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OAK RIDGE
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FOR THE DEPARTMENT OF ENERGY

Independent Verification Survey of the Clean Coral Storage Pile at the Johnston Atoll Plutonium Contaminated Soil Remediation Project

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ACRONYMS AND ABBREVIATIONS

Am	americium
ANS	American Nuclear Systems
ASO	Analytical Services Organization
Bq	bequerel
Ci	curie
cm	centimeter
DCGL	derived concentration guideline level
DTRA	Defense Threat Reduction Agency
ETS	Environmental Technology Section
FCDTRA	Field Command Defense Threat Reduction Agency
FIDLER	field instrument for the detection of low-energy radiation
ft	feet
g	gram
h	hour
IV	Independent Verification
JA	Johnston Atoll
JAPCSRP	Johnston Atoll Plutonium Contaminated Soil Remediation Project
k	kilo
keV	kiloelectron volt
m	meter
MARSSIM	Multi-Agency Radiological Site Survey Investigation Manual
MDC	minimum detectable concentration
MDCR	minimum detectable concentration rate
min	minute
n	nano
ORNL	Oak Ridge National Laboratory
p	pico
Pu	plutonium
QC	quality control
RCA	radiological control area
RPD	relative percent difference
SAP	sampling and analysis plan
TRU	transuranic
VSP	Visual Sample Plan

EXECUTIVE SUMMARY

The Oak Ridge National Laboratory (ORNL) Environmental Technology Section conducted an independent verification (IV) survey of the clean storage pile at the Johnston Atoll Plutonium Contaminated Soil Remediation Project (JAPCSRP) from January 18–25, 1999.

The goal of the JAPCSRP is to restore a 24-acre area that was contaminated with plutonium oxide particles during nuclear testing in the 1960s. The selected remedy was a soil sorting operation that combined radiological measurements and mining processes to identify and sequester plutonium-contaminated soil. The soil sorter operated from about 1990 to 1998. The remaining clean soil is stored on-site for planned beneficial use on Johnston Island. The clean storage pile currently consists of approximately 120,000 m^3 of coral.

ORNL conducted the survey according to a Sampling and Analysis Plan, which proposed to provide an IV of the clean pile by collecting a minimum number (99) of samples. The goal was to ascertain with 95% confidence whether 97% of the processed soil is less than or equal to the accepted guideline (500-Bq/kg or 13.5-pCi/g) total transuranic (TRU) activity.

In previous IV tasks, ORNL has (1) evaluated and tested the soil sorter system software and hardware and (2) evaluated the quality control (QC) program used at the soil sorter plant. The IV has found that the soil sorter decontamination was effective and significantly reduced plutonium contamination in the soil processed at the JA site. The Field Command Defense Threat Reduction Agency currently plans to re-use soil from the clean pile as a cover to remaining contamination in portions of the radiological control area. Therefore, ORNL was requested to provide an IV.

The survey team collected samples from 103 random locations within the top 4 ft of the clean storage pile. The samples were analyzed in the on-site radioanalytical counting laboratory with an American Nuclear Systems (ANS) field instrument used for the detection of low-energy radiation. Nine results exceeded the JA soil screening guideline for distributed contamination of 13.5 pCi/g for total TRUs, ranging from 13.7 to 125.9 pCi/g. Because of these results, the goal of showing with 95% confidence that 97% of the processed soil is less than or equal to 13.5 pCi/g TRU activity cannot be met. The value of 13.5 pCi/g represents the 88th percentile rather than the 95th percentile in a nonparametric one-sided upper 90% confidence limit. Therefore, at the 95% confidence level, 88% of the clean pile is projected to be below the 13.5-pCi/g goal.

The Multi-Agency Radiation Survey and Site Investigation Manual recommends use of a nonparametric statistical "Sign Test" to demonstrate compliance with release criteria for TRU. Although this survey was not designed to use the sign test, the data herein would demonstrate that the median (50%) of the clean storage pile is below the13.5-pCi/g derived concentration guideline level. In other words, with the caveat that additional investigation of elevated concentrations was not performed, the data pass the sign test at the 13.5-pCi/g level.

Additionally, the lateral extent of the pile was gridded, and 10% of the grid blocks was scanned with field instruments for the detection of low-energy radiation coupled to ratemeter/ scalers to screen for the presence of hot particles. No hot particles were detected in the top 1 cm of the grid blocks surveyed.

1. INTRODUCTION

This report describes an independent verification (IV) survey of the clean coral storage pile (clean pile) at the Johnston Atoll Plutonium Contaminated Soil Remediation Project (JAPCSRP) from January 18–25, 1999. A photograph log of the site and survey effort is provided in Appendix A. Johnston Atoll (JA), an unincorporated territory of the United States, consists of four primarily manmade islands approximately 800 miles west-southwest of Hawaii. Contamination from plutonium (Pu) and americium (Am) is a result of THOR missile aborts during a 1962 testing series. Cleanup that employed mining techniques to remediate contaminated soil was discontinued in 1998 (DNA 1992). The techniques involved a soil cleanup plant (soil sorter) that sorted out contamination to allow recycling of uncontaminated soil.

In 1992, the Field Command Defense Threat Reduction Agency (FCDTRA) contracted the Oak Ridge National Laboratory (ORNL) Environmental Technology Section (ETS) to provide IV support at the JAPCSRP. The objective of an IV is to assure that the cleanup criteria, standards, and/or guidelines specific to JA contamination are appropriately applied and met. The purpose of IV is to validate the accuracy and completeness of field measurements and the credibility of procedures followed, resulting in an independent assessment of site conditions. The goal of the independent assessment is to document that radiological contamination on the island no longer poses a threat to human health or the environment.

Figure 1 shows the location of the 24-acre radiological control area (RCA) on JA, where the clean pile currently resides, consisting of approximately 120,000 m^3 of clean coral. The pile encompasses 175,000 ft^2 (16,257 m^2) and is approximately 8-ft (2.4-m) deep. Further historical and background information about the project can be found in the ORNL IV report on the project (ORNL 1998a).

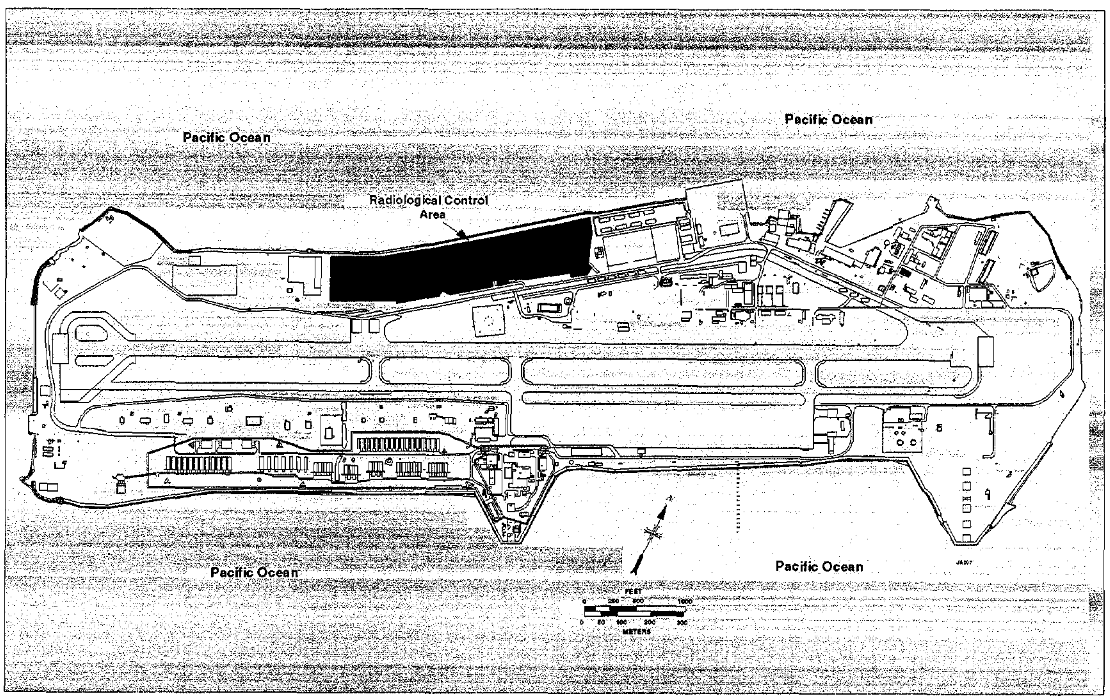

Fig. 1. JA showing RCA.

ORNL proposed to provide an IV of the clean pile by collecting a minimum number (99) of samples. These samples were collected to show with 95% confidence that 97% of the processed soil is less than or equal to the guideline established by FCDTRA of 500-Bq/kg or 13.5-pCi/g total transuranic (TRU) activity. This was agreed upon by FCDTRA after review of a proposal in June 1998 (ORNL 1998b).

A Sampling and Analysis Plan (SAP) was developed and provided details of the survey design (ORNL 1999). The locations of the samples were selected randomly by using specialized computer software and were located using a 10- by 10-m grid placed over the areal extent of the pile. Finally, 10% of the grid blocks was selected randomly for gamma scanning to determine if hot particles were present in the top 1 cm of the pile.

1.1 PREVIOUS IVs

In previous IV tasks (ORNL 1998a), ORNL has (1) evaluated and tested the soil sorter system software and hardware and (2) evaluated the quality control (QC) program used at the soil sorter plant. The IV has found that the soil sorter decontamination was effective and significantly reduced plutonium contamination in the soil processed at the JA site. The FCDTRA plans to use soil from the clean pile to cover remaining contamination in portions of the RCA. Therefore, FCDTRA requested ORNL to provide a final IV of the radiological condition of the material comprising the clean pile.

1.2 CONTAMINANTS OF CONCERN

Contamination from the missile launches is insoluble plutonium oxide (PuO_2) present as dispersed activity (volume) and hot particles (point sources) (DNA 1991). Particles approximately 10 μm in diameter, with approximately 10 Bq of TRU activity, are widely dispersed; the plutonium apparently had been dissolved as carbonate complexes, which were subsequently adsorbed to the coral surface (Wolf et al. 1995). Discrete, hot particles (<45 μm in diameter with an activity >1 kBq) are not so widely dispersed and are found relatively near the source of contamination. At this time, erosion appears to be the primary process affecting migration and distribution of the plutonium. The contamination from the missile launches includes TRUs [elements of the actinide series including plutonium isotopes and Am-241 (^{241}Am)]. The ^{241}Am is the daughter product of ^{241}Pu, which has a 14.35-year half-life. The primary types of radiation associated with TRUs are alpha radiation, characteristic X-rays from ^{239}Pu, and 60-keV gamma from ^{241}Am.

1.3 APPLICABLE GUIDELINES

The guideline for the sorter plant assigned by FCDTRA for distributed and particulate contamination was 500 Bq/kg (13.5 pCi/g) total TRU averaged over 0.1 m^3 and 5000 Bq (135 nCi) total TRU per hot particle, respectively. ORNL has evaluated and agreed with the soil-screening limit during past IV tasks (ORNL 1998a). Because it is economically unfeasible to verify that no hot particles over 5000 Bq exist in 80,000 metric tons of material, the survey used the distributed guideline as its goal. However, gamma scans conducted over approximately 10% of the surface area of the clean pile provided a general assessment of whether there is an abundance of remaining hot particles. The Defense Threat Reduction Agency (DTRA) requested that the survey use the Multi-Agency Radiological Site Survey Investigation Manual (MARSSIM) (U.S. EPA 1997) as a general guide, and therefore, the screening limit was adopted as the derived concentration guideline level (DCGL) for this task. Data were evaluated using the nonparametric one-sided upper confidence limits on percentiles statistical test for the distributed DCGL. The MARSSIM also recommends use of a nonparametric statistical "Sign Test" to demonstrate compliance with release criteria for TRU. Therefore, the sign test was also conducted for additional information. The analyses were performed for ^{241}Am; the resulting concentration values are multiplied by a factor of 6.17 total TRU alpha per picocurie of ^{241}Am.

PROJECT MANAGEMENT

Key project personnel and project responsibilities are as follows:

FCDTRA Project Manager	Captain David Rynders	(505) 846-8445
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ORNL Project Manager	Mary Wilson-Nichols	(970) 248-6232
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ORNL Field Characterization Leader/ Health Physics Technician	Robert L. Schlosser	(970) 248-6261
ORNL H&S Technician/ Graphics Technician	Edward Roemer	(970) 248-6217
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2. APPROACH AND METHODS

2.1 ASSUMPTIONS

To use the statistical approach described in the sampling and analysis plan (SAP), it was assumed that the material in the outer 4 ft of the clean pile is the same as its core. This is reasonable because the material has been crushed and sorted, and with 95% confidence Thermo NUTech (the remedial action contractor) thinks that particles exceeding the guideline have been diverted by the system. Therefore, sampling was performed on the outer accessible 4 ft of the clean pile material. Obtaining deeper samples would be costly and logistically difficult and would require heavy equipment that would alter the condition of the pile. The clean pile is classified as a Class II area under MARSSIM nomenclature (U.S. EPA 1997); that is, areas have a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL. Because the soil was contaminated and has a potential for residual contamination, but is not expected to exceed the DCGL (hot particles are not part of the scope of the statistical test), a Class II designation is appropriate. The area was treated as one survey unit. The hypothesis planned for testing follows:

H_O: The one-sided upper 95% confidence limit for the 97th percentile is greater than or equal to 13.5 pCi/g (i.e., the survey unit is contaminated).

H_A: The one-sided 95% confidence limit for the 97th percentile is less than 13.5 pCi/g (i.e., the survey unit is not contaminated).

2.2 BACKGROUND RADIATION

The MARSSIM methodology uses two approaches to radiological surveys: (1) surveys for radionuclides present in background and (2) surveys for radionuclides not present in background. Weapons-grade TRUs are not naturally present in background in measurable quantities, but at JA are ubiquitous because of the high-altitude tests conducted there historically. This is the reason that two guidelines were established for cleanup, a distributed DCGL and a hot particle DCGL. Estimating background concentrations according to MARSSIM requires an area unaffected by site operations that is of similar geology. This is not possible at JA because all the islands were exposed to fallout from the atmospheric tests originating from the site. Therefore, results of sample analyses will be directly compared to the distributed soil limit. Ambient gamma will be subtracted by the spectroscopy system as a routine function of the system. Qualitative field measurements collected also account for ambient gamma fluence detected by the instruments.

