BROOKHAVEN NATIONAL LABORATORY

FINAL

CLOSEOUT REPORT FOR AREA OF CONCERN 16 LANDSCAPE SOIL

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AOC 16 LANDSCAPE SOILS CLOSEOUT REPORT

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1.0 Introduction

1.1 Purpose

The purpose of this closeout report is to document the activities supporting the remediation of radiologically-contaminated landscape soil at Brookhaven National Laboratory (BNL). The remedial activities consisted of the characterization, excavation, walkover surveys, sampling, loading, transporting, and disposal of contaminated soil from Area of Concern (AOC) 16, as required in the Operable Unit (OU) I Record of Decision (ROD). The scope of remedial work is outlined in detail in the *Final Remedial Action Work Plan AOC 16 Landscape Soil* (CDM Federal, April 2000) and in the *Final Remedial Action Field Sampling Plan AOC 16 Landscape Soil* (CDM Federal, April 2000).

1.2 Regulatory Framework

On December 21, 1989, the BNL site was included on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List (NPL). In May 1992, the Department of Energy (DOE) entered into an Interagency Agreement (IAG) with the United States Environmental Protection Agency (EPA) and the New York State Department of Environmental Conservation (NYSDEC) under CERCLA, Section 120. The IAG established the framework and schedule for characterizing, assessing and remediating the site in accordance with the requirements of CERCLA, and the Resource Conservation and Recovery Act (RCRA). BNL originally grouped the AOCs into seven OUs (BNL Response Strategy Document, SAIC, 1992) which have subsequently been combined into six OUs.

The nature and extent of the AOC 16 radiologically-contaminated soils have been addressed in the *Final Operable Unit II/VII Remedial Investigation Report* (IT Corporation, February, 1999), *OU II/VII Supplemental Sampling Report* (BNL, July, 1999), and ThermoRetech sampling data collected in August, 1999. An evaluation and recommendation of remedial activities for the AOC 16 areas was presented in the *Final Feasibility Study Report Operable Unit I and Radiologically-Contaminated Soils* (CDM Federal, March, 1999). Cs-137 was determined to be the primary radionuclide present in concentrations above the risk-based soil remediation goal, as defined in the OU I Record of Decision. No other radioisotopes were identified that exceeded the remediation goals. As a result, The Record of Decision for OU I (DOE, August 1999) selected excavation and off-site disposal as the remedial alternative for the AOC 16 radiologically-contaminated soil.

1.3 Site Cleanup Criteria

The Feasibility Study (FS) for site wide radiologically-contaminated soil and the Record of Decision identify the cleanup criteria for the BNL site. The cleanup goals are based on a limiting annual dose of 15 mrem above background following 50 years of institutional control of the BNL site. Cleanup goals for specific radionuclides were calculated using the DOE Residual Radioactive Material Guidelines (RESRAD) computer model. The cleanup goal for Cs-137, which is the only radionuclide at AOC 16 greater than the soil cleanup goal, was based on exposure to surface soils, and was determined to be 23 pCi/g for future residential land use and 67 pCi/g for future industrial land use. The ROD established residential land use as the criteria for the soil cleanup goals for this AOC.

1.4 Site History

The radiologically-contaminated soil was originally generated at BNL's Hazardous Waste Management Facility and was later used as fill and landscaping soil at several locations throughout BNL. Aerial radiation surveys performed in 1980 and 1983 indicated unanticipated external exposure rates exceeding background levels. Areas discovered in 1980 were investigated and soil was determined to be radiologically-contaminated. The 1983 survey identified ten additional areas and found the dominant radioisotope to be Cs-137, with lower levels of Sodium (Na-22), Manganese (Mn-54), and Cobalt (Co-60). Subsequent analysis of soil samples collected within these areas in 1996 revealed only Cs-137 to be of concern. The contamination in the soil was believed to have resulted from spills of aged fission products stored and removed from the Former Hazardous Waste Management Facility. Soil was reportedly scraped to a depth of 15 to 20 centimeters (cm) in 1954, 1955, 1958 and the mid-1960s, and banked at the former landfill. The contaminated soil was later used as fill and landscaping soil at locations adjacent to or near several buildings including Buildings 30 (Brookhaven Center), 355 (Contracts and Procurement), 490 (Medical), 510 (Physics), 515 (Information Technology Division), 555 (Chemistry), and 930 (Linear Accelerator).

AOC 16 consists of several sites located in the western half of the BNL property and near the center of BNL. Figure 1 shows the locations of the various radiologically-contaminated landscape soil at BNL. Contaminant concentrations for each AOC 16 area have been summarized in Section 4 of the *Final Operable Unit II/VII Remedial Investigation Report* (IT Corporation, February, 1999).

2.0 Remediation Activities

Landscape soils were excavated from the AOCs listed below in Table 1. Excavation began on May 15, 2000 and was completed on November 2, 2000. Table 1 provides a summary of the estimated excavated soil volumes, the areas of excavation, and the average depths of excavation.

Table 1: Excavated Landscape Soil Volumes

AOC	Description	Excavated Soil Volume* (cyd)	Area of Excavation* (sq. yd)	Average Depth of Excavation (ft)
16E.1	Field south of Bldg. 490	1037	2756	1.1
16E.4	Soils at the Medical Research Reactor	3	18	0.5
16E.2	Field near Bldg. 494	275	435	1.9
16E.3	Field south of Pavilion No. 4, Bldg. 490	74	263	0.8
16F	Field northwest of Bldg. 555	288	624	1.4
16G	Field east of Bldg. 30	513	2010	0.8
16S.2	Soils south and southwest of Bldg. 515	80	325	0.7

AOC	Description	Excavated Soil Volume* (cyd)	Area of Excavation* (sq. yd)	Average Depth of Excavation (ft)
16S.3	Soils south and west of Bldg. 515	11	22	1.5
16S.5	Soils east of Bldg. 355	96	380	0.7
16S.6a-f	Soils adjacent to Bldg. 930	263	950	0.8
Total		2640	7803	

*Estimated +/- 10%

The original walkover radiological survey contours completed during the OU II/VII Remedial Investigation for each AOC are provided in Figures 2 through 10. Details on the radiological walkover survey results prior to excavation activities and after excavation activities are provided in Sections 2.12 and 2.13 of this report, respectively. The areas that were excavated, processed and disposed of off-site and the areas that were not excavated are described below.

2.1 AOC 16E.1& 2

AOCs 16E.1 & 2 are fields located south of Building 490 (Medical Research Center) near Building 494 (Records Storage Building) where landscaping soil was placed. During the Remedial Investigation activities, soil samples collected within these areas showed Cs-137 concentrations up to 348 pCi/g.

Approximately 1312 cubic yards of soil were excavated from these two areas. The final excavation cut lines for this area are provided in Figure 11. Of the 1312 cubic yards of soil excavated, 551 cubic yards of soil were processed by the Segmented Gate System. The Segemented Gate System (SGS) is discussed in detail in Section 2.2.1 of this report.

A small area adjacent to the Brookhaven Medical Research Reactor (AOC16E.4) was also identified during completion of the Brookhaven Medical Research Reactor Groundwater Contamination Investigation. This investigation identified Cs-137 up to 65 pCi/g in soils at the former haul-away tank area located adjacent to the south side of the Brookhaven Medical Research Reactor. Approximately 3 cubic yards of soil were excavated from this area. The final excavation cut lines for this area are provided in Figure 13.

2.2 AOC 16E.3

AOC 16E.3 includes a field south of Hospital Pavilion No. 4, Building 490. During the RI and the supplemental sampling activities, soil samples collected within this AOC indicated Cs-137 concentrations of 32.9 pCi/g and 77.45 pCi/g, respectively. Approximately 74 cubic yards of soil were excavated from this area and processed through the Segmented Gate System. The final excavation cut lines are provided in 12. Figure 21 shows this area following excavation.

Figure 21: Building 490 - Medical (May 24, 2000) Following Excavation

2.2.1 Segmented Gate System

A pilot study was conducted on the ThermoRetech Segmented Gate System which is a combination of conveyor systems, radiation detectors, and computer controls that segregates contaminated soil from a moving feed supply. The soil is diverted to conveyor belts, then deposited into a container or a soil pile for further processing or final disposal. Further details on the Segmented Gate System are provided in the Operating Procedures Manual for the Segmented Gate System, ThermoRetech, January, 2000 (see Appendix B, *Final Remedial Action Work Plan AOC 16 Landscaping Soil*, (CDM Federal, April, 2000)).

The Segmented Gate System was used to process and sort 551 cubic yards of soil from AOC 16E.1 & 2 and 74 cubic yards of soil from AOC 16E.3. Of the total 625 cubic yards of soil sorted, 95 cubic yards of clean soil were returned to AOC 16E.1. To confirm the effectiveness of the Segmented Gate System, soil samples were collected from the processed soil exiting both streams. These results are summarized below in Table 2 and provided in Attachment 3.

Table 2: Maximum Cs-137 Concentrations from Soils Processed through SGS

AOC	Maximum Cs-137 Concentration (pCi/g)	
	Contaminated Soil from SGS	Clean Soil from SGS
AOC 16E.1	21.0	9.1
AOC 16E.2	21.2	6.07
AOC 16E.3	35.8	12.6

The Segmented Gate System ceased operations on June 2, 2000 due to low return efficiencies of clean soils.

