INDEPENDENT VERIFICATION SURVEY REPORT FOR THE WASTE LOADING AREA BROOKHAVEN NATIONAL LABORATORY UPTON, NEW YORK

P.C. Weaver

Prepared for the
U.S. Department of Energy

ORISE

Oak Ridge Institute for Science and Education

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FOR THE
WASTE LOADING AREA
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK

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FINAL REPORT

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ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission
AOC	area of concern
b_i	number of background counts in the interval
d'	index of sensitivity
μg	micrograms
$\mu\text{R/h}$	microroentgens per hour
$\mu\text{rem/h}$	microrem per hour
BKG	background
BNL	Brookhaven National Laboratory
BSO	Brookhaven Site Office
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
cm^2	square centimeter
CO	cleanup objectives
COC	contaminants of concern
cpm	counts per minute
Cs-137	cesium-137
DCGL	derived concentration guideline level
DOE	U.S. Department of Energy
D&D	decontamination and decommissioning
EPA	Environmental Protection Agency
FIPS	Federal Information Processing Standard
FHWMF	Former Hazardous Waste Management Facility
FSP	Field Sampling Plan
FSS	final status survey
FSSR	final status survey report
g	gram
GPS	global positioning system
HS	hot spot
ISM	Integrated Safety Management
ITP	Intercomparison Testing Program
IV	independent verification
IVC	Independent Verification Contractor
IVT	Independent Verification Team
JHA	job hazard analysis
keV	kiloelectron volts
kg	kilogram
m	meter
mg	milligram
MAPEP	Mixed Analyte Performance Evaluation Program
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MeV	million electron volts

ABBREVIATIONS AND ACRONYMS (continued)

m ²	square meter
min	minute
mm	millimeter
mrem	millirem
NaI	sodium iodide
NIST	National Institute of Standards and Technology
NPL	National Priorities List
NRIP	NIST Radiochemistry Intercomparison Program
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
OU	Operable Unit
pCi/g	picocuries per gram
P _o	fixed threshold
PSP	project-specific plan
RA	remedial actions
Ra-226	radium-226
RCRA	Resource Conservation and Recovery Act
RSS	ranked set sampling
sec	second
SPCS	State Plane Coordinate System
Sr-90	strontium-90
SU	survey unit
TAP	total absorption peak
VSP	Visual Sampling Plan
WLA	Waste Loading Area
yr	year
yd ³	cubic yard

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FOR THE WASTE LOADING AREA
FORMER HAZARDOUS WASTE MANAGEMENT FACILITY
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK**

INTRODUCTION AND SITE HISTORY

The Brookhaven National Laboratory (BNL) located in Upton, Suffolk County, New York conducts research and development for the Department of Energy (Figure A-1). BNL was originally occupied by the U.S. Army as Camp Upton during both World Wars I and II. In 1947, the site was transferred to the Atomic Energy Commission (AEC). The AEC was resolved into the Energy Research and Development Administration, and later into the Department of Energy (DOE) Brookhaven Site Office (BSO).

On December 21, 1989, BNL was included on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List. The DOE-BSO entered into an agreement to establish the framework and schedule for characterizing, assessing, and remediating the site in accordance with CERCLA and the Resource Conservation and Recovery Act (RCRA) requirements. BNL generated the Response Strategy Document that identified various Areas of Concern (AOC) and grouped each AOC into seven “Operable Units” (OU). OU-1 is the Former Hazardous Waste Management Facility (FHWMF); a 12-acre controlled compound that once served as the central receiving facility for processing, limited treatment, and storage of radioactive wastes during the late 1940s to 1997. RCRA hazardous wastes were handled at the facility from 1976 until it closed in 1997. In 2003, remediation of the FHWMF began with the removal of several building structures and operations areas. Remediation of soils and subsurface structures followed with completion of remedial actions (RA) in 2006. BNL recently completed the final stage of remediation at the FHWMFs Waste Loading Area (WLA), which had been used to stage and load waste materials excavated during the previous FHWMF remediation tasks.

DOE-BSO is responsible for oversight of remedial actions that are conducted at the BNL. It is the policy of the DOE to perform independent (third party) verification of final status survey (FSS) activities (DOE 2006). The purpose of independent verification (IV) is to confirm that remedial actions have been effective in meeting established guidelines and that documentation accurately and

adequately describes the final site conditions. Oak Ridge Institute for Science and Education (ORISE) has been requested by DOE-BSO to perform IV of the WLA. Through a third party, DOE can provide a level of assurance to the stakeholders that the as-left radiological concentration in the WLA will be well below the approved remediation guidelines. ORISE had previously performed IV of the larger phase of FHWMF remediation (ORISE 2005).