2.3 METHODS

2.3.1 Gridding/Mapping

A grid was established on the clean pile using local monuments and benchmarks. The grid was laid out in 10- by 10-m increments (Fig. 2). The grid was tied into the local survey coordinate system by overlaying the grid on existing electronic maps. A computer program, Visual Sample Plan (VSP) (ORNL 1998b), was used to place 103 sample locations in a simple random fashion using quasi-random placement to avoid clustering. The map coordinates (X, Y coordinates) were provided by VSP, and sampling points marked with pin flags. The depths of the samples (Z coordinate) were selected randomly from 0 to 4 ft using a random number generator. Figure 3

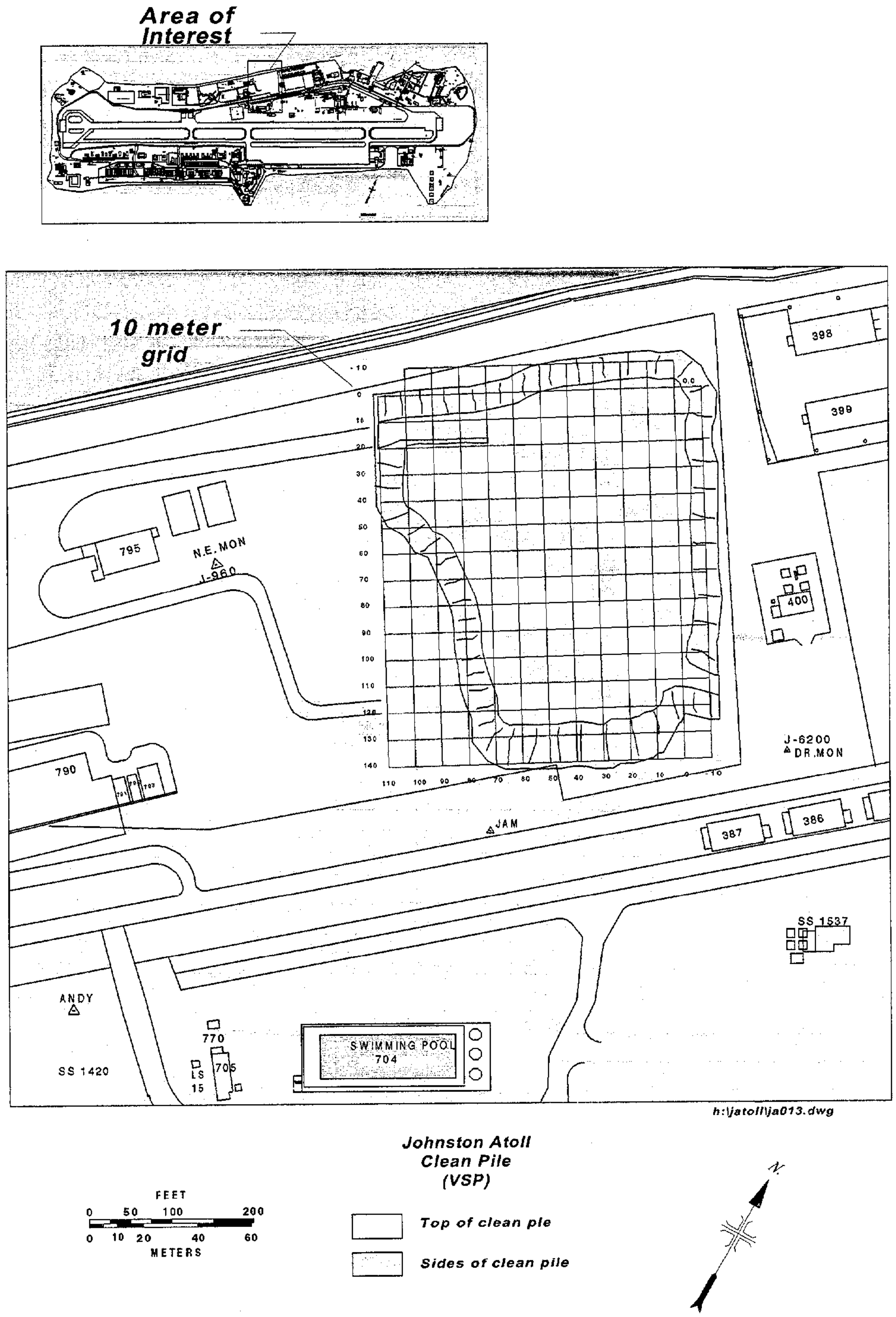

Fig. 2. Overlay of 10- by 10-m grid on clean storage pile.

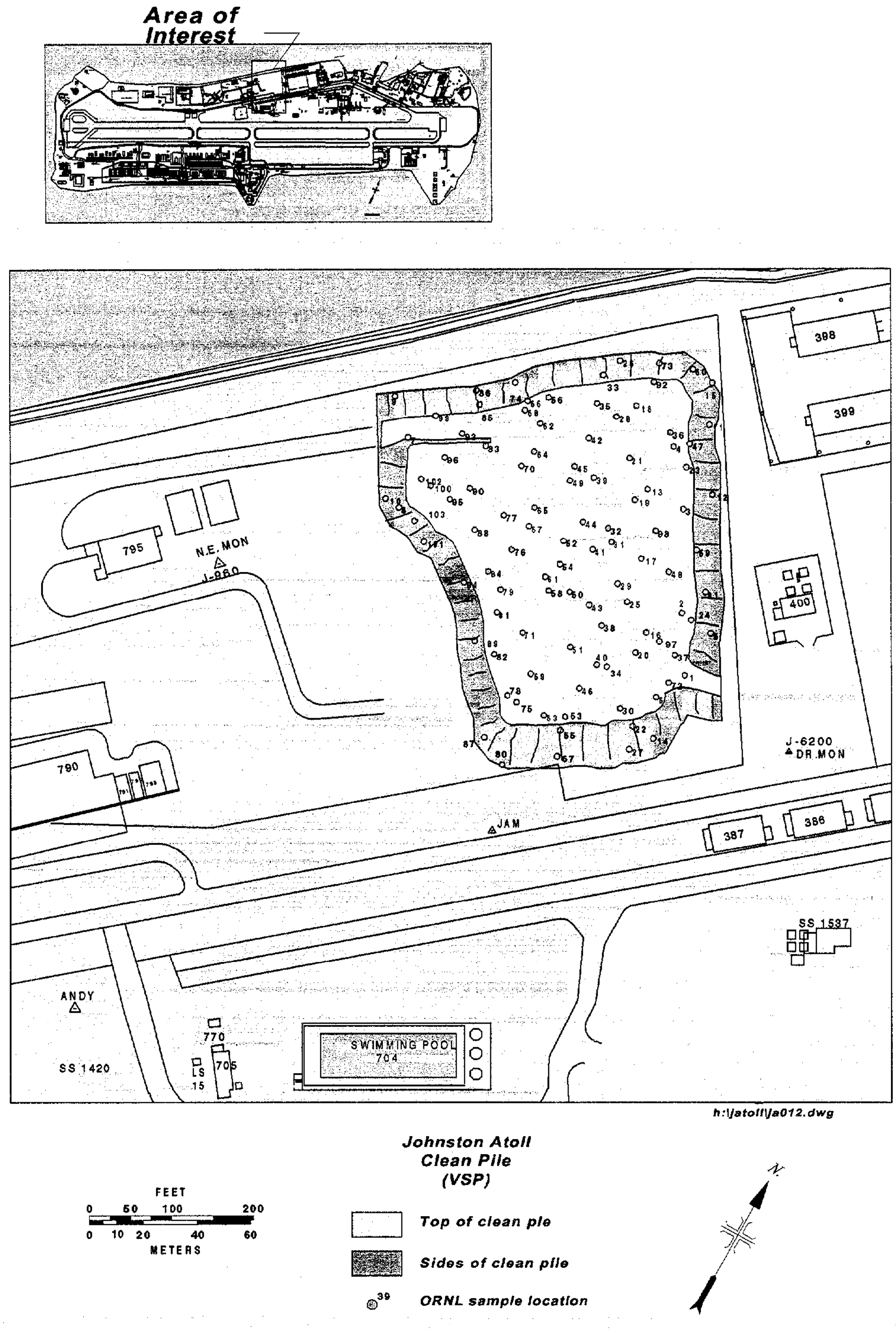

Fig. 3. Soil sample locations.

and Table 1 show a generalized conception of the clean pile, random sample locations, and sample depths and coordinates.

2.3.2 Instrumentation

Three types of radiological instrumentation were used during the survey. Alpha scintillation detectors were used for frisking personnel going in and out of the RCA and for checking sampling equipment after decontamination. Field instruments for the detection of low-energy radiation (FIDLERs) coupled to ratemeter/scalers were used for scanning and screening of the pile, and an on-island gamma spectroscopy system was used for analyzing the samples after collection. The FIDLERs and alpha scintillometers were calibrated at the ORNL facility in Grand Junction using approved U.S. Department of Energy (DOE) methods, which also follow ANSI N323. Table 2 lists instrument parameters.

Operational checks were conducted at the beginning and midpoint of each sample day for the FIDLERs, which are susceptible to humidity and temperature fluctuations. The alpha scintillometers and gamma spectrometers were checked daily. Care, maintenance, and operation were recorded in the instrument logbook. Field personnel updated the instrument logbook at each operational field check.

2.3.3 Soil Sample Collection and Analysis

Sampling was conducted using a Geoprobe® brand sampler with an approximate size of 2.5 by 30 cm. The sampler was driven to the desired depth using handheld power tools (hammer drill). After the sample was recovered, it was placed in a plastic bag. A discrete measurement was taken using a FIDLER. The material was blended, sieved through a 10-mesh sieve, and dried at 100°C for a minimum of 12 h. An aliquot of material (approximately 100 g) was placed in a petri dish, sealed, and labeled (see photograph log, Appendix A). Sample excess was archived on JA. Decontamination of sampling equipment consisted of wiping with a wire brush and screening with an alpha scintillometer.

Samples were analyzed after collection using the on-site gamma spectroscopy. Samples were counted for 15 min, yielding sample results for TRU and minimum detectable concentrations (MDCs) in picocuries per gram. Results of the analysis were kept on the spectrometer system as well as copied over to laptop computer for data manipulation.

All soil samples were packaged and shipped to ORNL in Oak Ridge, Tennessee, for confirmatory analysis and archival. Confirmatory analysis was performed on ~30% of samples by gamma spectroscopy (using hyperpure germanium detection) for ^{241}Am. Also, analysis of four samples (~10%) for ^{241}Am, $^{239/240}$Pu, ^{238}Pu, and $^{243/244}$Cm was performed by alpha spectroscopy. The purpose of the confirmatory analysis was as a quality assurance measure, to evaluate the accuracy of the on-site results. Analytical methods were detailed in the SAP.

2.3.4 Gamma Scanning

Of the grid blocks, 10% were chosen randomly and scanned for hot particles. The scans were conducted using FIDLERs coupled to ratemeter/scalers in ratemeter mode. These walkover gamma scans were performed with the detectors held to within 10 cm of the coral surface. The detectors were swung in a serpentine manner over a 1-m wide swath, and the scan rate did not exceed 465 m^2 (5000 ft^2) per person-hour. Scan rate minimum detectable concentration rates (MDCRs) were calculated on-site based on ambient gamma exposure rate ranges. In addition to calculating an action level based on MDCR, surveyors used the audio response of the instruments to screen for hot particles. The MARSSIM procedure for calculating scan MDC was used (EPA 1997). Scan ranges in counts were recorded on the field maps and in the project logbook.

Table 1. Sample locations and depths

Location No.	X (m)	Y (m)	Z (ft)	Location No.	X (m)	Y (m)	Z (ft)
1	0.04	108.35	0.7	51	42.23	96.56	4.0
2	0.41	84.77	3.1	52	43.73	56.38	2.7
3	−1.08	45.46	0.1	53	44.85	122.76	2.8
4	1.91	21.88	3.2	54	45.22	65.11	2.8
5	−10.04	92.63	0.0	55	46.71	128.00	1.0
6	10.87	116.21	3.4	56	47.83	2.22	3.4
7	100.48	15.98	0.7	57	48.21	137.83	1.6
8	104.59	42.19	2.1	58	49.70	74.94	3.0
9	104.96	0.26	3.2	59	−5.56	61.18	1.4
10	109.44	38.69	1.3	60	−5.94	−6.95	2.0
11	−11.54	14.02	3.8	61	50.82	69.70	3.5
12	−11.91	40.22	1.1	62	51.19	12.05	3.9
13	11.99	37.60	1.2	63	52.69	122.11	1.1
14	12.36	131.93	2.2	64	53.81	22.53	2.0
15	−13.03	−1.71	0.9	65	54.18	43.50	2.9
16	13.85	91.75	2.9	66	55.67	3.32	3.2
17	14.97	63.80	2.0	67	56.42	50.48	2.5
18	15.35	6.16	3.7	68	56.79	6.81	1.8
19	16.84	41.53	0.4	69	57.17	106.39	2.6
20	17.96	99.18	3.5	70	58.66	27.77	2.5
21	18.33	25.81	2.5	71	59.78	90.66	3.2
22	19.83	127.13	2.7	72	6.01	110.97	1.0
23	−2.57	29.74	4.0	73	6.39	−9.57	2.6
24	−2.95	87.39	2.2	74	60.15	−3.67	2.4
25	20.58	79.96	3.6	75	62.77	116.87	2.2
26	20.95	−10.88	0.2	76	63.14	59.22	2.8
27	21.32	135.86	0.5	77	65.75	46.12	0.9
28	22.82	10.09	0.1	78	66.13	114.25	4.0
29	23.94	72.98	3.3	79	67.62	74.07	0.7
30	24.31	120.14	3.7	80	68.74	140.45	3.0
31	25.80	57.25	0.2	81	69.12	82.80	0.8
32	26.92	52.01	2.3	82	70.61	98.52	2.4
33	27.30	−5.64	2.2	83	71.73	19.91	3.4
34	28.79	104.42	0.2	84	72.10	67.08	1.7
35	29.91	4.85	0.4	85	73.60	4.19	1.2
36	3.03	16.64	2.7	86	74.72	−1.05	1.2
37	3.40	100.49	0.5	87	75.09	129.97	3.6
38	30.28	88.70	3.1	88	76.58	51.36	0.3
39	31.78	32.80	2.6	89	77.70	93.28	1.4
40	32.52	103.55	0.8	90	78.08	35.63	0.2
41	32.90	59.87	2.6	91	−8.55	76.91	0.3
42	33.27	17.95	3.6	92	8.63	−2.58	1.6
43	34.76	80.84	1.2	93	80.32	15.11	3.2
44	36.26	49.39	2.3	94	81.06	71.01	2.5
45	38.87	28.43	1.4	95	85.54	39.57	1.5
46	39.24	112.28	1.0	96	87.04	23.84	3.5
47	−4.07	21.00	1.4	97	9.00	95.25	3.8
48	4.89	69.04	1.1	98	9.37	53.32	0.3
49	40.74	33.67	2.5	99	90.03	8.12	1.5
50	41.86	75.60	1.7	100	92.64	34.32	1.1
				101	95.63	55.29	3.1
				102	96.00	31.70	0.3
				103	98.99	47.43	1.3

