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INDEPENDENT CONFIRMATORY SURVEY REPORT FOR THE SECTION 4 AREA AT THE RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO

W. C. Adams

Prepared for the
U.S. Nuclear Regulatory Commission

ORISE
Oak Ridge Institute for Science and Education

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ABBREVIATIONS AND ACRONYMS

BKG	background
CFR	Code of Federal Regulations
cm	centimeter
CP	closure plan
cpm	counts per minute
D&D	decontamination and decommissioning
DCGL	derived concentration guideline level
DOE	U.S. Department of Energy
DP	decommissioning plan
EPA	U.S. Environmental Protection Agency
FSS	final status survey
FSSP	final status survey plan
GPS	global positioning system
ha	hectare
IEAV	Independent Environmental Assessment and Verification Program
ISM	integrated safety management
ITP	Intercomparison Testing Program
JHA	job hazard analyses
kg	kilogram
KOMEX	Komex Environmental and HG Engineering Ltd.
km	kilometer
MAPEP	Mixed Analyte Performance Evaluation Program
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MeV	million electron volts
m	meters
m^2	square meter
NaI(Tl)	sodium iodide (thallium-activated)
NatU	natural uranium
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
NRIP	NIST Radiochemistry Intercomparison Program
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
RAM	Rio Algom Mining
Ra-226	radium-226
ROC	radionuclides of concern
RP	relative precision
RSS	ranked set sampling
SOR	sum-of-ratios
TAP	total absorption peak
TER	technical evaluation report
Th-230	thorium-230

ABBREVIATIONS AND ACRONYMS (CONTINUED)

UMTRCA	Uranium Mill Tailings Radiation Control Act
VSP	Visual Sample Plan

CONFIRMATORY SURVEY REPORT FOR THE SECTION 4 AREA AT THE RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO

INTRODUCTION AND SITE HISTORY

The Rio Algom Mining (RAM) Limited Liability Corporation Ambrosia Lake site began processing uranium-bearing ore in 1958. Operating under U. S. Nuclear Regulatory Commission (NRC) Source Material License SUA-1473, the site processed approximately 33 million tons of ore through 1985 and continued to be an active uranium production facility through December 2002. Reclamation of the tailings began in 1989 and included the excavation and disposal of unlined evaporation pond residues, contaminated soil cleanup, construction of surface water erosion protection features and the demolition of the mill buildings (NRC 2006).

Construction of the Section 4 evaporation ponds commenced in 1976 and was completed in 1979. The ponds were used to evaporate liquid wastes generated from RAM's processing mill. The ponds remained in active service until April 2004; reclamation activities included the pond sediments being relocated to the main tailings disposal area (KOMEX 2006). Other reclamation activities included the excavation and disposal of unlined evaporation pond residues, contaminated soil clean-up, completion of the majority of the required reclamations for Impoundments 1 and 2, construction of a rock apron on Impoundment 2 and demolition of the conventional milling structures and most support facilities. Additional activities at the site included the construction of erosion protection features adjacent to the tailings disposal facility.

On January 19, 2005, the RAM submitted a *Soil Decommissioning Plan* for its Ambrosia Lake uranium mill tailings facility, specifically the evaporation ponds, to the NRC. The NRC requested, in several comment letters, that RAM provide additional information and a revised plan (NRC 2006). RAM issued a revised decommissioning plan (DP) that addresses the methods and procedures implemented to ensure soil remediation meets the requirements of the *Uranium Mill Tailings Radiation Control Act* (UMTRCA) and NRC regulations contained within the *Code of Federal Regulations* (CFR) Title 10, Part 40, Appendix A. The DP presents the geographical site, pertinent background information and the design for surface reclamation of the Section 4 evaporation ponds sediment material which is considered byproduct material as defined by the Atomic Energy Act of 1954.

As per the CFR requirements, the DP addresses the disposal of the uranium mill tailings in a manner as to protect human health and the environment (NRC 2006).

At the request of the NRC's Headquarters and Region IV Offices, the Oak Ridge Institute for Science and Education (ORISE) performed confirmatory radiological surveys of the Section 4 Area evaporation ponds at the RAM Ambrosia Lake facility in Ambrosia Lake, New Mexico.

SITE DESCRIPTION

RAM's Ambrosia Lake site is located in the Ambrosia Lake mining district in the southeastern part of McKinley County, New Mexico, approximately 25 miles north of Grants, New Mexico (Figure A-1). The Grants Uranium Belt, specifically the Ambrosia Lake mining district, contained numerous mining companies which operated two uranium ore processing mills and over 20 underground uranium mines within the Ambrosia Lake valley. Forty years of mining and milling activities throughout the valley has led to extensive surface disturbance within the area. The Section 4 evaporation ponds, consisting of Ponds 11 through 21, are located entirely within Section 4 along the southeastern portion of the site (Figure A-2). Overall, the Section 4 Ponds cover approximately 300 acres.

RADIONUCLIDES OF CONCERN

The radionuclides of concern (ROCs) for the RAM Ambrosia Lake Facility are those associated with the uranium decay series and are natural uranium (NatU), thorium-230 (Th-230), and radium-226 (Ra-226). These radionuclides, in addition to being present as natural background constituents, may also be present in the surrounding area as a result of extensive uranium mining activities that occurred adjacent to the RAM mill facility.

OBJECTIVES

The objectives of the confirmatory survey were to verify that remedial actions were effective in meeting established release criteria and that documentation accurately and adequately described the final radiological conditions of the RAM Ambrosia Lake, Section 4 Areas.

DOCUMENT REVIEW

ORISE personnel reviewed the DP, closure plan (CP), the final status survey plan (FSSP) and the technical evaluation report (TER) for the soil decommissioning in preparation for confirmatory survey activities for the Section 4 Areas (KOMEX 2006, MAXIM 2004, NRC 2006). Information was evaluated to assure that final status survey (FSS) procedures were appropriate for the ROCs and that residual radionuclide concentration levels satisfied the established radiological release criteria.

CONFIRMATORY SURVEY PROCEDURES

ORISE personnel visited the Ambrosia Lake Facility from September 21 through 24, 2009 to perform visual inspections and independent measurements and sampling. The confirmatory survey activities were conducted in accordance with a site-specific confirmatory survey plan, the ORISE Survey Procedures Manual and the Oak Ridge Associated Universities (ORAU) Quality Program Manual (ORISE 2009a and 2008 and ORAU 2009).

RAM has delineated the areas into affected, unaffected areas, and mining-affected areas. Areas not expected to contain radioactive contamination attributable to licensed activities and that have not been impacted by mining activities were classified as unaffected areas (natural background). Unaffected areas were generally located upwind and possess natural background concentrations of ROCs and gamma radiation levels. Mining-affected areas were those areas near the site unaffected by *milling-related* activities but where soils have been affected by *mining-related* activities (non-11e.(2) material). The impacted (affected) site area where ORISE performed confirmatory surveys was within Section 4 and included eleven evaporation ponds [Ponds 11 through 21 (Figure A-2)].

For the confirmatory surveys, ORISE divided the Section 4 Ponds into three survey areas. In each of the areas, ORISE performed a ranked set sampling (RSS) approach for randomly selecting one hundred square meters (100 m^2) areas for confirmatory investigations—the fundamental compliance unit—and for determining confirmatory soil sample locations (EPA 2002). ORISE performed gamma surface scans and soil sampling in each randomly selected 100 m^2 area grid block. Due to the size of the three survey areas, the logistics for surveying the uneven terrain, and the time constraints for the confirmatory survey activities, with concurrence from the NRC lead inspector, ORISE reduced the originally planned confirmatory survey activities by 40% (54 grid blocks instead of 90 and 18 soil samples instead of 30). This deviation was documented in the site logbook.

There were three area sample planning groups as follows (Table 1): Area 1 consisted of Section 4 Ponds 11 through 14, Area 2 consisted of Section 4 Ponds 15 through 17 and Pond 21, and Area 3 consisted of Section 4 Ponds 18 through 20. The decision to pool the confirmatory survey data for the survey units was based on the site logistics and grouping of contiguous areas.

TABLE 1:
CONFIRMATORY SURVEY AREA DESIGNATIONS

Survey Area	Section 4 Ponds	Size (acres)
Area 1	11 through 14	101.6
Area 2	15 through 17, 21	100.9
Area 3	18 through 20	96.4