2.3 AOC 16F

AOC 16F is a field located northwest of Building 555 (Chemistry Department). During the Remedial Investigation, three of the soil samples collected within this area showed elevated Cs-137 concentrations ranging from 59.6 to 198 pCi/g. Approximately 288 cubic yards of soil were excavated from AOC 16F. Figure 14 provides the final excavation cut lines for this area. Figure 22 shows the excavation of soil from AOC 16F.

Figure 22: Building 555 - Chemistry (July 14, 2000)

2.4 AOC 16G

AOC 16G is a field located on the east side of Building 30 (Brookhaven Center). Two soil samples collected at this area during the RI resulted in observed Cs-137 concentrations of 26.7 and 56.5 pCi/g. Approximately 513 cubic yards of soil were excavated from this area. The excavation cut lines for AOC 16G are provided in Figure 15. Figure 23 shows AOC 16G after excavation.

Figure 23: Building 30 - Brookhaven Center (June 30, 2000)

2.5 AOC 16S.1

AOC 16 S.1 is a small area north of Building 510 (Physics). Cs-137 was detected up to 10 pCi/g. This area was not excavated since Cs-137 was not detected above the cleanup goal. Confirmatory samples were taken from this area to verify that Cs-137 levels are below the cleanup goal. The confirmatory sample locations for AOC 16S.1 are provided in Figure 16.

2.6 AOC 16S.2

AOC 16S.2 is an area abutting the south and west sides of Building 515 (Information Technology Division). During the Remedial Investigation, no radionuclide or chemical contaminants were detected above the remediation goals. However, based on the *OU II/VII Supplemental Sampling Report (BNL,1999)*, Cs-137 was detected in one sample at a concentration of 25.9 pCi/g. Approximately 80 cubic yards of soil were excavated from this area. The excavation cut lines are shown on Figure 17.

2.7 AOC 16S.3

AOC 16S.3 is an area south and west of Building 515. During the supplemental sampling activities, a maximum Cs-137 concentration of 9.68 pCi/g was observed. However, Lead (Pb) concentration of

2310 mg/kg, exceeding the cleanup goal of 400 mg/kg as specified in the OU I ROD, was observed in one of the two collected soil samples. Samples submitted for TCLP analysis demonstrated that the soil was not a hazardous waste. The TCLP result for lead was 34.1 ug/l. Approximately 11 cubic yards of soil were excavated from this area as shown in Figure 17.

2.8 AOC 16S.4

AOC 16S.4 is the traffic island south of Building 515. Cs-137 was detected at concentrations up to 17 pCi/g. Since concentrations were below the cleanup goal, this area was not excavated. Confirmatory samples were taken from this area to verify that Cs-137 levels are below the cleanup goal. The confirmatory sample locations for AOC 16S.4 are shown in Figure 17.

2.9 AOC 16S.5

AOC 16S.5 is comprised of contaminated landscaping soil located east of Building 355 (Contracts and Procurement). Radionuclide or chemical contaminants were not observed in the surface and subsurface soils during the Remedial Investigation activities. However, two soil samples collected within this area during the supplemental sampling event showed Cs-137 concentrations of 28.1 and 76.1 pCi/g. Additionally, Cs-137 concentration of 136 pCi/g was detected during the ThermoRetec sampling activities. Approximately 96 cubic yards of soil were excavated from this area. The final excavation cut lines are provided in Figure 18.

2.10 AOC 16S.6a-f

AOC 16S.6a-f is an area comprised of contaminated landscaping soil, located adjacent to Building 930 (Linear Accelerator) and southeast of Building 930. During the Remedial Investigation, one sample indicated a Cs-137 concentration above the remediation goal. Moreover, five of the eight soil samples collected during the supplemental sampling activities showed Cs-137 concentrations ranging from 69.8 to 149.7 pCi/g. Approximately 263 cubic yards of soil were excavated from AOC16S.6a-f. The excavation cut lines for these areas are provided in Figures 19 and 20.

2.11 Waste Soil Volume Summary

A total of approximately 2854 cubic yards of waste were generated for shipment to Envirocare, Utah. Table 3 provides a summary of the estimated waste volumes disposed of and the dates of shipment. The total estimated waste volume is within ten percent of the estimated excavated volume.

Table 3: Landscape Soils Waste Shipments

Date	Shipped* Volume (ft3)	Weight** (Lbs)
7/28/00	2,691	199,400
7/28/00	2,663	197,300
7/28/00	2,645	196,000
7/28/00	2,533	187,700
7/27/00	2,653	196,600
7/28/00	2,683	198,800
8/17/00	2,114	156,607
8/17/00	2,469	182,892
8/17/00	2,596	192,330
8/17/00	2,612	193,544
8/17/00	2,590	191,853
8/17/00	2,489	184,371
8/17/00	2,200	163,449
8/17/00	2,200	163,913
8/22/00	2,666	197,500
8/22/00	2,631	194,900
8/22/00	2,604	192,900
8/22/00	2,478	183,550
8/22/00	2,643	195,800
9/20/00	2,541	188,200
9/20/00	2,581	191,200
9/20/00	2,626	194,500
9/20/00	2,660	197,000
9/20/00	2,577	190,900
9/20/00	2,703	200,200
10/17/00	2,668	197,600
10/17/00	2,599	192,500
10/17/00	2,637	195,300
10/17/00	2,669	197,700
11/17/00	2,646	195,800
Total	77,067	5,710,309
Total	2,854 CY	2,855 Tons

*Assumes average soil density of 74.1 lbs/feet^3
**Weight estimated at +/-10%

2.12 Field Screening Methods Prior to and During Excavation

Just prior to and during excavation, a Sodium Iodide (NaI) detector (Ludlum Micro-R Meter Model #19) was utilized for confirming and locating areas of elevated Cs-137 concentrations above the cleanup level of 23 pCi/g. Any areas found to exceed 20 uR/hr were excavated.

Earlier gamma surveys and soil sampling described in the *Final Remedial Action Work Plan Area of Concern 16 Landscape Soil (CDM Federal, April 2000)* were used to define and map the primary areas (Class 1) and secondary areas (Class 2). The primary areas (Class 1) designated for excavation contained Cs-137 at concentrations above 23 pCi/g in the surface layer (approximately upper 6 inches to 12 inches). Secondary areas (Class 2) contained Cs-137 which are at or above background levels (0.5 pCi/g), but generally below the cleanup level, but which may contain small areas with concentrations greater than 23 pCi/g. The Class 1 and Class 2 areas for each AOC are shown in Figures 11 through 20. The figures also show the final excavation cut lines for each Class 1 area.

2.13 Post Excavation Final Status Surveys

Following remediation, a final radiological status survey was performed to demonstrate that residual radioactivity in each area satisfies the clean-up criteria identified by the ROD. The final walkover survey consisted of a 100% surface scan of the excavated Class 1 areas and a 10% surface scan of Class 2 areas using an Eberline E600 2X2 inch Sodium Iodide detector. In addition, the Oak Ridge Institute for Science and Education (ORISE) and the NYSDEC performed independent verification to support that clean-up goals were achieved. Results of the independent verification are provided in Attachment 1.

