APPENDIX E
GAMMA SURVEY DATA

APPENDIX E-1
GAMMA SURVEY METHODS

1.0 PURPOSE OF GAMMA SURVEY

The purpose of the gamma survey was to document existing gamma exposure rates at the Ross Adams project site. The gamma survey provided a direct spatial characterization of terrestrial sources of radioactivity, helped define the limits of disturbance and/or radiological impacts from historical uranium mining, and aided in selection of soil sampling locations at the site.

1.1 Introduction

The EE/CA and Risk Assessment Project at the Ross Adams site requires characterization of the spatial distributions of gamma exposure rates and radionuclide concentrations in soil. This information is important for assessment of the extent of areas that may require removal action. Past approaches for conducting gamma surveys involve taking discrete gamma measurements and soil samples across a systematic grid pattern. For example, a radial grid sampling approach is indicated by the U.S. Nuclear Regulatory Commission (NRC) in Regulatory Guide 4.14 for uranium mills (NRC, 1980), with soil samples collected along a radial grid and individual discrete gamma measurements collected along a similar pattern (Figure E-1a).

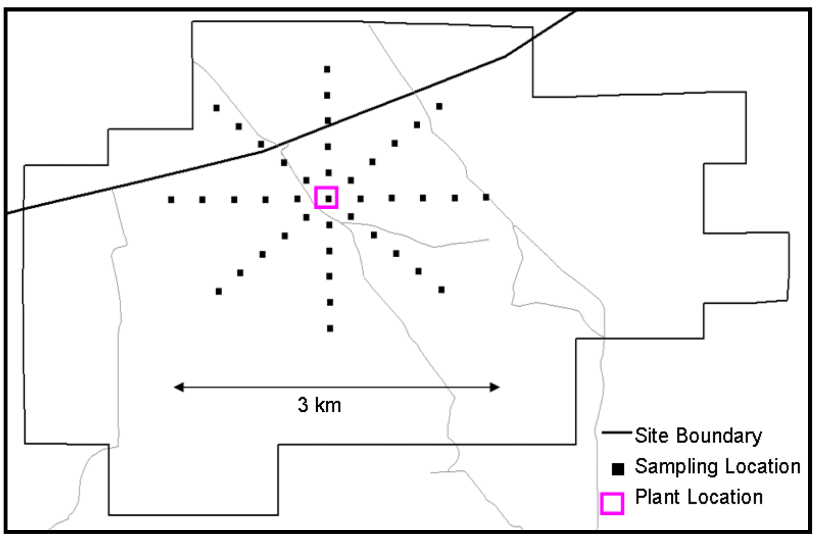

Figure E-1a: Example soil sampling location grid design as indicated in NRC Regulatory Guide 4.14.

More recent radiological survey guidelines found in MARSSIM, the Multi-Agency Radiation Survey and Site Investigation Manual (NRC, 2000), also indicate grid-based designs for soil sampling and direct measurement of radionuclides in soil. However, the number of soil samples needed varies according to statistical requirements. Continuous gamma scanning (rather than discrete gamma measurements) is used to augment the soil sampling by detection of any radiologically elevated areas between grid soil sampling locations.

At the Ross Adams site, concentrations of natural uranium and thorium along with their decay products in surface soils strongly influence the spatial distribution of gamma survey readings. Spatial variability in these parameters is high due to the nature of disturbances and impacts from historic mining activities, as well as from natural mineralization at or near the ground surface in certain areas.

Because of the expected high degree of small-scale spatial variability in soil radionuclide concentrations (e.g., large concentration differences within just a few feet), and because of the need to differentiate between natural mineralization and actual historical impacts in areas where both may be present, a comprehensive high-density gamma survey was necessary. This survey utilized GPS-based radiological survey systems and characterization techniques. The survey also included gamma-based characterizations of the spatial distributions of radionuclides and metals in surface soils. This information was developed based on accepted scientific principles and methods, as well as on applicable regulatory guidance protocols.

1.2 General Approach

Advanced GPS-based gamma scanning systems with automated electronic data collection have been developed by Tetra Tech Inc. (Fort Collins, CO) and used extensively in the field (Meyer et al., 2005a; Meyer et al., 2005b; Johnson et al., 2005; Whicker et al., 2008). 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 or backpacks can quickly survey large areas and rough terrain while providing a high spatial density of measurements.

GPS-based gamma scanning technologies have become widely used and are consistent with radiological survey guidelines outlined in MARSSIM (NRC, 2000). Tetra Tech has developed a variety of such systems specifically for radiological characterization surveys at uranium recovery sites, and has also refined associated methods for application of this technology to meet various analytical objectives and regulatory requirements (Whicker et al., 2008).

For this project, gamma surveys utilized two GPS-based gamma scanning systems mounted on backpacks (Figure E-1b). Each backpack had 1 or 2 independent scanning systems coupled to a central data collection computer. In some cases, the mounting system configuration was modified to suit site conditions, but the functionality of the basic system did not change.

In conjunction with the gamma scanning, the NaI-based scintillometers used for scanning were cross-calibrated against a micro-rem meter (a tissue-equivalent plastic scintillometer). These data were used to statistically convert raw NaI scan data to estimates of gamma dose rate. This allows a common (instrument independent) basis of comparison for evaluations with future gamma surveys (surveys that may use different gamma survey instruments, configurations, or measurement technologies), and also provides information that may be used for risk assessment purposes.

Figure E-1b: Backpack scanning systems and configurations.

In addition, the correlations between NaI gamma readings and concentrations of radionuclides and certain metals in surface soils (0-15 cm) was evaluated. Depending on the statistical strength of such regressions, spatial and statistical information about soil radionuclide and metal concentrations can be extracted from raw NaI gamma survey data. This approach can generate information that can be used to guide direct soil sampling locations and to better characterize small-scale spatial variability in soil parameter distributions across all scanned areas (including areas between sampling locations).

Once the data were collected and analyzed, geographical information systems (GIS) software was used for statistical conversions of raw scan data sets, interpolation with kriging methods, and for data mapping and presentation purposes.

2.0 SAMPLING FREQUENCY AND LOCATIONS

The gamma survey covered areas of the site that were readily and safely accessible by foot while carrying backpacks, and that may have been impacted by past mining activities. Attempts were made to survey enough of a survey margin around such areas to identify where disturbed areas and associated radiological impacts were no longer visibly or measurably apparent. Specific target areas included areas identified in the scope of work such as waste rock piles at the 300, 700, and 900-foot levels, mine portal entrance areas (no entry into portals or other enclosed spaces was allowed), the open surface mining pit, the former ore stockpile area, and haul roads around the site. Additional scanning was conducted in some areas (such as the unmined I&L claim area) to characterize and delineate natural occurrences of uranium/thorium mineralization at or near the soil surface. In some cases, dense vegetation or steep slopes limited or prevented scanning in areas otherwise deemed useful for data collection. Practical judgment was exercised and in all cases, safety was of paramount importance.

With respect to correlation plot gamma measurements and associated soil sampling, locations were determined based on gamma survey results across key areas to capture data from a representative range of gamma readings and other conditions found at the site.

3.0 PROCEDURES

The following subsections describe the basic procedures that were followed for the gamma survey.

3.1 Scanning Systems Equipment, Setup, and Use

Each individual scanning system consisted of a Ludlum 44-10 NaI gamma detector and paired SiiRF III GPS receiver (WAAS enabled). The NaI detector was coupled to a Ludlum 2350 rate meter carried in the backpack. Simultaneous GPS and gamma exposure rate data for each independent scanning system were recorded every 1-2 seconds on a personal computer using special data acquisition software developed by Tetra Tech (Tetra Tech, 2007). The detectors were positioned at approximately 3 feet above the ground surface.

For the site surveys, the detectors were unshielded to simulate gamma exposure to receptors. During the third event, limited surveys were performed at the 700-foot level, the open pit, and at the OSA using paired unshielded and tungsten shielded detectors. The shielded detectors measure gamma emissions in the immediate vicinity of the receptor; whereas the unshielded detectors measure contributions from adjacent areas as well. Unshielded measurements are higher than shielded measurements and are used to assess gamma exposure. In areas of highly variable gamma emissions, shielded measurements provided a more reasonable delineation of the boundaries between zones of differing gamma field strengths.

During scanning, GPS-based tracking software with a separate GPS receiver was used to track the progress and coverage of each day's scan trajectories. Base maps of site boundaries or other site features of primary interest were loaded on the tracking software to help guide and limit coverage to intended survey areas. This minimized trajectory overlap and helped to insure adequate ground coverage.

In general, the target ground coverage was greater than 50%. Terrain, accessibility, and safety issues often governed actual coverage attained. Scanning speeds ranged from about 1-4 mph, depending on terrain and accessibility.

After each day of gamma scanning, the data were downloaded into a project database and mapped using Gamma Viewer® software (Tetra Tech Inc., 2006). This enabled immediate onsite assessment of results for adequacy of coverage, and to identify potential issues that may have occurred during data acquisition throughout the day. One system malfunctioned during the survey and failed to work properly. Affected data were eliminated from the project database and the system was not used for further scanning as the problem could not be resolved in the field.

3.2 Cross-Calibration OF NaI Detectors Against a Micro-Rem Meter

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 less energy dependent instruments such as a high-pressure ionization chamber (HPIC) or a micro-rem meter (tissue equivalent plastic scintillometer). Depending on the radiological characteristics of a given site, NaI detector readings can differ significantly from corresponding HPIC or micro-rem meter measurement values. Such differences are usually proportional to the magnitude of exposure rate being measured (larger differences are typically observed in higher gamma fields).

Instrument cross-calibrations are necessary to estimate true exposure rates or approximate dose rates. Due to the difficulty of shipping a large HPIC filled with pressurized argon gas, a handheld micro-rem meter was used for instrument cross-calibrations at the Ross Adams site.

To perform NaI/micro-rem cross-calibrations, static measurements were taken at each correlation plot location to span a representative range of exposure rates found at the site. At each measurement location, 10 individual readings were collected from the micro-rem meter as well as from a randomly chosen NaI detectors used for site scanning. Values for each instrument type were averaged for each location. The resulting paired NaI/micro-rem data were analyzed by polynomial regression to enable conversion of NaI-based gamma survey data to approximate tissue equivalent dose rates (Figure E-1c). The gamma exposure rate is a function of the K-40 and Th-232 decay series radionuclides, as well as the Ra-226 concentration. The K-40 and Th-232 ratio is not necessarily a constant in an area with a mixture of geologic materials, which is the case at the Site. As such, the polynomial relationship more accurately and realistically defines the relationship of the paired NaI/micro-rem data. Validity of applying cross-calibration results from a single randomly selected NaI detector used for the survey to all scan data is supported by the data quality control results (Section 3.4).

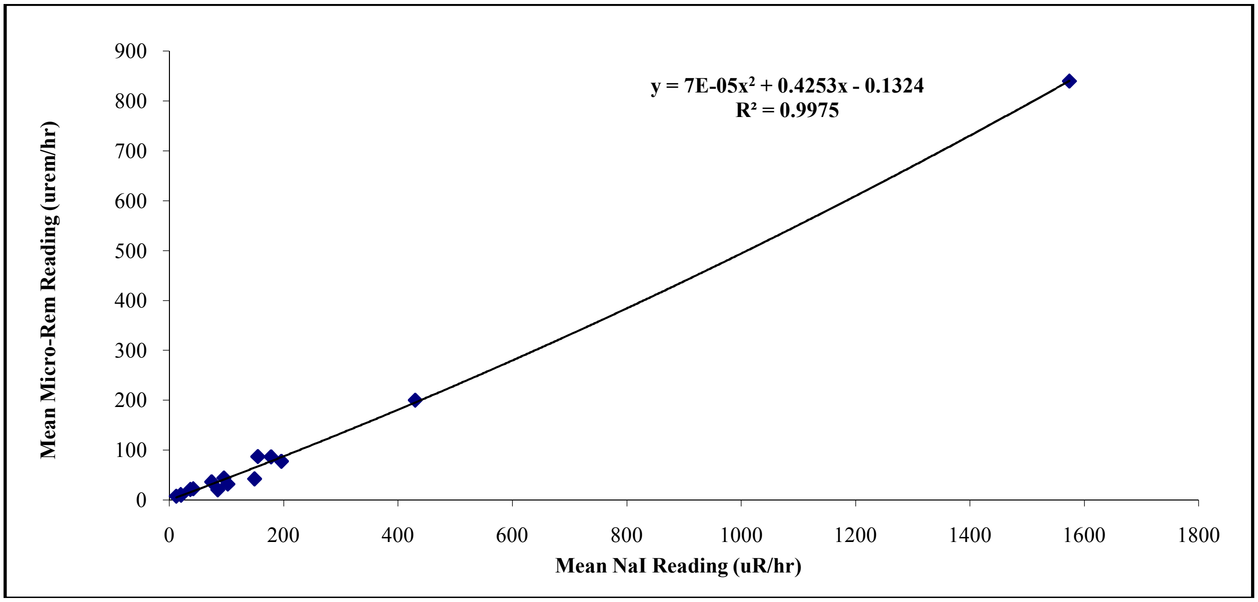

Figure E-1c: Cross-Calibration Plot Micro-Rem Reading vs NaI Reading (2nd Order Polynomial)

3.3 Soil Sampling and Gamma/Soil Parameter Correlations

The primary objective of soil sampling conducted in conjunction with the gamma survey was to develop a predictive relationship between gamma readings and concentrations of select radionuclides and, potentially, metals in surface soils (e.g. Ra-226, U-nat, Th-232, As, Pb). This relationship could be used to estimate concentrations of these soil parameters across scanned areas. Cosmic sources of gamma radiation are relatively constant at locations with a given latitude and elevation (Stone et al., 1999). Differences in gamma survey readings at the Site are thus expected to be due to differences in gamma-emitting radionuclides in soils at or near the ground surface. Concentrations of Ra-226 and Th-232 and their decay products are expected to correlate well with gamma readings. In areas of past mining disturbance, these decay series are also expected to be elevated along with certain metals associated with uranium ore. However, the two decay series have the potential to confound individual correlations, depending on the relative consistency of Ra-226/Th-232 concentration ratios.

