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Lawrence Livermore National Laboratory
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# Characterization Work Plan for the Building 812 Operable Unit Lawrence Livermore National Laboratory Site 300

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## August 2011

*Weiss Associates, Emeryville CA

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Environmental Restoration Department

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# Table of Contents

# List of Figures

# List of Tables

# Appendices

# 1. Introduction

## 1.1. Purpose

This work plan describes proposed activities to further characterize contaminants of potential concern (COPCs) and contaminants of potential ecological concern (COPECs) that were identified in the screening-level risk assessment (SLRA) conducted for the Lawrence Livermore National Laboratory (LLNL) Site 300 Building 812 Operable Unit (OU). Also, an independent panel of scientists commissioned by the U.S. Department of Energy Office of Environmental Management (DOE-EM) recommended that many of these characterization activities be conducted to provide additional input to support the baseline human health and ecological risk assessment and the development of remedial alternatives for surface and subsurface soil at Building 812. This contamination resulted from explosives experiments conducted at an outdoor firing table.

The LLNL Environmental Restoration Department (ERD) will conduct this work for the DOE in accordance with the existing plans and procedures developed for LLNL's ongoing Site 300 assessment and site cleanup under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

CERCLA activities at LLNL Site 300 are overseen by the U.S. Environmental Protection Agency (EPA), California Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB) – Central Valley Region.

## 1.2. Project Objectives

The objectives of the activities outlined in this work plan are to:

- Provide better definition of the lateral and vertical extent of uranium in subsurface soil in the Building 812 area.
- Define the relationship between soil grain size and uranium activity in surface and subsurface soil.
- Determine the chemical form of the uranium in soil as a means of determining its solubility and bioavailability.
- Define the geometry of soil and decomposed bedrock that can be excavated with conventional equipment.
- Determine the lateral extent of phreatic vegetation within the Building 812 Canyon stream channel area.
- Quantify uranium uptake in local vegetation and invertebrates.
- Further characterize uranium and metals concentrations in surface water, shallow ground water, and sediment, and the factors controlling bioavailability.
- Conduct additional characterization of lithium and radium-226 in ground water.

## 1.3. Summary of Scope of Work

The distribution of uranium-238 ($^{238}$U) in surface and subsurface soil was previously delineated in samples collected and analyzed between 1988 and 2008. Based on these data, preliminary areas of soil that might require remediation were presented in the initial Draft Building 812 Remedial Investigation/Feasibility Study (RI/FS) (Taffet et al., 2008).

This work plan proposes a phased approach to more discretely define the nature and lateral and vertical extent of $^{238}$U in soil. A companion work plan (Energy Solutions, 2011) defines objectives and scope for a surface soil gamma radiation survey within a 33.7 acre area around Building 812 that includes the area potentially containing $^{238}$U in surface soil in excess of background activity. The results of this gamma survey will be used to identify sample locations for the characterization activities summarized in this work plan.

These activities include the following:

- Augering and drilling boreholes,
- Gamma radiation measurements of soil and rock within boreholes to determine uranium-238 activity,
- Sampling and analysis of subsurface soil from the boreholes for uranium isotopes,
- Determination of correlation between uranium content and surface and subsurface soil grain size,
- Determination of mineralogy of solid-phase uranium,
- Seismic refraction survey to define the geometry of valley fill alluvium and decomposed bedrock within Building 812 Canyon,
- Determination of the areal extent of phreatic vegetation,
- Analysis of uranium content in vegetation, and
- Analysis of uranium content in invertebrates.

This work plan also describes additional characterization activities that were identified in the SLRA, including:

- Sampling and analysis of surface water and shallow ground water samples for uranium, metals, pH, total hardness, total dissolved solids and total suspended solids.
- Sampling and analysis of sediment for uranium, metals, total organic carbon, and pH.
- Sampling and analysis of ground water samples for lithium and radium-226.

## 1.4. Data Quality Objectives

The EPA's Data Quality Objectives (DQOs) Process is a series of seven logical steps that guides planners to the resource-effective acquisition of environmental data. The DQO process is used to establish performance and acceptance criteria, which serve as the basis for designing a plan for collecting data of sufficient quality and quantity to support the goals of the study. Use of the DQO process leads to efficient and effective expenditure of resources; consensus on the type, quality, and quantity of data needed to meet the project goals; and appropriate documentation of actions taken during the development of the project. The ERD conducts its work projects in accordance with the approved Quality Assurance Project Plan (QAPP) (Dibley, 1999) requirements for planning, performing, documenting, and verifying the quality of activities and data. The QAPP was prepared for CERCLA compliance and ensures that the precision, accuracy, completeness, and representativeness of project data are known and are of acceptable quality. The QAPP is used in conjunction with the LLNL ERD Standard Operating Procedures (SOPs), Work Plans, Integration Work Sheets (IWSs), Site Safety Plans, and any other applicable Environmental Safety and Health (ES&H) and/or quality assurance (QA) documentation. Additionally, for the investigations described in this work plan, the EPA guidance *Systematic Planning Using the DQO Process* (EPA, 2006) was followed. Table 1 summarizes the specific DQO steps and corresponding information for the proposed Building 812 characterization activities. Additional information is included in the descriptions of the individual activities in Section 3.

# 2. Site History Summary

The following sections provide descriptions of the site setting, geology and hydrogeology, previous investigations, and the conceptual site model for contaminant release and transport. Additional information can be found in the initial Draft Building 812 RI/FS (Taffet et al., 2008).

## 2.1. Site Description

The Building 812 OU covers approximately 0.35 square miles in the east-central portion of Site 300 (Figure 1). The Building 812 Complex (Figures 2 and 3) was built in the late 1950s to early 1960s to conduct explosive tests and diagnostics in support of national defense programs.

The Building 812 Complex is located at the base of the Building 812 Canyon, a southwest-northeast trending valley that rises from an elevation of about 940 feet (ft) above mean sea level (MSL) near its junction with Elk Ravine to over 1,200 ft above MSL on the steep ridges to the north. Elk Ravine trends northwest to southeast in the southern portion of the OU (Figure 3). A deeply incised north-south oriented channel within the Building 812 Canyon intersects Elk Ravine.

The climate at Site 300 is classified as semi-arid. Rainfall averages 10 to 11 inches per year, most of which falls during winter storms. During these storms, ephemeral surface water may flow within the Building 812 Canyon drainage towards Elk Ravine (Figure 3). Discharge from Spring 6 flows to a perennial surface water body that extends southeast beyond the junction of the two valleys. Surface water flowing locally in channels after rainfall events quickly infiltrates into the ground after traveling short distances.

The Building 812 OU is characterized by steep native and exotic grass-covered ridges and valleys. Due to the rugged terrain, safe and accessible drilling locations are often limited to paved areas near buildings, fire trails, and other dirt roads. The local topography and locations of springs and ground water monitor wells are shown on Figure 3. Physical characteristics of the OU are shown on the panoramic photograph (Figure 2). These features are described in more detail in Section 2.2.2.

## 2.2. Geology and Hydrogeology

Quaternary alluvium (Qal) occurs as stream channel sediment within Elk Ravine and the Building 812 Canyon (Figure 3). The alluvial deposits of the Qal stratigraphic unit are comprised of silty clays, clayey and silty sands, and some gravel. The maximum thickness of alluvial deposits in the Building 812 OU is about 10 ft in the Building 812 Canyon and about 24 ft in Elk Ravine.

Rocks beneath the Building 812 area comprise two formations, the Neroly Formation and the underlying Cierbo Formation. The uppermost bedrock stratigraphic unit is a conglomerate and sandstone of the Neroly Formation ($Tnbs_1$) that contains interbeds of sandstone and siltstone. Beneath the $Tnbs_1$ conglomerate is a blue sandstone unit with interbeds of claystone and siltstone ($Tnbs_0$). The base of the Neroly Formation is a siltstone and claystone-dominated unit ($Tnsc_0$). The Neroly Formation rests on an erosional contact with massive sandstones and interbedded siltstones and claystones of the underlying Cierbo Formation (Tmss).

The hydrogeology of the Building 812 OU is controlled by stratigraphy, structure, and topography.

Four hydrostratigraphic units (HSUs) have been defined for the Building 812 OU:

- Quaternary alluvium/Weathered bedrock (Qal/WBR) HSU.
- $Tnbs_1$/$Tnbs_0$ HSU.
- $Tnsc_0$ HSU.
- Tmss HSU.

The Building 812 Canyon conveys surface runoff from a large catchment (dimensions of roughly 1,200 ft by 4,000 ft) during heavy rainfall events. Much of this runoff recharges the Qal/WBR HSU within the base of the canyon. The Qal/WBR HSU may also be recharged by spring discharge and/or baseflow from the underlying bedrock in the Building 812 Canyon and Elk Ravine. Phreatic vegetation in the canyon adjacent to the firing table and near Spring 6 in Elk Ravine is presumably supported by this shallow ground water. Perennial surface water occurs within Elk Ravine discharging from Spring 6 to beyond the intersection of the Building 812 Canyon and Elk Ravine.

## 2.3. Previous Investigations

The following is a summary of the nature and extent of uranium at the Building 812 OU based on previous characterization results. Additional information on the nature and extent of chemicals at Building 812 is contained in the initial Draft Building 812 RI/FS (Taffet et al., 2008).

### 2.3.1. Uranium Isotopes in Surface Soil

Surface soil samples were analyzed to evaluate the activities of individual uranium isotopes. The maximum total uranium activity detected in Building 812 surface soil was 93 picocuries per gram (pCi/g). The highest total uranium activities were generally detected in surface soil located around the west and north sides of the Building 812 Firing Table. All of the surface soil samples that contained quantifiable uranium-235 ($^{235}U$) exhibited $^{235}U/^{238}U$ atom ratios below 0.007, indicating the presence of some depleted uranium. Most of the samples containing the highest fraction of depleted uranium were collected near the firing table.

The maximum $^{235}$U activity detected in surface soil sample was 0.95 pCi/g; which exceeds both the 0.386 pCi/g U.S. EPA-Region IX industrial soil Preliminary Remediation Guideline (PRG) for $^{235}$U, and the 0.0737 pCi/g Site 300 background activity for $^{235}$U in surface soil. As shown on Figure 4, the extent of $^{235}$U in surface soil at concentrations that exceed the PRG is limited to within 400 ft of the Building 812 Firing Table and is bounded by samples that contain less than the PRG. PRGs and background levels are used as preliminary screening criteria to identify constituents that will be carried forward in the baseline risk assessment. The extent of constituents in excess of PRGs and background levels are also used to define areas that may require additional characterization, such as the activities discussed later in this report.

The maximum $^{238}$U activity detected in a Building 812 surface soil sample was 93 pCi/g; which exceeds both the 1.65 pCi/g PRG for $^{238}$U, and the 3.1 pCi/g Site 300 background activity for $^{238}$U in surface soil. As shown on Figure 5, the extent of $^{238}$U at activities that exceed the 3.1 pCi/g background is predominantly oriented to the east and northeast and extends about 700 ft northeast of the Building 812 Firing Table.

### 2.3.2. Uranium in Subsurface Soil and Rock

A maximum activity of 22,740 pCi/g of total uranium was detected in a subsurface soil sample collected at a depth of 5 ft below the Building 812 Firing Table. The sample contained 110 pCi/g of $^{235}$U and 22,630 pCi/g of $^{238}$U. A split soil sample collected from the same depth interval yielded a $^{235}$U activity of 0.120 pCi/g and a $^{238}$U activity of 3.135 pCi/g (3.255 pCi/g of total uranium). The extent of depleted uranium in subsurface soil and rock in Building 812 OU appears to be restricted to the area beneath and adjacent to the Building 812 Firing Table to a depth of approximately 35 ft and nearby stream channel alluvium (Taffet et al., 2008). Figure 6 displays uranium-238 activity data for subsurface soil and rock samples.

### 2.3.3. Uranium, Lithium, Radium-226, and Metals in Ground Water and Surface Water

Recent and historic uranium activities exceeded the drinking water MCL for total uranium of 20 pCi/L in ground water samples from nine wells: two Qal/WBR HSU wells, two $Tnbs_1$/$Tnbs_0$ HSU wells and five $Tnsc_0$ wells. The maximum uranium activity detected during 2007 was 82 pCi/L in the February ground water sample from Qal/WBR HSU well W-812-1921, which contained depleted uranium. The March 2010 sample from this well contained 74 pCi/L. Historic ground water samples from Qal/WBR wells have also had copper and nickel concentrations exceeding ecological screening levels. Shallow ground water in the Qal/WBR HSU may be accessible to phreatic vegetation in the Building 812 Canyon drainage, and may discharge into surface water in the Spring 6/Elk Ravine area downgradient (east) of the confluence of the Elk Ravine and Building 812 Canyon drainages.