2.13.1 Final Radiological Status Survey Design

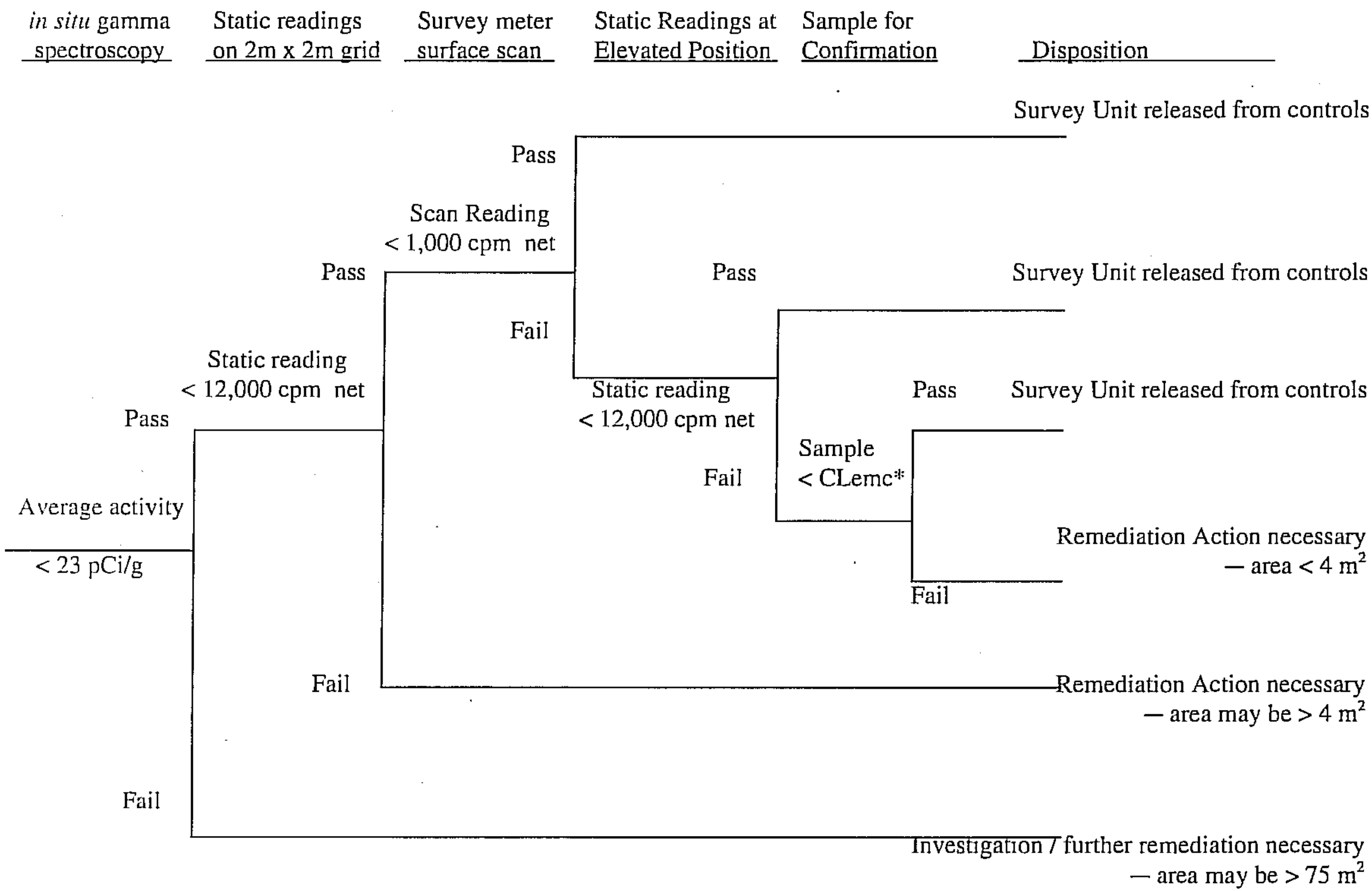
The design of the final status survey was based on guidance provided in the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM). Details of the survey design are provided in the *BNL Final Remedial Action Field Sampling Plan AOC 16 Landscape Soil.* The survey was an integrated design, combining:

- Measurements at random positions to determine the average concentration of activity distributions in relatively large areas (Class 1, Class 2 and Reference areas);
- Stationary meter readings on a 2 m x 2 m grid, to identify areas of elevated activity possibly larger than 4 m^2 (Class 1 and Class 2 areas);
- A surface scanning meter survey to identify localized areas of elevated activity smaller than 4 m^2, (100% of Class 1 and 10% of Class 2 areas); and
- Analysis of soil samples to confirm instrument readings (100% of high readings) or to verify *in situ* analysis (10% of *in situ* positions).

The logic basis for determining the disposition of a survey unit is provided in Figure A. Decision criteria and survey components are discussed further in the following sections.

a. <u>Classifying survey units</u>
Areas within the AOCs were categorized using MARSSIM methods to define the survey design. Class 1 Areas were those areas with contamination levels greater than the clean-up goal of 23 pCi/g Cs-137. Class 2 Areas were those which had been found to be contaminated, but at levels below the

Figure A: BASIS FOR DETERMINING DISPOSITION OF A SURVEY UNIT



Note: "Remediation Action" may involve sampling to confirm elevated area, surveys to bound elevated area, and/or excavation.
*CLemc is the elevated measurement comaprison

clean-up goal of 23 pCi/g Cs-137. Small areas of AOC16 in local proximity have been combined into survey units, resulting in six Class 1 survey units, six Class 2 survey units, and one reference area, as indicated in Table 4.

Table 4: Description of Survey Units

AOC	Area Class	Planned			Actual		
		Area (m^2)	**# of samples**	**Separation Distance (m)**	**Area (m^2)**	**# of samples**	**Separation Distance (m)**
16E.1	Class 1	1,879	16	11.2	2,320	18	12
16E.1	Class 2	3,620	9	21.1	3,110	12	20
16E.2-3	Class 1	374	9	6.4	584	14	6
16E.2-3	Class 2	1,800	9	14.7	2,050	14	12
16F	Class 1	445	9	7.1	560	9	6
16F	Class 2	1,000	9	10.8	1,030	9	12
16G	Class 1	403	9	6.7	1,680	20	10
16G	Class 2	8,000	10	29.3	10,720	13	25
16S.1-5	Class 1	244	9	5.1	525	13	6
16S.1-5	Class 2	1,915	14	12.1	2,810	26	12
16S.6a-f	Class 1	319	9	5.5	794	15	6
16S.6a-f	Class 2	1,900	14	12.1	2,040	17	12
Reference Area (Helipad) (See Figure 21)			16 samples; equivalent to largest number of samples needed for any one survey unit				

b. Determining sampling grid size and number of samples

Since Cs-137, the contaminant of concern, appears in background soils, due to atmospheric fallout, the MARSSIM recommends a statistical analysis based on the Wilcoxon Rank Sum Test. Using the methods recommended in MARSSIM, Chapter 5, a calculation of number and spacing for a systematic sampling pattern was performed. This number of systematic samples, and the corresponding grid spacing between the samples, assures a statistically sufficient database for determining whether the average radioactivity concentration in each of the survey units meets or exceeds the cleanup goal. The number and spacing of the samples planned before excavation and those performed for the actual excavated areas are listed in Table 4. The calculation of the grid separation distance and of the number of sample points is detailed in *BNL Final Remedial Action Work Plan AOC 16 Landscape Soil, Appendix D.*

c. Elevated Measurement Comparison

The MARSSIM statistical tests on the results of the systematic sampling evaluate whether or not the average residual radioactivity in a survey unit exceeds the cleanup goal (CG_W), which is 23 pCi/g Cs-137. Since the average includes values that are higher and lower than the cleanup goal, there should be a reasonable level of assurance that any small areas of elevated residual radioactivity are not too high. In MARSSIM, the process of determining the value that is "too high" is termed the cleanup goal elevated measurement comparison CG_{EMC}.

One method for determining values for the CG_{EMC} is to modify the CG_W using a correction factor that accounts for the difference in area and the resulting change in dose or risk. That is, as the concentration of Cs-137 is elevated, the area must be reduced to keep the risk from rising. The area factor (AF) is the magnitude by which the concentration within the small area of elevated activity can exceed CG_W while maintaining compliance with the dose-based release criteria.

Table 5 provides area factors for the AOC 16 remediated areas. The AFs were generated using the RESRAD exposure pathway model for a unit concentration of 37 Bq/kg (1 pCi/g). For consistency with the post remediation residential land use, the meat, milk, and aquatic foods ingestion pathways were suppressed, and the thickness of the residual contamination layer was assumed to be 0.15 m. The area of contamination in RESRAD defaults to 10,000 m^2; for this AF calculation, the area was varied to values of 9, 16, 25, 50, 100, 400, 900, or 5,000 m^2. Other parameter values for the RESRAD code were not changed from the default values. Since the actual areas of elevated activity are very small, there is little influence in not using site-specific parameters. The area factors were then computed by taking the ratio of the dose (or risk) generated by RESRAD for the default 10,000 m^2 to the dose generated for the other areas listed. If the CG_W for residual radioactivity distributed over 10,000 m^2 is multiplied by this AF value, the resulting concentration distributed over the specified smaller area delivers the same calculated radiation dose.

Table 5: Outdoor Area Dose Factor for BNL Landscape Soils Containing Cs-137

Area of Elevated Activity (m^2)	9	16	25	50	100	400	900	5,000	10,000
Area Factor	2.5	1.9	1.7	1.4	1.2	1.1	1.0	1.0	1.00

For example, from Table 5 an area factor of approximately 1.7 is calculated for Cs-137 for an area of 25 m^2. Thus for the cleanup goal of 23 pCi/g which corresponds to the annual dose criterion, an area of activity up to 39 pCi/g (1.7 x 23) will not exceed the annual dose criterion, if the elevated area is limited to 25 m^2 or less.

If residual radioactivity is found as an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule can be used to ensure that the total dose is within the release criterion [MARSSIM Equation 8-2]:

$$\frac{\delta}{CG_W} + \frac{(\text{average concentration in elevated area} - \delta)}{(\text{area factor for elevated area}) \times CG_W} < 1 ,$$

where $\delta =$ the average concentration in the survey unit .

If there is more than one elevated area in a survey unit, a separate term can be included for each, or for ease of calculation and conservative interpretation, the areas may be combined and handled as a total elevated area with the limiting activity applied to each smaller area individually. For example, using the values in Table 5;

- if an area of 9 m^2 were elevated, the concentration must be less than 57 pCi/g (2.5 x 23);
- if the elevated area were 16 m^2, the concentration must be less than 43 pCi/g (1.9 x 23); but
- both areas were present (9+16=25 m^2), then the concentration in each elevated area must be less than 39 pCi/g (1.7 x 23, where 1.7 is the AF for 25 m^2, the total of all elevated areas).

d. Nal detector surveys

A walkover survey of each excavated area was performed using a sodium iodide (NaI) detector (Eberline E600 meter with a 2" x 2" detector and Ludlum Model 19 with a 1" x 1" detector). The NaI detectors had been correlated to measure Cs-137 concentration in the surface soil by comparing instrument response to locations of elevated soil activity, which were then sampled and analyzed at an off-site laboratory. For the Ludlum Model 19 micro-R meter, 20 μR/hr is approximately equal to the cleanup goal of 23 pCi/g; for the Eberline E600 meter, 20,000 counts per minute (cpm) or 20 kcpm is approximately equal to the cleanup goal. The correlation curves of instrument response to measured soil activity are provided in Attachment 2.