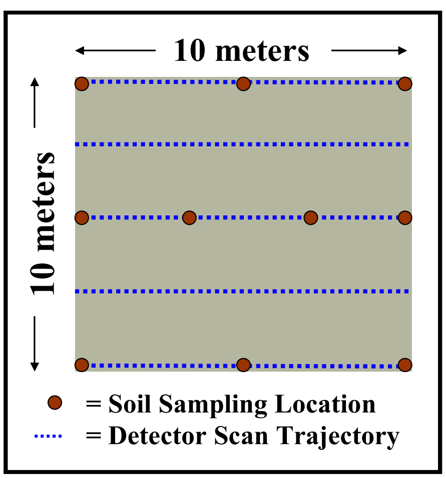

Figure E1-d: Approximate design of 100 m^2 soil sampling/scanning correlation plots.

Gamma/soil sampling correlation data were collected at locations covering a representative range of gamma readings found at the site. Composite soil samples were collected at these locations across 100 m^2 plots. A diagram depicting the approximate sampling design for 100 m^2 plot sampling and gamma measurements is shown in Figure E-1d. Within each 100 m^2 plot, 10 soil sub-samples were collected to a depth of 15 cm then composited into a single sample. A separate gamma scan of each 100 m^2 plot was also conducted, and the average reading for the plot was calculated to pair with the corresponding soil sampling results for individual radionuclides and metals of interest.

GPS readings were collected at the center of each correlation plot location and recorded in the field log book. Soil samples were placed in plastic baggies and labeled. An analytical request and chain-of-custody form were filled out and shipped with the samples to ALS Laboratory in Fort Collins, CO for analysis of radionuclides and metals.

3.4 Data Quality Assurance/Quality Control

All radiological characterization projects conducted by the Tetra Tech include data QA/QC protocols. In general, quality assurance (QA) includes qualitative factors that provide confidence in the results, while quality control (QC) includes quantitative evidence that supports the validity of results (e.g., data accuracy and precision).

Quality control documentation for this project includes the following:

- The gamma survey was conducted on three separate sampling events (in June, July, and September of 2009). Just prior to each visit to the site, static instrument QC measurements were performed in Fort Collins, CO for each NaI detector used for scanning. This was done in a controlled indoor environment to quantify the consistency of readings between detectors under identical measurement geometries. The mean of 20 individual QC measurements of background, as well as a Cs-137 check-source was determined under a designated and consistent geometry. For normally distributed count data, over 99% of measurements are expected to fall within ± 3 standard deviations from the mean. Any instrument with measurements falling outside ± 3 standard deviations from the mean of all QC measurements on both background and check source charts indicates unacceptable instrument performance. All detectors taken to the site for field scanning performed within acceptable QC limits under these criteria. Control charts were constructed to document this information (Figure E-1e - Figure E-1f).

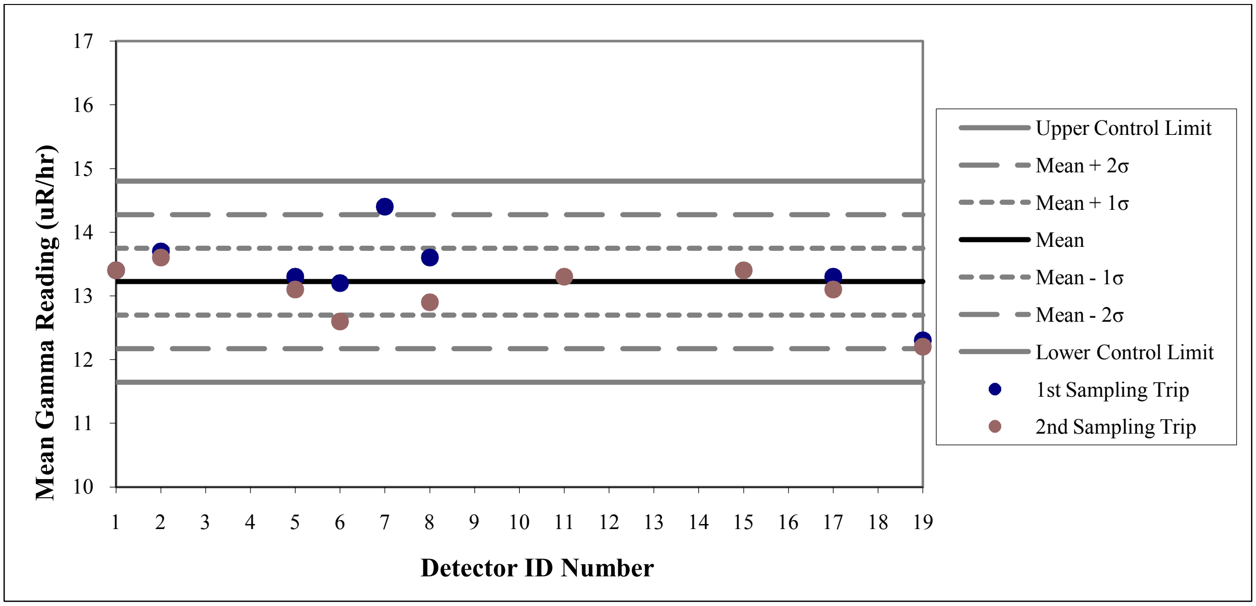

Figure E-1e: Background Instrument QC Charts for Gamma Scanning System (1st and 2nd Sampling Events)

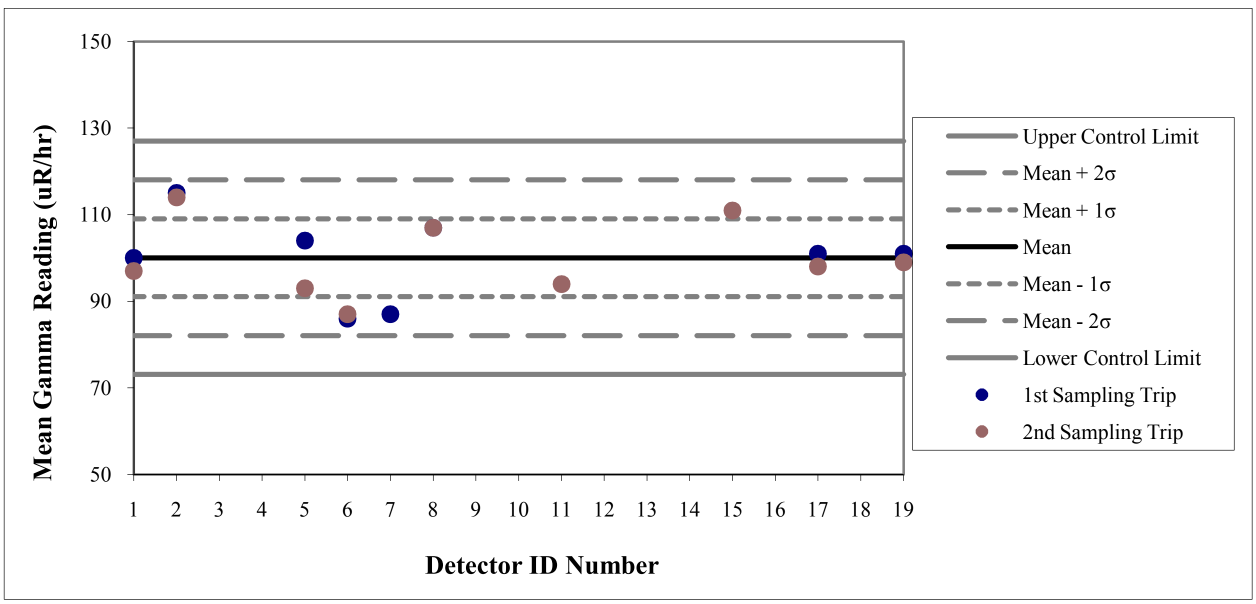

Figure E-1f: Source Instrument QC Charts for Gamma Scanning System (1st and 2nd Sampling Events)

- During the survey, the actual performance of each scanning system was tested in the field each day by scanning along a designated strip. At a minimum, these "field strip" scans were conducted before each day's scanning (sometimes at the end of the day as well, weather and other factors permitting). There were two field strips for the project: an initial one along the haul road several hundred meters west of the staging area, and subsequent one that was established just east of the staging area for greater efficiency. The day that field strip measurements were moved from the west strip to the east strip (on July 21, 2009), field strip measurements were conducted at each of the two different locations with the same scanning detectors. This ties the two field strips together in terms of verification of system performance at the two different locations. Under actual field conditions, scanning systems performed within acceptable QC limits throughout the project (Figure E-1g and Figure E-1h). As previously mentioned one system malfunctioned during the survey and failed to work properly (backpack one, right side; "B1-R"on 7-22-09). The affected data were eliminated from the project database and the system was not used for further scanning as the problem could not be resolved in the field. Limited gamma scanning was required during the 3rd sampling event and therefore only one detector was used in each backpack for the duration of the scanning.

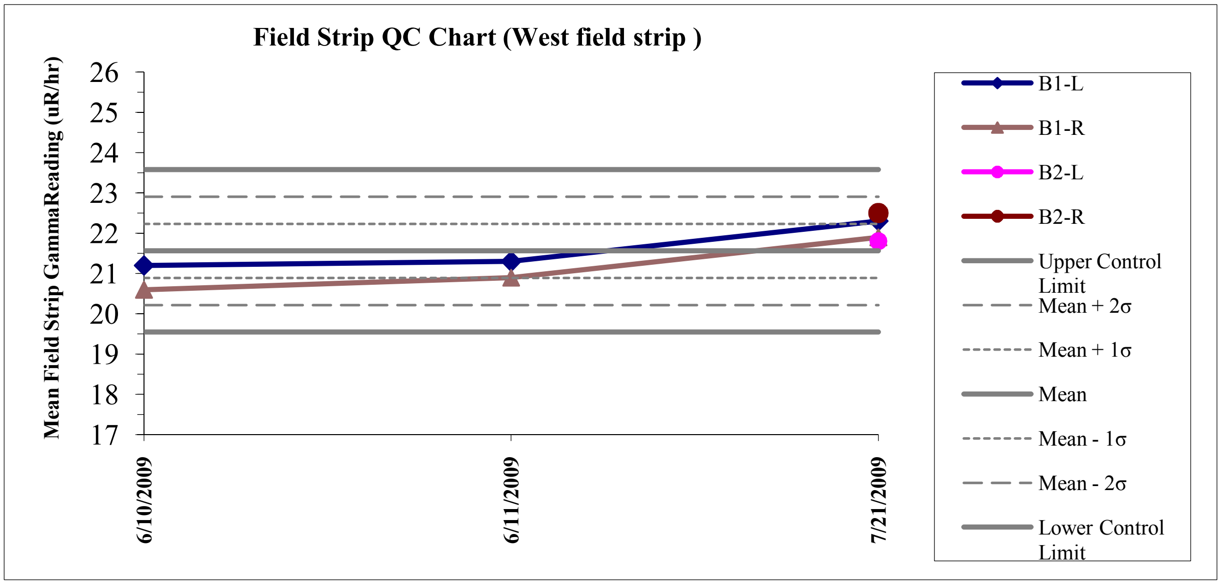

Figure E-1g: Field strip QC Chart (West Field Strip)

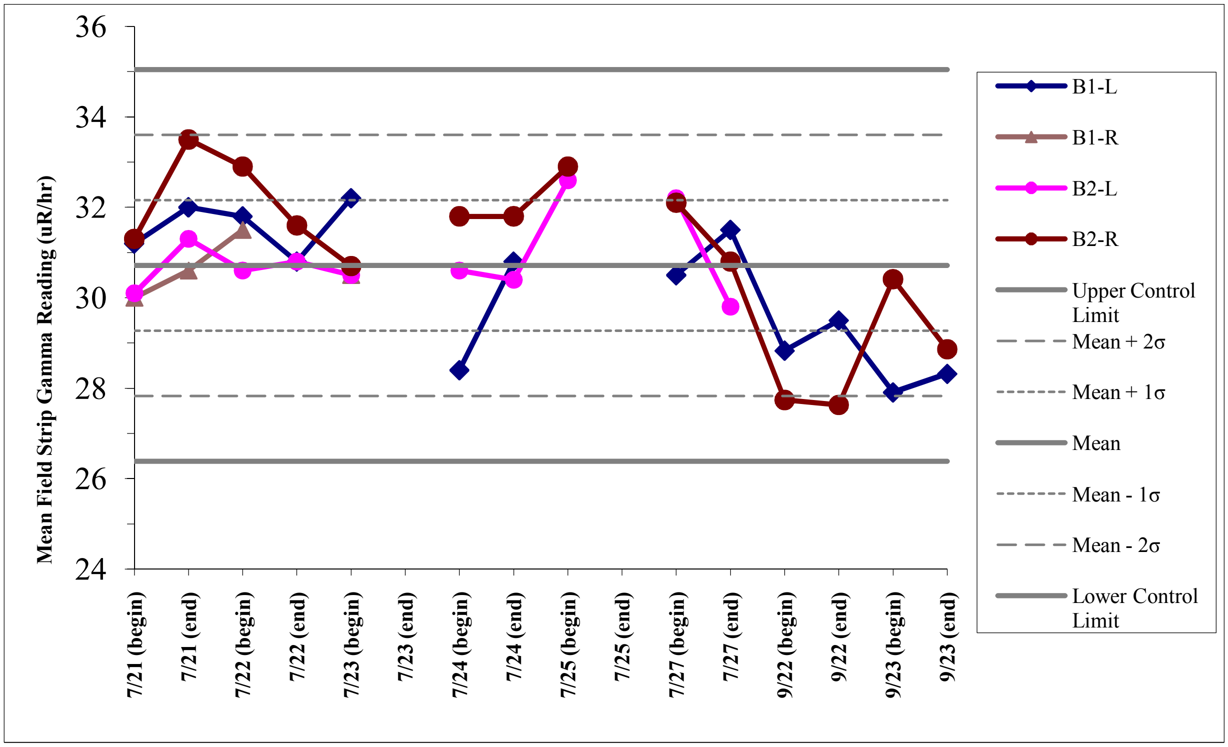

Figure E-1h: Field strip QC Chart (East Field Strip)