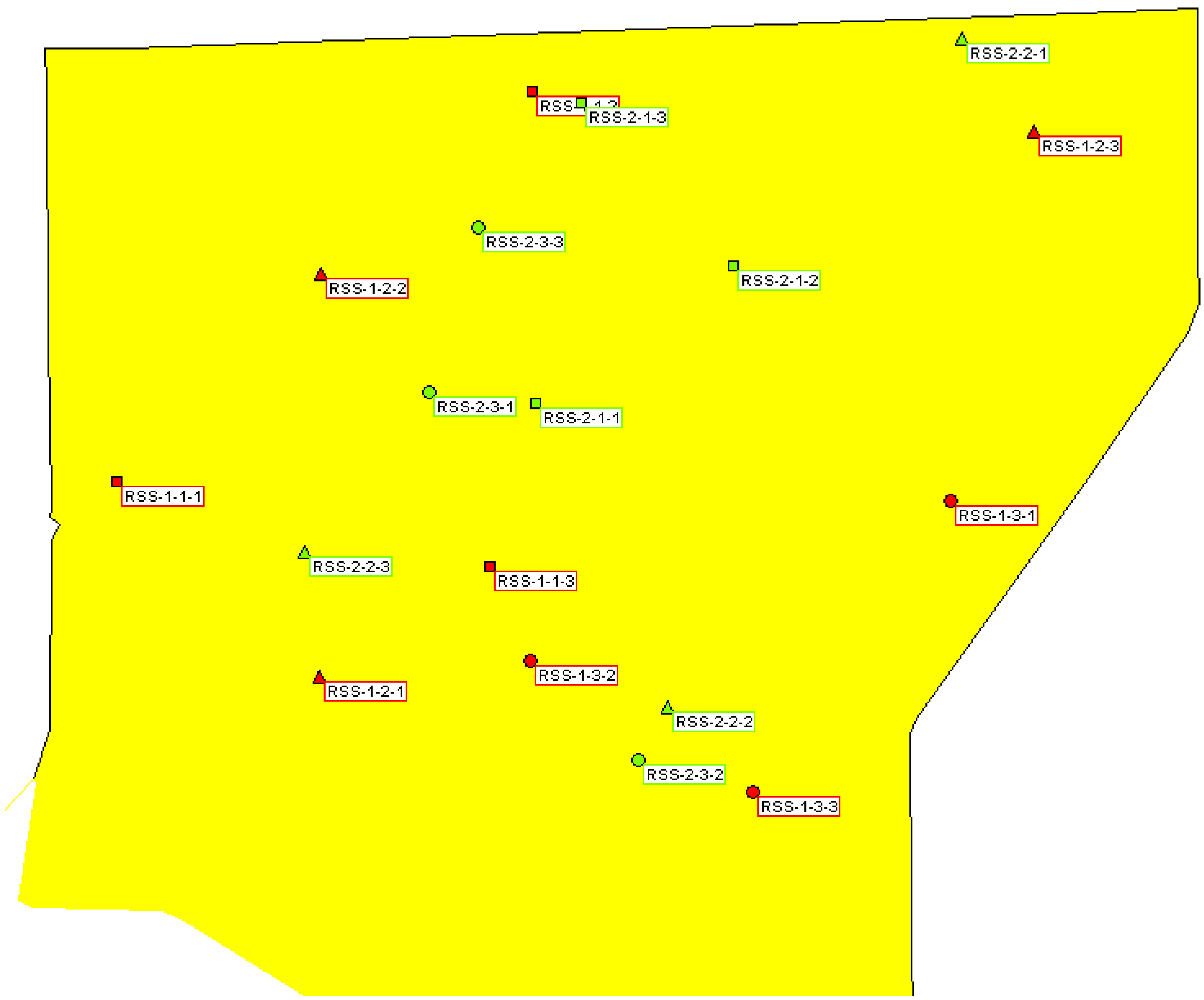
An RSS approach was used to design the confirmatory soil sampling plan (EPA 2002). RSS provided a methodology to estimate the mean concentration of a population without requiring the assumption of a normal distribution. The process combines random sampling with the use of professional judgment to select sampling locations. The professional judgment relied 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 ROCs. The count rate data obtained were then used to select a specific sampling location.

The following example explains the process. A more detailed description is provided in Appendix E.

- The Visual Sampling Plan v.5.4.1, or higher, RSS module was used to determine the necessary number of soil samples to estimate the mean. The number of measurements was based on the expected standard deviation and desired confidence level of the estimated mean.
- For this example, assume that the systematic planning process resulted in n = 18 soil samples to estimate the mean. Since the Section 4 Ponds were divided into three areas of

approximately equal size, each area required six soil samples. Therefore, $n_a = 6$ soil samples for each area.

- The next step was to use a replication process on a larger random population from which the locations for the 18 soil samples will be selected.
- The replication process was referred to as a cycle, designated as r.
- Each cycle (r) consists of multiple sets; sets were designated as m.
- Each set (m) is comprised of a set size, or field assessment locations. The data from each set were ultimately the values that were ranked, for this example the ranked values were direct gamma counts. The set size should consist of two to five field assessment locations. For this project, a set size consisted of three locations. The gamma count data collected from the three locations associated with each set were ranked as being either low, medium, or high gamma count locations. The three ranking categories established the set size.
- The total number of repetitive cycles (r) is a function of n_a (6) and m (3)—or simply defined as $n_a = m \times r$. r for this example would therefore be 2 ($r = 6/3$).
- The number of field assessment locations per cycle, was a function of the set size and is simply m^2. The total number of field assessment locations for each area was then defined as $m^2 \times r$ or in this example $3^2 \times 2 = 18$. For the three areas, the total number of field assessments was $18 \times 3 = 54$.
- The 18 locations (for each area) were then both randomly grouped into cycle/sets and distributed in the survey area. The nomenclature for identifying a specific assessment location was cycle #-set#-arbitrary sequence # (1, 2, or 3). The first location in cycle 1 of set 1 was designated as 1-1-1. Mapping is color coded (based on cycle ID: in this example red or green) using geometric shapes (based on set ID: in this example ■, ▲, ●) to visually show the population of assessment locations.
- Specific measurement locations were generated via either a pseudo- or quasi-random approach.



Refer to Figure A-3

Cycle 1 Gamma Measurement Locations

■, ▲, ●

Set: 1, 2, 3

Cycle 2 Gamma Measurement Locations

■, ▲, ●

Set: 1, 2, 3

Figure 1: Example of an RSS Measurement/Sampling Plan for Area 1

Six random surface (0 to 15 cm) samples (consisting of a 100 m^2 grid block four-point composite soil sample) were collected from each survey area. The specific random coordinate sampled was from a preliminary random coordinate pool of 18 locations for each survey area. Eighteen sets of three locations (54 total locations for the combined three survey areas) each were then ranked as exhibiting either the lowest, middle, or highest gamma count rate. One composite sample was then collected in a cyclic process from the 100 m^2 area with either the lowest, middle, or highest gamma radiation from each of these eighteen sets. The software Visual Sample Plan (VSP) v.5.4.1 was used to generate the random locations. Figures A-3 through A-8 illustrate the random ranking locations and the soil sample locations.

REFERENCE SYSTEM

Global positioning system (GPS) coordinates were used for referencing measurement and sampling locations. The specific reference system used was the New Mexico State Plane Coordinate System (NAD 27 horizontal). ORISE also used the GPS system to define the center of each randomly-selected 10 meter (m) x 10 m grid blocks (100 m^2 areas) for which RSS survey activities were performed.

SURFACE SCANS

Randomly-Selected 100 m^2 Areas

High density (refer to Table 2) gamma radiation surface scans were conducted over the soil surface within each of the randomly-selected 100 m^2 areas—54 such areas were selected (18 from each of the three survey areas). Surface scans were performed using sodium iodide (thallium-activated) [NaI(Tl)] scintillation detectors coupled to a ratemeters or ratemeter-scalers with audible indicators. Detectors were also coupled to GPS systems that enabled real-time gamma count rate and position data capture. Field personnel relied on the audio output to identify and mark for further investigations any locations of elevated direct gamma radiation that might suggest the presence of residual contamination.

Remaining Areas

Due to time constraints and site conditions (vegetation, uneven terrain, etc.), ORISE performed very low density (refer to Table 2) gamma radiation surface scans (less than 5%) of the remaining portions of the Section 4 surface soils (Figure A-3). Locations of elevated radiation, suggesting the presence of residual contamination, were marked and identified for further investigation. The NRC lead inspector discovered several areas of elevated gamma radiation which led to additional remediation activities by the RAM personnel.

TABLE 2: ORISE GAMMA SCAN DENSITY/PERCENTAGE (%)		
RSS Selected Affected Areas	High Density	75 to 100 %
Other Affected Areas	Very Low Density	Up to 5 %

GAMMA DIRECT MEASUREMENTS

Gamma direct measurements were performed at four points equidistant from the grid block corners and the center of each of the 54 randomly selected 100 m^2 areas. A 30-second gamma count, at 0.5 m height, was performed at each direct measurement location. The detector height for the gamma measurement was selected to ensure that the detector field-of-view encompassed the full 25 m^2 within each quadrant of the individual grid block. The four gamma count measurements from within the respective 100 m^2 area were summed for a total count for that grid block. The grid block total gamma counts collected at each of the 54 assessment locations and the data within a given cycle-set were then ranked as exhibiting either the lowest, medium, or highest gamma count.

SOIL SAMPLING

Randomly-Selected 100 m^2 Areas

Soil samples were collected in accordance with the following process within the 2 RSS cycles of each area: Set 1, lowest gamma radiation location; Set 2 medium location; Set 3 highest location. Table B-1 provides the RSS method showing field assessment data and the location selected for soil sampling.

Based on the RSS gamma direct measurement results, six grid blocks (100 m^2 areas) were sampled for radionuclide concentrations in soil. From these six locations, four surface soil samples (0 to 15 cm) were collected from four points midway between the center and grid block corners. These four samples were field composited into one soil sample from that area grid block.

Judgmentally-Selected Locations

Judgmental surface soil samples were collected from three locations based on NRC and ORISE gamma scan results. Specifically, it was determined while on site, that at several locations where there was white seepage from underneath the soil surface, that the seepage was sometimes indicative of elevated gamma radiation levels and soil contamination boundaries.

Background Soil Samples

ORISE did not collect background soil samples. For consistency with the licensee, background soil concentrations were not subtracted from soil samples collected in the impacted areas (KOMEX 2006).

SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and data were returned to the ORISE laboratory in Oak Ridge, Tennessee for analysis and interpretation. Sample analyses were performed in accordance with the ORISE Laboratory Procedures Manual (ORISE 2009b). Gamma measurement results were reported in units of counts per minute (cpm). Soil samples were analyzed by gamma spectroscopy for Th-230, Ra-226 and NatU. The spectra were also reviewed for other identifiable photopeaks that would not be expected at this site and none were identified. 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 RAM. Additional information regarding instrumentation and procedures may be found in Appendices C and D.

FINDINGS AND RESULTS

The results for each verification component are discussed below.

DOCUMENT REVIEW

Komex Environmental survey unit FSS data were used to determine the number of random confirmatory samples necessary to verify the mean concentrations. Specifically, the inputs used were the respective derived concentration guideline level (DCGLs) for the primary natural radionuclides Th-230, Ra-226 and Natural Uranium.

Surface Scans

RSS Grid Block Surface Scans

Gamma radiation surface scans, within the RSS selected grid blocks, did not identify any areas of elevated gamma radiation. The RSS grid blocks [represented by their associated RSS symbols (■,▲, ●, ■, ▲, and ●)] that received gamma scans are presented in Figures A-3 to A-5. The gamma scan ranges within each grid block are provided in Table B-1 and ranged from 2,450 to 9,430 cpm for Area 1; 3,858 to 7,397 cpm for Area 2; and, 2,609 to 7,294 cpm for Area 3.

Judgmental Surface Scans

Judgmental gamma scan walkover results are illustrated in Figures A-3 through A-5 for each area. Survey area gamma scan count rates generally ranged from 4,500 to 7,000 cpm with the variability in the ambient gamma radiation levels consistent with the localized area topography and geology. Data are provided as the gross, observed count rates. Figures A-9 through A-11 provides frequency histograms of the judgmental walkover gamma count rate data population for each of the survey areas.