To facilitate data recording and to ensure uniform coverage of the surface, each area was subdivided into a 2 m x 2 m square grid. The walkover surveys were performed in two stages.

In the initial post-excavation survey, static or stationary readings were obtained with the detector within 1 inch (2 cm) of the surface at each intersection point (node) on the 2 m grid. Readings were performed at 100% of nodes in the excavated areas (Class 1) and at approximately 50% of nodes in the adjacent, un-excavated areas (Class 2). All readings were recorded and mapped, and high readings were flagged for follow-up.

The final walkover survey consisted of a 100% surface scan of the excavated Class 1 areas and a 10% surface scan of Class 2 areas using an Eberline E600 2X2 Sodium Iodide detector. The detector was moved at a slow speed (approximately 2 inches or 5 cm per second) with the detector within 1 inch (2 cm) of the surface. When the instrument indicated a response above background (approximately 1,000 cpm above the ambient 8,000 cpm), the survey stopped, located the position of highest response, and performed a stationary reading with the detector within 1 inch (2 cm) of the surface. If the static reading exceeded 12,000 cpm (net) or 20,000 cpm (total), a sample was obtained to quantify the activity.

e. Performing *in situ* gamma spectroscopy at systematic grid locations

The MARSSIM method of survey design establishes a number of and location for finite samples to be obtained for contaminant quantification. In this final status survey, *in situ* gamma spectrum analysis was performed. *In situ* analysis has the advantage of the availability of results in real-time, as well as the elimination of effort, materials, shipping and analysis expenses of physical samples. One disadvantage is that *in situ* analysis usually reports a concentration value less than the laboratory sample, since *in situ* analysis is based on field samples that contain ambient moisture as well as non-radioactive rocks and biomass that are removed prior to laboratory analysis.

The BNL gamma spectrometer was calibrated to surface soil activity by acquiring gamma ray spectra *in situ* at locations of elevated activity in AOC16E1, prior to remediation. Samples were obtained from the *in situ* locations, and the samples were submitted for laboratory gamma spectrum analysis. The correlation curve of *in situ* instrument response to measured soil activity is provided in Attachment 2. The correlation curve exhibits a strong linear response relation between the two methods. The slope of the line (0.70) is indicative of the under-response of the *in situ* measurement; the *in situ* results are made comparable to laboratory analysis results by adjusting upwards the *in situ* results (divide the reported *in situ* results by 0.70).

Any areas found to exceed 23 pCi/g for Cs-137 were further excavated, resurveyed, and resampled.

2.13.2 Final Status Survey Results

The results of the surveys and sampling were used with the MARSSIM statistical methods to demonstrate that clean-up criteria have been achieved successfully in each survey unit.

a. NaI Final Walkover Survey

A walkover survey performed following excavation identified localized areas of activity above the cleanup goal remaining in the soil. The locally elevated areas were re-excavated, and another walkover survey of the re-excavated areas was performed to verify final compliance with the cleanup goal. In a few cases where single readings were near the screening levels for cleanup, readings were averaged with adjacent grids. In all cases, these average values were well below the screening criteria.

The final walkover survey consisted of a 100% surface scan of the excavated Class 1 areas and a 10% surface scan of Class 2 areas using an Eberline E600 2X2 inch Sodium Iodide detector. A static reading was taken of all scanned areas that had elevated readings of 1,000 cpm above background. If the static reading exceeded 12,000 cpm (net) or 20,000 cpm (total), a sample was taken according to criteria given in Figure A. Results of this sampling are given in Table 7.

The final walkover survey performed in each survey unit consisted of scans at the surface for each of the 2m x 2m areas in the survey unit and static readings at any observed elevated scans positions. Thus the largest area of elevated activity noted would be 4 m^2 or less. For ease of explanation and review of criteria, consider the case of a total elevated area of 25 m^2, corresponding to an Area Factor of 1.7

(from Table 5). If in an individual survey unit there were 25 m^2 of elevated area (ie, as many as six elevated areas, each approximately 4 m^2), the elevated area criteria would be met if each of the six areas in a survey unit had activity that met the unity rule criteria for an Area Factor of 1.7. Table 6 provides the unity rule criteria for the case of elevated area and Area Factor (AF) for each of the survey units in the Landscape Soil Project. Area Factors and Maximum Elevated Activities have been rounded to two significant figures.

Table 6: Maximum Activity Allowed for Elevated Area

Survey Unit	Area (m^2)	δ [Final Soil Concentration] (pCi/g)	Maximum Elevated Activity Allowed (pCi/g) for area		
			25 m^2 AF = 1.7	16 m^2 AF = 1.9	9 m^2 AF = 2.5
AOC16e1	2,320	1.07	38	43	56
AOC16e2/3	584	1.44	38	42	55
AOC16f	560	2.27	38	42	54
AOC16g	1,680	5.54	35	39	49
AOC16S1-5	525	7.07	34	37	47
AOC16s6	794	2.08	38	42	54

Table 7 identifies the 45 locations where the static reading with the NaI detector was 20,000 cpm (20 kcpm) or more. Surface soil samples were obtained at each location and submitted for quantification of the Cs-137 concentration. Those sample results are also listed in Table 7.

There were two areas (three locations) where the activity was high enough to require further remediation:

- In AOC16F, two locations had sample results of 72 pCi/g and 45.7 pCi/g. The two locations were hand excavated and a re-survey indicated that each location was no longer elevated.
- In AOC16G, one location had sample results of 58.8 pCi/g. The location was hand excavated and a re-survey indicated that the location was no longer elevated.

Following these three additional remediation actions, the remaining sample results were analyzed with the elevated measurements comparison and unity rule procedure, described in Section 2.13.1c, above. The analysis of the sample data indicated:

- In AOC16E1, there were no locations that were identified as suspect elevated by the stationary readings in the walkover survey. The survey unit complies.
- In AOC16E2-3 there was one location identified and one location sampled was above 23 pCi/g. The elevated area was less than 4 m^2 in extent and the observed concentration was 30.3 pCi/g. Table 6 indicates for AOC16E2-3 that for an activity less than 38 pCi/g, the elevated area could be up to 25 m^2. The survey unit complies.
- In AOC16F, there were two locations identified and one location sampled was above 23 pCi/g. The elevated area was less than 4 m^2 in extent and the observed concentration was 33.8 pCi/g. Table 6 indicates for AOC16F that for an activity less than 38 pCi/g, the elevated area could be up to 25 m^2. The survey unit complies.

- In AOC16G, there were 13 locations identified and 10 locations sampled were above 23 pCi/g. The combined elevated area was less than 25 m^2 in extent and the maximum observed concentration was 33.6 pCi/g. Table 6 indicates for AOC16G that for an activity less than 35 pCi/g, the elevated area could be up to 25 m^2. The survey unit complies.
- In AOC16S1-5, there were 21 locations identified and one location sampled was above 23 pCi/g. The elevated area was less than 4 m^2 in extent and the observed concentration was 28.3 pCi/g. Table 6 indicates for AOC16S1-5 that for an activity less than 34 pCi/g, the elevated area could be up to 25 m^2. The survey unit complies.
- In AOC16S6a-f, there were six locations identified and three location sampled were above 23 pCi/g. The combined elevated area was less than 10 m^2 in extent and the maximum observed concentration was 27.6 pCi/g. Table 6 indicates for AOC16S6a-f that for an activity less than 38 pCi/g, the elevated area could be up to 25 m^2. The survey unit complies.

The analysis indicates that all six survey units comply with the elevated measurement comparison.