Data quality assurance factors for this project include the following:

- All detectors used for gamma scanning at the site(s) were calibrated by the manufacturer within one year prior to the date of use on this project (calibration certificates are on file at Tetra Tech's Fort Collins office).
- The micro-rem meter was calibrated within one year prior to the dates of use on the project (calibration certificate is on file at Tetra Tech's Fort Collins office).
- Chain-of-custody protocols were followed for soil sampling and contract laboratory analyses (relevant forms are included in the appendices report).
- Tetra Tech's Radiation Protection and Measurements Group staff has extensive qualifications and well over 100 years of combined experience for performing radiological measurements and related site assessments (CV's provided on request).
- Tetra Tech's radiological survey methodologies and technologies 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., 2008; Whicker et al., 2006).

3.5 Documentation and Record Keeping

A field log was maintained daily during the scan. Date, field strip data, site conditions, correlation plot and cross-calibration locations and measurement data, and other pertinent information were recorded and are included in the report appendices. Gamma scan data was backed up on external storage devices and Tetra Tech servers.

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APPENDIX E-2
SOIL CORRELATION RESULTS

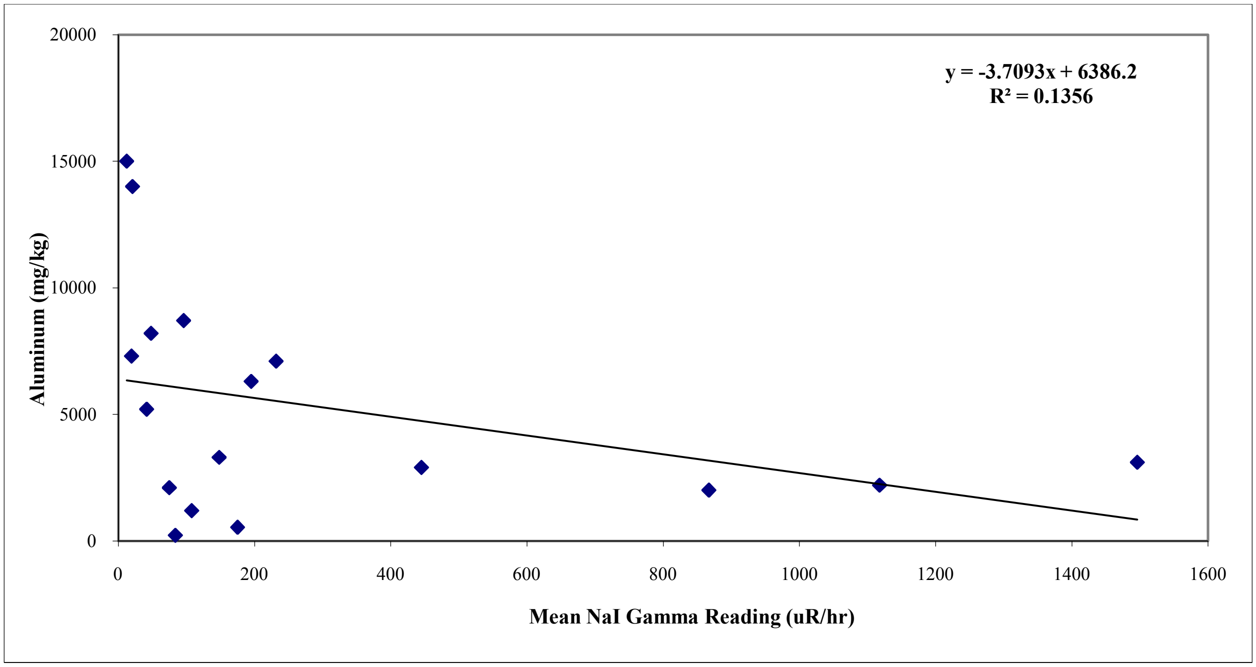

Figure E-2a: Aluminum vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

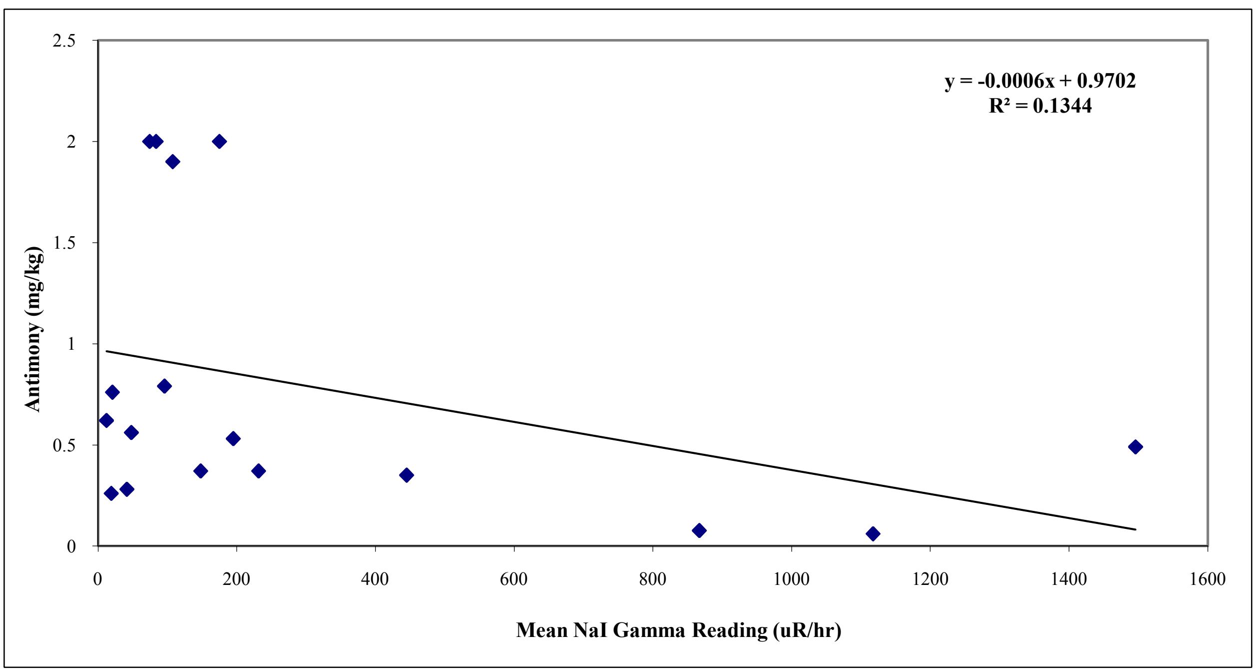

Figure E-2b: Antimony vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

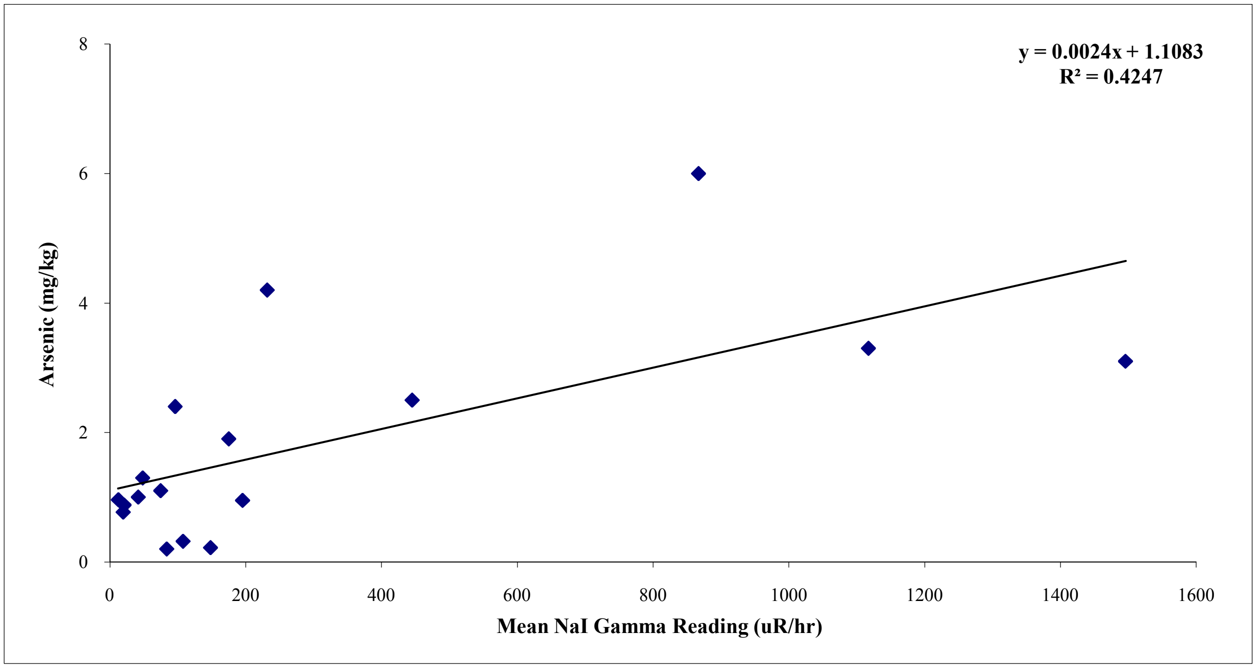

Figure E-2c: Arsenic vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

