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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 ($100m^2$) 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 ($100m^2$) 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 vitaes [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^2) 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 (μR/hr), there was no evidence that readings from the two detector heights were different. For areas with measured values greater than 25 μR/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 μR/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 μR/hr. Thus, the total amount of potential uncertainty in measurements at the staging area approached plus or minus four μR/hr. The staging area had measured background gamma readings in the range of 17 to 27 μR/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_2O_3: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 4th 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^2 [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^3, 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^2-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 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.