In May of 2008, ORISE conducted IV of the remediation process through document reviews and field verification to confirm that the FSS sampling results could be independently verified. ORISE implemented various survey activities that included walkover gamma scans and soil sampling, to evaluate the WLA. The elements of the IV were based on the objectives specified in the scope of work for the FHWMF (ORISE 2007a).

The primary contaminants are Cs-137 and Sr-90 (Table 1). However, Ra-226 has been identified at the WLA in limited areas in small quantities.

SITE DESCRIPTION

The WLA is located in the northeast corner of the 12 acre FHWMF (Figure A-2). The WLA also included a staging area and raised platform to load waste onto railcars for off-site shipments. The small area of the WLA consists of approximately 2 acres, divided into 4 Class 1 survey units (SUs).

OBJECTIVES

The objective of the verification survey was to obtain evidence by means of measurements and sampling to confirm that the final radiological conditions were less than the established release criteria. This objective was achieved via multiple verification components including document reviews to determine the accuracy and adequacy of FSS documentation.

DOCUMENT REVIEW

ORISE reviewed the BNL Field Sampling Plan (FSP) for compliance with the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) and for technical content (BNL 2008, NRC 2000). Comments made by ORISE focused on the application of the MARSSIM process by BNL for determining if remedial actions were sufficient to meet guideline expectations (ORISE 2007b). ORISE also reviewed available site data as provided.

PROCEDURES

ORISE personnel visited the BNL site from May 19 through 21, 2008 to perform visual inspections and independent measurements and sampling. The verification activities were conducted in accordance with the project-specific verification plan, the IEAV Survey Procedures, and Quality Program Manuals (ORISE 2008a and 2008b, and ORAU 2007). The collective site areas verified consisted of four SUs measuring between 1900 m² to 2000 m² each. All 4 SUs were designated Class 1 in accordance with MARSSIM guidance because of the potential for contamination from the nature of the activities conducted in the area.

REFERENCE SYSTEM

ORISE used a global positioning system (GPS) for documenting survey area boundaries and tracking data. The specific geological reference system used was the State Plane Coordinate System (SPCS) New York Long Island Federal Information Processing Standard (FIPS) 3104. A shape file for each SU boundary and dimension was created and then loaded into a GPS for use by the Independent Verification Team (IVT) for tracking survey data and identifying measurement and sampling locations. Coordinate measurements collected using the GPS were accurate to within one meter.

SURFACE SCANS

High density surface scans for gamma radiation were conducted over the accessible Class 1 SU areas and low density scans performed around the western perimeter of the WLA. Surface scans were performed using NaI scintillation detectors coupled to a ratemeters or ratemeter-scalers with audible indicators. Detectors were coupled to GPS systems that enable real-time gamma count rate and

position data capture. Locations of elevated direct radiation, suggesting the presence of residual contamination, were marked and identified for further investigation.

SOIL SAMPLING

The Visual Sampling Plan (VSP) software was used to generate random coordinates for gamma measurements and soil sampling. These measurement/sample points were down-loaded to the GPS and were based upon the reference grid system established by the site. These predetermined random field assessment and the resultant soil sample locations were designed and generated based on the ranked set sampling (RSS) approach (EPA 2006).

RSS provides a methodology to estimate the mean concentration of a population; however, it does not require the assumption of a normal distribution. The process combines random sampling with the use of professional judgment to select sampling locations. Professional judgment relies upon the ability to assess the relative magnitude of gamma radiation levels between randomly selected locations. In this case, the gamma count rate data collected at randomly selected locations provided the measurable field screening method that correlates with the relative concentrations of the gamma-emitting contaminants of concern. The count rate data obtained were then used to select a specific sampling location.

The following example explains the process:

- The VSP v.5.0, or higher, RSS module was used to determine the necessary number of soil samples to estimate the mean radionuclide concentration in each SU (DOE 2007). The number of measurements is based on the expected standard deviation and desired confidence level of the estimated mean.
- For this example, assume that the VSP systematic planning process resulted in $n = 6$ soil samples to estimate the mean.
- The next step uses a replication process on a larger random population from which the locations for the 6 soil samples are selected.
- The replication process is referred to as a cycle, designated as r .
- Each cycle (r) consists of multiple sets; sets are designated as m .
- Each set (m) is comprised of a set size, or field assessment locations. The data from each set are ultimately the values that are ranked, for this project the ranked values were direct

gamma counts. The set size normally consists of 2 to 5 field assessment locations. For this project a set size consisted of 3 locations, the gamma count data collected from the 3 locations associated with each set were ranked as being the low, medium, or high gamma count locations. The three ranking categories establish the set size.