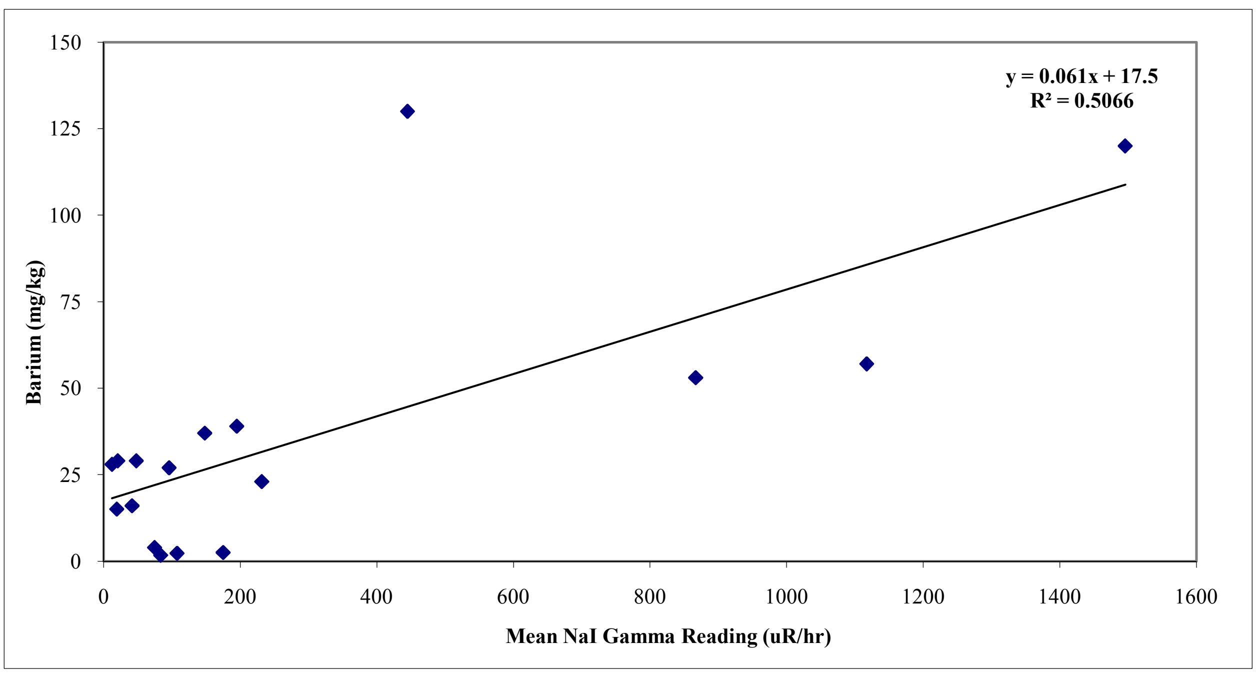

Figure E-2d: Barium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

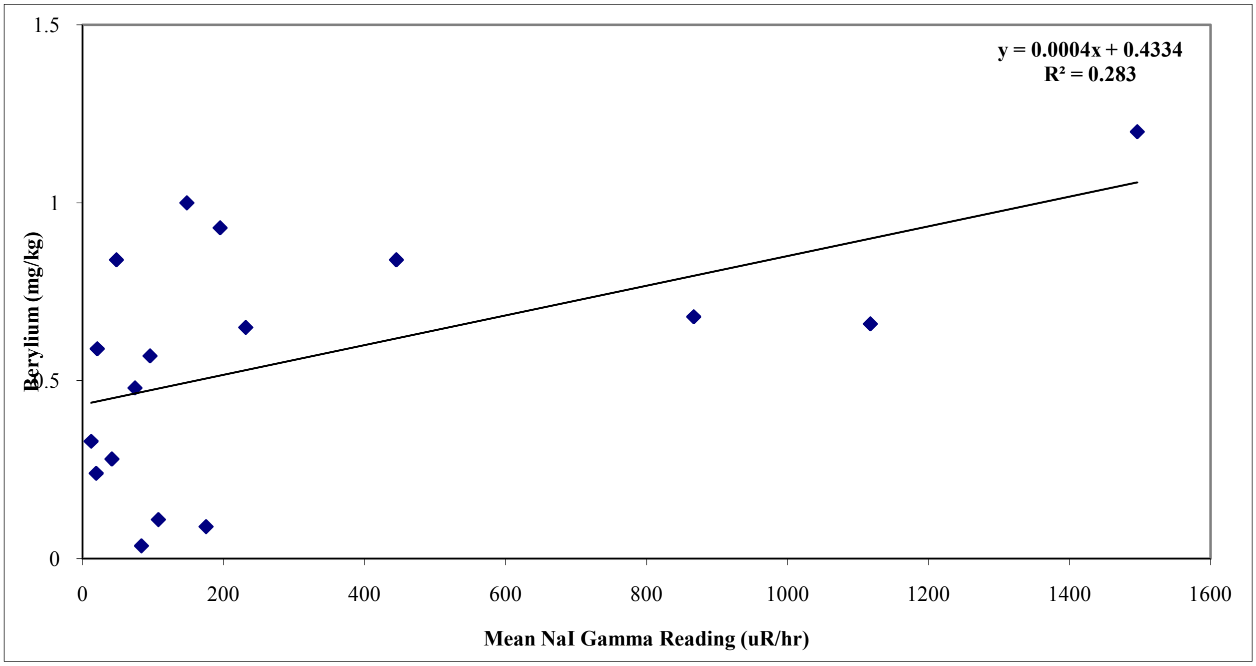

Figure E-2e: Beryllium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

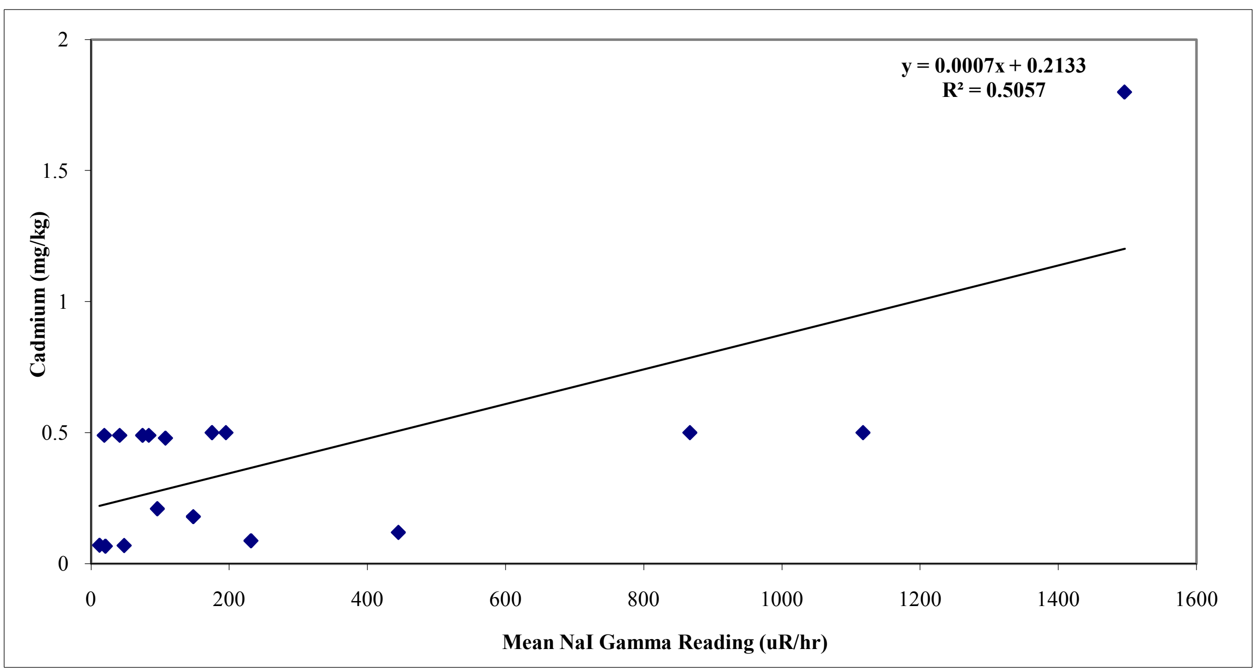

Figure E-2f: Cadmium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

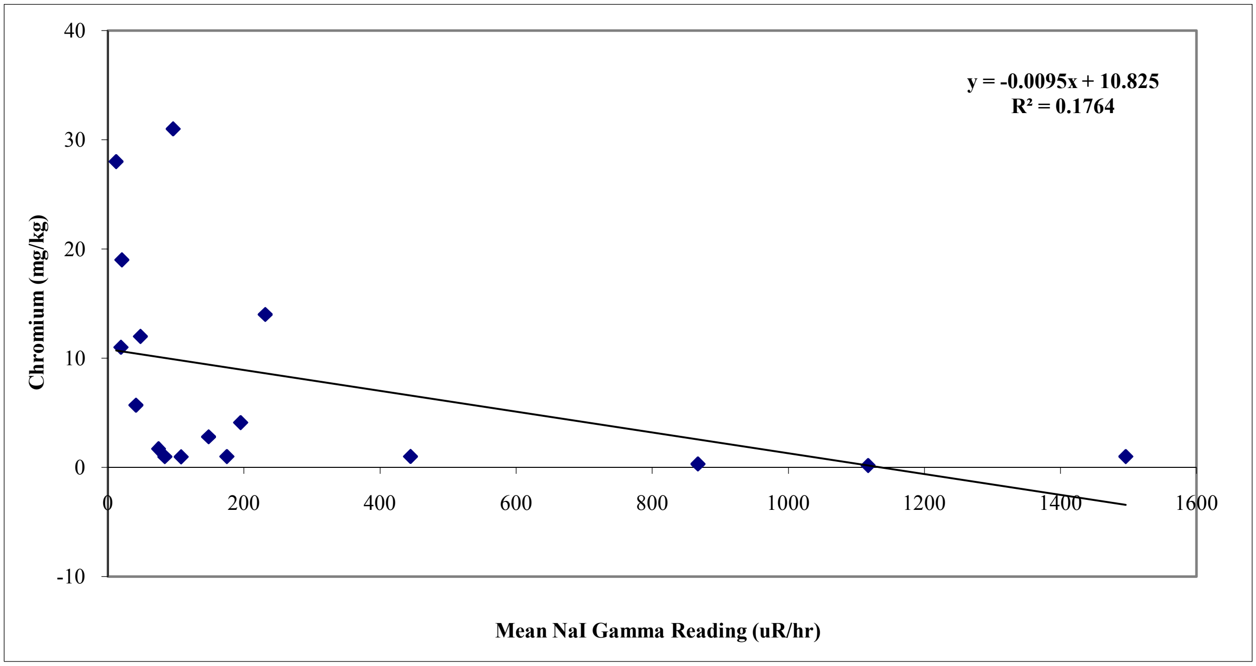

Figure E-2g: Chromium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

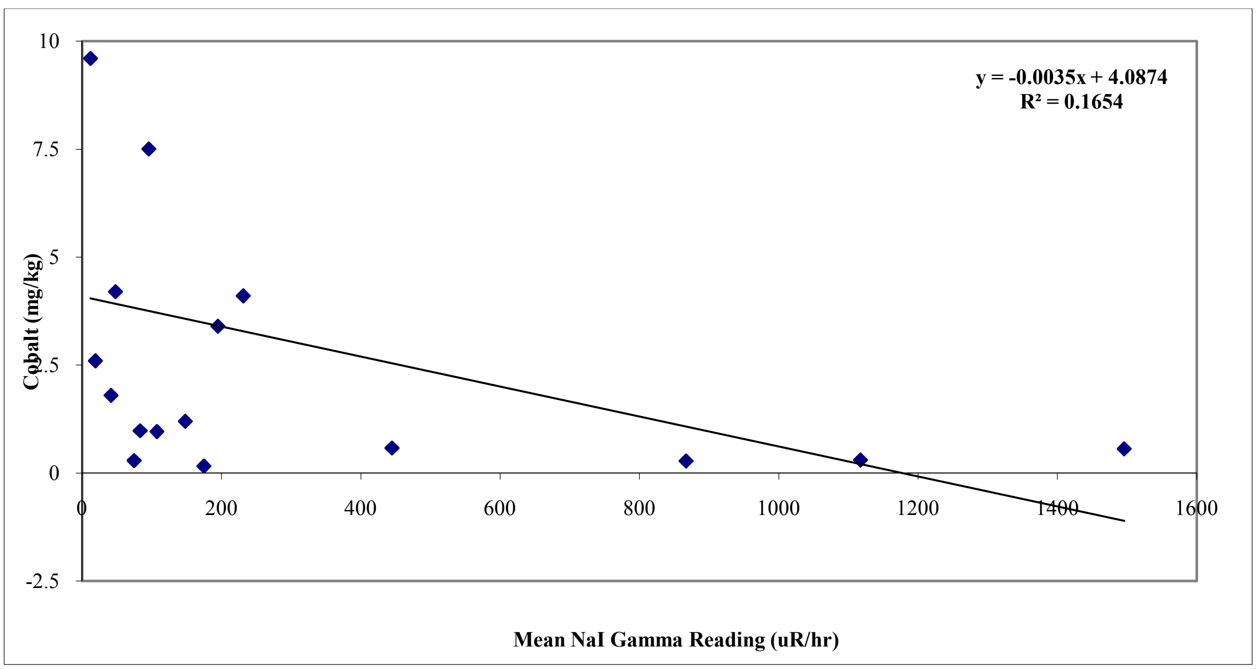

Figure E-2h: Cobalt vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

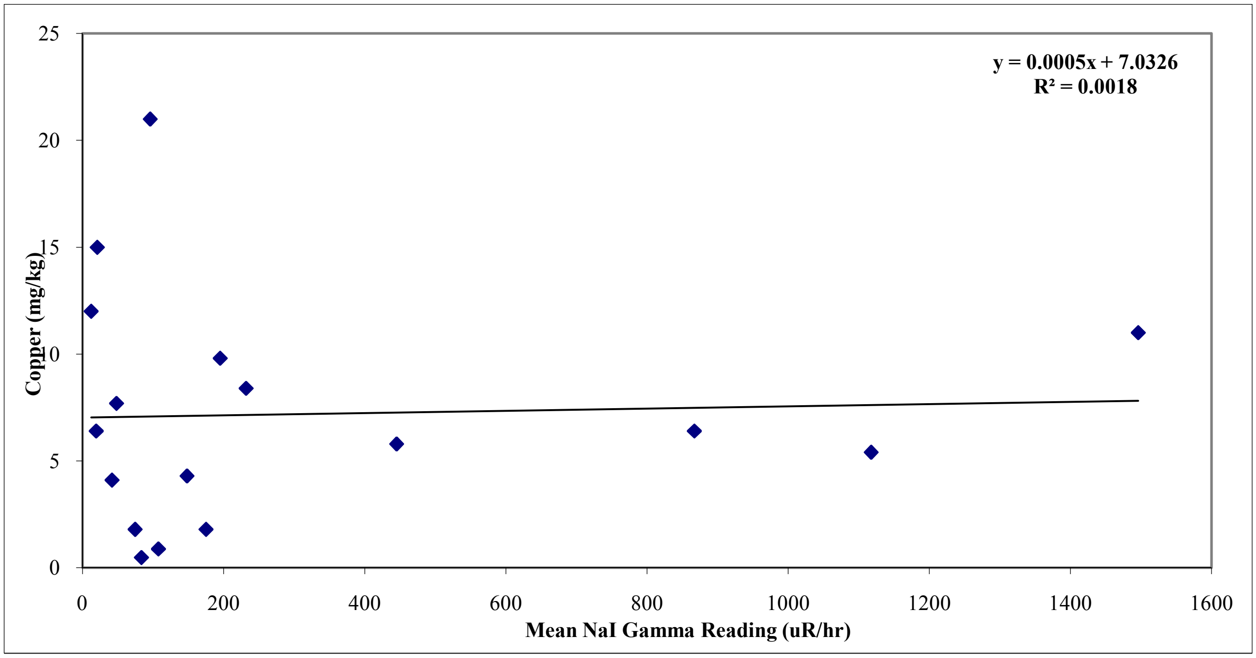

Figure E-2i: Copper vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

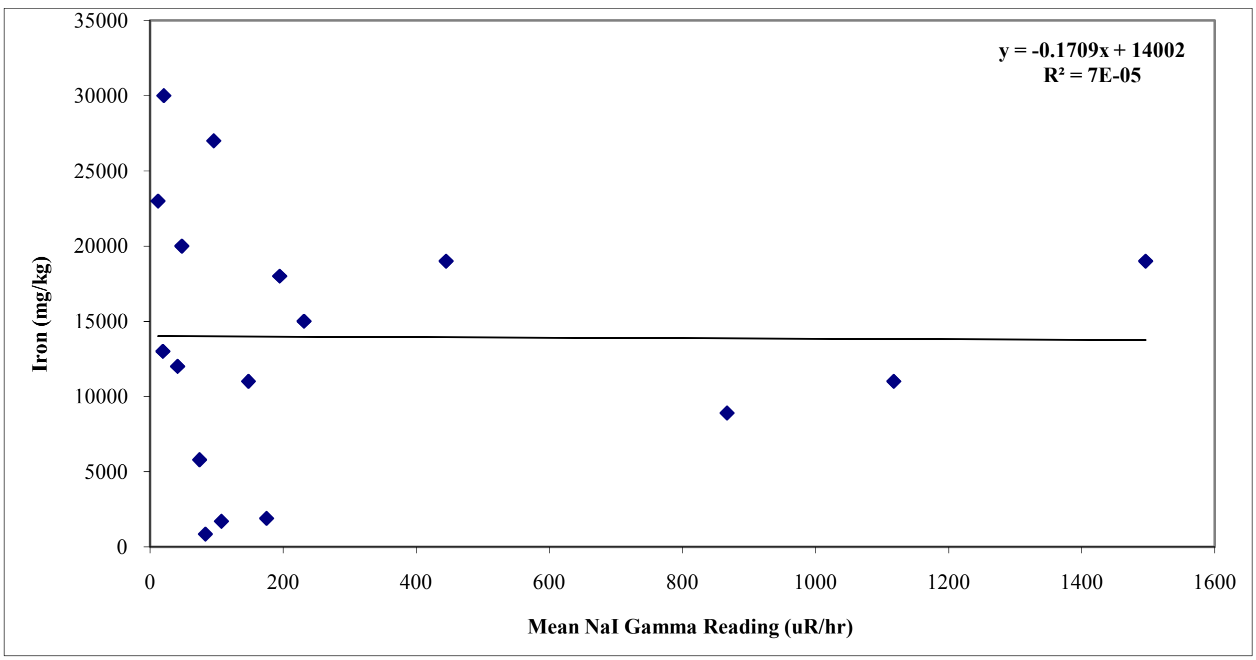

Figure E-2j: Iron vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

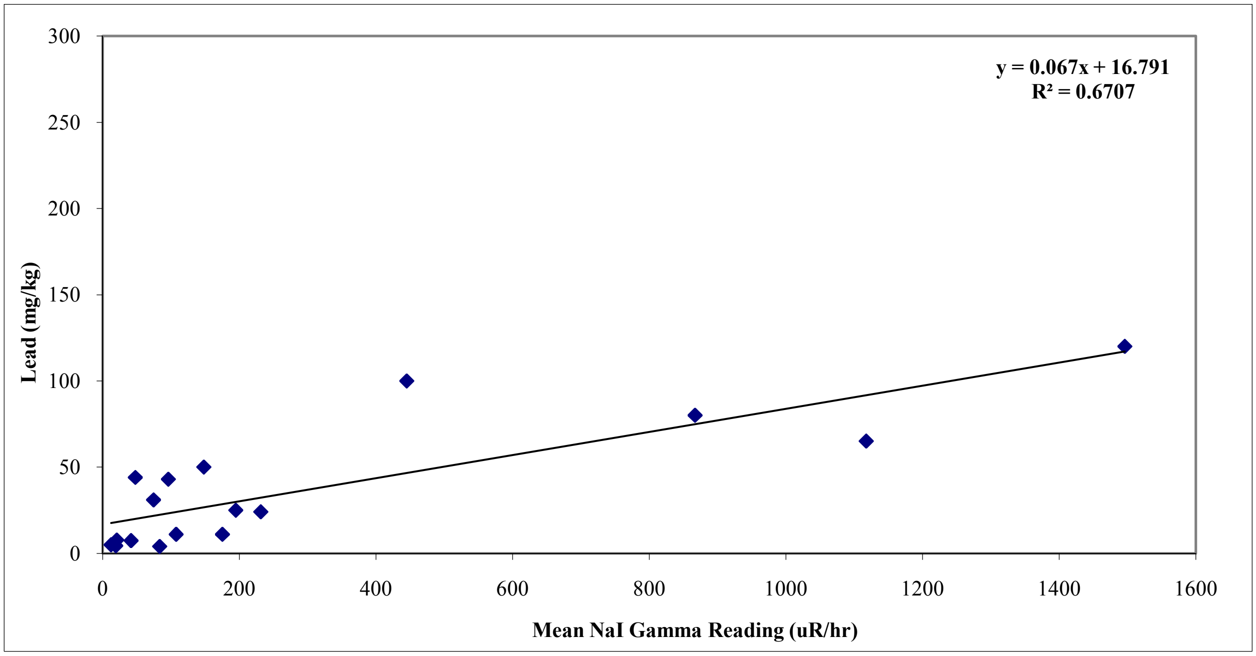