Table 2. Instrumentation parameters

Instrument	Detector	Calibration nuclide	Active area of detector $(cm)^2$	Instrument efficiency (%)	Minimum detectable concentration (dpm/100 cm^2)	Type of radiation	Calibration geometry and spacing
Ludlum Data Logger Model 2360 Ludlum Measurements, Inc. Sweetwater, TX	Ludlum Plastic Scintillator Model 43-89 Ludlum, Sweetwater, TX	^{239}Pu $Sr/^{90}Y$	126	9.0—^{239}Pu 27.0—$Sr/^{90}Y$ (distributed) 16.0—^{239}Pu 48.0—$Sr/^{90}Y$ (point source)	65 (α) 250 (β) (distributed) 38 (α) 138 (β) (point source)	Alpha, beta	Distributed[a] and point source geometries, ¼-in. spacing
Ludlum Model 2221 Ratemeter-Scaler Ludlum Measurements, Inc. Sweetwater, TX	FIDLER G-5 Bicron NE Solon, OH	^{241}Am	300	25.0—^{241}Am	~65 nCi	Gamma	Point source geometry
ANS 2000 R Multi-Channel Analyzer American Nuclear Systems Oak Ridge, TN	ANS FIDLERs	^{241}Am	300	48	<1	Gamma	3-mm Distributed coral

[a]ANS = American Nuclear Systems.

3. RESULTS

Results of the on-site analysis of the soil samples are shown in Table 3 and detailed in Appendix B. Results of gamma scanning are shown in Fig. 4. Results of confirmatory (QC) analysis are provided in Tables 4–6, Fig. 5, and detailed in Appendix C. Table 7 provides results of fixed-point measurements taken at grid point locations to supplement the gamma scanning data.

The total TRU activity results in Table 3 are sorted from high to low activity. Nine samples exceeded the soil screening criteria established by the DTRA. These samples were collected from various random locations and depths within the pile (Fig. 3) and indicate that there is no particular pattern or boundary of contamination in the pile.

After sample analysis on site, samples were shipped to Oak Ridge, Tennessee, for confirmatory analysis as a QC measure. The highest 32 results from on-site analysis were selected for confirmatory analysis, and they constitute approximately 30% of total results, as planned. Results of this analysis are compared with the on-site analysis in Tables 5 and 6 and Fig. 5, and they show that the relative percent difference (RPD) for the majority (25 out of 32) of samples was <75%, which shows a fair agreement between the two values. Fourteen (a little less than one-half) have an RPD less than 60%, which indicates that the two values generally agree. With the exception of sample 28, the RPDs that were more than 100% (poor agreement) were results below the soil screening value of 13.5, and not significant to the evaluation. Figure 5 further demonstrates that the QC results were nearly systematically lower than the on-site results. This issue is not significant to the conclusions, but should be investigated prior to future surveys. Seven of the QC results exceed the soil-screening limit. The on-site analytical results are considered reliable and suitable for the statistical tests discussed in the following section. The higher RPDs of the on-site and QC analyses could be due to several factors including (1) different reference material used for calculating efficiency and (2) difference in position of contaminants within the petri dish from shipping and settling.

Further QC was provided by the analysis of four samples by radiochemistry, shown in Table 5. The samples were selected in a bias manner and represent high and low RPDs. Three of the four results of the radiochemical analysis were lower than the on-site measurements. The sample aliquot for radiochemical analysis is small (~10 g) compared to the sample counted on the gamma spectroscopy systems, and it is possible that contamination detected in the gamma specification sample is not contained in the aliquot for the radiochemical analysis. Because of the heterogeneous nature of the contaminant and the small sample size (n = 4), no conclusions should be drawn from the radiochemical data, other than the basic trend of lower results. The ratio of TRU/Am, as stated by ANS (6.17) predicted slightly higher results than those observed in the radiochemical analysis (Table 5). However, RPDs were calculated for comparative purposes only (Table 6).

Results of the gamma scan on 10% of the grid blocks (Fig. 4) show gamma flux to range from 30 to 1100 cpm, averaging 260 cpm. To supplement the gamma scan data, 124 fixed-point measurements were collected at grid intersections and are presented in Tables 5 and 6. Fixed-point background measurements were collected in four locations and ranged from 276 to 388 cpm. In comparison to this threshold range, fixed-point measurements ranged from 112 to 652 cpm, with a mean average of 322 and a median of 297. These averages are well within the threshold range. The elevated gamma fluence detected from 388 to 652 cpm is consistent with previous scans at JA where locations of high gamma fluence were sampled and were not explained by total TRU activity results or variation in background radionuclides (ORNL 1998). The survey team did not detect any hot particles, which range orders of magnitude higher (~20,000 to 100,000 cpm) than the maximum scan measurement of 1100 cpm.

Table 3. Total TRUs in coral samples from clean storage pile

Location	ANS No.	Date counted	Time	Weight (g)	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
57	C000034	23-Jan-99	11:09	89	11259.9	277.2	125.9	3.1	0.1
22	C000008	21-Jan-99	14:57	81	3056.9	124.1	37.8	1.5	0.1
86	C000038	25-Jan-99	7:56	98	3159.1	140.3	32.3	1.4	0.1
58	C000050	23-Jan-99	16:54	88	1973.6	106.0	22.4	1.2	0.1
28	C000005	22-Jan-99	9:57	88	1408.5	95.2	16.0	1.1	0.1
10	C000047	23-Jan-99	15:53	95	1474.7	97.5	15.5	1.0	0.1
60	C000008	24-Jan-99	12:41	90	1382.2	95.7	15.4	1.1	0.1
102	C000053	25-Jan-99	13:48	90	1354.8	113.1	15.1	1.3	0.1
23	C000007	21-Jan-99	14:36	85	1160.2	91.4	13.7	1.1	0.1
25	C000003	21-Jan-99	13:20	74	902.1	87.2	12.2	1.2	0.1
89	C000041	25-Jan-99	8:50	89	980.6	107.9	11.0	1.2	0.1
14	C000010	21-Jan-99	15:35	84	874.2	86.7	10.5	1.0	0.1
20	C000009	21-Jan-99	15:16	87	863.4	86.5	9.9	1.0	0.1
30	C000014	22-Jan-99	13:57	84	832.2	85.7	9.9	1.0	0.1
33	C000022	22-Jan-99	16:51	91	892.4	86.7	9.9	1.0	0.1
53	C000051	23-Jan-99	17:10	92	864	87.6	9.4	1.0	0.1
54	C000049	23-Jan-99	16:34	90	775.8	86.2	8.6	1.0	0.1
63	C000011	24-Jan-99	13:35	89	758.6	85.6	8.5	1.0	0.1
74	C000021	24-Jan-99	17:14	92	771.5	85.8	8.4	0.9	0.1
47	C000007	22-Jan-99	10:42	94	772	84.8	8.2	0.9	0.1
67	C000014	24-Jan-99	14:59	98	797.3	86.2	8.2	0.9	0.1
12	C000015	21-Jan-99	17:29	87	684.9	83.7	7.9	1.0	0.1
26	C000015	22-Jan-99	14:17	89	701.1	83.6	7.9	0.9	0.1
41	C000003	24-Jan-99	11:09	90	711.3	84.8	7.9	0.9	0.1
65	C000029	23-Jan-99	9:20	84	662.3	83.5	7.9	1.0	0.1
50	C000025	22-Jan-99	17:44	96	739.8	84.2	7.7	0.9	0.1
27	C000045	23-Jan-99	15:13	91	691.9	84.9	7.6	0.9	0.1
91	C000043	25-Jan-99	9:33	95	707.5	104.4	7.5	1.1	0.1
46	C000008	22-Jan-99	11:02	90	666.6	83.1	7.4	0.9	0.1
56	C000042	23-Jan-99	14:22	93	683.3	84.7	7.3	0.9	0.1
45	C000013	22-Jan-99	13:28	96	690.3	83.4	7.2	0.9	0.1
3	C000014	21-Jan-99	17:06	92	654.8	83.2	7.1	0.9	0.1
29	C000020	22-Jan-99	15:55	106	752.7	84.4	7.1	0.8	0.1
84	C000032	24-Jan-99	21:01	90	631.7	83.6	7.0	0.9	0.1
82	C000030	24-Jan-99	20:28	92	616.6	83.3	6.7	0.9	0.1
101	C000052	25-Jan-99	13:31	90	602.1	103	6.7	1.1	0.1
83	C000031	24-Jan-99	20:44	88	575.8	82.7	6.6	0.9	0.1
5	C000003	22-Jan-99	9:14	86	539.8	81.1	6.3	0.9	0.1
55	C000041	23-Jan-99	14:05	96	599.4	83.4	6.3	0.9	0.1
94	C000046	25-Jan-99	10:37	85	533.3	102.2	6.3	1.2	0.1
17	C000044	23-Jan-99	14:56	94	584.4	83.2	6.2	0.9	0.1
69	C000017	24-Jan-99	15:59	97	603.7	83.1	6.2	0.9	0.1
11	C000015	24-Jan-99	15:16	85	517.7	81.8	6.1	1.0	0.1
48	C000033	23-Jan-99	10:32	103	630.1	83.0	6.1	0.8	0.1
66	C000013	24-Jan-99	14:42	83	500.5	81.5	6.0	1.0	0.1
80	C000028	24-Jan-99	19:55	85	511.3	81.7	6.0	1.0	0.1
96	C000005	24-Jan-99	11:44	92	541.4	82.2	5.9	0.9	0.1
37	C000043	23-Jan-99	14:38	92	537.1	82.4	5.8	0.9	0.1
49	C000018	22-Jan-99	15:20	101	587.1	81.8	5.8	0.8	0.1

Table 3. (continued)

Location	ANS No.	Date counted	Time	Weight (g)	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
71	C000002	24-Jan-99	10:48	91	522	81.9	5.8	0.9	0.1
79	C000027	24-Jan-99	19:39	84	489.8	81.4	5.8	1.0	0.1
13	C000012	22-Jan-99	13:08	100	574.2	81.6	5.7	0.8	0.1
9	C000052	23-Jan-99	17:31	87	464	81.3	5.3	0.9	0.1
78	C000026	24-Jan-99	19:18	97	511.3	81.7	5.3	0.8	0.1
72	C000019	24-Jan-99	16:39	87	442.5	80.6	5.1	0.9	0.1
76	C000024	24-Jan-99	18:43	90	455.4	80.8	5.1	0.9	0.1
1	C000001	21-Jan-99	11:16	75	377.4	78.9	5.0	1.0	0.1
75	C000022	24-Jan-99	18:08	92	459.7	80.9	5.0	0.9	0.1
21	C000011	21-Jan-99	15:56	78	381.7	78.9	4.9	1.0	0.1
31	C000010	22-Jan-99	12:31	98	477.4	80.1	4.9	0.8	0.1
59	C000004	22-Jan-99	9:40	96	471	80	4.9	0.8	0.1
81	C000029	24-Jan-99	20:11	89	440.3	80.6	4.9	0.9	0.1
16	C000004	21-Jan-99	13:38	102	491.4	80.6	4.8	0.8	0.1
61	C000009	24-Jan-99	12:58	93	446.8	80.7	4.8	0.9	0.1
19	C000039	23-Jan-99	13:26	88	410.2	80.5	4.7	0.9	0.1
62	C000010	24-Jan-99	13:19	92	433.9	80.5	4.7	0.9	0.1
6	C000012	21-Jan-99	16:15	83	364.5	78.7	4.4	1.0	0.1
40	C000009	22-Jan-99	11:19	90	400	78.9	4.4	0.9	0.1
2	C000001	22-Jan-99	8:34	84	350.5	78.1	4.2	0.9	0.1
42	C000023	22-Jan-99	17:08	89	369.9	78.4	4.1	0.9	0.1
85	C000033	24-Jan-99	21:19	93	380.1	79.7	4.1	0.9	0.1
92	C000044	25-Jan-99	9:56	95	391.4	100.4	4.1	1.1	0.1
87	C000039	25-Jan-99	8:13	91	363.4	100.1	4.0	1.1	0.1
35	C000016	22-Jan-99	14:37	95	369.9	78.4	3.9	0.8	0.1
36	C000004	24-Jan-99	11:27	97	375.8	79.6	3.9	0.8	0.1
44	C000023	24-Jan-99	18:26	94	354.3	79.3	3.8	0.8	0.1
95	C000047	25-Jan-99	11:20	86	322.6	99.6	3.8	1.2	0.1
8	C000031	23-Jan-99	9:54	102	378.5	79.1	3.7	0.8	0.1
32	C000006	24-Jan-99	12:04	95	343.5	79.1	3.6	0.8	0.1
70	C000018	24-Jan-99	16:21	97	354.3	79.3	3.6	0.8	0.1
34	C000017	22-Jan-99	15:00	97	339.8	77.9	3.5	0.8	0.1
52	C000019	22-Jan-99	15:38	104	361.3	78.3	3.5	0.8	0.1
93	C000045	25-Jan-99	10:16	89	316.1	99.5	3.5	1.1	0.1
4	C000028	23-Jan-99	9:00	95	326.9	78.3	3.4	0.8	0.1
100	C000051	25-Jan-99	13:14	94	305.4	99.4	3.3	1.1	0.1
51	C000038	23-Jan-99	13:08	84	272.6	78.4	3.2	0.9	0.1
24	C000030	23-Jan-99	9:38	86	262.4	77.3	3.1	0.9	0.1
103	C000054	25-Jan-99	14:06	94	294.6	99.2	3.1	1.1	0.1
97	C000048	25-Jan-99	12:18	96	288.2	99.2	3.0	1.0	0.1
15	C000032	23-Jan-99	10:12	97	281.7	77.6	2.9	0.8	0.1
77	C000025	24-Jan-99	19:02	93	274.7	78.1	2.9	0.8	0.1
64	C000012	24-Jan-99	14:23	98	272.6	78	2.8	0.8	0.1
39	C000011	22-Jan-99	12:48	96	258.1	76.7	2.7	0.8	0.1
73	C000020	24-Jan-99	16:57	90	242.5	77.6	2.7	0.9	0.1
38	C000007	24-Jan-99	12:24	93	240.3	77.6	2.6	0.8	0.1
7	C000001	24-Jan-99	10:29	92	227.4	77.4	2.5	0.8	0.1
88	C000040	25-Jan-99	8:30	92	230.1	98.5	2.5	1.1	0.1
43	C000040	23-Jan-99	13:46	90	212.4	77.5	2.4	0.9	0.1
18	C000046	23-Jan-99	15:33	95	167.2	76.8	1.8	0.8	0.1
68	C000016	24-Jan-99	15:35	97	154.3	76.3	1.6	0.8	0.1
98	C000049	25-Jan-99	12:38	93	103.2	97	1.1	1.0	0.1
99	C000050	25-Jan-99	12:54	93	94.6	96.9	1.0	1.0	0.1
90	C000042	25-Jan-99	9:06	90	−2.2	95.8	0.0	1.1	0.1