Cursory gamma scans by the NRC lead inspectors for the site and ORISE personnel identified several locations of elevated gamma radiation levels on soil surfaces associated with a white seepage from beneath the soil surface. These locations were logged into the GPS units and were reported to RAM personnel for further evaluation. These judgmental locations are referenced on Figure A-6 and are represented as (J#).

Gamma Direct Measurements

RSS Gamma Measurements

The summary data for the three combined survey groupings are presented in Table 3 below; the average background gamma count rate was 6,138 cpm. The data for the individual direct gamma measurements are provided in Table B-1.

TABLE 3: RANKED SET SAMPLING GAMMA DIRECT MEASUREMENTS SUMMARY RESULTS		
Survey Areas by Ponds	**Gamma Direct Measurement (cpm)**	
	Minimum	**Maximum**
Area 1: Ponds 11 to 14	9,261	12,307
Area 2: Ponds 15 to 17, 21	8,907	11,187
Area 3: Ponds 18 to 20	8,041	10,987
Background (North of site)	5,111	8,128

Judgmental Gamma Measurements

The judgmental gamma direct measurements at the five locations (J1 through J5) as indicated on Figure A-6 ranged from 14,000 to 29,000 cpm on the surface and from 23,000 to 66,000 cpm at 45 cm depth. Based on these measurements, the licensee initiated further remedial actions in these areas. At the end of the ORISE survey activities, ORISE performed post-remediation measurements at two locations where RAM personnel had completed remediation activities (J2 and J4) and the gamma measurements were 5,400 and 5,300 cpm, respectively.

Radionuclide Concentrations in Soil Samples

RSS Soil Samples

The summary data for the three combined survey groupings are presented in Table 4 below. The data for the radionuclide concentrations in individual samples and the sum-of-ratios are provided in Table B-2. The gamma count rate data used for selecting the appropriate sample locations are shown in Table B-1.

TABLE 4: RADIONUCLIDE CONCENTRATIONS IN RSS SOIL SAMPLES SUMMARY RESULTS				
Survey Areas by Ponds	Radionuclide Concentrations (pCi/g)			
	Th-230	**Ra-226**	**NatU**	**SOR[a]**
Area 1: Ponds 11 to 14	3.4 to 92.8	1.16 to 2.39	2.6 to 21.0	0.45 to 6.01
Mean Concentration	***25.75***	***1.50***	***7.14***	***1.92***
Area 2: Ponds 15 to 17, 21	0.3 to 26.3	0.87 to 1.17	1.8 to 13.2	0.25 to 1.88
Mean Concentration	***8.95***	***1.03***	***5.11***	***0.81***
Area 3: Ponds 18 to 20	1.2 to 58.3	0.80 to 1.74	2.3 to 6.4	0.37 to 3.85
Mean Concentration	***13.07***	***1.16***	***4.23***	***1.05***
Site Mean	***15.92***	***1.23***	***5.49***	***1.26***

[a]Sum of ratios.

Judgmental Soil Samples

Two judgmental soil samples were collected from locations identified as having elevated gamma radiation levels during the gamma surface scans. After remediation activities by the licensee, ORISE collected two more samples from remediated areas. The radionuclide concentrations in these samples are provided in Table 5 below.

TABLE 5: RADIONUCLIDE CONCENTRATIONS IN JUDGMENTAL SOIL SAMPLES				
Area 1 Ponds	**Radionuclide Concentrations (pCi/g)**			
	Th-230	**Ra-226**	**NatU**	**SOR[a]**
Pre-remediation	923 to 1,500	18.1 to 21.5	16.4 to 55.4	58.82 to 91.25
Post-Remediation	3.2 to 12.3	0.78 to 1.53	1.9 to 3.6	0.35 to 1.04

[a]Sum of ratios

COMPARISON OF RESULTS WITH RELEASE CRITERIA

The primary ROCs are natural uranium (U-234, U-235 and U-238), Th-230 and Ra-226. The applicable site-specific cleanup levels for the ROCs are provided in Table 6. To demonstrate compliance with the Table 6 criteria, each radionuclide concentration should be less than its respective cleanup level—with consideration for small areas of elevated activity—as well as application of the unity rule [sum-of-ratios (SOR)]. The unity rule requires that the sum of the concentration of each contaminant divided by the respective guideline be less than one.

TABLE 6: RIO ALGOM MINING SURFACE SOIL CLEANUP LEVELS	
Radionuclide	**Soil Guidelines(pCi/g)[a]**
Natural Uranium	38
Th-230	17[b]
Ra-226	7

[a]Cleanup levels from Section 8: Final Status Survey Plan within the Soil Decommissioning Plan (KOMEX 2006). These values include background. Also, the sum-of-ratios (SOR) must be less than 1.

[b]Section 8.1.1.3 initial Th-230 cleanup level was 14 pCi/g. As this level did not include background, the Th-230 cleanup level was revised to 17 pCi/g (RAM 2008).

Radionuclide concentrations in soil samples were directly compared with the Th-230, Ra-226, and NatU release limits of 17.0, 7.0 and 38 pCi/g, respectively. ORISE also applied the unity rule SOR in the activity calculations for each composite soil samples.

Four of the 18 RSS soil sample results exceeded the individual ROC release criteria for Th-230 and six of the RSS soil sample results exceeded the SORs. Furthermore, the mean concentration results for Th-230 and SOR for Area 1 and the SOR mean concentration for Area 3 exceeded the soil cleanup criteria as provided above in Table 4. The calculated site mean concentrations of 15.92 pCi/g for Th-230, 1.23 pCi/g for Ra-226 and 5.49 pCi/g for NatU did not exceed the individual ROC soil cleanup levels; however, the site mean SOR of 1.26 exceeds the unity rule. ORISE did not compare to RAM FSS mean concentrations since FSS data was not provided to ORISE.

Two judgmental soil samples (S019 and S020) collected prior to additional remediation by the licensee exceeded the individual ROC release criteria. Soil sample location S019 was remediated while ORISE was onsite and ORISE collected a post-remediation sample (S021). The results indicate that the ROC concentrations were significantly reduced with individual ROC concentrations below their individual DCGL release criteria; however, the SOR for SO21 still exceeded unity.

SUMMARY

During the period of September 21 through 24, 2009, ORISE performed independent confirmatory measurements and sampling activities on the Section 4 Ponds at the RAM Ambrosia Lake Facility in New Mexico. The confirmatory survey results indicate that further investigation and possible remediation are necessary before the release limits are satisfied.