The Building 812 screening-level human health risk assessment identified lithium as a potential contaminant of concern in ground water, and radium-226 as a potential contaminant of concern in surface water. Lithium and radium-226 were only sampled for in wells NC2-23 (constructed in the shallow Qal/WBR HSU) and NC2-22 (constructed in the deeper $Tnsc_0$ HSU). Lithium was detected in both wells, and was detected in NC2-22 at 0.0782 mg/L, slightly above the EPA Regional Screening Level (RSL) of 0.073 mg/L. Although radium-226 was below detection limits in both wells, a single sample obtained from Spring 6 contained radium-226 activities (0.393 pCi/L) above the PRG (0.000906 pCi/L), but below the current Maximum Contaminant Level (MCL) (5 pCi/L).

Uranium and metals are currently found in Spring 6 water and sediment at or below background levels. However, the Spring 6 sampling location is located west of the confluence of Spring 6/Elk Ravine and the Building 812 Canyon drainage. Data are not available on uranium or metals in surface water downgradient from this confluence.

## 2.4. Conceptual Site Model for Contaminant Release and Transport

Depleted uranium was used in explosives experiments at the Building 812 Firing Table. Typically, at the time of a test, ejecta containing depleted uranium were scattered symmetrically into the air. Ejecta often consisted of pyrophoric particles of metallic depleted uranium. Some depleted uranium shrapnel was also likely driven beneath the ground surface by the force of the explosive blasts. Based on the shape of the region of surface soil containing uranium-238 in excess of background, the north-northeast preferential wind direction over much of the year elongated the pathway of these particles in that direction, resulting in preferential deposition. Surface water flow, following topography, likely has resulted in transport of uranium in surface soil from higher elevations into lower elevations, especially the Building 812 Canyon and the deeply incised channel within it.

Some dissolution and precipitation of uranium may also be responsible for accumulation of solid phase uranium below the ground surface. Infiltration of rainwater may mobilize contaminants in subsurface soil to ground water within the $Tnbs_1/Tnbs_0$ and Qal/WBR HSUs. Overland flow of water from rainfall and resuspension of contaminated surface soil and subsequent deposition into the surface water may result in the migration of contaminants to surface water in the Spring 6/Elk Ravine area. Runoff also recharges the Qal/WBR HSU within the base of the canyon. The Qal/WBR HSU may also be recharged by spring discharge and/or baseflow from the underlying bedrock in the Building 812 Canyon and Elk Ravine. In addition, Qal/WBR HSU ground water may also subsequently discharge to surface water in the Spring 6/Elk Ravine area.

## 2.5. Investigation Areas

Based on the sampling and analysis of soil and rock samples from the Building 812 OU and historical information, the areas discussed below and shown on Figure 7 have been identified for further characterization of the lateral and vertical extent of uranium, studies of uranium grain size analysis and mineralogy, and the seismic refraction survey. Areas where surface and subsurface soil samples will be collected for follow on studies will be determined during the surface soil gamma radiation survey. The rationales for selecting sample locations are discussed in the individual scope of work sections in Section 3.

Investigation areas include:

- Building 812 Firing Table – Area of the firing table and vicinity.
- Potential Debris Area – An area that may have been impacted by deposition and re-working of firing table debris.

- Building 812 Canyon – This area includes: (1) the vegetated area shown on Figure 7, and (2) portions of the canyon that extend several hundred feet further south including an area of potential gravel (not firing table gravel).

Miscellaneous locations for additional samples in support of the baseline risk assessment are depicted on Figures 8 and 9. Locations for the seismic refraction survey lines are shown on Figure 10.

# 3. Proposed Characterization Activities and Methods

The following sections discuss the uses, requirements, scope of work, methodology, QA/QC, and data analysis for each characterization activity. Table 1 summarizes the DQOs, with additional details provided in the text. Table 2 summarizes the sampling and analysis plan for the proposed characterization activities.

## 3.1. Subsurface Soil Uranium Characterization

To obtain data and samples for subsurface characterization, boreholes will be augered by hand or drilled with a motorized drilling rig. The lithologies encountered in each borehole will be described and logged by a geologist. Gamma radiation spectra will be measured *in situ* at discrete 1 to 2 ft intervals to determine uranium-238 activities in the soil and decomposed bedrock. Subsurface soil and rock samples will be collected from selected discrete depth intervals where elevated $^{238}U$ activity was identified *in situ* and analyzed for uranium isotopes. Samples will also be collected for characterization of uranium mineralogy and correlation of uranium concentration with grain-size (see Sections 3.3 and 3.4).

Best professional judgment was used to determine that nine hand auger boreholes and 10 deeper boreholes would be adequate to generate additional data to build on existing subsurface uranium data from existing borehole locations to complete definition of the vertical extent of uranium and to collect subsurface soil samples for determining site-specific uranium sold form and grain size distribution. The boreholes will be located in areas where elevated uranium-238 (at least one to two orders of magnitude in excess of background, i.e., tens to hundreds of picocuries per gram [pCi/g]) was detected in alluvial channels and potential areas where firing table debris may have accumulated due to proximity to the firing table. The proposed locations of these boreholes will be provided to the regulatory agencies after the gamma radiation surveys in these areas are completed. Samples for grain-size uranium correlation and uranium solids characterization will also be collected from intervals within boreholes and surface soil locations that yield tens to hundreds of pCi/g of uranium-238 based on gamma survey results.

During the summers of 2011 and 2012, a total of nine 4-inch diameter boreholes will be advanced with a hand auger to a maximum depth of 6 ft or to auger refusal. Most of the hand-augered boreholes will be vertical but some may be inclined if located on a hillslope. The locations of these boreholes will be determined after evaluation of preliminary surface soil gamma survey results. One or more borehole location map(s) will be prepared and discussed with the regulatory agencies.

In the summer of 2012, 10 deep boreholes will be drilled with a motorized air-mist rotary rig to a maximum depth of 25 ft or the contact between alluvium/weather bedrock and coherent bedrock. The locations of these boreholes will be selected after collection and review of surface soil gamma survey data indicating locations of elevated areas of $^{238}$U activity within the investigation areas listed in Section 2.5. Each borehole will be located in one of the general areas depicted on Figure 7: (1) adjacent to the firing table, (2) within the potential debris area, or (3) in the valley fill areas.

The soil and fill removed from these boreholes will be segregated by depth and stored onsite in sealed buckets while awaiting gamma radiation logging data. These data will be collected with a 2-inch diameter downhole High-Purity Germanium (HPGe) gamma detector to define $^{238}$U content with depth. Upon completion of the gamma radiation measurements within the boreholes, samples from intervals displaying elevated $^{238}$U activity will be collected from the stored soil and submitted for uranium isotope analysis and other studies, as described in Section 3.1.3. The boreholes will be backfilled with cuttings not reserved for chemical analysis or additional characterization work.

### 3.1.1. Drilling Methods

The borehole locations will be staked and surveyed using a Trimble Pathfinder Pro XR Global Positioning System (GPS) device. For the hand-augered boreholes, each collected interval of soil or fill, measuring approximately 6-inches long by 4-inches wide, will be placed in a clean weather-tight bucket, core box, or similar container for segregating material by depth. A geologist will describe the lithology and other notable characteristics of each auger bucket of soil and alluvium as it is placed into the container. Soil from the entire depth of each borehole will be segregated and stored in these containers at the field site or indoors at Site 300 for use in subsequent characterization studies described later in this section. DOE/LLNL will attempt to use gamma detectors to identify and collect depleted uranium-bearing soil and alluvium from these containers for the solids characterization activities described in this Work Plan.

Maps of proposed borehole locations will be submitted to the regulatory agencies for concurrence.

A drilling rig will be used to drill the deep boreholes. The MITO rig will use the existing fire trail on the east side of the Building 812 valley to access all potential drilling sites within the Building 812 valley. For the locations within the deeply incised channel, the drill rig will likely descend from the fire trail down the channel slope without need to create a new road. Any drilling locations in the vicinity of the firing table would be accessed from the paved road.

Cuttings from each borehole will constitute a maximum volume of about 5 cubic feet, before subtracting any soil collected for chemical analysis or other laboratory studies. The hand-auger holes will generate substantially less cuttings. Rather than using a mud pit, cuttings from all boreholes will be containerized in 55-gallon drums at the drilling sites. The soil for potential chemical and laboratory studies will be collected with coring devices or modified split-spoon sampler tubes and will be segregated by depth and stored onsite in sealed tubes or transferred to buckets or similar containers. Alternatively, sealed weather-tight core boxes may be used for storing the core collected from the deeper boreholes.

The deep boreholes will be drilled to an initial diameter of 8-inches for the first 8 ft depth, a 6-inch diameter surface casing installed, and a several foot thick grout plug poured to an 8 ft depth to isolate the shallow depleted uranium-bearing soil zone. After the grout has hardened, a 4-inch diameter borehole will be drilled through the grout plug and underlying soil and alluvium, to the total depth of coherent bedrock, or 25 ft, whichever comes first. Upon completion of gamma radiation measurements within the boreholes, selected samples from intervals displaying elevated $^{238}$U activity (> 10 pCi/g) will be collected from the stored soil and submitted for chemical analysis and other characterization-related analyses. The remainder of the soil and fill will be used to backfill the holes to the ground surface. The boreholes will be covered with plywood until they are backfilled.

If ground water is encountered during the drilling of any boreholes, samples will be collected and submitted for mass spectrometric uranium isotope analysis.

### 3.1.2. Borehole Gamma Radiation Measurements

Despite sampling and analysis for uranium isotopes in subsurface soil and decomposed bedrock, uncertainty remains as to the vertical extent of uranium-238 (from depleted uranium) in Qal/WBR soil and sediments at the firing table, stream channel, and debris areas. A downhole gamma radiation detector will be used to measure uranium-238 activities in subsurface soil and decomposed bedrock within the hand-auger and rotary-drilled boreholes.

#### *3.1.2.1. Scope of Work*

Gamma radiation measurements will be collected with a High-Purity Germanium (HPGe) detector at several discrete depth intervals within each borehole to define the uranium-238 activity in the first four radial inches of soil or decomposed rock adjacent to the borehole. Depending on background radiation from all isotopes and other factors, a vertical depth interval of about 12 to 18 inches of borehole can be scanned and the uranium-238 activity concentration quantified per measurement. An average of 1 to 2 measurements will be taken every 2 ft within the upper 6 ft of each borehole, with a lower frequency of 1 to 2 measurements every 4 vertical ft at greater depths.

The analysis of $^{238}$U cannot be measured directly and must be derived from counting the decay of daughter progeny thorium-234 and protactinium-234. Performance and acceptance criteria will be employed to maintain a Minimal Detectable Activity (MDA) of 3 pCi/g, including background. The sampling design may include application of the Microshield model to facilitate proper counting times and physical configuration of the detector. A downhole collimator will limit the field of view of the detector and reduce background and Compton scattering. Preliminary gamma radiation measurement within a box filled with unimpacted background reference area soil from Site 300 or in a hand auger hole at Site 300 will also be performed. The reference area soil and/or location will be selected to have the same soil type and geology as the Building 812 area. The proposed background reference area location will be provided to the regulatory agencies.

#### *3.1.2.2. Field Methods*

A 2.75-inch diameter p-type HPGe detector will be employed to collect downhole gamma spectroscopy measurements with 35% nominal efficiency. The high efficiency, low background p-type detector will meet or exceed the required MDA. A 60% p-type detector (GEM60P4) has 1.95 Kilo electron volts (KeV) Full Width Half Maximum (FWHM) at 1332 KeV. This resolution translates to favorable signal-to-noise and peak separation within the spectral energies of interest for measuring uranium-238 from decay of thorium-234 and protactinium-234m. An

ORTEC digiDART, a hand-held portable HPGe-grade spectroscopy instrument with 32k channels, will collect spectra from the detector. It can be operated with or without attachment to a PC. The physical connection to the detector is via a custom cable and a Detector Instrument Module (DIM).