- The total number of repetitive cycles (r) is a function of n (6) and m (3)—or simply defined as $n = m \times r$. r for this example would therefore, be $r = 6/3$.
- The number of field assessment locations per cycle, is a function of the set size and is simply m^2 . The total number of field assessment locations is then defined as $m^2 \times r$ or in this example $3^2 \times 2 = 18$.
- The 18 locations are then both randomly grouped into cycle/sets and distributed in the survey area. The nomenclature for identifying a specific assessment location is cycle#-set#-arbitrary sequence # (1, 2, or 3). The first location in cycle 1 of set 1 would be designated as 1-1-1. Mapping is color coded (based on cycle ID) using geometric shapes (based on set ID) to visually show the population of assessment locations.
- Specific measurement locations are generated via either a pseudo- or quasi-random approach. Figure 1 shows the RSS measurement/sampling plan developed by ORISE for use at the WLA.

**FIGURE 1: WLA SURVEY UNITS RANKED SET SAMPLING
CYCLE, SETS, AND LOCATIONS**

Cycle 1 Gamma Measurement Locations

■, ▲, ●
Set: 1, 2, 3

Cycle 2 Gamma Measurement Locations

■, ▲, ●
Set: 1, 2, 3

A one-minute static gamma count rate measurement was performed at each of the 18 assessment locations (Figure A-3). The data within a given cycle-set are then ranked as exhibiting either the lowest, medium, or highest gamma count (Tables B-1 through B-4). Six soil samples were collected from each survey unit. The following process was used to select the specific sampling location within each of the 2 cycles: Set 1, lowest gamma radiation location; Set 2 medium location; Set 3 highest location. Tables B-1 through B-4 provide the RSS cycle set with field assessment data and ranked set soil sample identification.

Figures A-4 through A-7 show the random ranking and the soil sample locations. Judgmental samples were collected from locations of elevated direct gamma radiation requiring additional investigation that ORISE identified (Figure A-8).

SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and data were returned to the ORISE/IEAV laboratory in Oak Ridge, Tennessee for analysis and interpretation. Sample analyses were performed in accordance with the ORISE Laboratory Procedures Manual (ORISE 2008c). Soil samples were analyzed by gamma spectroscopy for Ra-226 and Cs-137. The spectra were reviewed for other identifiable photopeaks. Sr-90 was quantified by radiochemical separation and counting on a low background proportional counter. Soil sample results were reported in units of picocuries per gram (pCi/g). The data generated were compared with the approved release criteria established for the WLA (BNL 2008).

APPLICABLE SITE GUIDELINES

The radiological contaminants of concern and the soil cleanup levels for the WLA are shown in Table 1 and have been previously identified in the OU I ROD (BNL1999). This FSP relies on the previously developed cleanup goals and derived concentration guideline levels (DCGL), because the WLA was originally a portion of the FHWMF. Because multiple contaminants are present, application of the unity rule is involved requiring calculation of the sum-of-ratios (SORs) in accordance with the following equation:

$$\frac{Conc_{Ra-226}}{DCGL_{Ra-226}} + \frac{Conc_{Cs-137}}{DCGL_{Cs-137}} + \frac{Conc_{Sr-90}}{DCGL_{Sr-90}} \leq 1$$

TABLE 1 RADIONUCLIDES OF CONCERN IN THE WASTE LOADING AREA – INDUSTRIAL LAND USE BROOKHAVEN NATIONAL LABORATORY	
Radionuclide	OU I ROD (pCi/g)
Cs-137	67
Sr-90	15
Ra-226	5

FINDINGS AND RESULTS

The results for each verification component at the FHWMF are discussed below.

Document Review

The ORISE review of BNL's FSP for the WLA project identified several items associated with the application of the MARSSIM guidance. A primary area of concern was how BNL would implement the application of the unity rule and demonstrating compliance using various techniques. This included the use of the appropriate instrumentation, development of a scan-MDC, application of the DCGL and hot spot comparison, and appropriate calculation methods. Comments were provided to the DOE (ORISE 2007b). ORISE also had the opportunity to review scan and sample data gathered during the FSS effort by BNL (DOE 2008a, b, and c). Actions were implemented by BNL in accordance with the FSP reviewed by ORISE. BNL has not provided an FSS report or equivalent at the time this draft document was prepared.

Surface Scans

Gamma surface scans identified elevated direct gamma radioactivity upwards of 72,000 cpm in SUs 2 and 3. Hot spot locations were marked and reported to BNL to be remediated to allow ORISE to rescan the area. Gamma area scan count rates generally ranged from 8,000 to approximately 50,000 counts per minute (cpm). The mean gamma count rate for the WLA was approximately 17,000 cpm. The count rate frequency distributions of the gamma scans for all of the WLA have been illustrated in Figure A-9. The variability in the distribution of the count rate is skewed to the right

due to the generally elevated Cs-137 concentrations in the soil. Gamma scan patterns and count rate ranges have been provided in Figures A-10 through A-13. During the walkover scan in SU4 the gamma count rates were monitored via the audio output; however, the count rate data were not electronically captured for the entire survey unit. The detector positions were logged and illustrated in Figure A-13. Each individual SU gamma scan pattern and count rate is provided in Figures A-14 to A-17. A background reference area was not defined by ORISE prior to the survey; therefore, all point measurements contain gross data results.