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APPENDIX A
FIGURES

Figure A-1: Location of Rio Algom Mining (RAM), Ambrosia Lake, New Mexico

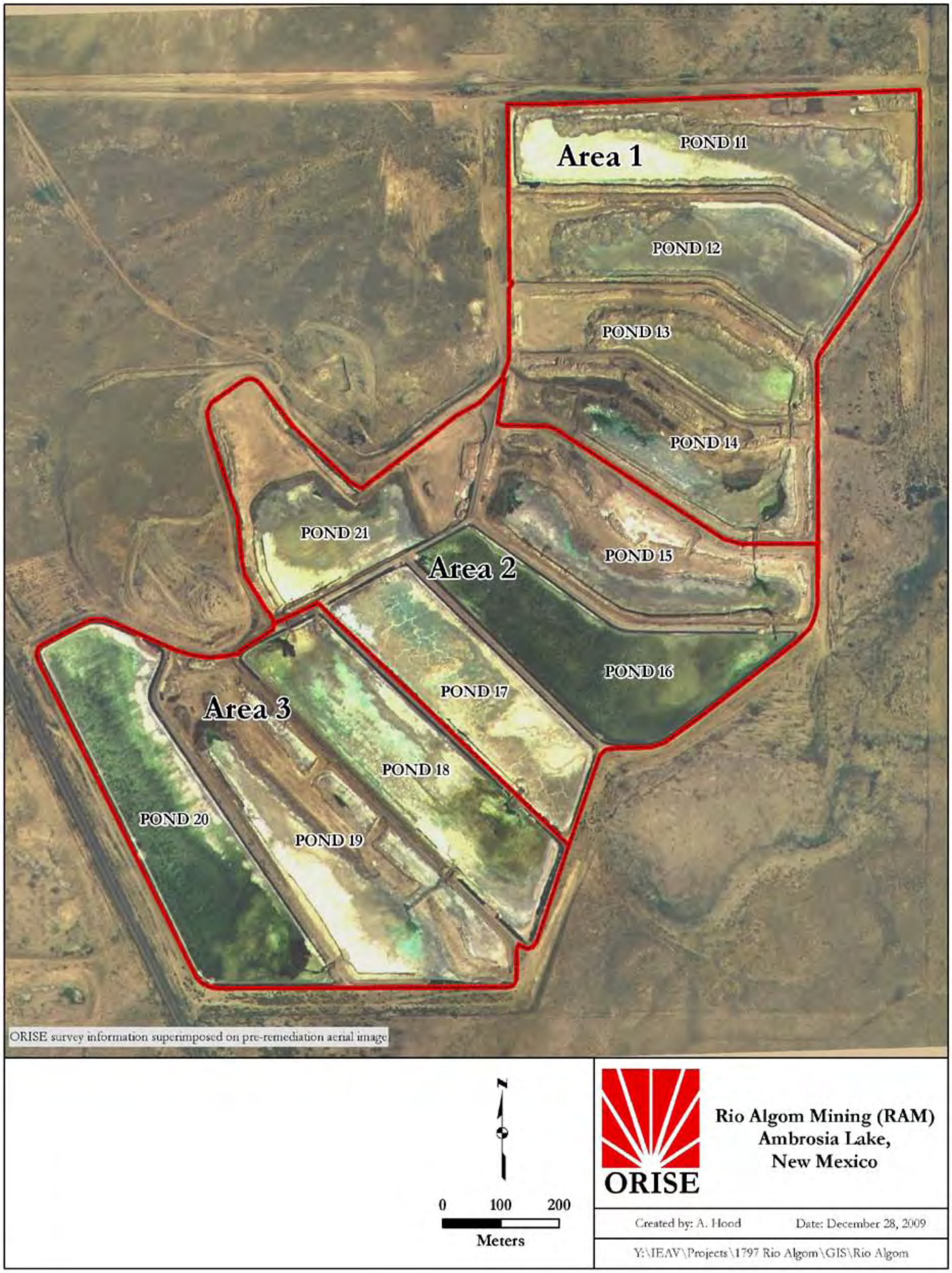
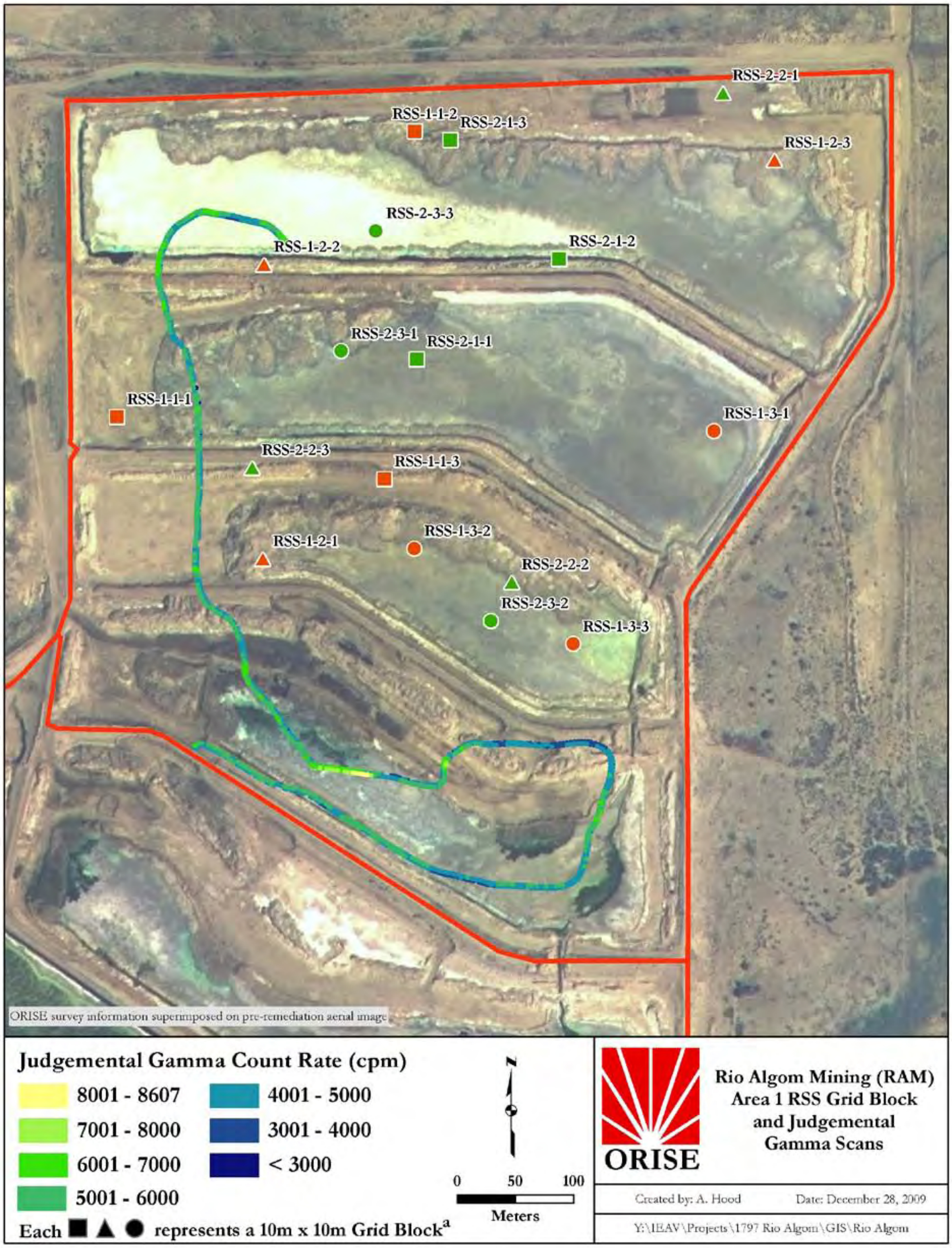
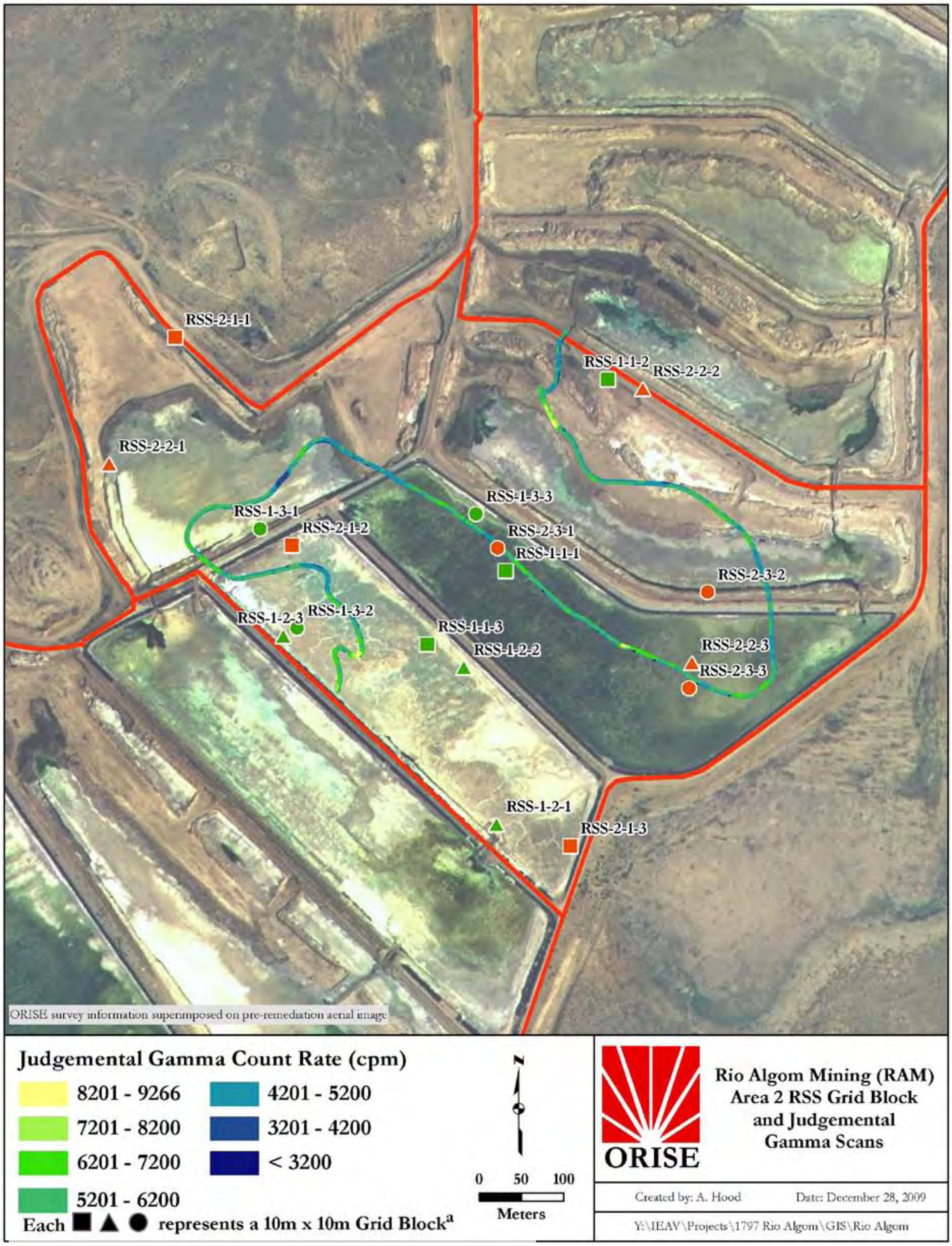


Figure A-2: Aerial Photo of Section 4 Pond Area Indicating ORISE Survey Areas



[a]Gamma scan ranges for each RSS grid block provided in Table B-1.

Figure A-3: RAM Section 4 Ponds, Area 1 – Gamma Scans and Measurements



[a]Gamma scan ranges for each RSS grid block provided in Table B-1.

Figure A-4: RAM Section 4 Ponds, Area 2 – Gamma Scans and Measurements

[a]Gamma scan ranges for each RSS grid block provided in Table B-1.

Figure A-5: RAM Section 4 Ponds, Area 3 – Gamma Scans and Measurements

Figure A-6: RAM Section 4 Ponds, Area 1 – Elevated Gamma Radiation and Soil Sample Locations