Table 7: Elevated Results (>20 kcpm for NaI Meter) from Walkover Survey

COC-ID	Site ID/ Sample No.	Figure #	Grid Location	NaI Meter Total kcpm	Cs-137 Activity pCi/g	2-sigma Error pCi/g
7784-22	AOC16F-WO2	14	9N,19E	22.9*	45.7*	3.8
7784-23	AOC16F-WO3	14	8N,20E	27.9*	72.0*	5.8
7802-3	AOC16G-W011	15	16N,28E	27.3*	58.8*	4.8
7786-1	AOC16E2-WO1	11	4N,14E	25.4	30.3	2.7
7784-21	AOC16F-WO1	14	14N,13E	20.5	33.8	2.9
7784-24	AOC16F-WO4	14	11N,25E	23.3	11.6	1.1
7781-2	AOC16G-WO2	15	19N,48E	24.0	28.7	2.5
7781-3	AOC16G-WO1	15	23N,53E	29.0	16.8	1.6
7781-4	AOC16G-WO5	15	20N,36E	25.3	33.6	2.9
7781-6	AOC16G-WO7	15	19N,23E	24.5	24.8	2.2
7781-7	AOC16G-WO4	15	20N,38E	20.0	27.9	2.4
7781-8	AOC16G-WO8	15	16N,34E	23.5	15.5	1.5
7781-9	AOC16G-WO6	15	19N,24E	21.7	24.1	2.1
7785-1	AOC16G-WO5-2	15	20N, 36E	25.3	24.4	2.1
7785-2	AOC16G-WO7-2	15	19N,23E	24.5	30.3	2.7
7798-1	AOC16G-WO3-2	15	22N, 52E	20.0	31.6	2.7
7802-1	AOC16G-W09	15	16N,61E	24.1	6.5	0.7
7802-2	AOC16G-E010	15	18N,37E	28.3	30.1	2.6
7784-1	AOC16S2-WO1	17	7N,3E	22.6	18.7	1.8
7784-2	AOC16S2-WO2	17	21N,7E	20.8	15.7	1.5

COC-ID	Site ID/ Sample No.	Figure #	Grid Location	NaI Meter Total kcpm	Cs-137 Activity pCi/g	2-sigma Error pCi/g
7784-3	AOC16S2-WO4	17	8N,1E	20.4	11.3	1.2
7784-4	AOC16S2-WO5	17	9N,2E	21.8	12.7	1.3
7784-5	AOC16S2-WO6	17	10N,1E	20.0	13.8	1.4
7784-6	AOC16S2-WO7	17	5N,3E	22.6	9.4	1.0
7784-7	AOC16S2-WO8	17	6N,2E	20.6	10.3	1.1
7784-8	AOC16S2-WO9	17	7N,3E	22.6	14.5	1.4
7784-9	AOC16S2-WO10	17	3N,4E	21.0	22.9	2.1
7784-10	AOC16S2-WO11	17	2N,11E	21.4	11.0	1.1
7784-11	AOC16S2-WO12	17	5N,10E	22.0	13.3	1.3
7784-12	AOC16S2-WO13	17	5N,10E	22.0	17.0	1.6
7784-13	AOC16S2-WO14	17	6N,8E	23.4	13.8	1.4
7784-14	AOC16S3-WO1	17	2N,4E	20.6	17.1	1.6
7784-15	AOC16S3-WO2	17	2N,3E	23.5	18.0	1.7
7784-16	AOC16S3-WO3	17	1N,3E	21.8	15.4	1.5
7784-17	AOC16S4-WO1	17	9N,3E	24.9	19.7	1.8
7784-18	AOC16S4-WO2	17	4N,17E	20.1	7.2	0.9
7784-19	AOC16S4-WO3	17	5N,16E	21.7	13.0	1.4
7784-20	AOC16S4-WO4	17	6N,15E	24.5	21.5	2.1
7781-1	AOC16S5-WO1	18	13N,14E	23.0	28.3	2.5
7787-1	AOC16S6f-WO1	20	9N,1E	21.1	15.0	1.5
7787-2	AOC16S6f-WO2	20	8N,4E	20.6	24.6	2.2
7787-3	AOC16S6f-WO3	20	6N,4E	21.3	17.2	1.6
7787-4	AOC16S6a-WO1	19	9N,2E	20.5	27.3	2.4
7787-5	AOC16S6a-WO2	19	8N,3E	21.5	27.6	2.4
7787-6	AOC16S6b-WO1	19	18N,10E	19.5	14.7	0.4
7797-1	AOC16E1-Bkg1	11	22N,15E	6.3	0.3	0.3
7797-2	AOC16S1-Bkg2	16	10N,14E	8.9	0.7	0.2
7797-3	AOC16S6f-Bkg3	20	10N,0E	7.8	0.5	0.2
7797-4	Helipad-Bkg4	21	10N,21E	8.7	0.6	0.2

* Areas re-excavated. AOC16G resurvey found 17.1 kcpm and 1.4 pCi/gm. Resurvey for AOC 16F found 16.2 kcpm (6.2 pCi/gm) and 16.7 kcpm (11.6 pCi/gm).

b. *In situ* Gamma Spectroscopy.

Positions for the *in situ* gamma spectra acquisition are identified in Figures 11 through 21. Table 8 summarizes the number of sampling positions and the areas evaluated for each of the survey units. While the survey planning based on MARSSIM guidance developed precisely defined grid spacing for each individual survey unit, in practice the grid spacings were rounded to convenient distances (6 m, 12 m, 20 m, etc.). The triangular grid points were mapped to the 2 m by 2 m grid to facilitate locating sampling positions in the survey units. Often, the *in situ* instrument needed to be displaced from the mapped position due to the odd shapes of the excavated areas or due to interference from natural phenomena (trees, rocky terrain, etc) or man-made objects (concrete sewers, asphalt roads and curbs, buildings, etc). When this occurred, the *in situ* instrument was reposition 2-5 meters away from the interference while remaining within the Area Classification boundaries.

Results of the *in situ* gamma spectroscopy analysis for Cs-137 are provided in Table 8; other than naturally occurring radionuclides, the only radionuclide detected in the analysis was Cs-137. The values in Table 8 are gross Cs-137 soil activity - the ambient activity observed in the reference area, the Helipad area, shown in Figure 21, has not been subtracted. The Table 8 concentration values have been corrected for comparison to laboratory analysis results (by dividing the *in situ* results by 0.7) to account for the under-reporting of the *in situ* analysis.

c. <u>Laboratory Confirmation Samples</u>

Surface soil samples were obtained at positions coinciding with *in situ* analysis locations. Samples were submitted to Severn Trent Laboratories St Louis, Missouri for gamma spectroscopy analysis and for Sr-90 analysis.

- Results of the laboratory gamma spectroscopy analysis are provided in Table 9. Other than natural occurring radionuclides, the only radionuclide detected in the analysis was Cs-137. For ease of comparison, the corresponding *in situ* results from Table 8 have been repeated in Table 9.
- The results of the analysis for Sr-90 are provided in Table 10. In all cases, the laboratory analysis did not detect Sr-90 above the laboratory reporting limit of 0.5 pCi/g.

Table 8: Post Remediation Cs-137 Concentration in Soil Measured by *in situ* Gamma Spectroscopy

Area	Class	Concentration pCi/g*	1 sigma pCi/g	Det_lim pCi/g	Sample Number	Area Statistics
AOC16E1	1	2.51	0.14	0.10	AOC16E1-CS30	
AOC16E1	1	1.47	0.09	0.09	AOC16E1-CS29	
AOC16E1	1	0.38	0.03	0.07	AOC16E1-CS26	
AOC16E1	1	1.22	0.07	0.07	AOC16E1-CS25	
AOC16E1	1	0.58	0.04	0.06	AOC16E1-CS24	AOC16E1
AOC16E1	1	0.55	0.04	0.06	AOC16E1-CS23	Class 1
AOC16E1	1	0.97	0.06	0.06	AOC16E1-CS22	
AOC16E1	1	1.72	0.09	0.06	AOC16E1-CS21	Average
AOC16E1	1	0.97	0.06	0.06	AOC16E1-CS20	1.18
AOC16E1	1	2.45	0.12	0.06	AOC16E1-CS19	
AOC16E1	1	2.26	0.11	0.06	AOC16E1-CS18	Standard Dev
AOC16E1	1	0.52	0.03	0.06	AOC16E1-CS17	0.84
AOC16E1	1	0.59	0.04	0.09	AOC16E1-CS16	
AOC16E1	1	0.17	0.02	0.09	AOC16E1-CS15	
AOC16E1	1	0.30	0.02	0.09	AOC16E1-CS14	Number of Points
AOC16E1	1	2.23	0.11	0.09	AOC16E1-CS13	18
AOC16E1	1	2.10	0.11	0.09	AOC16E1-CS12	
AOC16E1	1	0.17	0.02	0.09	AOC16E1-CS11	