Figure E-2k: Lead vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

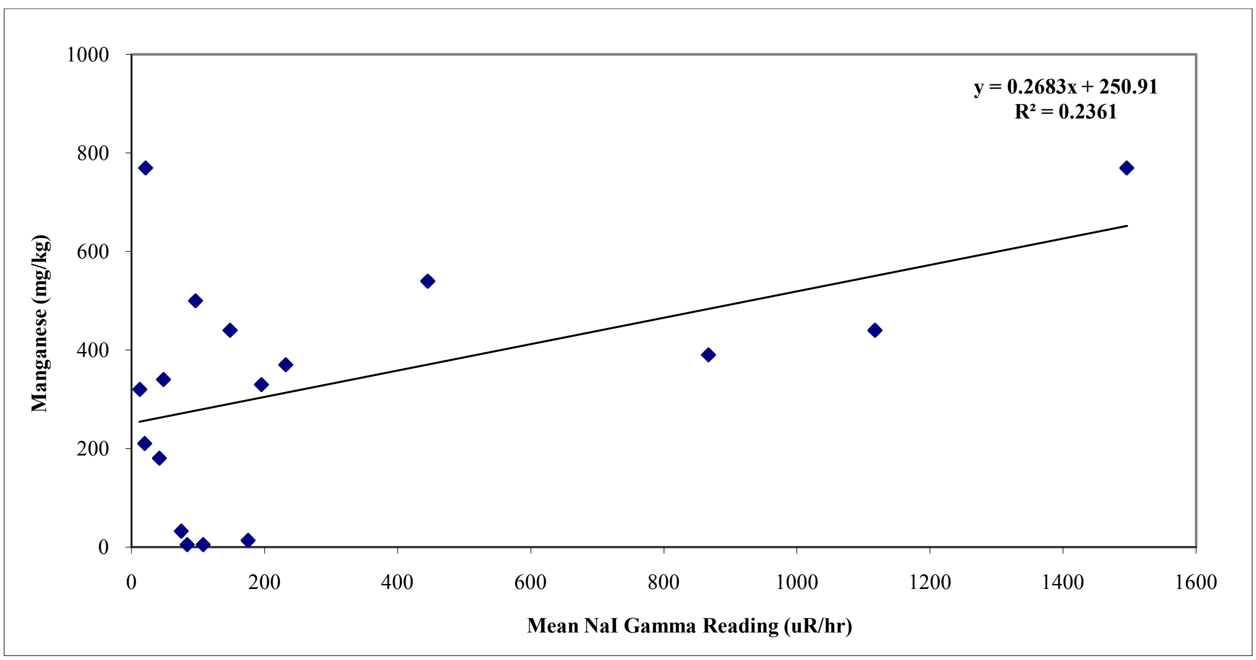

Figure E-2l: Manganese vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

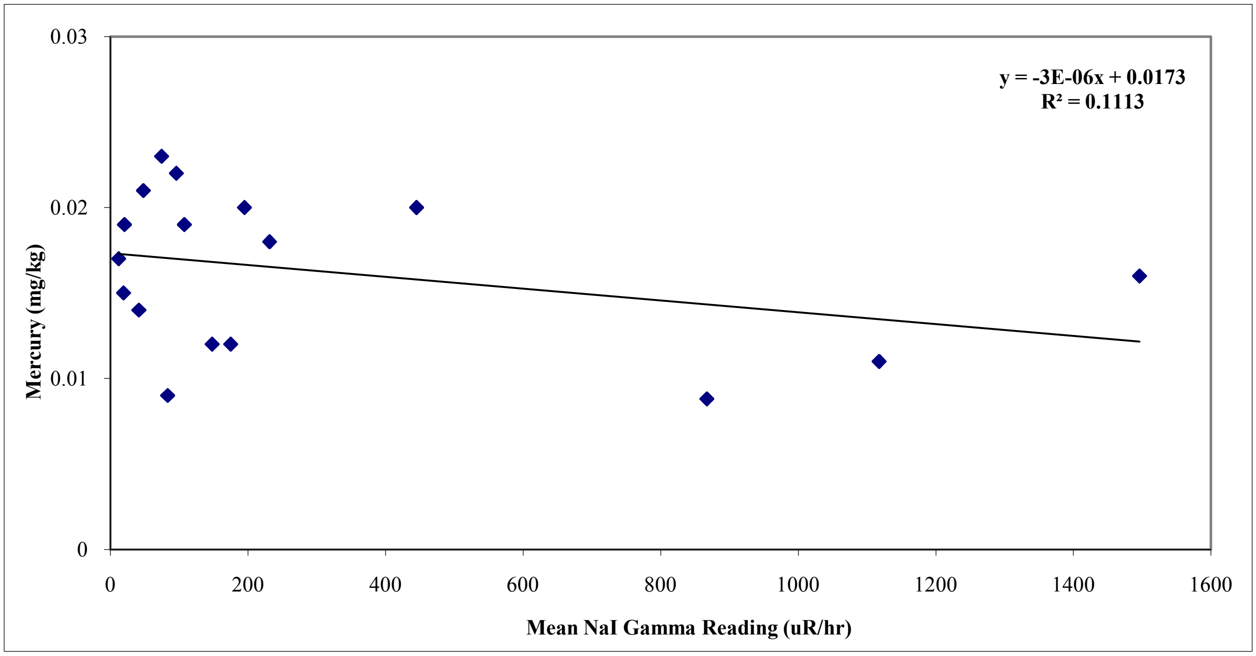

Figure E-2m: Mercury vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

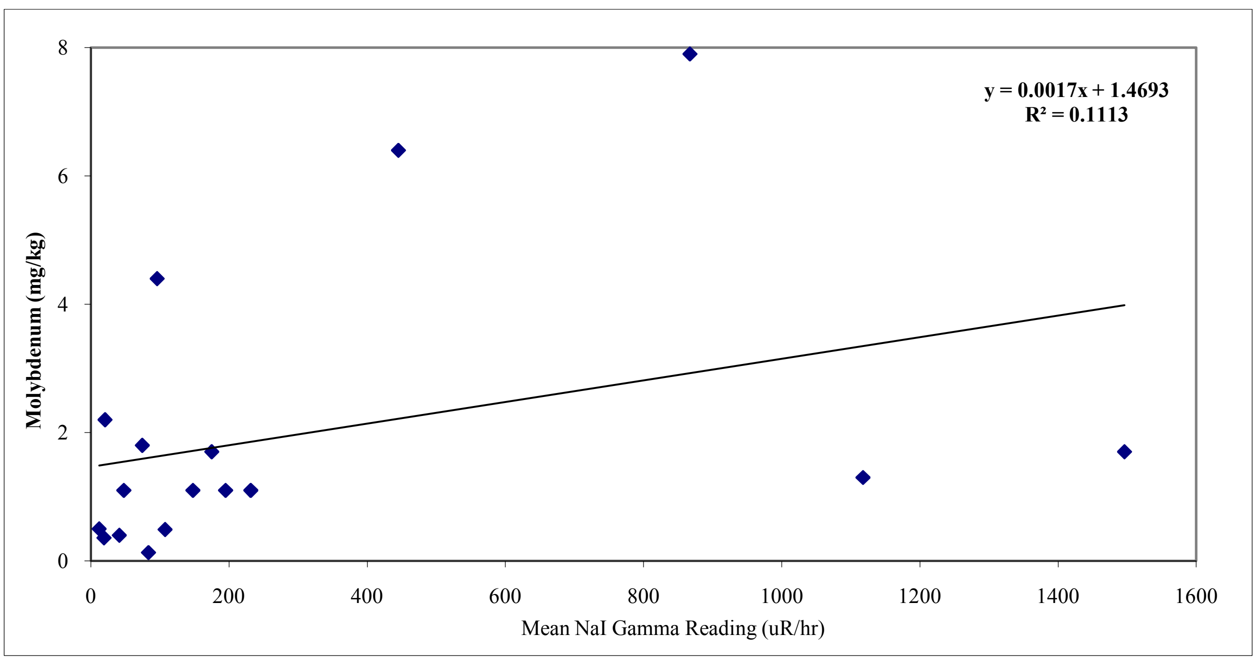

Figure E-2n: Molybdenum vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

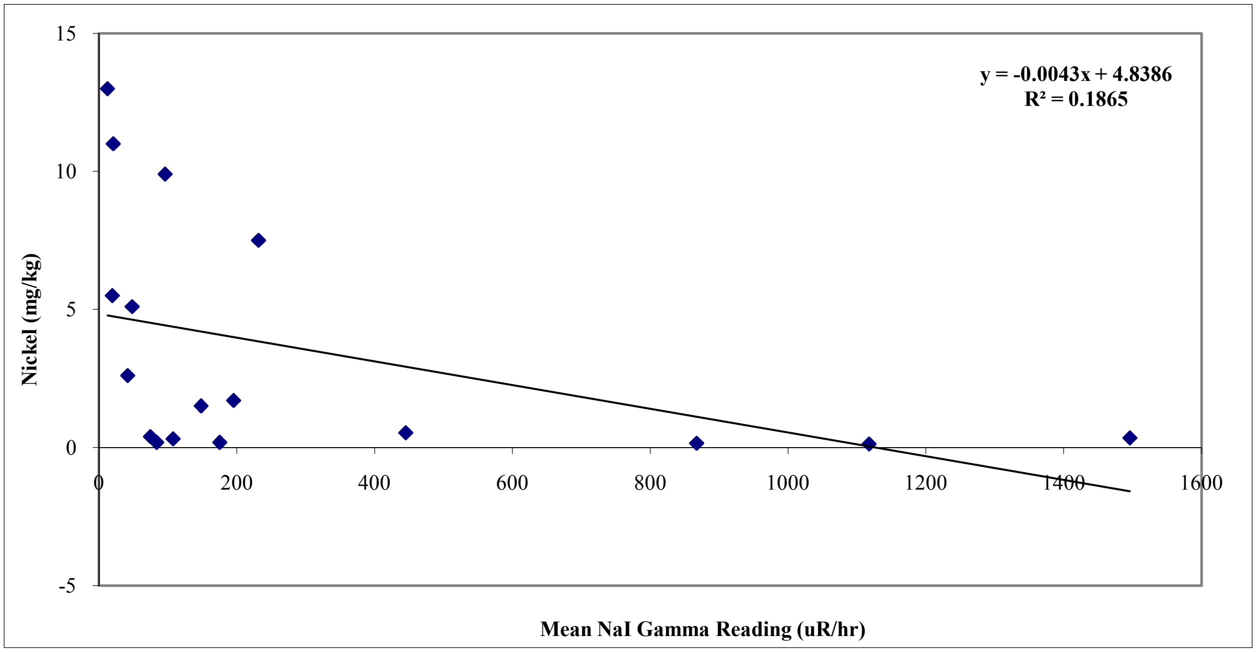

Figure E-2o: Nickel vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

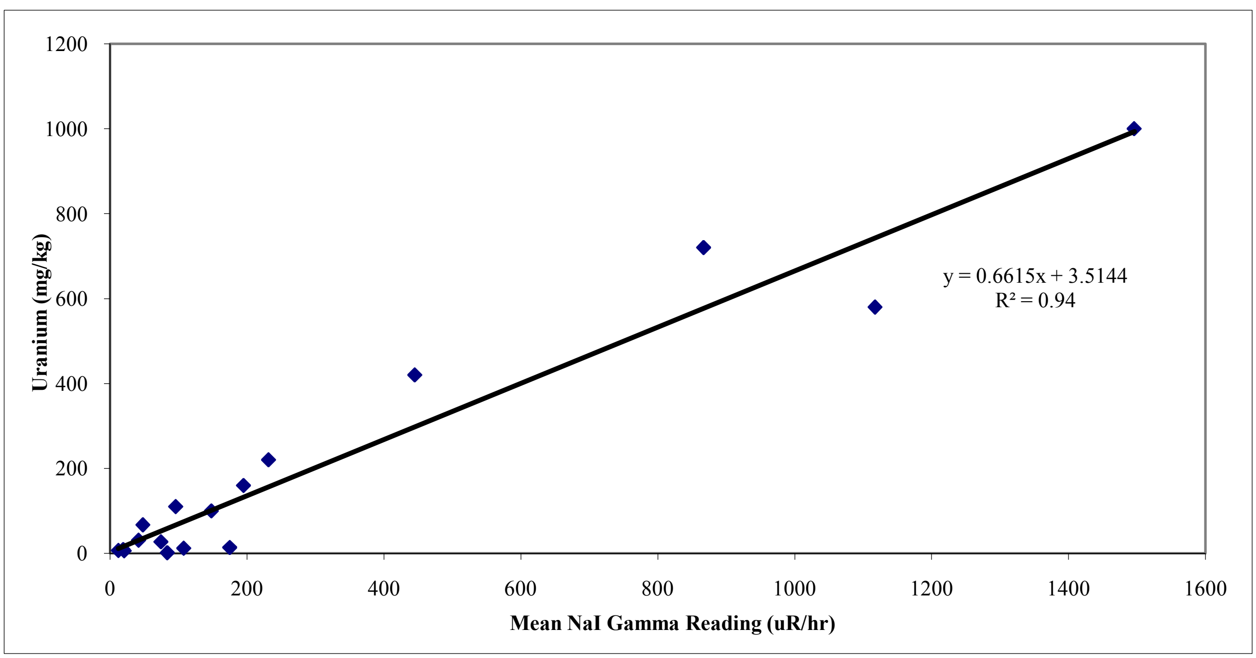

Figure E-2p: Uranium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

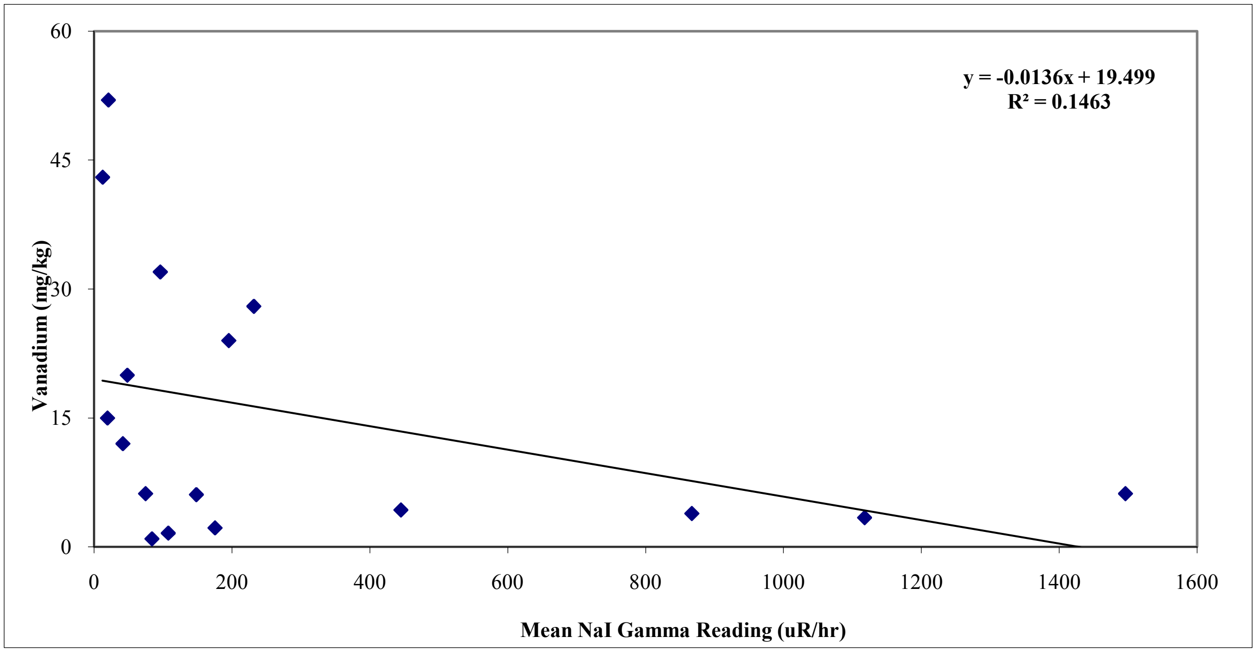

Figure E-2q: Vanadium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

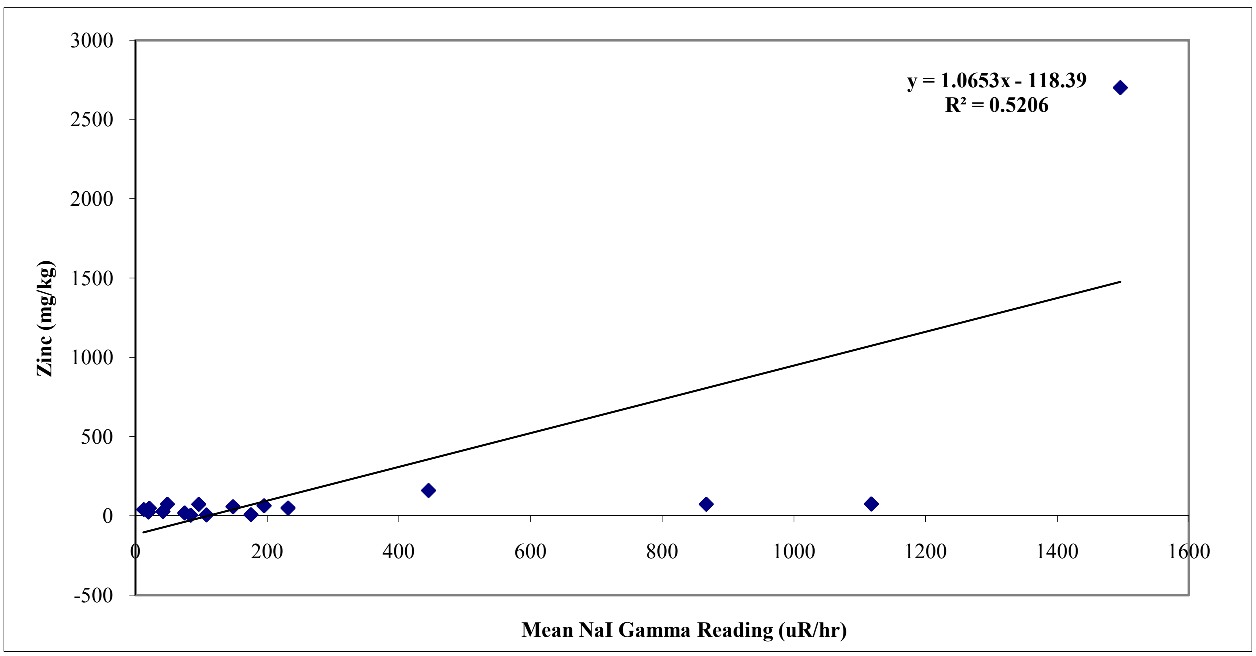

Figure E-2r: Zinc vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

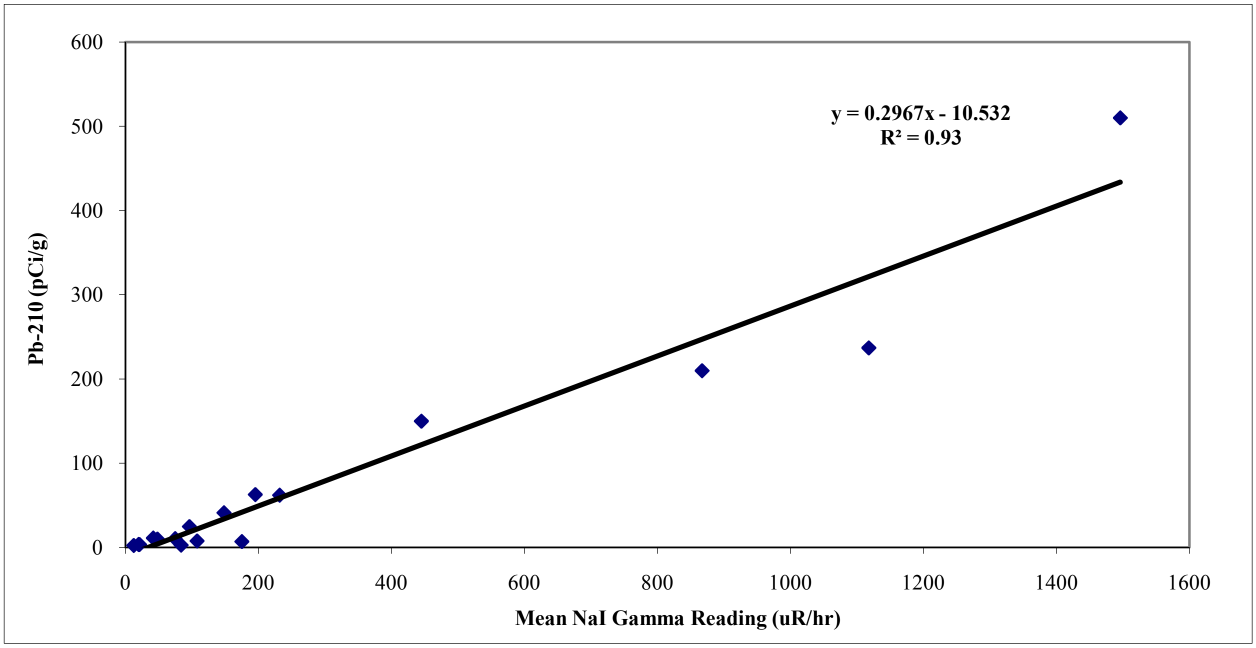