Trimble GPS hardware and software will be used to geospatially reference sampling locations. The detector will be lowered by hand to the bottom of each borehole and carried on foot to the location of each borehole. When accessible, a truck containing supporting equipment will be driven on existing fire trails and roads to the borehole location. Access to additional instrumentation in the truck may improve measurement efficiency.

#### *3.1.2.3. Equipment Calibration and QA/QC*

For daily quality assurance/quality control (QA/QC) requirements, the detector performance will be tracked with GammaVision software and control charts. A daily job log will record relevant operational data. Daily logs are kept in accordance with field operation procedures and the instruments are calibrated with NIST traceable standards. At least 10% of the borehole intervals that are measured will be re-measured to ensure replicable measurements. The borehole intervals to be re-measured will be selected randomly. Calibration acceptance criteria are within three sigma standard deviations and a 99% confidence interval. The true positive proportion will be set to 95%. The false positive proportion will be set to 60%. The statistical test method for these true positive and false positive proportions is the Sine Test. Soil samples (see Section 3.1.3) will be analyzed for uranium isotopes to measure correlation with gamma detector measurements. It should be noted that because these measurements are made on two separate samples, lack of correlations does not indicate an error in measurement but is more likely an indication of heterogeneity in uranium distribution.

#### *3.1.2.4. Data Analysis*

The original gamma spectrum and count data and the calculated $^{238}$U activity for each interval measured, along with any QA/QC calibration and duplicate measurement data, will be recorded for each borehole. The digiDART datalogger has limited spectroscopic analysis capabilities. Thus, the spectra are downloaded to a portable computer for post-processing. The software applications, GammaVision, Maestro, and Isotopic are employed for calibration and analysis. The uranium-238 data for each measured interval will be used to better define the vertical extent of $^{238}$U in subsurface soil.

Every attempt will be made to keep boreholes open until data validation is completed so in the event that less than 80% of the uranium-238 data from the boreholes is rejected, the rejected borehole interval(s) can be re-measured to obtain acceptable data.

The preliminary results of the borehole gamma radiation survey will be presented and discussed with the regulatory agencies. A summary of the results of the borehole gamma radiation survey will be included in the Building 812 RI/FS.

### 3.1.3. Uranium Soil Sampling and Analysis

Soil samples will be collected from selected depth intervals within each borehole where elevated uranium activities are measured with the gamma radiation detector. The samples will be submitted for alpha spectrometric or mass spectrometric analysis of uranium isotopes.

Analytical results from these selected depth samples will calibrate/verify the gamma detector results and provide additional quantitative determination of the vertical extent of uranium in subsurface soil and rock at Building 812. Thus, these data will assist in determining the extent and volume of soil that may require remediation. Table 2 summarizes the sampling and uranium analysis plan for subsurface soil.

#### *3.1.3.1. Scope of Work*

Subsurface soil sampling is planned for late summer or early fall of 2011 and the summer of 2012 as part of borehole drilling. Approximately 25 subsurface soil samples will be submitted for isotopic uranium analysis. Results of uranium analyses from the grain size study (Section 3.2) and the sequential extractions (Section 3.3) will supplement these data.

#### *3.1.3.2. Field Methods*

Sampling will be collected from individual buckets of soil corresponding to discrete depth intervals from each borehole and packaged following the applicable SOPs (Table 3).

#### *3.1.3.3. Laboratory Methods*

Samples will be submitted to the analytical laboratories using standard shipping and chain-of-custody procedures (Table 3). Sample preparation and analyses will be conducted by analytical laboratories under contract to Lawrence Livermore National Laboratory (LLNS) or an LLNL laboratory. Analytical methods (alpha spectrometry and mass spectrometry) are listed in Table 4.

#### *3.1.3.4. QA/QC*

All sampling will be conducted in accordance with the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). Sample preparation and analysis conducted by the analytical laboratories will follow QA requirements specified in the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). All offsite contract analytical laboratories will use methods and procedures functionally equivalent to the methods and procedures defined in the EPA Contract Laboratory Program and the California DTSC Certified Laboratory Program. These offsite contract analytical laboratories must maintain a California Department of Health Services (DHS) Environmental Laboratory Accreditation Program certification for analytical tests for which the DHS offers certification. Although there are no EPA protocols for uranium mass analysis by inductively coupled mass spectrometry (ICPMS), the LLNL onsite laboratory performing these analyses follows good lab practice, participates in the State's Environmental Laboratory Accreditation Program (ELAP)), and DOE's Mixed Analyte Performance Program (MAPEP). The laboratory is ISO17025 accredited and maintains that certification through the Forensic Science Center.

#### *3.1.3.5. Data Analysis*

Analytical data and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Data derived from borehole gamma radiation measurements will be validated following the relevant "The Multi-Agency Radiation Survey and Site Investigation Manual" (MARSSIM) procedures and validation methods. Only validated data will be used in defining the extent of contamination and baseline risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If less than 18 of the approximately 25 soil samples locations yield usable data, samples from the locations with rejected data or new samples will be re-analyzed. Validated data will be tabulated for use in the baseline risk assessment.

The preliminary results of the uranium solids characterization data and analysis will be presented to and discussed with the regulatory agencies. A summary of the results of the uranium solids characterization data and analysis from these activities will be included in the Building 812 RI/FS.

## 3.2. Uranium Grain Size Distribution Analysis

Knowledge of the relationship between uranium-238 activity and grain size is important in defining soil remediation strategies. If high correlation exists between grain size and uranium-238 content, remedial strategies that physically segregate particular grain sizes can be evaluated as remedial options that can effectively concentrate the contaminated soil into a smaller volume.

### 3.2.1. Scope of Work

Upon completion of the surface soil gamma survey, locations of elevated uranium-238 activity in surface soil will be selected and surface soil samples will be collected. A surface soil sample location map will be prepared and discussed with the regulatory agencies. Subsurface soil samples will be collected from depth intervals of boreholes where elevated uranium-238 activity is defined by the downhole gamma radiation survey. Definition of the relationship between grain size and uranium content requires separating grain size fractions with sieving, weighing the resulting fractions, and analyzing each fraction by alpha or mass spectrometry. Approximately 25 soil samples will be processed and analyzed for uranium grain-size analysis.

### 3.2.2. Soil Sampling

The samples from areas or depth intervals of elevated uranium-238 activity will be placed in 500 mL jars and transported to a laboratory for sieving each soil sample into the various size fractions. To evaluate spatial variability, samples will be collected from various depths within the three investigation areas discussed in Section 2.5.

### 3.2.3. Laboratory Methods

Dry sieving with a stacked sieve set and a mechanical shaker will be employed to separate the soil size fractions. After spreading on a clean tray and drying at laboratory room temperature, a mass of 50-500 grams (g) of soil will be placed in the top of a standard stack of sieves of mesh widths of 2 millimeter (mm), 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm. The actual mass of soil to be sieved will be based on providing enough resulting soil mass from each size fraction to ensure sufficient soil to perform final uranium analysis. The resulting masses within each size fraction will be analyzed for uranium isotopes by alpha or mass spectrometry using the soil same analysis methods described in Section 3.1.3. If wet sieving is necessary to separate the silt-clay fraction (diameter < 0.063), due to high clay content in any sample, minimal quantities of de-ionized water will be used. If wet sieving is required, an initial analysis of one or more samples of the resulting water will be analyzed for uranium by alpha or mass spectrometry to ascertain whether the de-ionized water used in wet sieving removed uranium from the fine fraction. If the de-ionized water is found to liberate uranium from a limited set of samples, pipette methods will be used to segregate size fractions below < 0.063 mm. If it is not found to liberate uranium in one or two initial samples, additional wet sieving will be conducted without analyzing the de-ionized water.

In addition to analyzing the silt-clay fraction for uranium activity, scanning electron microscopy (SEM) and energy dispersive spectral (EDS) x-ray analysis will be used to measure fine particle sizes of uranium, and whether these uranium particles occur as agglomerates or single grains (Danesi, et al., 2003; Torok et al., 2004).

Samples will be submitted to the analytical laboratories using standard shipping and chain-of-custody procedures (Table 3). Sample preparation and analyses will be conducted by analytical laboratories under contract to LLNS or an LLNL laboratory. The analytical methods listed in Table 4 will be used to measure uranium isotopes by alpha or mass spectrometry.

### 3.2.4. QA/QC

Please see Section 3.1.3.4, Section 4, and Appendix B for QA/QC details.

### 3.2.5. Data Analysis

Total uranium, individual uranium isotopes, and $^{234}U/^{238}U$ activity ratios and $^{235}U/^{238}U$ atom ratios will be graphed against grain size ranges to define correlations. These data will also be displayed in a Geographical Information System (GIS) to define correlation with location and depth. If less than 80% of the soil size fraction samples yield usable data, samples with rejected data will be re-analyzed or new samples of size fractions will be analyzed. Pearson's correlation will be used to measure the correlation between grain size ranges and uranium content and isotope ratios. The degree of correlation for the samples from surface soil and subsurface soil will also evaluated together and separately and reported in the Remedial Investigation (RI) portion of the RI/Feasibility Study (FS) to define any differences in the correlation for these two environmental media. The range of acceptable correlations for remediation technologies, such as size fractionation, will be evaluated in the Feasibility Study portion of the RI/FS.

The preliminary results of the uranium grain size distribution analysis will be presented to and discussed with the regulatory agencies. A summary of the results of the uranium grain size distribution analysis will be included in the Building 812 RI/FS.

## 3.3. Uranium Solid Phase Characterization

The goal of solid phase characterization is to assess the potential for entering different exposure pathways, i.e., solubility (leachability and mobility in water) and bioavailability. Because sorbed and solid uranium species have known solubilities, identification of the range of uranium solids from depleted uranium will enable direct determination of mobility in water and bioavailability. Several methods will be applied in succession to determine the mineralogy of depleted uranium and authigenic phases that may arise from it. These methods include sequential extractions, SEM-EDS and x-ray diffraction (XRD). A study integrating data obtained from these methods was recently applied to characterizing depleted uranium particles at a firing range in the UK (Sajih et al., 2010). Other notable studies on characterization of depleted uranium particles include Lind et al., 2009 and Torok et al., 2004.

### 3.3.1. Scope of Work

#### *SEM-EDS Analysis*

Soil samples from a range of depths and locations in the investigation areas will be examined with SEM-EDS. Grains will be imaged in the SEM and EDS spectra will be used to confirm that the observed grains are composed of uranium by verifying uranium peaks. A library of characteristic x-ray peaks enables determination of the presence of elements in mineral grains.

#### *Sequential Extractions*

Sequential extraction will be performed on approximately 15 soil samples from a range of depths within the three investigation areas. In general, each soil sample will be subjected to a series of chemical treatments, each designed to dissolve/desorb a unique class of geochemical solid phase (exchangeable [sorbed], organic matter, carbonates, oxides, and residuum) within the sample. In each step, the sample and reagent are usually shaken or agitated and kept at a constant temperature for a specified duration (Schultz et al., 1998). Following this reaction period, the solid and aqueous phases are separated by centrifugation and/or filtration. The residual sediment is reserved for the next reaction step in the sequence and the fluid phase is analyzed for uranium.

#### *XRD Analysis*

Uranium solids collected from selected representative areas and intervals of elevated $^{238}$U activity identified during the surface soil and subsurface gamma measurements will be ground to a fine powder and placed in a point X-ray diffractometer for analysis. The sample locations will be selected to obtain the widest range of uranium-bearing solids in the OU. The theory of XRD is based on the phenomenon that when x-rays enter a mineral crystal, they can scatter in a coherent and regular way due to the periodic arrangement of atoms in the lattice. When the resulting x-rays, based on an incident beam of prescribed wavelength, are in phase and a detector is properly positioned, the detector can measure the diffraction pattern. This diffraction pattern can then be resolved into a spectrum of intensities and counts (peaks) in electron energies that is unique for each mineral. This spectrum can be compared by computer to a library of mineral diffraction patterns to enable identification of one or more minerals in the sample (Hill, 1999).

### 3.3.2. Soil Sampling

Samples will be selected from areas/depths of surface soil and archived subsurface soil samples where elevated $^{238}$U activities are present. The samples will be placed in jars or plastic bags and transported to the laboratory. Samples of visible depleted uranium particles may also be collected where observed in the field. To evaluate spatial variability, samples will be collected from various depths within the three investigation areas discussed in Section 2.5.