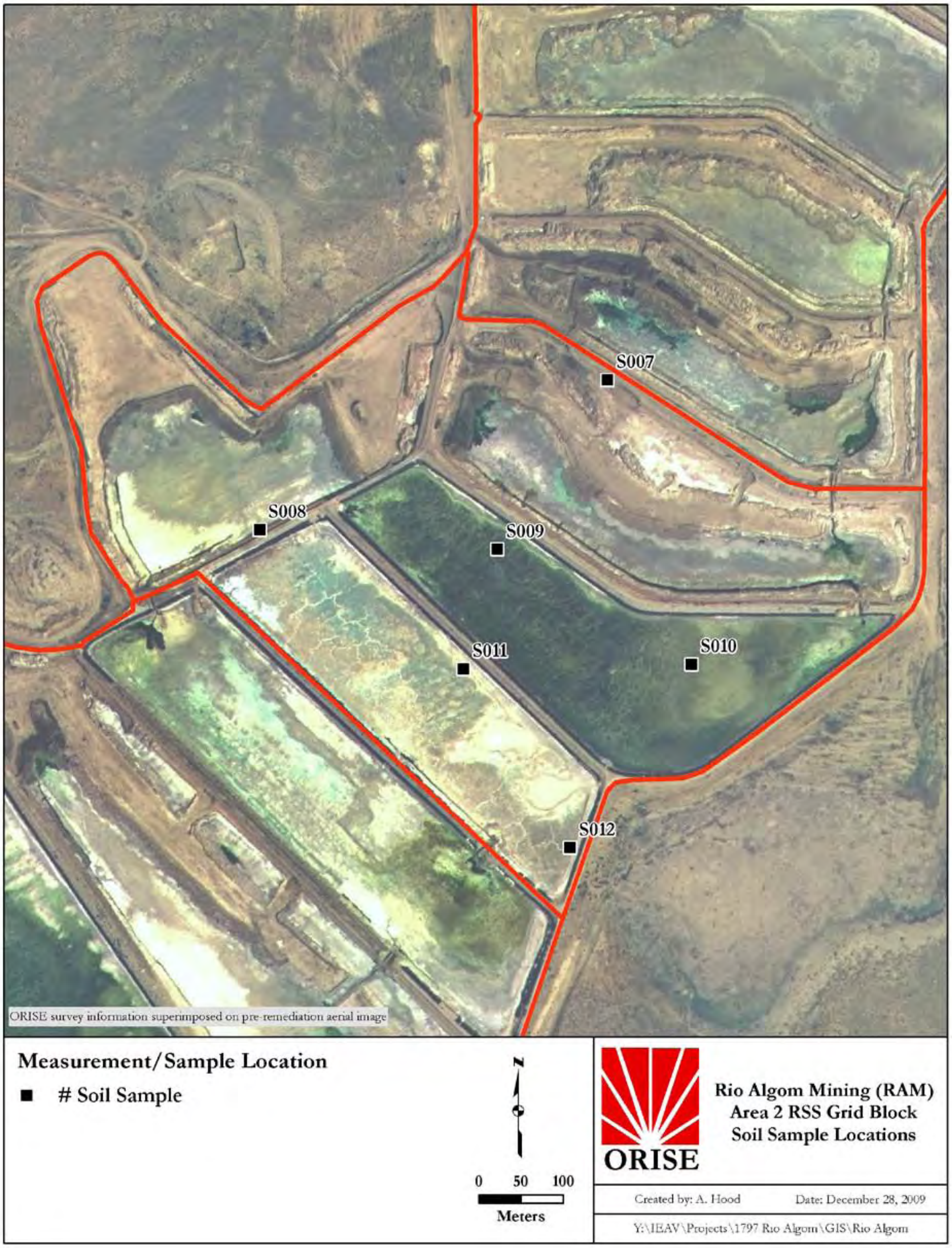


Figure A-7: RAM Section 4 Ponds, Area 2 – Soil Sample Locations

Figure A-8: RAM Section 4 Ponds, Area 3 – Soil Sample Locations

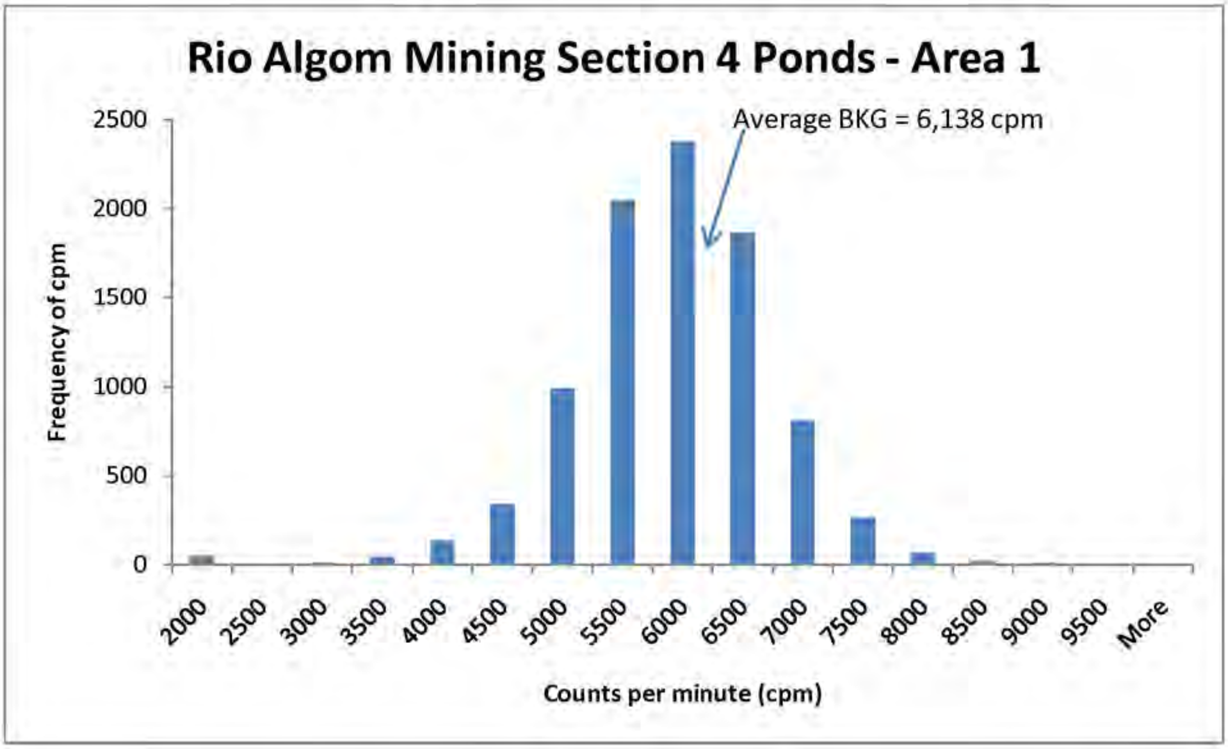


Figure A-9: RAM Section 4 Ponds, Area 1 – Judgmental Gamma Scan Count Rate Distribution

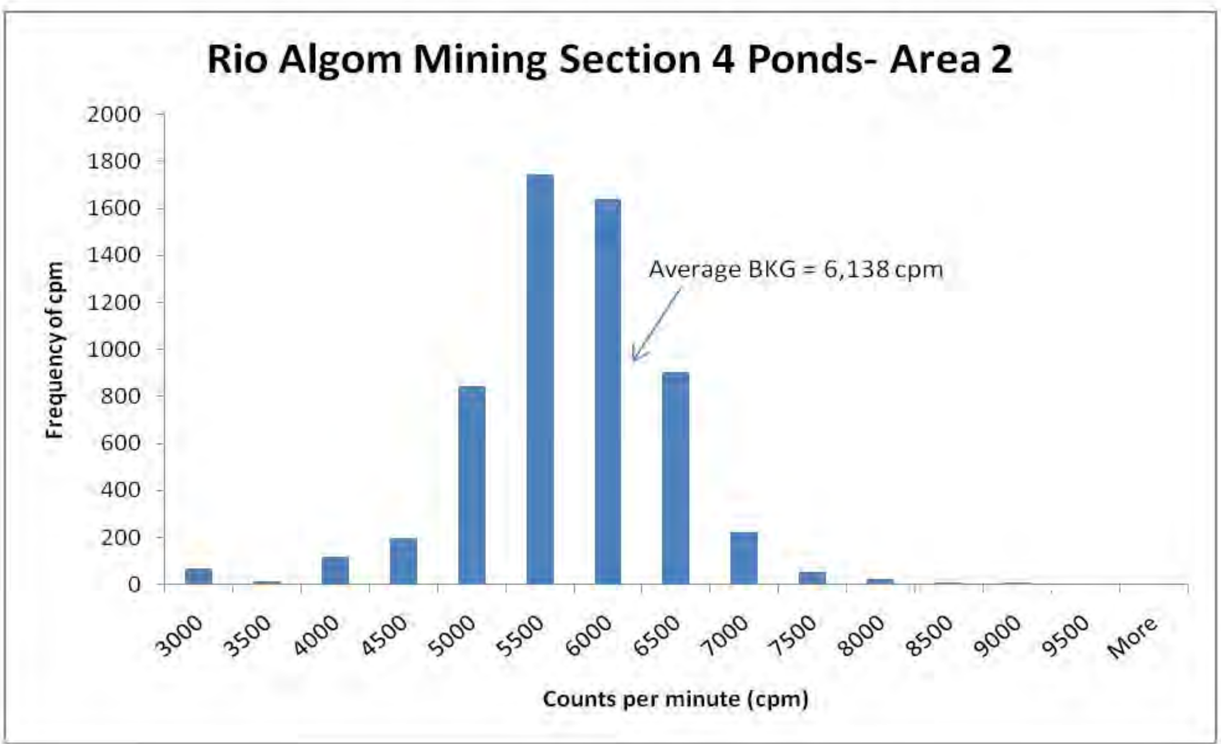


Figure A-10: RAM Section 4 Ponds, Area 2 – Judgmental Gamma Scan Count Rate Distribution

