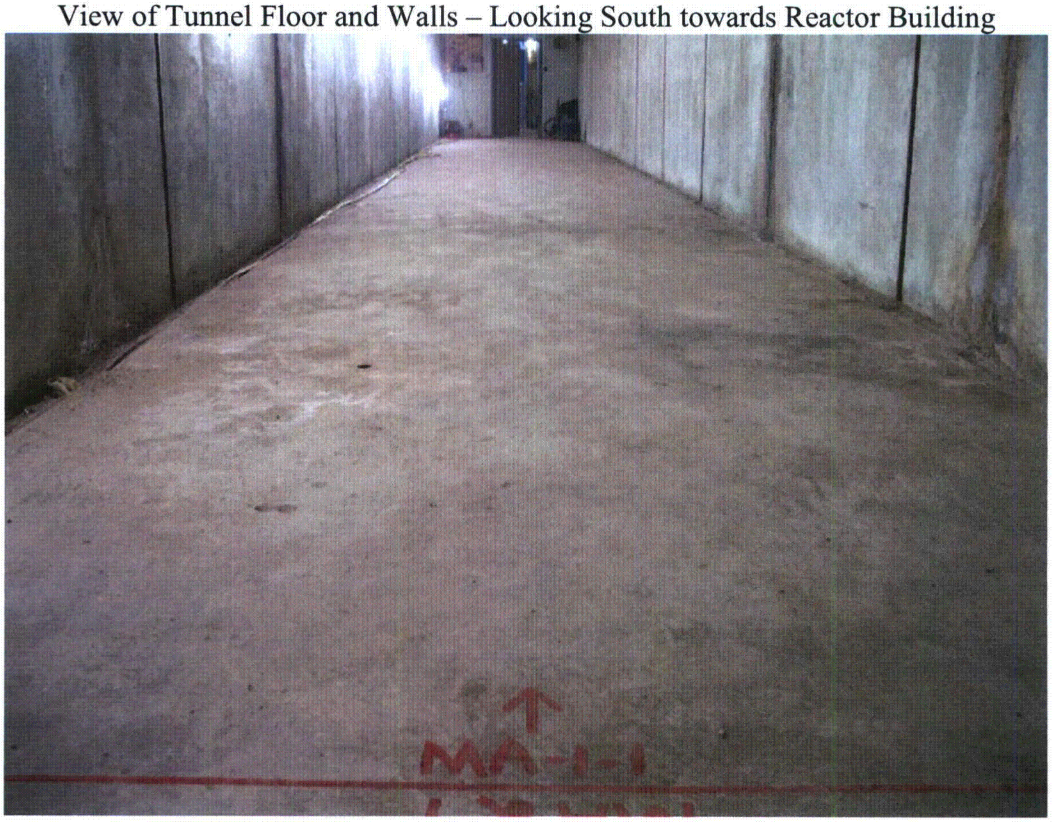


Exhibit 2, Cooling Tower Basin

Sump Floor NE Area - Survey Unit MA-2-1

Sump Ceiling SE Area – Survey Unit MA-2-2

Exhibit 3, Cooling Tower Basin – Upper Sump Area

Basin Floor Looking West – Survey Unit MA-2-9

Basin Walls NW Section Showing Sump Gate Guides – Survey Unit MA-2-12

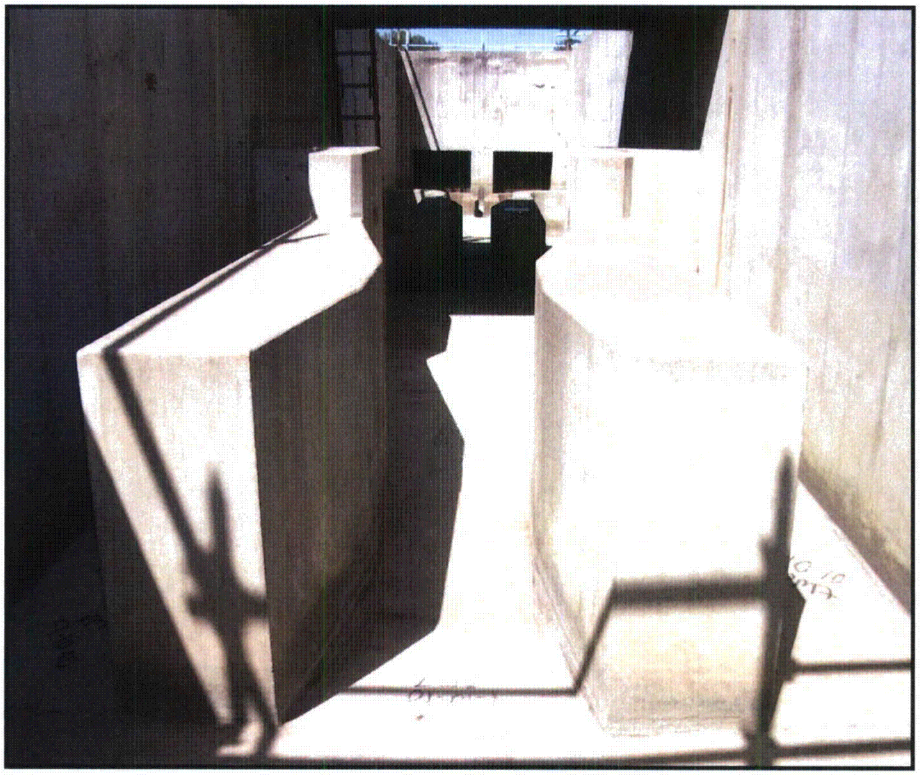
Exhibit 4, WEMS Sump

Sump Floor West Side with Scaffold and Access ladder – Survey Unit MA-3-1

Sump South Wall and Flume Entrance – Survey Unit MA-3-2

Exhibit 5, WEMS Flumes and Gates

Flumes from South End looking North – Survey Unit MA-3-5



Trash Screen Area, South and East walls – Survey Unit MA-3-6

Exhibit 6, WEMS Upper Horizontal Surfaces and Pads
WEMS South End Looking Southeast – Survey Unit MA-3-3

