

## TABLE OF CONTENTS

---

2.9	Background Radiological Characteristics.....	2.9-1
2.9.1	Background Gamma Radiation Survey and Initial Soils Sampling 2.9-1	
2.9.1.1	Methods.....	2.9-2
2.9.1.2	Data Quality Assurance and Quality Control .....	2.9-6
2.9.1.3	Results.....	2.9-7
2.9.1.4	Additional Information about the Survey .....	2.9-11
2.9.2	Passive Gamma and Radon Monitoring .....	2.9-11
2.9.3	Supplementary Radiological Studies .....	2.9-12
2.9.3.1	Supplementary MILDOS Modeling .....	2.9-12
2.9.3.2	Vegetation and Associated Surface Soil Sampling.....	2.9-14
2.9.3.3	Soil Profile Sampling.....	2.9-15
2.9.3.4	Sediment Sampling .....	2.9-15
2.9.3.5	Food and Fish Sampling .....	2.9-16
2.9.3.6	Radon Flux Measurements .....	2.9-16
2.9.3.7	Radiological Air Particulate (High-Vol) Sampling .....	2.9-16
2.9.4	2010-11 Baseline Radiological Studies .....	2.9-19

## LIST OF FIGURES

---

Figure 2.9-1	Scanning System Equipment and Configuration
Figure 2.9-2	Correlation Grid Sampling Design
Figure 2.9-3	NaI-Based Gamma Survey Results
Figure 2.9-4	NaI Gamma Survey Results and HPIC Measurement Locations
Figure 2.9-5	OHV Re-Scan Results
Figure 2.9-6	Soil Sampling and Gamma Survey Results Overlay
Figure 2.9-7	Ra-226 Soil Concentration and Gamma Exposure Rate Correlation
Figure 2.9-8	Ra-226 and Uranium Soil Concentration Correlation
Figure 2.9-9	Calibration Curves for HPIC versus NaI Detectors
Figure 2.9-10	Three-Foot NaI Detector Height Data
Figure 2.9-11	Three-Foot and 4.5-Foot NaI Detector Height Readings Correlation
Figure 2.9-12	Calculated Three-Foot-HPIC-Equivalent Gamma Exposure Rates
Figure 2.9-13	Kriged Estimates of the Three-Foot-HPIC-Equivalent Gamma Exposure Rates
Figure 2.9-14	Regression Used to Predict Soil Ra-226 Concentrations
Figure 2.9-15	Estimated Soil Ra-226 Concentrations
Figure 2.9-16	Radon and Passive Gamma Sensor Locations
Figure 2.9-17	2009 MILDOS Receptors
Figure 2.9-18	Top 10 Predicted Total Ground Concentration Locations
Figure 2.9-19	Top 10 Predicted Total Ground Concentration Locations Outside Plant Fenceline
Figure 2.9-20	Modeled Isopleths of Ground Concentrations for Year 6
Figure 2.9-21	2008 Vegetation Sampling Locations
Figure 2.9-22	2009 Vegetation and Surface Soils Sampling Locations
Figure 2.9-23	Soil Profile Sampling Locations
Figure 2.9-24	Sediment Sampling Locations

Figure 2.9-25 Radiological Air Particulate Sampling Locations  
Figure 2.9-26 Radon, Passive Gamma, and Radiological Air Particulate Sampling Locations, 2006-09  
Figure 2.9-27 Radon, Passive Gamma, and Radiological Air Particulate Sampling Locations, 2010-11

## TABLES

---

Table 2.9-1 Soil Sampling and Correlation Grid Results  
Table 2.9-2 Gamma Exposure Rate Differences from Two NaI Detector Heights  
Table 2.9-3 Analytical Results for Passive Radon and Gamma Sampling  
Table 2.9-4 Analytical Results for Radiological Air Particulate (High-Vol) Sampling

## ATTACHMENTS

---

Attachment 2.9-1 Data Quality Assurance Documentation  
Attachment 2.9-2 Data Quality Control Documentation  
Attachment 2.9-3 Final Baseline Gamma Survey and Ra-226 Soil Maps  
Attachment 2.9-4 HPIC-Adjusted Gamma Datasets (Electronic Dataset Only)  
Attachment 2.9-5 Additional Information - Background Gamma Radiation Survey and Soils Sampling  
Attachment 2.9-6 Technical Memorandum: 2008 Vegetation Sampling  
Attachment 2.9-7 Technical Memorandum: Vegetation, Soil, and Sediment Sampling  
Attachment 2.9-8 2008 and 2009 Tissue Sampling Results  
Attachment 2.9-9 Technical Memorandum: Radiological Air Particulate Sampling

## 2.9 Background Radiological Characteristics

A baseline radiological survey was performed within the Permit Area to establish and document the pre-operation radiological environment. The baseline radiological measurements: identify areas with anomalously high radiological activity; establish preliminary surface background radiological levels in air, water, soil, sediment, vegetation, and food resources; and provide source data for MILDOS radiation dispersion and dose calculation modeling.

Based on the recommendations of NRC's Regulatory Guide (RG) 4.14 and precedents set by previous Source Material License applications for ISR projects without yellowcake dryers, the initial baseline radiology survey for this Project consisted of: radiological analyses of stormwater and quarterly groundwater samples (**Section 2.7**); hundreds of thousands of spatially-linked gamma measurements throughout the site, associated with soil sample and laboratory analysis for radiological parameters (**Section 2.9.1**); and passive samplers used to measure natural gamma and Rn-222 at multiple locations within and outside of the Permit Area (**Section 2.9.2**, previously in **Section 2.5.5.2**). In response to various Requests for Additional Information (RAIs) from NRC, additional baseline data was collected subsequent to LC ISR, LLC's initial submittal of the Technical Report (TR). Supplementary information includes baseline radiological data for: surface soils, the soil profile, sediment, air particulates, vegetation, and food resources (beef tissue). These supplementary data are presented in **Section 2.9.3**.

### 2.9.1 Background Gamma Radiation Survey and Initial Soils Sampling

Baseline environmental studies in the Permit Area began in January 2006. As part of the overall baseline study, a radiological baseline survey of naturally occurring gamma exposure rates and soil radionuclide concentrations was performed. To detect areas of anomalously high radiological activity on the surface, sodium iodide (NaI) detectors linked to data loggers and a GPS were used to take hundreds of thousands of gamma measurements throughout the Permit Area. These measurements were correlated with radiation levels in soil samples, and with gamma levels measured by High-Pressure Ionization Chambers (HPICs). Radiological baseline surveys in the Permit Area began in late August 2006.

Basic guidance for radiological baseline surveys at uranium recovery sites can be found in RG 4.14. This regulatory guide, intended for conventional uranium mill recovery facilities, includes a pre-operational radial gamma survey design that covers a maximum

area of 1,750 acres with up to 80 individual gamma exposure rate measurements. The recommended sampling design calls for a higher density of measurements near the mill location, and more dispersed measurements in a radial pattern at greater distances from the mill location.

Although RG 4.14 does not address special considerations associated with uranium ISR sites, NRC and WDEQ-LQD (WDEQ-LQD, 2007) currently recommend following RG 4.14 for conducting radiological baseline surveys of ISR uranium projects. Consistent with ISR permit application guidelines described in RG 3.46 (NRC, 1982) and NUREG-1569 (NRC, 2003), as well as with decommissioning considerations outlined in MARSSIM, the Multi-Agency Radiation Survey and Site Investigation Manual (NRC, 2000), Tetra Tech proposed using state-of-the-art GPS-based scanning technologies capable of providing uniform, high-density gamma measurements across very large areas. This scanning system can be mounted in various configurations including in backpacks, OHVs, or trucks, and has been used in the US and abroad for remedial support at multiple uranium mill site decommissioning projects as well as for other site characterization applications.

During a site visit at the beginning of gamma survey activities (August 30, 2006), discussions between: Tetra Tech; LC ISR, LLC; AATA International, Inc.; and NRC representative Bob Lukes resulted in a general consensus that using an OHV-mounted version of this scanning system for baseline radiological surveys would meet or exceed minimum guidelines outlined in RG 4.14 and would provide more detailed information on baseline radiological conditions in the Permit Area.

### **2.9.1.1 Methods**

The background radiation survey of the Permit Area consisted of a number of methods including high density gamma scanning with NaI detectors, measurements with a HPIC, and soil sampling as described below.

#### **Gamma Surveys and Mapping**

Although various GPS-based scanning system configurations used previously by Tetra Tech were well developed and extensively field tested prior to the Project, unique aspects and challenges of scanning the Permit Area presented the need for different vehicles and mounting systems. Given the rugged terrain, sagebrush vegetation and the large Permit Area, two-seater OHVs with roll-bar cages and conventional driver control systems with steering wheel, and gas and brake pedals were best suited for the Project. The OHV models selected were Yamaha Rhinos. Equipped with extra-wide tires, these Rhino OHVs were well suited to safely negotiate the Permit Area while minimizing environmental impacts.

Roll-bar cages on the Rhino OHVs addressed safety considerations and provided a support system for adjustable outriggers. Three Ludlum 44-10 NaI gamma detectors and paired GPS receivers were mounted on the outriggers of each OHV (**Figure 2.9-1**). The detectors were coupled to Ludlum 2350 rate meters housed in a cooler carried in the OHV cargo bed. Simultaneous GPS and gamma exposure rate data were recorded using an onboard personal computer (PC) with data acquisition software developed by Tetra Tech.

After several days of field testing, site scanning, and mounting system modifications, a final system design was achieved that proved stable, reliable, and practical for the terrain. The final system configuration was about ten-foot spacing between detectors (measured perpendicular to the direction of travel), with each detector positioned 4.5 feet above the ground surface. A three-foot detector height is generally accepted, but not mandated, by NRC. This height was impractical in the Permit Area given the tall brush, ravines, and fence gate crossings. A detector height of 4.5 feet was the lowest practical height for the system under the conditions. Experimental measurements were later performed to statistically quantify any measurement difference between the three-foot and 4.5-foot detector heights.

Based on previous experiments conducted under similar scanning geometries, lateral detector response to significantly elevated planar (non-point) gamma sources at the ground surface is about five feet, giving each detector an estimated “field of view” of about ten feet in diameter at the ground surface. This does not imply that a system detector can pick up readings from a small point source five feet away, but does suggest that scattered photons from larger elevated source areas (e.g., 1,076 square feet or 100 square meters [ $m^2$ ]) are likely to be detected at that distance. Within this conceptual framework, the scanning track width for each vehicle’s scanning system is estimated to be about 30 feet across, perpendicular to the direction of travel. The vehicle speed while scanning ranged between two and eight miles per hour (mph), depending on the roughness of the terrain, with an average speed of four to five mph.

Data were downloaded daily into a Project database and mapped using Gamma Viewer software developed by Tetra Tech (Tetra Tech Inc., 2006). In addition to daily quality control (QC) measurements used to evaluate instrument performance and insure data quality (discussed later), daily scan results were evaluated in terms of general agreement between onboard detectors to help identify any problems that may have occurred during data acquisition throughout the day. Evaluation of updated gamma maps each day also helped in planning the next day’s scanning activities.

Initial results indicated that spatial variability in gamma exposure rates across the Permit Area was higher than expected. In areas near orebodies or proposed operational facilities, attempts were made to achieve scanning coverage close to 100 percent. After assessment of initial scanning results for these areas, a distance of 15 to 30 feet between the adjacent detectors in both vehicles was deemed practical and sufficient to resolve smaller-scale variability in the areas targeted for higher-density scanning coverage. This vehicle spacing provided an estimated effective ground scan coverage of 75 to 90 percent. In other portions of the Permit Area, five to ten percent was the initial target coverage, though practical considerations such as safety, terrain, and natural obstructions often dictated actual distances maintained between vehicles. For most areas of the Permit Area, a target distance of 300 feet between vehicles was a conservative goal employed during scanning, as this provides an estimated scan coverage of about 15 percent.

### **Cross-calibration between NaI Detectors and the HPIC**

Gamma exposure rates measured by NaI detectors are only relative measurements, as response characteristics of NaI detectors are energy dependent. True gamma exposure rates are best measured with an energy independent system such as an HPIC. Depending on the radiological characteristics of a given site, NaI detectors can have measurement values significantly higher than corresponding HPIC measurement values. NaI systems are useful for ISR sites; because they can quickly and effectively demonstrate relative differences between pre- and post-ISR gamma exposure rate conditions. Unless the exact same equipment is used for both surveys; however, it is necessary to normalize the data to a common basis of comparison. This is the purpose of performing NaI/HPIC cross-calibration measurements. Cross-calibration insures that the results of future gamma scans, which are likely to use different detectors (and perhaps different detector models or technologies), can be meaningfully compared against the results of the pre-ISR baseline gamma surveys.

To perform NaI/HPIC cross-calibrations, static measurements were taken at various discrete locations covering a range of exposure rates representative of the Permit Area. Many locations were selectively chosen to be at or near earlier soil sampling grids for verification purposes. At each cross-calibration measurement location, ten to 20 individual HPIC readings were recorded and averaged. The center of the HPIC is positioned about three feet above the ground surface. A pin flag was pushed into the ground directly below the center of the HPIC to mark the exact spot for subsequent NaI measurements. The OHVs were then systematically positioned, such that each NaI detector was located directly above the pin flag, when taking measurements. For each NaI detector, 20 individual NaI readings at both three-foot and 4.5-foot detector heights were automatically collected and averaged using a special data acquisition software program. Mean values were recorded.

## Soil Sampling and Gamma Correlation Grids

Regulatory Guide 4.14 specifies that baseline soil sampling be conducted in a radial pattern originating at the center of the milling area, with samples collected at 984-foot (300-meter) intervals in eight compass directions. At the time of this portion of baseline survey activities, the exact location and types of ISR processing facilities to be employed were uncertain. This, coupled with the expected high density of gamma survey information, resulted in a decision to initially focus on developing a correlation between soil Ra-226 concentrations and gamma exposure rates. Depending on the statistical strength of any such relationship, the resulting correlation can be used to infer approximate Ra-226 concentrations across the Permit Area based on the gamma survey results.

Other radiological soil sample analyses were also conducted per RG 4.14 recommendations. Those recommendations indicate that, in addition to Ra-226 analysis for all soil samples, ten percent of samples should be analyzed for natural uranium (U-nat), thorium-230 (Th-230), and lead-210 (Pb-210). In this case, all ten correlation grid samples were analyzed for these additional radionuclides, providing a reasonably representative characterization across the Permit Area.

Soil sampling was conducted as composite sampling over 33-by-33 foot (ten-by-ten meter) grids. Within each grid, ten soil sub-samples were collected to a depth of six inches (15 centimeters) then composited into a single sample. GPS coordinates were taken at the center of each sampling grid and recorded. Samples were sent to Energy Laboratories Incorporated (ELI) in Casper, Wyoming, for analysis of Ra-226 and other select radionuclide concentrations, as stated above. Samples were dried, crushed, and thoroughly homogenized prior to analysis to insure a representative average radionuclide concentration over each 1,076-square-foot (100m<sup>2</sup>) grid. For high-purity germanium (HPGe) gamma spectroscopy analyses (method E901.1), samples were first canned, sealed, and held 21 days prior to counting to allow sufficient ingrowth of radon and short-lived progeny. Separate aliquots of homogenized samples were used for analyses requiring wet radiochemistry methods.

Each 1,076-square-foot (100m<sup>2</sup>) soil sampling grid was also scanned to determine the average gamma exposure rate over the same area, following methods described in Johnson et al. (2006). A diagram depicting the sampling design for correlation grid measurements is shown in **Figure 2.9-2**.

This Project does not include a yellowcake dryer in the Permit Area. As such, the correlation soil samples and related estimates of Ra-226 concentrations across the Permit Area (discussed later), along with the other recommended radiological parameters at

representative correlation grid locations, provide sufficient information on baseline soil radionuclide concentrations for the proposed operations which are described **Section 3.0**.

### **2.9.1.2 Data Quality Assurance and Quality Control**

Sources of gamma measurement uncertainty include instrument variability, spatial variability in gamma exposure rates (differences in readings due to small differences in the measurement location or geometry), and temporal variability in gamma exposure rates (differences over time due to changes in soil moisture, barometric pressure, etc. that can affect ambient radon levels and/or photon attenuation characteristics of the soil profile).

Data quality assurance (QA) and QC issues for the radiological surveys in the Permit Area are addressed in various ways. In general, QA includes qualitative factors that provide confidence in the results, while QC includes quantitative evidence that supports the accuracy and precision of results.

Data QA factors for the Project include the following.

- The investigators have extensive qualifications and over 100 years worth of combined experience for performing radiological measurements and site assessments (curriculum vitae [CVs] provided in **Attachment 2.9-1**).
- Scanning system methodologies and technology are published in peer-reviewed radiation protection and measurement research publications (Johnson et al., 2006; Meyer et al. 2005a; Meyer et al. 2005b; Whicker et al., 2006).
- All NaI and HPIC gamma detectors were calibrated by the manufacturer within one year prior to use on the Project (calibration certificates are provided in **Attachment 2.9-1**).
- Chain-of-custody protocols were followed for soil sampling and contract laboratory analyses (relevant forms are provided in **Attachment 2.9-1**).
- Soil samples were analyzed by ELI. ELI is certified by EPA as well as by seven different states, including Wyoming. The laboratory follows chain-of-custody protocols, uses certified standards of the National Institute of Standards and Technology (NIST) for instrument calibrations, and performs measurements on EPA or other certified reference material standards with each set of client samples to provide information on measurement accuracy.

A detailed field log book of daily activities was maintained and is provided in **Attachment 2.9-2**.

Quantification of data QC for the Project included the following:

- Daily QC measurements were performed for each NaI detector used in gamma scanning; and results were plotted on system instrument control charts. Background as well as cesium-137 (Cs-137) check-source QC measurements were taken each day. Detectors performed within acceptable limits throughout the Project (instrument control charts are provided in **Attachment 2.9-2**).
- Daily scan results for each vehicle were reviewed for consistency along track paths for all onboard detectors. Obvious inconsistencies prompted further investigation. On the few occasions where this occurred, technical problems were discovered and the affected data were removed from the Project database. Affected scanning systems were not used again until technical problems were resolved.
- NaI detectors were cross-calibrated in the field at each site against an HPIC. Results were consistent with cross-calibrations at other uranium sites as well as with the literature in terms of the energy dependence of NaI detectors (Ludlum, 2006; Schiager, 1972).
- One or more days in the Permit Area were used for re-scans of areas previously scanned. As part of this effort, certain higher activity locations of particular interest were targeted for static or mobile re-scanning measurements. Re-scanning demonstrated that measurements were reproducible, generally showing good agreement with the original scans.
- ELI performs duplicate analyses on ten percent of all samples to provide information on measurement variability. The results of all duplicate sample analyses, blanks, laboratory control samples, and sample matrix spikes were within acceptable QC limits, as reported in the ELI QA/QC Summary Report (provided in **Attachment 2.9-2**).

### **2.9.1.3 Results**

#### **Baseline Gamma Survey**

The gamma survey results in the Permit Area are shown in **Figure 2.9-3**. There is an unexpected degree of variability in gamma exposure rates in the Permit Area. Even within regions of five-to-ten-percent scanning coverage, localized trends or “pockets” of higher gamma activity are evident across the Permit Area. The area of higher-density scanning covers an approximate region of primary subsurface ore deposits and is a probable area of future operational facilities. The smaller bordered area to the south of that region was an additional Permit Area added after initial survey activities had commenced.

Some areas with slightly elevated background radiation occurred near the Permit Area boundaries. Commonly, there was no visible evidence of certain landscape features in these areas that might help explain such findings (e.g., exposed bedrock outcrops or unusual soil layers). Subsequent correlation sampling, re-scanning, and HPIC cross-calibration activities were selectively conducted along some of these boundary areas. Those investigations generally confirmed the original readings (**Figures 2.9-4 and 2.9-5**). The evidence indicates that some portions of the Permit Area boundaries fall on areas where natural terrestrial radioactivity is slightly elevated at the soil surface.

### **Baseline Soil Sampling**

Soil sampling was conducted in a roughly radial pattern with the origin located near a potential general area of operational facilities. Sample locations were generally selected to try and cover the range of gamma values found across the Permit Area rather than to employ a rigidly fixed spatial pattern. Overlays of soil sampling locations and baseline gamma survey results are shown in **Figure 2.9-6**. The soil sampling results represent the mean Ra-226 concentrations of the 1,076-square-foot (100-m<sup>2</sup>) sampling grids; and concentric circles have been added to illustrate the approximate radial pattern of the sampling locations (Sample Location LC-1 was within the potential Permit Area as defined at the time of the survey, but just outside the current Permit Area. The soils at that location are nevertheless representative of the soils within the Permit Area)

A general relationship between gamma exposure rates and Ra-226 concentrations at the soil surface is visually apparent in **Figure 2.9-6**. Statistical analysis demonstrated a significant linear relationship (**Figure 2.9-7**) between the mean Ra-226 soil concentration and the mean gamma exposure rate across all of the sampling grids (**Table 2.9-1**). In general, uranium and Ra-226 in these soils do not appear to be in equilibrium (**Figure 2.9-8**). On average, the uranium concentration was less than 45 percent of the Ra-226 concentration, suggesting a considerable degree of uranium mobility in the surface soil environments in the Permit Area.

### **HPIC / NaI Cross-Calibration**

The results of the cross-calibration between the HPIC and NaI detectors positioned at both three-foot and 4.5-foot detector heights are shown in **Figure 2.9-9**. Regression coefficients for both curves are similar to those measured by Tetra Tech at other uranium recovery sites and to other reported values (Ludlum, 2006; Schiager, 1972). Initial OHV scanning in the Permit Area was conducted with the detectors set three feet above the ground surface until problems with the detector clearance necessitated a change to 4.5 feet. All areas scanned at three-foot detector heights are shown in **Figure 2.9-10**.

Numerical differences between the three-foot and 4.5-foot NaI detector height readings are shown in **Table 2.9-2**. The relationship between the two detector heights is shown in **Figure 2.9-11**. For measured gamma values less than 25 microRoentgens per hour ( $\mu\text{R/hr}$ ), there was no evidence that readings from the two detector heights were different. For areas with measured values greater than 25  $\mu\text{R/hr}$ , the difference is proportional to the magnitude of exposure rate being measured.

### **Three-Foot HPIC Equivalent Gamma Exposure Rate Mapping**

All final gamma survey data presented have been normalized to a three-foot HPIC equivalent to create a uniform final gamma baseline survey dataset of the Permit Area. The appropriate regressions from **Figure 2.9-9** were used for the data conversions.

A final map of results, showing Permit Area boundaries and the three-foot HPIC equivalent gamma exposure rate data, is presented in **Figure 2.9-12**, with an E-sized version included in **Attachment 2.9-3**. Note that the legend scale increments in **Figure 2.9-12** differ from the maps in previous figures because the raw NaI scan data have been normalized to an HPIC equivalent.

A kriging program in ArcGIS was used to develop continuous estimates of three-foot-HPIC-equivalent gamma exposure rates throughout the Permit Area. Kriging is a geostatistical interpolation procedure that fits a mathematical function to a specified number of nearest points within a defined radius to determine an output value for each location. A given "location" is represented by a cell of specified dimensions that may or may not include any measured data points. Values closer to the cell are given more weight than values further away; and distances, directions, and overall variability in the data set are all considered in the predictive semivariogram model. The input parameters used for this application were as follows:

- cell size: ten feet by ten feet;
- maximum search radius: 350 feet;
- semivariogram model: exponential; and
- number of nearest data points: ten.

A map of the estimated three-foot-HPIC-equivalent gamma exposure rates throughout the Permit Area is presented in **Figure 2.9-12**, with a larger version included in **Attachment 2.9-3**. Note that for the central area of the highest-density scan coverage shown in **Figure 2.9-12**, there is an apparent difference in distribution between the scan track data and the corresponding kriged region in **Figure 2.9-13**. This is because the scan data symbol sizes in **Figure 2.9-12** have been somewhat enlarged for illustrative purposes, and higher values prevail where adjacent data symbols overlap. In such cases, the kriged map is believed to provide a more accurate representation of the actual distribution. The

larger version of **Figure 2.9-12 (Attachment 2.9-3)** or the raw electronic dataset (**Attachment 2.9-4**) should be used to identify values at individual locations.

### **Soil Ra-226 Concentration Mapping**

Using the NaI /HPIC cross-calibration results, along with the gamma/Ra-226 correlation data, raw NaI scan data were also converted into estimates of soil Ra-226 concentrations. The regression associated with the Project data shown in **Figure 2.9-14** was used for this conversion. Also shown in **Figure 2.9-14** is another correlation developed for the nearby Lost Soldier study area that shares similar geophysical and geochemical soil characteristics. One data point for the Lost Creek correlation appears to be a mild outlier that increases the slope of the regression relative to that of the Lost Soldier study area. Without this data point, the two regressions are nearly identical, suggesting that the basic relationship between the gamma reading and the Ra-226 concentration is reasonably consistent in this region of Wyoming.

Using the regression for the Project data shown in **Figure 2.9-14**, kriging was performed to produce continuous estimates of soil Ra-226 concentrations across the Permit Area as shown in **Figure 2.9-15**, with an E-sized version included in **Attachment 2.9-3**.

QC measurements performed each day at the field staging area indicated that instrument variability for background readings was generally on the order of plus or minus one  $\mu\text{R/hr}$  (based on the standard deviations of 20 successive readings). OHVs were parked overnight in the same general locations; but the exact location of detectors for daily QC measurements varied by five to ten meters. Day-to-day variability in background QC measurements at the field staging area, thus, provides an indication of respective small-scale spatial variability, as well as temporal variability over successive days. Based on the instrument control charts, these sources of variability approached plus or minus three  $\mu\text{R/hr}$ . Thus, the total amount of potential uncertainty in measurements at the staging area approached plus or minus four  $\mu\text{R/hr}$ . The staging area had measured background gamma readings in the range of 17 to 27  $\mu\text{R/hr}$ , which is at the lower end of the range of values found in the Permit Area. In areas of higher gamma exposure rates, the degree of uncertainty in measurements may be higher.

### **Correlation Uncertainty**

LC ISR, LLC acknowledges that there is uncertainty in the second order correlation between gamma readings and uranium, via intermediate relationships for these parameters with soil Ra-226. Estimation error for each intermediate correlation relationship is additive and the total uncertainty of a direct correlation between gamma radiation and uranium in soil would include the combined uncertainties in gamma/Ra-226 and Ra-226/uranium correlations.

Although considerable uncertainty exists for estimating baseline uranium concentrations based on gamma readings, the basic recommendations and intent of the regulatory guidance for characterizing baseline uranium and other radionuclides in soil at Lost Creek are satisfied by the direct soil sampling and analysis that was conducted across the site. Additional uranium concentration estimates, based on the intensive gamma survey and the second order correlation, represent added data analysis (performed in addition to current regulatory guidance) in an attempt to improve knowledge of this parameter and reduce overall uncertainty in baseline characterization of uranium in soils at the site. These data will be helpful in the event of spills or other events during the operational life of the facility, to provide evidence of pre-existing conditions at the site in addition to the soil sampling data discussed above

#### **2.9.1.4 Additional Information about the Survey**

Following review of this section in November, 2008, NRC asked a series of questions regarding details of the survey presented in **Section 2.9.1**. NRC's questions and LC ISR, LLC ISR, LLC's responses are included as **Attachment 2.9-5**.

### **2.9.2 Passive Gamma and Radon Monitoring**

Radon and passive gamma air monitoring for the Project was initiated in November 2006 at sampling locations shown in **Figure 2.9-16**. Sampling locations were established at the closest full-time residence, which is in Bairoil, (URPA1 [Ur-Energy Passive Air 1]), at the western site boundary (URPA7), at the southeastern site boundary (URPA8), at the northeastern site boundary (URPA10), and at the center of the site, which coincides with the ore trend (URPA9). An additional monitoring site was added (URPA13) after the first quarter, to reflect changes to the proposed Permit Area. **Figure 2.9-16** shows that the passive radiological monitoring locations represent conditions at both upwind (west) and downwind (east) Permit Area boundaries. NRC has requested additional information about the criteria used for positioning the radon and gamma sensors (Dec 2009 RAI #5.a.(2)). The monitoring site selection is discussed in more detail in the subsection of **Section 2.9.3.2** entitled **Locations of Radon, Passive Gamma, and Air Particulate Instrumentation**.

Radon gas measurements were made using Landauer Radtrak® long-term radon monitors equipped with a thoron-proof filter in order to measure radon-222, only. The radiosensitive element in these detectors is a CR-39 (allyl-diglycol carbonate) based passive alpha-track detector, sensitive to levels as low as 6 picoCuries per liter (pCi/l) days (0.07 pCi/l), and the detectors are designed for outdoor use. The detectors are suspended three feet above the ground in inverted cups, which shield the monitors from

the elements but allow for a continuous free flow of air. The detectors are delivered in a film-foil bag that prevents exposure prior to deployment, and a metallic label is affixed to the detectors during retrieval to prevent ongoing exposure during return shipping.

X9 Environmental/Low Level Dosimetry badges manufactured by Landauer, Inc. were used to measure gamma levels in the air. These detectors are specifically designed for outdoor applications, and have a linear response between 0.1 millirem (mrem) and 1000 rem using an aluminum oxide (Al<sub>2</sub>O<sub>3</sub>:C) thermoluminescent element read by optically stimulated luminescence technology. X9 badges are protected from the elements by a polypropylene holder sealed within a vinyl pouch, and deployed at a height of three feet. Net dosage is calculated by subtracting gamma levels measured by transit and deployment/retrieval control badges from the gross dosage measured by each badge deployed on site.

Monitors were retrieved quarterly, and results are presented in **Table 2.9-3**. (Note: these results were initially submitted as **Table 2.5-6**, and the 4<sup>th</sup> quarter of data was inadvertently omitted. The table has been updated with all available data.) The elevated radon measurement at URPA9 during the first quarter may be due to radon retention by snow cover. When retrieved, the sensor was buried in a snow drift; thereafter, the sampler was relocated five feet away. The gamma sensor at URPA10 was missing at the end of the second quarter, but was replaced.

The radon equilibrium fraction for baseline measurements at the site should represent the global equilibrium fraction and vary significantly from season to season. RG 4.14 does not require either pre-operational or operational radon decay product measurements for environmental assessments, and it is not useful to measure the equilibrium fraction for radon originating from the site operations for the purpose of assessing potential doses to members of the public. Therefore, the equilibrium fraction was not specifically measured or evaluated.

### **2.9.3 Supplementary Radiological Studies**

Additional baseline radiological studies were conducted from 2008 to 2009 as part of the ongoing effort to characterize the site, or in response to various RAIs from NRC. These are presented below.

#### **2.9.3.1 Supplementary MILDOS Modeling**

MILDOS modeling was initially conducted in 2007 and early 2008 to estimate potential exposures and doses to human receptors and populations surrounding the Permit Area (**Section 7.2.1.2 and Attachment 7.2-1**). A set of 17 receptors was modeled, all of which

were at the Permit Area boundary. In response to an NRC RAI (Nov 2008 RAI §2.9 #3), a subsequent MILDOS simulation was conducted in mid-2009 with the objective of predicting radiological activity on the ground closer to the Plant. The 2009 MILDOS results were used to help select vegetation and soil sampling locations near the Plant, and also support the location of radiological air particulate samplers. In early 2010, MILDOS was used to evaluate whether the difference in wind and stability data between the LS and LC meteorological stations significantly affected the exposure and dose assessments at the permit boundaries (**Section 7.1.2.2**), which was not the case.

For the 2009 'near-Plant' MILDOS modeling, no operational parameters were changed from the initial 2007-08 modeling (**Section 7.2.1.2** and **Attachment 7.2-1**). Because only radon-222 will be released from the facility, the ground concentrations represent radon decay products. A grid with 37 receptors was devised, surrounding the Plant at distances of up to approximately 1.25 miles (2 km). The receptors were modeled as having the same elevation as the Plant, since elevation differences of less than 500 m have a negligible effect on MILDOS results.

In order to provide more spatial resolution in the area with maximum predicted concentrations, a near-field set of receptors was created in a radial pattern surrounding the Plant. A total of 40 receptors were aligned in 100 m intervals out to 500 m in eight compass directions, as shown in **Figure 2.9-17**. The release point for the Plant is point 0,0, and receptor locations were identified by the direction and distance from the origin. For example, receptor N100 is 100 m north of the Plant center, and SE400 is 400 m southeast of the Plant center. The approximate location of the fence line surrounding the Plant is shown in **Figure 2.9-17** for reference.

Results of the 40 radial receptors were compiled using total ground concentrations for each 1-year time step. Total concentrations include concentrations of Po-218, Pb-214, Bi-214 and Pb-210. The results at each time step are shown in **Figure 2.9-18** for the ten receptor locations with the highest predicted ground concentrations. The four highest (and 8 of the top 10) predicted ground concentrations in each time step are within the approximate 200m Plant boundary. The remaining two, N200 and E200 are just outside the Plant fence-line. Removing the locations that are closer than 200 m yields the results shown in **Figure 2.9-19**. Isopleths of predicted ground concentrations are shown in **Figure 2.9-20** for year 6, which has the greatest releases according to model output.

Outside the Plant fence-line, the maximum value is 5,000 pCi/m<sup>2</sup> [average over year], at location N200, which is 200 m straight north of the Plant center on the Plant fence-line. Assuming that all activity resides in the top 1 cm of soil which has a density of 1.2 g/cm<sup>3</sup>, this equates to approximately 0.4 pCi/g of soil. Over the course of a year, it is unlikely that such low concentrations would be detected in soil or vegetation sample.