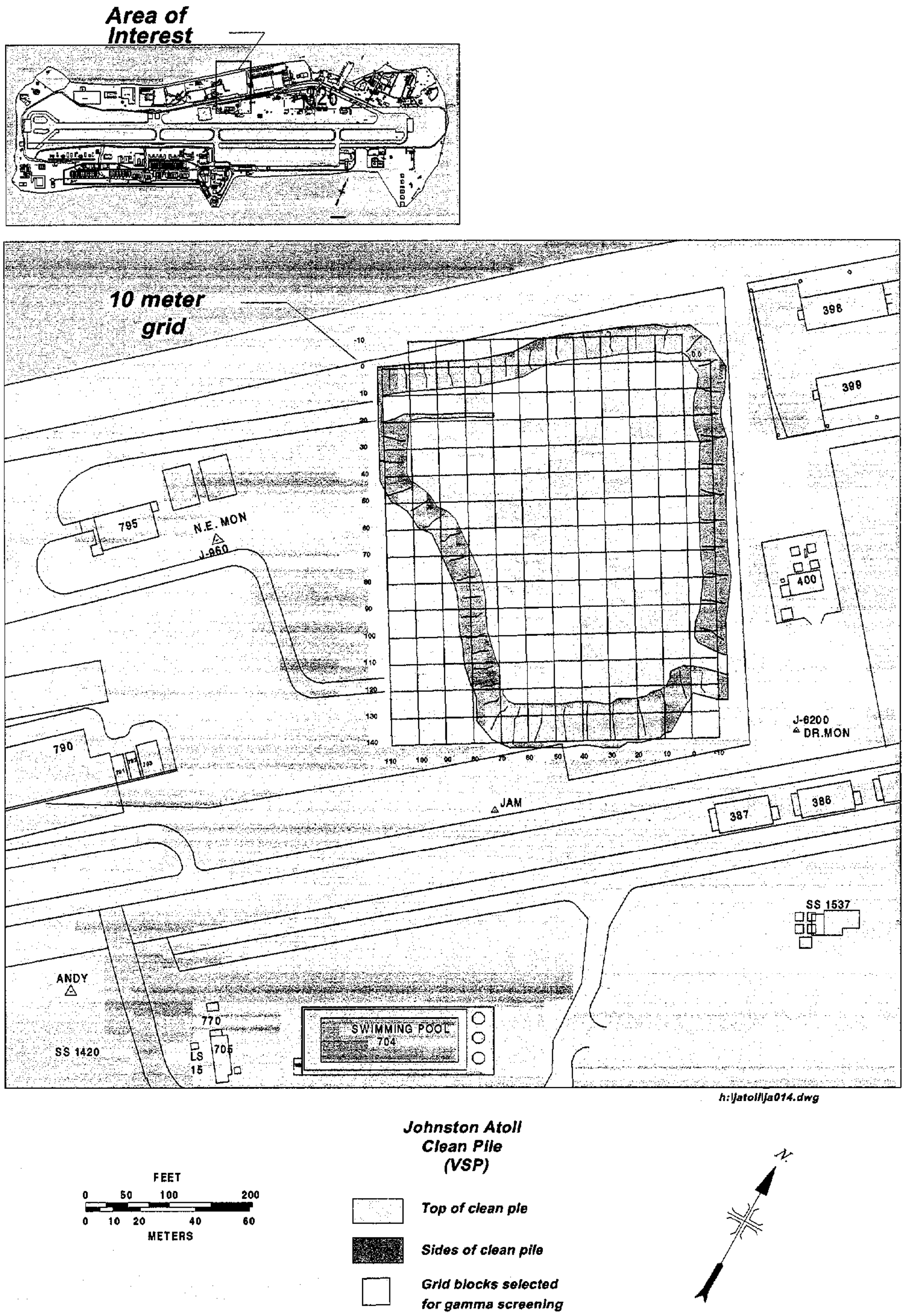

Fig. 4. Locations of blocks selected for surface gamma scan.

Table 4. Results of confirmatory analysis for total TRU

Location	ANS No.	Date	ANS specific activity[a] (pCi/g)	QC specific activity[b] (pCi/g)	Relative percent difference
57	C000034	23 January 1999	125.9	98.7	24.2
22	C000008	21 January 1999	37.8	26.5	35.0
86	C000038	25 January 1999	32.3	38.8	–18.4
58	C000050	23 January 1999	22.4	18.5	19.0
28	C000005	22 January 1999	16	1.6	163.5
10	C000047	23 January 1999	15.5	11.7	27.7
60	C000008	24 January 1999	15.4	8.6	56.2
102	C000053	25 January 1999	15.1	19.1	–23.5
23	C000007	21 January 1999	13.7	28.9	–71.6
25	C000003	21 January 1999	12.2	6.7	57.0
89	C000041	25 January 1999	11	5.1	71.8
14	C000010	21 January 1999	10.5	5.4	62.6
20	C000009	21 January 1999	9.9	2.7	112.3
30	C000014	22 January 1999	9.9	4.6	72.5
33	C000022	22 January 1999	9.9	8.6	13.6
53	C000051	23 January 1999	9.4	4.9	62.2
54	C000049	23 January 1999	8.6	8.6	–0.4
63	C000011	24 January 1999	8.5	21.5	–87.0
74	C000021	24 January 1999	8.4	8.0	4.6
47	C000007	22 January 1999	8.2	2.0	120.4
67	C000014	24 January 1999	8.2	3.8	72.7
12	C000015	21 January 1999	7.9	5.6	32.7
26	C000015	22 January 1999	7.9	6.7	15.1
41	C000003	24 January 1999	7.9	6.0	26.5
65	C000029	23 January 1999	7.9	5.3	38.1
50	C000025	22 January 1999	7.7	3.4	76.1
27	C000045	23 January 1999	7.6	4.6	47.3
91	C000043	25 January 1999	7.5	3.2	80.1
46	C000008	22 January 1999	7.4	3.4	72.6
56	C000042	23 January 1999	7.3	1.9	114.8
45	C000013	22 January 1999	7.2	2.8	85.1
3	C000014	21 January 1999	7.1	3.7	61.4

[a]Value from on-site radioanalytical laboratory.
[b]Value from QC third party analyzed in Oak Ridge, Tennessee.

Table 5. Results of radiochemistry

Sample ID	Nuclide	Result	Uncertainty	Units	Predicted TRU result	Observed TRU/^{241}Am ratio
026	^{241}Am	1.1	0.11	pCi/g		
026	$^{243/244}$Cu	0.004	0.009	pCi/g		
026	^{238}Pu	0.088	0.022	pCi/g		
026	$^{239/240}$Pu	5.3	0.55	pCi/g		
	Total	6.49			6.79	5.90
028	^{241}Am	0.4	0.063	pCi/g		
028	$^{243/244}$Cu	–0.004	0.008	pCi/g		
028	^{238}Pu	0.026	0.013	pCi/g		
028	$^{239/240}$Pu	2	0.22	pCi/g		
	Total	2.43			2.47	6.06
058	^{241}Am	1.9	0.19	pCi/g		
058	$^{243/244}$Cu	–0.005	0.006	pCi/g		
058	^{238}Pu	0.14	0.032	pCi/g		
058	$^{239/240}$Pu	9.6	1	pCi/g		
	Total	11.64			11.72	6.12
086	^{241}Am	0.75	0.094	pCi/g		
086	$^{243/244}$Cu	–0.002	0.007	pCi/g		
086	^{238}Pu	0.071	0.021	pCi/g		
086	$^{239/240}$Pu	4	0.42	pCi/g		
	Total	4.82			4.63	6.43

Table 6. Radiochemistry vs gamma spectral results (total TRU in pCi/g)

Sample ID	ANS	QC	ASO	RPD[a]	RPD[b]	RPD[c]
026	7.9	6.8	6.5	15.2	19.6	4.4
028	16.0	1.6	2.4	163.5	147.4	–40.6
086	32.3	38.9	4.8	–18.5	148.1	155.9
058	22.4	18.5	11.6	19.0	63.3	45.6

RPD = relative percent difference = $100 \times 2 \times |x_1 - x_2|/(x_1 + x_2)$.
[a]American Nuclear Systems (ANS)/QC (gamma spec.).
[b]ANS/Analytical Services Organization (ASO) (on-site vs radiochemistry).
[c]QC/ASO [Oak Ridge National Laboratory (ORNL) QC vs radiochemistry].

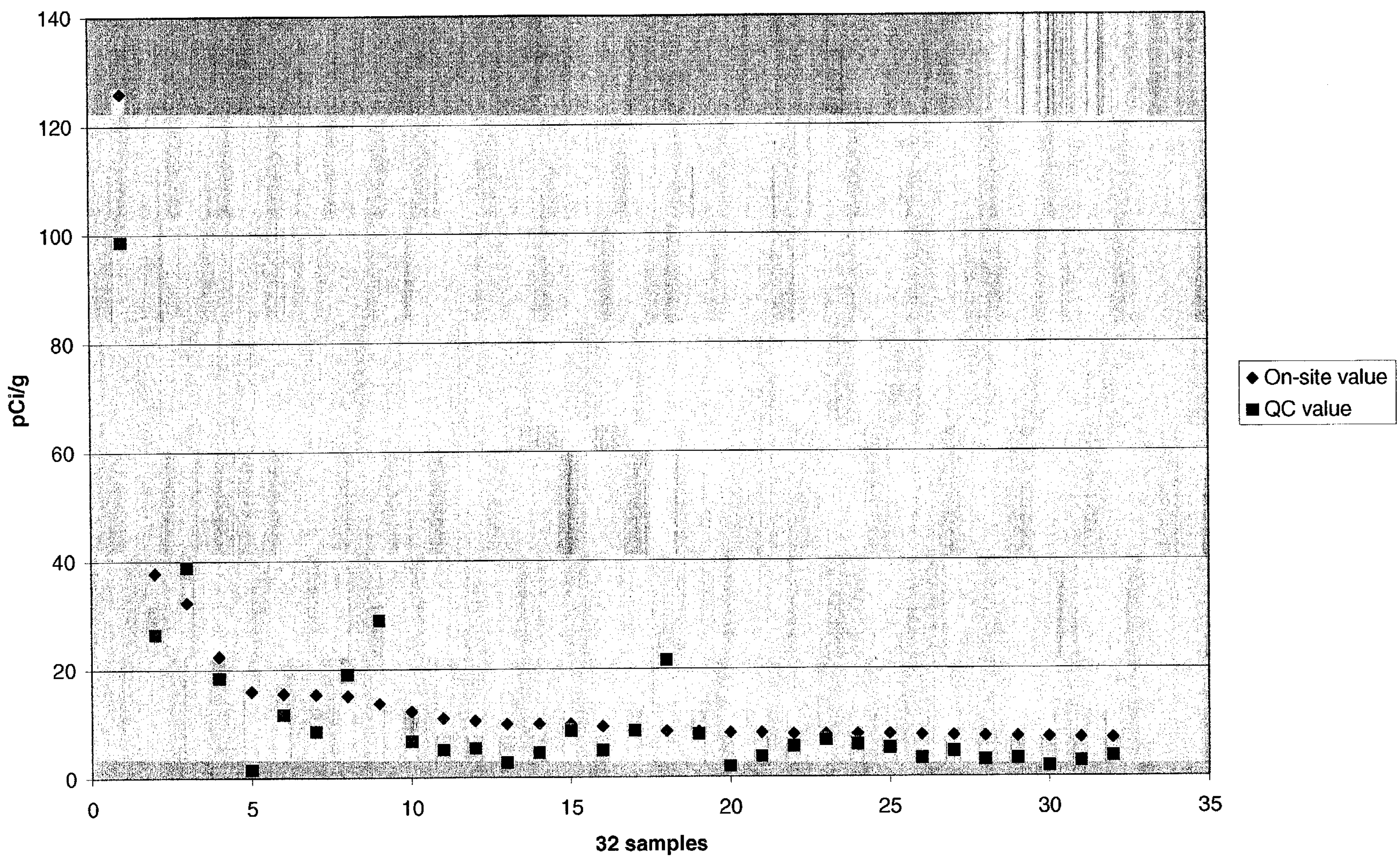

Fig. 5. On-site vs QC results.