ORISE identified gamma radiation levels in SU 1 and SU 3 that were greater than the site action level of 49,000 cpm. Both areas were documented by ORISE and BNL was notified of the finding. BNL removed additional material from the areas after which ORISE re-evaluated and determined that radiation levels had decreased significantly.

ORISE was asked by DOE to scan at least a 10 meter (m) perimeter area adjacent to the WLA to determine if there might have been some migration of contaminants during the time the WLA was in operation (Figure A-18). Only the western portion of WLA perimeter was scanned; however, this area was surveyed as part of the IV phase of the initial clean-up of the FHWMF that was conducted in 2005 (ORISE 2005). No areas exceeding the 49,000 cpm action level were identified. The gamma count rate level in this area ranged from 8,000 up to 42,000 cpm (Figure A-19).

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

The gamma count rate data used for selecting the appropriate random sample locations can be found in Tables B-1 to B-4. The summary radionuclide concentration data for each survey unit have been presented in Table B-5. The data for the radionuclide concentrations in individual samples and the sum-of-ratios are provided in Table B-6. The concentration of Ra-226 in random samples ranged from 0.39 to 0.73 pCi/g, Cs-137 ranged from 1.61 to 45.4 pCi/g, and Sr-90 ranged from 0.14 to 1.62 pCi/g. The highest concentration of Cs-137 (45.4 pCi/g) was identified in sample S015.

Two judgmental soil samples were collected by ORISE; samples S019 and S026 from SU 3 and 4, respectively (Figure A-8). These soil samples were collected based upon surface scan radiation levels

in the area. The results have been provided in Table B-6. The concentrations in samples S019 and S026 for Ra-226 were 0.43 and 0.79, 45.0 and 34.6 for Cs-137, and 0.30 and 0.42 for Sr-90, respectively.

COMPARISON OF RESULTS WITH GUIDELINES

The final radionuclide concentration for the WLA must meet the guidance per the BNL FSP for each individual soil sample and the SOR for the average concentration must be less than one. In all individual soil samples the SOR was determined to be below one. SOR for individual samples are included in Table B-6. Ra-226 results were well below the site guideline of 5 pCi/g; the highest Ra-226 was identified in the judgmental sample S026 at 0.79 pCi/g. Sr-90 concentrations were also below the guideline (15 pCi/g). Sample S001 had the highest activity at 1.62 pCi/g. The highest concentration of Cs-137 was 45.4 pCi/g in sample S015, which is below the 67 pCi/g guideline. The mean survey unit concentrations for Cs-137 ranged from 4.77 to 18.73 pCi/g, with the highest mean Cs-137 concentration determined for SU 4. Both judgmental samples were below guideline values for the primary radionuclides of concern. Normally, the mean concentration values would be compared with the FSS results. However, this information has not been provided at the time of this report.

SUMMARY

During the period between May 19 through 21, 2008, an independent verification team with the Oak Ridge Institute for Science and Education conducted measurements and sampling of the Waste Loading Area on the Brookhaven National Laboratory site. The WLA is a small area located at the northeast end of the 12 acre Former Hazardous Waste Management Facility that was used to load contaminated debris and soil into railcars. It consists of four Class 1 survey units. Gamma scans identified a couple of small areas of elevated radiation that were reported to BNL for additional remediation. ORISE collected 24 random soil samples using the Ranked Set Sample methodology and two judgmental soil samples. All individual samples and the corresponding survey unit mean concentration were determined to be below the established guidelines. ORISE performed walkover gamma scans along the western side of the WLA. Gamma count rate activity was below 49,000 cpm, which would have required additional investigation. No soil samples were collected by ORISE from the perimeter area.