AOC16E1	2	0.51	0.04	0.11	AOC16E1-CS28	
AOC16E1	2	0.93	0.06	0.12	AOC16E1-CS27	AOC16E1
AOC16E1	2	3.50	0.17	0.07	AOC16E1-CS10	Class 2
AOC16E1	2	0.75	0.04	0.07	AOC16E1-CS9	
AOC16E1	2	2.24	0.10	0.07	AOC16E1-CS8	Average
AOC16E1	2	0.77	0.04	0.07	AOC16E1-CS7	0.98
AOC16E1	2	0.44	0.03	0.07	AOC16E1-CS6	
AOC16E1	2	0.50	0.03	0.07	AOC16E1-CS5	Standard Dev
AOC16E1	2	0.52	0.03	0.07	AOC16E1-CS4	0.94
AOC16E1	2	0.56	0.03	0.07	AOC16E1-CS3	Number of Points
AOC16E1	2	0.51	0.03	0.07	AOC16E1-CS2	12
AOC16E1	2	0.49	0.03	0.07	AOC16E1-CS1	
AOC16E2	1	0.63	0.04	0.08	AOC16E2-CS5	
AOC16E2	1	0.58	0.04	0.08	AOC16E2-CS6	AOC16E2/3
AOC16E2	1	0.35	0.03	0.08	AOC16E2-CS7	Class 1
AOC16E2	1	2.10	0.09	0.08	AOC16E2-CS8	
AOC16E2	1	0.31	0.02	0.08	AOC16E2-CS9	
AOC16E2	1	0.49	0.04	0.08	AOC16E2-CS14	Average
AOC16E2	1	4.71	0.24	0.13	AOC16E2-CS16	1.61
AOC16E3	1	1.76	0.08	0.07	AOC16E3-CS5	
AOC16E3	1	1.35	0.07	0.07	AOC16E3-CS6	Standard Dev
AOC16E3	1	1.32	0.06	0.07	AOC16E3-CS7	1.31
AOC16E3	1	2.82	0.12	0.07	AOC16E3-CS8	
AOC16E3	1	1.14	0.07	0.12	AOC16E3-CS12	Number of Points
AOC16E3	1	1.33	0.07	0.07	AOC16E3-CS9	14
AOC16E4	1	3.60	0.19	0.13	AOC16E4-CS2	
AOC16E2	2	0.19	0.02	0.10	AOC16E2-CS1	
AOC16E2	2	0.39	0.03	0.08	AOC16E2-CS10	AOC16E2/3
AOC16E2	2	0.19	0.03	0.11	AOC16E2-CS12	Class 2
AOC16E2	2	1.04	0.07	0.12	AOC16E2-CS13	
AOC16E2	2	0.22	0.02	0.10	AOC16E2-CS2	Average
AOC16E2	2	0.23	0.02	0.10	AOC16E2-CS3	0.73
AOC16E2	2	4.60	0.19	0.10	AOC16E2-CS4	
AOC16E3	2	0.49	0.03	0.08	AOC16E3-CS1	Standard Dev
AOC16E3	2	0.42	0.04	0.16	AOC16E3-CS10	1.14
AOC16E3	2	0.28	0.03	0.10	AOC16E3-CS11	
AOC16E3	2	0.54	0.03	0.08	AOC16E3-CS2	Number of Points
AOC16E3	2	0.68	0.04	0.08	AOC16E3-CS3	14
AOC16E3	2	0.65	0.04	0.08	AOC16E3-CS4	
AOC16E4	2	0.33	0.03	0.11	AOC16E4-CS1	
AOC16F	1	0.81	0.05	0.08	AOC16F-CS18	AOC16F
AOC16F	1	1.5	0.08	0.08	AOC16F-CS17	Class 1
AOC16F	1	1.9	0.10	0.07	AOC16F-CS16	
AOC16F	1	3.8	0.18	0.08	AOC16F-CS15	Average
AOC16F	1	1.7	0.09	0.07	AOC16F-CS14	2.27
AOC16F	1	1.8	0.09	0.07	AOC16F-CS13	Standard Dev
AOC16F	1	4.6	0.22	0.09	AOC16F-CS12	1.34
AOC16F	1	3.5	0.17	0.07	AOC16F-CS11	Number of Points
AOC16F	1	0.87	0.05	0.09	AOC16F-CS10	9

AOC16F	2	3.01	0.15	0.09	AOC16F-CS9	AOC16F Class 2 Average 2.43 Standard Dev 3.38 Number of Points 9
AOC16F	2	0.47	0.03	0.09	AOC16F-CS8	
AOC16F	2	11.15	0.51	0.10	AOC16F-CS7	
AOC16F	2	0.78	0.05	0.11	AOC16F-CS6	
AOC16F	2	0.69	0.04	0.07	AOC16F-CS5	
AOC16F	2	0.78	0.05	0.07	AOC16F-CS4	
AOC16F	2	1.65	0.09	0.08	AOC16F-CS3	
AOC16F	2	1.00	0.06	0.07	AOC16F-CS2	
AOC16F	2	2.36	0.12	0.06	AOC16F-CS1	
AOC16G	1	12.4	0.57	0.09	AOC16G-CS18	AOC16G Class 1 Average 5.54 Standard Dev 5.21 Number of Points 20
AOC16G	1	18.2	0.83	0.09	AOC16G-CS19	
AOC16G	1	5.9	0.28	0.09	AOC16G-CS20	
AOC16G	1	3.5	0.17	0.09	AOC16G-CS21	
AOC16G	1	2.5	0.12	0.09	AOC16G-CS22	
AOC16G	1	5.8	0.27	0.09	AOC16G-CS23	
AOC16G	1	0.1	0.02	0.09	AOC16G-CS24	
AOC16G	1	14.7	0.67	0.09	AOC16G-CS25	
AOC16G	1	6.9	0.32	0.09	AOC16GCS-26	
AOC16G	1	4.8	0.23	0.09	AOC16G-CS27	
AOC16G	1	0.4	0.04	0.10	AOC16G-CS32	
AOC16G	1	0.2	0.03	0.11	AOC16G-CS33	
AOC16G	1	1.5	0.09	0.13	AOC16G-CS34	
AOC16G	1	10.3	0.47	0.09	AOC16G-CS3	
AOC16G	1	1.2	0.07	0.09	AOC16G-CS4	
AOC16G	1	0.2	0.02	0.09	AOC16G-CS5	
AOC16G	1	9.6	0.44	0.09	AOC16G-CS6	
AOC16G	1	5.8	0.27	0.09	AOC16G-CS7	
AOC16G	1	5.9	0.28	0.09	AOC16G-CS8	
AOC16G	1	1.0	0.06	0.09	AOC16G-CS9	
AOC16G	2	0.30	0.03	0.09	AOC16G-CS1	AOC16G Class 2 Average 0.42 Standard Dev 0.06 Number of Points 13
AOC16G	2	0.38	0.03	0.09	AOC16G-CS11	
AOC16G	2	0.48	0.03	0.09	AOC16G-CS12	
AOC16G	2	0.47	0.03	0.09	AOC16G-CS13	
AOC16G	2	0.48	0.03	0.09	AOC16G-CS14	
AOC16G	2	0.39	0.03	0.09	AOC16G-CS15	
AOC16G	2	0.46	0.03	0.09	AOC16G-CS16	
AOC16G	2	0.47	0.03	0.09	AOC16G-CS17	
AOC16G	2	0.41	0.03	0.09	AOC16G-CS2	
AOC16G	2	0.50	0.03	0.09	AOC16G-CS28	
AOC16G	2	0.37	0.04	0.11	AOC16G-CS29	
AOC16G	2	0.39	0.04	0.20	AOC16G-CS30	
AOC16G	2	0.42	0.04	0.13	AOC16G-CS31	

AOC16S2	1	4.74	0.16	0.05	AOC16S2-CS10	AOC16S1-5
AOC16S2	1	9.94	0.32	0.07	AOC16S2-CS4	Class 1
AOC16S2	1	13.05	0.42	0.08	AOC16S2-CS5	
AOC16S2	1	6.60	0.22	0.10	AOC16S2-CS8	
AOC16S2	1	5.13	0.17	0.06	AOC16S2-CS9	Average
AOC16S5	1	2.82	0.14	0.09	AOC16S5-CS5	7.07
AOC16S5	1	7.72	0.36	0.09	AOC16S5-CS6	
AOC16S5	1	5.23	0.25	0.09	AOC16S5-CS7	Standard Dev
AOC16S5	1	7.54	0.35	0.09	AOC16S5-CS8	2.86
AOC16S5	1	5.50	0.26	0.09	AOC16S5-CS9	
AOC16S5	1	8.64	0.40	0.09	AOC16S5-CS10	Number of Points
AOC16S5	1	4.55	0.22	0.09	AOC16S5-CS11	13
AOC16S3	1	10.41	0.34	0.17	AOC16S3-CS-2	
AOC16S5	2	1.54	0.08	0.11	AOC16S5-CS1	
AOC16S5	2	8.20	0.38	0.09	AOC16S5-CS12	AOC16S1-5
AOC16S5	2	7.95	0.37	0.10	AOC16S5-CS13	Class 2
AOC16S5	2	2.22	0.11	0.09	AOC16S5-CS14	
AOC16S5	2	8.61	0.40	0.09	AOC16S5-CS15	
AOC16S5	2	1.33	0.07	0.11	AOC16S5-CS16	
AOC16S5	2	0.21	0.02	0.07	AOC16S5-CS2	
AOC16S5	2	0.42	0.03	0.09	AOC16S5-CS3	Average
AOC16S5	2	2.21	0.11	0.24	AOC16S5-CS4	3.91
AOC16S1	2	1.56	0.58	0.06	AOC16S1-CS1	
AOC16S1	2	0.45	0.02	0.06	AOC16S1-CS2	
AOC16S1	2	0.34	0.06	0.04	AOC16S1-CS3	Standard Dev
AOC16S1	2	0.18	0.01	0.03	AOC16S1-CS4	4.05
AOC16S1	2	0.30	0.02	0.04	AOC16S1-CS5	
AOC16S1	2	0.50	0.02	0.05	AOC16S1-CS6	Number of Points
AOC16S1	2	0.27	0.02	0.52	AOC16S1-CS7	26
AOC16S2	2	5.07	0.17	0.07	AOC16S2-CS1	
AOC16S2	2	5.40	0.18	0.07	AOC16S2-CS2	
AOC16S2	2	8.52	0.39	0.10	AOC16S2-CS3	
AOC16S2	2	5.22	0.25	0.09	AOC16S2-CS6	
AOC16S2	2	0.29	0.02	0.08	AOC16S2-CS7	
AOC16S3	2	0.71	0.03	0.06	AOC16S3-CS1	
AOC16S4	2	14.01	0.45	0.08	AOC16S4-CS1	
AOC16S4	2	6.94	0.23	0.07	AOC16S4-CS2	
AOC16S4	2	10.14	0.33	0.14	AOC16S4-CS3	
AOC16S4	2	9.15	0.30	0.08	AOC16S4-CS4	
AOC16S.6a-f	1	1.94	1.11	0.12	AOC16S6a-CS2	
AOC16S.6a-f	1	1.69	0.10	0.18	AOC16S6a-CS3	AOC16S.6a-f
AOC16S.6a-f	1	4.86	0.24	0.14	AOC16S6a-CS4	Class 1
AOC16S.6a-f	1	2.74	0.15	0.13	AOC16S6a-CS5	
AOC16S.6a-f	1	1.46	0.09	0.11	AOC16S6b-CS4	Average
AOC16S.6a-f	1	2.14	0.12	0.11	AOC16S6b-CS5	2.08
AOC16S.6a-f	1	2.06	0.12	0.11	AOC16S6b-CS6	
AOC16S.6a-f	1	3.27	0.17	0.11	AOC16S6c-CS1	
AOC16S.6a-f	1	2.50	0.14	0.11	AOC16S6c-CS2	Standard Dev
AOC16S.6a-f	1	0.87	0.06	0.11	AOC16S6d-CS2	1.15
AOC16S.6a-f	1	0.78	0.06	0.09	AOC16S6d-CS6	
AOC16S.6a-f	1	1.07	0.07	0.09	AOC16S6d-CS7	Number of Points
AOC16S.6a-f	1	0.47	0.04	0.11	AOC16S6d-CS8	15
AOC16S.6a-f	1	3.33	0.17	0.12	AOC16S6e-CS3	
AOC16S.6a-f	1	2.08	0.12	0.13	AOC16S6e-CS4	