Table 7. Fixed point measurements at grid point locations

X-axis	Y-axis	cpm	X-axis	Y-axis	cpm	X-axis	Y-axis	cpm
0	0	160	70	60	330	20	50	342
0	10	626	70	50	170	20	40	208
0	20	364	70	40	238	20	30	304
0	30	350	70	30	204	20	20	274
0	40	448	70	20	394	20	10	140
0	50	328	70	10	520	20	0	230
0	60	420	80	10	380	40	0	348
0	70	552	90	10	484	40	10	164
0	80	320	100	10	630	40	20	240
0	90	470	110	10	622	40	30	178
30	120	152	100	20	398	40	40	274
30	110	318	100	30	426	40	50	336
30	100	552	100	40	226	40	60	258
30	90	488	70	40	450	40	70	256
30	80	312	70	40	402	40	80	152
30	70	504	50	50	474	40	90	282
30	60	382	30	50	344	40	100	252
30	50	238	30	40	600	40	110	188
30	30	584	30	30	380	40	120	220
30	20	368	30	20	544	60	120	292
30	10	516	10	0	198	60	110	336
30	0	320	10	10	240	60	100	196
50	0	652	10	20	248	60	90	274
50	10	452	10	30	204	60	180	162
50	20	266	10	40	262	60	70	222
50	30	464	10	50	198	60	60	198
50	40	382	10	60	304	60	50	202
50	50	676	10	70	142	60	40	318
50	60	394	10	80	258	60	30	304
50	80	378	10	90	280	60	20	184
50	90	576	10	100	234	60	10	204
50	100	338	10	110	300	80	20	182
50	110	400	20	110	172	80	30	234
50	120	242	20	100	280	80	40	176
70	110	592	20	90	252	80	50	264
70	100	532	20	80	134	80	60	196
70	90	380	20	70	300	90	50	318
70	80	294	20	60	112	90	40	242
70	70	564	20	30	228	90	30	192
40	0	286	20	10	138	90	20	228
40	20	124	10	0	338	60	10	166

4. STATISTICAL EVALUATION OF DATA

Summary statistics are presented in Table 8. The statistical approach was a nonparametric equation for estimating one-sided upper confidence limits on percentiles (quantiles) and was described in the SAP (ORNL 1998a). The minimum sample size needed to use this test was 99. The null hypothesis presented in Sect. 2.1 cannot be rejected using a sample size of n = 103 (results in Table 3). This is because the one-sided upper 95% confidence limit for the 97th percentile is greater than the 13.5-pCi/g DCGL (Fig. 6). Therefore, the original goal of demonstrating that 97% of the pile is clean at a 95% confidence level was not achieved. However, the test is able to show that 88% of the pile can be projected to be below the 13.5-pCi/g limit at the 90% confidence level. Accordingly, the nonparametric one-sided upper 95% confidence limit for the 86.5th percentile of this data is 13.6 (Fig. 6).

Table 8. Summary statistics

Sample size	103
Minimum value	0.00
25th percentile	3.75
Median value	5.70
Mean value	7.77
95% UCL of mean	9.89
75th percentile	7.65
Maximum value	125.90
Standard deviation	12.91

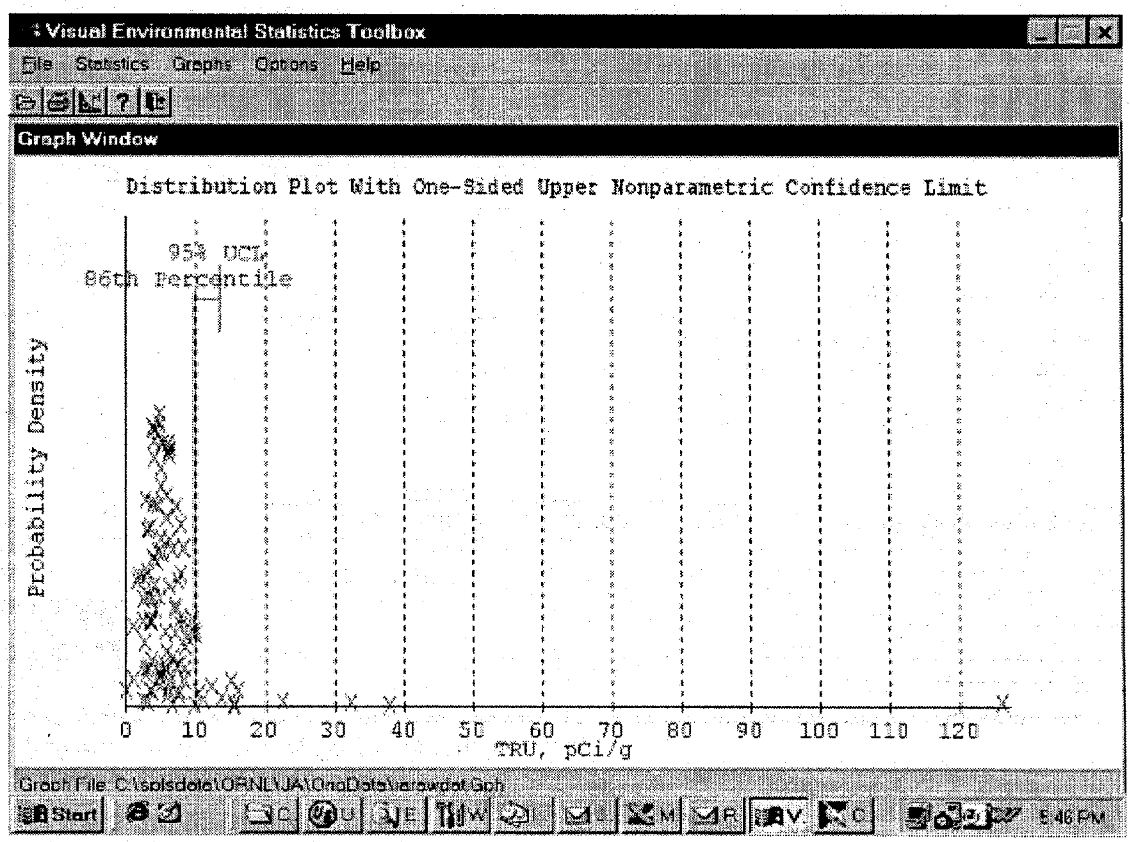

Fig. 6. Distribution of results.

Tables 9 and 10 provide many different percentiles and nonparametric one-sided upper confidence limits. These "upper limits" are equivalent to nonparametric one-sided upper tolerance bounds, which are used in another statistical test for release surveys (Eger 1992). The one-sided upper 95% confidence limits for the mean (7.77 pCi/g) and the median (5.7 pCi/g) were both well below the 13.5-pCi/g concentration. The standard deviation of the concentrations is 12.91 pCi/g.

Table 9. 90% Upper confidence limits

Percentile	Estimate (pCi/g)	Upper limit (pCi/g)	Percentile	Estimate (pCi/g)	Upper limit (pCi/g)
50th	5.70	6.00	91th	11.98	15.45
75th	7.65	8.20	92th	13.46	15.68
80th	8.08	9.24	93th	14.90	17.14
85th	9.16	10.67	94th	15.36	22.20
86th	9.76	11.28	95th	15.49	29.67
87th	9.90	12.37	96th	15.96	34.88
88th	9.90	13.68	97th	22.02	51.78
89th	10.37	14.89	98th	31.90	106.60
90th	10.90	15.31	99th	37.69	N/A

Table 10. 95% Upper confidence limits

Percentile	Estimate (pCi/g)	Upper limit (pCi/g)	Percentile	Estimate (pCi/g)	Upper limit (pCi/g)
50th	5.70	6.10	91th	11.98	15.80
75th	7.65	8.35	92th	13.46	18.36
80th	8.08	9.90	93th	14.90	23.58
85th	9.16	11.79	94th	15.36	30.76
86th	9.76	12.97	95th	15.49	35.26
87th	9.90	14.20	96th	15.96	54.65
88th	9.90	15.16	97th	22.02	107.20
89th	10.37	15.40	98th	31.90	N/A
90th	10.90	15.48	99th	37.69	N/A

The statistical approach here (Sect. 2.1 and ORNL 1998a) is a relatively stringent test compared to other statistical methods such as the sign test described in the MARSSIM (EPA 1997). According to the MARSSIM, the sign test should be used with an elevated measurement comparison (EMC) where each measurement is compared to the DCGL-EMC. The MARSSIM states "If a measurement exceeds this DCGL, then additional investigation is recommended, a least locally, to determine the actual extent of the elevated concentration."

Although this survey was not designed to use the sign test, the data here would demonstrate that the median (50%) of the clean storage pile is below the13.5-pCi/g DCGL. With the caveat that additional investigation of elevated concentrations was not performed, the data pass the sign test at 13.5 pCi/g.

5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this IV survey was to show with high confidence (95%) that a large proportion (97%) of the clean storage pile was less than the selected guideline of 13.5 pCi/g. Although the results of the survey failed to achieve this goal, several projections can be applied to the radiological status of the clean pile using the same test, such as suggesting that 88% of the clean storage pile was below 13.5 pCi/g. Furthermore, no hot particles were found within the top 1 cm of the survey units that were gamma scanned (10% of the total area). Although it is nearly impossible to statistically prove that no hot particles exist in over 80,000 metric tons of material, the gamma scan data are good indicators that hot particles have been significantly reduced.

The SAP proposed to examine both QC soils sample data and soil sorter data collected by Thermo NUtech and to present a general distribution of activity from the many years of soils sorting. This evaluation was not completed because Thermo NUtech has not issued its final report as the remedial action contractor and has not submitted six of the last sets of QC data. Previous examination of Thermo NUtech's QC samples analyzed for total TRU activity data by the IV contractor (for one quarter only) showed all results to be below 13.5 pCi/g (ORNL 1998a). Furthermore, the IV examination of the soil sorter hardware and software indicated that the decontamination was effective and significantly reduced plutonium contamination in the soil processed at the site.

Based on the results of this survey, we have the following recommendations to support any further decision-making by the DTRA: (1) examine Thermo NUtech's final report and the entirety of the soil sorting data and QC results, (2) restate the soil screening limit in terms of an acceptable confidence level, (3) reevaluate the appropriateness of the selected soil screening limit, (4) conduct another IV survey after any planned recontouring of the clean storage pile, (5) conduct a data quality objectives process before performing further verification efforts, and (6) acquire regulatory approval of the release of the clean storage pile. Historical information and other recommendations are provided in ORNL 1988a.

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Appendix A
PHOTOGRAPH LOG

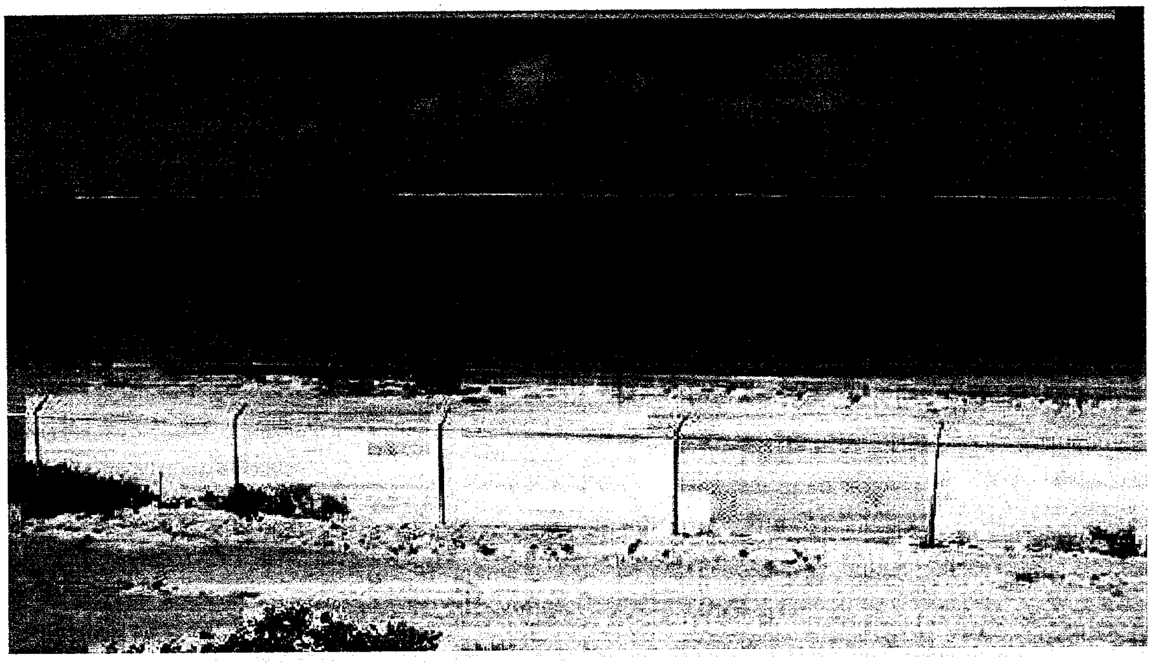

Fig. A.1. Looking north–northwest at lagoon from the plutonium decommissioning site.

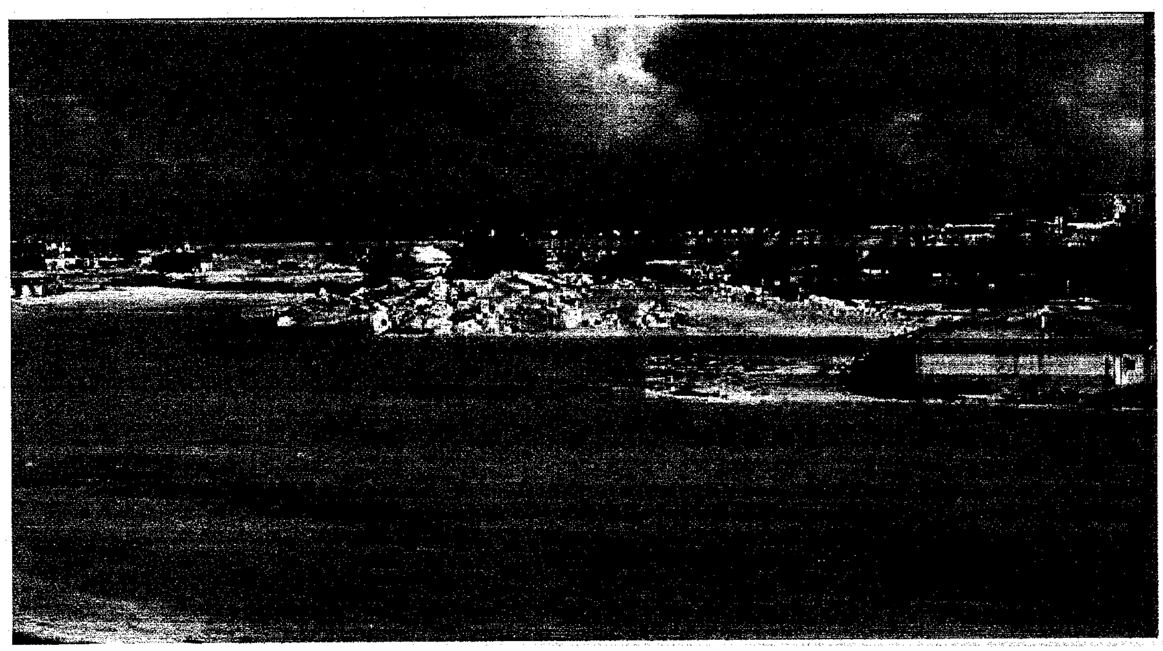

Fig. A.2. Looking east at concrete rubble and the analytical laboratory at the plutonium decommissioning site.