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APPENDIX A

FIGURES

**FIGURE A - 1: LOCATION OF BROOKHAVEN NATIONAL LABORATORY,
UPTON NEW YORK**

FIGURE A - 2: WASTE LOADING AREA AT THE FHWMF

FIGURE A - 3: WASTE LOADING AREA RANKED SET SAMPLING LOCATIONS

FIGURE A - 4: WASTE LOADING AREA SURVEY UNIT 1 SAMPLE LOCATIONS

FIGURE A - 5: WASTE LOADING AREA SURVEY UNIT 2 SAMPLE LOCATIONS

FIGURE A - 6: WASTE LOADING AREA SURVEY UNIT 3 SAMPLE LOCATIONS

FIGURE A - 7: WASTE LOADING SURVEY UNIT 4 SAMPLE LOCATIONS

FIGURE A - 8: WASTE LOADING AREA JUDGMENTAL SAMPLE LOCATIONS

FIGURE A - 9: WASTE LOADING AREA GAMMA SCAN COUNT RATE HISTOGRAM

**FIGURE A - 10: WASTE LOADING AREA SURVEY UNIT 1
GAMMA ACTIVITY SCAN PATTERN**

**FIGURE A - 11: WASTE LOADING AREA SURVEY UNIT 2
GAMMA ACTIVITY SCAN PATTERN**

**FIGURE A - 12: WASTE LOADING AREA SURVEY UNIT 3
GAMMA ACTIVITY SCAN PATTERN**

**FIGURE A - 13: WASTE LOADING AREA SURVEY UNIT 4
GAMMA ACTIVITY SCAN PATTERN**

FIGURE A - 14: SURVEY UNIT 1 COUNT RATE HISTOGRAM

FIGURE A - 15: SURVEY UNIT 2 COUT RATE HISTOGRAM

FIGURE A - 16: SURVEY UNIT 3 COUNT RATE HISTOGRAM

FIGURE A - 17: SURVEY UNIT 4 COUNT RATE HISTOGRAM

FIGURE A - 18: WLA PERIMETER GAMMA SCAN PATTERN

FIGURE A - 19: WLA PERIMETER GAMMA SCAN COUNT RATE HISTOGRAM

APPENDIX B

TABLES

TABLE B-1
RANKED SET SAMPLING GAMMA MEASUREMENTS
FORMER WASTE LOADING AREA
SURVEY UNIT 1

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK

LOCATION GPS NAD 83 SPCS NY Long Island FIPS 3104 Northing Easting	Ranked Set Sampling	Gamma	Sample Select ^b /ID L=Low M=Medium H=High	SOIL SAMPLE
	Cycle-Set-Loc	cpm		
254547, 1300058	1-1-1 ■	12147	L	
254401, 1300026	1-1-2 ■	9916	L	S007
254511, 1300128	1-1-3 ■	11142	L	
254450, 1300052	1-2-1 ▲	11638	M	
254377, 1299988	1-2-2 ▲	15535	M	S008
254486, 1300090	1-2-3 ▲	23545	M	
254596, 1300039	1-3-1 ●	10366	H	
254389, 1300074	1-3-2 ●	14587	H	
254535, 1300099	1-3-3 ●	24369	H	S010
254551, 1300087	2-1-1 ■	14543	L	
254369, 1300036	2-1-2 ■	10598	L	S012
254478, 1300137	2-1-3 ■	12897	L	
254588, 1300010	2-2-1 ▲	12823	M	S009
254515, 1300061	2-2-2 ▲	10866	M	
254454, 1300080	2-2-3 ▲	23545	M	
254564, 1300030	2-3-1 ●	8494	H	
254417, 1300055	2-3-2 ●	11850	H	S011
254393, 1300017	2-3-3 ●	11826	H	

TABLE B-2
RANKED SET SAMPLING GAMMA MEASUREMENTS
FORMER WASTE LOADING AREA
SURVEY UNIT 2

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK

LOCATION GPS NAD 83 SPCS NY Long Island FIPS 3104 Northing Easting	Ranked Set Sampling	Gamma	Sample Select ^b /ID L=Low M=Medium H=High	SOIL SAMPLE
	Cycle-Set-Loc	cpm		
254570, 1300181	1-1-1 ■	13661	L	S017
254651, 1300037	1-1-2 ■	20437	L	
254516, 1300152	1-1-3 ■	27839	L	
254597, 1300095	1-2-1 ▲	41603	M	
254624, 1300138	1-2-2 ▲	20984	M	S015
254706, 1300080	1-2-3 ▲	14838	M	
254552, 1300131	1-3-1 ●	11343	H	
254633, 1300073	1-3-2 ●	32228	H	S016
254588, 1300160	1-3-3 ●	16982	H	
254670, 1300102	2-1-1 ■	16255	L	
254534, 1300217	2-1-2 ■	16327	L	
254562, 1300116	2-1-3 ■	12984	L	S013
254589, 1300127	2-2-1 ▲	15001	M	
254671, 1300069	2-2-2 ▲	18643	M	S014
254535, 1300185	2-2-3 ▲	25527	M	
254653, 1300026	2-3-1 ●	11381	H	
254517, 1300142	2-3-2 ●	15873	H	
254599, 1300084	2-3-3 ●	20315	H	S018