### **2.9.3.2 Vegetation and Associated Surface Soil Sampling**

Initially, LC ISR, LLC did not conduct preoperational vegetation sampling because a yellowcake dryer is not included in this application. Subsequently, the feasibility of a yellowcake dryer was assessed and an amendment for a dryer was considered. Vegetation was sampled at three locations downwind (to the east and southeast) of the Plant (**Figure 2.9-21**) in July and August 2008 to support a possible amendment request. In an RAI dated November 2008 (RAI §2.9 #3), NRC requested vegetation samples. The sampling program and results were presented to NRC as a Technical Memorandum dated January 16, 2009, and are included in this document as (**Attachment 2.9-6**)

Following the review of **Attachment 2.9-6**, NRC questioned whether the LC ISR, LLC vegetation sampling program adequately addressed areas where deposition of radon daughters was anticipated to be the greatest (April, 23 2009 RAI #5 (1) ). Consequently, LC ISR, LLC conducted the 2009 MILDOS analysis discussed in **Section 2.9.3.1**, and initiated a second preoperational vegetation and surface soil sampling program to better establish a baseline against which to assess future radon daughter deposition.

In summer 2009, vegetation and surface soil samples were collected from sites that would be subject to maximum radon daughter deposition according to the 2009 'near-Plant' MILDOS analysis. Vegetation and soil samples were also collected from sites within the Permit boundary with high and low gamma activity, according to the baseline gamma scan (**Section 2.9.1**). In total, vegetation and surface soils were sampled at seven locations in 2009 (**Figure 2.9-22**):

- Two locations (D & E) where total ground concentrations were predicted to be the greatest during operations, based on the 2009 'near-Plant' MILDOS analysis;
- Four locations (F,G,H,I) where the baseline direct gamma scan survey indicated elevated gamma activity;
- One location (J) where the baseline direct gamma scan survey indicated comparatively low gamma activity, that is upwind of the Plant and where Project-related radon deposition is expected to be low or non-existent.

The first set of vegetation samples were collected on June 24-25, 2009, and two more sets of samples were collected from the same locations at approximately two-week intervals. Samples were analyzed for natural uranium, radium-226, thorium-230, lead-210, and polonium-210. Surface soil samples were collected on June 24-25, 2009, and analyzed for natural uranium, radium-226, thorium-230, and lead-210. 2009 vegetation and surface soil results are presented in **Sections 2.0** and **3.0** of **Attachment 2.9-7**.

### **2.9.3.3 Soil Profile Sampling**

Initially, LC ISR, LLC did not conduct subsurface soil sampling; these samples were requested by NRC in a November 2008 RAI (RAI §2.9 #7.d.). Six sites were selected for soil profile sampling, as shown in **Figure 2.9-23**. In accordance with RG 4.14, one sampling site was placed near the center of the Plant, with four additional sites approximately 2500 feet (750 m) away, in each of the cardinal directions. A detailed soil survey had identified three soil types in the permit area; therefore, an additional sampling site was selected approximately 500 feet east of the central site, so that all three soil types were represented. Depending on the soil profile, 2-4 samples were collected at each site, to a minimum depth of 40 inches (1 m). Samples were analyzed for natural uranium, radium-226, thorium-230, and lead-210. Analytical results from soil profile sampling are presented in **Section 4.0 of Attachment 2.9-7**.

### **2.9.3.4 Sediment Sampling**

LC ISR, LLC did not initially conduct baseline sediment sampling, as it was believed that the background gamma scan (**Section 2.9.1**) provided sufficient information regarding the distribution of radionuclides within the drainages. Sediment samples were requested by NRC in a November 2008 RAI (RAI §2.9 #5). In accordance with RG 4.14, sediment samples were collected from sites at the upstream and downstream Permit area boundaries (**Figure 2.9-24**) in December 2008. Sediment samples were analyzed for natural uranium, radium-226, thorium-230, and lead-210. Analytical results from sediment sampling are presented in **Section 5.0 of Attachment 2.9-7**.

Regulatory Guide 4.14 also recommends sampling sediment from any impoundments that could receive contaminated surface waters. The only onsite impoundment, Crooked Well Reservoir, is located upstream of any project activities, and is not subject to contamination by the Project, however, sediment samples were also collected at this location. There are four additional 'stock ponds' in the vicinity of the Permit Area, each associated with a groundwater right, as shown in **Figure 2.2-4**. None of these is subject to drainage from potentially contaminated areas. The stock ponds associated with BLM East Eagle Nest Draw Well and BLM Boundary Well No. 4775 are in a separate drainage system or upgradient of the Permit Area, respectively, and BLM Battle Spring Well No. 4777 is a stock watering tank located outside the drainage network (**Figure 2.2-5b**). BLM Battle Springs Draw Well No. 4451 feeds an impoundment of a small tributary to East Battle Springs Draw, but no operational activities are planned within the contributing area of this impoundment (**Figure 3.1-2**).

### **2.9.3.5 Food and Fish Sampling**

Because there is no crop production near the Permit Area, no perennial surface water to sustain fish, and very limited use of the Permit area for cattle grazing, tissue samples were not initially collected by LC ISR, LLC. Tissue samples were requested by NRC in a November 2008 RAI (RAI §2.9 #6). In accordance with RG 4.14, tissue samples were collected at the time of slaughter in fall 2008 and 2009 from cattle with access to grazing fodder within three kilometers of the Plant site. Samples of meat (muscle tissue), kidney, and bone were analyzed for natural uranium, radium-226, thorium-230, lead-210, and polonium-210. A liver sample was also analyzed in 2009. Analytical results are included as **Attachment 2.9-8**.

There are no fish-sustaining bodies of water subject to seepage or surface drainage from LC ISR, LLC ISR activity within many miles of the Permit Area, nor agricultural crops grown in the vicinity of the Permit Area.

### **2.9.3.6 Radon Flux Measurements**

Radon flux measurements were not conducted as a component of the baseline study. Radon Flux measurements were requested by NRC in a November 2008 RAI (RAI §2.9 #2), however, these measurements have not been provided, as they are not relevant to the Lost Creek Project (**Section 3.0**). There will be no tailings impoundments, and the planned storage ponds are small and will be lined. Any residues that may accumulate in these ponds will be disposed of off-site in compliance with all regulatory requirements. Upon site decommissioning, soils in the vicinity of the former pond locations will be remediated if necessary as part of site closure plans, and will subsequently be surveyed according to applicable regulatory guidance to demonstrate compliance with all applicable soil cleanup standards.

In addition, the national emission standard for radon flux from the disposal of uranium ore byproduct materials in onsite impoundments (40 CFR 61, Subpart T) appears to be a prescriptive gross value (20 pCi/m<sup>2</sup>-sec). Baseline radon flux is not considered in this standard and as such, the related protocol from RG 4.14 appears to be inconsistent with the corresponding federal standard. Baseline radon flux measurements are not planned at this time.

### **2.9.3.7 Radiological Air Particulate (High-Vol) Sampling**

Radiological air particulate sampling was not initially conducted because no yellowcake drying facility is proposed in this document. Based on sampling programs at other

facilities, it was believed there was an established precedent to not conduct air particulate sampling for radionuclides in cases where the proposed project did not include a yellowcake dryer.

However, in anticipation of a possible license amendment request for installation of a dryer at the Lost Creek Project, LC ISR, LLC began collection of air particulate samples for radiological parameters in November 2007. Five sites were selected in November 2007 based on: the RG 4.14 requirements; site knowledge; and available meteorological data from the on-site meteorological station and the LS and Muddy Gap stations. Sampling locations are shown in **Figure 2.9-25**. Composite quarterly samples were analyzed for natural uranium, thorium-230, radium-226, and lead-210.

In response to Request for Additional Information (RAI) from NRC (Nov 2008 RAI §2.9 #4), the results of the first year of the sampling were submitted to NRC in January 2009 as a Technical Memorandum, which is included in this document as **Attachment 2.9-9**. The table of the analytical results from **Attachment 2.9-9** has been updated with more recent results and is included as **Table 2.9-4**. All of the analytical results were either non-detect or less than 4% of the respective effluent concentration limit from Appendix B of 10 CFR 20.

After reviewing the January 2009 Technical memorandum, NRC requested additional information about the criteria used for positioning the radiological air particulate samplers and the passive gamma and radon sensors (Dec 2009 RAI #5.a.(2)). The selection of sampling locations is discussed in more detail below.

#### **Locations of Radon, Passive Gamma, and Air Particulate Instrumentation**

NRC requested information about the positioning of the passive gamma, radon, and radiological air particulate instrumentation relative to the recommendations in RG 4.14 (Nov 2008 RAI §2.5 #1a; Dec 2009 RAI #5.a.(2)). The placement of the instrumentation reflects the evolving state of project planning during baseline studies, and a good-faith effort to closely follow the intent of RG 4.14.

Radon, passive gamma, and radiological air particulate sampling locations are shown in **Figure 2.9-26**. Radon and passive gamma samplers were installed in November 2006. At that time, the ore trend was relatively well defined (**Figure 3.1-2**), but MILDOS analysis had not been conducted, and the location of the Plant had not been determined. Two possible Plant locations were under consideration, one near the center of T25N, R92W, Section 18 and the other in the southeast portion of T25N, R92W, Section 19 (**Figure 7.2-2**); to avoid construction of the Plant on top of economic ore, the final decision was contingent upon exploration drilling results. Therefore, the radon and passive gamma monitoring locations were selected to represent: the center of the Permit Area (URPA-9),

which would coincide with the ore trend; upwind (western) and downwind (eastern) locations (URPA-7 and URPA-10, respectively); the southeastern Project Area boundary (URPA-8), which is closest to the Sweetwater Mill; and the closest residence, in Bairoil (URPA-1). In February 2007, an additional sampling location (URPA-13) was added due to the expansion of the proposed Permit Area and for proximity to the alternate Plant location in T25N, R92W, Section 19.

The radiological air particulate samplers were installed a year later, in November 2007. By that time, the selection of the Plant location was closer to resolution (T25N, R92W, Section 18), and predictions for operational radionuclide concentrations from the 2007-08 MILDOS runs were available (**Attachment 7.2-1**). In addition, the site-wide gamma survey results were available, providing detailed information about the gamma distribution across the site (**Section 2.9.1**). It was determined that the best course of action was to select air particulate sampling locations based on the most current project planning and baseline radiological information available. This approach would allow the air particulate samplers to remain in the same locations during both the pre-operational and operational phases, as recommended in Section C.1.1.1 of RG 4.14. In many cases the air particulate samplers were sited independently of the existing radon and passive gamma sensors, but instrumentation was co-located at two sites (**Figure 2.9-26**): HV-4 and URPA-10 at the eastern Permit Area Boundary, and HV-1 and URPA-1 in Bairoil.

The locations of the air particulate samplers were based on the recommendations outlined in RG 4.14. Per Section C.1.1.1 of RG 4.14, the air particulate sampling should include “a minimum of three locations at or near the site boundary”. LC ISR, LLC installed five air particulate samplers, including three samplers (HV-3, HV-4, and HV-5) at the site boundaries. The guidance also indicates that one sampling location should be representative of background conditions. Site HV-3 is representative of background conditions, because it is the location furthest from the Plant (over 2 miles) and the mine units (over 1 mile) in a westerly, generally upwind, direction. The guideline also indicates a sampling location should be positioned as closely as possible to the area where airborne radionuclide concentrations related to the ISR operation is predicted to be the highest; therefore, Site HV-2 was located immediately downwind of the 10-acre Plant Site. Site HV-4 was placed at the eastern Permit Area boundary, generally downwind of the Plant Site and all the mine units. Site HV-5 was located at a Permit Area boundary, less than one mile northwest (generally upwind) of the Plant Site and mine units.

Section C.1.1.1 of the guide also refers to sampling locations relative to “residences or occupiable structures within 10 kilometers of the site” and areas “where predicted doses exceed 5 percent of the standards in 40 CFR Part 190”. There are no residences within 10 km of the site, and all of the dose is attributable to radon decay products, which is excepted from 40 CFR Part 190 [40 CFR 190.10(a)]. Even so, LC ISR, LLC installed a

sampler HV-1 at the closest residence (Bairoil) about 15 miles (24 km) northeast, and generally downwind, of the site.

MILDOS results confirm that the four on-site air particulate sampling locations effectively represent the range of airborne radionuclide concentrations that are predicted within the Permit Area. The HV-2 air particulate sampler, immediately east (downwind) of the Plant site, is near the E200 receptor point for the 2009 MILDOS run, which had the second highest predicted total ground concentrations among the receptors outside the fenced area (**Figure 2.9-19**). The HV-3 air particulate sampler is located at the SWB-3 receptor for the 2007-08 MILDOS run, which had the lowest total effective dose equivalent (TEDE) of any modeled receptor (**Figure 4 in Attachment 7.2-1**), and could therefore represent background conditions during the Operations phase. The HV-4 and HV-5 air particulate samplers represent areas where Project-related airborne radiation is predicted to be at intermediate levels.

Air Particulate Monitors are much more complex units than Passive Gamma and Radon Samplers. They require a fixed, semi-permanent installation. Annual wind distributions are variable (as are daily fluctuations), so the Air Particulate Monitors will not necessarily be in the exact "optimal" location at all times regardless of placement. LC ISR, LLC has strategically located the samplers in accordance with RG 4.14 recommendations, in a scheme that effectively represents the range of radiological conditions that are currently present and predicted for the site.

## **2.9.4 2010-11 Baseline Radiological Studies**

When radon and passive gamma sampling began in November 2006, meteorological data was incomplete, MILDOS simulations had not been run, site plans were not fully developed, and air particulate sampling locations had not been selected (see **Sections 2.9.2 and 2.9.3.7**). Many of the radon and passive gamma sampling sites were not in the most strategic locations for air particulate samplers, so only two of the five air particulate samplers are co-located with radon and passive gamma sensors (**Figure 2.9-26**). In multiple RAIs, NRC questioned the placement of radon and passive gamma sensors (Nov 2008 RAI §2.5 #1.a; April 2009 RAI 5.(2); December 2009 meeting minutes 5.a.(2)(b) and 5.c.(1)), and the absence of radon and passive gamma data for three of the five air particulate sampling locations (April 2009 RAI 5.(2); December 2009 meeting minutes 5.a.(2)(a) and 5.c.(1)).

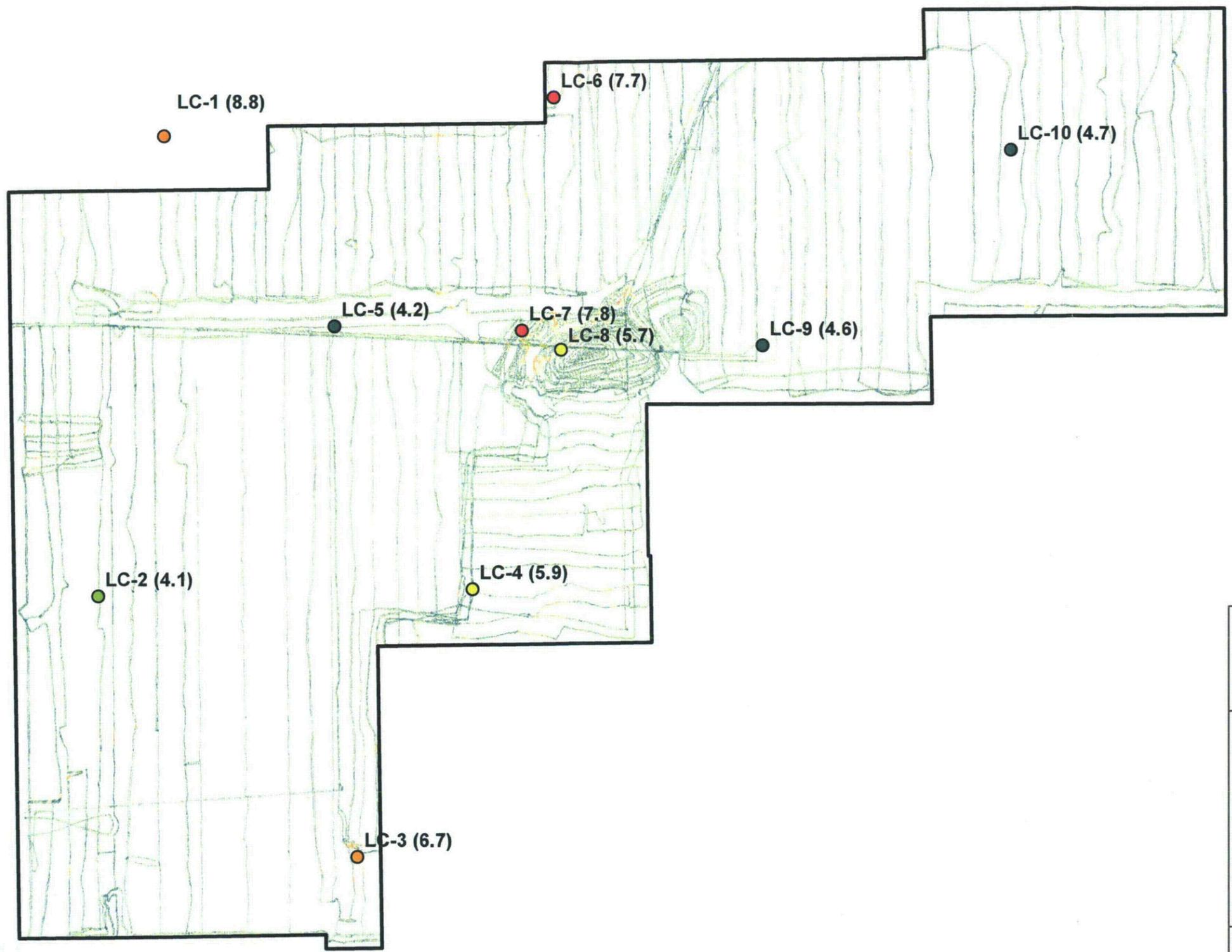
In light of additional information now available, LC ISR, LLC has elected to collect additional radon and passive gamma data. In order to provide baseline radon and passive gamma measurements in the areas with maximum predicted Project-related radiological

activity, and measurements co-located with all air particulate samplers, LC ISR, LLC will collect four additional quarters of baseline measurements at a total of twelve locations.

**Figure 2.9-27** shows the 2010-11 radon and passive gamma sampling sites, denoted with the “PR” prefix, as well as the radiological air particulate sampling locations and the 2006-08 radon and passive gamma sampling sites. Of the twelve 2010-11 radon and passive gamma sampling sites, five (PR-1, -2, -3, -5, and -10) will be co-located with radiological air particulate samplers, and four (PR-7, -8, -9, and -11) will be located at the 2006-08 radon and gamma sites not associated with air particulate samplers. Three additional sites will be sampled based on 2007-08 and 2009 MILDOS analyses (**Attachment 7.2-1** and **Section 2.9.3.1**, respectively), and onsite wind patterns (**Section 2.5.1.4**). The PR-12 site corresponds to the SEB-1 receptor that was identified as having elevated radiation by the 2007-08 MILDOS analysis. The PR-4 site corresponds to the N200 receptor that had the highest total concentration of the sites outside the Plant area in the 2009 MILDOS analysis, and is directly south of the N receptor that was identified as elevated radiation by the 2007-08 MILDOS analysis. PR-5 is co-located with the HV-2 air sampler, and in close proximity to the E200 receptor point that was identified as having elevated radiation by the 2009 MILDOS analysis. PR-6 is located to the northeast of the Plant, in order to provide full coverage of all areas generally downwind of the Plant and mine units. PR-7 is located along the western Permit Area boundary, upwind of the plant site, and therefore will represent background conditions during Plant Operations.

The sampling locations shown in **Figure 2.9-27** were selected based on the existing baseline data and Project plans, in accordance with RG 4.14. A radon and passive gamma site is associated with each air particulate sampler. Nine radon and passive gamma sites are located on Project area boundaries. Three radon and passive gamma sites are placed at locations where radiological impacts are predicted to be highest, according to two MILDOS analyses.

In order to collect 12 months of quarterly samples prior to the initiation of Plant operations, sampling will begin in April 2010. Sensors will be identical to those described in **Section 2.9.3.1**. Sampling results will be reported to NRC prior to the initiation of Plant Operations.



**Legend**

Lost Creek Permit Area

**Gamma Scan (Ur/hr)**

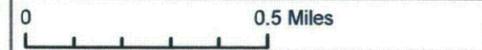
- <25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- >45

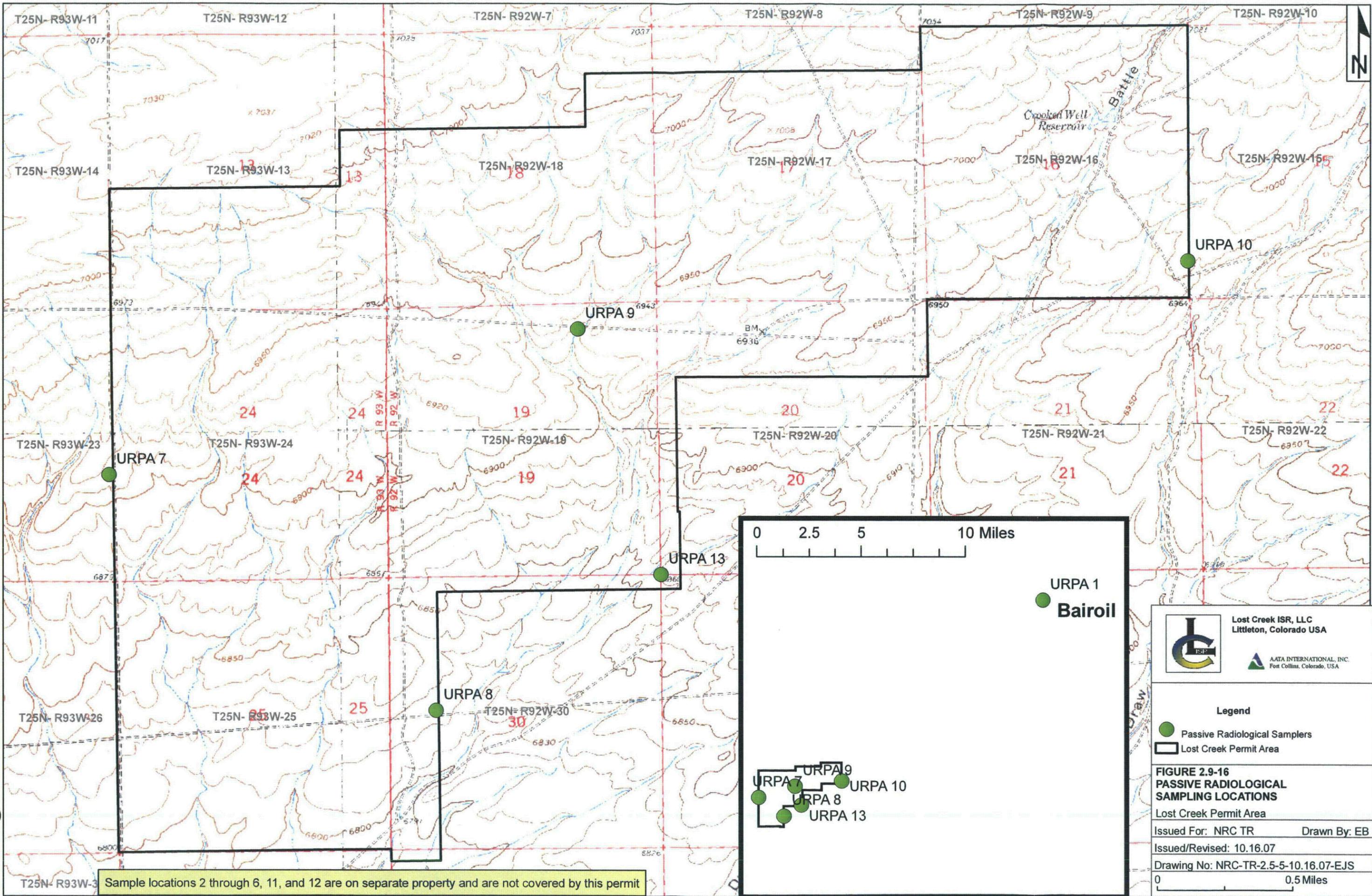
**Figure 2.9-6**  
**Overlay of Soil Sampling (Ra-226) and**  
**Gamma Survey Results**  
 Lost Creek Permit Area

Issued For: NRC TR      Drawn By: EJS

Issued/Revised: 04.12.10

Drawing No: NRC-TR-2.9-6-10.18.07-EJS





Sample locations 2 through 6, 11, and 12 are on separate property and are not covered by this permit


**Lost Creek ISR, LLC**  
 Littleton, Colorado USA  

**AATA INTERNATIONAL, INC.**  
 Fort Collins, Colorado, USA

**Legend**

- Passive Radiological Samplers
- Lost Creek Permit Area

**FIGURE 2.9-16**  
**PASSIVE RADIOLOGICAL SAMPLING LOCATIONS**

Lost Creek Permit Area

Issued For: NRC TR      Drawn By: EB

Issued/Revised: 10.16.07

Drawing No: NRC-TR-2.5-5-10.16.07-EJS

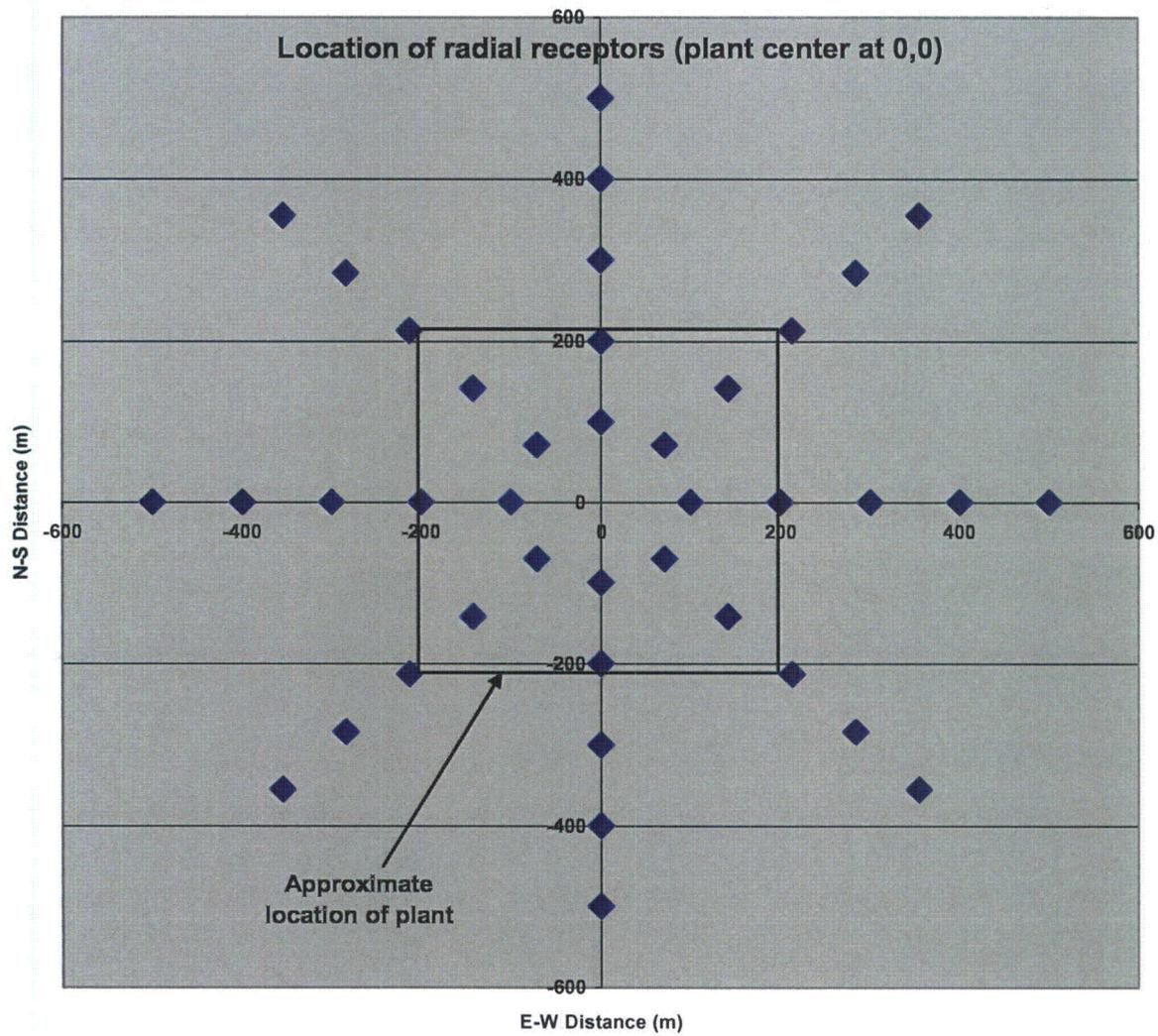
0      0.5 Miles

0    2.5    5    10 Miles

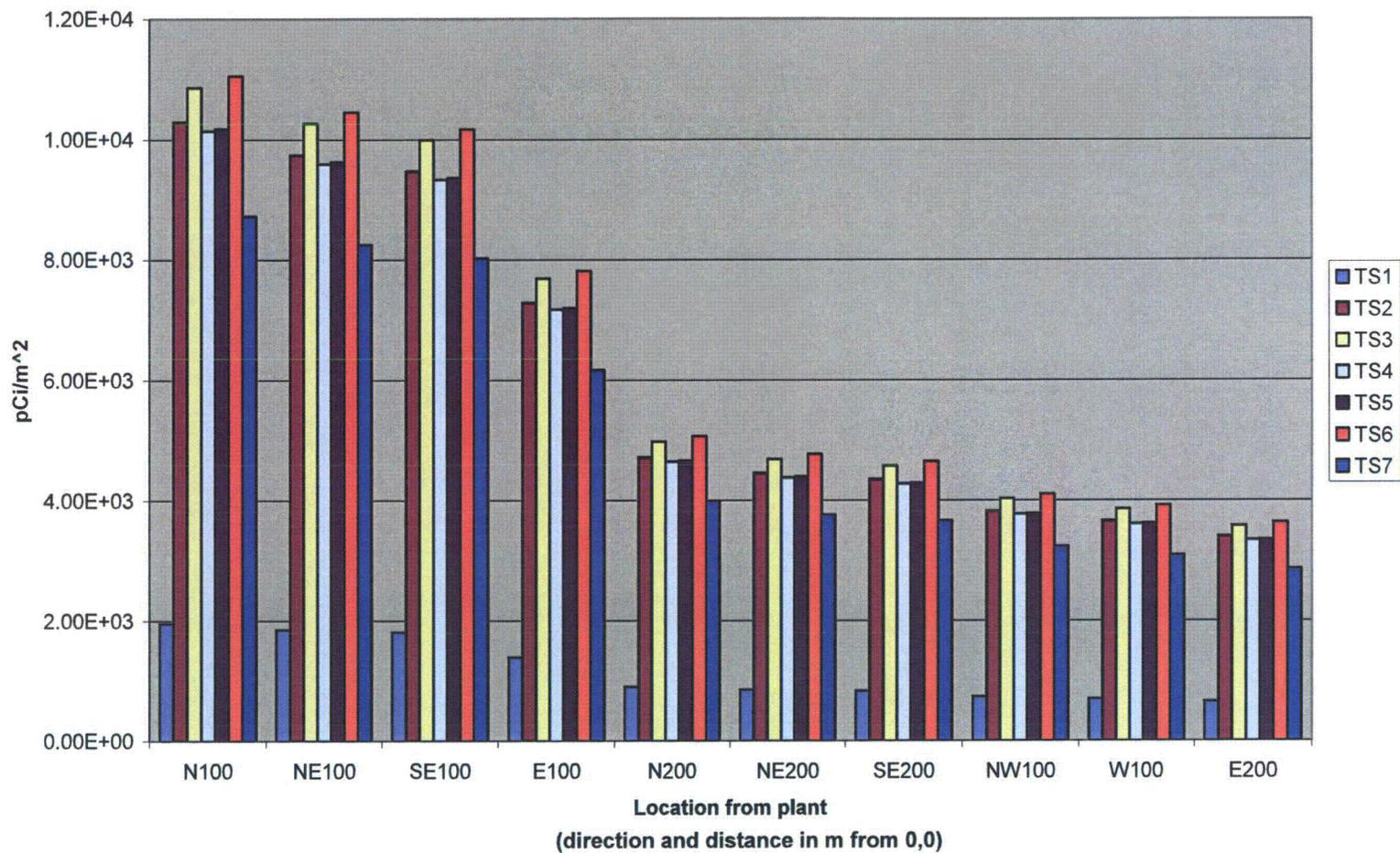
URPA 1  
 Bairoil

URPA 7    URPA 9    URPA 10  
 URPA 8    URPA 13

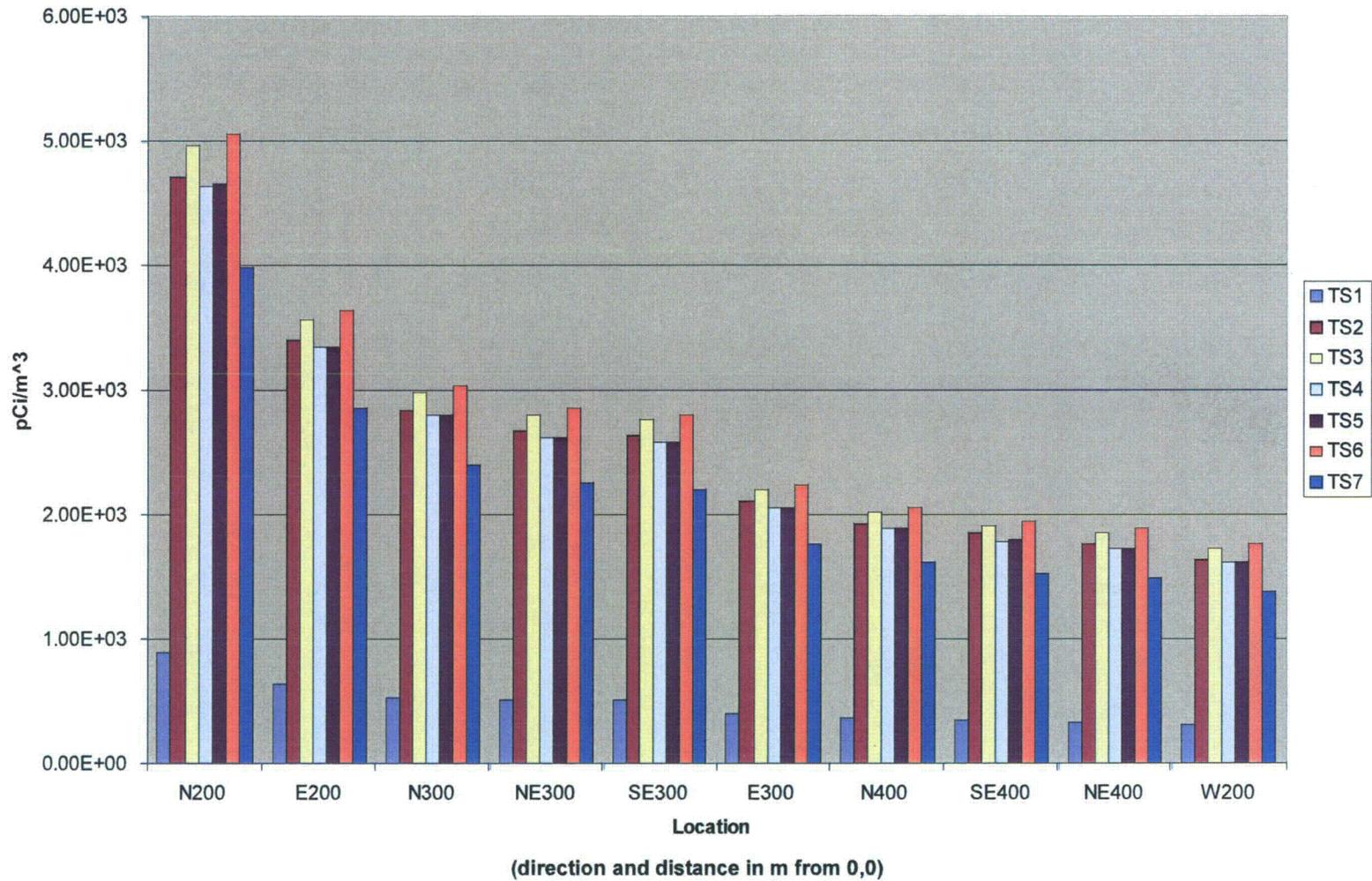
Figure 2.9-17 'Near Plant' MILDOS Receptors - August 2009