Fig. A.3. Collecting coral samples at 1- to 4-ft depths from the clean pile.

Fig. A.4. Waste storage at the plutonium decontamination project.

Fig. A.5. Looking north at "Mount Pluto."

Fig. A. 6. Looking north at the clean storage pile.

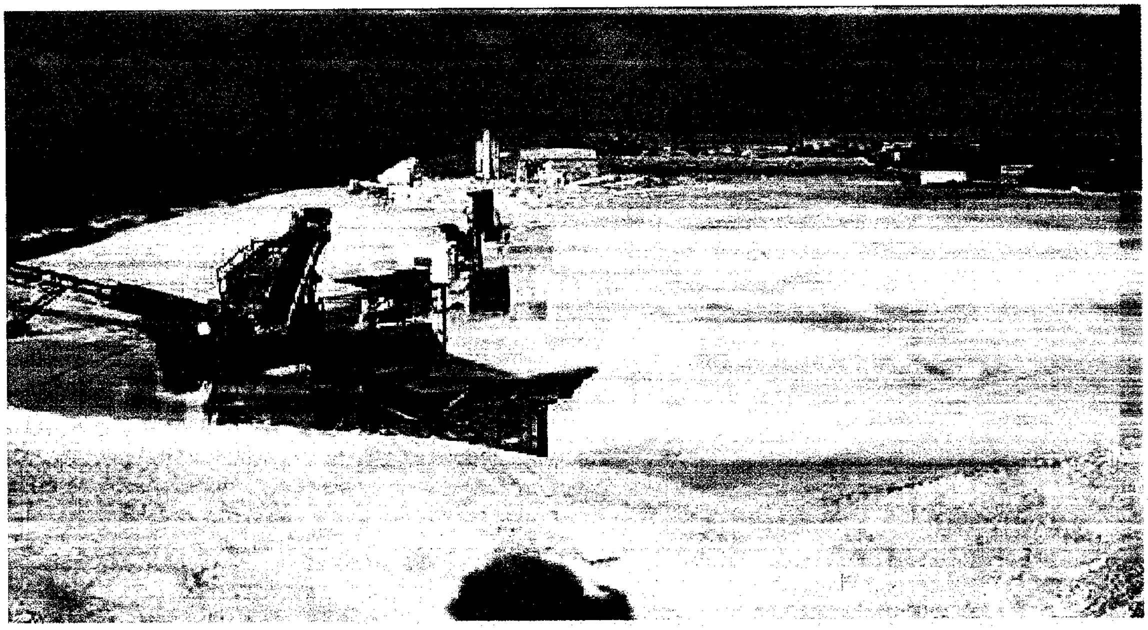

Fig. A.7. Looking northeast at the clean storage pile.

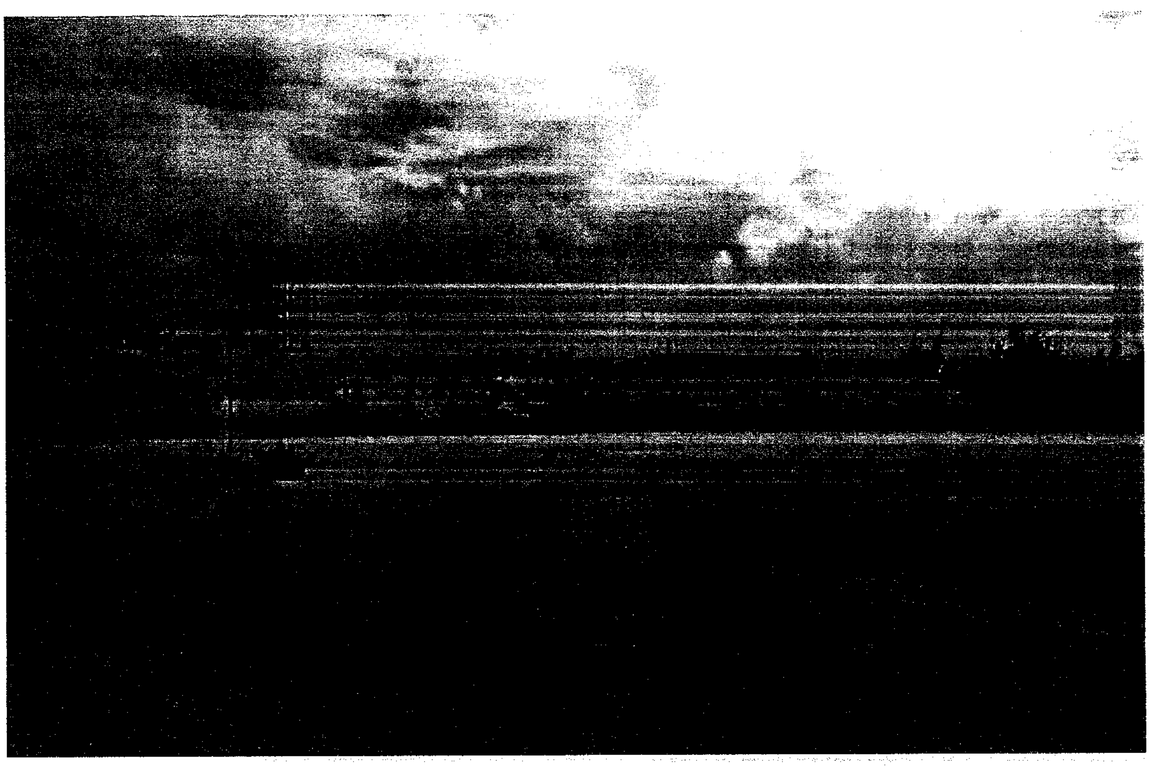

Fig. A.8. Looking northeast at the clean storage pile.

Fig. A.9. Looking northeast at the access to the clean storage pile.

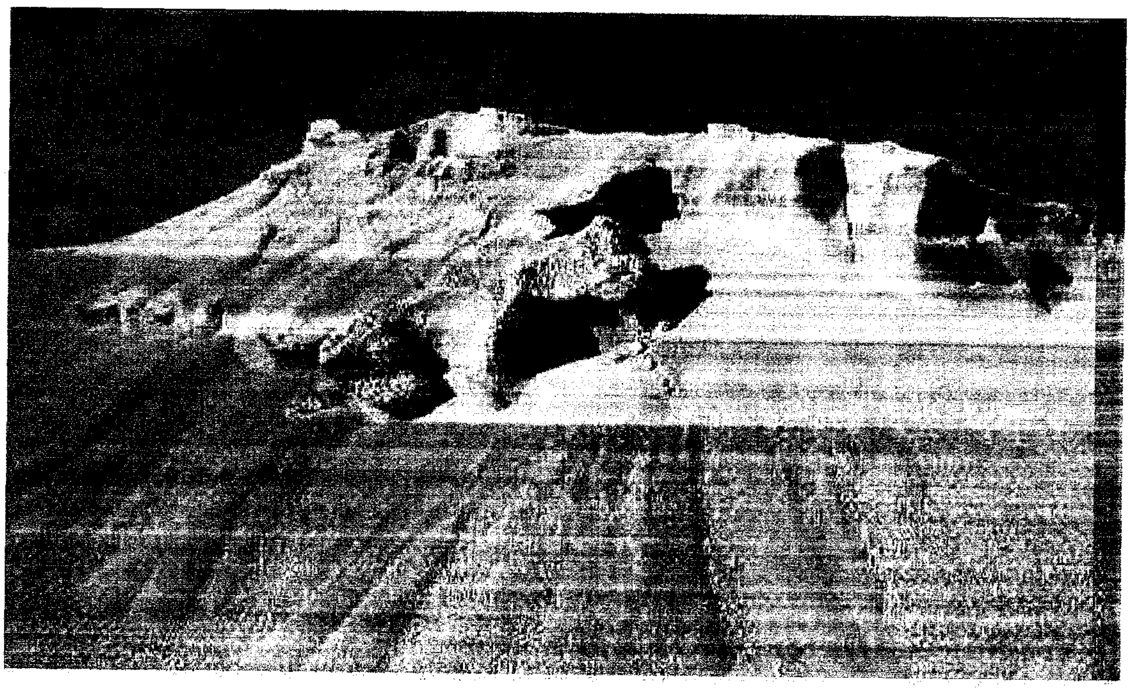

Fig. A.10. Effects of erosion on "Mount Pluto."

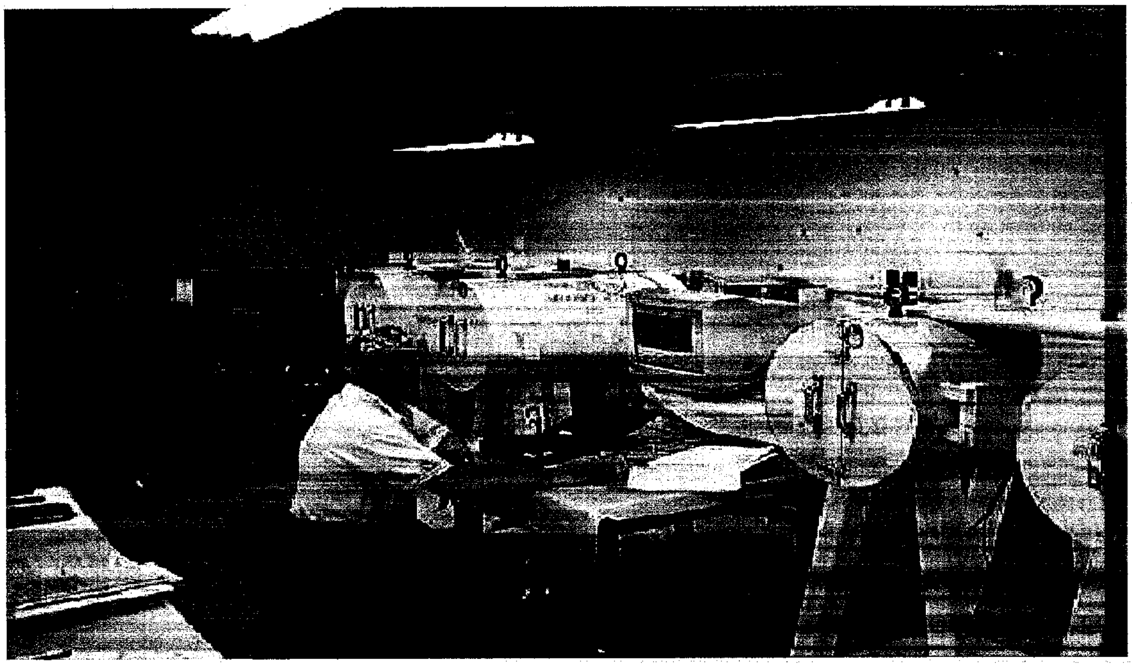

Fig. A.11. Radioanalytical counting laboratory at JA.

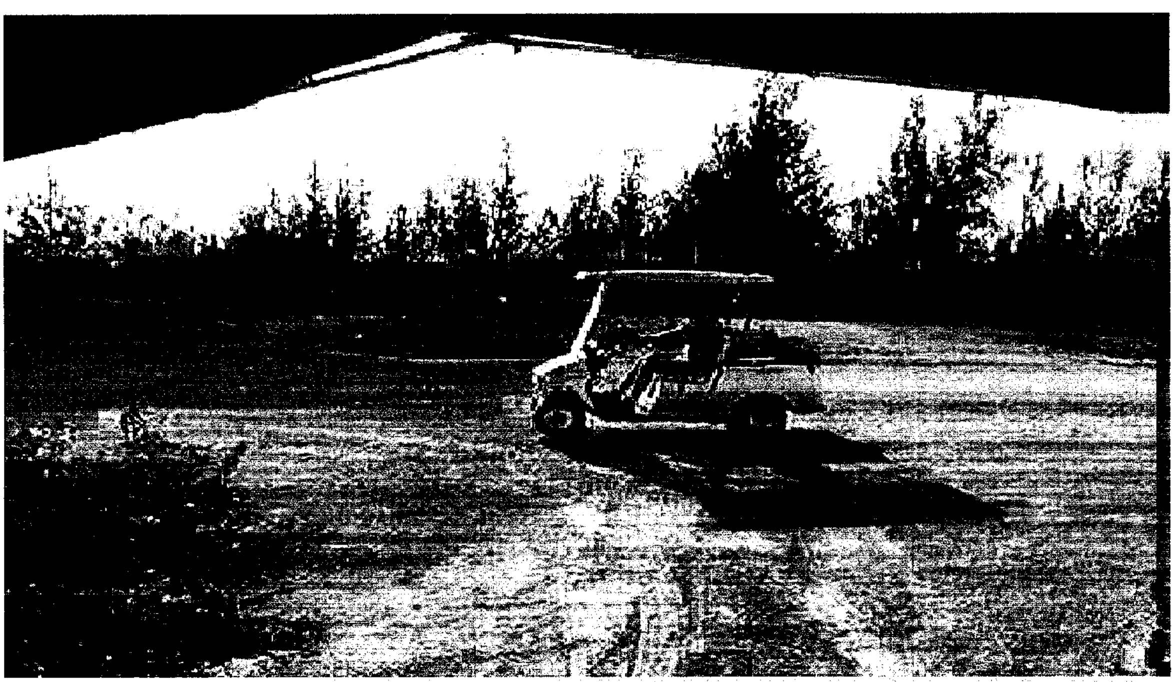

Fig. A.12. Using motorized vehicle to collect samples from the clean pile.