Figure E-2s: Pb-210 vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

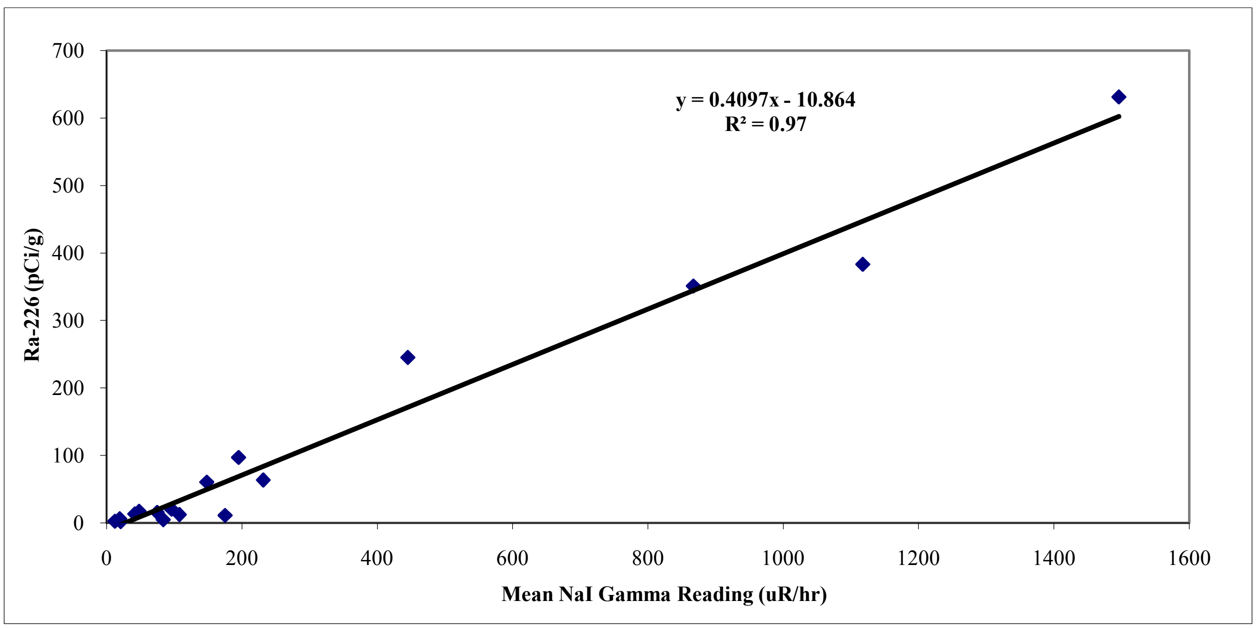

Figure E-2t: Ra-226 vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

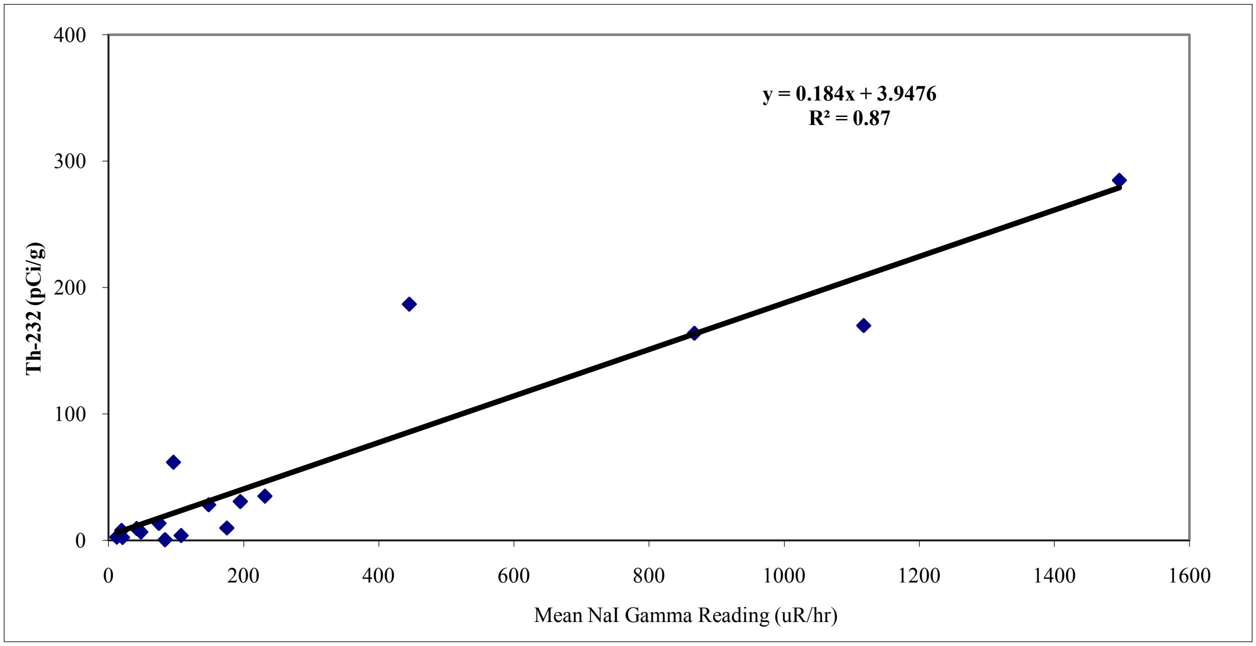

Figure E-2u: Th-232 vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

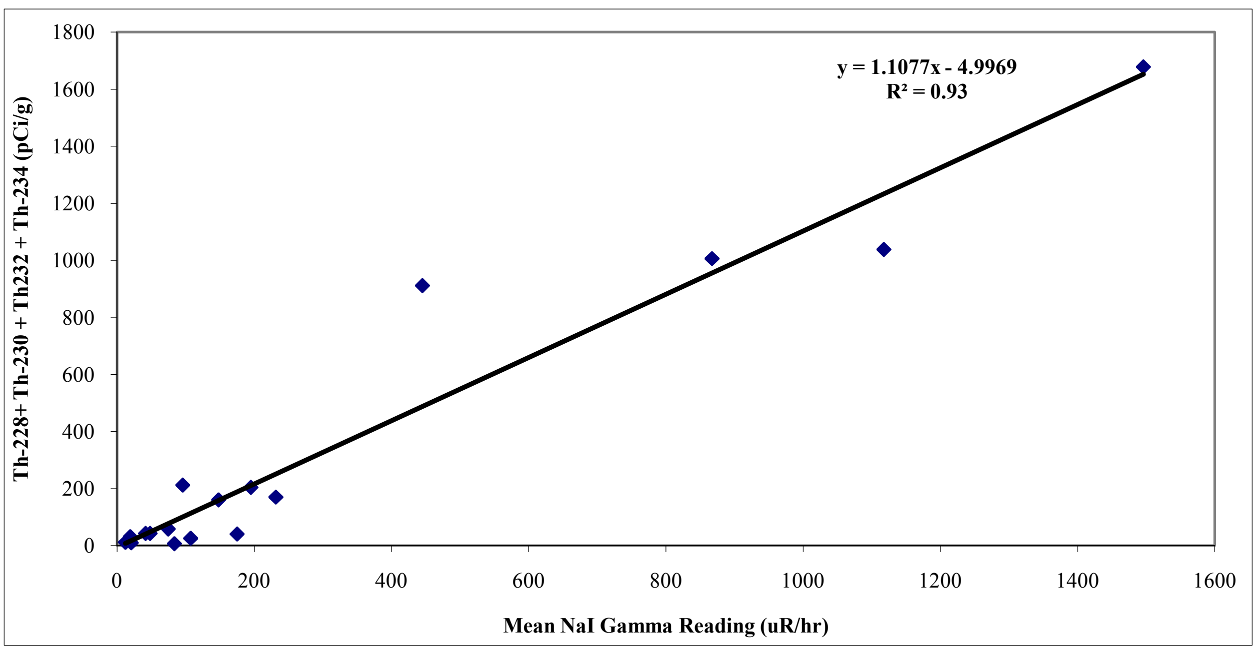

Figure E-2v: Total Thorium vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

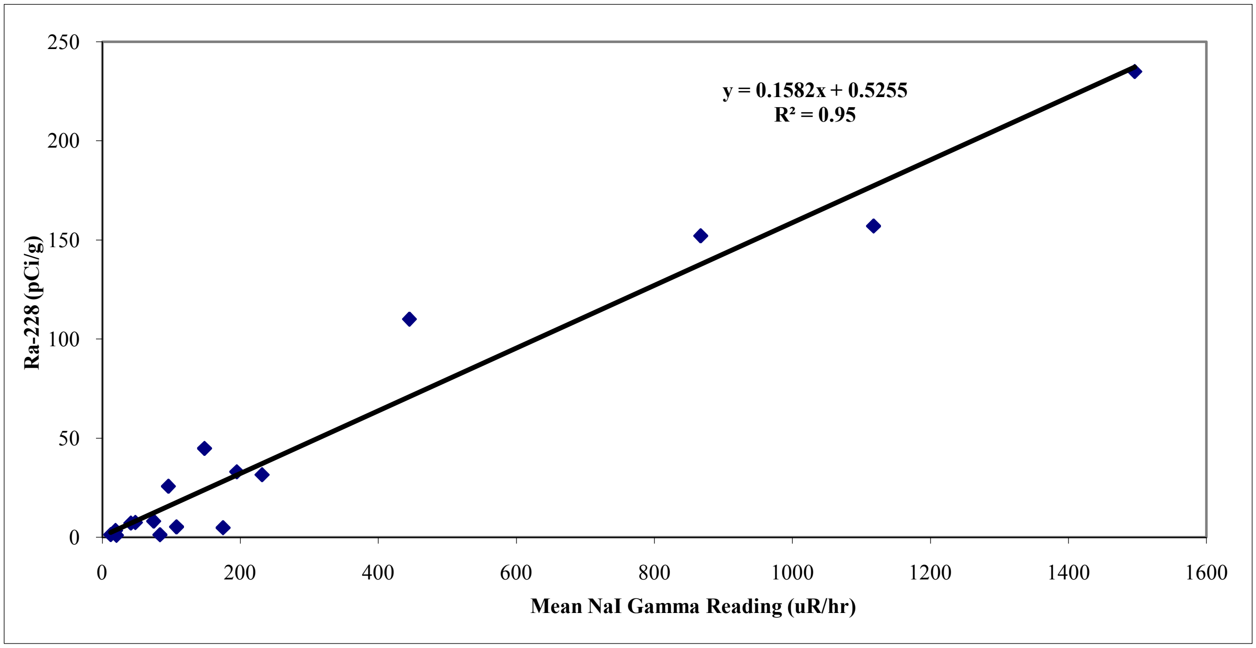

Figure E-2w: Ra-228 vs. Gamma Reading Soil Correlation Plot – Linear Regression Model

Note: Analysis was performed on Selenium, Silver, and Thallium; however, the results are not included in this Appendix because the majority of the metals analysis were below detection limits

APPENDIX E-3
GAMMA SURVEY MAPS

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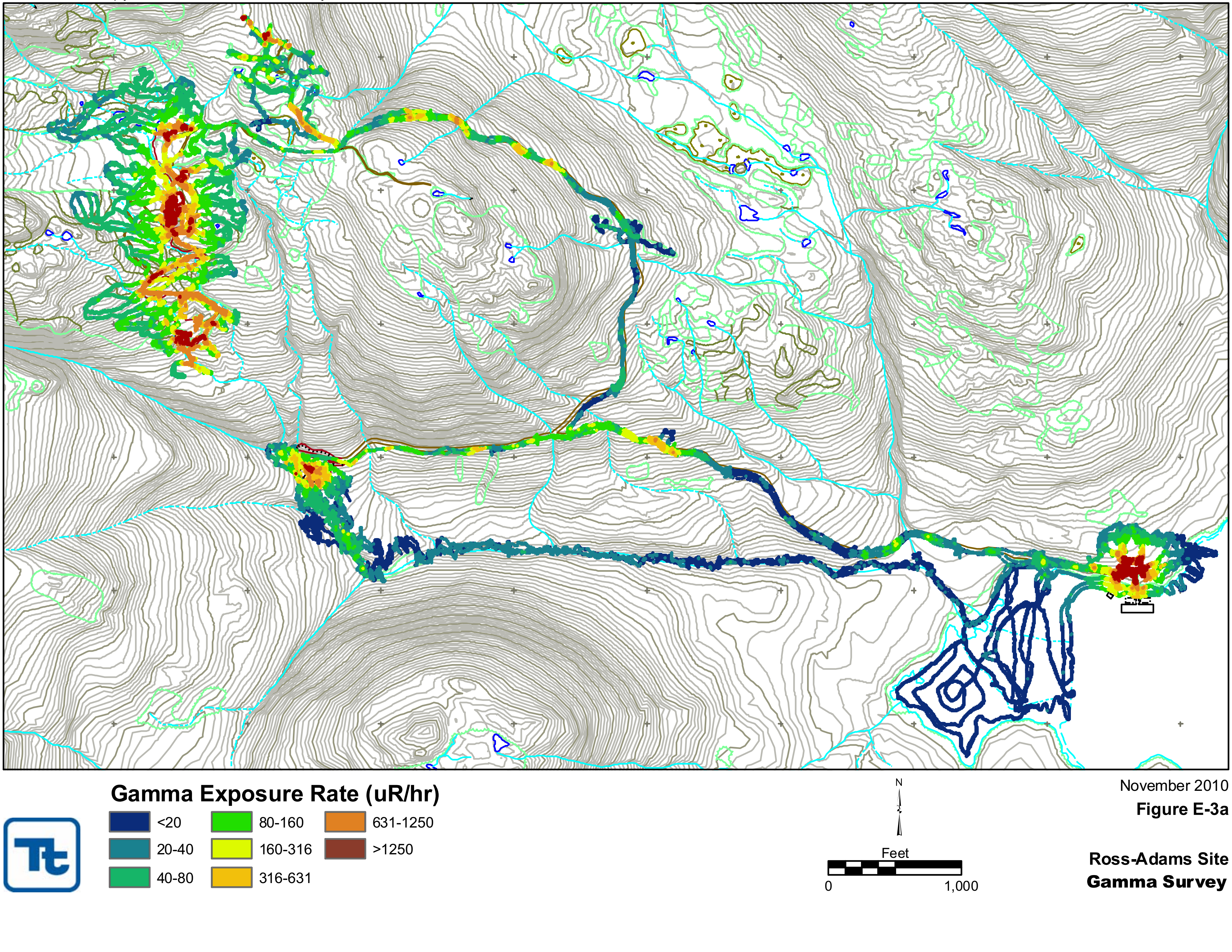