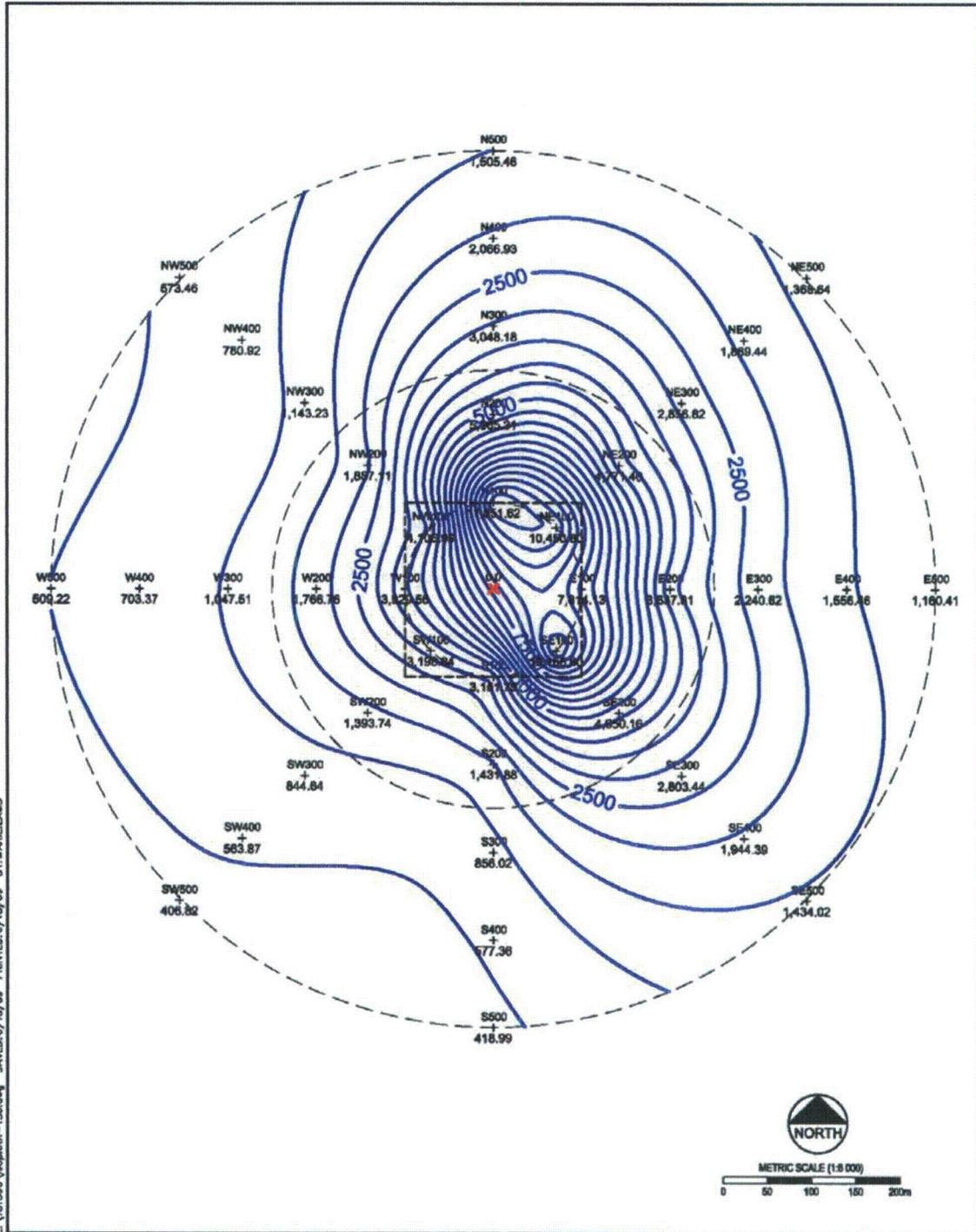
**Figure 2.9-18** Locations of the Highest Predicted Total Ground Concentrations  
 'Near Plant' MILDOS Results - August 2009



**Figure 2.9-19 Locations of the Highest Predicted Total Ground Concentrations Outside Plant Fence  
'Near Plant' MILDOS Results - August 2009**



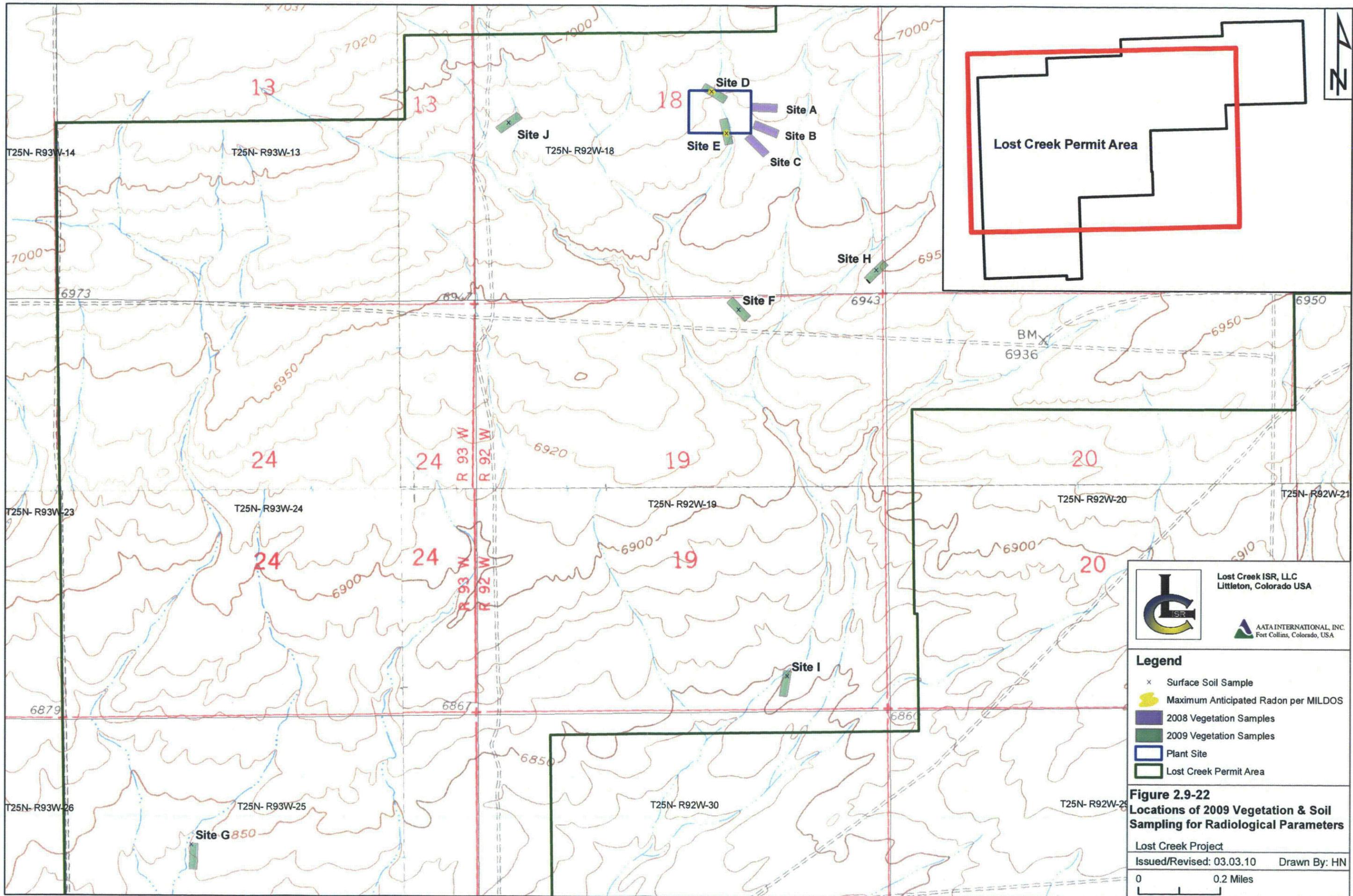
**Figure 2.9-20 Modeled Isopleths of Ground Concentrations for Year 6  
 'Near Plant' MILDOS Results - August 2009**



E:\181890\isopleth-TSE.dwg SAVED: 6/18/09 PRINTED: 6/18/09 BY: MARELAUB



pCi/m<sup>3</sup> Total Ground Concentration



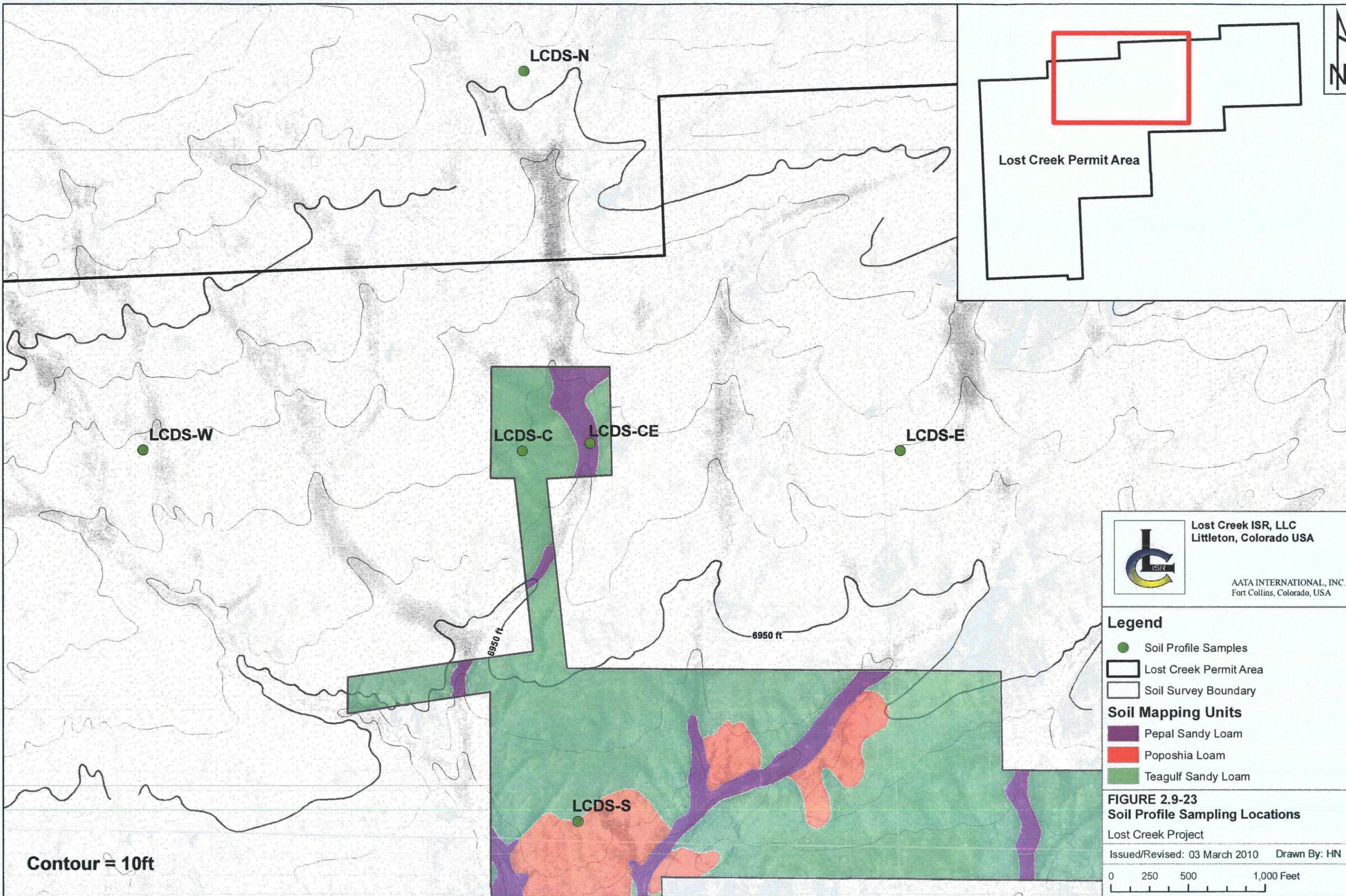

**Lost Creek ISR, LLC**  
 Littleton, Colorado USA  

**AATA INTERNATIONAL, INC.**  
 Fort Collins, Colorado, USA

- Legend**
- × Surface Soil Sample
  -  Maximum Anticipated Radon per MILDOS
  -  2008 Vegetation Samples
  -  2009 Vegetation Samples
  -  Plant Site
  -  Lost Creek Permit Area

**Figure 2.9-22**  
**Locations of 2009 Vegetation & Soil Sampling for Radiological Parameters**

Lost Creek Project  
 Issued/Revised: 03.03.10 Drawn By: HN  
 0 0.2 Miles



LCDS-N

LCDS-W

LCDS-C

LCDS-CE

LCDS-E

LCDS-S

Lost Creek Permit Area



Lost Creek ISR, LLC  
Littleton, Colorado USA

AATA INTERNATIONAL, INC.  
Fort Collins, Colorado, USA

**Legend**

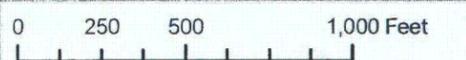
- Soil Profile Samples
- Lost Creek Permit Area
- Soil Survey Boundary

**Soil Mapping Units**

- Pepal Sandy Loam
- Poposhia Loam
- Teagulf Sandy Loam

**FIGURE 2.9-23**  
**Soil Profile Sampling Locations**

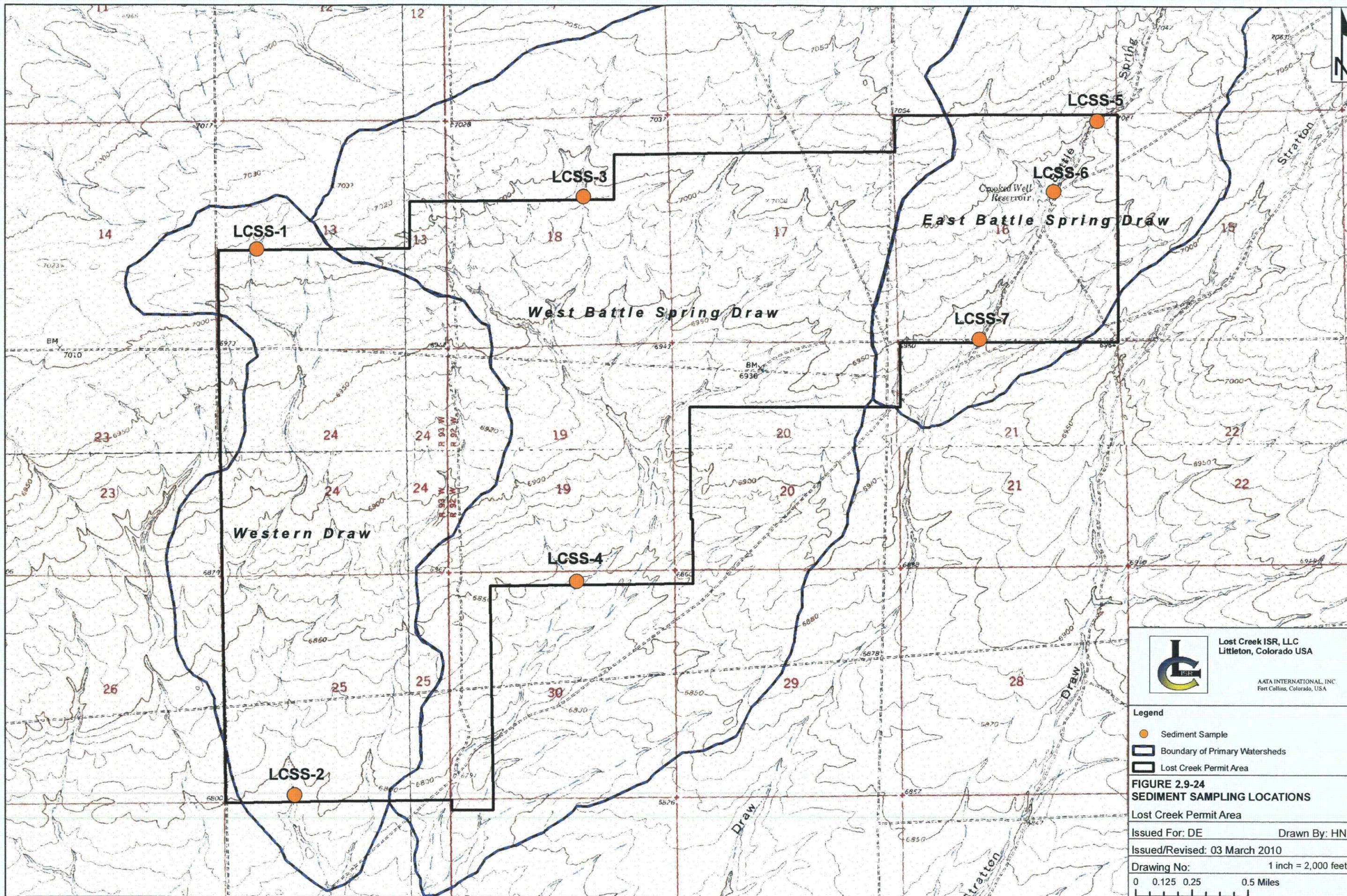
Lost Creek Project  
Issued/Revised: 03 March 2010 Drawn By: HN



Contour = 10ft

6950 ft

6950 ft



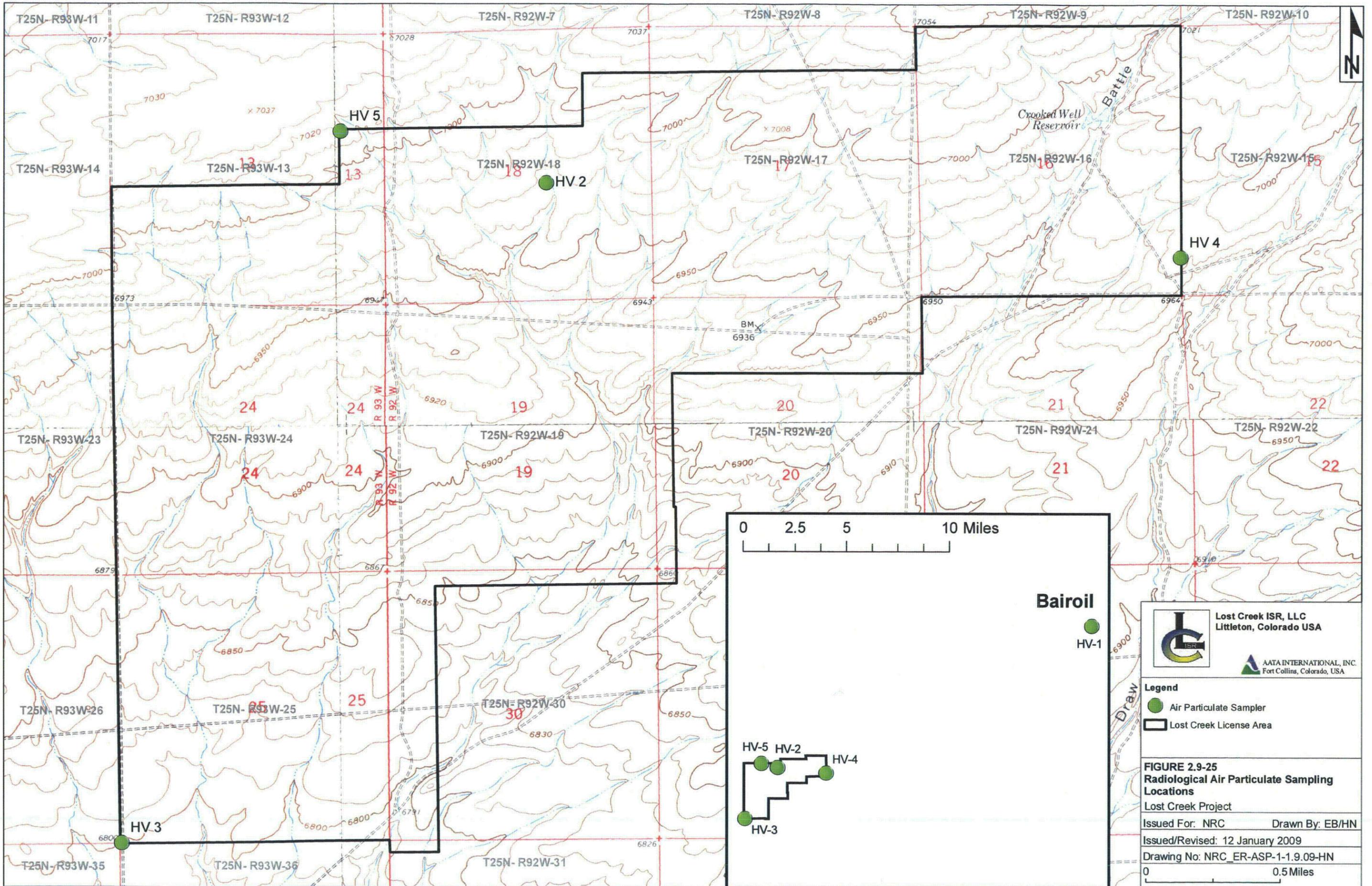
Lost Creek ISR, LLC  
Littleton, Colorado USA

AATA INTERNATIONAL, INC.  
Fort Collins, Colorado, USA

- Legend**
- Sediment Sample
  - Boundary of Primary Watersheds
  - Lost Creek Permit Area

**FIGURE 2.9-24  
SEDIMENT SAMPLING LOCATIONS**

Lost Creek Permit Area	
Issued For: DE	Drawn By: HN
Issued/Revised: 03 March 2010	
Drawing No:	1 inch = 2,000 feet
0 0.125 0.25 0.5 Miles	



**Lost Creek ISR, LLC**  
 Littleton, Colorado USA

**AATA INTERNATIONAL, INC.**  
 Fort Collins, Colorado, USA

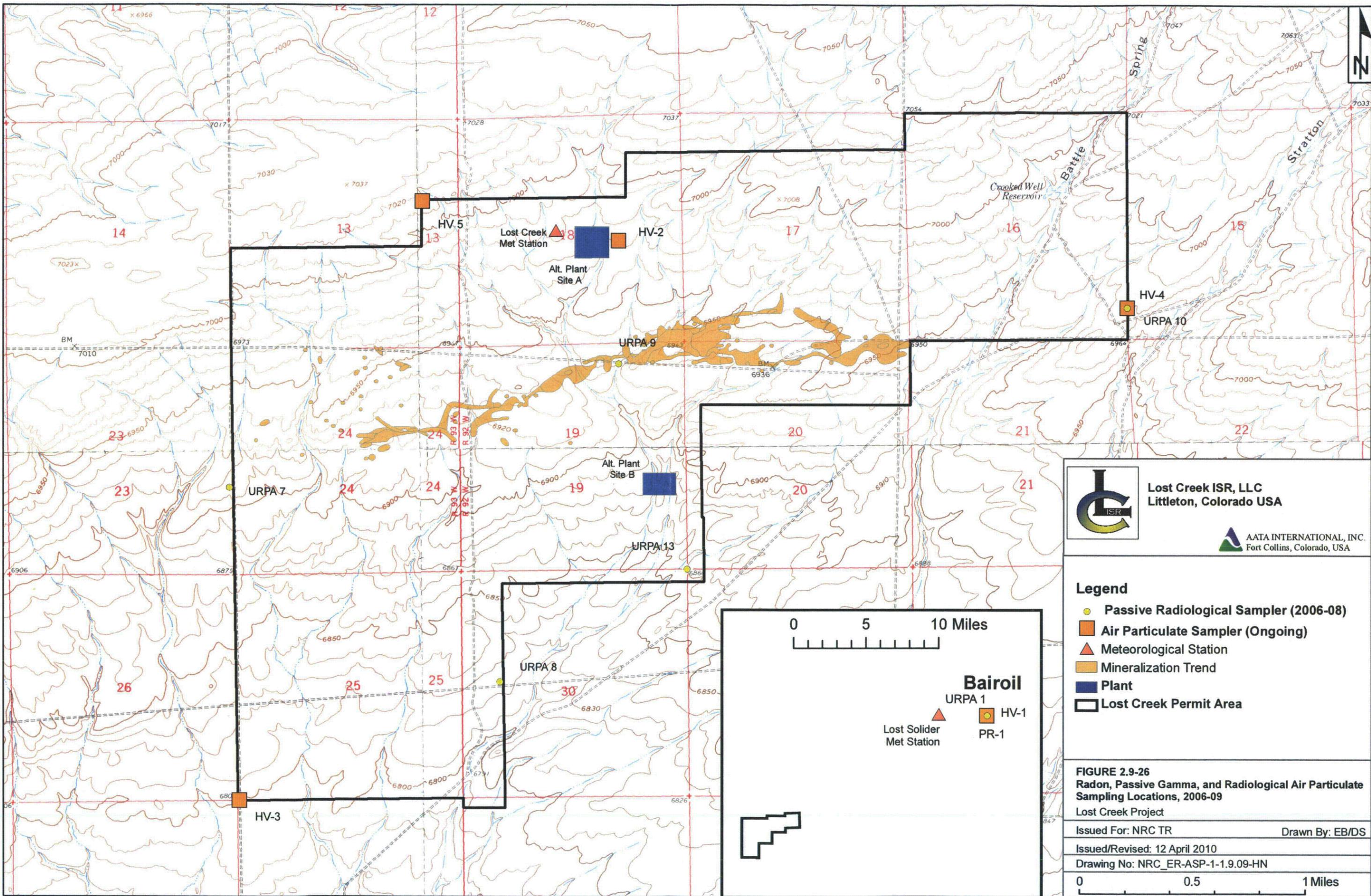
**Legend**

- Air Particulate Sampler
- Lost Creek License Area

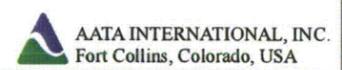
**FIGURE 2.9-25**  
**Radiological Air Particulate Sampling**  
**Locations**  
 Lost Creek Project

Issued For: NRC      Drawn By: EB/HN  
 Issued/Revised: 12 January 2009  
 Drawing No: NRC\_ER-ASP-1-1.9.09-HN

0      0.5 Miles



**Lost Creek ISR, LLC**  
Littleton, Colorado USA



**Legend**

- Passive Radiological Sampler (2006-08)
- Air Particulate Sampler (Ongoing)
- ▲ Meteorological Station
- Mineralization Trend
- Plant
- Lost Creek Permit Area

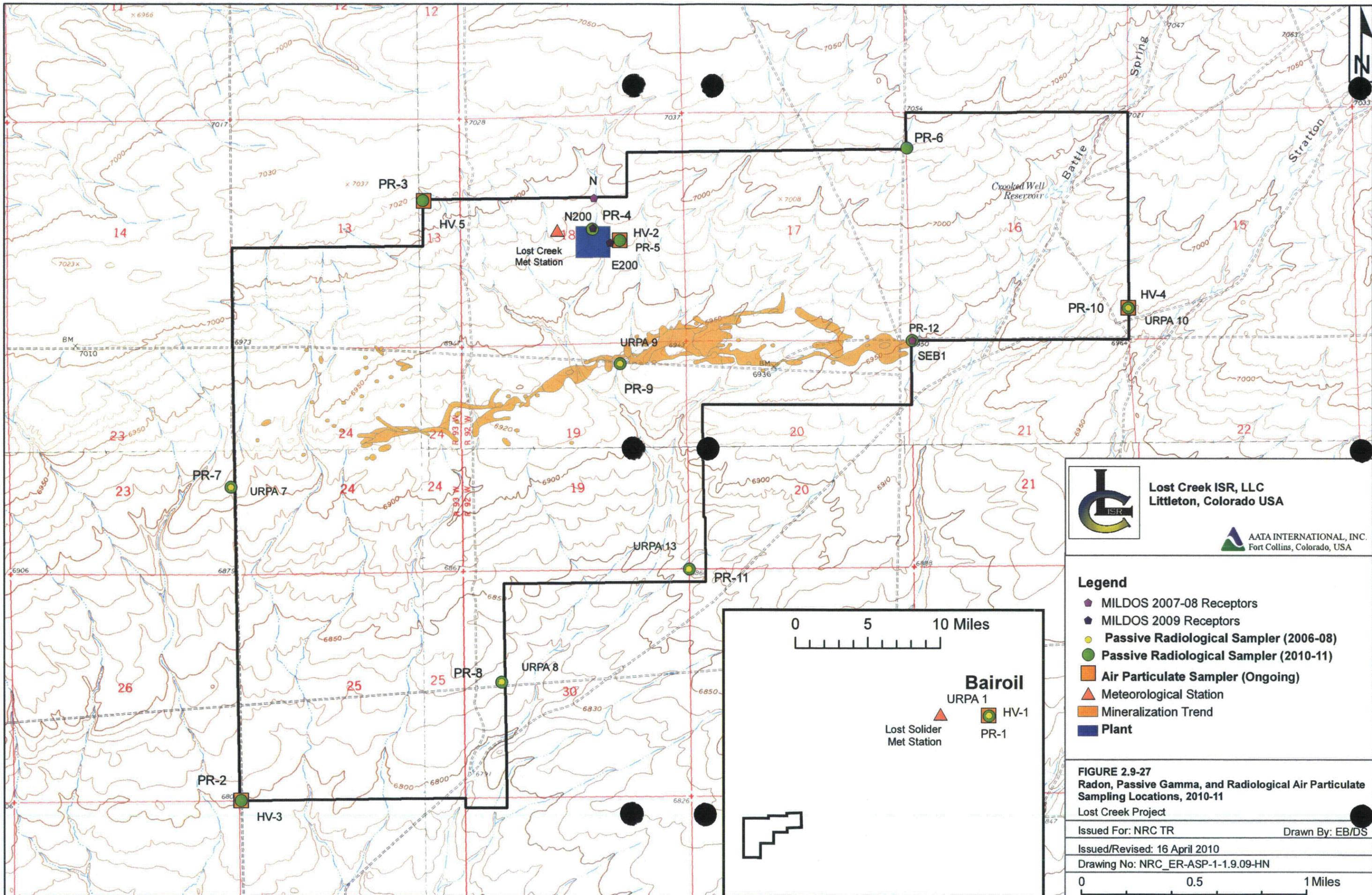
**FIGURE 2.9-26**  
**Radon, Passive Gamma, and Radiological Air Particulate**  
**Sampling Locations, 2006-09**  
Lost Creek Project

Issued For: NRC TR Drawn By: EB/DS

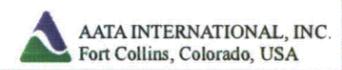
Issued/Revised: 12 April 2010

Drawing No: NRC\_ER-ASP-1-1.9.09-HN

0 0.5 1 Miles

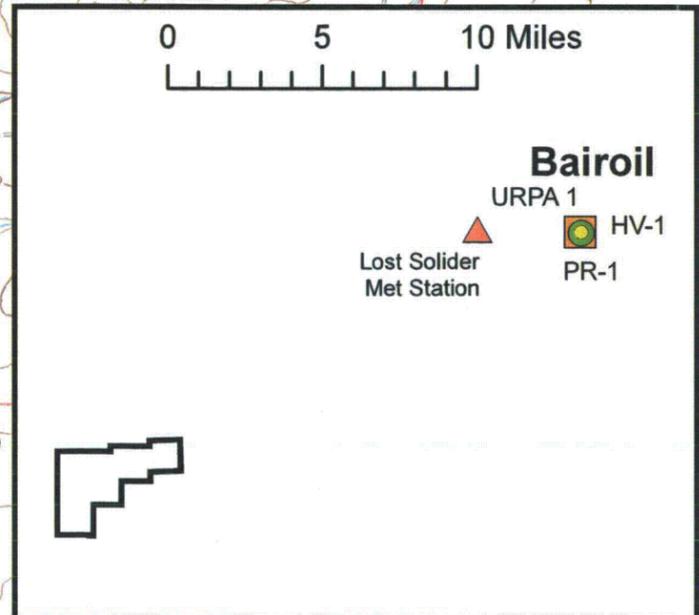


**Lost Creek ISR, LLC**  
Littleton, Colorado USA



**Legend**

- ◆ MILDOS 2007-08 Receptors
- ◆ MILDOS 2009 Receptors
- Passive Radiological Sampler (2006-08)
- Passive Radiological Sampler (2010-11)
- Air Particulate Sampler (Ongoing)
- ▲ Meteorological Station
- Mineralization Trend
- Plant



**FIGURE 2.9-27**  
Radon, Passive Gamma, and Radiological Air Particulate  
Sampling Locations, 2010-11  
Lost Creek Project

Issued For: NRC TR Drawn By: EB/DS

Issued/Revised: 16 April 2010  
Drawing No: NRC\_ER-ASP-1-1.9.09-HN



**Table 2.9-1 Soil Sampling and Correlation Grid Results**

Sample ID	Latitude dd North	Longitude dd West	Mean Ra-226 (pCi/g)	Ra-226 Precision (±pCi/g)	Uranium (mg/kg)	Uranium (pCi/g)	Mean Th-230 (pCi/g)	Th-230 Precision (±pCi/g)	Mean Pb-210 (pCi/g)	Pb-210 Precision (±pCi/g)	Mean Gamma Exposure Rate (µR/hr)
LC-1	42.14155	107.88055	8.8	1.4	12.9	8.7	2.1	0.6	4.9	0.5	31.6
LC-2	42.11874	107.88639	4.1	1.1	2.9	2.0	1.0	0.4	0.6	0.1	23.4
LC-3	42.10628	107.87012	6.7	1.5	3.9	2.6	1.9	0.6	1.1	0.2	29.4
LC-4	42.11892	107.86263	5.9	1.1	4.4	3.0	0.8	0.4	0.4	0.2	28.6
LC-5	42.13146	107.87123	4.2	1.1	1.7	1.1	0.3	0.3	ND 0.1 <sup>(1)</sup>	- <sup>(2)</sup>	23.2
LC-6	42.14215	107.85717	7.7	1.3	5.0	3.4	0.7	0.4	0.4	0.2	34.6
LC-7	42.13118	107.85932	7.8	1.2	6.5	4.4	1.5	0.5	0.4	0.1	33.4
LC-8	42.13024	107.85688	5.7	1.1	2.9	1.9	0.6	0.4	1.0	0.2	26.9
LC-9	42.13038	107.84396	4.6	1.1	1.6	1.1	0.4	0.3	ND 0.1	-	24.4
LC-10	42.13951	107.82803	4.7	1.1	1.7	1.1	ND 0.1	-	ND 0.1	-	24.4
LC-10	<i>Duplicate Analysis</i>		4.8	1.1	NA <sup>(3)</sup>	-	NA	-	NA	-	24.4

<sup>(1)</sup> ND = Not Detected at indicated Reporting Limit.