### 3.3.3. Laboratory Methods

#### *SEM-EDS Analysis*

Soil samples will be placed on a tray and inspected in the laboratory for visible grains of depleted uranium. Fine particles of uranium may be separated and accumulated by liquid separation, autoradiography, or other techniques. Visible grains of yellow-green depleted uranium will be placed on small carbon stubs and inserted in a JEOL SEM. All gases in the SEM chamber will be evacuated prior to focusing the electron beam on the sample. The definition of peaks representing other elements such as calcium, carbon, silicon, sulfur, and phosphorus can assist in defining uranium mineral families. Electron micrographs of uranium minerals will be taken from representative samples to document solids morphologies and sizes. EDS spectra will be archived.

#### *Sequential Extractions*

Each sample will be soaked overnight with de-ionized water, following dry weight determination. Following hydration, sequential extractions will proceed following procedures described in Tessier et al., 1979 and Blanco et al., 2004. All reagent/sample ratios will be 15:1 by mass. All reactions are performed in shaken batch vessels. Exchangeable uranium will be removed by employing 0.4 molar (M) $MgCl_2$ solution at pH 5 at room temperature twice for 0.5 hour (hr). Organically bound uranium will be removed by employing 5-6% NaOCl solution at pH 7.5 at 96° Centigrade (C) for 1 hour (hr). Carbonate uranium will be removed by employing 1 M Na-acetate in 25% H-acetate solution at pH 4 at room temperature twice for 2 hr. Oxide uranium will be removed by employing 0.04 M $NH_2OH$-HCl solution at pH 2 ($HNO_3$) at room temperature for 5 hr. Remaining residual uranium will be removed by employing total digestion using a strong acid such as HF, HCl, $HNO_3$, or $HClO_4$. Following each reaction step, the solid and aqueous phases are separated by centrifugation for 45 minutes. The residual sediment is reserved for the next reaction step in the sequence and the fluid phase is analyzed for uranium by alpha or mass spectrometry.

#### *XRD Analysis*

Uranium solids will be ground to a fine powder in a mortar and pestle. Each sample will be front-loaded into a poly(methyl methacrylate) (PMMA) sample holder with a centered 15mm wide x 1mm deep well. Care will be taken to ensure a flat surface for analysis while inserting the sample into the Bruker Model D8 x-ray diffractometer. The step scan parameters are 0.02° step with a 2 second counting time per step with a 0.499° divergence slit and a 0.499° anti-scatter slit for all samples and standards. The samples will be x-rayed with Ni-filter Cu radiation from a sealed tube operated at 40kV and 40mA. Solid phases in the samples will be identified by comparison of observed electron energy spectra peaks to those in the International Centre for Diffraction Data powder diffraction database (ICDD, 2009). All XRD spectra will be archived.

### 3.3.4. QA/QC

#### *SEM-EDS Analysis*

Spectra and images will be collected from uranium-bearing grains in the range of available size fractions to develop an overview and verify that the full range of uranium-bearing phases present in Building 812 soils are characterized by these methods.

#### *Sequential Extractions*

QA/QC will be assured as described in previous laboratory and analytical sections for characterization activities described in this work plan and Appendix B.

#### *XRD Analysis*

X-ray reference material (Bruker supplied $Al_2O_3$ standard) will periodically be analyzed with samples to ensure goniometer alignment. Verification will be made that no peak shift in the standards are observed in the scans during the time frame that the actual samples are analyzed.

### 3.3.5. Data Analysis

The data sets collected during the various uranium solids characterization activities will be integrated to define the major uranium-bearing solids at Building 812 that are derived from depleted uranium. The preliminary results of the uranium solids characterization data and analysis will be presented to and discussed with the regulatory agencies. A summary of the results of the uranium solids characterization data and analysis will be included in the Building 812 RI/FS.

#### *SEM-EDS Analysis*

Grain sizes of uranium particles will be logged to define the range of sizes and frequencies observed. The definition of peaks representing other elements such as calcium, carbon, silicon, sulfur, and phosphorus will assist in defining uranium mineral families and provide focus to follow-on solids characterization. Morphology of grains, including chemical alteration rinds, clumping and agglomeration of smaller grains, and zoned regions of differential composition will be evaluated. Electron micrographs of uranium minerals will be taken from representative samples to document morphologies and sizes. EDS spectra will be archived.

#### *Sequential Extractions*

Isotopic analysis of the leachate from each progressive extraction will be used to evaluate the provenance and potential diagenetic history of depleted uranium in solids at Building 812. If less than 80% of the sequential extraction samples yield usable data, leachate yielding rejected data will be re-analyzed. Total uranium concentration and ratios of $^{234}U/^{238}U$ and $^{235}U/^{238}U$ will be plotted for each extraction step of each sample to define the uranium mineral families containing the uranium and relative variability in different areas of Building 812.

***XRD Analysis***

If sufficient mass of uranium mineral solids can be sequestered from a range of size fractions and identified by XRD, these data would provide diagnostic evidence of the presence of particular uranium solid phases at Building 812.

## 3.4. Seismic Refraction Survey

Seismic refraction is a surface geophysical method that provides information regarding the seismic velocity structure of the subsurface. A mechanical source is used to produce compressional wave (P-wave) seismic energy. The P-waves propagate into the subsurface and are refracted along interfaces related to contrasts in seismic velocity. A portion of the P-wave energy is refracted back to the surface where it is detected by a sensor array (geophone line) that is implanted on the ground surface. The detected signals are recorded as waveforms on a digital multi-channel seismograph. The waveforms are analyzed for first arriving P-wave travel times. These travel times, along with seismic source station and geophone coordinates, are inverted by specialized computer software to create two-dimensional, depth versus seismic velocity profiles that can be interpreted to define the subsurface lithologic layering beneath each geophone seismic line. The resulting data will enable construction of a 3-dimensional rendering of the shallow lithologic structure beneath the Building 812 Canyon. The goal of the seismic refraction survey is to identify the contact between "rippable" material (alluvial fill and decomposed bedrock) and coherent bedrock. This information, together with the results of the characterization work to define the vertical extent of uranium in the alluvium, will be used to assist in defining the potential volume of alluvial material that may require remediation.

High quality and high resolution refraction seismic data are required to determine the geometry and depth of rippable soil within the Building 812 Canyon. The seismic refraction data will be acquired along multiple linear transects as shown in Figure 10. The survey will be configured to acquire data at a density sufficient to resolve the base of rippable material (< 5 meters) along each seismic refraction transect to +/- 0.25 meters. Based on previous excavation and surface geophysical data, including seismic refraction data collected at similar areas at Site 300, the thickness of rippable material within the Building 812 Canyon is expected to vary from 0 to < 30 ft. The base of rippable material is expected to be deepest within the Building 812 canyon and shallower (0 to 1 meter) along the adjacent hillslopes. The Pwave velocity of rippable materials is estimated to range from 150 to 300 meters per second (m/sec) (500 to 1,000 feet per second [ft/sec]); the velocity of material below rippable depth is estimated to be $\geq$ 650 m/sec (2,000 ft/sec).

### 3.4.1. Scope of Work

A seismic refraction survey will be performed to determine the extent of overburden and depth of rippable material in the Building 812 canyon. The shallow (< 5 meters) rippable, geologic materials in the survey area consist of soil, alluvium, colluvium, decomposed bedrock, and fill materials that may contain firing table. The survey data will be acquired along multiple linear transects as shown on Figure 10.

### 3.4.2. Field Methods and Equipment

Seismic data will be collected along 12 seismic refraction lines (or linear transects), each about 120-feet long. Six of the lines will be aligned end-to-end along Building 812 Canyon, and six perpendicular to the canyon spaced about 36.5 meters (120 ft) apart as shown on Figure 10. Each seismic line will consist of 24 geophones and 9 shot points distributed in a collinear array. The geophones will be distributed at 5 ft intervals. The shot point interval will be every 15 ft across the refraction spread starting 2.5 ft from the first geophone in the array. This will result in refraction profile lengths (end-shot-point to end-shot-point) of 120 ft.

Seismic energy will be produced at each shot point via multiple impacts with a 16-pound sledgehammer against a metal plate placed on the ground surface. An accelerometer attached to the hammer transmits an electrical pulse to the seismograph each time the plate is struck, triggering a recording event. The resulting compressional P-wave seismic energy will be detected by the geophone array and transmitted through seismic cables to a 24-channel seismograph. The data from repeated impacts at each shot point are algebraically summed to improve the signal-to-noise ratio and enhance the data quality. In addition, the seismic data will be amplified, filtered, digitized and stored in the seismographs built-in memory.

The P-waves will be detected by a collinear array of 24-Mark Products geophones with a natural frequency of 8-Hertz (Hz). The geophones will be connected by seismic spread cables to a Geometrics Geode 24-channel seismograph. The analog signals transmitted by the geophones will be digitized by the Geode's 24-bit digital to analog converters, amplified, conditioned and processed, then displayed on a field computer. Upon completion of the fieldwork the digital files will be transferred to an office computer for subsequent processing.

A crew composed of two people, one of which is a California Professional Geophysicist, will perform the seismic refraction survey. The coordinates of the beginning and end of each seismic line will be determined using a sub-meter accuracy GPS system and topographic variations along each line will be determined by hand leveling.

### 3.4.3. QA/QC and Equipment Calibration Data Collection and Conversion

The base of the rippable material will be mapped as a boundary defined by a contrast in density and the resulting seismic wave refraction along that boundary. Rippable material is considered to be geologic material that can be excavated with conventional excavation equipment such as backhoes, excavators, and bulldozers. It is expected that rippable depth within the survey area will vary between 0 to < 5 meters. In addition, seismic refraction data will be correlated to surface geology and subsurface data collected from boreholes located along the seismic lines.

### 3.4.4. Data Analysis

The seismic refraction data will be analyzed using the computer program SeisOpt2D by Optim Software of Reno, Nevada. This is an interactive program that uses non-linear optimization technology to derive a sophisticated velocity model representing earth structure. The subroutine SeisOpt Picker is used first to determine the shot point to geophone travel times for each seismic line. Once the travel times are determined, the program will use these times, along with the shot point and geophone elevations and locations, to compute a preliminary two-dimensional seismic velocity model. A maximum of seven different models will be computed for each seismic line using different vertical resolution parameters. Of the seven models, the one having the closest fit to the observed data and the densest sampling of the subsurface will be used to represent the subsurface velocity distribution. The computer program Surfer by Golden Software, Ltd of Golden, Colorado will then be used to contour the modeled seismic data to produce a color-contoured cross-section illustrating the distribution of seismic velocity vs. depth and distance.

The preliminary results of the seismic refraction survey will be presented to and discussed with the regulatory agencies. Methods used for data acquisition and analysis, field procedures, results, and data interpretation, and a site map in AutoCAD format showing the locations of each seismic line and the respective interpreted seismic refraction velocity profiles will be included in the Building 812 RI/FS. Seismic refraction data will not be validated.

## 3.5. Surface Water and Shallow Ground Water Characterization

Surface water in Elk Ravine is currently sampled at the location designated as Spring 6. This location is upgradient of the confluence between Elk Ravine and the Building 812 Canyon drainage (Figure 3). However, uranium concentrations exceeding ecological screening levels and activities exceeding human health MCLs have been detected in the shallow alluvial (Qal) ground water and surface water that ultimately discharges into Elk Ravine at and to the southeast (downgradient) of the Building 812 drainage. Recent data on uranium concentrations in surface water runoff are available from samples collected in the fall and early spring of 2010. Six surface water samples were collected in the vicinity of the firing table and within the Building 812 Canyon. Concentrations ranged from 2.8 to 130 μg/L, with the higher concentrations found in the southern portion of the Building 812 Canyon.

Ground water samples from the Qal/WBR HSU have yielded concentrations of the metals copper and nickel above background and ecological screening levels. Uranium and zinc have also been detected in Spring 6 water above background and ecological screening levels. Some of the samples yielding these concentrations were collected before 2005, and thus may not represent current conditions. Concentrations of the metals copper, lead, nickel and zinc have also been detected in surface soil exceeding ecological screening levels and above background, which may impact the underlying ground water.