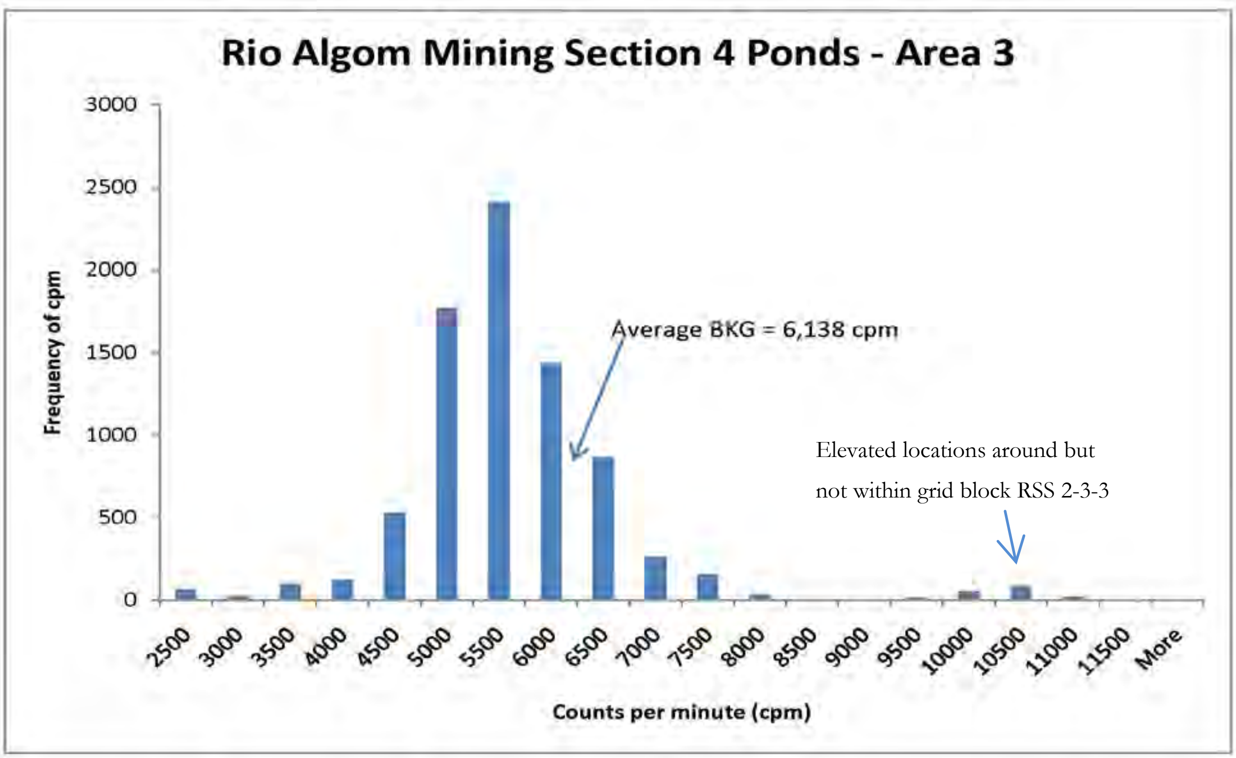


Figure A-11: RAM Section 4 Ponds, Area 3 – Judgmental Gamma Scan Count Rate Distribution

APPENDIX B
TABLES

TABLE B-1: RANKED SET SAMPLING GAMMA MEASUREMENTS RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO									
East	North	RSS Measurement Location				Grid Block Gamma Scan Range (cpm)	Gamma Count[a]	Code[b]	Soil Sample #
		Cycle	Set	#	Symbol				
Area 1[c]									
511908	1596698	1	1	1	■ (red)	--[d]	10,236	**L**	**S002**
512749	1597505	1	1	2	■ (red)	4,030 to 7,967	10,517	L	
512663	1596522	1	1	3	■ (red)	5,035 to 7,047	11,281	L	
512321	1596295	1	2	1	▲ (red)	5,368 to 7,355	11,906	M	
512324	1597128	1	2	2	▲ (red)	4,819 to 7,441	10,551	M	
513766	1597422	1	2	3	▲ (red)	4,959 to 6,903	10,772	**M**	**S004**
513595	1596658	1	3	1	● (red)	4,107 to 6,341	9,543	H	
512748	1596326	1	3	2	● (red)	5,662 to 7,718	12,307	**H**	**S006**
513196	1596056	1	3	3	● (red)	4,398 to 7,182	9,261	H	
512755	1596861	2	1	1	■ (green)	4,223 to 8,571	10,283	L	
513157	1597145	2	1	2	■ (green)	4,971 to 7,358	10,928	L	
512850	1597480	2	1	3	■ (green)	4,699 to 7,567	10,052	**L**	**S001**
513620	1597612	2	2	1	▲ (green)	4,460 to 7,229	10,133	M	
513023	1596230	2	2	2	▲ (green)	4,156 to 9,430	11,126	M	
512290	1596553	2	2	3	▲ (green)	4,800 to 7,383	11,116	**M**	**S003**
512541	1596884	2	3	1	● (green)	2,450 to 7,087	11,498	**H**	**S005**
512965	1596122	2	3	2	● (green)	4,747 to 7,658	10,530	H	
512639	1597224	2	3	3	● (green)	4,474 to 6,522	9,562	H	

TABLE B-1: (continued) RANKED SET SAMPLING GAMMA MEASUREMENTS RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO									
East	North	RSS Measurement Location				Grid Block Gamma Scan Range (cpm)	Gamma Count[a]	Code[b]	Soil Sample #
		Cycle	Set	#	Symbol				
Area 2[e]									
511891	1594836	1	1	1	■	4,922 to 7,397	10,773	L	
512288	1595582	1	1	2	■	4,405 to 6,011	9,124	**L**	**S007**
511587	1594550	1	1	3	■	--	9,846	L	
511855	1593849	1	2	1	▲	3,858 to 7,056	11,187	M	
511729	1594459	1	2	2	▲	5,257 to 6,724	9,794	**M**	**S011**
511028	1594582	1	2	3	▲	4,121 to 6,321	9,664	M	
510937	1595000	1	3	1	●	4,451 to 6,804	10,678	**H**	**S008**
511081	1594614	1	3	2	●	4,458 to 6,307	9,725	H	
511776	1595058	1	3	3	●	4,992 to 7,137	10,373	H	
510607	1595745	2	1	1	■	4,646 to 6,528	9,926	L	
511061	1594935	2	1	2	■	4,401 to 6,565	9,891	L	
512143	1593765	2	1	3	■	4,403 to 6,565	9,798	**L**	**S012**
510351	1595252	2	2	1	▲	4,021 to 6,493	8,907	M	
512424	1595543	2	2	2	▲	4,526 to 6,791	9,501	M	
512615	1594477	2	2	3	▲	--	9,410	**M**	**S010**
511860	1594925	2	3	1	●	5,103 to 7,055	10,616	**H**	**S009**
512676	1594753	2	3	2	●	4,716 to 6,746	10,461	H	
512604	1594380	2	3	3	●	4,470 to 6,490	9,188	H	

TABLE B-1: (continued)
RANKED SET SAMPLING GAMMA MEASUREMENTS
RIO ALGOM AMBROSIA LAKE FACILITY
AMBROSIA LAKE, NEW MEXICO

East	North	RSS Measurement Location				Grid Block Gamma Scan Range (cpm)	Gamma Count[a]	Code[b]	Soil Sample #
		Cycle	Set	#	Symbol				
Area 3[f]									
511746	1593113	1	1	1	■	2,738 to 6,307	9,342	L	
510437	1593919	1	1	2	■	4,235 to 6,386	9,407	L	
511271	1593812	1	1	3	■	3,286 to 6,123	9,320	**L**	**S016**
509739	1594232	1	2	1	▲	4,698 to 6,387	9,685	M	
511296	1593071	1	2	2	▲	--	10,425	**M**	**S017**
510016	1593034	1	2	3	▲	3,604 to 6,881	10,777	M	
510466	1593262	1	3	1	●	3,136 to 6,390	9,811	**H**	**S018**
510887	1593629	1	3	2	●	2,866 to 5,711	8,706	H	
510711	1594177	1	3	3	●	4,160 to 6,524	9,273	H	
511233	1593022	2	1	1	■	4,292 to 7,215	10,329	L	
509908	1593971	2	1	2	■	3,653 to 5,765	8,041	**L**	**S014**
510553	1592760	2	1	3	■	3,747 to 6,971	9,929	L	
509937	1594262	2	2	1	▲	2,609 to 5,796	8,962	M	
511843	1593327	2	2	2	▲	3,103 to 7,066	10,661	M	
510611	1593748	2	2	3	▲	2,813 to 6,172	9,421	**M**	**S015**
509455	1593953	2	3	1	●	3,046 to 7,294	10,987	**H**	**S013**
510985	1592974	2	3	2	●	4,464 to 6,044	9,717	H	
510923	1594600	2	3	3	●	--	10,393	H	

[a]Gamma counts represents the sum of the 4 individual 30 second gamma counts within each grid block.
[b]Sample select code specifies which location is sampled for a given cycle/set based on the gamma count rate.
[c]Refer to Figure A-3.
[d]Gamma scan range not recorded.
[e]Refer to Figure A-4.
[f]Refer to Figure A-5.

TABLE B-2: RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO																		
Sample #[a]	Sample Location[a]		Radionuclide Concentrations (pCi/g)															SOR[c]
	East	North	Th-230			Ra-226			U-235			U-238			NatU[b]			
Area 1																		
S001	512850	1597480	3.7	±	2.1[d]	1.16	±	0.07	0.46	±	0.06	10.28	±	0.72	21.0	±	1.6	0.94
S002	511908	1596698	92.8	±	7.1	2.39	±	0.14	0.90	±	0.09	3.60	±	0.40	8.1	±	1.5	6.01
S003	512290	1596553	3.4	±	1.9	1.26	±	0.08	0.09	±	0.04	1.34	±	0.19	2.8	±	1.4	0.45
S004	513766	1597422	7.7	±	2.2	1.16	±	0.07	0.10	±	0.04	1.26	±	0.24	2.6	±	1.4	0.69
S005	512541	1596884	35.2	±	3.5	1.47	±	0.09	0.35	±	0.06	2.20	±	0.27	4.8	±	1.4	2.41
S006	512748	1596326	11.7	±	2.7	1.54	±	0.10	0.10	±	0.07	1.75	±	0.30	3.6	±	1.4	1.00
Area 1 Mean Concentrations			*25.75*			*1.50*			*0.33*			*3.41*			*7.14*			*1.92*
Area 2																		
S007	512288	1595582	3.8	±	1.1	0.87	±	0.06	0.08	±	0.03	0.88	±	0.12	1.8	±	1.4	0.40
S008	510937	1595000	26.3	±	2.5	1.17	±	0.07	0.30	±	0.04	2.99	±	0.27	6.3	±	1.4	1.88
S009	511860	1594925	0.3	±	3.3	1.17	±	0.09	0.08	±	0.04	1.11	±	0.17	2.3	±	1.4	0.25
S010	512615	1594477	3.9	±	1.6	0.92	±	0.06	0.09	±	0.04	1.39	±	0.20	2.9	±	1.4	0.44
S011	511729	1594459	16.5	±	1.8	1.15	±	0.07	0.22	±	0.03	1.98	±	0.19	4.2	±	1.4	1.24
S012	512143	1593765	2.9	±	1.3	0.88	±	0.06	0.35	±	0.04	6.41	±	0.46	13.2	±	1.5	0.64
Area 2 Mean Concentrations			*8.95*			*1.03*			*0.19*			*2.46*			*5.11*			*0.81*
Area 3																		
S013	509455	1593953	58.3	±	4.7	1.74	±	0.12	0.57	±	0.06	2.89	±	0.28	6.4	±	1.4	3.85
S014	509908	1593971	3.4	±	1.5	0.80	±	0.05	0.05	±	0.04	1.11	±	0.18	2.3	±	1.4	0.37
S015	510611	1593748	6.5	±	1.3	0.97	±	0.06	0.10	±	0.03	1.17	±	0.14	2.4	±	1.4	0.59
S016	511271	1593812	7.4	±	1.5	0.95	±	0.07	0.10	±	0.03	1.25	±	0.17	2.6	±	1.4	0.64
S017	511296	1593071	1.2	±	4.2	1.46	±	0.09	0.13	±	0.04	3.10	±	0.30	6.3	±	1.4	0.45