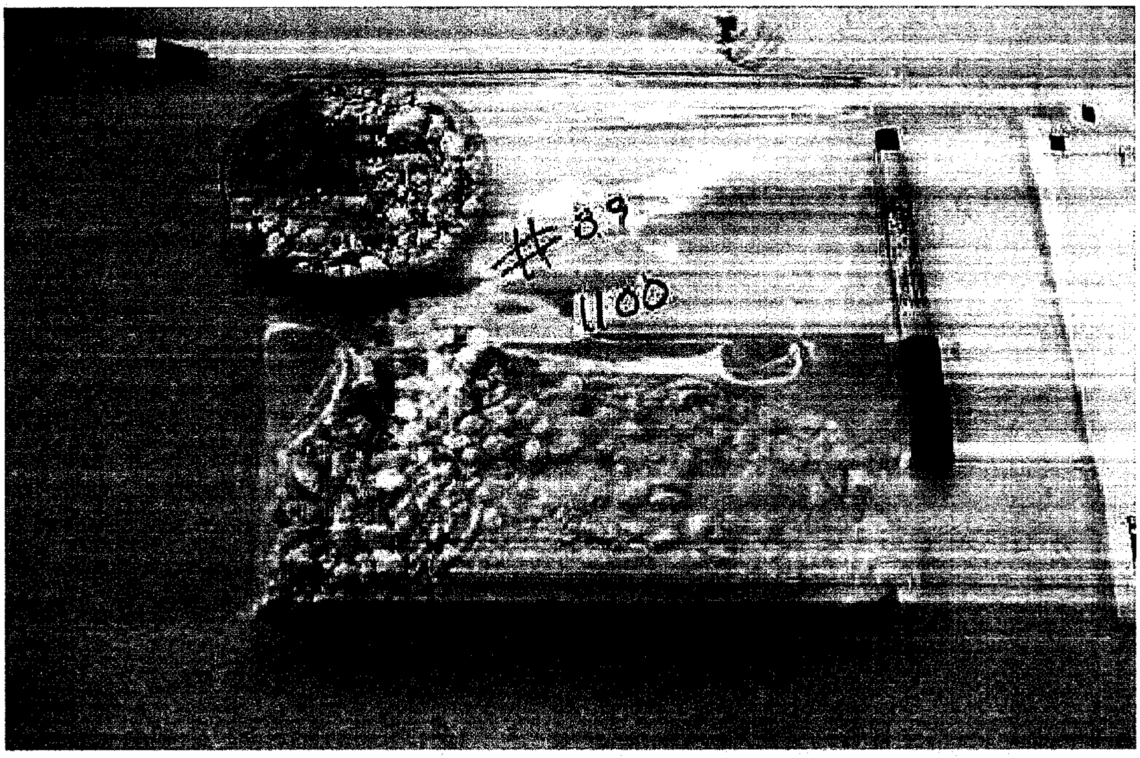

Fig. A.13. IV sample (unsieved) from the clean storage pile.

Fig. A.14. Packaged samples from the clean storage pile.

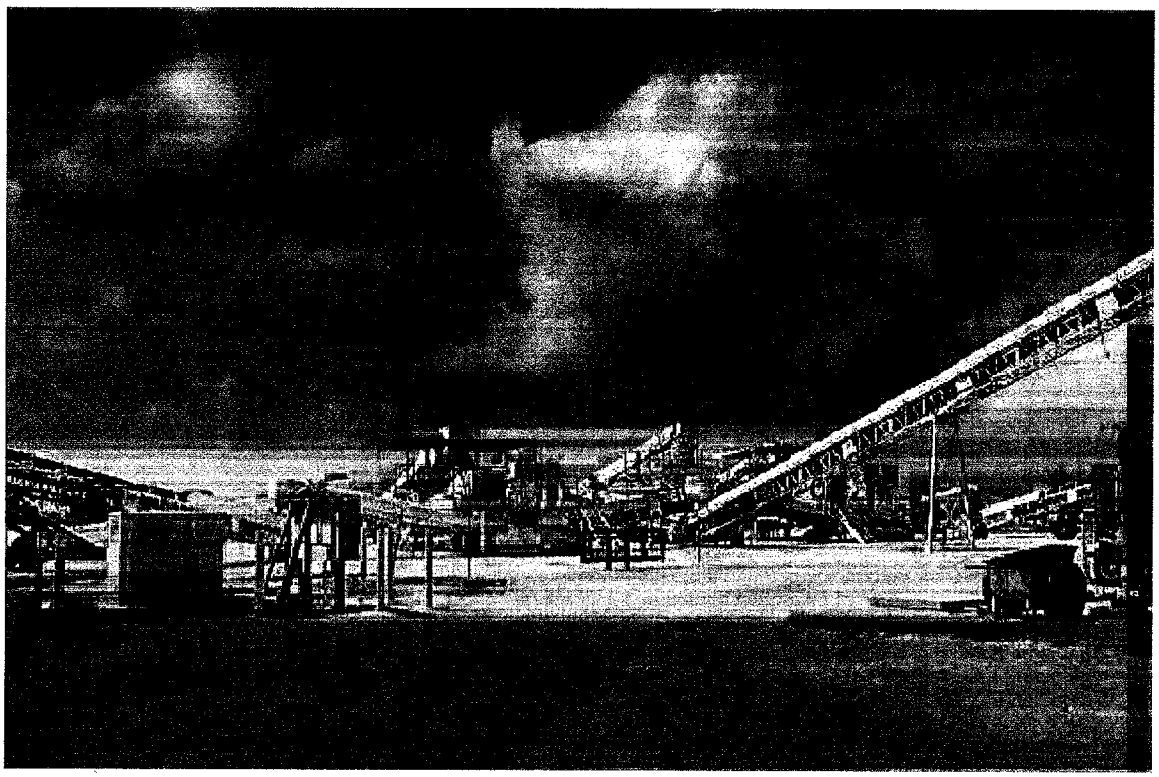

Fig. A.15. Remains of the soil sorting system at JA.

Appendix B

RESULTS FROM ON-SITE RADIOANALYTICAL LABORATORY

Table B.1. Results of on-site analysis[a]

Location No.	X (m)	Y (m)	Z (ft)	Date collected	Time	ANS No.	Date counted	Time	Weight (g)	Live time (s)	Ambient back-ground counts	Gross counts	Net counts	Sigma	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
1	0.04	108.35	0.7	1/20/1999	1436	C000001	1/21/1999	11:16	75	900	927	1102	176	37	377.4	78.9	5	1	0.1
2	0.41	84.77	3.1	1/20/1999	1448	C000001	1/22/1999	8:34	84	900	917	1080	163	36	350.5	78.1	4.2	0.9	0.1
3	−1.08	45.46	0.1	1/20/1999	1628	C000014	1/21/1999	17:06	92	900	927	1231	305	38	654.8	83.2	7.1	0.9	0.1
4	1.91	21.88	3.2	1/21/1999	807	C000028	1/23/1999	9:00	95	900	931	1083	152	36	326.9	78.3	3.4	0.8	0.1
5	−10.04	92.63	0	1/20/1999	1510	C000003	1/22/1999	9:14	86	900	917	1168	251	37	539.8	81.1	6.3	0.9	0.1
6	10.87	116.21	3.4	1/20/1999	1517	C000012	1/21/1999	16:15	83	900	927	1096	170	36	364.5	78.7	4.4	1	0.1
7	100.48	15.98	0.7	1/21/1999	1220	C000001	1/24/1999	10:29	92	900	947	1053	106	36	227.4	77.4	2.5	0.8	0.1
8	104.59	42.19	2.1	1/21/1999	1230	C000031	1/23/1999	9:54	102	900	931	1107	176	37	378.5	79.1	3.7	0.8	0.1
9	104.96	0.26	3.2	1/21/1999	1235	C000052	1/23/1999	17:31	87	900	957	1173	216	38	464	81.3	5.3	0.9	0.1
10	109.44	38.69	1.3	1/21/1999	1240	C000047	1/23/1999	15:53	95	900	957	1643	686	43	1474.7	97.5	15.5	1	0.1
11	−11.54	14.02	3.8	1/20/1999	1611	C000015	1/24/1999	15:16	85	900	947	1188	241	38	517.7	81.8	6.1	1	0.1
12	−11.91	40.22	1.1	1/20/1999	1602	C000015	1/21/1999	17:29	87	900	927	1245	319	38	684.9	83.7	7.9	1	0.1
13	11.99	37.6	1.2	1/21/1999	901	C000012	1/22/1999	13:08	100	900	917	1184	267	38	574.2	81.6	5.7	0.8	0.1
14	12.36	131.93	2.2	1/20/1999	1526	C000010	1/21/1999	15:35	84	900	927	1333	407	40	874.2	86.7	10.5	1	0.1
15	−13.03	−1.71	0.9	1/21/1999	1248	C000032	1/23/1999	10:12	97	900	931	1062	131	36	281.7	77.6	2.9	0.8	0.1
16	13.85	91.75	2.9	1/20/1999	1536	C000004	1/21/1999	13:38	102	900	927	1155	229	37	491.4	80.6	4.8	0.8	0.1
17	14.97	63.8	2	1/21/1999	812	C000044	1/23/1999	14:56	94	900	957	1229	272	38	584.4	83.2	6.2	0.9	0.1
18	15.35	6.16	3.7	1/21/1999	845	C000046	1/23/1999	15:33	95	900	957	1035	78	36	167.2	76.8	1.8	0.8	0.1
19	16.84	41.53	0.4	1/21/1999	1256	C000039	1/23/1999	13:26	88	900	957	1148	191	37	410.2	80.5	4.7	0.9	0.1
20	17.96	99.18	3.5	1/20/1999	1545	C000009	1/21/1999	15:16	87	900	927	1328	402	39	863.4	86.5	9.9	1	0.1
21	18.33	25.81	2.5	1/20/1999	1622	C000011	1/21/1999	15:56	78	900	927	1104	178	37	381.7	78.9	4.9	1	0.1
22	19.83	127.13	2.7	1/20/1999	1557	C000008	1/21/1999	14:57	81	900	927	2348	1422	51	3056.9	124.1	37.8	1.5	0.1
23	−2.57	29.74	4	1/20/1999	1615	C000007	1/21/1999	14:36	85	900	927	1466	540	41	1160.2	91.4	13.7	1.1	0.1
24	−2.95	87.39	2.2	1/21/1999	852	C000030	1/23/1999	9:38	86	900	931	1053	122	36	262.4	77.3	3.1	0.9	0.1
25	20.58	79.96	3.6	1/20/1999	1634	C000003	1/21/1999	13:20	74	900	927	1346	420	40	902.1	87.2	12.2	1.2	0.1
26	20.95	−10.88	0.2	1/21/1999	1300	C000015	1/22/1999	14:17	89	900	917	1243	326	38	701.1	83.6	7.9	0.9	0.1
27	21.32	135.86	0.5	1/21/1999	1305	C000045	1/23/1999	15:13	91	900	957	1279	322	39	691.9	84.9	7.6	0.9	0.1
28	22.82	10.09	0.1	1/21/1999	1310	C000005	1/22/1999	9:57	88	900.01	917	1572	655	42	1408.5	95.2	16	1.1	0.1
29	23.94	72.98	3.3	1/21/1999	745	C000020	1/22/1999	15:55	106	900	917	1267	350	39	752.7	84.4	7.1	0.8	0.1
30	24.31	120.14	3.7	1/21/1999	754	C000014	1/22/1999	13:57	84	900	917	1304	387	39	832.2	85.7	9.9	1	0.1
31	25.8	57.25	0.2	1/21/1999	1307	C000010	1/22/1999	12:31	98	900	917	1139	222	37	477.4	80.1	4.9	0.8	0.1
32	26.92	52.01	2.3	1/21/1999	759	C000006	1/24/1999	12:04	95	900	947	1107	160	37	343.5	79.1	3.6	0.8	0.1
33	27.3	−5.64	2.2	1/21/1999	910	C000022	1/22/1999	16:51	91	900	917	1332	415	40	892.4	86.7	9.9	1	0.1
34	28.79	104.42	0.2	1/21/1999	1253	C000017	1/22/1999	15:00	97	900	917	1075	158	36	339.8	77.9	3.5	0.8	0.1
35	29.91	4.85	0.4	1/21/1999	1302	C000016	1/22/1999	14:37	95	900	917	1089	172	36	369.9	78.4	3.9	0.8	0.1
36	3.03	16.64	2.7	1/21/1999	917	C000004	1/24/1999	11:27	97	900	947	1122	175	37	375.8	79.6	3.9	0.8	0.1
37	3.4	100.49	0.5	1/21/1999	1303	C000043	1/23/1999	14:38	92	900	957	1207	250	38	537.1	82.4	5.8	0.9	0.1
38	30.28	88.7	3.1	1/21/1999	820	C000007	1/24/1999	12:24	93	900	947	1059	112	36	240.3	77.6	2.6	0.8	0.1
39	31.78	32.8	2.6	1/21/1999	924	C000011	1/22/1999	12:48	96	900	917	1037	120	36	258.1	76.7	2.7	0.8	0.1
40	32.52	103.55	0.8	1/21/1999	1308	C000009	1/22/1999	11:19	90	900	917	1103	186	37	400	78.9	4.4	0.9	0.1
41	32.9	59.87	2.6	1/21/1999	833	C000003	1/24/1999	11:09	90	900	947	1278	331	39	711.3	84.8	7.9	0.9	0.1
42	33.27	17.95	3.6	1/21/1999	930	C000023	1/22/1999	17:08	89	900	917	1089	172	36	369.9	78.4	4.1	0.9	0.1
43	34.76	80.84	1.2	1/21/1999	937	C000040	1/23/1999	13:46	90	900	957	1056	99	36	212.4	77.5	2.4	0.9	0.1

Table B.1. (continued)