Therefore, it is necessary to characterize the shallow ground water and surface water to the south of the Building 812 drainage for the presence of uranium and metals for both the baseline human health and ecological risk assessment (ERA). The current Spring 6 sampling location, surface water present in Elk Ravine south of the Building 812 drainage, and the shallow alluvial ground water will be sampled and analyzed for uranium, copper, lead, nickel, and zinc. In addition, the surface water locations will be sampled for total hardness (as $CaCO_3$), TDS, TSS and pH to better assess the bioavailability and toxicity of these metals in the Spring 6/Elk Ravine area surface water. Table 2 summarizes the sampling and analysis plan for surface water and shallow ground water.

### 3.5.1. Scope of Work

Surface water sampling is planned for two periods: 1) low flow during the late summer or early fall of 2011 (for uranium isotopes, copper, lead, nickel, zinc, total hardness, TDS, TSS, and pH), and 2) high flow during the winter of 2011-2012 (for uranium isotopes only). The proposed three surface water locations include: (1) the current Spring 6 sampling location, (2) immediately downgradient of the confluence of the 812 drainage and Elk Ravine, and (3) the Elk Ravine pools. The five wells that are completed in the shallow alluvium (NC2-23, W-812-2321, W-812-1921, W-812-08 and W-812-1932) will be sampled once in late summer or early fall 2011 for uranium isotopes, copper, lead, nickel, and zinc. Figure 8 shows the approximate surface water and Qal/WBR ground water sampling locations. All surface water sampling locations in Elk Ravine south of the Building 812 drainage will be mapped using a GPS. Final sampling locations will be selected depending on the availability of surface water.

### 3.5.2. Field Methods

Sampling will be conducted using qualified LLNS personnel following the appropriate SOPs as outlined in Goodrich and Lorega (2009). Table 3 lists the applicable SOPs.

### 3.5.3. Laboratory Methods

Samples will be submitted to the analytical laboratory using standard shipping and chain-of-custody procedures (Table 3). All metals will be analyzed as dissolved metals. Uranium analyses will be conducted by the LLNL ICP-MS facility or by alpha spectometry. A contract analytical laboratory will perform all other analyses. Table 4 lists the applicable laboratory analytical methods.

### 3.5.4. QA/QC

All sampling will be conducted in accordance with the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). One surface water location and one ground water location will be sampled in duplicate and submitted to the analytical laboratory. Section 3.1.3.4, Section 4, and Appendix B for QA/QC contain additional details.

### 3.5.5. Data Analysis

Analytical data and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Only validated data will be used in baseline ecological risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If any uranium or metals data from any of the three surface water locations are rejected, the location will be resampled for the rejected analytes. Locations will not be resampled if data on pH, total hardness, total dissolved solids, and total suspended solids are rejected. If uranium or metals data are rejected from two of the five monitor wells, those wells will be resampled for the rejected analytes. Validated data will be tabulated for use in the baseline risk assessment. Surface water sampling location data collected by GPS will be corrected and managed as described in SOP 4.14 (Mapping with the Trimble Pathfinder Pro XR GPS System). A summary of the results of the surface water and shallow ground water sampling and analysis, and a map of surface water sampling locations will be included in the Building 812 RI/FS.

## 3.6. Sediment Characterization

Concurrent with the additional surface water characterization conducted in Elk Ravine, an additional sediment sample will be collected. Results from three sediment samples collected southeast of the confluence between Elk Ravine and the Building 812 drainage down to the Elk Ravine pools are available. However, data is not available from the pool that is primary habitat for the California red-legged frog, or south of the pools. Therefore, an additional sample is necessary to completely characterize the presence of uranium, copper, lead, nickel, and zinc and potential bioavailability in the sediment downgradient from Building 812 for the baseline ecological risk assessment. This sample will be collected at the Elk Ravine pool and analyzed for uranium isotopes. Table 2 summarizes the sampling and analysis plan for sediment.

### 3.6.1. Scope of Work

Sediment sampling is planned for the late summer or early fall of 2011. Proposed sampling will occur in pool within Elk Ravine southeast of the drainage confluence. The sediment sampling location will be mapped using a GPS and is shown on Figure 8.

### 3.6.2. Field Methods

Sampling will be conducted using qualified LLNS personnel following the appropriate SOPs as outlined in Goodrich and Lorega, 2009. As the surface water is extremely shallow in Elk Ravine, surface soil sampling procedures will be followed (Table 3).

### 3.6.3. Laboratory Methods

Samples will be submitted to the analytical laboratory using standard shipping and chain-of-custody procedures (Table 3). All sample preparation and analysis will be conducted by the analytical laboratory following the QA requirements specified in the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pg. 15-25). Uranium analyses will be conducted by the LLNL ICP-MS facility or an offsite laboratory under contract to LLNS. Either of the analytical methods listed in Table 3 may be used.

### 3.6.4. QA/QC

All sampling will be conducted in accordance with the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). Please see Section 3.1.3.4, Section 4, and Appendix B for additional QA/QC details.

### 3.6.5. Data Analysis

Analytical data and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Only validated data will be used in baseline risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If any uranium or metals data from the single sediment location are rejected, the location will be resampled (or existing sample material re-analyzed). The location will not be resampled if pH and total organic carbon data are rejected. Validated data will be tabulated for use in the baseline risk assessment. Sediment sampling location data collected by GPS will be corrected and managed as described in SOP 4.14 (Mapping with the Trimble

Pathfinder Pro XR GPS System). A summary of the results of the sediment sampling and analysis, and a map of sediment sampling locations will be included in the Building 812 RI/FS.

## 3.7. Phreatic Vegetation Mapping

The Building 812 screening-level ecological risk assessment (SLERA) identified the phreatic vegetation within the Building 812 Canyon drainage as a potential mechanism to expose terrestrial vertebrates species to uranium via uptake of the shallow ground water and subsequent foraging by the terrestrial species. The extent of the phreatic vegetation, and the plant species present, is not well defined. In preparation for the vegetation uranium uptake characterization planned for the spring of 2012, the extent and identities of phreatic vegetation present in the Building 812 Canyon drainage will be determined. Table 2 summarizes the sampling and analysis plan for mapping phreatic vegetation.

### 3.7.1. Scope of Work

Phreatic vegetation mapping is planned for the late summer or early fall of 2011. Phreatic species present will be identified to a minimum of genus level.

### 3.7.2. Field Methods

Phreatic vegetation within the Building 812 drainage will be mapped by GPS by a qualified LLNS biologist following SOP 4.14 (Mapping with a Trimble Pathfinder Pro XR GPS System). Genus and species data will be collected a controlled field logbook (SOP 5.8).

### 3.7.3. QA/QC

All mapping will be conducted in accordance with the Livermore Site and Site 300 Quality Assurance Project Plan (QAPP) (Dibley 1999, Section 2.9, pg. 20).

### 3.7.4. Data Analysis

Mapping data collected by GPS will be corrected and managed as described in SOP 4.14 (Mapping with the Trimble Pathfinder Pro XR GPS System). A summary of the results of the phreatic vegetation mapping, including a map of the aerial extent of phreatic vegetation and tabulated genus and species data will be included in the Building 812 RI/FS.

## 3.8. Characterization of Uranium Uptake by Vegetation

A pilot study was initiated in May 2010 to develop a vegetation sampling and analysis protocol for use in the baseline ERA. The goals of the study were to: (1) develop a sampling methodology for the vegetation types found in the Building 812 area (annual exotic and native perennial grasses in the upland areas, phreatic vegetation in the Building 812 drainage), (2) determine if uranium detection limits in vegetation were adequate for baseline ERA, and (3) obtain preliminary information concerning uptake characteristics along a uranium concentration gradient. Four locations were sampled in the pilot study, which spanned a uranium concentration gradient of 3.6 to 65 pCi/g. The scope of work presented here is based on the results of the pilot study. Table 2 summarizes the sampling and analysis plan for vegetation.

### 3.8.1. Scope of Work

Vegetation sampling is planned for the spring of 2012. A minimum of ten locations spanning a uranium concentration gradient will be sampled. Final locations will be selected based on the results of the uranium surface soil characterization, planned for the summer of 2011. In addition, available results of from the uranium grain size distribution analysis (Section 3.2) and uranium solid phase characterization (Section 3.3) will be used to identify areas of potentially higher bioavailability for sample location. A vegetation sample location map will be prepared and discussed with the regulatory agencies.

### 3.8.2. Field Methods

Sample collection will be conducted by a qualified LLNS biologist. Based on information gained from the pilot study, only wild oat (*Avena* sp.) is present in the Building 812 upland areas in sufficient quantity to provide the required amount of biomass. If *Avena* is not present in sufficient quantity, *Bromus diandrus* (rip gut brome) or *Poa secunda* (pine blue grass) will be selected. In addition to these upland plants, at least one location will be selected in the Building 812 drainage. Phreatic vegetation present in the drainage will be sampled. Nettles (*Urtica* sp.) are the plant most likely to be present in the drainage. At each location, all plants to be composited will be the same species. At the time of the pilot study, seeds were not present and thus were not sampled. However, the 2012 sampling event will be conducted earlier in the spring, which should allow for seed sampling. Provided sufficient funding is available, one additional sample (for a total of 11 sample locations) will be co-located in the area of highest uranium concentration. This sample will consist of a composite of all plant species within the quadrat.

The sampling location coordinates will be logged using a GPS. A 60 cm quadrat will be placed at the center of the sampling location. The percent cover each plant species within the quadrat will be recorded. A sufficient number of plants will be carefully excavated with a trowel from within the quadrat so that the roots can be removed along with the soil. The soil adjacent to the roots from each plant is composited and placed in a labeled 500 ml quorpak jar. Depending on the resolution of the uranium surface soil characterization to be conducted in 2011, soil samples may not be necessary in 2012.

Plants will be rinsed thoroughly with water available at Building 812 to remove the majority of soil and dust from the plants prior to removing them from the site, and will be placed in labeled ziplock bags. After transporting the samples to a preparation area, plants will be segregated into roots, shoots and seed. All plant tissues will be thoroughly rinsed using DI water to make sure no soil or dust remains on the plant tissues. The plants will then be patted dry with paper towels and placed in labeled paper bags to dry.

### 3.8.3. Laboratory Methods

Samples will be submitted to the LLNL ICP-MS facility using standard chain-of-custody procedures (Table 3). Individual dried tissues from each location (roots, shoots, and seeds) will be composited and ground. Tissue material will be ashed at 125°C for 4 hours in a muffle furnace. The temperature will then be ramped up by steps to 500°C for 24 hours to destroy organic content. Remaining material will be digested in 1:1 concentrated nitric and hydrochloric acid. Digestate will be run through an UTEVA resin column to isolate uranium. The final solution from the UTEVA column will be sent to the ICPMS laboratory for analysis. Soil will be prepared using EPA Method 305B. Prepared sample extracts will be analyzed for uranium isotopes using ICPMS.

### 3.8.4. QA/QC

All sampling will be conducted in accordance with the Livermore Site and Site 300 Quality Assurance Project Plan (QAPP, Section 2, pp. 15-25) (Dibley 1999). Collecting a field duplicate is not feasible. However, one location will be analyzed as a laboratory split. Please see Section 3.1.3.4, Section 4, and Appendix B for additional QA/QC details.

### 3.8.5. Data Analysis

Uranium isotopes in pCi/g and total uranium in mg/kg and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Only validated data will be used in baseline risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If less than 8 of the 10 locations yield usable data for any of the individual plant tissues, the locations with rejected data will be resampled (or existing sample material re-analyzed). Validated data will be tabulated for use in the baseline ERA. Vegetation sampling location data collected by GPS will be corrected and managed as described in SOP 4.14 (Mapping with the Trimble Pathfinder Pro XR GPS System). A summary of the results of the uranium vegetation uptake characterization, including a map of the vegetation sampling locations will be included in the Building 812 RI/FS.

## 3.9. Characterization of Uranium Uptake by Soil Invertebrates

A pilot study is planned for the fall of 2011 to develop a soil invertebrate sampling and analysis protocol for use in the baseline ecological risk assessment. The goals of the study are to: (1) develop a sampling methodology for the types of soil invertebrates found in the Building 812 area, (2) determine if uranium detection limits in soil invertebrates are adequate for the baseline ERA, and (3) obtain preliminary information concerning uptake characteristics along a uranium concentration gradient. The results of the pilot study will be used to adjust the protocol as needed. Four locations are planned for the pilot study, which span a uranium concentration gradient of 3.6 to 65 pCi/g. The locations to be used in the invertebrate pilot study are coincident with the locations used in the vegetation pilot study. Table 2 summarizes the sampling and analysis plan for soil invertebrates.