<sup>(2)</sup> Not reported when parameter not detected.

<sup>(3)</sup> NA = Not Analyzed.

**Table 2.9-3 Analytical Results for Passive Radon and Gamma Sampling**

Location	Period <sup>(1)</sup>	Radon Concentration (pCi/l)	Radon Exposure (pCi/l-days)	Gamma Exposure (millirems)	Gamma Exposure Rate (millirems/day)
<b>URPA1 (Bairoil)</b>	Q1	0.5	50.3	11.3	0.12
	Q2	0.3	22.5	16.9	0.20
	Q3	0.9	90.5	18.6	0.19
	Q4	0.6	58.9	44.2	0.43
	Q5	0.8	89.1	23.0	0.20
<b>URPA7 (W of LC)</b>	Q1	1.5	147.6	33.0	0.34
	Q2	0.7	56.3	23.2	0.28
	Q3	1.6	153.7	41.7	0.43
	Q4	2.8	297.6	53.6	0.51
	Q5	NA <sup>(2)</sup>	NA <sup>(2)</sup>	NA <sup>(2)</sup>	NA <sup>(2)</sup>
<b>URPA8 (SE of LC)</b>	Q1	2.7	258.4	13.6	0.14
	Q2	1.3	108.1	23.4	0.28
	Q3	2.1	203.1	38.2	0.39
	Q4	3.2	331.3	69.6	0.66
	Q5	NA <sup>(2)</sup>	NA <sup>(2)</sup>	NA <sup>(2)</sup>	NA <sup>(2)</sup>
<b>URPA9 (Central LC)</b>	Q1	3.8	370.6	23.7	0.24
	Q2	0.8	67.5	18.0	0.21
	Q3	1.5	148.8	42.1	0.43
	Q4	2.8	295.2	67.4	0.64
	Q5	1.7	184.8	20.7	0.18
<b>URPA10 (NE of LC)</b>	Q1	2.1	201.7	24.4	0.25
	Q2	1.2	100.7	NA <sup>(3)</sup>	NA <sup>(3)</sup>
	Q3	1.8	173.2	50.4	0.52
	Q4	1.0	100.4	55.3	0.53
	Q5	2.0	206.9	32.6	0.29
<b>URPA13 (SE of new LC)</b>	Q1	NA <sup>(4)</sup>	NA <sup>(4)</sup>	NA <sup>(4)</sup>	NA <sup>(4)</sup>
	Q2	2.0	167.2	25.6	0.30
	Q3	1.5	146.8	24.8	0.26
	Q4	2.5	259.2	42.6	0.41
	Q5	2.7	290.9	37.7	0.37

<sup>(1)</sup> Beginning dates: Q1, 11/10/06; Q2, 2/15/07; Q3 5/10/07; Q4, 8/16/07; Q5 11/28/07.  
Sampling concluded 3/14/08.

<sup>(2)</sup> No 5th quarter data collected at this sites.

<sup>(3)</sup> Sensor missing; a new undamaged sensor installed for the next quarter.

<sup>(4)</sup> No data available for first quarter due to later sample installation.

**Table 2.9-4 Lost Creek Radiological Air Particulate (High-Vol) Sampling Results (Page 1 of 2)**

Period	Location	Start Date	End Date	Volume (mL)	U-nat (uCi/mL)	Th-230 (uCi/mL)	Ra-226 (uCi/mL)	Pb-210 (uCi/mL)
Q1	HV1	11/30/2007	3/1/2008	3.85E+09	<1.00E-16	<1.00E-16	2.86E-16	1.78E-14
	HV2	11/30/2007	3/1/2008	3.84E+09	<1.00E-16	<1.00E-16	2.34E-16	1.53E-14
	HV3	11/30/2007	3/8/2008	4.08E+09	<1.00E-16	<1.00E-16	2.23E-15	1.31E-14
	HV4	11/30/2007	3/1/2008	3.70E+09	<1.00E-16	1.62E-16	3.51E-16	2.38E-14
	HV5	11/30/2007	3/1/2008	3.78E+09	<1.00E-16	2.38E-16	2.91E-16	1.81E-14
Q2	HV1	3/1/2008	6/5/2008	4.08E+09	<1.00E-16	<1.00E-16	<1.00E-16	6.81E-15
	HV2	3/1/2008	6/5/2008	3.70E+09	<1.00E-16	<1.00E-16	<1.00E-16	3.02E-15
	HV3	3/8/2008	6/5/2008	4.11E+09	<1.00E-16	<1.00E-16	<1.00E-16	5.01E-15
	HV4	3/1/2008	6/5/2008	4.11E+09	<1.00E-16	<1.00E-16	<1.00E-16	9.24E-15
	HV5	3/1/2008	6/5/2008	4.11E+09	<1.00E-16	<1.00E-16	<1.00E-16	5.28E-15
Q3	HV1	6/5/2008	8/29/2008	3.39E+09	5.61E-15*	1.95E-16	<1.00E-16	2.22E-14
	HV2	6/5/2008	8/29/2008	3.39E+09	1.48E-15*	<1.00E-16	<1.00E-16	1.62E-14
	HV3	6/5/2008	8/29/2008	3.39E+09	1.18E-15*	2.59E-16	<1.00E-16	1.41E-14
	HV4	6/5/2008	8/29/2008	3.39E+09	<1.00E-16*	<1.00E-16	<1.00E-16	1.95E-14
	HV5	6/5/2008	8/29/2008	3.17E+09	2.21E-15*	<1.00E-16	<1.00E-16	1.51E-14
Q4	HV1	8/29/2008	12/2/2008	4.07E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.69E-14
	HV2	8/29/2008	12/2/2008	4.08E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.62E-14
	HV3	8/29/2008	12/2/2008	4.04E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.91E-14
	HV4	8/29/2008	12/2/2008	4.08E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.72E-14
	HV5	8/29/2008	12/2/2008	3.85E+09	<1.00E-16	<1.00E-16	<1.00E-16	2.31E-14
Q5	HV1	12/2/2008	3/19/2009	4.58E+09	<1.00E-16	2.28E-16	<1.00E-16	1.11E-14
	HV2	12/2/2008	3/19/2009	4.58E+09	1.55E-16	<1.00E-16	<1.00E-16	1.15E-14
	HV3	12/2/2008	3/19/2009	4.51E+09	1.48E-16	<1.00E-16	<1.00E-16	1.67E-14
	HV4	12/2/2008	3/19/2009	4.56E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.57E-14
	HV5	12/2/2008	3/19/2009	3.77E+09	1.36E-16	2.01E-16	<1.00E-16	1.05E-14

**Table 2.9-4 Lost Creek Radiological Air Particulate (High-Vol) Sampling Results (Page 2 of 2)**

Q6	HV1	3/19/2009	6/15/2009	3.70E+09	<1.00E-16	1.15E-16	<1.00E-16	1.05E-14
	HV2	3/19/2009	6/15/2009	3.76E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.15E-14
	HV3	3/19/2009	6/15/2009	3.39E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.12E-14
	HV4	3/19/2009	6/15/2009	3.74E+09	<1.00E-16	<1.00E-16	<1.00E-16	1.11E-14
	HV5	3/19/2009	6/15/2009	3.80E+09	<1.00E-16	<1.00E-16	<1.00E-16	9.53E-15
Q7	HV1	6/15/2009	9/18/2009	4.01E+09	1.98E-16*	<1.00E-16	<1.00E-16	8.20E-15
	HV2	6/15/2009	9/18/2009	4.08E+09	1.21E-16*	<1.00E-16	<1.00E-16	9.43E-15
	HV3	6/15/2009	9/18/2009	4.07E+09	1.44E-16*	<1.00E-16	<1.00E-16	1.38E-14
	HV4	6/15/2009	9/18/2009	4.11E+09	1.29E-16*	<1.00E-16	<1.00E-16	1.30E-14
	HV5	6/15/2009	9/18/2009	4.10E+09	1.56E-16*	<1.00E-16	<1.00E-16	7.16E-15

\*Method blank or entire sample batch apparently exposed to uranium contamination during the digestion process  
(See Attachment 2.9-2).

**Attachment 2.9-5    Additional Information - Background Gamma Radiation  
Survey and Soils Sampling**

## Attachment 2.9-5

The following is the LCI ISR, LLC's January 16, 2009 response to NRC's November 2008 Request for Additional Information 2.9 #7. A footer has been added to indicate the attachment number to the Technical Report and page number in that attachment. The article referenced in Subsection 7.j of the response is included after the response.

### 2.9 Background Radiological Characteristics

#### 7. Background gamma radiation survey and soils sampling:

- a. Considering that LCI has stated "There is an unexpected degree of variability in gamma exposure rates in the Permit Area" and that increased exposure rates were detected over ore bodies and at Permit Area boundaries, it is not clear why only ten correlation grids were chosen and how these ten correlation grids accurately represent the Permit Area as a whole. Demonstrate and provide justification that the ten correlation grid samples are representative of the Permit Area as a whole.*

An intensive gamma survey with hundreds of thousands of individual measurements across the entire site was conducted prior to selecting correlation plot locations and performing related measurements and soil sampling. The gamma survey data provided a highly detailed and comprehensive basis for selecting correlation plot locations that are clearly representative of the site as a whole with respect to the intent of the correlation and its connection to the gamma survey data. In this context, "representativeness" rests on several facts:

- 1) The elevation across the site is relatively constant and the gamma survey was essentially completed within a few weeks. Cosmic sources of gamma radiation are likely to have been fairly constant across the site during the survey, and diurnal fluctuations in ambient radon and associated progeny in air usually produce only minor variations in gamma exposure rates (NRC, 1994). Thus, significant variations in gamma readings across the site are expected to be largely due to variations in terrestrial sources of gamma radiation residing in surface soils.
- 2) Radium-226 (Ra-226) levels in surface soils are known to influence gamma survey readings, primarily due to photon emissions from lead (Pb-214) and bismuth (Bi-214) (both of which are short-lived decay products of radon-222 (Rn-222)). Because Ra-226 and its decay products normally exist in approximate secular equilibrium in soil, soil Ra-226

concentrations and ambient gamma exposure rates above the soil surface can often be well correlated, particularly under baseline conditions at undisturbed sites. This was true at the Lost Creek site.

- 3) Based on maps of the gamma survey data, correlation plot locations were selected to span the range of gamma readings observed across the entire site, with a reasonably even distribution of intermediate gamma levels represented. Furthermore, the spatial distribution of correlation plot locations across the site was also taken into account (locations were spread out across various areas of the site, rather than clustered in a small area). This latter consideration should help to account for potential variability in soil properties that might influence the correlation such as potential variability in the concentrations of other gamma-emitting radionuclides like potassium-40 (K-40).

The approach used to characterize gamma exposure rates and Ra-226 concentrations in surface soils at Lost Creek has advantages in terms of representativeness because the gamma survey component of the methodology captures spatially extensive portions of the entire population of possible values (well distributed across the entire site). These results, in turn, can be used to select correlation locations that are representative of the range of gamma exposure rates (and likely soil Ra-226 concentrations as well) found at the site.

Assuming other location selection criteria are also adequately addressed (e.g. gamma shine issues are avoided, plots have uniform gamma readings, etc), as few as five or six carefully-selected plots can result in a regression model that provides reasonably reliable estimates of soil Ra-226 concentration based on gamma survey data. Although five or six grids is a minimum number, ten plots is usually a minimum goal as this provides a more robust statistical analysis.

Based on the Lost Creek gamma survey data, the correlation results, and considerable experience with successful application of this technique at many other sites (e.g. Whicker et al., 2008, Johnson et al., 2006), the number of correlation plots and their locations are considered adequately representative of the entire site with respect to converting gamma survey data into estimates of approximate soil Ra-226 concentrations in surface soils.

The gamma survey and correlation methodology used at Lost Creek is not intended to replace the soil sampling recommendations provided in NRC Regulatory Guide 4.14. This methodology has been developed to help address spatial limitations of grid-based sampling approaches such as the one described in Regulatory Guide 4.14. It also helps to address other, more recent and ISR-specific guidance such as

NUREG-1569 (NRC, 2003) which indicates that 15-centimeter soil depths should also be characterized for consistency with decommissioning protocols and methods as outlined in the Multi-Agency Radiation Surveys and Site Investigation Manual (MARSSIM) (NRC, 2000). The overall approach used at Lost Creek draws on a combination of relevant regulatory guidance, state-of-the-art scanning technologies, and basic correlation techniques that have been used and accepted for decades. The goal was to produce the most detailed and comprehensive baseline characterization possible with respect to the spatial distribution of gamma exposure rates and Ra-226 concentrations in surface soils.

LC ISR, LLC acknowledges that baseline radiological data for surface soils at Lost Creek deviate from Regulatory Guide 4.14 recommendations in that 10 rather than 40 surface soil samples were collected and analyzed for Ra-226. However, the intensive gamma survey in conjunction with the correlation results and related sampling/analyses of surface soils as provided in the application should be sufficient to meet the basic intent and technical basis of relevant regulatory guidance with respect to surface soils at the site.

LC ISR, LLC also acknowledges that the lack of subsurface soil samples deviates from Regulatory Guide 4.14 guidance. LC ISR, LLC has collected baseline subsurface soil sampling consistent with Regulatory Guide 4.14 recommendations and will submit results to the NRC as an addendum to the Technical Report as soon as results are available.

References:

Johnson, J.A. Meyer, H.R., and Vidyasagar, M. 2006. *Characterization of Surface Soils at a Former Uranium Mill*. Operational Radiation Safety. Supplement to Health Physics, Vol. 90, February, 2006.

U.S. Nuclear Regulatory Commission (NRC). 2000. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), Revision 1*. NUREG 1575. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1994. *NUREG-1501, Background as a Residual Radioactivity Criterion for Decommissioning*. Division of Regulatory Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 2003. *NUREG-1569, Standard Review Plan for In Situ Leach Uranium Extraction License Applications*. Final Report. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. Washington, D.C.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. *Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques*. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

***b. Estimates in the literature (e.g., Faw and Shultis, 1993) indicate that the average concentration of K-40 in soils is 12 pCi/g. Considering that the method proposed to characterize Lost Creek depends on exposure rate correlated to radium concentrations, how is the presence and variation of K-40 and other naturally occurring radionuclides taken into consideration in the proposed methodology?***

The correlation is site-specific. Because correlation plot measurements and sampling was conducted in a consistent manner at various representative onsite locations, correlation results include a representative measure of all sources of variability that might influence the correlation. This includes variability associated with K-40 and other naturally occurring radionuclides. A site-specific regression provides a statistical tool for estimating soil Ra-226 concentrations that takes into account site-specific and method-specific sources of variability in paired gamma/Ra-226 data including:

- Heterogeneity in soil Ra-226 concentrations and all other terrestrial sources of ambient gamma radiation, including K-40 and other gamma-emitting radionuclides.
- Scattered radiation reaching the detectors from adjacent areas or subsurface soils (i.e. "gamma shine"). Mild gamma shine effects are believed to introduce small amounts of variability into most correlation data sets as horizontal and vertical distributions of soil radionuclide concentrations are seldom perfectly uniform. Associated variability will be reflected in data collected from representative correlation plot locations and will thus be accounted for in the regression statistics. Strong gamma shine affects, however, can produce strong outliers that badly affect the predictive reliability of the regression. Any location with an abrupt, dramatic transition between low and high soil radionuclide levels has the potential for such effects. Fortunately, areas with strong gamma shine are normally limited to very small portions of any given site and are thus not representative of the site as a whole. Such areas are avoided when selecting correlation plot locations. There was no evidence of strong gamma shine effects at the correlation plots used for Lost Creek.

- Uncertainty in field measurements due to variability in instrument response characteristics. In addition to inherent variability in the precision or reproducibility of readings within or between specific instruments, this factor includes potential differences in counting efficiencies for photons of different energies (e.g. counting efficiency for primary K-40 photons may be less than that attained for lower-energy primary photons from Ra-226 and its decay products, or from secondary scattered radiation).
- Uncertainty in laboratory results due to counting error and all other potential sources of total propagated analytical uncertainty (e.g. incomplete homogenization of composite samples, slight errors in sample weights, etc.)
- Uncertainty in results due to sampling error (e.g. slight inconsistencies in sampling depths, slight differences in volumes of each sub-sample that make up the composite sample, tendency to sample between vegetation rather than near root systems, tendency to avoid collecting larger rocks, etc.).

There are likely other sources of variability as well. Using site-specific data and a consistent methodology helps to account for various sources of sampling and measurement variability in the predictive model. There is considerable evidence to support this view. At a number of other uranium recovery sites, separate soil sampling has been conducted and direct laboratory analysis results for these samples have been compared to corresponding gamma-based estimates of Ra-226 concentrations (Whicker et al., 2008). To date, such "verification" sampling efforts have demonstrated that the scanning/correlation methodology is generally effective and reliable. This does not mean that gamma-based estimates of soil Ra-226 will agree perfectly with direct soil sampling results, but in most cases differences observed by Tetra Tech have been relatively small (e.g. within  $\pm 1-2$  pCi/g). In general, this level of agreement does not greatly exceed typical uncertainties reported by analytical laboratories for direct measurement of Ra-226 in baseline soil samples:

The coefficient of determination (R-squared) of the linear relationship between mean Ra-226 and Gamma reading at the Lost Creek site was 0.88. Therefore, the mean Sodium Iodide (NaI) gamma reading was able to explain 88% of the observed variability in mean Ra-226 concentration, despite many additional sources of potential variability and uncertainty as described above. The specific influence of variability from naturally occurring radionuclides other than Ra-226 and its decay products (such as K-40) is believed to be comparatively small.

Reference:

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. *Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques*. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

- c. Considering that the main product from Lost Creek is uranium in slurry form, and that uranium is not well correlated to radium on the Lost Creek site, demonstrate that the proposed preoperational soil sampling methodology is sufficient to allow LCI to clean up land as a result of spills and accidents, including on proposed transport routes, and meet the requirements of 10 CFR 40, Appendix A, Criterion 6(6), for decommissioning for radionuclides other than radium.***

NRC Regulatory Guide 4.14 recommends that 40 surface soil samples be collected in a radial grid surrounding the mill, and 10% (four) of these samples be analyzed for uranium (NRC, 1980). In addition, it recommends that soil samples collected at the five air particulate monitoring stations be analyzed for uranium. Therefore Regulatory Guide 4.14 recommends that fewer than ten surface soil samples be analyzed for uranium.

At the Lost Creek site, ten surface soil samples were collected in a roughly radial pattern relative to the center of the site. These samples were analyzed for Ra-226, U-nat, Th-230, and Pb-210. For characterizing baseline uranium in surface soils, this sampling design is reasonably consistent with the Regulatory Guide 4.14 recommendations, and should satisfy the basic intent and technical basis of the regulatory guidance. Furthermore, the gamma survey goes far beyond Regulatory Guide 4.14 recommendations and this information can be used to indirectly estimate approximate baseline concentrations of both Ra-226 and uranium in surface soils anywhere on the site.

The statement that uranium is not well correlated with radium at the Lost Creek site is inconsistent with the statistical analysis provided in the application. Although the data suggest that uranium and radium in surface soils at the site may commonly be in moderate disequilibrium, the R-squared value on the statistical regression between the two parameters was 0.73 and the p-value (0.001502) indicates that the correlation is statistically significant at a confidence level greater than 99.8%. This suggests that approximate baseline uranium concentrations could be estimated reasonably well anywhere on the site based on the Ra-226/U-nat regression equation, and using the kriged contour map of estimated soil Ra-226 values across the site (both of which are provided in Section 2.9 of the Technical Report).

The baseline sampling design for radionuclides in surface soils in Regulatory Guide 4.14 calls for discrete grab samples spaced 300 meters apart. Plant decommissioning standards and assessment criteria described in MARSSIM call for more detailed measurements. Radiological survey results from Lost Creek and other proposed ISR sites in Wyoming have demonstrated that baseline soil radionuclide concentrations can occasionally vary by an order of magnitude across areas significantly smaller than this amount of grid spacing. The survey described by Regulatory Guide 4.14 may not include measurements in areas where spills or accidents are most likely, and also has the potential to mischaracterize areas between designated grid sampling points. The increased density of measurements and improved spatial detail provided offers a distinct advantage over the sampling design recommended in Regulatory Guide 4.14.

The intensive gamma survey performed across the entire site helps to overcome limitations of a Regulatory Guide 4.14 design for characterizing spatial variability in baseline concentrations of Ra-226 in surface soils. The statistical correlation between Ra-226 and uranium suggests that survey data can also be used to indirectly infer approximate uranium concentrations. Had the baseline soil sampling and gamma survey designs for this site strictly adhered to Regulatory Guide 4.14, far less spatial information relevant to the question of assessing potential uranium contamination due to spills and accidents would be available.

Reference:

U.S. Nuclear Regulatory Commission (NRC). 1980. *Regulatory Guide 4.14. Radiological Effluent and Environmental Monitoring at Uranium Mills. Revision 1.* Nuclear Regulatory Commission Office of Standards Development. Washington, D.C.

- d. LCI states: "Within each grid, ten soil sub-samples were collected to a depth of six inches (15 centimeters) then composited into a single sample." Demonstrate that the subsurface (greater than 15 cm below the surface) is properly characterized so as to be able to comply with 10 CFR 40 Appendix A, Criteria 6 (6).**

The gamma survey and correlation methodology was not intended to characterize radiological conditions in subsurface soils. LC ISR, LLC will perform baseline subsurface soil sampling consistent with Regulatory Guide 4.14 recommendations and will submit results to the NRC as an addendum to the Technical Report as soon as results are available.

- e. *In discussing the cross-calibration of the sodium iodide (NaI) detector with a High-Pressure Ionization Chamber (HPIC), LCI states: "NaI detectors were crosscalibrated in the field at each site against an HPIC. Results were consistent with cross-calibrations at other uranium sites as well as with the literature in terms of the energy dependence of NaI detectors (Ludlum, 2006; Schiager, 1972)." Regarding the Schiager reference, please address the following: The Schiager paper describes a process where the NaI detector was calibrated with a radium point source which was then used to measure exposure from radium. The NaI detectors used in the Lost Creek evaluation were calibrated with cesium-137 (Cs-137) then used to measure exposure from radium. Explain why Cs-137 was chosen as the calibration source and the relevance of the Schiager paper to the Lost Creek survey cross-calibration.*

Cesium-137 (Cs-137) is the normal source routinely used by Ludlum for calibration of their Ludlum Model 44-10 NaI detectors. The Schiager paper provides a graph of cross-calibration measurement results showing relative response characteristics of a NaI detector versus a high-pressure ionization chamber, with two of the locations measured directly above a tailings pile (see Figure 3 in the Schiager paper).

The corresponding equation from Schiager's cross-calibration was:

Equation (a)

$$\text{HPIC reading (microRem/hour, } \mu\text{R/hr)} = 0.46 \times (\text{NaI reading in } \mu\text{R/hr)} + 7.9$$

The two cross-calibration equations measured at Lost Creek (for the two different NaI detector heights) were:

Equation (b)

$$\text{HPIC reading (} \mu\text{R/hr)} = 0.57 \times (\text{3-ft NaI reading in } \mu\text{R/hr)} + 6.97$$

Equation (c)

$$\text{HPIC reading (} \mu\text{R/hr)} = 0.69 \times (\text{4.5-ft NaI reading in } \mu\text{R/hr)} + 3.99$$

In the Schiager paper, radium was the point source used for calibration of the NaI instrument. The photon energies from Ra-226 and its decay products (namely Pb-214 and Bi-214) are lower, and the mix of energies more complex, than that for Cs-137. We are not suggesting that there are no differences in energy response characteristics between our instruments and the instrument used by Schiager.

The intent of the reference is to demonstrate that the regression coefficients shown in Figure 3 of the Schiager paper are reasonably consistent with those observed for

the cross-calibration from Lost Creek, particularly considering the fact that Schiager took two measurements directly above a tailings pile and performed a number of measurements at other locations with gamma readings well in excess of those found anywhere at Lost Creek. Presumably, Schiager positioned the NaI detector at the same height as the HPIC, so Equation (b), above, would be the most applicable to compare with Schiager's regression, Equation (a).

As ambient gamma exposure rates increase, the difference between NaI and HPIC readings becomes more pronounced and the slope of any corresponding regression should theoretically decrease. Although differences in calibration sources between instruments probably contribute to the observed differences in regression coefficients, the mix of terrestrial sources present at each site and differences in ambient gamma exposure rates could easily be responsible for most of the difference between these regressions. Again, the point is that the differences are not large.

Schiager points out that each cross-calibration is unique to the NaI instrument; each cross-calibration is also site- and geometry specific. Further discussion of the nature of differences between NaI and HPIC readings at various sites and factors that can affect such cross-calibrations (as well as gamma/Ra-226 correlations) can be found in Whicker et al. (2008).

Finally, the correct reference for the Schiager paper is:

Schiager, K. J. 1974. *Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles*. Radiation Data and Reports, Vol. 15, No. 7. Office of Radiation Programs. US EPA. July 1974.

The correct publication date is 1974, not 1972.

References:

Schiager, K. J. 1974. *Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles*. Radiation Data and Reports, Vol. 15, No. 7. Office of Radiation Programs. US EPA. July 1974.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. *Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques*. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

*f. The intent of the Schiager paper is to demonstrate that the exposure rate over a uranium mill tailings pile can be estimated if there is a known uniform concentration of radium in the tailings. The technique proposed in the Lost Creek analysis attempts to correlate known exposure rates with unknown radium concentrations that may or may not be uniform outside of the correlation grids. Aside from the references noted, are there other outside references that establish this type of relationship?*

The 100 m<sup>2</sup> correlation plot technique has been proven effective at statistically determining a valid average relationship between mean gamma readings and mean soil Ra-226 concentrations (Whicker et al. 2008, Johnson et al., 2006). Elements of the technique designed to address issues of variability include: 1) use a correlation plot large enough to significantly reduce measurement error associated with small-scale spatial variability; 2) select plots that have generally uniform gamma readings; and 3) collect a sufficient number of soil sub-samples to provide a good representation of the true mean concentration.

Relating point measurement gamma readings to Ra-226 concentrations in discrete soil samples can yield unreliable results. Data variability is much higher with unshielded (non-collimated) detectors because the gamma detector senses photons that originate across a significantly wider area. An individual soil sample is less likely to accurately represent the true mean Ra-226 concentration across the field of view of the gamma detector versus a composite soil sample.

We acknowledge that results from a 100 m<sup>2</sup> correlation plot model are applied to point data across the site (and areas outside of correlation plots may not be uniform). Furthermore, the converted point data are subsequently kriged in GIS to provide continuous estimates across the site. Kriging has advantages and disadvantages with respect to spatial accuracy. It tends to reduce small-scale spatial detail associated with individual point data and interpolates between vehicle scan tracks where no data exist. It can also, however, help to improve overall survey reproducibility along the scan tracks themselves as it tends to average out variability in point data associated with sources of measurement and estimation error (e.g. small inaccuracies in GPS readings, random variability in gamma count data, application of a 100 m<sup>2</sup> correlation plot model to point data, etc.).

Aside from advantages and limitations of the overall method, larger scale distributional characteristics are most relevant to baseline characterizations at such large sites and the method appears to be reasonably reliable in this regard. On a number of occasions, we have evaluated locations corresponding to given contour lines in kriged gamma exposure rate maps and verified good agreement between

measured and predicted values (e.g. within  $\pm 2$   $\mu\text{R/hr}$  from one another). In addition, soil Ra-226 sampling results to date have generally agreed well with the values predicted based on the gamma survey data, the correlation, and the kriging technique. The data indicate that the overall methodology is generally reliable.

We are aware of the limitations of the technique, but believe that these limitations relative to those of traditional grid-based sampling or measurement approaches are fewer and less problematic. The sheer volume of information on terrestrial radiation that can now be efficiently collected overcomes many of the spatial limitations of earlier techniques. Short of collecting thousands of soil samples along a high-density grid across the entire site, we are not aware of a viable approach that is as effective or reliable as the method selected. The most pertinent and current reference for this issue is Whicker et al. (2008).

References:

Johnson, J.A. Meyer, H.R., and Vidyasagar, M. 2006. *Characterization of Surface Soils at a Former Uranium Mill*. Operational Radiation Safety. Supplement to Health Physics, Vol. 90, February, 2006.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. *Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques*. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

- g. ***LCI states: "Each 1,076-square-foot (100m<sup>2</sup>) soil sampling grid was also, scanned to determine the average gamma exposure rate over the same area, following methods described in Johnson et al. (2006)." The Johnson reference indicates that the site was scanned with a "shielded sodium iodide detector." Verify if a shielded sodium iodide detector was used to survey Lost Creek and if so provide details on the shielding, including its purpose and how it alters the unshielded energy response.***

The NaI detectors used for the gamma survey or for cross-calibration and correlation measurements were not shielded.