AOC16S.6a-f	2	4.80	0.24	0.13	AOC16S6a-CS1	AOC16S.6a-f Class 2 Average 1.48 Standard Dev 1.96 Number of Points 17
AOC16S.6a-f	2	5.54	0.27	0.13	AOC16S6a-CS6	
AOC16S.6a-f	2	0.79	0.06	0.11	AOC16S6a-CS7	
AOC16S.6a-f	2	6.08	0.30	0.14	AOC16S6b-CS1	
AOC16S.6a-f	2	0.30	0.03	0.10	AOC16S6b-CS2	
AOC16S.6a-f	2	0.67	0.05	0.10	AOC16S6b-CS3	
AOC16S.6a-f	2	0.48	0.04	0.10	AOC16S6b-CS7	
AOC16S.6a-f	2	0.54	0.04	0.12	AOC16S6c-CS3	
AOC16S.6a-f	2	0.39	0.04	0.10	AOC16S6c-CS4	
AOC16S.6a-f	2	0.18	0.03	0.09	AOC16S6d-CS1	
AOC16S.6a-f	2	0.22	0.03	0.08	AOC16S6d-CS3	
AOC16S.6a-f	2	0.88	0.06	0.10	AOC16S6d-CS4	
AOC16S.6a-f	2	0.87	0.06	0.10	AOC16S6d-CS5	
AOC16S.6a-f	2	0.36	0.04	0.10	AOC16S6e-CS1	
AOC16S.6a-f	2	1.18	0.08	0.13	AOC16S6e-CS2	
AOC16S.6a-f	2	1.72	0.10	0.11	AOC16S6f-CS1	
AOC16S.6a-f	2	0.18	0.03	0.09	AOC16S6f-CS2	
094-14	ref	0.39	0.08	0.11	094-14-CS1	Reference Class ref Average 0.47 Standard Dev 0.21 Number of Points 20
094-14	ref	1.01	0.20	0.33	094-14-CS2	
094-14	ref	0.43	0.08	0.11	094-14-CS3	
094-14	ref	1.14	0.20	0.23	094-14-CS4	
094-14	ref	0.40	0.08	0.10	094-14-CS5	
094-14	ref	0.37	0.07	0.12	094-14-CS6	
094-14	ref	0.47	0.08	0.10	094-14-CS7	
094-14	ref	0.44	0.08	0.09	094-14-CS8	
094-14	ref	0.47	0.08	0.13	094-14-CS9	
094-14	ref	0.43	0.08	0.12	094-14-CS10	
094-14	ref	0.49	0.09	0.13	094-14-CS11	
094-14	ref	0.23	0.06	0.10	094-14-CS12	
094-14	ref	0.41	0.08	0.11	094-14-CS13	
094-14	ref	0.44	0.08	0.14	094-14-CS14	
094-14	ref	0.43	0.08	0.12	094-14-CS15	
094-14	ref	0.37	0.08	0.10	094-14-CS16	
094-14	ref	0.41	0.08	0.10	094-14-CS17	
094-14	ref	0.41	0.08	0.14	094-14-CS18	
094-14	ref	0.43	0.08	0.10	094-14-CS19	
094-14	ref	0.32	0.07	0.12	094-14-CS20	

* Concentration adjusted by dividing *in situ* results by 0.7.

Table 9: Post Remediation *in situ* Gamma Spectroscopy Results Compared to Confirmatory Laboratory Sample Analysis

Area	Class	Activity of Cs-137 (pCi/g)			Sample Number
		Concentration*	2 Sigma	MDA	
AOC16E1	1	0.59	0.076	0.086	AOC16E1-CS16 : ISOCS
AOC16E1	1	0.34	0.093	0.072	AOC16E1-CS16 : STL
AOC16E1	1	0.97	0.11	0.057	AOC16E1-CS20 : ISOCS
AOC16E1	1	0.43	0.11	0.07	AOC16E1-CS20 : STL
AOC16E1	2	0.49	0.062	0.071	AOC16E1-CS1 : ISOCS
AOC16E1	2	0.6	0.14	0.11	AOC16E1-CS1 : STL
AOC16E2/3	1	2.82	0.24	0.077	AOC16E3-CS8 : ISOCS
AOC16E2/3	1	1.35	0.13	0.14	AOC16E3-CS8 : STL
AOC16E2/3	1	0.305	0.046	0.077	AOC16E2-CS9 : ISOCS
AOC16E2/3	1	0.274	0.099	0.099	AOC16E2-CS9 : STL
AOC16E2/3	2	0.49	0.06	0.08	AOC16E3-CS1 : ISOCS
AOC16E2/3	2	0.47	0.13	0.08	AOC16E3-CS1 : STL

Area	Class	Activity of Cs-137 (pCi/g)			Sample Number
		Concentration*	2 Sigma	MDA	
AOC16G	1	1.2	0.14	0.09	AOC16G-CS4 : ISOCS
AOC16G	1	0.03	0.08	0.15	AOC16G-CS4 : STL
AOC16G	1	28.4**	2.6	0.08	AOC16G-CS10 : ISOCS
AOC16G	1	36.8**	4.4	0.1	AOC16G-CS10 : STL
AOC16G	2	0.47	0.06	0.09	AOC16G-CS17 : ISOCS
AOC16G	2	0.37	0.13	0.12	AOC16G-CS17 : STL
AOC16F	2	2.36	0.24	0.06	AOC16F-CS1 : ISOCS
AOC16F	2	3.50	0.49	0.10	AOC16F-CS1 : STL
AOC16F	1	0.81	0.10	0.08	AOC16F-CS18 : ISOCS
AOC16F	1	0.98	0.18	0.09	AOC16F-CS18 : STL
AOC16S5	2	1.54	0.16	0.11	AOC16S5-CS1 : ISOCS
AOC16S5	2	0.41	0.10	0.07	AOC16S5-CS1 : STL
AOC16S5	1	8.64	0.80	0.09	AOC16S5-CS10 : ISOCS
AOC16S5	1	3.63	0.49	0.06	AOC16S5-CS10 : STL
AOC16S2	1	9.94	0.64	0.07	AOC16S2-CS4 : ISOCS
AOC16S2	1	5.92	0.78	0.06	AOC16S2-CS4 : STL
AOC16S2	2	5.07	0.34	0.07	AOC16S2-CS1 : ISOCS
AOC16S2	2	5.33	0.70	0.10	AOC16S2-CS1 : STL
AOC16S2	1	13.05	0.84	0.08	AOC16S2-CS5 : ISOCS
AOC16S2	1	9.90	1.20	0.10	AOC16S2-CS5 : STL
AOC16S3	1	10.41	0.68	0.17	AOC16S3-CS2 : ISOCS
AOC16S3	1	6.27	0.71	0.07	AOC16S3-CS2 : STL
AOC16S3	1	10.4	0.7	0.17	AOC16S3-CS2 : ISOCS
AOC16S3	1	14.8	1.9	0.1	AOC16S3-CS3 : STL
AOC16E4	1	3.6	0.38	0.13	AOC16E4-CS2 : ISOCS
AOC16E4	1	3.66	0.47	0.07	AOC16MR-CS1 : STL
AOC16E4	1	4.49	0.62	0.06	AOC16MR-CS2 : STL
AOC16E4	1	2.38	0.30	0.07	AOC16MR-CS3 : STL
AOC16E4	1	4.28	0.56	0.08	AOC16MR-CS4 : STL

* Concentrations adjusted by dividing *in situ* results by 0.7.
** Location subsequently excavated since it exceeded the clean-up goal.