### 3.9.1. Scope of Work

Soil invertebrate sampling is planned for the spring of 2012. Ten locations spanning a uranium concentration gradient are planned. Final locations will be selected based on the results of the uranium surface soil characterization, planned for the fall of 2011. A soil invertebrate sample location map will be prepared and discussed with the regulatory agencies.

### 3.9.2. Field Methods

Samples will only be collected by a qualified LLNS biologist. Soil invertebrates expected in the Building 812 area include ants, beetles, spiders, millipedes, centipedes, Jerusalem crickets, camel crickets and scorpions. The pilot study will use a combined sampling method of pit traps and manual investigation of burrows, rocks and crevices. Unlike plants, soil invertebrates are mobile. Ants can travel distances up to 200 m (700 ft) from their nests (Carroll and Janzen, 1973). Therefore, soil invertebrate uranium concentrations will be an integrated value representing all the soil the invertebrate came into contact.

All pit trap location coordinates will be logged using a GPS. A pit trap will be installed at the point of the GPS coordinates, and at four corners 10 ft from the center locations, for a total of 5 pit traps per location. The details of the pit trap to be constructed and used are still under development, but are expected to be typical of pit traps used by other researchers (Majer, 1978, Clark and Bloom, 1992, Blancila and Plaiasu, 2009). They consist of an open-ended container sunk into the ground flush with the surface. A small amount of preservative fluid is placed in the bottom of the container. Typical preservatives include alcohol with glycerol, ethylene glycol, and propylene glycol. Test tubes and small cans have been used as the trap. The pit trap to be used at Site 300 will have a large enough opening to trap soil invertebrates but prevent accidental vertebrate capture. In addition, ethylene glycol will be avoided as a preservative due to its ability to attract vertebrates.

Pit traps will be examined daily and all invertebrates captured will be collected. Invertebrates will be counted, identified at least to family, and composited for each sample location. Traps will be examined until sufficient biomass (at least 5 g) has been collected for analysis. Collected invertebrates will be transported to the laboratory, thoroughly rinsed with deionized water, and dried.

In addition to examining the pit traps, nearby rocks, crevices and burrows will be examined for soil invertebrates, and any found counted, identified, and placed in a jar containing preservative. Invertebrates collected in such manner will be added to the composite pit trap samples.

### 3.9.3. Laboratory Methods

Samples will be submitted to the LLNL ICP-MS facility using standard chain-of-custody procedures (Table 3). Collected invertebrates will be dried, composited, and ground. Tissue material will be prepared for ICPMS analysis as described for the vegetation samples. Prepared sample extracts are analyzed for uranium isotopes using ICPMS.

### 3.9.4. QA/QC

All sampling will be conducted in accordance with the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). Collecting a field duplicate is not feasible. However, one location will be analyzed as a laboratory split. Please see Section 3.1.3.4, Section 4, and Appendix B for additional QA/QC details.

### 3.9.5. Data Analysis

Uranium isotopes in pCi/g and total uranium in mg/kg and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Only validated data will be used in baseline risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If less than 8 of the 10 locations yield usable data, the locations with rejected data will be resampled (or existing sample material re-analyzed). Validated data will be tabulated for use in the baseline ERA. Pit trap location data collected by GPS will be corrected and managed as described in SOP 4.14 (Mapping with the Trimble Pathfinder Pro XR GPS System). A map of all pit trap locations will be produced. A summary of the results of the soil invertebrate uranium uptake characterization, including a map of the vegetation sampling locations will be included in the Building 812 RI/FS.

## 3.10. Ground Water and Surface Water Characterization for Lithium and Radium-226

### 3.10.1. Data Quality Objectives, Uses, and Requirements

The Building 812 screening-level human health risk assessment identified a need to conduct additional ground water and surface water characterization for lithium and radium-226 (see Section 2.3.3 above). Analytical methods are not available that can analyze for radium-226 at the risk-based PRG (0.000906 pCi/L). Current reporting limits from analytical laboratories for radium-226 is 0.25 pCi/L. Additional ground water characterization for lithium and radium-226 are being conducted at the request of the regulatory agencies.

### 3.10.2. Scope of Work

Sampling is planned for the late summer or fall of 2011. Three wells monitoring the $Tnbs_1$/$Tnbs_0$ HSU directly adjacent to or near the Building 812 firing table (W-812-01, W-812-02, and W-812-2009), three wells monitoring the Qal/WBR HSU downgradient of the firing table (NC2-23, W-812-08 and W-812-1921), and three wells screened in the $Tnsc_0$ HSU downgradient of the firing table (NC2-22, W-812-07 and W-812-09) will be sampled (total of 9 wells). Samples collected from these wells will be analyzed for lithium and radium-226. Spring 6 will also be sampled. Figure 9 shows the Spring 6 and well locations.

### 3.10.3. Ground Water Sampling

Sampling will be conducted using qualified LLNS personnel following the appropriate SOPs as outlined in Goodrich and Lorega (2009). Applicable SOPs are listed in Table 3.

### 3.10.4. Laboratory Methods

Samples will be submitted to the analytical laboratory using standard shipping and chain-of-custody procedures (Table 3). All metals will be analyzed as dissolved metals. The analytical methods listed in Table 4 will be used.

### 3.10.5. QA/QC

Sampling will be conducted in accordance with the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). One location will be sampled in duplicate and submitted to the analytical laboratory. All sample preparation and analyses will be conducted by an analytical laboratory under contract to ERD following the QA requirements specified in the Livermore Site and Site 300 QAPP (Dibley 1999, Section 2, pp. 15-25). Contract analytical laboratories must use methods and procedures functionally equivalent to the methods and procedures used the EPA Contract Laboratory Program and the California DTSC Certified Laboratory Program. Contract analytical laboratories must maintain a DHS Environmental Laboratory Accreditation Program certification for analytical tests for which the DHS offers certification.

### 3.10.6. Data Analysis

Analytical data and associated QC data will be managed in accordance with SOPs 5.1 through 5.4 (Table 3). Data will be validated in accordance with SOP 4.6 (Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories). 100% of data received from analytical laboratories will be validated. Only validated data will be used in baseline risk assessment. Locations with rejected data will be reviewed to determine if resampling is required. If less than seven of the nine wells yield usable data, the wells with rejected data will be resampled for the rejected analyte(s). If data for Spring 6 are rejected, this spring will be resampled for the rejected analyte(s). Validated data will be tabulated for use in the baseline human health risk assessment. A summary of the results of lithium and radium-226 ground water and surface water sampling and analysis will be included in the Building 812 RI/FS.

## 3.11. Safety Procedures

Site-specific drilling, sample collection, and laboratory procedure controls have been developed by LLNL and are documented in Integrated Safety Work Sheets (IWSs) for drilling and geophysical activities, sample collection, and onsite laboratory operations. IWSs also specify the training requirement for workers engaged in these activities. The IWSs are reviewed and approved by LLNL Environmental Safety and Health Teams comprised of industrial hygienists and health physicist before work can be conducted. The IWSs are also reviewed by subject matter experts and facility managers to ensure that activity-specific and location-specific hazards and appropriate controls are identified. “Responsible Individuals” are designated for each IWS who oversee the work and ensure that workers are appropriately trained, safety procedures are followed, and hazard controls are implemented. The controls described in the applicable IWSs shall be followed during all field and laboratory work described in this work plan.

## 3.12. Contamination Control and Sampling Equipment Decontamination Procedures

Contamination control procedures, outlined in laboratory-specific IWSs will be followed to prevent contamination of facilities and personnel. To control contamination, all soil cuttings at borehole drilling sites will be placed in buckets, weather-tight containers, or sealed drums, as discussed in Section 3.1. These soil cuttings will be placed back in the borehole once all borehole sampling and surveying is complete.

Drilling equipment will be decontaminated after leaving each investigation area following guidance provided in ERD SOP 4.5: General Equipment Decontamination. Sampling equipment decontamination is conducted in accordance with SOP 4.5, General Equipment Decontamination (Table 3).

## 3.13. Sample Control, Sample Tracking, and Data Control

Analytical sample custody and the analytical sample custody logbooks are to be handled according to applicable SOPs (Table 3).

# 4. Quality Assurance/Quality Control

Quality assurance is a management system for ensuring that all information, data, and decisions are technically sound and properly documented. The Livermore Site and Site 300 QAPP (Dibley, 1999), and associated SOPs (Goodrich and Lorega, 2009) contains guidance for the following parameters:

- Sampling and decontamination.
- Sample custody.
- Calibration procedures and frequency.
- Analytical procedures.
- Data reduction, validation, and reporting.
- Internal quality control checks.
- Frequency, performance, and system audits.
- Specific routine procedures used to assess data precision, accuracy, and completeness.
- Corrective actions.
- QA reports to management.

Appendix B discusses QA objectives for the procedures and the data relevant to this work plan. QA considerations for procedures include field and laboratory methods. To assess data quality the precision, accuracy, representativeness, comparability, and completeness (PARCC) parameters are determined. Details of these procedures are presented in Appendix B.

# 5. Summary and Next Steps/Process

The characterization activities outlined in this Work Plan will provide essential information for completing the assessment of the nature and extent of depleted uranium in soil at the Building 812 OU, miscellaneous data required for the baseline risk assessment, and information on solid phase uranium essential for evaluating uranium mobility in water, bioavailability, and potential remedial technologies that can be efficiently applied to the remediation of soils impacted by depleted uranium at Building 812.

Results and progress on these activities will periodically reported at the monthly Remedial Project Manager meetings. The results of these activities will be presented and applied in the nature and extent of contamination, baseline risk assessment, remedial technology screening, and remedial alternative development sections of the Building 812 RI/FS document.

# 6. Schedule

This work plan is currently scheduled for final regulatory approval by late August 2011, at which time fieldwork is schedule to begin and continue until the onset of the rainy season. Field work will recommence in the spring of 2012, at the end of the rainy season. The first phases of laboratory work will begin after field work commences in 2011 and will continue until late 2012. The final schedule is contingent upon weather conditions and funding.

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# 8. Acronyms and Abbreviations

| | |
|---|---|
| bgs | Below ground surface |
| C | (degrees) Centigrade |
| CALs | Contract Analytical Laboratories |
| CAP | Consolidated Audit Program |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COPEC | Contaminant of potential ecological concern |
| COPC | Contaminant of potential concern |
| CoC | Chain of custody |
| DHS | California Department of Health Services |
| DI | Deionized |
| DIM | Detector Instrument Mode |
| DOE | U.S. Department of Energy |
| DQOs | Data Quality Objectives |
| DTSC | California Department of Toxic Substances Control |
| EDS | Energy dispersive spectral |
| EPA | Environmental Protection Agency |
| ERA | Ecological risk assessment |
| ERD | Environmental Restoration Department |
| ES&H | Environmental Safety & Health |
| HSU | Hydrostratigraphic unit |
| ICP-MS | Inductively coupled – plasma mass spectrometry |
| ID | Identification |
| ISM | Integrated Safety Management |
| IWS | Integration Work Sheet |
| KeV | Kilo electron volt |
| LLNL | Lawrence Livermore National Laboratory |
| LLNS | Lawrence Livermore National Security, Limited Liability Corporation |
| LSO | Livermore Site Office |
| M | Molar |
| MCL | Maximum Contaminant Level |
| ml | Milliliter |
| MDA | Minimal detectable activity |
| mm | Millimeter |
| mg/kg | Milligram per kilogram |
| m/sec | Meters per second |
| MSL | Mean sea level |
| NELAP | National Environmental Laboratory Accreditation Program |

| | |
|---|---|
| NIST | National Institute of Standards and Technology |
| OSHA | Occupational Safety and Health Administration |
| OU | Operable Unit |
| pCi/g | Picocuries per gram |
| pCi/L | Picocuries per liter |
| PMMA | Poly(methyl methacrylate) |
| PPE | Personal protection equipment |
| QA | Quality assurance |
| Qal | Quaternary alluvium |
| QAPP | Quality Assurance Project Plan |
| Qal/WBR | Quaternary alluvium/weathered bedrock |
| QC | Quality control |
| QSAS | Quality Systems for Analytical Services |
| RI/FS | Remedial Investigation/Feasibility Study |
| %RPD | Relative percent difference |
| RSL | U.S. EPA Regional Screening Levels |
| RWQCB | Regional Water Quality Control Board-Central Valley Region |
| %RVC | Percent recovery |
| SARA | Superfund Amendments and Reauthorization Act |
| SEM | Scanning electron microscope |
| SL | Screening level |
| SLERA | Screening-level ecological risk assessment |
| SLHHRA | Screening-level human health risk assessment |
| SLRA | Screening-level risk assessment |
| SOP | Standard operating procedure |
| SPACT | Sample Planning and Chain-of-Custody Tracking |
| STLC | Soluble Threshold Limit Concentration |
| SWAMP | Surface Water Ambient Monitoring Program |
| TDS | Total dissolved solids |
| TEIMS | Taurus Environmental Information Management System |
| TOC | Total organic carbon |
| TTLC | Total Threshold Limit Concentration |
| $^{235}$U | Uranium-235 |
| $^{238}$U | Uranium-238 |
| U.S. EPA | United States Environmental Protection Agency |
| XRD | X-ray diffraction |