TABLE B-2: (continued) RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES RIO ALGOM AMBROSIA LAKE FACILITY AMBROSIA LAKE, NEW MEXICO																		
Sample #[a]	Sample Location[a]		Radionuclide Concentrations (pCi/g)															SOR[c]
	East	North	Th-230			Ra-226			U-235			U-238			NatU[b]			
Area 3 (Continued)																		
S018	510466	1593262	1.6	±	1.4	1.06	±	0.09	0.15	±	0.04	2.62	±	0.26	5.4	±	1.4	0.39
Area 3 Mean Concentrations			*13.07*			*1.16*			*0.18*			*2.02*			*4.23*			*1.05*
Section 4 Ponds Mean Concentration			***15.92***			***1.23***			***0.23***			***2.63***			***5.49***			***1.26***
Elevated Areas as Determined by Gamma Scans																		
S019	512530	1596456	1500	±	100	18.1	±	1.0	1.95[e]	±	0.14	7.2	±	1.7	16.4[e]	±	2.2	91.25
S020	513083	1597176	923	±	65	21.5	±	1.2	2.01[e]	±	0.13	26.7	±	2.4	55.4[e]	±	2.8	58.82
Elevated Areas after Remediation by Licensee																		
S021	512530	1596456	12.3	±	1.7	1.53	±	0.09	0.34	±	0.04	1.61	±	0.19	3.6	±	1.4	1.04
S022	512269	1596360	3.2	±	2.7	0.78	±	0.06	0.10	±	0.04	0.89	±	0.15	1.9	±	1.4	0.35

[a]Refer to Figures A-6 through A-8.
[b]Natural Uranium (NatU) is calculated by 2 x U-238 + U-235.
[c]SOR = Sum of Ratios.
[d]Uncertainties are total propagated uncertainties, based on the 95% confidence interval.
[e]Due to the presence of radionuclides (Th-227 and Ra-226) that emit gammas which interfere with the 143 and 186 keV peaks of U-235, the U-235 and NatU values may be overestimated for these two samples. The 186 keV peak for U-235 was used for this calculation.

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 his employer.

SCANNING AND MEASUREMENT INSTRUMENT/DETECTOR COMBINATIONS

Gamma

Victoreen NaI Scintillation Detector Model 489-55, Crystal: 3.2 cm x 3.8 cm
(Victoreen, Cleveland, OH)
coupled to:
Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, TX)
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
Canberra's Apex Gamma Software
Dell 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
Canberra's Apex Gamma Software
Dell Workstation
(Canberra, Meriden, CT)

Laboratory Analytical Instrumentation (continued)

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
Canberra's Apex Gamma Software
Dell Workstation
(Canberra, Meriden, CT)

APPENDIX D
SURVEY AND ANALYTICAL PROCEDURES

APPENDIX D
SURVEY AND ANALYTICAL PROCEDURES

PROJECT HEALTH AND SAFETY

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

Pre-survey activities included the evaluation and identification of potential health and safety issues. Survey work was performed per the ORISE generic health and safety plans and a site-specific integrated safety management (ISM) pre-job hazard checklist. Rio Algom personnel also provided site-specific safety awareness training.

CALIBRATION AND QUALITY ASSURANCE

Calibration of all field and laboratory instrumentation was based on standards/sources, traceable to the National Institute of Standards and Technology (NIST).

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

- Survey Procedures Manual (May 2008)
- Laboratory Procedures Manual (June 2009)
- Quality Program Manual (June 2009)

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 Mixed-Analyte Performance Evaluation Program (MAPEP), NIST Radiochemistry Intercomparison Testing Program (NRIP), and Intercomparison Testing Program (ITP) Laboratory Quality Assurance Programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

SURVEY PROCEDURES

Surface Scans

A NaI scintillation detector was used to scan for elevated gamma radiation. Identification of elevated radiation levels was based on increases in the audible signal from the recording and/or indicating instrument. Additionally, the detectors were coupled to GPS units with data loggers enabling real-time recording in one-second intervals of both geographic position and the gamma count rate. 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). Position and gamma count rate data files were transferred to a computer system, positions differentially corrected, and the results plotted on geo-referenced aerial photographs. Positional accuracy was within 0.5 meters at the 95^{th} percentile.

The scan minimum detectable concentrations for the NaI scintillation detectors were 3,000 pCi/g for Th-230, 115 pCi/g for natural uranium, and 4.5 pCi/g for Ra-226, as provided in NUREG-1507. An audible increase in the activity rate was investigated by ORISE. It is standard procedure for the ORISE staff to 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 a plastic bag, sealed, and labeled in accordance with ORISE survey procedures.

The judgmental soil samples were collected as individual samples from an area of elevated gamma radiation based on gamma scans. The RSS grid blocks (100 m^2 areas) samples were collected as follows: four surface soil samples (0 to 15 cm) were collected from four points midway between the center and 100 m^2 grid block corners. These four samples were field composited into one soil sample from that 100 m^2 area grid block.

Radiological Analysis

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 and volumes 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 ROCs were reviewed for consistency of activity. TAPs used for determining the activities of ROCs and the typical associated minimum detectable concentration (MDCs) for a four-hour count time were:

Radionuclide	TAP[a] (MeV)	MDC (pCi/g)
Th-230	0.067	5.09
Ra-226 by Pb-214	0.351	0.04
U-235	0.143	0.12
U-238 by Th-234	0.063	0.49

[a]Spectra were also reviewed for other identifiable TAPs that would not be expected at this site.

Uncertainties

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

DETECTION LIMITS

Detection limits, referred to as minimum detectable concentrations, were based on 3 plus 4.65 times the standard deviation of the background count [3 + (4.65 $(BKG)^{1/2}$)]. 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.

APPENDIX E
ORISE STATISTICAL SURVEY DESIGN FOR THE SECTION 4 PONDS AT THE RIO ALGOM MINING FACILITY AMBROSIA LAKE, NEW MEXICO

APPENDIX E

ORISE STATISTICAL SURVEY DESIGN FOR THE SECTION 4 PONDS AT THE RIO ALGOM MINING FACILITY AMBROSIA LAKE, NEW MEXICO

SURVEY DESIGN SUMMARY

ORISE used available pre-final status survey data to develop a defensible statistical sampling and survey design for the Section 4 Ponds at the Rio Algom Ambrosia Lake Facility. The selected VSP statistical approach, as set forth in U.S. Environmental Protection Agency (EPA) QA/G-5S, calculates the number of samples required to determine a confidence interval for the mean that meets the boundaries provided by the user. A RSS design was selected using associated statistical assumptions as well as general guidelines for conducting post-sampling data analysis. The sampling plan components included how many sampling locations to choose and where within the sampling area to collect those samples.

The following table summarizes the balanced ranked set sampling design developed.

SUMMARY OF SAMPLING DESIGN FOR EACH AREA	
Primary Objective of Design	**Estimate the population mean**
Sample Placement (Location) in the Field	Simple random sampling
Formula for calculating number of sampling locations	Balanced ranked set sampling equations in EPA QA/G-5S (EPA, 2001)
Number of Ranks (m) (Chosen Set Size)	3
Calculated Number of Cycles (r)	2
Number of Samples to Analyze (m x r)	6
Number of Field Locations to Rank (m x m x r)	18
Number of selected sample areas [a]	3
Specified sampling area [b]	13020216 ft^2

[a] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[b] The sampling area is the total surface area of the selected colored sample areas on the map of the site.

Figure E-1 demonstrates the VSP measurement locations in the field. There were 18 measurement locations within each survey area from which six samples were collected from each area.