TABLE B-3
RANKED SET SAMPLING GAMMA MEASUREMENTS
FORMER WASTE LOADING AREA
SURVEY UNIT 3
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK

LOCATION GPS NAD 83 SPCS NY Long Island FIPS 3104 Northing Easting	Ranked Set Sampling	Gamma	Sample Select ^b /ID L=Low M=Medium H=High	SOIL SAMPLE
	Cycle-Set-Loc	cpm		
254724, 1300249	1-1-1 ■	14718	L	S023
254784, 1300291	1-1-2 ■	18265	L	
254808, 1300217	1-1-3 ■	17933	L	
254682, 1300313	1-2-1 ▲	24604	M	
254728, 1300277	1-2-2 ▲	17518	M	
254716, 1300306	1-2-3 ▲	22460	M	S021
254701, 1300260	1-3-1 ●	15743	H	S024
254664, 1300354	1-3-2 ●	10851	H	
254744, 1300226	1-3-3 ●	13423	H	
254690, 1300278	2-1-1 ■	13280	L	S022
254719, 1300316	2-1-2 ■	23657	L	
254796, 1300269	2-1-3 ■	17525	L	
254669, 1300361	2-2-1 ▲	10161	M	
254702, 1300349	2-2-2 ▲	15828	M	S020
254625, 1300177	2-2-3 ▲	18278	M	
254661, 1300327	2-3-1 ●	16670	H	
254757, 1300270	2-3-2 ●	16416	H	
254754, 1300297	2-3-3 ●	20294	H	S025
254797, 1300268	NA ^a	31689	Judgmental	S026

^aNA = Not applicable.

**TABLE B-4
RANKED SET SAMPLING GAMMA MEASUREMENTS
FORMER WASTE LOADING AREA
SURVEY UNIT 4**

**BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK**

LOCATION GPS NAD 83 SPCS NY Long Island FIPS 3104 Northing Easting	Ranked Set Sampling	Gamma	Sample Select ^b /ID L=Low M=Medium H=High	SOIL SAMPLE
	Cycle-Set-Loc	cpm		
254725, 1300246	1-1-1 ■	19049	L	
254783, 1300290	1-1-2 ■	21889	L	
254808, 1300214	1-1-3 ■	16217	L	S003
254684, 1300315	1-2-1 ▲	19013	M	S002
254758, 1300265	1-2-2 ▲	7666	M	
254717, 1300303	1-2-3 ▲	27842	M	
254791, 1300252	1-3-1 ●	13047	H	S006
254667, 1300353	1-3-2 ●	8487	H	
254742, 1300227	1-3-3 ●	9709	H	
254692, 1300277	2-1-1 ■	11289	L	S004
254721, 1300312	2-1-2 ■	19437	L	
254795, 1300261	2-1-3 ■	23297	L	
254671, 1300363	2-2-1 ▲	13346	M	
254704, 1300350	2-2-2 ▲	12467	M	S005
254779, 1300223	2-2-3 ▲	10246	M	
254654, 1300325	2-3-1 ●	18648	H	
254729, 1300274	2-3-2 ●	28739	H	S001
254754, 1300293	2-3-3 ●	11839	H	

Table B-5
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
SUMMARY RESULTS

Survey Unit	Ra-226 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)
Survey Unit 1	0.39 to 0.66	1.93 to 10.76	0.21 to 0.98
<i>Mean Concentration</i>	<i>0.55</i>	<i>4.77</i>	<i>0.54</i>
Survey Unit 2	0.41 to 0.61	1.61 to 45.4	0.14 to 0.74
<i>Mean Concentration</i>	<i>0.51</i>	<i>15.4</i>	<i>0.39</i>
Survey Unit 3	0.49 to 0.73	7.11 to 28.1	0.28 to 1.14
<i>Mean Concentration</i>	<i>0.60</i>	<i>14.04</i>	<i>0.70</i>
Survey Unit 4	0.40 to 0.66	2.95 to 37.0	0.18 to 1.62
<i>Mean Concentration</i>	<i>0.57</i>	<i>18.73</i>	<i>0.97</i>