# Figures

# List of Figures

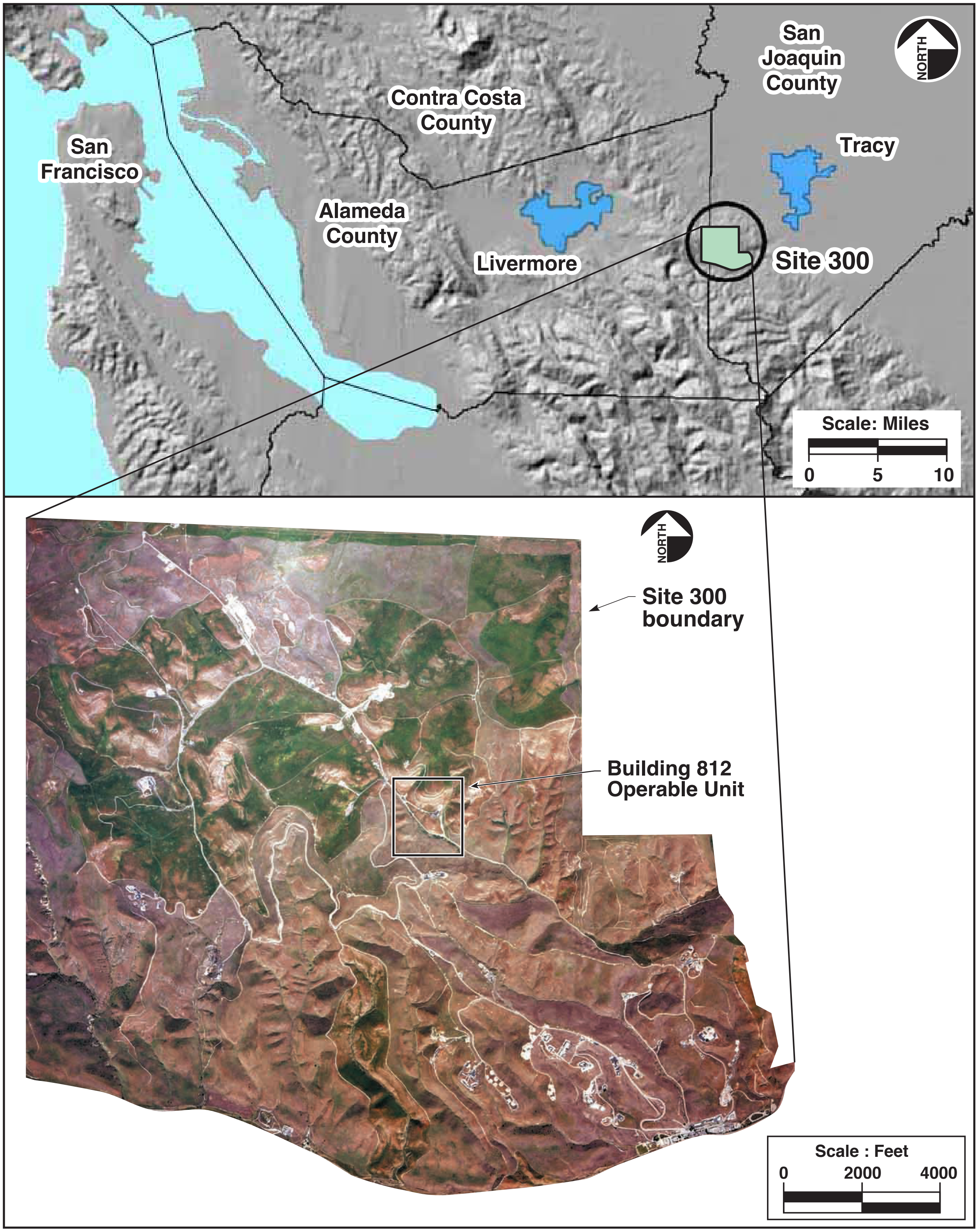

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Figure 1. Location of LLNL Site 300 and the Building 812 Operable Unit.

**Figure 2. Panoramic photograph of Building 812 area looking northeast, February 2008.**

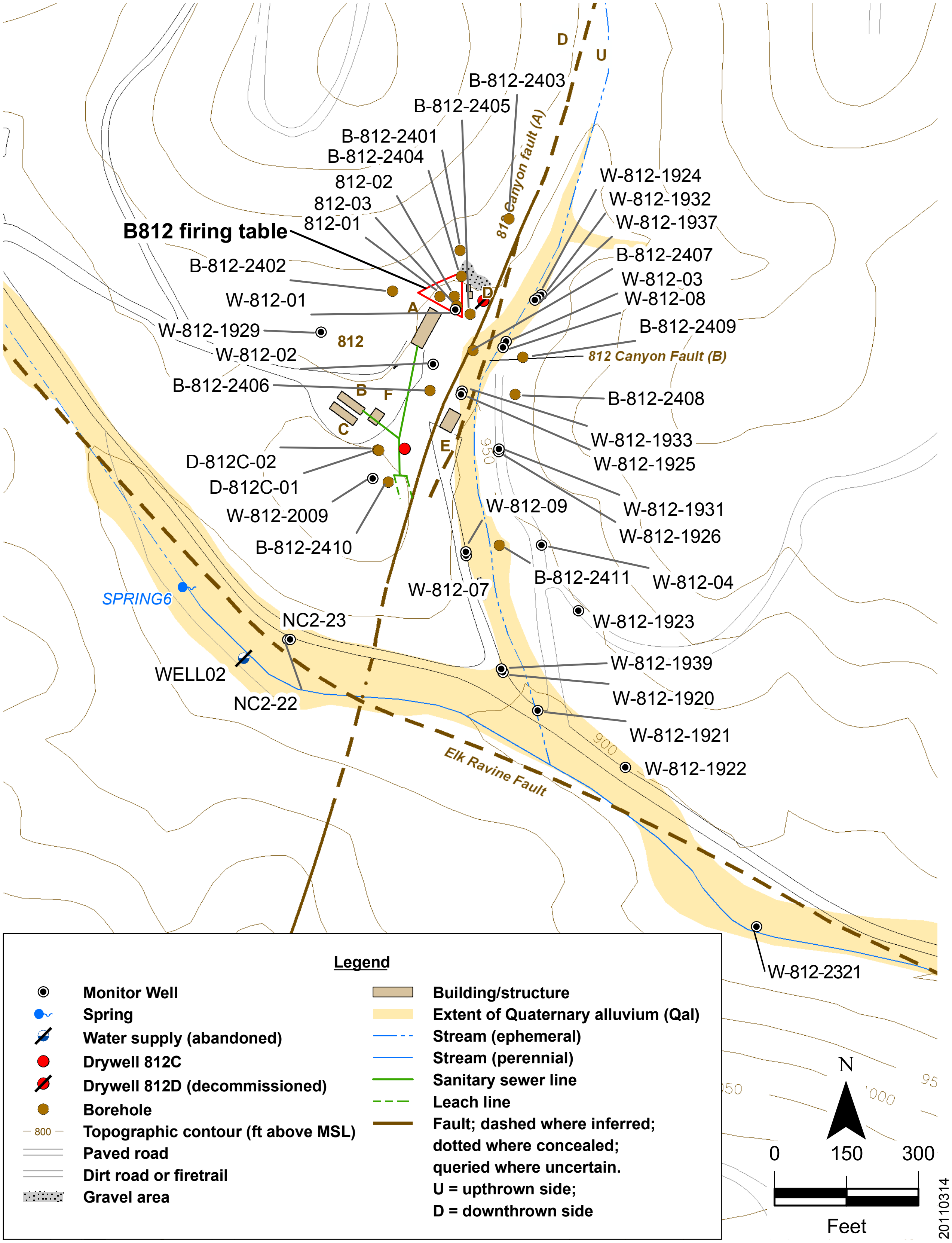

**Figure 3. Locations of buildings, firing table, boreholes, monitor wells, dry wells, and springs in the Building 812 Operable Unit.**