Table 10: Post Remediation Sr-90 Laboratory Sample Analysis

Area	Class	Activity of Sr-90 (pCi/g)			Data Qualifier	Sample Number
		Concentration	2 sigma	MDA		
AOC16G	1	0.33	0.29	0.47	U	AOC16G-CS4 : STL
AOC16G	1	0.65	0.27	0.37	J	AOC16G-CS10 : STL
AOC16G	2	0.18	0.25	0.41	U	AOC16G-CS17 : STL
AOC16S5	2	0.50	0.18	0.24	J	AOC16S5-CS1 : STL
AOC16S5	1	0.15	0.16	0.26	U	AOC16S5-CS10 : STL
AOC16S2	1	0.20	0.18	0.28	U	AOC16S2-CS4 : STL
AOC16S2	2	0.06	0.13	0.21	U	AOC16S2-CS1 : STL
AOC16S2	1	0.43	0.29	0.45	U	AOC16S2-CS5 : STL
AOC16S3	1	0.42	0.26	0.40	J	AOC16S3-CS2 : STL
AOC16S3	2	0.44	0.29	0.44	J	AOC16S3-CS3 : STL
AOC16E4	1	0.29	0.34	0.56	U	AOC16MR-CS1 : STL
AOC16E4	1	0.44	0.30	0.48	U	AOC16MR-CS2 : STL
AOC16E4	1	0.37	0.37	0.60	U	AOC16MR-CS3 : STL
AOC16E4	1	0.44	0.39	0.63	U	AOC16MR-CS4 : STL
AOC16E4	1	0.22	0.30	0.51	U	AOC16MR-CS4dup : STL

Codes J Result is greater than the sample detection limit but less than the reporting limit.
U Result is less than the sample detection limit.

2.13.3 Final Status Survey Conclusions

The statistical summary for the average activity in each survey unit, provided in the rightmost column of Table 8, indicates that the average activity in each of the survey units is below the clean-up goal. Since each of the final sample results at each of the *in situ* positions is less than the clean-up goal, in accordance with MARSSIM Section 8.2.2 further statistical testing is not necessary to demonstrate compliance with the clean-up- goal. Where the walkover survey demonstrated that small areas of activity elevated were above the clean-up goal, these areas were removed and resurveyed. Thus each area also meets the clean-up goal for elevated measurements.

2.13.4 Independent Verification

The Oak Ridge Institute for Science and Education (ORISE) served as an independent authority from BNL to verify that remediation efforts were sufficient to support the conclusion that clean-up goals were achieved. ORISE, under contract to DOE, prepared a separate survey plan, reviewed project surveys and analysis results, and performed an independent field verification sampling survey to evaluate the final status after remediation. In addition, the NYSDEC performed an independent verification to support that clean up goals were achieved. The radiation survey reports and conclusions of the independent verification are provided in the Attachment 1.

3.0 Waste Management

3.1 Waste Characterization and Handling

The waste management strategy, waste characterization, packaging, handling, and storage was in accordance with BNL's waste management procedures. The waste was designated as low-level radioactive waste and was stored, handled, and loaded for transport at the Former Chemical Holes Area.

The low-level radioactive waste was shipped to Envirocare Incorporated located in Clive, Utah. Based on the analytical data from soil samples collected during the Remedial Investigation, supplemental sampling performed by BNL in 1999, and data collected by ThermoRetec in 1999, the maximum Cs-137 level for all the contaminated sites was 348 pCi/g. This level was well below Envirocare's Waste Acceptance Criteria for Cs-137 of 60,000 pCi/g which is provided in Envirocare's State of Utah Radioactive Material License.

The sampling effort during the Remedial Investigation included sampling of the landscape soil waste stream for Total Metals and Total Pesticides. Based on these results, additional sampling was conducted for TCLP Metals and TCLP pesticides. These results confirmed that the soil was not hazardous in the areas identified for excavation and processing.

3.2 Waste Shipment and Disposal

Transport to Envirocare occurred by placing the contaminated soil into rail cars for transportation via rail lines. The contaminated soil processed by the SGS was deposited directly into eight rail cars. The remaining soils excavated were packaged in 10 cubic yard soft-sided containers and transported to the landfill area for loading onto railcars and shipping off site. Figure 24 shows the loading of the containers at AOC 16G.

Figure 24: AOC 16G Building 30 - Brookhaven Center June 30, 2000

4.0 Post Closure Dose Assessment

A post closure dose assessment was performed to measure post cleanup dose exposures for each remediated area and to verify that the total annual dose was less than 15 mrem. The dose assessment was completed by using the RESRAD model to calculate the future doses from residual contamination remaining after remediation. The doses were calculated assuming six inches of backfill in place and 50 years of continued DOE control. These calculations verify that the 15 mrem annual limit has been met for Cs-137 at each AOC. RESRAD runs are provided in Attachment 3.

4.1 Post Remediation Exposure Assessment

In the post remediation exposure assessment, three exposure scenarios were explored. The first was an industrial/commercial use scenario where present day workers were exposed to radiation from Cs-137 residual soil contamination within each AOC. The second was a future resident scenario where exposure occurs fifty years in the future to an individual (s) who constructs and lives in a home over the affected areas. The third was a current resident scenario where exposure occurs in the present to an individual (s) who constructs and lives in a home over the affected areas. All scenarios were modeled using RESRAD, version 5.95.

The demographic and hydrogeological parameters used for modeling the exposures were mostly the same as those used in the initial Remedial Investigation (RI) analysis done for OU II. The differences between the RI analysis and the post remediation exposure analysis consisted of the size of the areas of exposure, the levels of radioactivity within each of the areas and use of a soil cover for the excavated and backfilled area.

The soil radioactivity measurements are summarized in Table 11. Cs-137 (Cs-137) was the only contaminant of concern. The contribution of any other radionuclides to any current or future exposures are negligible and thus they need not be considered. A summary of the AOC areas and measurement data is provided in the following table.

Table 11: Soil Area and Concentration Summary for OU II AOCs

AOC	Class I		Class II	
	Areas (m²)	Mean Activity (pCi/g of Cs-137)	Areas (m²)	Mean Activity (pCi/g of Cs-137)
16E.1	2,320	1.07	3110	1.03
16E.2-3	584	1.44	2050	0.73
16F	560	2.27	1030	2.43
16G	1,680	5.54	10720	0.42
16S.1-5	525	7.07	2810	3.91
16S.6a-f	794	2.08	2040	1.48

It was necessary to perform two separate RESRAD assessments for each scenario (worker and future site resident) since the Class I areas were considered to have a six (6) inch soil cover and six (6) inch thick contamination zone, while the Class II areas had no soil cover and a one (1) foot thick contamination zone. The dose assessment results are summarized in Table 12.

Table 12: Dose Assessment Summary

AOC	Class I Annual Dose (mrem/yr)			Class II Annual Dose (mrem/yr)		
	Worker	Resident		Worker	Resident	
Years Post Remediation	**0**	**0**	**50**	**0**	**0**	**50**
16E.1	0.1	0.2	0.1	0.7	2.1	0.5
16E.2-3	0.1	0.3	0.1	0.5	1.5	0.4
16F	0.1	0.4	0.2	1.6	4.9	1.2
16G	3.2	1.0	0.4	0.3	0.9	0.2
16S.1-5	0.4	1.3	0.6	2.7	8.0	2.0
16S.6a-f	0.1	0.4	0.2	1.0	3.0	0.8

The remediation exposure analysis indicates that potential exposures to workers and future site residents are much less than the 15 mrem/yr criteria. At t = 0, a current site resident's annual dose would still meet the guideline of less than 15 mrem and the ALARA goal of 10 mrem/yr. The residential mean concentrations are below those of the residential goal for today of 7 pCi/g of Cs-137. Therefore, these areas require no postings or further institutional controls. The excavated areas will be included in the first five year review to document completion. The AOCs not addressed in this report (AOCs 16A-D, 16I, 16J, and 16M-Q) are active facilities that will be monitored and require institutional controls. These facilities will be decontaminated and decommissioned upon closure.

5.0 Lessons Learned

The following is a summary of the lessons learned from this project:

1. The same field instruments for measuring radioactivity should be used before, during, and after excavation to obtain consistent survey results.

2. Scanning surveys are more effective finding elevated concentrations than static measurements and should be used more extensively.

3. All remediation should be totally completed before scheduling the independent verification contractor and regulators to perform the final status verification sampling.

For example, several areas of elevated radioactivity were found during the independent validation survey conducted by ORISE and a survey conducted by NYSDEC. The validation team was requested to come based on results of the ISOCS field measurements but before BNL finished evaluating its radiological walk over survey data for the presence of elevated areas. Also, since BNL did not scan the areas and only measured static levels in a grid, several elevated spots were missed. These elevated areas found by ORISE and NYSDEC were further excavated by BNL until clean up goals were met. Following this spot clean up, criteria were developed, following the MARSSIM process, to establish the maximum concentration and numbers of spot concentrations allowed above the clean up goal. The final scanning walk over survey and soil sampling were performed by BNL and showed that all remediated areas met the clean up goal and that the number of elevated locations met the established criteria.

5.0 List of References

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