TABLE B-6
RADIONUCLIDE CONCENTRATION IN SOIL
WASTE LOADING AREA
FORMER HAZARDOUS WASTE MANAGEMENT FACILITY

BROOKHAVEN NATIONAL LABORATORY
UPTON, NY

Sample ID/Location ^a	Radionuclide Concentration (pCi/g)			
	Ra-226	Cs-137	Sr-90	SOR ^b
S001	0.45 ± 0.15 ^c	37.0 ± 3.2	1.62 ± 0.31	0.75
S002	0.65 ± 0.11	28.9 ± 3.0	1.41 ± 0.31	0.66
S003	0.40 ± 0.14	27.6 ± 1.9	1.61 ± 0.34	0.60
S004	0.66 ± 0.10	5.21 ± 0.47	0.18 ± 0.23	0.22
S005	0.63 ± 0.07	2.95 ± 0.31	0.42 ± 0.27	0.20
S006	0.63 ± 0.08	10.72 ± 0.98	0.59 ± 0.25	0.33
S007	0.54 ± 0.08	2.37 ± 0.18	0.66 ± 0.27	0.19
S008	0.57 ± 0.12	10.76 ± 0.95	0.98 ± 0.29	0.34
S009	0.51 ± 0.06	2.75 ± 0.26	0.28 ± 0.22	0.16
S010	0.66 ± 0.09	6.45 ± 0.60	0.73 ± 0.27	0.28
S011	0.39 ± 0.08	4.39 ± 0.32	0.37 ± 0.23	0.17
S012	0.64 ± 0.09	1.93 ± 0.19	0.21 ± 0.23	0.17
S013	0.60 ± 0.07	1.61 ± 0.16	0.21 ± 0.23	0.16
S014	0.42 ± 0.10	13.6 ± 1.2	0.48 ± 0.26	0.32
S015	0.61 ± 0.16	45.4 ± 3.1	0.40 ± 0.24	0.83
S016	0.42 ± 0.11	15.1 ± 1.3	0.74 ± 0.27	0.36
S017	0.59 ± 0.06	1.94 ± 0.20	0.14 ± 0.22	0.16
S018	0.41 ± 0.10	15.0 ± 1.3	0.19 ± 0.23	0.32
S019^d	0.43 ± 0.11	45.0 ± 4.2	0.30 ± 0.22	0.78
S020	0.49 ± 0.09	10.05 ± 0.70	0.67 ± 0.25	0.29
S021	0.57 ± 0.13	28.1 ± 2.5	1.14 ± 0.27	0.61
S022	0.51 ± 0.09	9.64 ± 0.85	0.50 ± 0.24	0.28
S023	0.59 ± 0.08	9.14 ± 0.85	0.28 ± 0.22	0.27
S024	0.70 ± 0.09	7.11 ± 0.65	0.63 ± 0.23	0.29
S025	0.73 ± 0.14	20.2 ± 1.4	1.00 ± 0.27	0.51
S026^d	0.79 ± 0.18	34.6 ± 3.0	0.42 ± 0.24	0.70

^aRefer to figures

^bSum of the ratios include Ra-226, Cs-137, and Sr-90.

^cUncertainties represent the 95% confidence level based on total propagated uncertainties.

^dJudgmental sample locations.

APPENDIX C

MAJOR INSTRUMENTATION

APPENDIX C

MAJOR INSTRUMENTATION

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or her employer.

SCANNING INSTRUMENT/DETECTOR COMBINATIONS

Ludlum NaI Scintillation Detector Model SPA-3, Crystal: 2 inch x 2 inch
(Ludlum Measurements, Inc., Sweetwater, TX)

Coupled to

Ludlum Ratemeter-Scaler Model 2221

Coupled to

Trimble GeoXH Receiver and Data Logger (Trimble Navigation Limited, Sunnyvale, CA)

Fluke NaI Scintillation Detector Model 489-55, Crystal: 3.2 cm x 3.8 cm
(Fluke, Cleveland, OH)

Coupled to

Ludlum Ratemeter-Scaler Model 2221

Coupled to

Trimble GeoXH Receiver and Data Logger (Trimble Navigation Limited, Sunnyvale, CA)

LABORATORY ANALYTICAL INSTRUMENTATION

High Purity Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195

(Canberra, Meriden, CT)

Used in conjunction with:

Lead Shield Model G-11

(Nuclear Lead, Oak Ridge, TN) and

Multichannel Analyzer

DEC ALPHA Workstation

(Canberra, Meriden, CT)

High Purity Extended Range Intrinsic Detector
Model No. GMX-45200-5

(AMETEK/ORTEC, Oak Ridge, TN)

used in conjunction with:

Lead Shield Model SPG-16-K8

(Nuclear Data)

Multichannel Analyzer

DEC ALPHA Workstation

(Canberra, Meriden, CT)

High-Purity Germanium Detector
Model GMX-30-P4, 30% Eff.
(AMETEK/ORTEC, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-16
(Gamma Products, Palos Hills, IL) and
Multichannel Analyzer
DEC ALPHA Workstation
(Canberra, Meriden, CT)

Low background alpha/beta counting system
Canberra/Tennelec LB5100W
(Canberra, Inc., Meriden, CT)

APPENDIX D

SURVEY AND ANALYTICAL PROCEDURES

APPENDIX D

SURVEY AND ANALYTICAL PROCEDURES

PROJECT HEALTH AND SAFETY

The survey and sampling procedures were evaluated to ensure that any hazards inherent to the procedures themselves were addressed in current job hazard analyses (JHAs). All survey and laboratory activities were conducted in accordance with ORISE health and safety and radiation protection procedures.