Exhibit 7, Sludge Basins - I

West Sludge Basin looking West – Survey Unit MA-4-1

East Sludge Basin Looking East – Survey Unit MA-4-6

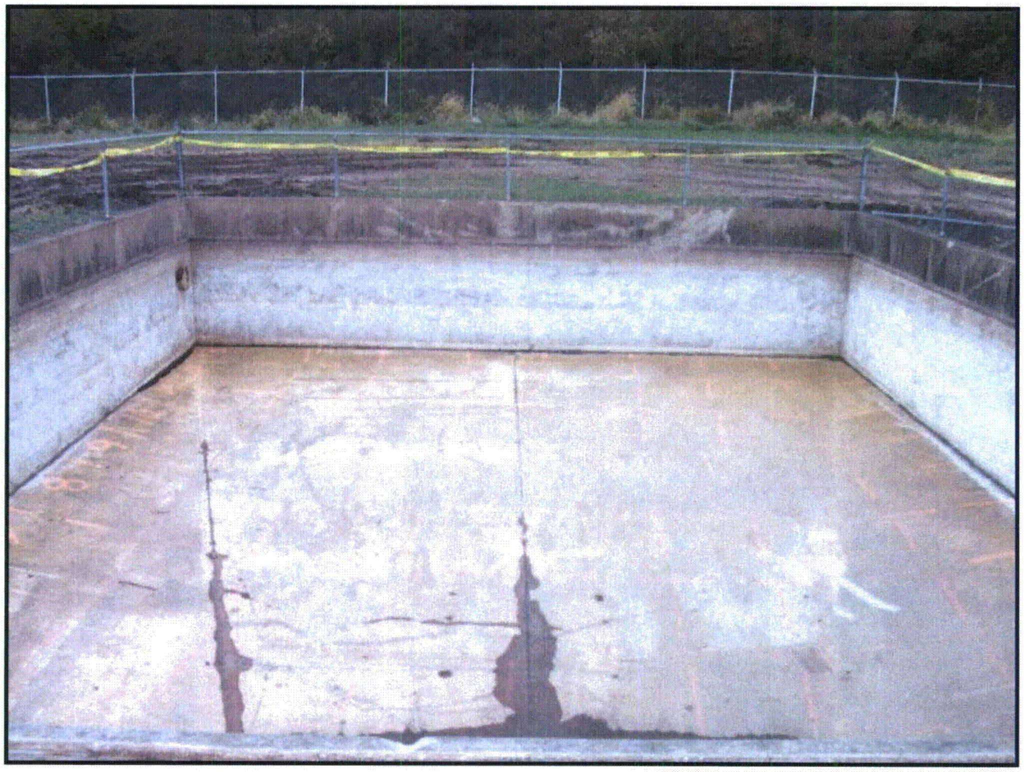
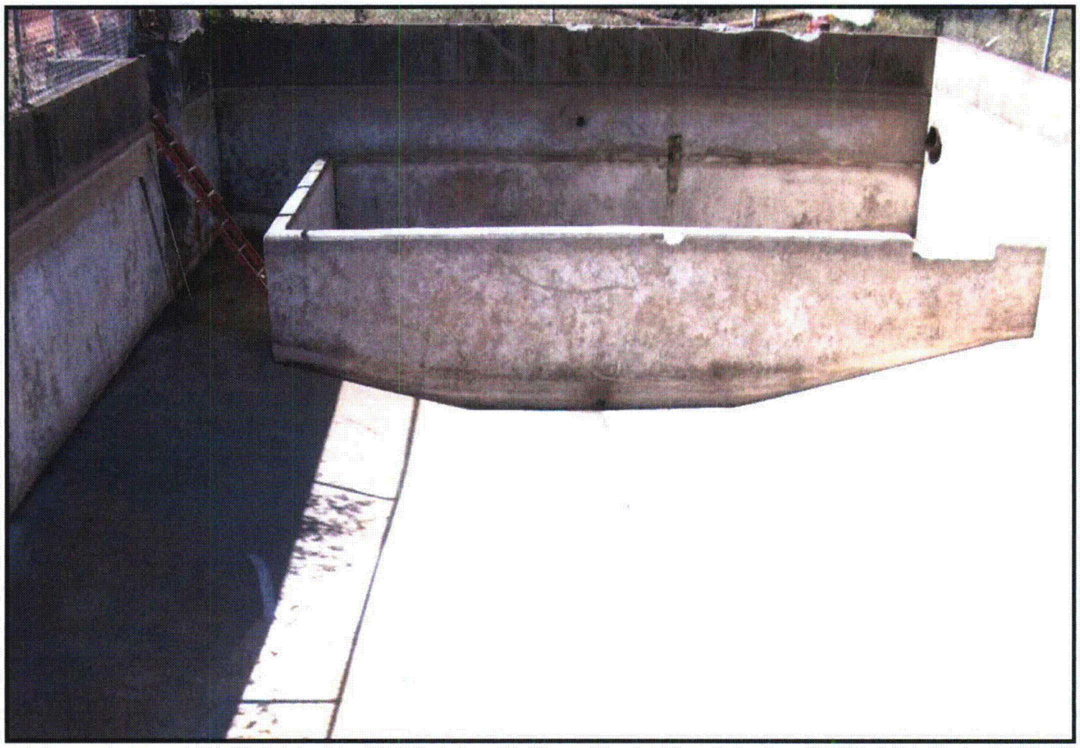


Exhibit 8, Sludge Basins - II

East Sludge Basin E side with Divider Walls – Survey Unit MA-4-8



East Sludge Basin Valve Pit – Survey Unit MA-4-8

Exhibit 9, Sludge Basins - III

West Sludge Basin Top Surfaces and Outside Walls - Survey Unit MA-4-9

Sludge Basin Central Sump – Survey Unit MA-4-9

Exhibit 10, Miscellaneous PADS - I
Reactor Substation Foundation – Survey Unit MA-5-1

Exhibit 11, Miscellaneous PADS - II

Main Sidewalk from Security Building to Reactor Building – Survey Unit MA-5-2

West End of Sidewalk from Security Building to Reactor Building – Survey Unit MA-5-2

Exhibit 12, Miscellaneous PADS - III

Reactor Building West Rollup Door Entrance Pad – Survey Unit MA-5-2

Hot Lab Viewing Gallery Entrance Pad – Survey Unit MA-5-2

Exhibit 13, Miscellaneous PADS - IV

Unit Substation 5 Transformer Pad – Survey Unit MA-5-2

Air Intake Structure for Reactor Building -25 ft. Elevation - Survey Unit MA-5-2