*h. For all linear regression analyses presented (Figures 2.9-7 – 2.9-9, 2.9-11 and 2.9-14), provide calculations and results of testing the null hypothesis (i.e., that no correlation exists).*

The p-value for the correlation in shown Figure 2.9-7 is 0.000054:

```

StatMost for Windows      Friday, November 21, 2008      5:15:36 AM
-----
                        Pearson Correlation Analysis Results
                        -----
Ra-226 vs. NaI_Gamma:

Column Name   Ra-226      NaI_Gamma
Sample Size   10          10
Minimum Sample Size = 10
Correlation = 0.939677
Fisher's z = 1.735278
Probability = 0.000054

***** The End *****

```

The p-value for the correlation in shown Figure 2.9-8 is 0.001502:

```

StatMost for Windows      Friday, November 21, 2008      5:12:05 AM
-----
                        Pearson Correlation Analysis Results
                        -----
Ra-226 vs. U-nat:

Column Name   Ra-226      U-nat
Sample Size   10          10
Minimum Sample Size = 10
Correlation = 0.857795
Fisher's z = 1.284938
Probability = 0.001502

***** The End *****

```

The p-values for the correlations in shown Figure 2.9-9 are 0.000275 (3-foot NaI vs HPIC) and 0.000579 (4.5-foot NaI vs HPIC).

```

StatMost for Windows      Friday, November 21, 2008      5:03:09 AM
-----
                        Pearson Correlation Analysis Results
                        =====
NaI_(3-ft) vs. HPIC:

Column Name   NaI_(3-ft)      HPIC
Sample Size   6                  6
Minimum Sample Size = 6
Correlation = 0.986434
Fisher's z = 2.493252
Probability = 0.000275

***** The End *****

```

```

StatMost for Windows      Friday, November 21, 2008      5:04:27 AM
-----
                        Pearson Correlation Analysis Results
                        =====
NaI_(4.5-ft) vs. HPIC:

Column Name   NaI_(4.5-ft)      HPIC
Sample Size   6                  6
Minimum Sample Size = 6
Correlation = 0.980291
Fisher's z = 2.304961
Probability = 0.000579

***** The End *****

```

The p-value for the correlation in shown Figure 2.9-11 is 0.000012:

```

StatMost for Windows      Friday, November 21, 2008      4:57:59 AM
-----
                        Pearson Correlation Analysis Results
                        =====
NaI_(3-ft) vs. NaI_(4.5-ft):

Column Name   NaI_(3-ft)      NaI_(4.5-ft)
Sample Size   6                  6
Minimum Sample Size = 6
Correlation = 0.997198
Fisher's z = 3.284658
Probability = 0.000012

***** The End *****

```

The p-values for the correlations in shown Figure 2.9-14 are 0.000055 (LC) and 0.000002 (LS):

```

StatMost for Windows      Friday, November 21, 2008      5:29:36 AM
-----
                        Pearson Correlation Analysis Results
                        -----
3-ft_HPIC_Eq_(LC) vs. Ra-226_(LC):

Column Name      3-ft_HPIC_Eq_(LC)      Ra-226_(LC)
Sample Size      10      10
Minimum Sample Size = 10
Correlation = 0.939430
Fisher's z = 1.733173
Probability = 0.000055

***** The End *****

```

```

StatMost for Windows      Friday, November 21, 2008      5:31:10 AM
-----
                        Pearson Correlation Analysis Results
                        -----
3-ft_HPIC_Eq_(LS) vs. Ra-226_(LS):

Column Name      3-ft_HPIC_Eq_(LS)      Ra-226_(LS)
Sample Size      10      10
Minimum Sample Size = 10
Correlation = 0.974875
Fisher's z = 2.182200
Probability = 0.000002

***** The End *****

```

The calculated p-values above indicate that all of these correlations are significant at a confidence level of at least 99.8%. In each case there is less than a 0.2% probability that the correlation has resulted from random chance, or that rejecting the null hypothesis would be an incorrect conclusion.

- i. *For Figures 2.9-7 – 2.9-9, 2.9-11 and 2.9-14, provide the paired X and Y coordinate data points and where these are located in the application.*

The locations of NaI/HPIC cross-calibration measurements and gamma/Ra-226 correlation plots are shown in Figure 2.9-4, with correlation plot locations shown again in Figure 2.9-6. Some of the analytical values used for the correlations provided in the cited figures are shown in Table 2.9-1 of the application. For

completeness and ease of reference, all sampling/measurement location coordinates and respective analytical data used for the correlations in the cited figures are presented in the table below.

Sampling Location ID	Latitude (DD North)	Longitude (DD West)	Mean Ra-226 (pCi/g)	Mean U-nat (pCi/g)	Mean HPIC Reading (uR/hr)	3-foot HPIC Equivalent (uR/hr)	Mean 4.5-foot Nat Reading (uR/hr)	Mean 3-foot Nat Reading (uR/hr)
LC-1	42.14155	107.88055	8.8	8.7		25.8	31.6	
LC-2	42.11874	107.88639	4.1	2.0		20.1	23.4	
LC-3	42.10628	107.87012	6.7	2.6		24.3	29.4	
LC-4	42.11892	107.86263	5.9	3.0		23.7	28.6	
LC-5	42.13146	107.87123	4.2	1.1		20.0	23.2	
LC-6	42.14215	107.85717	7.7	3.4		27.9	34.6	
LC-7	42.13118	107.85932	7.8	4.4		27.1	33.4	
LC-8	42.13024	107.85688	5.7	1.9		22.6	26.9	
LC-9	42.13038	107.84396	4.6	1.1		20.8	24.4	
LC-10	42.13951	107.82803	4.7	1.1		20.8	24.4	
PIC-LC-1	42.11733	107.86353			23.6		30.2	31.4
PIC-LC-2	42.10687	107.87045			33.0		41.4	44.0
PIC-LC-3	42.12827	107.87157			20.7		22.2	22.1
PIC-LC-4	42.13095	107.85934			25.7		34.3	35.5
PIC-LC-5	42.13122	107.85960			37.7		47.2	53.4
PIC-LC-6	42.13195	107.84903			21.7		24.9	25.3
LS-1	42.25496	107.62914	4.0			18.0		
LS-2	42.24552	107.63335	7.0			26.7		
LS-3	42.24333	107.62289	7.6			27.8		
LS-4	42.23494	107.61988	11.9			35.9		
LS-5	42.23527	107.62859	6.9			28.3		
LS-6	42.23888	107.62864	5.1			23.0		
LS-7	42.23656	107.63339	7.5			26.8		
LS-8	42.23776	107.63977	8.8			31.8		
LS-9	42.23095	107.65234	5.5			22.3		
LS-10	42.22769	107.63492	3.9			19.7		

- j. For the relevant dates that data was used for correlation, provide the quality control charts titled "Lost Creek: Check Source QC chart for ATV Instruments" or indicate where these can be found in the application.

After a careful review of all relevant information and data, instrument control charts have been revised to include all QC data collected during the survey. Explanations and discussion are provided in this response, along with supporting data and analyses to provide the most complete assessment possible concerning instrument performance and data uncertainty.

**QA/QC Program Overview**

The purpose of the QA/QC program for this project was to ensure and demonstrate that the data and information generated would be of sufficient quality to meet the project objectives. The project objectives were to provide reliable (reproducible)

characterizations of the spatial distributions of gamma exposure rates and gamma-based estimates of Ra-226 concentrations in surface soils (0-15 cm) across a large site (about 4,400 acres). A recent peer-reviewed paper discussing the same survey methodology used for this project has been published in the journal Health Physics (Whicker et al., 2008). That paper is included as an attachment to this response because it contains information pertinent to the reliability of this survey approach.

Overall components of the applied QA/QC program for the baseline gamma survey at Lost Creek are summarized in Section 2.9.1.2 of the application. Specific elements of the program that are most relevant to this discussion are as follows:

1. All gamma detectors used during the survey were calibrated by the manufacturer within one year prior to use on this project.

*Purpose:* Maintain detector accuracy relative to known gamma exposure rates from a Cs-137 calibration source under controlled measurement conditions at the manufacturer's laboratory

2. Daily QC measurements during the project included static readings of ambient background gamma exposure rates as well as readings from a Cs-137 check source.

*Purpose:* Establish the degree of measurement agreement (precision) within and between detectors on each individual day of survey activities, both at low gamma field intensities (background readings) and at high gamma field intensities (check source readings). These measurements are used to evaluate each instrument against performance acceptance criteria (quality control limits), and to provide a daily indication of data uncertainty due to normal instrument variability at different gamma field intensities. Another purpose is to provide an indication of the degree of data uncertainty associated with natural temporal variability in background gamma exposure rates.

3. Scan results for each vehicle are reviewed daily for consistency along scan track paths for all onboard detectors.

*Purpose:* Assess the degree of spatial agreement between onboard detectors along each vehicle's scan tracks and evaluate detector/system performance under actual scanning conditions. Obvious inconsistencies result in elimination of the questionable data from the project database and replacement of the subject detector with a factory-calibrated spare detector. Spare detectors immediately become subject to standard QC

assessment protocols to verify consistency with all other properly functioning scan detectors/systems.

Bullet number 2 above warrants additional discussion as it references "quality control limits" for evaluating instrument performance. Radioactive decay is a random process that follows a binomial probability distribution. Detector readings will thus naturally vary from one counting interval to the next. If the total number of measured counts exceeds about 20, both Poisson and normal distributions can be used to accurately describe radiation measurements (Martin & Lee, 2003). Both of these distributional approximations are valid for measurements of ambient gamma radiation with NaI scintillation detectors.

A Chi-Square dispersion test can be used to assess the performance of individual radiation measurement instruments against the Poisson distribution (Martin & Lee, 2003). This test is broadly applicable to many different types of instruments because in certain applications, the number of counts measured is less than 20 and only the Poisson distribution applies. For environmental gamma surveys using NaI detectors, properties of the normal distribution can be used as simple, effective way to assess individual detector performance.

With a correctly functioning NaI detector, a series of successive readings in a fixed location and measurement geometry should approximate a normal distribution, meaning that over 99% of the data should fall within  $\pm 3$  standard deviations from the mean of all measurements. Whether taking a single measurement, or the mean of several measurements, the normal distributional characteristics of the underlying count data are preserved (Martin & Lee, 2003). Taking the mean of several measurements, however, provides a better estimate of a true average count rate. The standard procedure for daily QC measurements from each NaI detector is to record the mean of 10-20 successive readings for assessment of instrument performance.

For this gamma survey application, we are equally concerned with the relative performance between instruments as multiple detectors are used. Even properly calibrated detectors will have slight differences in response characteristics between different instruments and this will add additional variability to survey data in the form of small relative biases between various detectors. Variability within and between detectors is additive. Analyses of various QC data sets, collected indoors under fixed counting geometries for different gamma survey projects, each indicate that combined variability from both sources will still approximate a normal distribution (Figure A). Properties of the normal distribution can thus be used to evaluate the performance of each detector relative to the total degree of measurement precision attained by the entire set of detectors used for the survey.

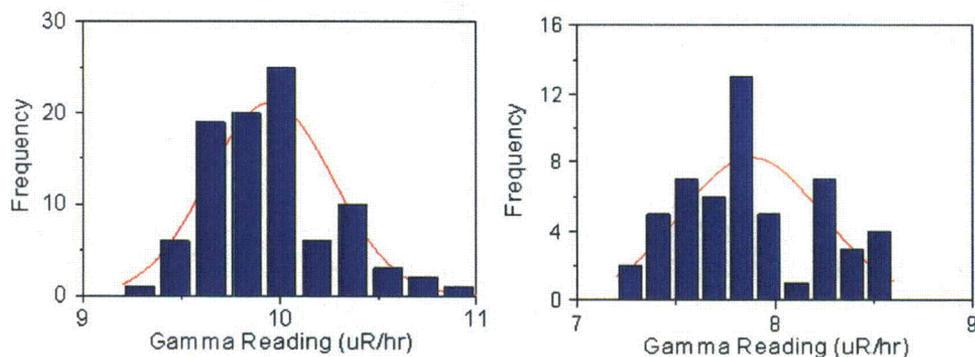


Figure A: Example frequency histograms for two series of QC measurements from different NaI detector sets used for two separate gamma survey projects. Each series was taken indoors under controlled measurement geometries. The red lines represent theoretical normal distributions.

Quality control data for each detector are plotted on QC charts that include control limit lines calculated for the particular set of detectors used on a given survey project. Field background and check source QC charts also show other lines that are useful for QC assessment, including the mean, as well as  $\pm 1$ , 2, and 3 standard deviations from the mean, as separately calculated from their respective QC data sets. This enables a quick visual assessment of individual QC data relative to the overall degree of measurement precision attained by the entire set of detectors used for the survey. For each individual detector, daily QC measurements plotted on QC charts should fall within  $\pm 3$  standard deviations from the mean of all QC measurements. If QC readings are outside of these control limits, further investigation is warranted. This is true for both background readings as well as check source readings.

Background QC readings can occasionally fall outside of respective control limits due to natural temporal variations in ambient gamma exposure rates. Temporal variability can result from changes in natural shielding factors for terrestrial or cosmic sources such as changes in soil moisture or barometric pressure, and from fluctuations in radon decay product concentrations in air. To help account for temporal sources of variability not related to actual detector performance, control limits are calculated on a moving average basis. In addition, when a control limit is exceeded, data from the affected detector are not automatically excluded from the survey data set unless control limits were exceeded on both background and check source QC charts. In cases where only one control limit is exceeded, the corresponding scan track data are carefully reviewed for spatial/quantitative consistency with tracks for other on-board detectors to make a final determination regarding data validity.

## Field Background QC Assessment for Lost Creek

An updated QC chart containing all field background QC data collected during the project is shown in Figure B. The indicated control limits ( $\pm 3$  standard deviations) are based only on data collected from 9/6/06 through 9/11/06 because scan system staging locations and related QC protocols were consistent during these dates. These control limits are conservative with respect to QC data collected outside of this period because the consistency of location helps limit data variability to that associated with the detectors themselves, effectively minimizing control limit width relative to the mean.

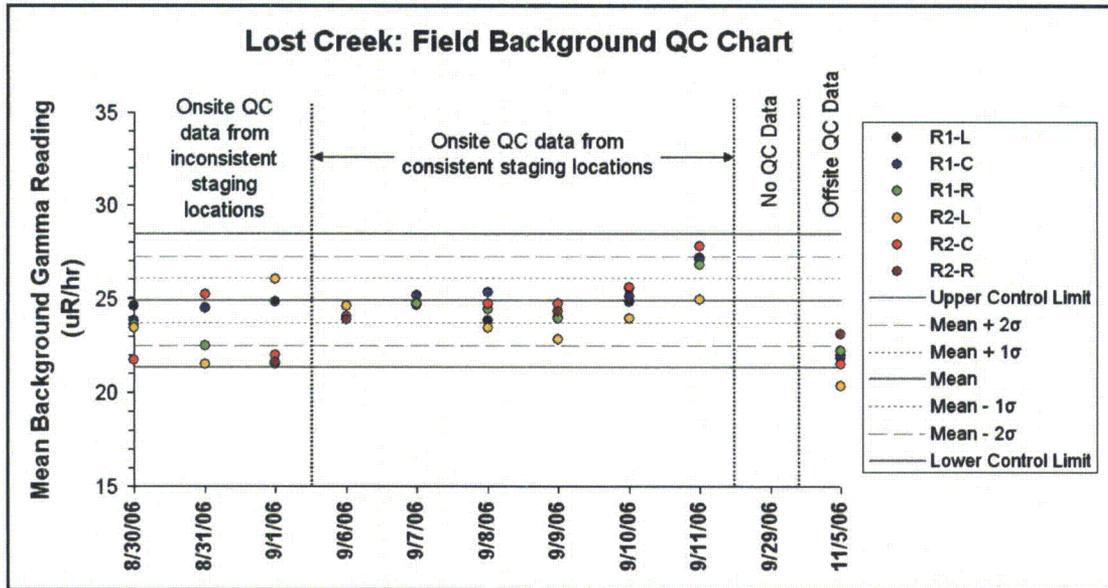


Figure B: Field background QC measurements for the dates of all activities related to the gamma survey at Lost Creek.

Although QC readings for the first three days of the survey are within conservatively calculated quality control limits, the variability of these data was higher because staging locations and related QC protocols were inconsistent during this initial period. These initial inconsistencies were related to: 1) a need to adapt the Rhino ATV systems' mounting infrastructure and suspension systems to handle unexpectedly rough micro-topography from soil mounds associated with the dense sagebrush vegetation; and 2) a determination that a 3-foot detector height was not practical for this type of survey given the frequency of deep ravine crossings, tall vegetation, and fence gate crossings.

These circumstances contributed to initial difficulties in determining a practical, consistent, and effective protocol for static QC measurements. As a result, background QC data through 9/1/06 are questionable and were not considered useful for assessment of data uncertainty, nor a valid reflection of actual instrument performance during this period, and were thus not included in the license application. We now recognize that a discussion explaining the excluded data could have facilitated complete review, had it been included in the original license application.

Background QC data from 9/6/06 through the final day of general site scanning on 9/11/06 were collected at a consistent staging location and are well within acceptable control limits. However, on 9/6/06 and 9/7/06, QC data were only collected for one of the two sets of Rhino ATV detectors. Rhino-1 measurements were missing on 9/6/06, and Rhino-2 measurements were missing on 9/7/06. It is believed that incomplete QC measurements on these two days were related to circumstances surrounding continued modifications or repairs to detector mounting systems. Background QC data from the period 9/8/06 through 9/11/06 were included in the application because these data provide a reliable measure of data uncertainty and instrument performance, and all six onboard detectors used for site scanning on these days were evaluated.

On 9/29/06, the day that gamma/soil Ra-226 correlation plot scanning and sampling was conducted, no static QC measurements were performed. These measurements were planned for the end of the day but insufficient time remained after performing all scheduled correlation activities. However, quantitative evidence of measurement precision within and between the detectors used on this date is inherent in the nature of the data collected. Mean scan data for each of the three individual detectors used at each correlation plot (Figure C) demonstrate excellent consistency of readings between detectors, at locations representing the most pertinent range of ambient gamma exposure rates with respect to the ultimate use of the data collected.

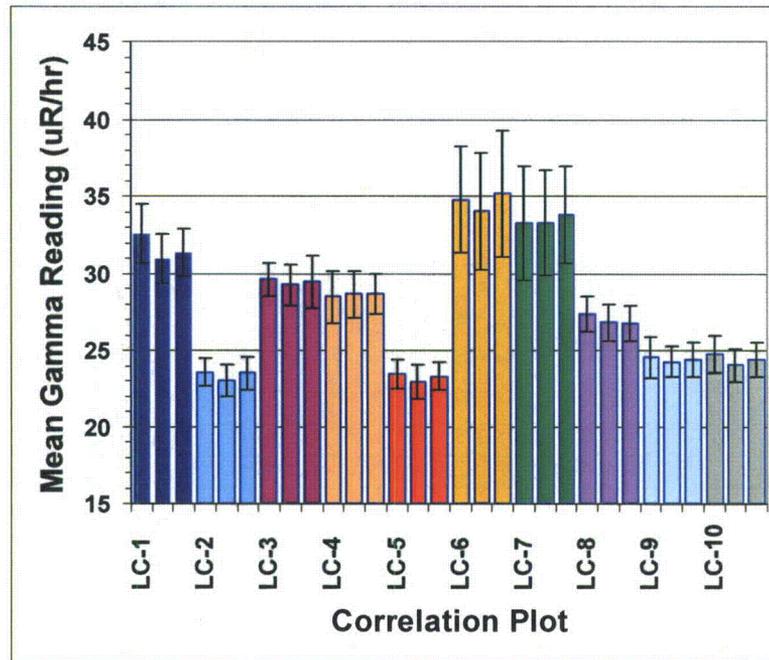


Figure C: Mean readings at each correlation plot location for each of the three individual detectors used for plot scanning. Error bars represent  $\pm 1$  standard deviation from the mean of approximately 45-50 readings for each detector across each plot.

The scale of the Y-axis shown in Figure C corresponds to the general range of virtually all gamma measurements at the Lost Creek site. As is readily apparent in Figure 2.9-3 of the license application, the vast majority of survey readings were between 20-35  $\mu\text{R/hr}$ . Because this latter range of survey readings is most representative of the entire site, it demonstrates the relevance of the range of the data shown in Figure C with respect to data QC issues. This is important to note because correlation data were used to convert gamma survey data into estimates of soil Ra-226 concentrations across the site. Error bars on mean readings from each detector ( $\pm 1$  standard deviation) suggest that on the day correlation measurements were performed, the detectors would have easily satisfied analogous control limit criteria across this range of values.

In addition to the above assessment of the data shown in Figure C, the coefficient of variation (CV) was calculated from the standard deviation of the three mean gamma scan results among the three detectors, divided by the average of the three

mean scan results, at each correlation plot (Table A). The average CV for all plots was 0.012, which demonstrates low variability between detectors, and a high degree of precision, across this key range of gamma levels.

Table A: Mean, standard deviation, and coefficient of variation for mean scan results among the 3 detectors at each correlation plot location.

<b>Correlation Plot</b>	<b>Average of the 3 mean scan results</b>	<b>Standard deviation of the 3 mean scan results</b>	<b>CV for mean scan results among the 3 Detectors</b>
LC-1	31.6	0.86	0.027
LC-2	23.4	0.30	0.013
LC-3	29.4	0.18	0.006
LC-4	28.6	0.10	0.004
LC-5	23.2	0.27	0.012
LC-6	34.7	0.60	0.017
LC-7	33.4	0.30	0.009
LC-8	27.0	0.33	0.012
LC-9	24.4	0.14	0.006
LC-10	24.4	0.35	0.014

Average CV = 0.012

Finally, background QC data for 9/11/06 and 11/5/06 also demonstrate consistency between detectors on dates that bracket 9/26/06 (see Figure B). QC measurements performed on 11/5/06 in association with high pressure ionization chamber (HPIC)/NaI cross-calibration activities were conducted in an offsite location, several miles from the original staging area. Although these data are not truly applicable to the control limits shown in Figure B, consistency of readings between detectors on this day is clear and there is no reason to suspect the validity of instrument performance during the cross-calibration measurements.

Based on the above follow up assessments of all available information relevant to field background QC data for this project, the evidence demonstrates that the detectors were performing within acceptable limits throughout the survey. The original estimates of data uncertainty as provided in the license application have not changed. Although there were several cases in which detectors exhibited suspect performance or actual malfunctions during the day's scanning (i.e. following morning QC measurements), associated scan track data were clearly identified as being spatially inconsistent with readings from other on-board detectors and the affected data files were eliminated from the project database.

### Check Source QC Assessment for Lost Creek

Regarding the collection of QC measurements using a Cs-137 check source (Figure D), additional discussion is required. On 9/9/06 it was discovered that small inconsistencies in the dimensions of protective foam padding placed around the detectors while mounted on the Rhino ATV support systems (intended to reduce vibration and potential impact damage to the detectors) may have introduced error into previous QC measurements [periods (1) and (2) as shown in Figure D] due to slight variations in distance between the check source and the detectors. As a result, none of the check source QC data collected prior to the removal of the foam padding from all detectors (on 9/9/06) were included in the license application. Other QC protocols, including documented calibration status of all instruments, background QC measurements, and daily review of the consistency of scan track data plotted with field mapping software, remained in effect during this period.

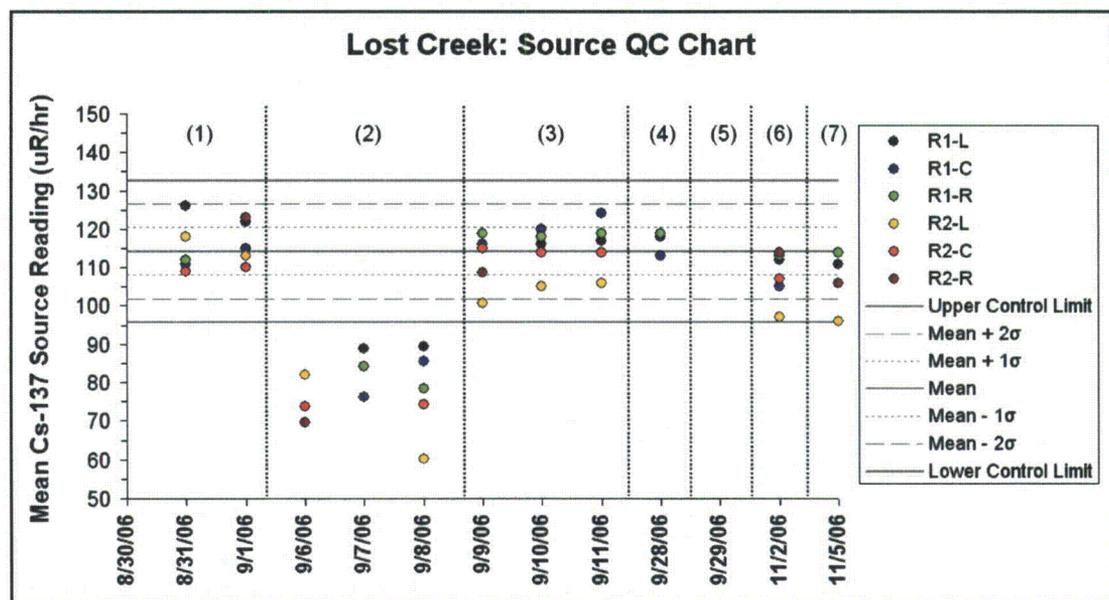


Figure D: Cesium-137 check source QC data for the dates of all activities related to the gamma survey at Lost Creek. Periods or dates of interest are numbered for ease of reference.

After the discovery of geometry problems associated with the protective foam padding, the padding was removed in favor of resilient nylon boom supports and the daily check source measurements became consistent. The control limits shown in Figure D are based only on data collected during period (3) and are thus the same as those provided in the application. Data review indicates that the reason for

the inconsistency in check source readings during time period (2) is related to the foam padding rather than to the detectors themselves. The other QC data and data reviews for this period confirm this conclusion.

After time period (1), the Rhinos were taken back to Fort Collins, CO and the detector mounting systems were modified or re-designed to better handle the rugged site conditions. However, the protective foam padding remained in place during time period (2). When the padding was removed on 9/9/06, the readings return to the normal range of check source QC values and remained this way throughout time period (3). It is likely that during mounting system redesign in Fort Collins, the foam pads were inadvertently shifted downwards, leaving more excess material extending below the detector than before. This could explain the reduction in count data as the distance from the source to the detector would have increased. When measuring a Cs-137 point source, small differences in counting geometry can make a large difference in readings and this element is critical to the applicability of such data.

The anomalous results shown for period (2) do not mean the detectors were functioning improperly during those particular days of scanning activities. The field background data for the same dates are very consistent and clearly indicate proper instrument function. More importantly, review of the scan track data for these dates showed spatial/quantitative consistency between onboard detectors, as well as consistency with other scan tracks along portions of site access roads that were repeatedly scanned throughout the survey. As described in the license application, re-scanning and daily review of consistency between on-board detectors are key components of an overall data QC program for this survey methodology. Such measures are more effective than static QC measurements in terms of evaluating instrument performance under actual scanning conditions. Static QC measurements are only part of an overall QC program to help quantify data uncertainty and assess instrument performance.

With respect to the lack of check source QC data on the date of gamma/Ra-226 correlation measurements [9/29/06, period (5) in Figure D], the correlation plot measurement data shown in Figure C clearly demonstrate the consistency of readings among detectors used on this date, across the pertinent range of gamma exposure rate values with respect to the correlation. Furthermore, check source data collected the previous day [9/28/06, period (4)] from a nearby proposed ISR site (the Lost Soldier project area) are also included in Figure D, along with check source data collected later at the Lost Soldier location [11/2/06, period (6)]. Although the Lost Soldier measurement locations were different from the staging location at Lost Creek, these data bracket the date of the missing check source QC

data for period (5) and indicate consistency in check source measurements between the detectors.

Finally, the day that HPIC/NaI cross-calibrations were performed [11/5/06, period (7) in Figure D], there had been a modification to the Rhino ATV mounting systems that allowed detectors to be easily removed from the vehicles and for QC measurements to be performed in a more controlled indoor environment at a hotel room in Rawlins, WY. Check source QC readings on this day were performed in the hotel room. Although this measurement location was different from the original survey staging area at Lost Creek, these results show consistency in check source measurements between the various detectors used on this day.

Based on the above follow up assessment of all available information relevant to check source QC data for this project, the evidence supports the conclusion that the detectors were performing properly throughout the survey, even at higher gamma radiation levels such as those found in several small areas at the site. It also reinforces the conclusion that the original estimates of data uncertainty provided in the application are based on reliable data.

### Summary

The above follow up assessments of data QC for this project demonstrate that throughout this survey, the detectors in use were performing properly and within acceptable limits at both lower (background) and higher (check source) levels of incident gamma radiation. Although there were several instances of missing or inconsistent QC data during the project, numerous other QA/QC measures and protocols were in place at all times, providing both quantitative evidence and qualitative assurance of continuous data reliability with respect to the results and analyses provided in the license application.

The estimates of data uncertainty provided in the license application were based on all available reliable data from field background and check source QC measurements. No changes to those estimates are warranted based on this follow up evaluation. Assessment of both data uncertainty and instrument performance is further strengthened by the data shown in Figure C and the accompanying analyses provided in this response.

Throughout this project, terrain, plant height and other environmental conditions required that constant attention be paid by the system operators to the operational status of each gamma detector instrument system. Only factory-calibrated detector systems were utilized during the work, and a combination of formal QA/QC procedures, combined with extensive operator experience in the application of a

variety of field quality control practices, has resulted in a data set that is of sufficient quality to meet the objectives established for the project.

#### References

Martin, J.E.; Lee, C. 2003. Principles of Radiological Health and Safety. John Wiley & Sons, Inc., Hoboken, New Jersey.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

Advances in radiological survey capabilities for large sites are discussed.

# Radiological Site Characterizations: Gamma Surveys, Gamma/ $^{226}\text{Ra}$ Correlations, and Related Spatial Analysis Techniques

Randy Whicker,\* Paul Cartier,† Jim Cain,‡ Ken Milmine,§ and Michael Griffin§

**Abstract:** Radiological surveys of a uranium mill site in Colorado and several proposed uranium recovery sites in Wyoming were conducted in 2006 and 2007. Advancements in Global Positioning System (GPS)-based gamma scanning systems combined with gamma/ $^{226}\text{Ra}$  correlations and Geographic Information Systems (GIS)-based spatial analysis techniques produced comprehensive and detailed characterizations of the spatial distributions of gamma exposure rates and  $^{226}\text{Ra}$  concentrations in surface soils across extensive study areas. Aside from limitations on gamma-based estimates of soil  $^{226}\text{Ra}$  related to soil heterogeneity or gamma shine effects, soil sampling results to date show good general agreement between estimated and measured values. Spatial characterization aspects of the survey approach are clearly more effective than conventional grid sampling methods, particularly for such large sites. Example project applications, data collection and analysis methods, challenges encountered, and resulting mapped estimates of various aspects of these radiological parameters are presented. *Health Phys.* 95(Supplement 5): S180–S189; 2008

**Key words:** operational topics; surveys;  $^{226}\text{Ra}$ ; soil

\* Tetra Tech Inc., 3801 Automation Way, Suite 100, Fort Collins, CO 80525; † Terrasat Inc., 1413 West 31st Avenue, Anchorage, AK 99501; ‡ Cotter Corporation, 0502 County Road 68, Canon City, CO 81212; § Uranium One, 907 North Poplar Street, Suite 260, Casper, WY 82601.



Randy Whicker holds an MS degree in the radiological health sciences with a specialization in radiochemistry and 13 years of radiological assessment work including a combination of applied research and environmental consulting projects. Currently, Randy is an Environmental Health Physicist with the Radiation Protection and Measurements Group at Tetra Tech, Inc. (Fort Collins, CO), providing expertise in project planning, experimental design, field sampling, analytical field and laboratory techniques, radiological measurements, and statistical analysis. His career efforts have supported entities both public and private in the areas of academic research, environmental assessments and remediation, radiation protection, and litigation cases.

WDEQ-LQD Permit to Mine Application  
Original Dec07; Rev4 Oct09

## INTRODUCTION

Remediation of uranium mining/milling sites or other sites where naturally occurring radioactive materials are present usually requires characterizations of gamma exposure rates and  $^{226}\text{Ra}$  concentrations in soil. Establishing pre-operational (background) and post-operational conditions for these radiological parameters is important for assessment of areas requiring remediation. Past approaches include taking discrete gamma measurements and soil samples across a systematic grid pattern. A grid sampling approach is indicated by the U.S. Nuclear Regulatory Commission (U.S. NRC) in Regulatory Guide 4.14 for uranium mills (U.S. NRC 1980), with 40 soil samples collected along a radial grid and 80 individual discrete gamma measurements collected along a similar pattern.

More recent radiological survey guidelines found in MARSSIM, the Multi-Agency Radiation Survey and Site Investigation Manual

(U.S. NRC 2000), also indicate grid-based designs for soil sampling and direct measurement of radionuclides in soil, but the number of soil samples needed varies according to statistical requirements and continuous gamma scanning (rather than discrete gamma measurements) is used to augment the soil sampling.

At some sites, natural background soil  $^{226}\text{Ra}$  concentrations are quite variable and may exceed levels commonly used as cleanup criteria. If such areas are not identified prior to site operations, they can be misidentified during decommissioning as contaminated areas in need of remediation. Improvement in radiological characterization methods for background and potentially impacted areas can help improve assessment of areas in need of remediation and verification of the effectiveness of that remediation.

Since the above mentioned agency guidance documents were published, advanced Global Positioning System (GPS)-based gamma scanning systems with automated electronic data collection have been developed and used in the field (Meyer et al. 2005a and b; Johnson et al. 2006). These systems can record up to 3,600 individual gamma readings and corresponding GPS measurements per hour, providing

a detailed record of gamma exposure rate conditions across scanned areas. Multiple scanning systems mounted on vehicles can quickly survey large areas and provide a high spatial density of measurements. This gamma survey technology represents a substantial increase in the amount of radiological information that can be efficiently collected relative to technology available when earlier agency guidance documents were published.

Gamma surveys of a uranium mill site in Colorado and several proposed in-situ recovery (ISR) uranium project areas in Wyoming were conducted in 2006 and 2007 using multiple GPS-based gamma scanning systems mounted on off highway vehicles (OHVs). In conjunction with these surveys, correlations between gamma readings and  $^{226}\text{Ra}$  concentrations in surface soils (0–15 cm) were established. These correlations enabled spatial and statistical information about soil  $^{226}\text{Ra}$  concentrations to be extracted from the gamma survey data to help meet various project characterization objectives. Geographical Information Systems (GIS) software was used for statistical conversion of large survey data sets, interpolation with kriging methods, field sampling support, special investigation/analysis needs, and for data presentation purposes.