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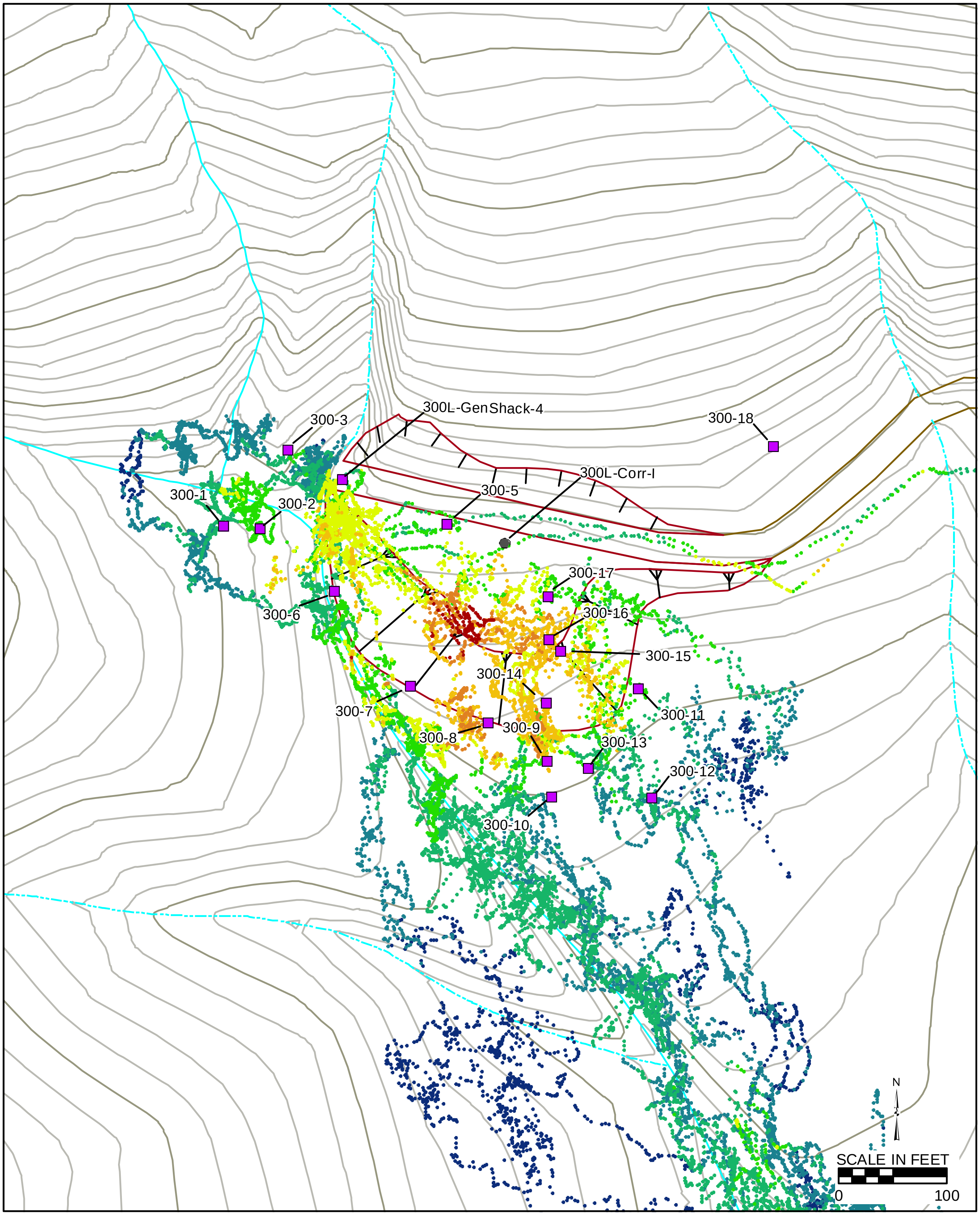
Figure E-3a

Ross-Adams Site
Gamma Survey



MAR 03, 2010 N:\arcprj2\Gamma\181862\mxd\E3B.mxd BY:jesse.carver

Gamma Exposure Rate (uR/hr)

<20	80-160	631-1250
20-40	160-316	>1250
40-80	316-631	

Outside of Limits of Gamma Survey

Gamma/Soil Correlation Plot Sample

Discrete Soil Sample

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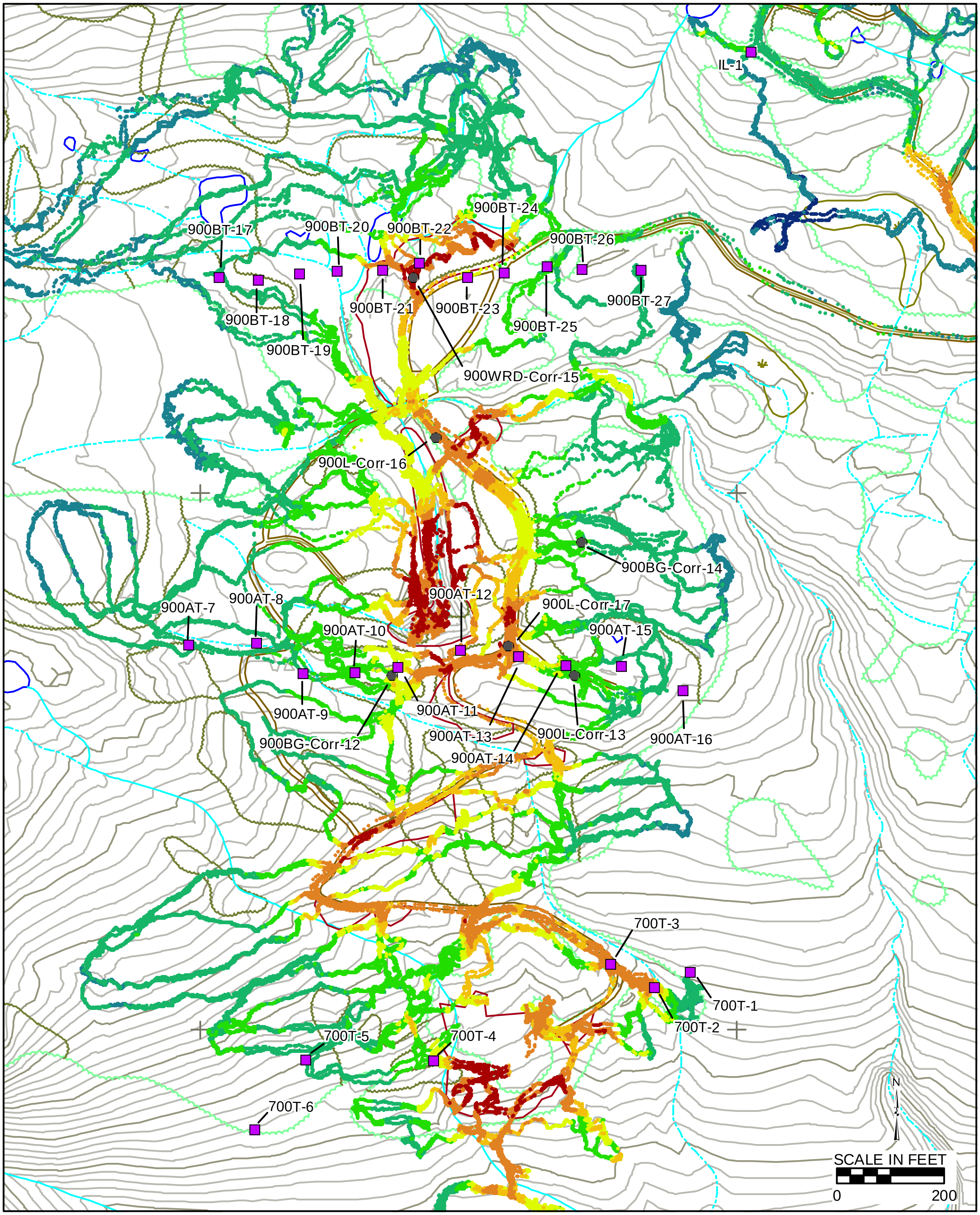
Figure E-3b

Ross-Adams Site

Gamma Survey

300-Foot Level



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Gamma Exposure Rate (uR/hr)

- <20
- 20-40
- 40-80
- 80-160
- 160-316
- 316-631
- 631-1250
- >1250
- Outside of Limits of Gamma Survey
- Gamma/Soil Correlation Plot Sample
- Discrete Soil Sample

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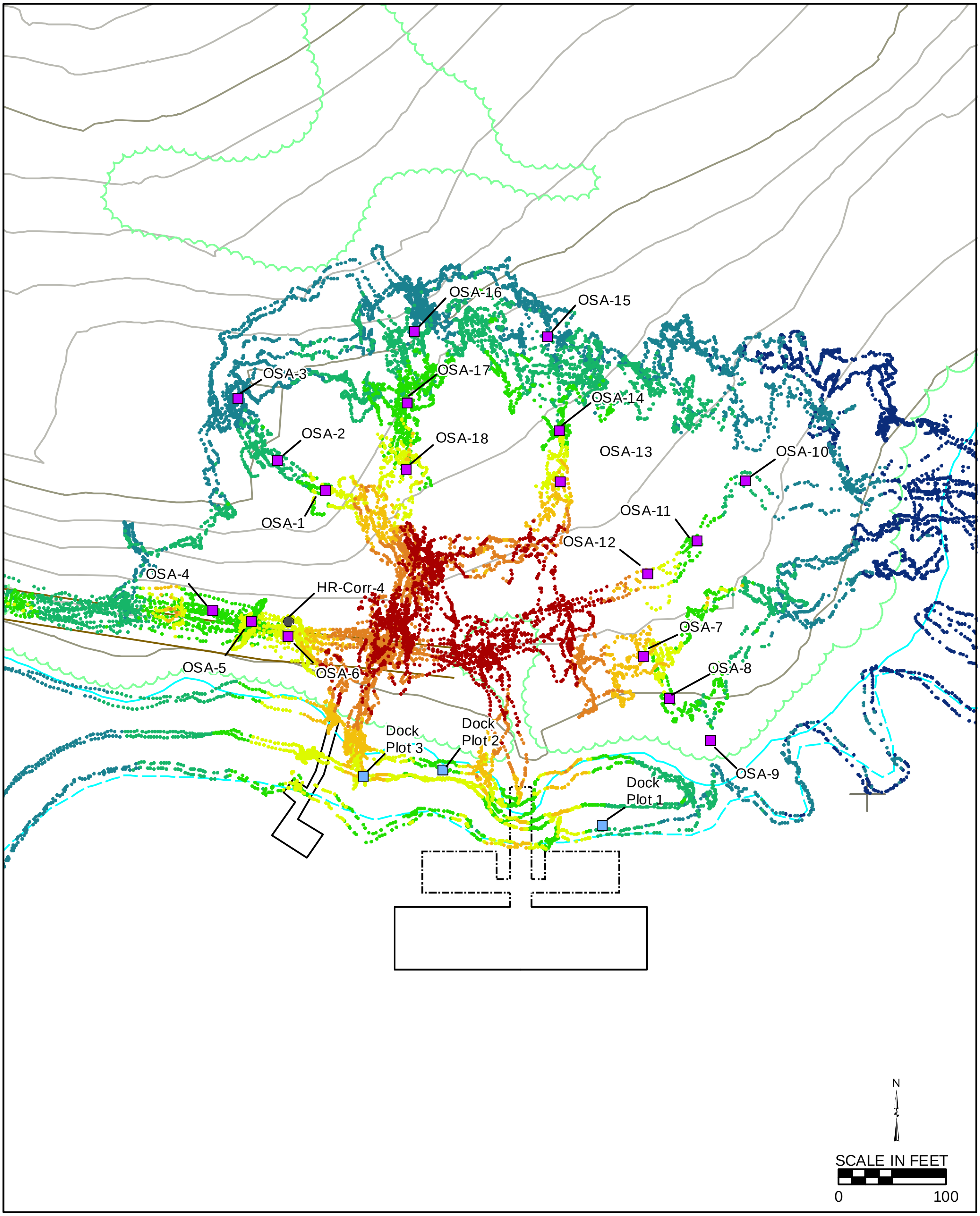
Figure E-3c

Ross-Adams Site

Gamma Survey

900-Foot and 700-Foot Level



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Gamma Survey (uR/hr)

- <20
- 20-40
- 40-80
- 80-160
- 160-316
- 316-631
- 631-1250
- >1250

- Outside of Limits of Gamma Survey
- Gamma/Soil Correlation Plot Sample
- Discrete Soil Sample
- Mine Rock Point Count Plot

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Figure E-3d

Ross-Adams Site

Gamma Survey

Ore Staging Area