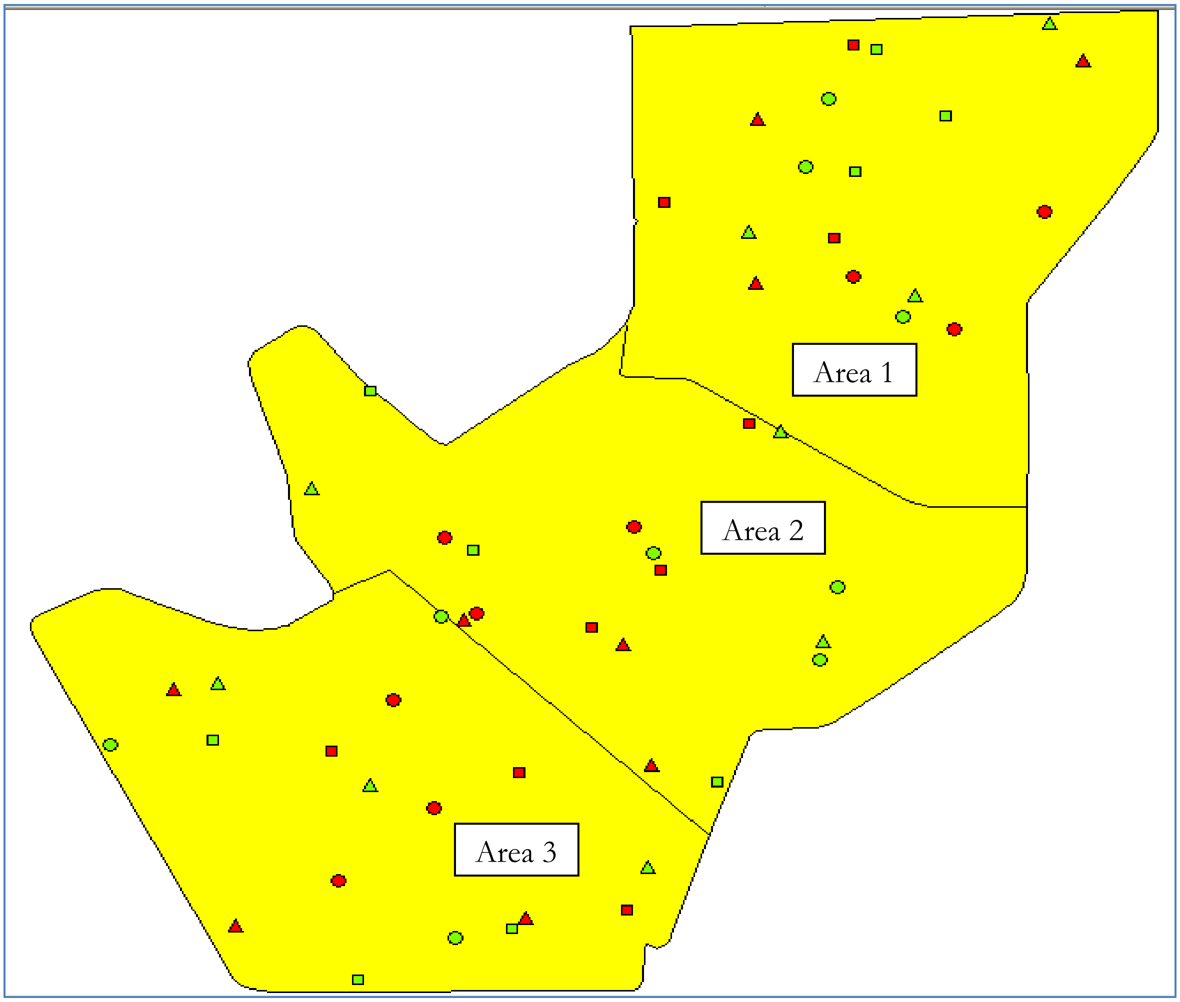


Figure E-1: Visual Sample Plan Generated Measurement Locations for the 3 Survey Areas

Table B-1 lists the sampling coordinates generated by VSP that were identified in the field.

The following VSP report was generated using site inputs and is as follows: RSS involves selecting a set of field locations using simple random sampling, then dividing the locations into subsets (called "sets"). Then either professional judgment (expert opinion) or a quantitative inexpensive field measurement method is used in the field to rank (order) the locations within each set with respect to the variable being measured. Then, within each set, only one location among the ranked locations is selected to be sampled for laboratory analysis. The method used to determine the number of locations that need to be ranked and the number of locations that need to be sampled for measurement in the laboratory is described in EPA QA/G-5S (EPA 2002).

RSS was chosen because that design was found to be more cost effective for estimating the mean than simple random sampling. It is expected to yield a narrower confidence interval for the mean than a simple random sampling design with the same number of laboratory analyzed samples. RSS sampling design can achieve cost savings by implementing relatively inexpensive qualitative (expert opinion and/or professional judgment) or quantitative field screening techniques in association with more expensive laboratory analytical measurements of samples. Additionally, RSS provides an unbiased estimate of the mean and can yield an increased ability to detect differences in the parameters of different populations (e.g., site and background areas).

The assumptions that underlie RSS are expected to be valid and will be examined in post-sampling data analysis. There are some limitations associated with ranked set sampling. The increased precision of the estimated mean obtained using ranked set sampling compared to simple random sampling is reduced if errors are made in ranking field locations. However, even when ranking errors occur, RSS is never expected to be less precise than if simple random sampling with the same number of measurements is used. Another limitation is that ranked set sampling may not be more cost effective than simple random sampling if field locations are clustered in space rather than selected randomly. In addition, computations needed to conduct some statistical analyses such as tests of hypotheses using data obtained from RSS are different that the standard computations used when sample locations are selected using simple random sampling. Hence, statistical expertise may be needed to determine the appropriate calculations. Finally, information collected from the ranking process, including any quantitative measurements that are used to conduct the ranking, is not used to calculate the mean (EPA 2002).

DETERMINATION OF NUMBER OF DATA POINTS

Number of Total Samples: Calculation Equation and Inputs

The number of samples is calculated by following the process for RSS outlined in EPA QA/G-5S. This process has been detailed in the following discussions of the points. The following steps outline the user inputs and calculations conducted within VSP to determine the RSS design.

1. Determine the number of samples required under simple random sampling, n_o
2. Select the "set size", m
3. Determine the relative precision *(RP)* of simple random sampling compared to ranked set sampling
4. Compute the number of cycles, r, of RSS that are required
5. Compute the total number of ranked set samples, n, that should be collected and measured to estimate the mean

1. Determine the number of samples required under simple random sampling, n_o;
In order to determine the number of samples to collect if simple random sampling were used, n_o, VSP requires the user to specify whether the distribution of measurements resulting from laboratory samples is expected to be symmetric or skewed to the right (a long right tail). If the expected distribution is symmetric, then a balanced ranked set sampling design will be used and the number of samples is calculated by VSP using either a one-sided or a two-sided confidence interval equation, as selected by the VSP user. If the expected distribution is skewed to the right, then an unbalanced ranked set sampling design will be used and the number of samples is computed using the method outlined by Perez and Lefante (1997).

The equation used to calculate n_o for the balanced RSS case is the same as VSP uses to compute the number of samples required for computing a two-sided confidence interval for the mean when simple random sampling is used. The calculated number of samples, n_o, using simple random sampling will result in a confidence interval that has a half-width that does not exceed the maximum acceptable half-width specified by the VSP user.

For a two-sided confidence interval, the equation used to calculate the number of samples under simple random sampling, n_o, when the expected distribution is symmetric and a balanced ranked set sampling design is used is:

$$n_o = s^2 \left(\frac{t_{1-\alpha/2,df}}{d} \right)^2$$

Where,

n_o is the recommended minimum number of samples for the study area if simple random sampling were used,

s is the estimated standard deviation of measurements of collected samples,

d is the maximum desired half-width of the confidence interval,

$t_{1-\alpha/2,\mathrm{df}}$ is the value of the Student's t-distribution with *n-1* degrees of freedom *(df)* such that the proportion of that distribution less than $t_{1-\alpha/2,\mathrm{df}}$ is 1-*a/2*

Because *n* appears on both sides of the above equation (on the right side it appears in the degrees of freedom of the t distribution), the equation must be solved iteratively. VSP does this automatically using the iteration scheme in Gilbert (1987, pg. 32).

2. Select the "set size", *m*;

The set size, *m*, is an integer between 2 and 8 selected by the VSP user. When a balanced RSS design is used, *m* is the number of field locations sampled in each cycle of RSS. The number of cycles is denoted by *r*. Hence, the total number of locations sampled when balanced ranked set sampling is used is $n = m \times r$. The value of *m* selected is usually based on practical constraints in ranking locations by professional judgment or quantitative field measurements. If professional judgment is used to rank potential field locations, G-5S recommends setting $m <= 5$ due to the potential lack of accuracy in ranking by professional judgment. If field quantitative measurements are used to rank potential locations, then the ranking may be accurate for larger values of *m*.

3. Determine the *RPs* of simple random sampling compared to ranked set sampling;

The estimated *RPs* is the estimated variance of the mean if simple random sampling is used divided by the estimated variance of the mean if ranked set sampling is used. When a balanced ranked set sampling design is used, VSP uses the *RP*s published by Patil et al. (1994, Table 1) for the normal distribution. The *RP*s depends only on the set size, *m*, specified by the VSP user. (If an unbalanced ranked set sampling design is used, then VSP uses a more complicated process to determine the *RP*, as described in EPA QA/G-5S.)

4. Compute the number of cycles, *r*, of ranked set samples that are required;

VSP calculates the number of cycles, *r*, needed in the ranked set sampling design by using the values of n_o, *m*, and *RP* as follows:

$$r = \left(\frac{n_o}{m} \right) \times \left(\frac{1}{RP} \right)$$

Where,

r is the number of cycles,

n_o is the number of samples required under simple random sampling,

m is the set size specified by the VSP user, *RP* is the relative precision.

5. Compute the total number of ranked set samples, *n*, that should be collected and measured to estimate the mean;

The number of field locations that are sampled and taken to the laboratory for measurement is calculated by VSP as

$$n = r * m$$

where,

n is the number of samples that are measured,
r is the number of cycles,
m is the set size.

The values of these inputs that result in the calculated number of sampling locations are:

Parameter	Value
m	3
s	2
d	1
α	5%
$t_{1-\alpha/2,df}$	2.10982[a]
RP	1.914 [b]
r	2

[a]This value is automatically calculated by VSP based upon the user defined value of α.
[b]This value is automatically calculated by VSP based upon the set size.

Statistical Assumptions

The assumptions used to determine the number of balanced RSS are:

1. The sample mean is normally distributed (used to compute n_o),
2. The variance estimate, s^2, is reasonable and representative of the population being sampled (used to compute n_o),
3. The data distribution is symmetric and approximately normally distributed (used to determine the *RP*),
4. The estimate of the sample mean is reasonable and representative of the population being sampled, and,
5. The field locations that will be ranked are selected using simple random sampling.

The first three assumptions will be assessed in a post data collection analysis. The fourth assumption is valid because the estimate of the mean will be an unbiased estimate of the mean.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, confidence level (1-α) (%), width of confidence interval and set size. The following table shows the results of this analysis.

Number of Samples							
Confidence Level/Interval		m=2		m=3		m=4	
		s=4	s=2	s=4	s=2	s=4	s=2
CL=99	d=0.5	294	76	225	60	184	48
	d=1	76	22	60	18	48	16
	d=1.5	36	12	27	9	24	8
CL=97	d=0.5	208	54	162	42	132	36
	d=1	54	16	42	12	36	12
	d=1.5	26	10	21	9	16	8
CL=95	d=0.5	170	44	132	36	108	28
	d=1	44	14	36	12	28	8
	d=1.5	22	8	18	6	16	8
CL=93	d=0.5	146	38	114	30	92	24
	d=1	38	12	30	9	24	8
	d=1.5	18	6	15	6	12	4
CL=91	d=0.5	128	34	99	27	80	24
	d=1	34	10	27	9	24	8
	d=1.5	16	6	15	6	12	4

s = Standard Deviation
CL = Confidence Level (1-α) (%)
d = Width of Confidence Interval
m = Set Size

This report was automatically produced* by VSP software version 5.3.

Software and documentation available at http://dqo.pnl.gov/vsp

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