The objectives of surveys at the uranium mill site were to develop various probability-based estimates of the areal extent of surface soils having  $^{226}\text{Ra}$  concentrations in excess of pre-specified cleanup criteria. At the proposed ISR uranium project areas, the objective was to establish pre-operational baseline gamma exposure rates and soil  $^{226}\text{Ra}$  concentrations for licensing/permitting applications. These project objectives each have implications with respect to eventual site decommissioning and termination of radioactive materials li-

censes. Continued improvement in methods to characterize gamma exposure rates and soil  $^{226}\text{Ra}$  concentrations at such sites can benefit all stakeholders.

## MATERIALS AND METHODS

### Gamma surveys

Various automated, GPS-based scanning system configurations have been developed for different site conditions. For projects discussed in this paper, two Yamaha Rhino (Yamaha Motor Corp., 6555 Katella Avenue, Cypress, CA 90630) OHV-mounted systems were used (Fig. 1). Given the large size of these sites, along with occasional rugged terrain, tall vegetation and other obstacles, Rhino OHVs were well suited for these projects. Backpack scanning systems were also used in a few small areas inaccessible to OHVs.

These OHVs are equipped with adjustable outriggers designed to mount three  $5 \times 5$  cm sodium iodide (NaI) scintillation gamma detectors (Ludlum Model 44-10; Ludlum Measurements, Inc., 501 Oak Street, Sweetwater, TX 79556) and paired GPS receivers. The gamma detectors are coupled to Ludlum Model 2350 rate meters housed in a container in the cargo bed. Simultaneous GPS and gamma exposure rate data are recorded every 1–2 s using an on-board PC with special data acquisition software (comReader; Tetra Tech, 3801 Automation Way, Fort Collins, CO 80525).

System configuration involves about 2.5 m spacing between detectors (measured perpendicular to direction of travel), with each detector positioned at either 1 or 1.4 m above the ground surface. For many of these projects a detector height of 1.4 m was the lowest practical height for the system under site conditions given the need for adequate clearance of frequently encountered obstacles such as tall vegetation, ravine crossings, and other features. As discussed later in this paper, experimental measurements were performed as needed to model approximate equivalent readings as measured by a high-pressure ionization chamber (HPIC) at 1 m above the ground surface (Fig. 1).

Based on qualitative field observations of detector response under similar measurement geometries, the scanning track width representing each vehicle's lateral range of general scanning sensitivity to elevated planar (non-point) source areas is estimated to be about 8 m across, perpendicular to the direction of travel. Vehicle scanning speeds range between 3 and 16  $\text{km h}^{-1}$  depending on the roughness of the terrain, with a typical average speed of 6–10  $\text{km h}^{-1}$ .

Data are downloaded daily into a project database and results are viewed each night with special field mapping software (Gamma Data Map Viewer; Tetra Tech, 3801 Automation Way, Fort Collins, CO



Figure 1. Three-detector OHV-mounted scanning systems (left) and static HPIC cross-calibration measurements (right).

80525). This allows scan coverage assessment and planning on a daily basis and helps to identify any problems with systems performance.

For routine scanning across large areas, a target distance of 100 m between vehicles is estimated to achieve about 14% ground scanning coverage. For areas of particular interest, higher-density target coverages can range from 25–100% but typically involve a vehicle spacing of 20–30 m (35–45% coverage). Practical considerations such as safety, terrain, and natural obstructions often dictate actual distances maintained between survey vehicles.

#### *HPIC/NaI cross-calibration*

Gamma exposure rates measured by NaI detectors are only relative measurements as response characteristics of NaI detectors are energy dependent. True gamma exposure rates are best measured with a less energy dependent system such as the HPIC. Depending on the radiological characteristics of a given site, NaI detectors can have measurement values significantly different from corresponding HPIC measurement values. NaI detectors are typically calibrated against a  $^{137}\text{Cs}$  source. At photon emission energies near that of  $^{137}\text{Cs}$  (662 keV), relative detector response is close to 100% (Ludlum 2006). Under field scanning conditions at uranium recovery sites, a preponderance of lower photon energies can be present due to primary and secondary scattered photons from naturally occurring terrestrial radionuclides. At these lower photon energies, response of NaI detectors relative to  $^{137}\text{Cs}$  is significantly greater than 100% and NaI detectors will overestimate true exposure rates. In some locations, terrestrial concentrations of gamma emitting radionuclides can be very low and HPIC/NaI cross-

mic sources can dominate detector response resulting in underestimates of true exposure rates.

NaI systems are useful because they can quickly and effectively demonstrate relative differences between pre- and post-remediation gamma exposure rate conditions. Unless the same equipment and scanning geometry are used for both surveys, however, it is necessary to normalize the data to a common basis of comparison. This is the purpose of performing HPIC/NaI cross-calibration measurements. Cross-calibration ensures that the results of future gamma scans, which may use different detectors, detector types, or measurement geometries, can be meaningfully compared against the results of pre-operational gamma surveys. HPIC/NaI cross-calibrations are also necessary in cases where external dose assessments are part of survey objectives.

To perform HPIC/NaI cross-calibrations, static measurements are taken at various discrete locations covering a range of exposure rates representative of the site. At each measurement location, 10–20 individual readings from the HPIC and each OHV-mounted NaI detector are separately collected and averaged. A picture of this process is shown in Fig. 1 (right). The resulting paired HPIC/NaI data are analyzed by linear regression to enable conversion of NaI-based gamma survey data to approximate 1 m HPIC equivalents.

#### *Gamma/ $^{226}\text{Ra}$ correlations*

Depending on the nature and strength of the relationship between gamma exposure rates and soil  $^{226}\text{Ra}$  concentrations at a given site, statistical correlations can be used to estimate approximate soil  $^{226}\text{Ra}$  concentrations across the entire site based on gamma survey results.

Following methods described in Johnson et al. (2006), correlation soil sampling is conducted as

composite sampling over  $10 \times 10$  m plots. Correlation plot locations are selected to be representative of the range of exposure rates found at the site, with additional efforts made to select plots having relatively homogeneous gamma readings in the general area. Gamma survey maps are used to help determine appropriate locations. Within each plot, 10 soil sub-samples are collected to a depth of 15 cm then composited into a single sample to give an average  $^{226}\text{Ra}$  concentration over each  $100 \text{ m}^2$  plot. Samples are sent to a qualified laboratory for  $^{226}\text{Ra}$  analysis.

Each  $100 \text{ m}^2$  soil sampling plot is also scanned using the same OHV-mounted systems and detector configuration used to scan the entire study area. The average NaI gamma reading over each plot is paired with the corresponding average  $^{226}\text{Ra}$  concentration for statistical regression analysis.

## **RESULTS AND DISCUSSION**

### *General observations*

Radiological survey study areas at individual sites ranged from 75–4,358 hectares (185–10,770 acres). Scanning rates ranged from about 12 to 135 acres  $\text{h}^{-1}$  depending on terrain and ground scanning coverage attained. In general, instrument quality control (QC) charts and field QC charts for scan systems demonstrated acceptable performance. In cases of unacceptable system performance, affected data were eliminated from the project database and the system was not used again until the issue was resolved.

Although some cases of unexpected and problematic results were observed during the course of these projects, supplementary field investigations and/or additional data analyses revealed possible explanations and provided a basis for appropriate ways to address

related issues. Final  $^{226}\text{Ra}$  estimates based on gamma survey data have thus far generally agreed well with confirmatory soil sampling results.

*Uranium mill site surveys*

Survey activities at the uranium mill site included two separate projects. The first involved a 75-hectare portion of the site scheduled for remedial action. The survey objective was to estimate the extent of areas with greater than 80% statistical probability of having surface soil  $^{226}\text{Ra}$  concentrations in excess of the respective cleanup criterion of  $6 \text{ pCi g}^{-1}$  ( $222 \text{ Bq kg}^{-1}$ ). Gamma scan results are shown in Fig. 2 (top).

A GIS-based spatial analysis program was used to krig the gamma survey data in order to provide continuous estimates of gamma exposure rate readings across the study area and better illustrate spatial distributions (Fig. 2, bottom). Kriging is a geostatistical interpolation procedure commonly used in various earth sciences.

Correlation plot measurements across the study area initially demonstrated a statistically weak linear relationship between gamma reading and  $^{226}\text{Ra}$  soil concentration. Horizontal and vertical heterogeneity in soil  $^{226}\text{Ra}$  concentrations and/or scattered photons reaching the gamma detectors from underlying subsurface sources or areas adjacent to the correlation plots (i.e., gamma "shine") may have been contributing factors to this result as the outliers all had unusually low concentration results relative to gamma readings.

To investigate potential reasons for weak initial correlation results, correlation plots were re-scanned using a shielded (collimated) gamma detector. Shielded measurements improved the correlation and revealed evidence that 4 of the 14 correlation plots may have been significantly af-

ected by gamma shine from adjacent areas and/or subsurface sources. When data from these potentially "shine impacted" plots were removed, the statistical strength of the unshielded correlation improved (Fig. 3) with an R-squared value nearly as high as the corresponding shielded correlation.

One-tailed upper and lower 80% prediction limits for the correlation were separately calcu-

lated and plotted along with the regression line (Fig. 3). Gamma values corresponding to the cleanup criterion for soil  $^{226}\text{Ra}$  concentration ( $6 \text{ pCi g}^{-1}$ ) at these prediction limits were used to create a soil  $^{226}\text{Ra}$  probability map as shown in Fig. 4. This spatial information is being used to help with remedial action planning. The small circular omitted portion of the study area represents a lined pond that could not be surveyed.

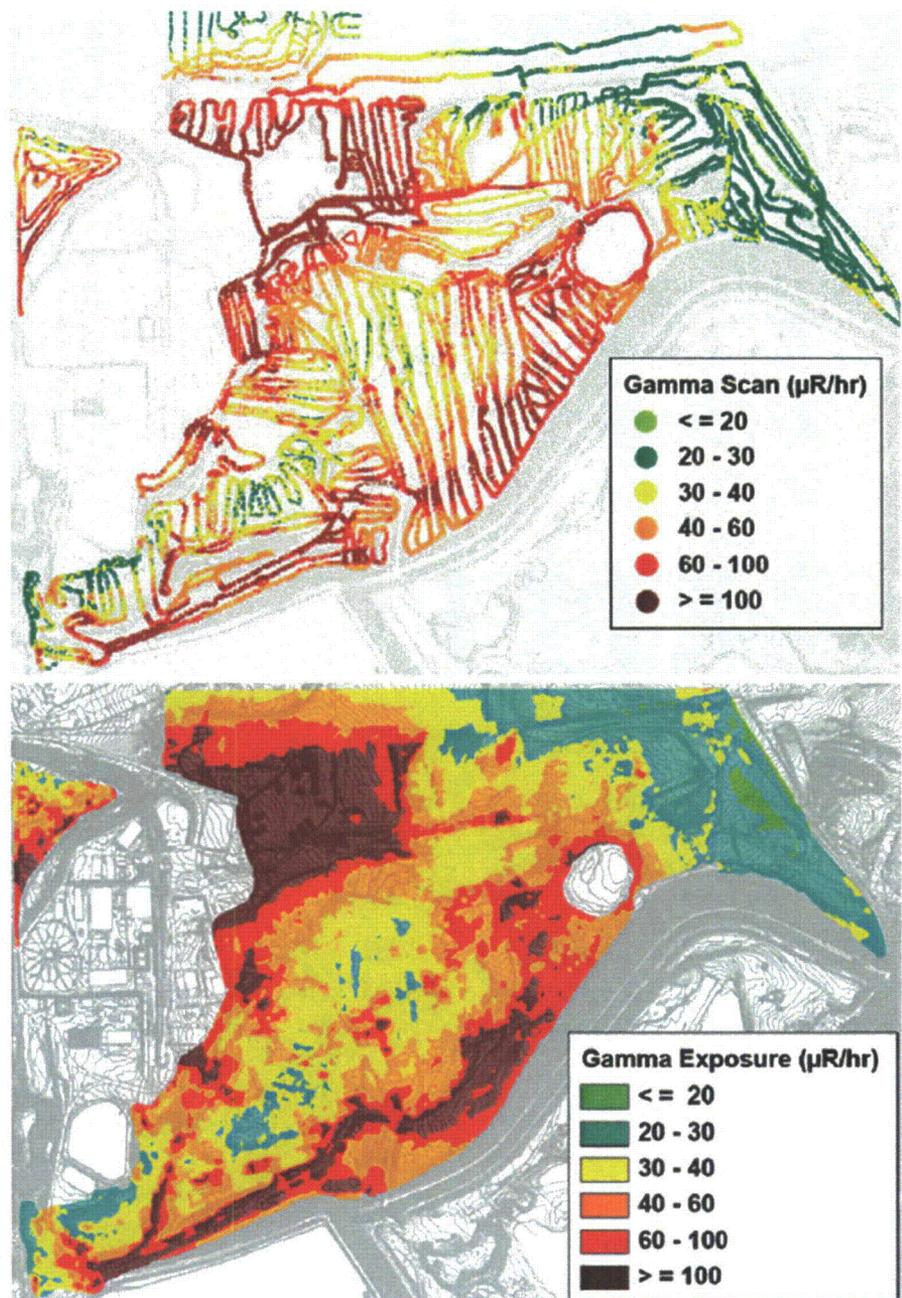


Figure 2. Gamma scan (top) and kriged mapping results (bottom) for the remedial action study area at the uranium mill site.

The second project at the uranium mill site involved a much larger portion of the site beyond the smaller remedial action study area. The objective for this project was also to estimate the areal extent of soil  $^{226}\text{Ra}$  concentrations exceeding the  $6 \text{ pCi g}^{-1}$  cleanup criterion, but in this case the information was used to determine a conservative estimate of the volume of surface soils that could potentially require remediation upon site decommissioning. This volume estimate will be used to update remedial surety bonding and thus a more conservative 95% statistical probability for the estimate was needed.

As with the remedial action survey project, initial results of the gamma/ $^{226}\text{Ra}$  correlation developed for the volume study area were relatively weak. Again, however, comparisons between shielded and unshielded gamma data for correlation plots revealed a few locations where gamma shine may have contributed to this result. When those data were omitted from the analysis the statistical strength of the regression improved (Fig. 5).

The UPL line in Fig. 5 indicates that for this study area a gamma reading of about  $23 \mu\text{R h}^{-1}$  has a 95% statistical probability of compliance with the  $6 \text{ pCi g}^{-1}$  criterion for soil  $^{226}\text{Ra}$ . An approximate boundary corresponding to  $23 \mu\text{R h}^{-1}$  was drawn on the kriged gamma survey map and confirmatory soil samples were collected just outside this line to verify the reliability of the estimate. Kriged survey results with overlays of the 95% UPL line and confirmatory sampling results are shown in Fig. 6. Areas outside the 95% UPL line above  $23 \mu\text{R h}^{-1}$  were not included in the volume estimate because they are included in remediation plans. Note that the actual regression line in Fig. 5 (rather than the UPL line) predicts that on average, areas with gamma readings of 23

$\mu\text{R h}^{-1}$  will have corresponding  $^{226}\text{Ra}$  soil concentrations of about  $3.2 \text{ pCi g}^{-1}$ . This prediction agrees well with the confirmatory sampling results (Fig. 6).

Limitations on spatial and probabilistic estimates regarding soil  $^{226}\text{Ra}$  concentrations for the uranium mill site study areas include uncertainty due to a limited number of correlation plots, analytical uncertainty in the measured correlation plot data, and significant potential for estimation error in areas where considerable gamma shine effects or soil  $^{226}\text{Ra}$  heterogeneity exist. For areas significantly influenced by these latter conditions, characterization using conventional grid soil sampling approaches would likely prove more effective provided sufficient sampling density were used. The data suggest, however, that such areas represent a small fraction of overall study areas and that the correlation method was an effective overall approach.

An important lesson learned from all project examples presented in this paper is that correlation plot selection criteria are very important. Careful evalua-

tion and planning must be exercised when selecting correlation plot locations to ensure that the data are representative of the range of gamma values found at the site, and that gamma readings in the general vicinity of each plot are as homogeneous as possible. This can be difficult to achieve for locations selected to represent higher readings as these areas tend to be small with a higher degree of small scale spatial variability. It is also desirable to try and avoid choosing locations with nearby regions of significantly higher readings to help avoid shine issues. A related problem that is more difficult to address is that it is seldom possible to predict areas that may be affected by shine from shallowly buried subsurface materials.

#### Proposed ISR uranium project area surveys

Because survey objectives at the various proposed ISR uranium project areas in Wyoming were focused on pre-operational baseline characterizations, NaI-based scan data were normalized to 1 m HPIC readings to approximate true gamma exposure rates

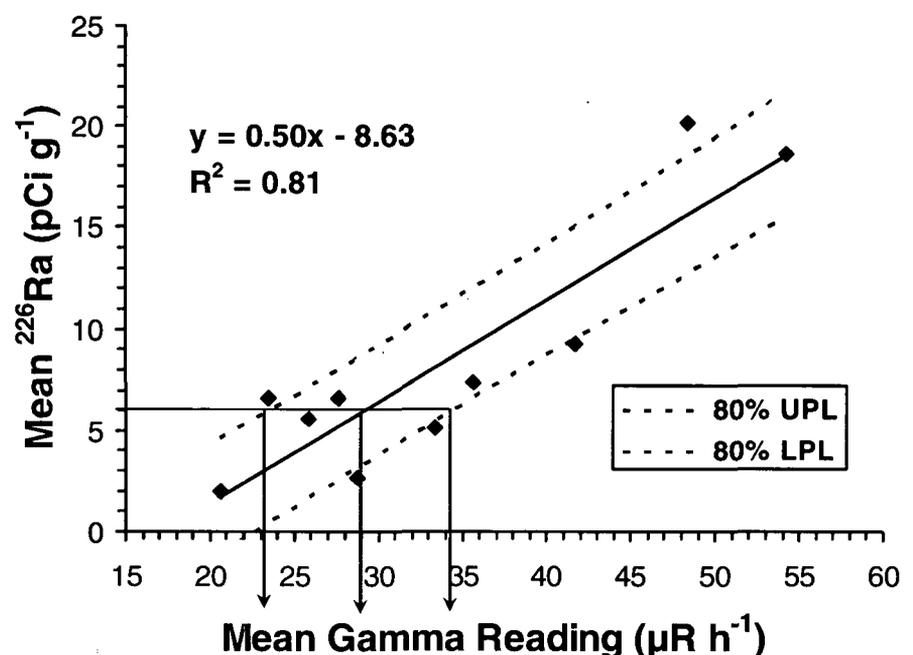


Figure 3. Correlation results for the remedial action study area at the uranium mill site.

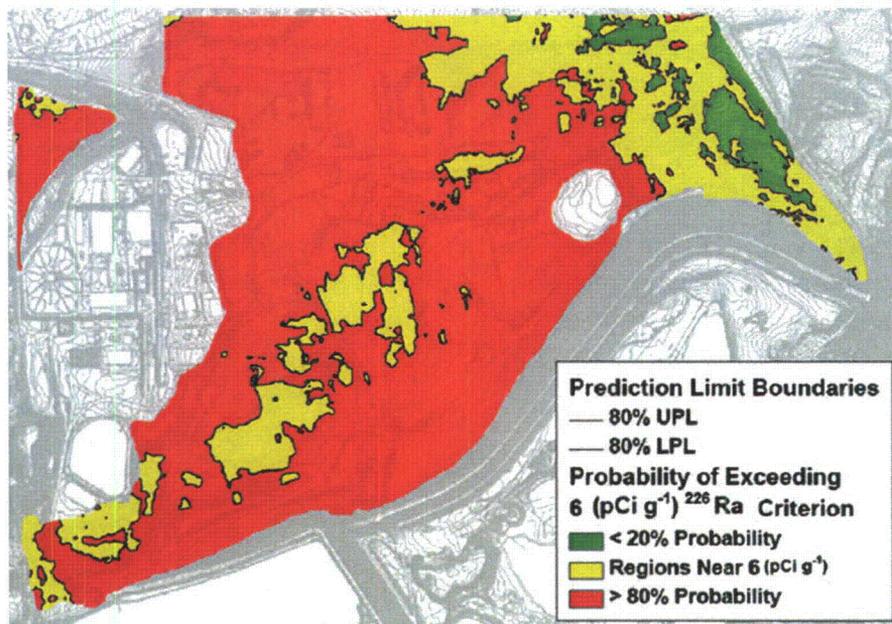


Figure 4. Soil <sup>226</sup>Ra probability map for the remedial action study area at the uranium mill site.

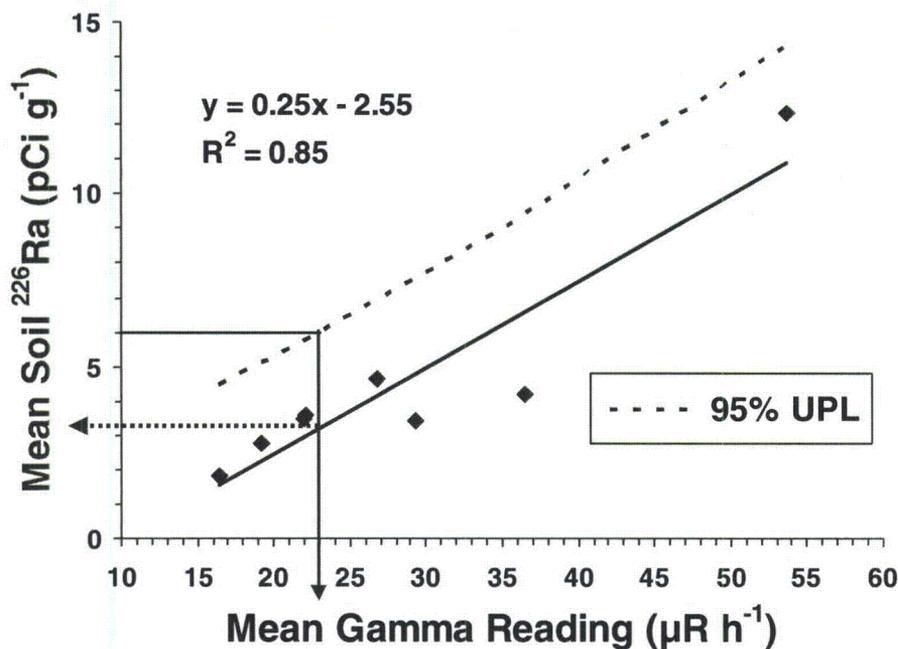


Figure 5. Gamma/<sup>226</sup>Ra correlation results for the volume study area.

and provide a common basis of comparison for post-operational surveys. Typically, HPIC/NaI cross-calibration curves demonstrated highly significant linear relationships (Fig. 7, left). As illustrated at right in Fig. 7, the numerical difference between NaI readings and HPIC readings was proportional to the magnitude of exposure rate being measured (HPIC/NaI Project Mod-

eled based on the regression equation shown at left in Fig. 7, and using a range of hypothetical NaI readings as the independent variable).

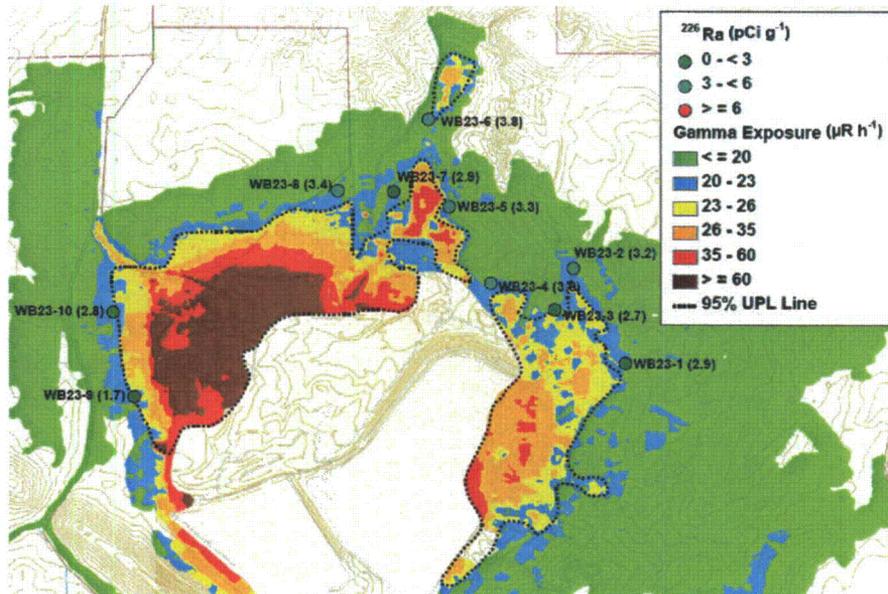
An example map of kriged HPIC equivalent gamma exposure rate survey data for a proposed ISR site in Wyoming is shown in Fig. 8. The use of kriged survey data overlays on aerial photos can be an effective way of

illustrating distributional patterns of gamma exposure rates or soil <sup>226</sup>Ra concentrations in relation to certain geomorphic features. Note that the lowest gamma exposure rates at the site shown in Fig. 8 tend to coincide with drainage channel basins. Areas of higher gamma readings tend to coincide with areas of higher topographical relief such as ridges or hill tops.

For these proposed ISR sites, cases of apparent spatial relationships between geomorphic features and baseline gamma exposure rates are likely related to erosional and depositional processes that may expose elevated deposits of terrestrial radionuclide concentrations at the surface, bury such deposits, or gradually transport elevated materials off site. Sometimes, transitions between areas of consistently higher and lower gamma exposure rates are relatively abrupt. Such transitions can occasionally be associated with visible features like changes in slope, rock type, and soil color or texture (Fig. 9). In other cases, there are no obvious features associated with areas of higher or lower readings or with transition zones.

With respect to gamma-based estimates of baseline <sup>226</sup>Ra concentrations in surface soils at proposed ISR sites, conservative estimation using statistical prediction limits on correlations was not relevant. Instead, actual regression equations from correlation plot data were used to provide the average or "best" statistical estimates of soil <sup>226</sup>Ra concentrations based on the gamma survey data.

Relative to the Colorado mill site surveys, correlation plot measurements for proposed ISR sites in Wyoming tended to demonstrate stronger statistical relationships between gamma readings and soil <sup>226</sup>Ra soil concentrations. In general, fewer cases of unusually low <sup>226</sup>Ra concentrations in areas of high gamma readings were observed.



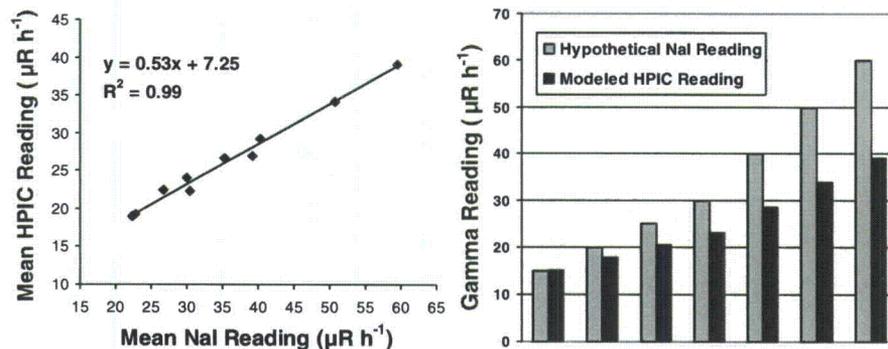
**Figure 6.** Gamma survey results for the volume study area showing approximate regions with gamma readings above and below 23  $\mu\text{R h}^{-1}$ , the gamma value with a 95% statistical probability of compliance with the  $^{226}\text{Ra}$  cleanup criterion. Confirmatory soil sampling locations and annotated  $^{226}\text{Ra}$  results ( $\text{pCi g}^{-1}$ , in parentheses) are also shown.

trations (e.g.,  $1 \text{ pCi g}^{-1}$ ) tended to exhibit nonlinear correlation characteristics, with relatively little change in  $^{226}\text{Ra}$  concentration over the lower range of measured gamma values until a kind of threshold is reached and  $^{226}\text{Ra}$  begins to increase with increasing gamma readings.

Reasons for this threshold effect are likely partially related to those mentioned in the earlier discussion of differences between NaI detector and HPIC readings. At a given site, cosmic sources are relatively constant and variations in NaI readings are due to variations in terrestrial radionuclide concentrations. When terrestrial  $^{226}\text{Ra}$  sources begin to exceed about  $1 \text{ pCi g}^{-1}$  at these sites, a greater percentage of lower energy photons interact with the NaI detectors and relative response appears to cross a threshold between underprediction and overprediction of true exposure rates. As gamma readings increase above this threshold, a more linear correlative relationship between  $^{226}\text{Ra}$  and gamma readings becomes apparent.

Despite the potential explanations above for an apparent threshold effect, both linear and nonlinear models were used to convert gamma survey data to estimates of  $^{226}\text{Ra}$  concentrations in surface soils. Both data sets were kriged and mapped to help assess which model at each site is best supported by subsequent radial grid soil sampling results (U.S. NRC Regulatory Guide 4.14 soil sampling protocols are also being implemented as part of baseline studies at these sites). This type of confirmation sampling can also help to assess the representativeness of correlation plot sampling locations.

Spatial differences in the distributions of estimated soil  $^{226}\text{Ra}$  concentrations based on linear and nonlinear models for a proposed ISR site are shown in Fig. 11. In terms of remedial issues, the



**Figure 7.** Example HPIC/NaI cross-calibration curve (left) and corresponding modeled differences between NaI and HPIC readings (right) for a proposed ISR uranium site in Wyoming.

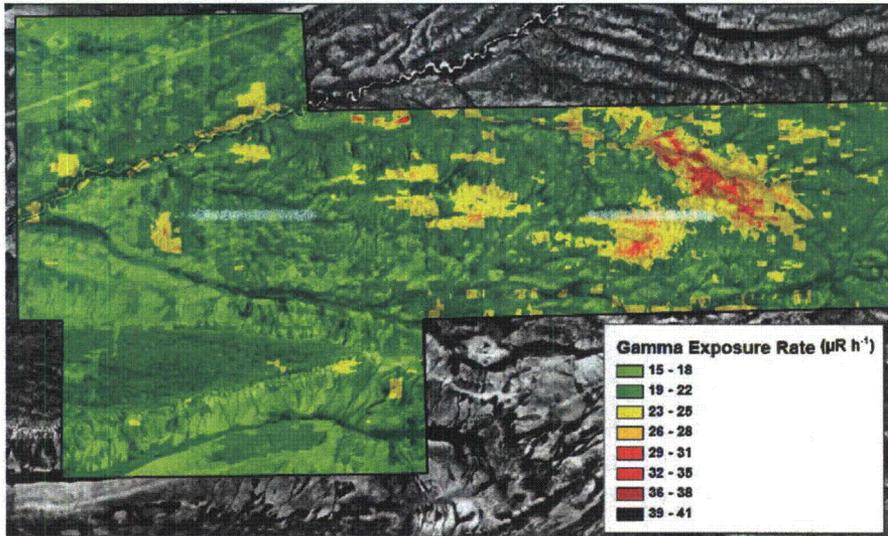
Again, such cases are likely related to gamma shine from adjacent areas and/or subsurface sources and those data were not used for the correlations.

Another notable feature of correlation results for the Wyoming ISR sites was that the data sometimes demonstrated nonlinear characteristics (Fig. 10). This raised the possibility that use of nonlinear “best fit” models in such cases could reduce potential prediction error for soil  $^{226}\text{Ra}$  estimates based on gamma survey data.

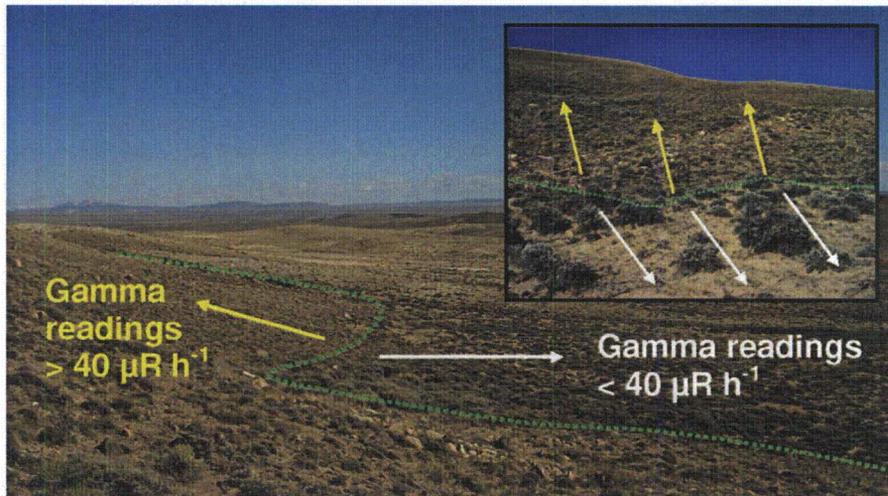
Reasons for apparent nonlinearity observed in correlation data from some sites appear to be

related to a kind of threshold effect in the relationship between detector response and the ratio of terrestrial to cosmic sources of gamma radiation. Cosmic sources can dominate detector response until terrestrial sources become concentrated enough to have significant correlative impact on readings. This idea is consistent with a comparison of observed correlation data between various sites.