Pre-survey activities included an overview of potential health and safety issues. Representatives with the Brookhaven National Laboratory provided site-specific safety awareness at for each individual ORISE survey effort. In-process and verification surveys were performed according to the ORISE generic health and safety plan, site-specific integrated safety management (ISM) pre-job hazard checklist, and safety procedures discussed during the on-site training.

QUALITY ASSURANCE

Analytical and field survey activities were conducted in accordance with procedures from the following ORAU and ORISE documents:

- Survey Procedures Manual
- Laboratory Procedures Manual
- Quality Program Manual

The procedures contained in these manuals were developed to meet the requirements of 10 CFR 830 Subpart A, *Quality Assurance Requirements*, Department of Energy Order 414.1C *Quality Assurance*, and the U.S. Nuclear Regulatory Commission *Quality Assurance Manual for the Office of Nuclear Material Safety and Safeguards* and contain measures to assess processes during their performance.

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.
- Participation in MAPEP, NRIP, and ITP Laboratory Quality Assurance Programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

CALIBRATION

Calibration of all field and laboratory instrumentation was based on standards/sources, traceable to the National Institute of Standards and Technology (NIST), when such standards/sources were available. In cases where they were not available, standards of an industry-recognized organization were used.

SURVEY PROCEDURES

Surface Scans

Scans for elevated gamma radiation were performed by passing the detector slowly over the surface. The distance between the detector and surface was maintained at a nominal of about 1 to 5 cm. NaI scintillation detectors were coupled to GPS units that enabled real-time recording of position in one-second intervals. Identification of elevated radiation levels was based on increases in the audible signal from the instrument. Positioning data files were downloaded from field data loggers for plotting using commercially available software (http://trl.trimble.com/docushare/dsweb/Get/Document-261826/GeoExpl2005_100A_GSG_ENG.pdf).

The scan minimum detectable concentrations (MDCs) for the NaI scintillation detector for the contaminants of concern in surface soil were obtained directly from NUREG-1507 when available or estimated using the calculational approach described in NUREG-1507¹. A typical NaI 2 inch by 2 inch detector MDC for Cs-137 is 6.4 pCi/g. An audible increase in the activity rate was investigated by ORISE. It is standard procedure for the ORISE staff to

¹NUREG-1507. Minimum Detectable Concentrations With Typical Radiation Survey Instruments for Various Contaminants and Field Conditions. U.S. Nuclear Regulatory Commission. Washington, DC; June 1998.

pause and investigate any locations where gamma radiation is distinguishable from background levels.

Soil Sampling

Approximately 0.5 to 1 kg of soil was collected at each sample location. Collected samples were placed in plastic bags, sealed, and labeled in accordance with ORISE survey procedures.

RADIOLOGICAL ANALYSIS

DETECTION LIMITS

Detection limits, referred to as MDC, were based on 3 plus 4.65 times the standard deviation of the background count [$3 + (4.65 (\text{BKG})^{1/2})$]. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument.

Strontium Analysis

Soil samples were dissolved by a combination of potassium hydrogen fluoride and pyrosulfate fusions. The fusion cake was dissolved and strontium was coprecipitated on lead sulfate. The strontium was separated from residual calcium and lead by reprecipitating strontium sulfate from EDTA at a pH of 4.0. Strontium was separated from barium by complexing the strontium in DTPA while precipitating barium as barium chromate. The strontium was ultimately converted to strontium carbonate and counted on a low-background gas proportional counter. The typical MDC of the procedure is 0.4 pCi/g for a one hour count time.

Gamma Spectroscopy

Samples of soil were dried, mixed, crushed, and/or homogenized as necessary, and a portion sealed in a 0.5-liter Marinelli beaker or other appropriate container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined and the samples counted using intrinsic germanium detectors coupled to a pulse height analyzer system. Background and Compton stripping, peak search, peak

identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. All total absorption peaks (TAP) associated with the radionuclides of concern were reviewed for consistency of activity. Total absorption peaks used for determining the activities of radionuclides of concern and the typical associated MDCs for a one-hour count time were:

Radionuclide	TAP (MeV)	MDC (pCi/g)
Cs-137	0.662	0.05
Ra-226 (from Pb-214)	0.351	0.19

Spectra were also reviewed for other identifiable TAPs.

Uncertainties

The uncertainties associated with the analytical data presented in the tables of this report represent the total propagated uncertainties for those data. These uncertainties were calculated based on both the gross sample count levels and the associated background count level.