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D10 BACKGROUND RADIOLOGICAL CHARACTERISTICS

A baseline radiological survey was performed within the Permit Area to establish and document the pre-operation radiological environment. The primary goals were to: detect surface areas having anomalously high radiological activity; establish preliminary surface background radiological levels in water resources; and provide source data for MILDOS radiation dispersion and dose calculation modeling.

To detect areas of anomalously high radiological activity, 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 analysis was completed on quarterly groundwater and stormwater samples, and the results are presented in **Appendix D6**. Passive air samplers were used to measure natural gamma and Rn-222 at multiple locations within and outside of the Permit Area, and these results are presented in **Appendix D4**.

The Project will not directly produce particulate emissions because the end-product is yellowcake slurry. Therefore, there will be no radiological impact on vegetation, and baseline characterization of vegetation radiological characteristics was not conducted. Because there is no perennial surface water in the Permit Area, sediment sampling was not conducted.

D10.1 Background Gamma Radiation Survey and 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. 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 Regulatory Guide 4.14 (NRC, 1980a). 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 Regulatory Guide 4.14 does not address special considerations associated with uranium ISR sites, NRC and WDEQ LQD (WDEQ-LQD, 2007) currently recommend following Regulatory Guide 4.14 for conducting radiological baseline surveys of ISR uranium projects. Consistent with ISR permit application guidelines described in Regulatory Guide 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 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 Regulatory Guide 4.14 and would provide more detailed information on baseline radiological conditions in the Permit Area.

D10.1.1 Methods

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

D10.1.1.1 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 D10-1**). 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 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 (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.

D10.1.1.2 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.

D10.1.1.3 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 Regulatory Guide 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 (100 m^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 (100 m^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 D10-2**.

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, provides sufficient information on baseline soil radionuclide concentrations for the proposed operations which are described in the **Operations Plan**.

D10.1.2 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 this 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 D10-1**).
- 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 D10-1**).
- Chain-of-custody protocols were followed for soil sampling and contract laboratory analyses (relevant forms are provided in **Attachment D10-1**).
- 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 D10-2**.

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 D10-2**).

- 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 at 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 D10-2**).

D10.1.3 Results

D10.1.3.1 Baseline Gamma Survey

The gamma survey results in the Permit Area are shown in **Figure D10-3**. There is an unexpected degree of variability in gamma exposure rates at 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 Permit Area was expanded after the initial survey activities, so additional surveys were undertaken on the added area in 2007, which are included in the final dataset.

Some areas with slightly elevated background radiation occurred near 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 D10-4** and **D10-5**). The evidence indicates that some portions of Permit Area boundaries fall on areas where natural terrestrial radioactivity is slightly elevated at the soil surface.

D10.1.3.2 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 D10-6**. The soil sampling results represent the mean gamma exposure rates of the 1,076-square-foot (100-m^2) sampling grids. The sampling locations are in an approximate radial pattern.

Statistical analysis demonstrated a significant linear relationship (**Figure D10-7**) between the mean Ra-226 soil concentration and the mean gamma exposure rate across all of the sampling grids (**Table D10-1**). In general, uranium and Ra-226 in these soils do not appear to be in equilibrium (**Figure D10-8**). 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.

D10.1.3.3 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 D10-9**. 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 at 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 D10-10**.

Numerical differences between the three-foot and 4.5-foot NaI detector height readings are shown in **Table D10-2**. The relationship between the two detector heights is shown in **Figure D10-11**. 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.

D10.1.3.4 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 D10-9** were used for the data conversions.

A final map of official results, showing Permit Area boundaries and the three-foot HPIC equivalent gamma exposure rate data, is presented in **Figure D10-12**, with a plate-sized version included in **Attachment D10-3**. Note that the legend scale increments in **Figure D10-12** 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; 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 D10-12**, with a larger version included in **Attachment D10-3**. Note that for the central area of the highest-density scan coverage shown in **Figure D10-12**, there is an apparent difference in distribution between the scan track data and the corresponding kriged region in **Figure D10-13**, with an plate-sized version included in **Attachment D10-3**. This is because the scan data symbol sizes in **Figure D10-12** 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 D10-12** (**Attachment D10-3**) or the raw electronic dataset (**Attachment D10-4**) should be used to identify values at individual locations.

D10.1.3.5 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 Lost Creek data shown in **Figure D10-14** was used for this conversion. Also shown in **Figure D10-14** 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 site. 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 Lost Creek data shown in **Figure D10-14**, kriging was performed to produce continuous estimates of soil Ra-226 concentrations across the Permit Area as shown in **Figure D10-15**, with an plate-sized version included in **Attachment D10-3**.

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 somewhat higher.