Sites with higher minimum measured soil  $^{226}\text{Ra}$  concentrations (e.g.,  $4\text{--}5 \text{ pCi g}^{-1}$ ) tended to exhibit linear correlation characteristics. Sites with lower minimum measured soil  $^{226}\text{Ra}$  concen-



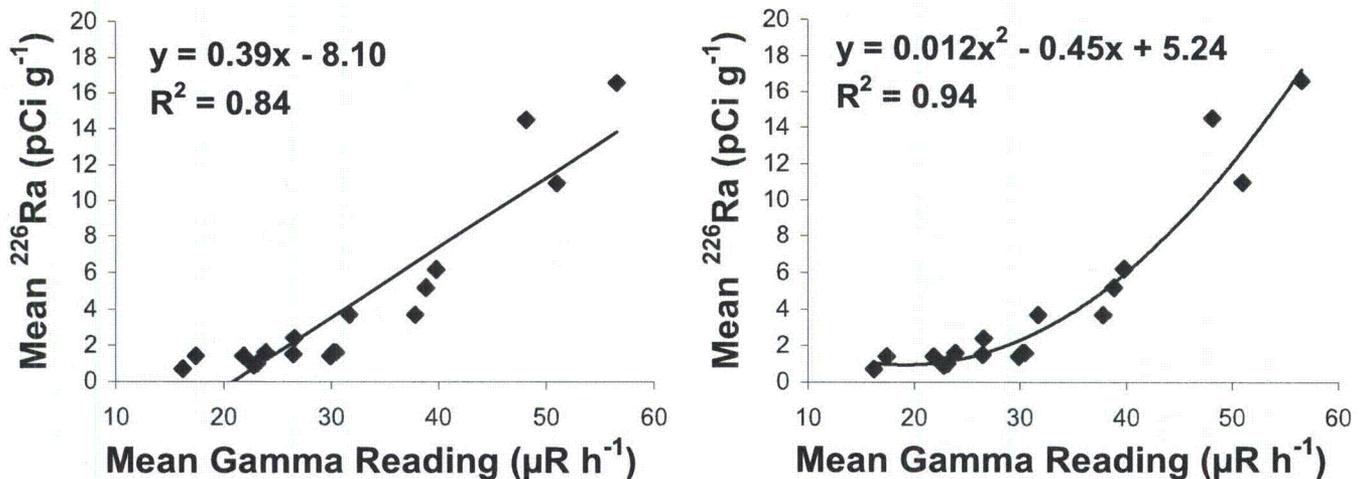
**Figure 8.** Kriged 1 m HPIC equivalent gamma survey map of a proposed 1,618 hectare (4,000 acre) ISR uranium project area in Wyoming.



**Figure 9.** Visible, geomorphic boundary delineating abrupt transition in gamma exposure rates.

implications of which predictive model is used are quite apparent at this particular site. Regardless of what model is ultimately used, it is unlikely that areas with elevated radiological baseline conditions would be adequately characterized based solely on grid sampling as indicated by currently applicable regulatory guidelines. These elevated areas are generally downwind of the proposed plant location and often fall just outside of respective radial grid sampling locations as indicated in Regulatory Guide 4.14. This observation highlights a key advantage of using GPS-based, high-density gamma scanning and correlation techniques to characterize entire sites.

Available data to date have enabled one proposed ISR site to be evaluated with respect to which type of predictive model is most strongly supported by confirmatory soil sampling results. Overall, a nonlinear model predicted soil <sup>226</sup>Ra concentrations at this site more accurately than a linear model. Nonlinear modeling estimates and actual soil sampling results are shown in Fig. 12. Optimal spatial detail at individual sampling locations is not resolved in this figure but locally enlarged views of the data indicate that



**Figure 10.** Comparison of linear (left) and nonlinear (right) models fitted to combined gamma/<sup>226</sup>Ra correlation plot data from two nearby ISR sites in Wyoming.

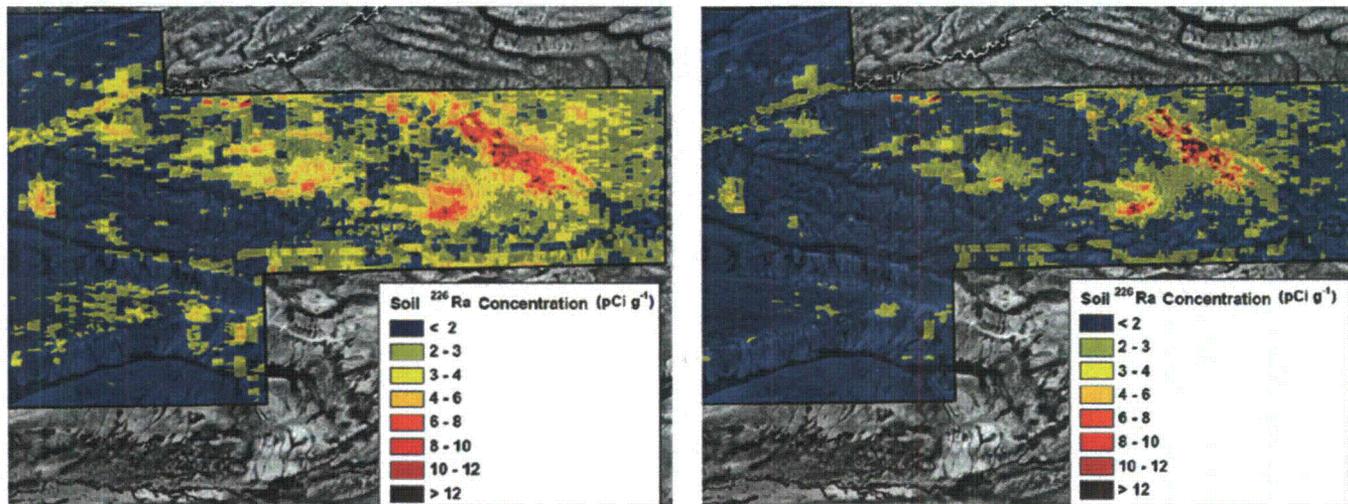


Figure 11. Comparison of continuously estimated soil <sup>226</sup>Ra concentrations based on linear (left) and nonlinear (right) models fitted to gamma/<sup>226</sup>Ra correlation plot data for a proposed ISR site in Wyoming.

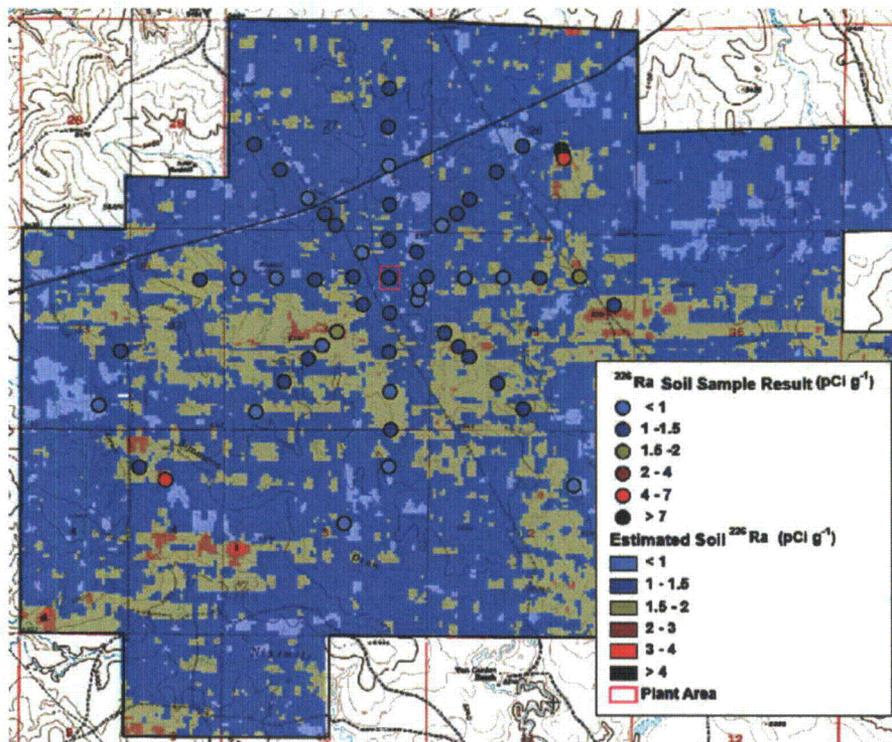


Figure 12. Comparison of continuous estimates of soil <sup>226</sup>Ra concentrations predicted with a nonlinear model vs. actual soil sampling results at a proposed ISR site in Wyoming.

differences between modeled and measured values are generally less than  $\pm 1 \text{ pCi g}^{-1}$ , not greatly different from analytical uncertainties reported by the laboratory (which ranged up to  $\pm 0.6 \text{ pCi g}^{-1}$ ). As mentioned, however, not all sites demonstrate nonlinear correlation characteristics and correlation data need to be adequately represented. Project have

the best chance of choosing the appropriate model.

Finally, caution must be exercised with respect to extrapolating predictive models beyond the range of measured correlation data. In these studies, prediction data outside this range were sometimes artificially truncated to avoid such extrapolation, depending on the nature of the cor-

relation and respective potential to significantly impact kriging results. In all cases, the validity of gamma-based estimates of <sup>226</sup>Ra are limited to the range of measured correlation data and beyond that range only general qualitative statements such as “less than” or “greater than” are justified. Furthermore, limitations mentioned earlier for uranium mill site estimates also apply to estimates developed for the proposed ISR uranium project area studies.

### CONCLUSION

Although gamma/<sup>226</sup>Ra correlation techniques are not new, the GPS-based scanning systems used for these projects involve more recent technology that can quickly and efficiently collect large amounts of information about the spatial distribution of terrestrial sources of gamma radiation across extensive areas. Mapped data presentations and confirmatory soil sampling results suggest that high-density gamma scanning combined with correlation techniques was an effective overall survey approach for these projects and represents general improvement in characterization capabilities for large sites.

Limitations on correlation-based  $^{226}\text{Ra}$  estimates include potential prediction error in areas with significant heterogeneity in soil  $^{226}\text{Ra}$  concentrations, gamma shine effects, or areas beyond the range of measured correlation data. Poor correlation results can result from insufficient sample size, inadequate representativeness of correlation plot locations, soil  $^{226}\text{Ra}$  heterogeneity, or gamma shine. Nonlinearity in correlation characteristics can result at sites where pervasively low  $^{226}\text{Ra}$  concentrations are reflected in the measured correlation data, possibly due to a threshold effect between detector response and the ratio of terrestrial to cosmic gamma sources.

Integrating a full range of GIS spatial analysis capabilities into this radiological survey approach

allows various and sometimes subtle types of information contained in the survey data to be successfully identified, interpreted, and assessed with respect to project objectives. Kriging results displayed on topographical contour maps or aerial photos can provide detailed and highly informative characterizations of various radiological parameters across entire sites. This information can have important implications with respect to site decommissioning and license termination.

## REFERENCES

- Johnson JA, Meyer HR, Vidyasagar M. Characterization of surface soils at a former uranium mill. *Health Phys* 90(Suppl 1):S29-S32; 2006.
- Ludlum Measurements, Inc. Energy response curve for Ludlum Model 44-10 NaI detector [online]. 2006. Available at: [http://www.ludlums.com/RespCurvHtm/RC\\_M44-10.htm](http://www.ludlums.com/RespCurvHtm/RC_M44-10.htm). Accessed 30 August 2008.
- Meyer R, Shields M, Green S. A GPS-based system for preliminary or remedial action gamma scanning. In: Proceedings of the American Nuclear Society Topical Meeting on Decommissioning, Decontamination, & Reutilization, Denver, Colorado, 7-11 August 2005. La Grange Park, IL; ANS; 2005a: 131-134.
- Meyer R, Shields M, Green S, Johnson J. A GPS-based system for radium/uranium contamination gamma scanning. In: Broder J, Merkel AH, eds. Uranium mining and hydrogeology IV. Uranium in the Environment, conference proceedings, 11-16 September 2005. Freiberg, Germany: Technische Universität Bergakademie Freiberg (TU BAF); 2005b: 751-756.
- U.S. Nuclear Regulatory Commission. Radiological effluent and environmental monitoring at uranium mills, Revision 1. Washington, DC: Nuclear Regulatory Commission Office of Standards Development; Regulatory Guide 4.14; 1980.
- U.S. Nuclear Regulatory Commission. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), Revision 1. Washington, DC: U.S. NRC; NUREG 1575; 2000.

**Attachment 2.9-6 Technical Memorandum: 2008 Vegetation Sampling**

## TECHNICAL MEMORANDUM

**TO:** Ur-Energy Inc.

**FROM:** AATA International, Inc.

**DATE:** January 16, 2009

**SUBJECT:** Vegetation Sampling for Radionuclides

Vegetation samples for radionuclide analyses were collected from three areas downwind of the Plant in the Lost Creek License Area in the summer of 2008. The samples were analyzed for natural uranium, lead-210 (Pb-210), polonium 210 (Po-210), radium-226 (Ra-226), and thorium-230 (Th-230).

**Figure Veg-1** shows the three areas from which the vegetation samples were collected. The sampling areas radiate from the Plant in the direction of the prevailing wind. A transect was established along the northern (or northeastern) boundary of each area during the first sampling event, and grazing fodder within 5 meters of those transects was sampled. During subsequent sampling events, the transects in each area were relocated 10 meters to the south or southwest of the previous transect in that area, and parallel to the first transect (**Figure Veg-2**).

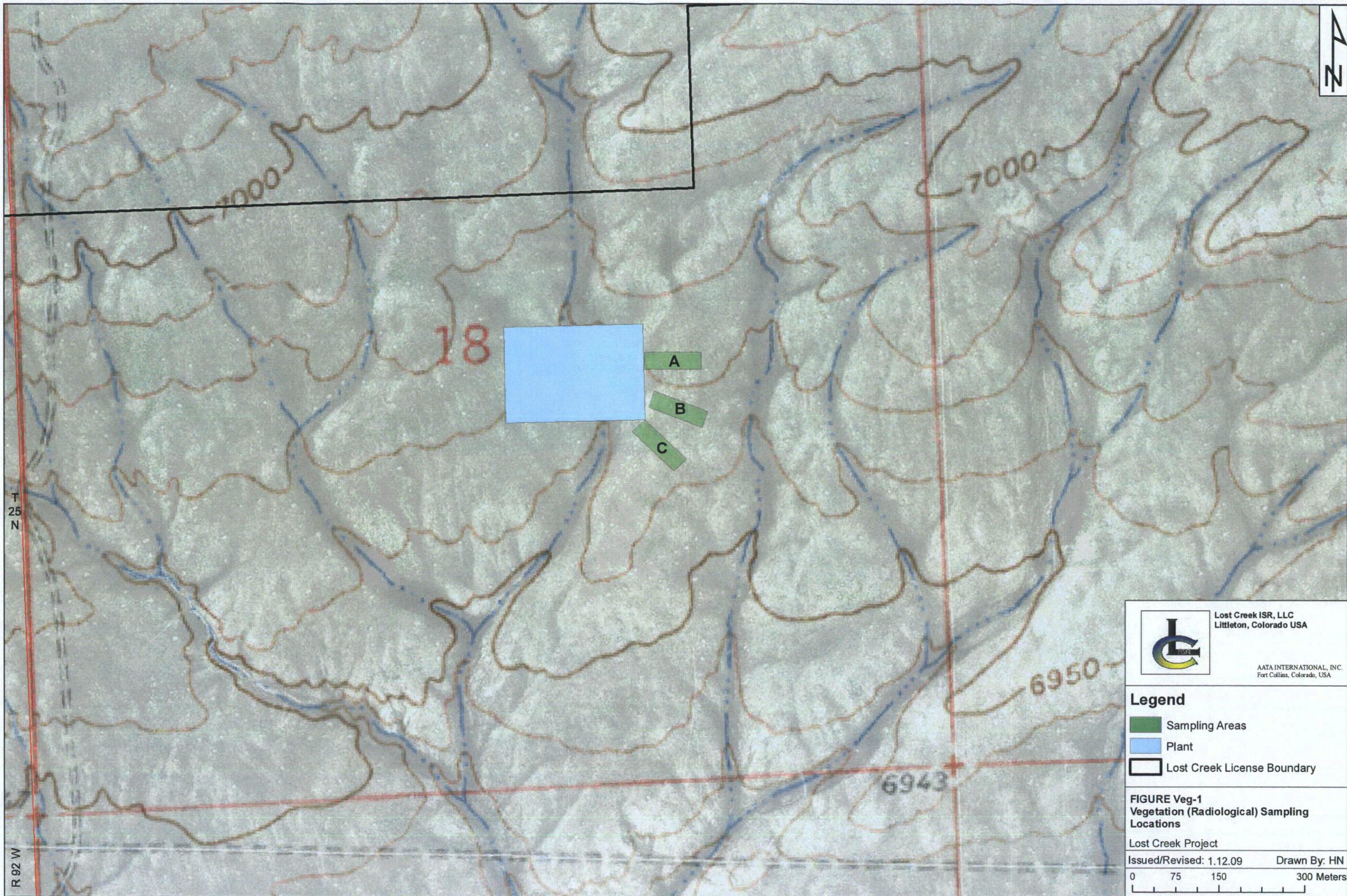
Sagebrush, rabbitbrush, succulents, and other non-grazing vegetation were avoided, since they are generally not consumed by cattle, and therefore any radionuclides that might be present in shrubs or succulents are less likely to enter the human food chain. In addition, sampling of shrubs (especially sagebrush) can be detrimental to the plant survival. Given the quantity of vegetative material needed for analysis, it was not considered prudent to collect significant quantities of sagebrush. Historical data at a different uranium project in Wyoming shows that levels of natural uranium, Pb-210, Po-210, Ra-226, and Th-230 are very similar between grasses and sagebrush (Conoco, 1980 in EMC, 2007).

**Table Veg-1** shows the analytical results for the vegetation sampling, and the laboratory data sheets are included in **Appendix Veg-1**. The overall average uranium concentration was 0.18 mg/kg. However, if the outlier value (0.76 mg/kg) is excluded, the average was 0.11 mg/kg. Uranium concentrations were greatest in the first sample, then fairly consistent between the second and third sample. Not surprisingly, uranium activity showed a similar trend, as did Pb-210, which averaged 0.0014 uCi/kg in the first sample, and 0.00051 and 0.00083 uCi/kg in the subsequent samples. Po-210 concentrations averaged 0.000062 uCi/kg, and generally increased over time, with the highest concentrations in the final samples. Noticeable changes in radiological activity after the first sample may be due to vegetation drying out and becoming dormant as summer progresses. No trends in time or space were apparent in Ra-226 or Th-230, which averaged 0.00012, and 0.000025 uCi/kg, respectively.

References:

Conoco, Inc. 1980. Environmental Report for the Sand Rock Mill Project, Campbell County, Wyoming. Docket No. 40-8743. July, 1980.

EMC (Energy Metals Corporation US). 2007. Application for US NRC Source Material License, Moore Ranch Uranium Project. Technical Report, Volume II. NRC website, ADAMS accession number ML072851268



Lost Creek ISR, LLC  
Littleton, Colorado USA

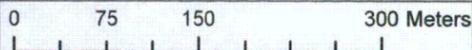
AATA INTERNATIONAL, INC.  
Fort Collins, Colorado, USA

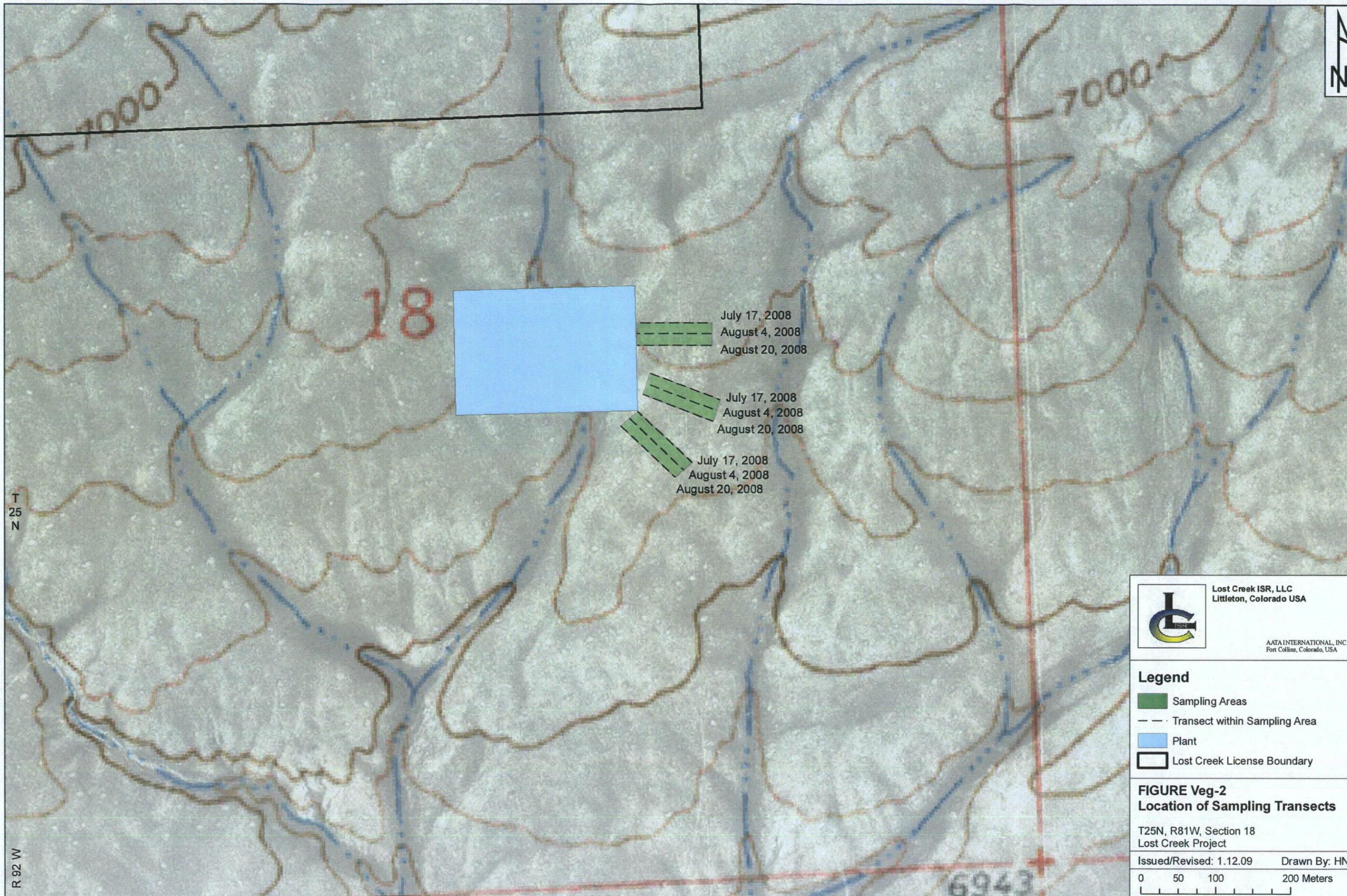
**Legend**

-  Sampling Areas
-  Plant
-  Lost Creek License Boundary

**FIGURE Veg-1**  
Vegetation (Radiological) Sampling Locations

Lost Creek Project  
Issued/Revised: 1.12.09      Drawn By: HN





18

July 17, 2008  
August 4, 2008  
August 20, 2008

July 17, 2008  
August 4, 2008  
August 20, 2008

July 17, 2008  
August 4, 2008  
August 20, 2008



Lost Creek ISR, LLC  
Littleton, Colorado USA

AATA INTERNATIONAL, INC.  
Fort Collins, Colorado, USA

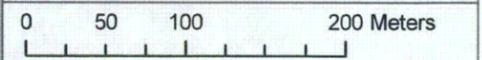
**Legend**

-  Sampling Areas
-  Transect within Sampling Area
-  Plant
-  Lost Creek License Boundary

**FIGURE Veg-2**  
**Location of Sampling Transects**

T25N, R81W, Section 18  
Lost Creek Project

Issued/Revised: 1.12.09      Drawn By: HN



T  
25  
N

R 92 W

6943

**Table Veg-1 Summary of Analytical Results - Vegetation Sampling for Radionuclides**

Sample Location	Analyte	Units	Sampling Date		
			7/17/2008	8/4/2008	8/20/2008
LC-A	Uranium	mg/kg-dry	0.76	0.08	0.11
	Uranium, Activity	uCi/kg	0.00052	0.00006	0.000076
	Lead 210	uCi/kg	0.0015	<0.00065	0.00069
	Polonium 210	uCi/kg	0.000072	0.000035	0.000100
	Radium 226	uCi/kg	0.000083	0.000075	0.00015
	Thorium 230	uCi/kg	0.000016	0.000014	0.000028
LC-B	Uranium	mg/kg-dry	0.17	0.06	0.06
	Uranium, Activity	uCi/kg	0.00012	0.00004	0.000042
	Lead 210	uCi/kg	0.0019	0.0009	0.001
	Polonium 210	uCi/kg	0.000035	0.000068	0.00008
	Radium 226	uCi/kg	0.000071	0.00015	0.00016
	Thorium 230	uCi/kg	0.000022	0.000024	0.000034
LC-C	Uranium	mg/kg-dry	0.2	0.09	0.08
	Uranium, Activity	uCi/kg	0.00013	0.00006	0.000052
	Lead 210	uCi/kg	0.00089	<0.00062	0.00079
	Polonium 210	uCi/kg	0.000032	0.000035	0.000097
	Radium 226	uCi/kg	0.00015	0.00015	0.00013
	Thorium 230	uCi/kg	0.000032	0.000039	0.000019
Overall Average	Uranium	mg/kg-dry	0.18		
	Uranium, Activity	uCi/kg	0.00012		
	Lead 210	uCi/kg	0.00092		
	Polonium 210	uCi/kg	0.000062		
	Radium 226	uCi/kg	0.00012		
	Thorium 230	uCi/kg	0.000025		



## ANALYTICAL SUMMARY REPORT

October 09, 2008

AATA International Inc  
300 E Boardwalk Dr STE 4A  
Fort Collins, CO 80525

Workorder No.: C08080492      Quote ID: C2889 - 301 UR Energy  
Project Name: Lost Creek 301

Energy Laboratories, Inc. received the following 6 samples from AATA International Inc on 8/12/2008 for analysis.

Sample ID	Client Sample ID	Collect Date	Receive Date	Matrix	Test
C08080492-001	LC-A	07/17/08 12:00	08/12/08	Vegetation	Metals by ICP/ICPMS, Total Digestion, Radiochemistry Digestion, Total Metals for Core Samples Lead 210 Polonium 210 Radium 226 Thorium, Isotopic
C08080492-002	LC-B	07/17/08 14:00	08/12/08	Vegetation	Same As Above
C08080492-003	LC-C	07/17/08 16:00	08/12/08	Vegetation	Same As Above
C08080492-004	LC-A	08/04/08 11:00	08/12/08	Vegetation	Same As Above
C08080492-005	LC-B	08/04/08 13:00	08/12/08	Vegetation	Same As Above
C08080492-006	LC-C	08/04/08 15:00	08/12/08	Vegetation	Same As Above

As appropriate, any exceptions or problems with the analyses are noted in the Laboratory Analytical Report, the QA/QC Summary Report, or the Case Narrative.

If you have any questions regarding these tests results, please call.

Report Approved By:   
STEVE CARLSTON



### LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
Project: Lost Creek 301  
Lab ID: C08080492-001  
Client Sample ID: LC-A

Report Date: 10/09/08  
Collection Date: 07/17/08 12:00  
Date Received: 08/12/08  
Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.76	mg/kg-dry		0.02		SW6020	08/27/08 20:53 / sml
Uranium, Activity	5.2E-04	uCi/kg		1.0E-05		SW6020	08/27/08 20:53 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	1.5E-03	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	5.3E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	8.5E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	7.2E-05	uCi/kg		5.4E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	2.4E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	8.3E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.2E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	6.6E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	1.6E-05	uCi/kg		1.1E-06		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	7.0E-06	uCi/kg				E907.0	09/05/08 16:15 / dmf

Report Definitions: RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



### LABORATORY ANALYTICAL REPORT

**Client:** AATA International Inc  
**Project:** Lost Creek 301  
**Lab ID:** C08080492-002  
**Client Sample ID:** LC-B

**Report Date:** 10/09/08  
**Collection Date:** 07/17/08 14:00  
**Date Received:** 08/12/08  
**Matrix:** Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.17	mg/kg-dry		0.02		SW6020	08/27/08 21:07 / sml
Uranium, Activity	1.2E-04	uCi/kg		1.0E-05		SW6020	08/27/08 21:07 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	1.9E-03	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	5.2E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	8.3E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	3.5E-05	uCi/kg		5.2E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	1.6E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	7.1E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.1E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	6.7E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	2.2E-05	uCi/kg		1.1E-06		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	8.4E-06	uCi/kg				E907.0	09/05/08 16:15 / dmf

**Report  
Definitions:**

RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



### LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
Project: Lost Creek 301  
Lab ID: C08080492-003  
Client Sample ID: LC-C

Report Date: 10/09/08  
Collection Date: 07/17/08 16:00  
Date Received: 08/12/08  
Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.20	mg/kg-dry		0.02		SW6020	08/27/08 21:13 / sml
Uranium, Activity	1.3E-04	uCi/kg		1.0E-05		SW6020	08/27/08 21:13 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	8.9E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	5.4E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	8.7E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	3.2E-05	uCi/kg		5.6E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	2.1E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	1.5E-04	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.7E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	7.1E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	3.2E-05	uCi/kg		1.1E-06		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	1.2E-05	uCi/kg				E907.0	09/05/08 16:15 / dmf

Report Definitions: RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
 Project: Lost Creek 301  
 Lab ID: C08080492-004  
 Client Sample ID: LC-A

Report Date: 10/09/08  
 Collection Date: 08/04/08 11:00  
 Date Received: 08/12/08  
 Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.08	mg/kg-dry		0.02		SW6020	08/27/08 21:20 / sml
Uranium, Activity	6.0E-05	uCi/kg		1.0E-05		SW6020	08/27/08 21:20 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	5.3E-04	uCi/kg	U			E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	3.9E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	6.5E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	3.5E-05	uCi/kg		4.1E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	1.7E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	7.5E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.0E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	5.2E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	1.4E-05	uCi/kg		8.2E-07		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	5.3E-06	uCi/kg				E907.0	09/05/08 16:15 / dmf

Report Definitions:  
 RL - Analyte reporting limit.  
 QCL - Quality control limit.  
 MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
 ND - Not detected at the reporting limit.  
 U - Not detected at minimum detectable concentration



### LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
Project: Lost Creek 301  
Lab ID: C08080492-005  
Client Sample ID: LC-B

Report Date: 10/09/08  
Collection Date: 08/04/08 13:00  
Date Received: 08/12/08  
Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.06	mg/kg-dry		0.02		SW6020	08/27/08 21:54 / sml
Uranium, Activity	4.0E-05	uCi/kg		1.0E-05		SW6020	08/27/08 21:54 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	9.0E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	4.2E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	6.8E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	6.8E-05	uCi/kg		4.3E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	2.2E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	1.5E-04	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.5E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	5.7E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	2.4E-05	uCi/kg		8.6E-07		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	1.2E-05	uCi/kg				E907.0	09/05/08 16:15 / dmf

Report Definitions: RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
 Project: Lost Creek 301  
 Lab ID: C08080492-006  
 Client Sample ID: LC-C

Report Date: 10/09/08  
 Collection Date: 08/04/08 15:00  
 Date Received: 08/12/08  
 Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.09	mg/kg-dry		0.02		SW6020	08/27/08 22:01 / sml
Uranium, Activity	6.0E-05	uCi/kg		1.0E-05		SW6020	08/27/08 22:01 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	6.1E-04	uCi/kg	U			E909.0M	09/04/08 09:45 / dm
Lead 210 precision (±)	3.8E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Lead 210 MDC	6.2E-04	uCi/kg				E909.0M	09/04/08 09:45 / dm
Polonium 210	3.5E-05	uCi/kg		3.9E-06		RMO-3008	09/04/08 19:15 / plj
Polonium 210 precision (±)	1.3E-05	uCi/kg				RMO-3008	09/04/08 19:15 / plj
Radium 226	1.5E-04	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 precision (±)	1.3E-05	uCi/kg				E903.0	09/08/08 22:46 / trs
Radium 226 MDC	4.8E-06	uCi/kg				E903.0	09/08/08 22:46 / trs
Thorium 230	3.9E-05	uCi/kg		7.9E-07		E907.0	09/05/08 16:15 / dmf
Thorium 230 precision (±)	1.7E-05	uCi/kg				E907.0	09/05/08 16:15 / dmf

Report Definitions:  
 RL - Analyte reporting limit.  
 QCL - Quality control limit.  
 MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
 ND - Not detected at the reporting limit.  
 U - Not detected at minimum detectable concentration



## QA/QC Summary Report

Client: AATA International Inc  
Project: Lost Creek 301

Report Date: 10/09/08  
Work Order: C08080492

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
<b>Method: E903.0</b>									Batch: 19597
Sample ID: LCS-19597 Radium 226	Laboratory Control Sample 4.2E-05 pCi/L			107	70	130			Run: BERTHOLD 770_080902A 09/08/08 22:46
Sample ID: MB-19597 Radium 226	Method Blank 3E-07 pCi/L								Run: BERTHOLD 770_080902A 09/08/08 22:46 U
Sample ID: C08080492-005AMS Radium 226	Sample Matrix Spike 0.00034 uCi/kg			114	70	130			Run: BERTHOLD 770_080902A 09/08/08 22:46
Sample ID: C08080624-002ADUP Radium 226	Sample Duplicate 1.0E-05 uCi/kg						7.3		Run: BERTHOLD 770_080902A 09/09/08 00:27 97.6
<b>Method: E907.0</b>									Batch: 19597
Sample ID: C08080492-006AMS Thorium 230	Sample Matrix Spike 0.00022 uCi/kg		7.9E-07	96	70	130			Run: EGG-ORTEC_080905D 09/05/08 16:15
Sample ID: C08080492-006AMSD Thorium 230	Sample Matrix Spike Duplicate 0.00020 uCi/kg		7.9E-07	97	70	130	9.3		Run: EGG-ORTEC_080905D 09/05/08 16:15 30
Sample ID: LCS-19597 Thorium 230	Laboratory Control Sample 9.5E-05 uCi/kg		4.0E-07	102	70	130			Run: EGG-ORTEC_080905D 09/05/08 16:15
Sample ID: MB-19597 Thorium 230	Method Blank 1E-06 uCi/kg								Run: EGG-ORTEC_080905D 09/05/08 16:15
<b>Method: E909.0M</b>									Batch: 19597
Sample ID: C08080492-002AMS Lead 210	Sample Matrix Spike 0.0090 uCi/kg			115	70	130			Run: PACKARD 3100TR_080904C 09/04/08 09:45
Sample ID: C08080492-002AMSD Lead 210	Sample Matrix Spike Duplicate 0.0078 uCi/kg			96	70	130	14		Run: PACKARD 3100TR_080904C 09/04/08 09:45 30
Sample ID: MB-R107765 Lead 210	Method Blank 4E-06 uCi/kg								Run: PACKARD 3100TR_080904C 09/04/08 09:45 U
Sample ID: LCS-R107765 Lead 210	Laboratory Control Sample 0.00010 uCi/kg			90	70	130			Run: PACKARD 3100TR_080904C 09/04/08 09:45
<b>Method: RMO-3008</b>									Batch: 19597
Sample ID: LCS-19597 Polonium 210	Laboratory Control Sample 6.7E-05 uCi/kg		1.0E-06	78	70	130			Run: EGG-ORTEC_080904B 09/04/08 19:15
Sample ID: MB-19597 Polonium 210	Method Blank 1E-07 uCi/kg		1E-06						Run: EGG-ORTEC_080904B 09/04/08 19:15 U

**Qualifiers:**

RL - Analyte reporting limit.