Location No.	X (m)	Y (m)	Z (ft)	Date collected	Time	ANS No.	Date counted	Time	Weight (g)	Live time (s)	Ambient back-ground counts	Gross counts	Net counts	Sigma	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
44	36.26	49.39	2.3	1/21/1999	944	C000023	1/24/1999	18:26	94	900	947	1112	165	37	354.3	79.3	3.8	0.8	0.1
45	38.87	28.43	1.4	1/21/1999	1015	C000013	1/22/1999	13:28	96	900	917	1238	321	38	690.3	83.4	7.2	0.9	0.1
46	39.24	112.28	1	1/21/1999	1309	C000008	1/22/1999	11:02	90	900	917	1227	310	38	666.6	83.1	7.4	0.9	0.1
47	–4.07	21	1.4	1/21/1999	1311	C000007	1/22/1999	10:42	94	900	917	1276	359	39	772	84.8	8.2	0.9	0.1
48	4.89	69.04	1.1	1/21/1999	1314	C000033	1/23/1999	10:32	103	900	931	1224	293	38	630.1	83	6.1	0.8	0.1
49	40.74	33.67	2.5	1/21/1999	1007	C000018	1/22/1999	15:20	101	900	917	1190	273	38	587.1	81.8	5.8	0.8	0.1
50	41.86	75.6	1.7	1/21/1999	1022	C000025	1/22/1999	17:44	96	900	917	1261	344	39	739.8	84.2	7.7	0.9	0.1
51	42.23	96.56	4	1/21/1999	1030	C000038	1/23/1999	13:08	84	900	957	1084	127	36	272.6	78.4	3.2	0.9	0.1
52	43.73	56.38	2.7	1/21/1999	1000	C000019	1/22/1999	15:38	104	900	917	1085	168	36	361.3	78.3	3.5	0.8	0.1
53	44.85	122.76	2.8	1/21/1999	1036	C000051	1/23/1999	17:10	92	900	957	1359	402	40	864	87.6	9.4	1	0.1
54	45.22	65.11	2.8	1/21/1999	952	C000049	1/23/1999	16:34	90	900	957	1318	361	39	775.8	86.2	8.6	1	0.1
55	46.71	128	1	1/21/1999	1315	C000041	1/23/1999	14:05	96	900	957	1236	279	38	599.4	83.4	6.3	0.9	0.1
56	47.83	2.22	3.4	1/21/1999	1316	C000042	1/23/1999	14:22	93	900	957	1275	318	39	683.3	84.7	7.3	0.9	0.1
57	48.21	137.83	1.6	1/21/1999	1318	C000034	1/23/1999	11:09	89	900	931	6167	5236	80	11259.9	277.2	125.9	3.1	0.1
58	49.7	74.94	3	1/21/1999	1330	C000050	1/23/1999	16:54	88	900	957	1875	918	46	1973.6	106	22.4	1.2	0.1
59	–5.56	61.18	1.4	1/21/1999	1342	C000004	1/22/1999	9:40	96	900	917	1136	219	37	471	80	4.9	0.8	0.1
60	–5.94	–6.95	2	1/22/1999	806	C000008	1/24/1999	12:41	90	900	947	1590	643	43	1382.2	95.7	15.4	1.1	0.1
61	50.82	69.7	3.5	1/22/1999	755	C000009	1/24/1999	12:58	93	900	947	1155	208	37	446.8	80.7	4.8	0.9	0.1
62	51.19	12.05	3.9	1/22/1999	801	C000010	1/24/1999	13:19	92	900	947	1149	202	37	433.9	80.5	4.7	0.9	0.1
63	52.69	122.11	1.1	1/22/1999	811	C000011	1/24/1999	13:35	89	900	947	1300	353	39	758.6	85.6	8.5	1	0.1
64	53.81	22.53	2	1/22/1999	816	C000012	1/24/1999	14:23	98	900	947	1074	127	36	272.6	78	2.8	0.8	0.1
65	54.18	43.5	2.9	1/22/1999	820	C000029	1/23/1999	9:20	84	900	931	1239	308	38	662.3	83.5	7.9	1	0.1
66	55.67	3.32	3.2	1/22/1999	822	C000013	1/24/1999	14:42	83	900	947	1180	233	38	500.5	81.5	6	1	0.1
67	56.42	50.48	2.5	1/22/1999	830	C000014	1/24/1999	14:59	98	900	947	1318	371	39	797.3	86.2	8.2	0.9	0.1
68	56.79	6.81	1.8	1/22/1999	835	C000016	1/24/1999	15:35	97	900	947	1019	72	35	154.3	76.3	1.6	0.8	0.1
69	57.17	106.39	2.6	1/22/1999	840	C000017	1/24/1999	15:59	97	900	947	1228	281	38	603.7	83.1	6.2	0.9	0.1
70	58.66	27.77	2.5	1/22/1999	845	C000018	1/24/1999	16:21	97	900	947	1112	165	37	354.3	79.3	3.6	0.8	0.1
71	59.78	90.66	3.2	1/21/1999	1333	C000002	1/24/1999	10:48	91	900	947	1190	243	38	522	81.9	5.8	0.9	0.1
72	6.01	110.97	1	1/22/1999	849	C000019	1/24/1999	16:39	87	900	947	1153	206	37	442.5	80.6	5.1	0.9	0.1
73	6.39	–9.57	2.6	1/22/1999	854	C000020	1/24/1999	16:57	90	900	947	1060	113	36	242.5	77.6	2.7	0.9	0.1
74	60.15	–3.67	2.4	1/22/1999	902	C000021	1/24/1999	17:14	92	900	947	1306	359	39	771.5	85.8	8.4	0.9	0.1
75	62.77	116.87	2.2	1/22/1999	910	C000022	1/24/1999	18:08	92	900	947	1161	214	37	459.7	80.9	5	0.9	0.1
76	63.14	59.22	2.8	1/22/1999	915	C000024	1/24/1999	18:43	90	900	947	1159	212	37	455.4	80.8	5.1	0.9	0.1
77	65.75	46.12	0.9	1/22/1999	920	C000025	1/24/1999	19:02	93	900	947	1075	128	36	274.7	78.1	2.9	0.8	0.1
78	66.13	114.25	4	1/22/1999	927	C000026	1/24/1999	19:18	97	900	947	1185	238	38	511.3	81.7	5.3	0.8	0.1
79	67.62	74.07	0.7	1/22/1999	933	C000027	1/24/1999	19:39	84	900	947	1175	228	38	489.8	81.4	5.8	1	0.1
80	68.74	140.45	3	1/22/1999	939	C000028	1/24/1999	19:55	85	900	947	1185	238	38	511.3	81.7	6	1	0.1
81	69.12	82.8	0.8	1/22/1999	942	C000029	1/24/1999	20:11	89	900	947	1152	205	37	440.3	80.6	4.9	0.9	0.1
82	70.61	98.52	2.4	1/22/1999	944	C000030	1/24/1999	20:28	92	900	947	1234	287	38	616.6	83.3	6.7	0.9	0.1
83	71.73	19.91	3.4	1/22/1999	949	C000031	1/24/1999	20:44	88	900	947	1215	268	38	575.8	82.7	6.6	0.9	0.1
84	72.1	67.08	1.7	1/22/1999	953	C000032	1/24/1999	21:01	90	900	947	1241	294	38	631.7	83.6	7	0.9	0.1
85	73.6	4.19	1.2	1/22/1999	957	C000033	1/24/1999	21:19	93	900	947	1124	177	37	380.1	79.7	4.1	0.9	0.1
86	74.72	–1.05	1.2	1/22/1999	1040	C000038	1/25/1999	7:56	98	900	993	2462	1469	59	3159.1	140.3	32.3	1.4	0.1

Table B.1. (continued)

Location No.	X (m)	Y (m)	Z (ft)	Date collected	Time	ANS No.	Date counted	Time	Weight (g)	Live time (s)	Ambient back-ground counts	Gross counts	Net counts	Sigma	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
87	75.09	129.97	3.6	1/22/1999	1049	C000039	1/25/1999	8:13	91	900	993	1162	169	46	363.4	100.1	4	1.1	0.1
88	76.58	51.36	0.3	1/22/1999	1056	C000040	1/25/1999	8:30	92	900	993	1100	107	46	230.1	98.5	2.5	1.1	0.1
89	77.7	93.28	1.4	1/22/1999	1100	C000041	1/25/1999	8:50	89	900	993	1449	456	49	980.6	107.9	11	1.2	0.1
90	78.08	35.63	0.2	1/22/1999	1110	C000042	1/25/1999	9:06	90	900	993	992	–1	45	–2.2	95.8	0	1.1	0.1
91	–8.55	76.91	0.3	1/22/1999	1220	C000043	1/25/1999	9:33	95	900	993	1322	329	48	707.5	104.4	7.5	1.1	0.1
92	8.63	–2.58	1.6	1/22/1999	1225	C000044	1/25/1999	9:56	95	900	993	1175	182	47	391.4	100.4	4.1	1.1	0.1
93	80.32	15.11	3.2	1/22/1999	1231	C000045	1/25/1999	10:16	89	900	993	1140	147	46	316.1	99.5	3.5	1.1	0.1
94	81.06	71.01	2.5	1/22/1999	1237	C000046	1/25/1999	10:37	85	900	993	1241	248	47	533.3	102.2	6.3	1.2	0.1
95	85.54	39.57	1.5	1/22/1999	1242	C000047	1/25/1999	11:20	86	900	993	1143	150	46	322.6	99.6	3.8	1.2	0.1
96	87.04	23.84	3.5	1/22/1999	1247	C000005	1/24/1999	11:44	92	900	947	1199	252	38	541.4	82.2	5.9	0.9	0.1
97	9	95.25	3.8	1/22/1999	1255	C000048	1/25/1999	12:18	96	900	993	1127	134	46	288.2	99.2	3	1	0.1
98	9.37	53.32	0.3	1/22/1999	1259	C000049	1/25/1999	12:38	93	900	993	1041	48	45	103.2	97	1.1	1	0.1
99	90.03	8.12	1.5	1/22/1999	1304	C000050	1/25/1999	12:54	93	900	993	1037	44	45	94.6	96.9	1	1	0.1
100	92.64	34.32	1.1	1/22/1999	1308	C000051	1/25/1999	13:14	94	900	993	1135	142	46	305.4	99.4	3.3	1.1	0.1
101	95.63	55.29	3.1	1/22/1999	1312	C000052	1/25/1999	13:31	90	900	993	1273	280	48	602.1	103	6.7	1.1	0.1
102	96	31.7	0.3	1/22/1999	1319	C000053	1/25/1999	13:48	90	900	993	1623	630	51	1354.8	113.1	15.1	1.3	0.1
103	98.99	47.43	1.3	1/22/1999	1324	C000054	1/25/1999	14:06	94	900	993	1130	137	46	294.6	99.2	3.1	1.1	0.1

[a]Collected by EKR/RMS.
ANS = American Nuclear Systems.
MDC = minimum detectable concentration.

Table B.2. Background counts

ANS No.	Date	Time	Weight (g)	Live time (s)	Ambient background counts	Gross counts
B000004	1/20/1999	18:45	0	3600.00	0	3979
B000006	1/20/1999	21:41	0	46870.62	0	50125
B000007	1/21/1999	8:28	0	3600.00	0	0
B000016	1/21/1999	17:49	0	49030.64	0	51503
B000017	1/22/1999	7:26	0	3600.00	0	3668
B000026	1/22/1999	18:05	0	49827.87	0	51787
B000027	1/23/1999	7:56	0	3600.00	0	3724
B000037	1/23/1999	7:56	0	3600.00	0	3829
B000001	1/24/1999	8:54	0	3600.00	0	3789

Table B.3. Duplicates

Location	X (m)	Y (m)	Z (ft)	Date collected	Time	ANS No.	Date counted	Time	Weight (g)	Live time (s)	Ambient back-ground counts	Gross counts	Net counts	Sigma	Gross activity (pCi)	Sigma	Specific activity (pCi/g)	Sigma	MDC (pCi/g)
6	10.87	116.21	3.4	1/21/1999	16:48	D000013	1/21/1999	16:48	83	900	927	1033	107	36	229	76.6	2.8	0.9	0.1
28	22.82	10.09	0.1	1/22/1999	10:18	D000006	1/22/1999	10:18	88	900	917	1375	458	40	984.9	88.2	11.2	1	0.1
29	23.94	72.98	3.3	1/22/1999	16:16	D000021	1/22/1999	16:16	106	900	917	1223	306	38	658	82.9	6.2	0.8	0.1
57	48.21	137.83	1.6	1/23/1999	11:28	D000035	1/23/1999	11:28	89	900	931	6112	5181	80	11141.6	274.9	124.6	3.1	0.1
10	109.44	38.69	1.3	1/23/1999	16:18	D000048	1/23/1999	16:18	95	900	957	1632	675	43	1451	97.2	15.3	1	0.1

Appendix C

QC RESULTS FROM ORNL ANALYTICAL LABORATORY

Table C.1. QC results from ORNL analytical laboratory

Location	ANS No.	Date	ANS specific activity[a] (pCi/g)	QC specific activity[b] (pCi/g)	Relative percent difference
57	C000034	1/23/1999	125.9	98.72	24.2008726
22	C000008	1/21/1999	37.8	26.531	35.0344313
86	C000038	1/25/1999	32.3	38.871	–18.4654
58	C000050	1/23/1999	22.4	18.51	19.01736
28	C000005	1/22/1999	16	1.6042	163.5496
10	C000047	1/23/1999	15.5	11.723	27.7485949
60	C000008	1/24/1999	15.4	8.638	56.2609202
102	C000053	1/25/1999	15.1	19.127	–23.53113
23	C000007	1/21/1999	13.7	28.999	–71.659758
25	C000003	1/21/1999	12.2	6.787	57.01796
89	C000041	1/25/1999	11	5.1828	71.8936154
14	C000010	1/21/1999	10.5	5.4913	62.642812
20	C000009	1/21/1999	9.9	2.7765	112.389066
30	C000014	1/22/1999	9.9	4.6275	72.5864739
33	C000022	1/22/1999	9.9	8.638	13.6152767
53	C000051	1/23/1999	9.4	4.936	62.2767857
54	C000049	1/23/1999	8.6	8.638	–0.4408864
63	C000011	1/24/1999	8.5	21.595	–87.024423
74	C000021	1/24/1999	8.4	8.021	4.61604044
47	C000007	1/22/1999	8.2	2.0361	120.434541
67	C000014	1/24/1999	8.2	3.8254	72.7559998
12	C000015	1/21/1999	7.9	5.6764	32.7568428
26	C000015	1/22/1999	7.9	6.787	15.1562606
41	C000003	1/24/1999	7.9	6.0466	26.5785209
65	C000029	1/23/1999	7.9	5.3679	38.1688135
50	C000025	1/22/1999	7.7	3.4552	76.1044177
27	C000045	1/23/1999	7.6	4.6892	47.3716759
91	C000043	1/25/1999	7.5	3.2084	80.1538979
46	C000008	1/22/1999	7.4	3.4552	72.6803744
56	C000042	1/23/1999	7.3	1.9744	114.845165
45	C000013	1/22/1999	7.2	2.8999	85.1513381
3	C000014	1/21/1999	7.1	3.7637	61.4210628

[a]Value from on-site radioanalytical laboratory.
[b]Value from QC third party analyzed in Oak Ridge, Tennessee.

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