U - Not detected at minimum detectable concentration

ND - Not detected at the reporting limit.



## QA/QC Summary Report

Client: AATA International Inc

Report Date: 10/09/08

Object: Lost Creek 301

Work Order: C08080492

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
<b>Method: RMO-3008</b>							<b>Batch: R107637</b>		
<b>Sample ID: C08080827-001FMS</b> Polonium 210	Sample Matrix Spike 55 pCi/L		1.0	127	70	130			09/04/08 19:15
<b>Sample ID: C08080827-001FMSD</b> Polonium 210	Sample Matrix Spike Duplicate 54 pCi/L		1.0	125	70	130	1.8	30	09/04/08 19:15
<b>Sample ID: LCS-19540</b> Polonium 210	Laboratory Control Sample 100 pCi/L		1.0	121	70	130			09/04/08 19:15
<b>Sample ID: MB-19540</b> Polonium 210	Method Blank 3 pCi/L								09/04/08 19:15
<b>Method: SW6020</b>							<b>Batch: 19576</b>		
<b>Sample ID: MB-19576</b> Uranium	Method Blank ND mg/kg-dry		0.003						08/27/08 20:33
<b>Sample ID: LCS1-19576</b> Uranium	Laboratory Control Sample 135 mg/kg-dry		0.50	131	91	133			08/27/08 20:40
<b>Sample ID: C08080981-002AMS3</b> Uranium	Sample Matrix Spike 19.4 mg/kg-dry		0.50	116	75	125			08/28/08 00:09
<b>Sample ID: C08080981-002AMSD3</b> Uranium	Sample Matrix Spike Duplicate 20.7 mg/kg-dry		0.50	126	75	125	6.3	20	08/28/08 00:16 S

**Qualifiers:**

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

S - Spike recovery outside of advisory limits.



# Chain of Custody and Analytical Request Record

PLEASE PRINT- Provide as much information as possible.

Company Name: <i>ATA Int'l</i>	Project Name, PWS, Permit, Etc. <i>Lost Creek 301</i>	Sample Origin State: <i>WY</i>	EPA/State Compliance: Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
Report Mail Address: <i>300 E. Boardwalk Ste 4A Ft. Collins CO 80525</i>	Contact Name: <i>Duncan Eccleston</i>	Phone/Fax: <i>970-223-1333</i>	Email: <i>duncan.eccleston@ata.com</i>

Invoice Address: <i>2240 Blake St. Ste 210 Denver CO 80205</i>	Invoice Contact & Phone: <i>Carol Collins 720-974-2550</i>	Purchase Order: <i>301-805</i>	Quote/Bottle Order: <i>C2889</i>
---	---	-----------------------------------	-------------------------------------

Special Report/Formats - ELI must be notified prior to sample submittal for the following:  <input type="checkbox"/> DW <input type="checkbox"/> A2LA <input type="checkbox"/> GSA <input type="checkbox"/> EDD/EDT (Electronic Data) <input type="checkbox"/> POTW/WWTP <input type="checkbox"/> Format: _____ <input type="checkbox"/> State: _____ <input type="checkbox"/> LEVEL IV <input type="checkbox"/> Other: _____ <input type="checkbox"/> NELAC	Number of Containers Sample Type: <input type="checkbox"/> A <input type="checkbox"/> W <input type="checkbox"/> S <input type="checkbox"/> V <input type="checkbox"/> B <input type="checkbox"/> O <input type="checkbox"/> Air Water <input type="checkbox"/> Soils/Solids <input type="checkbox"/> Vegetation <input type="checkbox"/> Bioassay <input type="checkbox"/> Other	ANALYSIS REQUESTED										RUSH Contact ELI prior to RUSH sample submittal for charges and scheduling - See Instruction Page  Comments:	Shipped by: <i>DRE ups APS Grm</i>
		SEE ATTACHED											Cooler ID(s): <i>N/A BOX</i>

SAMPLE IDENTIFICATION (Name, Location, Interval, etc.)	Collection Date	Collection Time	MATRIX	ANALYSIS REQUESTED										SEE ATTACHED	Normal Turnaround (TAT)	RUSH	Comments:	Receipt Temp <i>26 °C</i>	On Ice: Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>	Custody Seal Intact <input checked="" type="checkbox"/> N Signature Match <input checked="" type="checkbox"/> N	
<i>1 LC-A</i>	<i>7/17/08</i>	<i>12:00</i>	<i>Veg</i>	<i>NRC 4-14 permit</i>														<i>✓</i>			
<i>2 LC-B</i>	<i>↓</i>	<i>14:00</i>	<i>↓</i>															<i>✓</i>		<i>C08080492</i>	
<i>3 LC-C</i>	<i>↓</i>	<i>16:00</i>	<i>↓</i>															<i>✓</i>			
<i>4</i>																					
<i>5</i>																					
<i>6</i>																					
<i>7</i>																					
<i>8</i>																					
<i>9</i>																					
<i>10</i>																					

<b>Custody Record MUST be Signed</b>	Relinquished by (print): <i>Duncan Eccleston</i>	Date/Time: <i>8/11/08</i>	Signature: <i>[Signature]</i>	Received by (print):	Date/Time: <i>8-12-08 9:20</i>	Signature: <i>[Signature]</i>
	Relinquished by (print):	Date/Time:	Signature:	Received by (print):	Date/Time:	Signature:
	Sample Disposal: Return to Client: _____	Lab Disposal: <input checked="" type="checkbox"/>	Received by Laboratory:	Date/Time:	Signature:	

LABORATORY USE ONLY

In certain circumstances, samples submitted to Energy Laboratories, Inc. may be subcontracted to other certified laboratories in order to complete the analysis requested. This serves as notice of this possibility. All sub-contract data will be clearly notated on your analytical report. Visit our web site at [www.energylab.com](http://www.energylab.com) for additional information, downloadable fee schedule, forms, and links.



# Chain of Custody and Analytical Request Record

PLEASE PRINT- Provide as much information as possible.

Company Name: <i>NATA Mt'l</i>	Project Name, PWS, Permit, Etc. <i>Lost Creek 301</i>	Sample Origin State: <i>WY</i>	EPA/State Compliance: Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
Report Mail Address: <i>300 E Boardwalk Ste 4A Ft. Collins CO 80525</i>	Contact Name: <i>Duncan Eccleston</i>	Phone/Fax: <i>970-223-1333</i>	Email: <i>duncan.eccleston@nata.com</i>
Invoice Address: <i>2240 Blake St. Ste 210, Denver CO 80205</i>	Invoice Contact & Phone: <i>Carol Collins 720-974-2550</i>	Purchase Order: <i>301-805</i>	Quote/Bottle Order: <i>C2889</i>

Special Report/Formats - ELI must be notified prior to sample submittal for the following:  <input type="checkbox"/> DW <input type="checkbox"/> A2LA <input type="checkbox"/> GSA <input type="checkbox"/> EDD/EDT (Electronic Data) <input type="checkbox"/> POTW/WWTP <input type="checkbox"/> LEVEL IV <input type="checkbox"/> State: _____ <input type="checkbox"/> NELAC <input type="checkbox"/> Other: _____	Number of Containers Sample Type: <input type="checkbox"/> A <input type="checkbox"/> W <input type="checkbox"/> S <input type="checkbox"/> V <input type="checkbox"/> B <input type="checkbox"/> O <input type="checkbox"/> Air <input type="checkbox"/> Water <input type="checkbox"/> Soils/Solids <input type="checkbox"/> Vegetation <input type="checkbox"/> Bioassay <input type="checkbox"/> Other	ANALYSIS REQUESTED  SEE ATTACHED  Normal Turnaround (TAT)	<b>R U S H</b>	Contact ELI prior to RUSH sample submittal for charges and scheduling - See Instruction Page	Shipped by: <i>DTE UPS AFS Cm</i>
				Comments:	Cooler ID(s): <i>N/A BOX</i>

SAMPLE IDENTIFICATION (Name, Location, Interval, etc.)	Collection Date	Collection Time	MATRIX	LABORATORY USE ONLY																
<i>LC-A</i>	<i>8/4</i>	<i>11:00</i>	<i>Veg</i>	<i>WLC 4-A p/m/mk</i>																
<i>LC-B</i>	<i>↓</i>	<i>13:00</i>	<i>↓</i>																	
<i>LC-C</i>	<i>↓</i>	<i>15:00</i>	<i>↓</i>																	

<b>Custody Record MUST be Signed</b>	Relinquished by (print): <i>Duncan Eccleston</i>	Date/Time: <i>8/14/08</i>	Signature: <i>[Signature]</i>	Received by (print):	Date/Time: <i>8-12-08 9:20</i>	Signature: <i>[Signature]</i>
	Relinquished by (print):	Date/Time:	Signature:	Received by (print):	Date/Time:	Signature:
	Sample Disposal:	Return to Client:	Lab Disposal:	Received by Laboratory:	Date/Time:	Signature:

In certain circumstances, samples submitted to Energy Laboratories, Inc. may be subcontracted to other certified laboratories in order to complete the analysis requested. This serves as notice of this possibility. All sub-contract data will be clearly noted on your analytical report. Visit our web site at [www.energylab.com](http://www.energylab.com) for additional information, downloadable fee schedule, forms, and links.

# Energy Laboratories Inc

## Workorder Receipt Checklist



AATA International Inc

C08080492

Login completed by: Kimberly Humiston

Date and Time Received: 8/12/2008 9:20 AM

Reviewed by:

Received by: kh

Reviewed Date:

Carrier name: Ground

- |   |   |                             |  |
|---|---|-----------------------------|--|
| Shipping container/cooler in good condition?            | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> | Not Present <input type="checkbox"/>                       |
| Custody seals intact on shipping container/cooler?      | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> | Not Present <input type="checkbox"/>                       |
| Custody seals intact on sample bottles?                 | Yes <input type="checkbox"/>            | No <input type="checkbox"/> | Not Present <input checked="" type="checkbox"/>            |
| Chain of custody present?                               | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Chain of custody signed when relinquished and received? | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Chain of custody agrees with sample labels?             | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Samples in proper container/bottle?                     | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Sample containers intact?                               | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Sufficient sample volume for indicated test?            | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| All samples received within holding time?               | Yes <input checked="" type="checkbox"/> | No <input type="checkbox"/> |  |
| Container/Temp Blank temperature:                       | 26°C                                    |                             |  |
| Water - VOA vials have zero headspace?                  | Yes <input type="checkbox"/>            | No <input type="checkbox"/> | No VOA vials submitted <input checked="" type="checkbox"/> |
| Water - pH acceptable upon receipt?                     | Yes <input type="checkbox"/>            | No <input type="checkbox"/> | Not Applicable <input checked="" type="checkbox"/>         |

-----  
Contact and Corrective Action Comments:

None



CLIENT: AATA International Inc  
Project: Lost Creek 301  
Sample Delivery Group: C08080492

Date: 09-Oct-08

## CASE NARRATIVE

The following Case Narrative contains exceptions or comments pertaining to the analysis of samples submitted by AATA International Inc on 8/12/2008 09:20:00. These samples were assigned ELI Workorder Number C08080492.

### ORIGINAL SAMPLE SUBMITTAL(S)

All original sample submittals have been returned with the data package.

### SAMPLE TEMPERATURE COMPLIANCE: 4°C (±2°C)

Temperature of samples received may not be considered properly preserved by accepted standards. Samples that are hand delivered immediately after collection shall be considered acceptable if there is evidence that the chilling process has begun.

### GROSS ALPHA ANALYSIS

Method 900.0 for gross alpha and gross beta is intended as a drinking water method for low TDS waters. Data provided by this method for non potable waters should be viewed as inconsistent.

### RADON IN AIR ANALYSIS

The desired exposure time is 48 hours (2 days). The time delay in returning the canister to the laboratory for processing should be as short as possible to avoid excessive decay. Maximum recommended delay between end of exposure to beginning of counting should not exceed 8 days.

### SOIL/SOLID SAMPLES

All samples reported on an as received basis unless otherwise indicated.

### ATRAZINE, SIMAZINE AND PCB ANALYSIS USING EPA 505

Data for Atrazine and Simazine are reported from EPA 525.2, not from EPA 505. Data reported by ELI using EPA method 505 reflects the results for seven individual Aroclors. When the results for all seven are ND (not detected), the sample meets EPA compliance criteria for PCB monitoring.

### SUBCONTRACTING ANALYSIS

Subcontracting of sample analyses to an outside laboratory may be required. If so, ENERGY LABORATORIES will utilize its branch laboratories or qualified contract laboratories for this service. Any such laboratories will be indicated within the Laboratory Analytical Report.

### BRANCH LABORATORY LOCATIONS

eli-b - Energy Laboratories, Inc. - Billings, MT  
eli-g - Energy Laboratories, Inc. - Gillette, WY  
eli-h - Energy Laboratories, Inc. - Helena, MT  
eli-r - Energy Laboratories, Inc. - Rapid City, SD  
eli-t - Energy Laboratories, Inc. - College Station, TX

### CERTIFICATIONS:

USEPA: WY00002; FL-DOH NELAC: E87641; Arizona: AZ0699; California: 02118CA  
Oregon: WY200001; Utah: 3072350515; Virginia: 00057; Washington: C1903

### ISO 17025 DISCLAIMER:

The results of this Analytical Report relate only to the items submitted for analysis.

ENERGY LABORATORIES, INC. - CASPER, WY certifies that certain method selections contained in this report meet requirements as set forth by the above accrediting authorities. Some results requested by the client may not be covered under these certifications. All analysis data to be submitted for regulatory enforcement should be certified in the sample state of origin. Please verify ELI's certification coverage by visiting [www.energylab.com](http://www.energylab.com)

ELI appreciates the opportunity to provide you with this analytical service. For additional information and services visit our web page [www.energylab.com](http://www.energylab.com).

THIS IS THE FINAL PAGE OF THE LABORATORY ANALYTICAL REPORT



## ANALYTICAL SUMMARY REPORT

October 20, 2008

AATA International Inc  
300 E Boardwalk Dr STE 4A  
Fort Collins, CO 80525

Workorder No.: C08090017      Quote ID: C2889 - 301 UR Energy

Project Name: URE-LC

Energy Laboratories, Inc. received the following 3 samples from AATA International Inc on 9/2/2008 for analysis.

Sample ID	Client Sample ID	Collect Date	Receive Date	Matrix	Test
C08090017-001	LC-A	08/20/08 13:00	09/02/08	Vegetation	Metals by ICP/ICPMS, Total Digestion, Radiochemistry Digestion, Total Metals for Core Samples Lead 210 Polonium 210 Radium 226 Thorium, Isotopic
C08090017-002	LC-B	08/20/08 15:00	09/02/08	Vegetation	Same As Above
C08090017-003	LC-C	08/20/08 17:00	09/02/08	Vegetation	Same As Above

As appropriate, any exceptions or problems with the analyses are noted in the Laboratory Analytical Report, the QA/QC Summary Report, or the Case Narrative.

If you have any questions regarding these tests results, please call.

Report Approved By:

  
STEVE CARLSTON



LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
 Project: URE-LC  
 Lab ID: C08090017-001  
 Client Sample ID: LC-A

Report Date: 10/20/08  
 Collection Date: 08/20/08 13:00  
 Date Received: 09/02/08  
 Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.11	mg/kg-dry		0.01		SW6020	09/10/08 05:54 / sml
Uranium, Activity	8.0E-05	uCi/kg-dry		7.0E-06		SW6020	09/10/08 05:54 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	6.9E-04	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 precision (±)	6.4E-05	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 MDC	9.1E-05	uCi/kg				E909.0M	09/24/08 09:01 / dm
Polonium 210	1.0E-04	uCi/kg		2.6E-06		RMO-3008	10/01/08 08:45 / plj
Polonium 210 precision (±)	2.7E-05	uCi/kg				RMO-3008	10/01/08 08:45 / plj
Radium 226	1.5E-04	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 precision (±)	1.3E-05	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 MDC	4.6E-06	uCi/kg				E903.0	10/09/08 14:32 / trs
Thorium 230	2.8E-05	uCi/kg		5.1E-07		E907.0	10/06/08 13:38 / dmf
Thorium 230 precision (±)	5.6E-06	uCi/kg				E907.0	10/06/08 13:38 / dmf

Report  
 Definitions:

RL - Analyte reporting limit.  
 QCL - Quality control limit.  
 MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
 ND - Not detected at the reporting limit.



### LABORATORY ANALYTICAL REPORT

Client: AATA International Inc  
Project: URE-LC  
Lab ID: C08090017-002  
Client Sample ID: LC-B

Report Date: 10/20/08  
Collection Date: 08/20/08 15:00  
Date Received: 09/02/08  
Matrix: Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.06	mg/kg-dry		0.01		SW6020	09/10/08 06:01 / sml
Uranium, Activity	4.0E-05	uCi/kg-dry		7.0E-06		SW6020	09/10/08 06:01 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	1.0E-03	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 precision (±)	8.9E-05	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 MDC	1.2E-04	uCi/kg				E909.0M	09/24/08 09:01 / dm
Polonium 210	8.0E-05	uCi/kg		3.5E-06		RMO-3008	10/01/08 08:45 / plj
Polonium 210 precision (±)	2.6E-05	uCi/kg				RMO-3008	10/01/08 08:45 / plj
Radium 226	1.6E-04	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 precision (±)	1.6E-05	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 MDC	6.3E-06	uCi/kg				E903.0	10/09/08 14:32 / trs
Thorium 230	3.4E-05	uCi/kg		7.0E-07		E907.0	10/06/08 13:38 / dmf
Thorium 230 precision (±)	8.3E-06	uCi/kg				E907.0	10/06/08 13:38 / dmf

Report Definitions:  
RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



### LABORATORY ANALYTICAL REPORT

**Client:** AATA International Inc  
**Project:** URE-LC  
**Lab ID:** C08090017-003  
**Client Sample ID:** LC-C

**Report Date:** 10/20/08  
**Collection Date:** 08/20/08 17:00  
**Date Received:** 09/02/08  
**Matrix:** Vegetation

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
<b>METALS - TOTAL</b>							
Uranium	0.08	mg/kg-dry		0.01		SW6020	09/10/08 06:07 / sml
Uranium, Activity	5.0E-05	uCi/kg-dry		7.0E-06		SW6020	09/10/08 06:07 / sml
<b>RADIONUCLIDES - TOTAL</b>							
Lead 210	7.9E-04	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 precision (±)	9.2E-05	uCi/kg				E909.0M	09/24/08 09:01 / dm
Lead 210 MDC	1.3E-04	uCi/kg				E909.0M	09/24/08 09:01 / dm
Polonium 210	9.7E-05	uCi/kg		3.8E-06		RMO-3008	10/01/08 08:45 / plj
Polonium 210 precision (±)	3.0E-05	uCi/kg				RMO-3008	10/01/08 08:45 / plj
Radium 226	1.3E-04	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 precision (±)	1.6E-05	uCi/kg				E903.0	10/09/08 14:32 / trs
Radium 226 MDC	7.5E-06	uCi/kg				E903.0	10/09/08 14:32 / trs
Thorium 230	1.9E-05	uCi/kg		7.6E-07		E907.0	10/06/08 13:38 / dmf
Thorium 230 precision (±)	5.6E-06	uCi/kg				E907.0	10/06/08 13:38 / dmf

**Report  
Definitions:**

RL - Analyte reporting limit.  
QCL - Quality control limit.  
MDC - Minimum detectable concentration

MCL - Maximum contaminant level.  
ND - Not detected at the reporting limit.



## QA/QC Summary Report

Client: AATA International Inc

Report Date: 10/20/08

Project: URE-LC

Work Order: C08090017

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
<b>Method: E903.0</b>									Batch: R109081
Sample ID: C08090263-001FMS	Sample Matrix Spike					Run: BERTHOLD 770_081003D			10/09/08 14:32
Radium 226	180	pCi/L		114	70	130			
Sample ID: C08090263-001FMSD	Sample Matrix Spike Duplicate					Run: BERTHOLD 770_081003D			10/09/08 14:32
Radium 226	180	pCi/L		118	70	130	3.6	24.2	
Sample ID: LCS-19814	Laboratory Control Sample					Run: BERTHOLD 770_081003D			10/09/08 18:31
Radium 226	18	pCi/L		114	70	130			
Sample ID: MB-19814	Method Blank					Run: BERTHOLD 770_081003D			10/09/08 18:31
Radium 226	0.1	pCi/L							U
<b>Method: E907.0</b>									Batch: R109319
Sample ID: C08090263-002FMS	Sample Matrix Spike					Run: EGG-ORTEC_080929D			10/07/08 17:03
Thorium 230	84	pCi/L	0.20	85	70	130			
Sample ID: C08090263-002FMSD	Sample Matrix Spike Duplicate					Run: EGG-ORTEC_080929D			10/07/08 17:03
Thorium 230	90	pCi/L	0.20	98	70	130	7.6	40.3	
Sample ID: LCS-19814	Laboratory Control Sample					Run: EGG-ORTEC_080929D			10/08/08 08:37
Thorium 230	43	pCi/L	0.20	89	70	130			
Sample ID: MB-19814	Method Blank					Run: EGG-ORTEC_080929D			10/08/08 08:37
Thorium 230	0.06	pCi/L							U
<b>Method: E909.0M</b>									Batch: 19797
Sample ID: C08090017-003AMS	Sample Matrix Spike					Run: PACKARD 3100TR_080924B			09/24/08 09:01
Lead 210	0.0046	uCi/kg		87	70	130			
Sample ID: C08090017-003AMSD	Sample Matrix Spike Duplicate					Run: PACKARD 3100TR_080924B			09/24/08 09:01
Lead 210	0.0060	uCi/kg		118	70	130	26	30	
Sample ID: MB-R108856	Method Blank					Run: PACKARD 3100TR_080924B			09/24/08 09:01
Lead 210	2E-06	uCi/kg							U
Sample ID: LCS-R108856	Laboratory Control Sample					Run: PACKARD 3100TR_080924B			09/24/08 09:01
Lead 210	0.00011	uCi/kg		93	70	130			

**Qualifiers:**

RL - Analyte reporting limit.

U - Not detected at minimum detectable concentration

ND - Not detected at the reporting limit.



## QA/QC Summary Report

Client: AATA International Inc

Report Date: 10/20/08

Project: URE-LC

Work Order: C08090017

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
<b>Method: RMO-3008</b>							<b>Batch: R108821</b>		
<b>Sample ID: C08090354-002FMS</b>	<b>Sample Matrix Spike</b>				<b>Run: EGG-ORTEC_080925A</b>		<b>10/01/08 12:15</b>		
Polonium 210	120	pCi/L	1.0	60	70	130			S
- Spike response is outside of the acceptance range for this analysis. Since the LCS and the RPD for the MS MSD pair are acceptable, the response is considered to be matrix related. The batch is approved.									
<b>Sample ID: C08090354-002FMSD</b>	<b>Sample Matrix Spike Duplicate</b>				<b>Run: EGG-ORTEC_080925A</b>		<b>10/01/08 12:15</b>		
Polonium 210	100	pCi/L	1.0	50	70	130	17	52.5	S
- Spike response is outside of the acceptance range for this analysis. Since the LCS and the RPD for the MS MSD pair are acceptable, the response is considered to be matrix related. The batch is approved.									
<b>Sample ID: LCS-19814</b>	<b>Laboratory Control Sample</b>				<b>Run: EGG-ORTEC_080925A</b>		<b>10/01/08 12:15</b>		
Polonium 210	82	pCi/L	1.0	99	70	130			
<b>Sample ID: MB-19814</b>	<b>Method Blank</b>				<b>Run: EGG-ORTEC_080925A</b>		<b>10/01/08 12:15</b>		
Polonium 210	ND	pCi/L							U
<b>Method: SW6020</b>							<b>Batch: 19721</b>		
<b>Sample ID: MB-19721</b>	<b>Method Blank</b>				<b>Run: ICPMS4-C_080909A</b>		<b>09/10/08 04:25</b>		
Uranium	0.02	mg/kg-dry	0.0006						
<b>Sample ID: LCS1-19721</b>	<b>Laboratory Control Sample</b>				<b>Run: ICPMS4-C_080909A</b>		<b>09/10/08 04:32</b>		
Uranium	122	mg/kg-dry	0.50	118	91	133			
<b>Sample ID: C08090095-040AMS3</b>	<b>Sample Matrix Spike</b>				<b>Run: ICPMS4-C_080909A</b>		<b>09/10/08 07:48</b>		
Uranium	19.2	mg/kg-dry	0.50	116	75	125			
<b>Sample ID: C08090095-040AMSD3</b>	<b>Sample Matrix Spike Duplicate</b>				<b>Run: ICPMS4-C_080909A</b>		<b>09/10/08 07:55</b>		
Uranium	20.6	mg/kg-dry	0.50	121	75	125	7.5	20	

**Qualifiers:**

RL - Analyte reporting limit.

S - Spike recovery outside of advisory limits.

ND - Not detected at the reporting limit.

U - Not detected at minimum detectable concentration



# Chain of Custody and Analytical Request Record

PLEASE PRINT- Provide as much information as possible.

Company Name: <b>AAIA Int'l</b>	Project Name, PWS, Permit, Etc. <b>U/E-LC</b>	Sample Origin State: <b>WY</b>	EPA/State Compliance: Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
Report Mail Address: <b>300 E Boardwalk Ste 4A Ft. Collins, CO 80525</b>	Contact Name: <b>Duncan Eccleston</b>	Phone/Fax: <b>970-223-1333</b>	Email: <b>duncan.eccleston@eebz.com</b>
Invoice Address: <b>2240 Blake St. Ste. 200 Denver CO 80205</b>	Invoice Contact & Phone: <b>Carol Collins 720-974-2530</b>	Purchase Order:	Quote/Bottle Order: <b>C2889</b>

Special Report/Formats – ELI must be notified prior to sample submittal for the following:

<input type="checkbox"/> DW	<input type="checkbox"/> A2LA
<input type="checkbox"/> GSA	<input type="checkbox"/> EDD/EDT (Electronic Data)
<input type="checkbox"/> POTW/WWTP	Format: _____
<input type="checkbox"/> State: _____	<input type="checkbox"/> LEVEL IV
<input type="checkbox"/> Other: _____	<input type="checkbox"/> NELAC

Number of Containers Sample Type: A W S V B O Air Water Soils/Solids Vegetation Bioassay Other	ANALYSIS REQUESTED									
	SEE ATTACHED									

Contact ELI prior to RUSH sample submittal for charges and scheduling – See Instruction Page

Comments:

Shipped by: **DE**

Cooler ID(s): **BOX**

Receipt Temp: **19 °C**

On Ice: Yes  No

Custody Seal Intact:  N  Y

Signature Match:  N  Y

SAMPLE IDENTIFICATION (Name, Location, Interval, etc.)	Collection Date	Collection Time	MATRIX	LABORATORY USE ONLY											
1 LC-A Aug 20-08	8/20/08	15:00	✓	LABORATORY USE ONLY	SEE ATTACHED	Normal Turnaround (TAT)	RUSH	Contact ELI prior to RUSH sample submittal for charges and scheduling – See Instruction Page	Comments:	Shipped by: DE	Cooler ID(s): BOX	Receipt Temp: 19 °C	On Ice: Yes No	Custody Seal Intact: C Y N	Signature Match: Y N
2 LC-B Aug 20-08	↓	15:00	✓												
3 LC-C Aug 20-08	↓	17:00	✓												
4															
5															
6															
7															
8															
9															
10															

<b>Custody Record MUST be Signed</b>	Relinquished by (print): <b>Duncan Eccleston</b> Date/Time: <b>8/27/08</b> Signature: <i>[Signature]</i>	Received by (print): _____ Date/Time: _____ Signature: _____
	Relinquished by (print): _____ Date/Time: _____ Signature: _____	Received by (print): _____ Date/Time: _____ Signature: _____
	Sample Disposal: Return to Client: _____ Lab Disposal: <input checked="" type="checkbox"/>	Received by Laboratory: <b>Ashley Haynes</b> Date/Time: <b>9-02-08 8:45</b> Signature: <i>[Signature]</i>

In certain circumstances, samples submitted to Energy Laboratories, Inc. may be subcontracted to other certified laboratories in order to complete the analysis requested. This serves as notice of this possibility. All sub-contract data will be clearly notated on your analytical report. Visit our web site at [www.energylab.com](http://www.energylab.com) for additional information, downloadable fee schedule, forms, and links.

# Energy Laboratories Inc

## Workorder Receipt Checklist



C08090017

Login completed by: Kimberly Humiston

Date and Time Received: 9/2/2008 8:45 AM

Reviewed by:

Received by: ah

Reviewed Date:

Carrier name: Ground

Shipping container/cooler in good condition?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	Not Present <input type="checkbox"/>
Custody seals intact on shipping container/cooler?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	Not Present <input type="checkbox"/>
Custody seals intact on sample bottles?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	Not Present <input checked="" type="checkbox"/>
Chain of custody present?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Chain of custody signed when relinquished and received?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Chain of custody agrees with sample labels?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Samples in proper container/bottle?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sample containers intact?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sufficient sample volume for indicated test?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
All samples received within holding time?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Container/Temp Blank temperature:	19°C		
Water - VOA vials have zero headspace?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	No VOA vials submitted <input checked="" type="checkbox"/>
Water - pH acceptable upon receipt?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	Not Applicable <input checked="" type="checkbox"/>

---

Contact and Corrective Action Comments:

None



CLIENT: AATA International Inc  
Project: URE-LC  
Sample Delivery Group: C08090017

Date: 20-Oct-08

## CASE NARRATIVE

The following Case Narrative contains exceptions or comments pertaining to the analysis of samples submitted by AATA International Inc on 9/2/2008 08:45:00. These samples were assigned ELI Workorder Number C08090017.

### ORIGINAL SAMPLE SUBMITTAL(S)

All original sample submittals have been returned with the data package.

### SAMPLE TEMPERATURE COMPLIANCE: 4°C (±2°C)

Temperature of samples received may not be considered properly preserved by accepted standards. Samples that are hand delivered immediately after collection shall be considered acceptable if there is evidence that the chilling process has begun.

### GROSS ALPHA ANALYSIS

Method 900.0 for gross alpha and gross beta is intended as a drinking water method for low TDS waters. Data provided by this method for non potable waters should be viewed as inconsistent.

### RADON IN AIR ANALYSIS

The desired exposure time is 48 hours (2 days). The time delay in returning the canister to the laboratory for processing should be as short as possible to avoid excessive decay. Maximum recommended delay between end of exposure to beginning of counting should not exceed 8 days.

### SOIL/SOLID SAMPLES

All samples reported on an as received basis unless otherwise indicated.

### ATRAZINE, SIMAZINE AND PCB ANALYSIS USING EPA 505

Data for Atrazine and Simazine are reported from EPA 525.2, not from EPA 505. Data reported by ELI using EPA method 505 reflects the results for seven individual Aroclors. When the results for all seven are ND (not detected), the sample meets EPA compliance criteria for PCB monitoring.

### SUBCONTRACTING ANALYSIS

Subcontracting of sample analyses to an outside laboratory may be required. If so, ENERGY LABORATORIES will utilize its branch laboratories or qualified contract laboratories for this service. Any such laboratories will be indicated within the Laboratory Analytical Report.

### BRANCH LABORATORY LOCATIONS

eli-b - Energy Laboratories, Inc. - Billings, MT  
eli-g - Energy Laboratories, Inc. - Gillette, WY  
eli-h - Energy Laboratories, Inc. - Helena, MT  
eli-r - Energy Laboratories, Inc. - Rapid City, SD  
eli-t - Energy Laboratories, Inc. - College Station, TX

### CERTIFICATIONS:

USEPA: WY00002; FL-DOH NELAC: E87641; California: 02118CA  
Oregon: WY200001; Utah: 3072350515; Virginia: 00057; Washington: C1903

### ISO 17025 DISCLAIMER:

The results of this Analytical Report relate only to the items submitted for analysis.

ENERGY LABORATORIES, INC. - CASPER, WY certifies that certain method selections contained in this report meet requirements as set forth by the above accrediting authorities. Some results requested by the client may not be covered under these certifications. All analysis data to be submitted for regulatory enforcement should be certified in the sample state of origin. Please verify ELI's certification coverage by visiting [www.energylab.com](http://www.energylab.com)

ELI appreciates the opportunity to provide you with this analytical service. For additional information and services visit our web page [www.energylab.com](http://www.energylab.com).

THIS IS THE FINAL PAGE OF THE LABORATORY ANALYTICAL REPORT