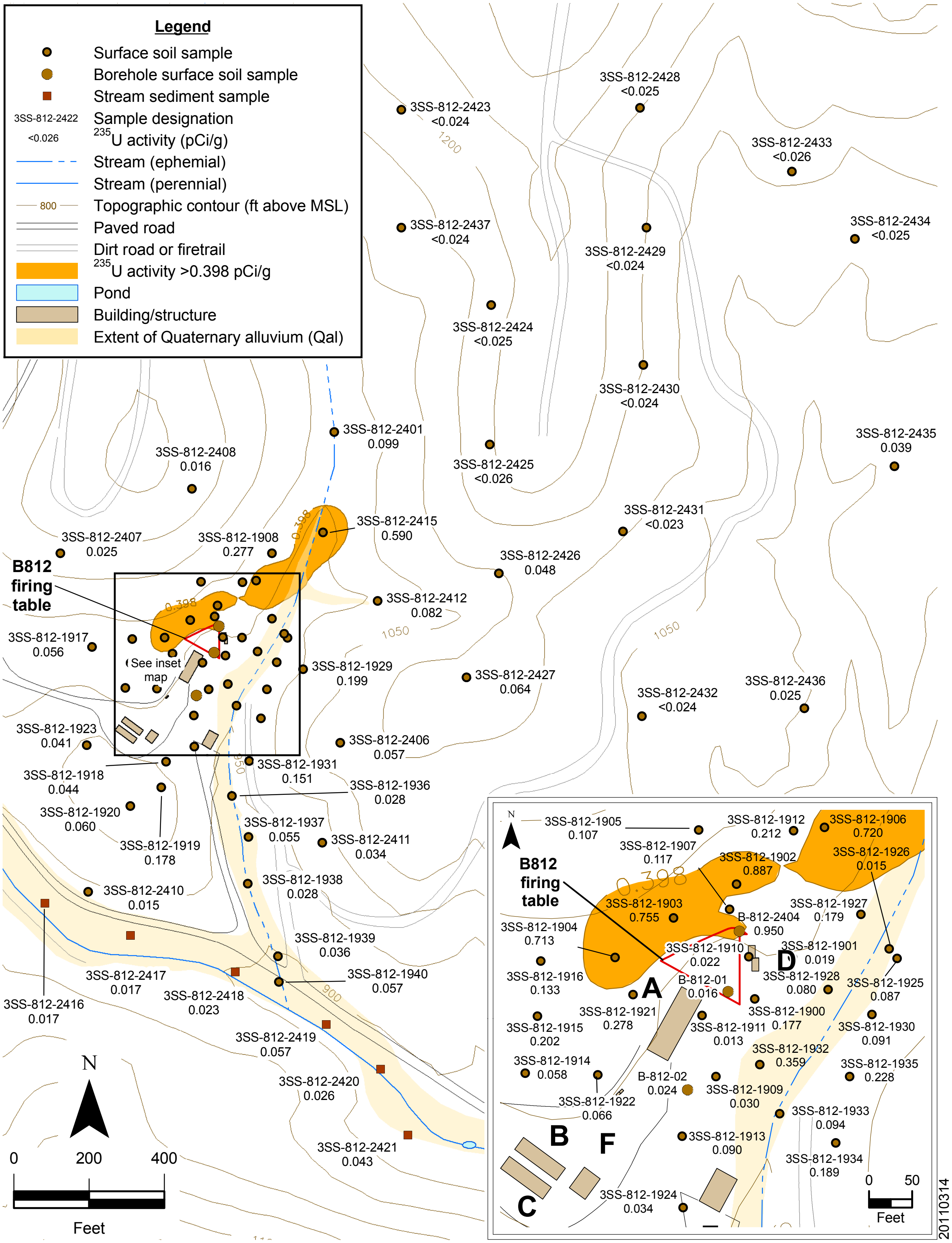

**Figure 4. Surface soil sample locations at the Building 812 Operable Unit showing uranium-235 activities.**

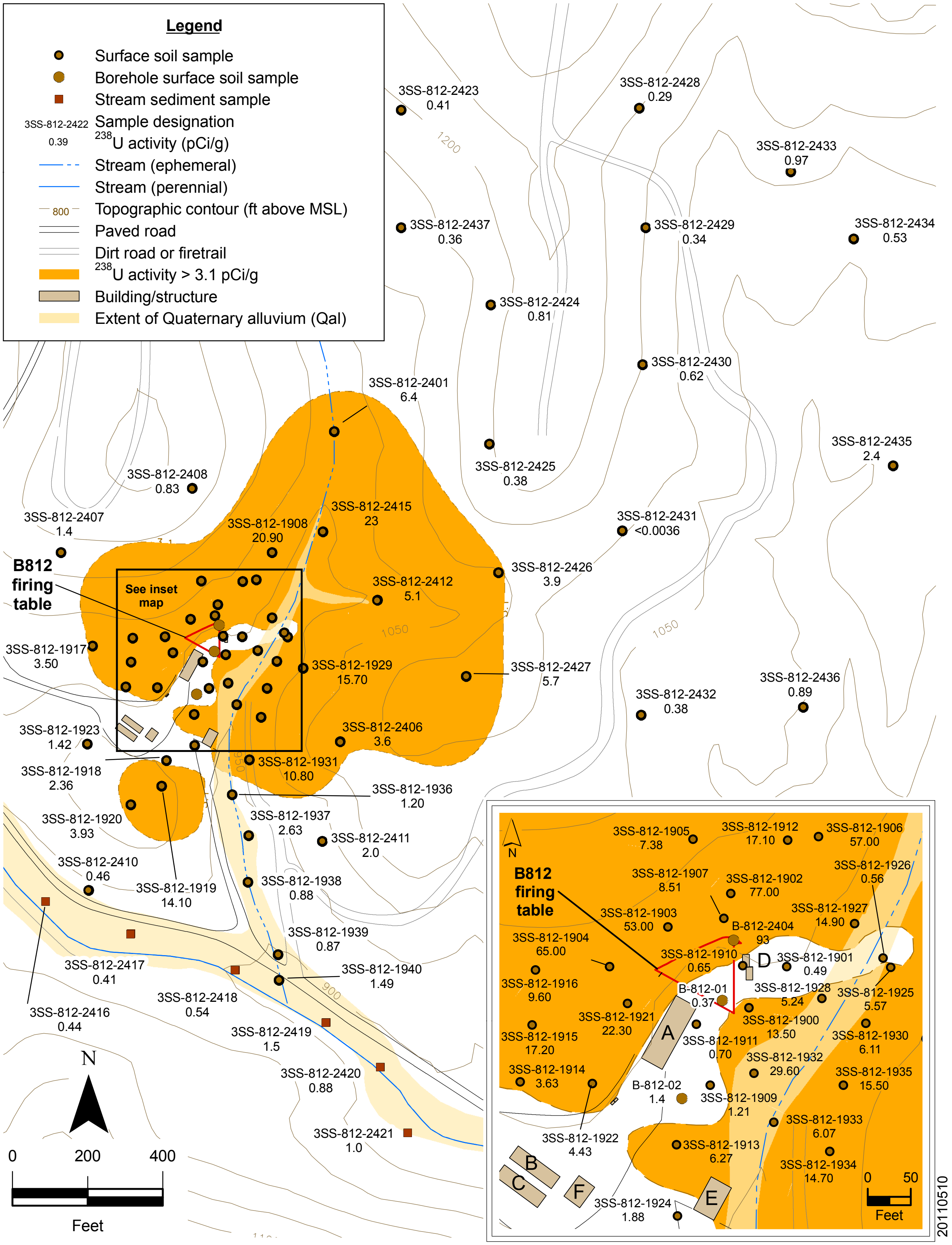

Figure 5. Surface soil sample locations at the Building 812 Operable Unit showing uranium-238 activities.

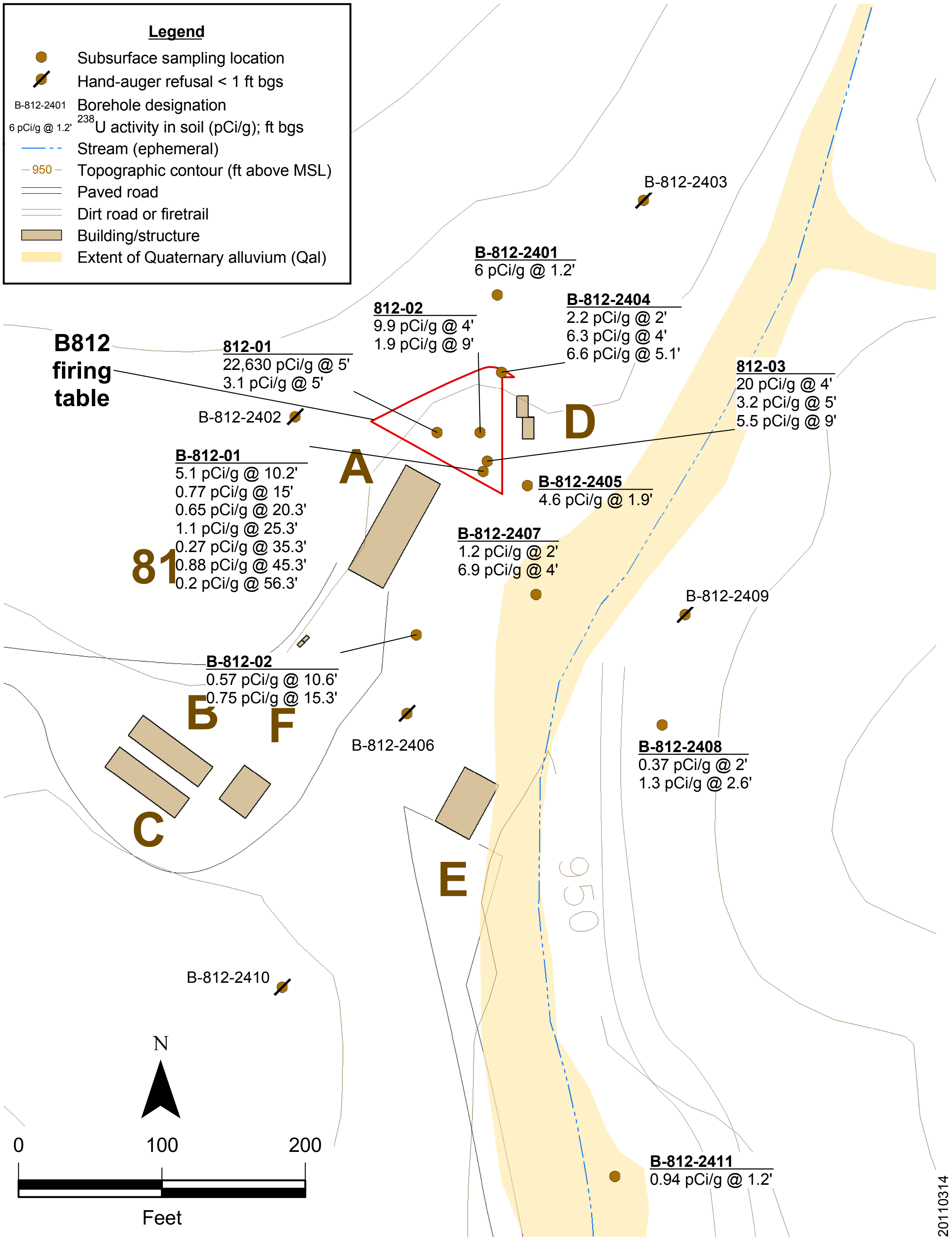

**Figure 6. Subsurface soil sample locations at the Building 812 Complex Operable Unit showing uranium-238 activities.**

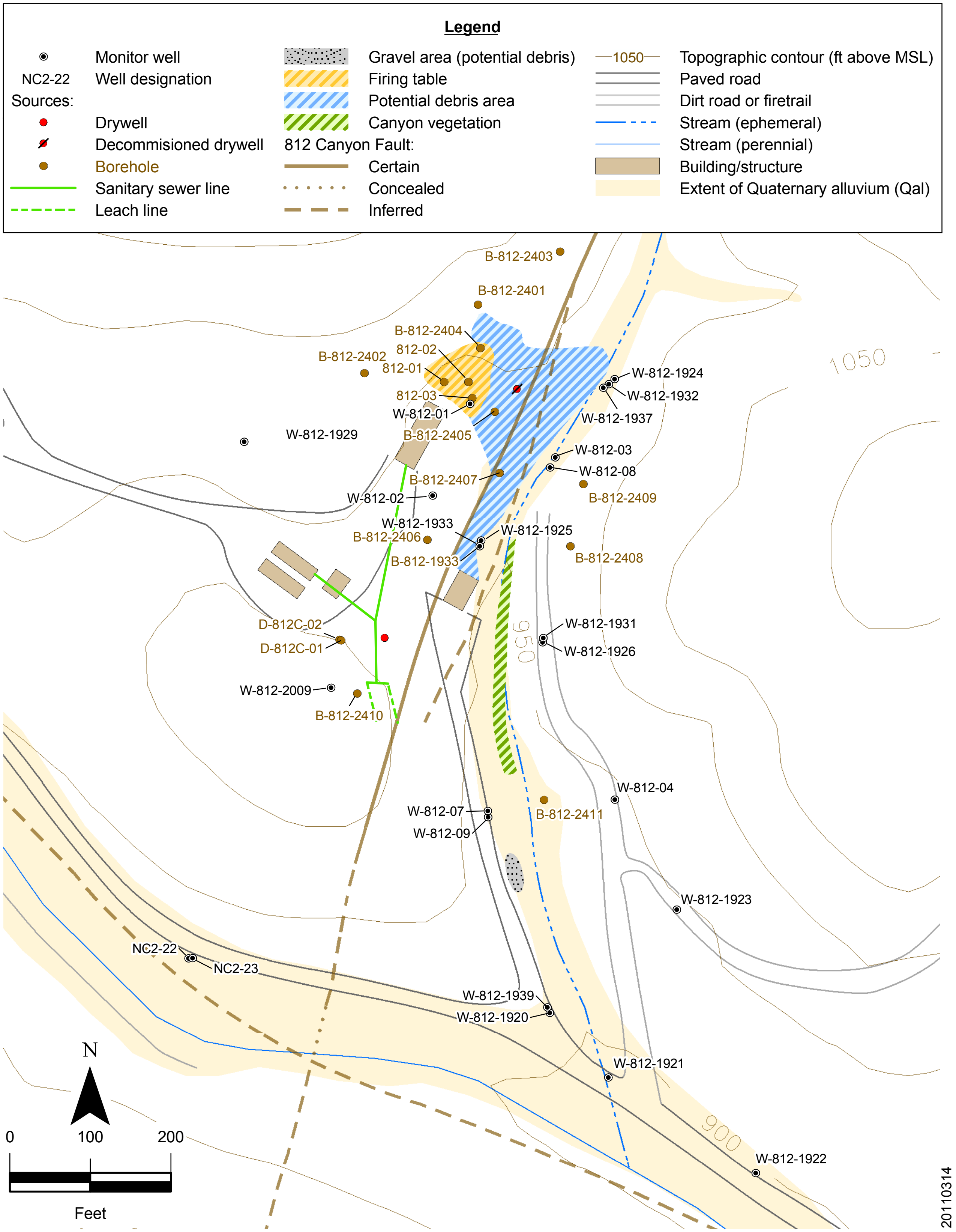

**Figure 7. Miscellaneous features and areas of additional investigation at the Building 812 Operable Unit.**

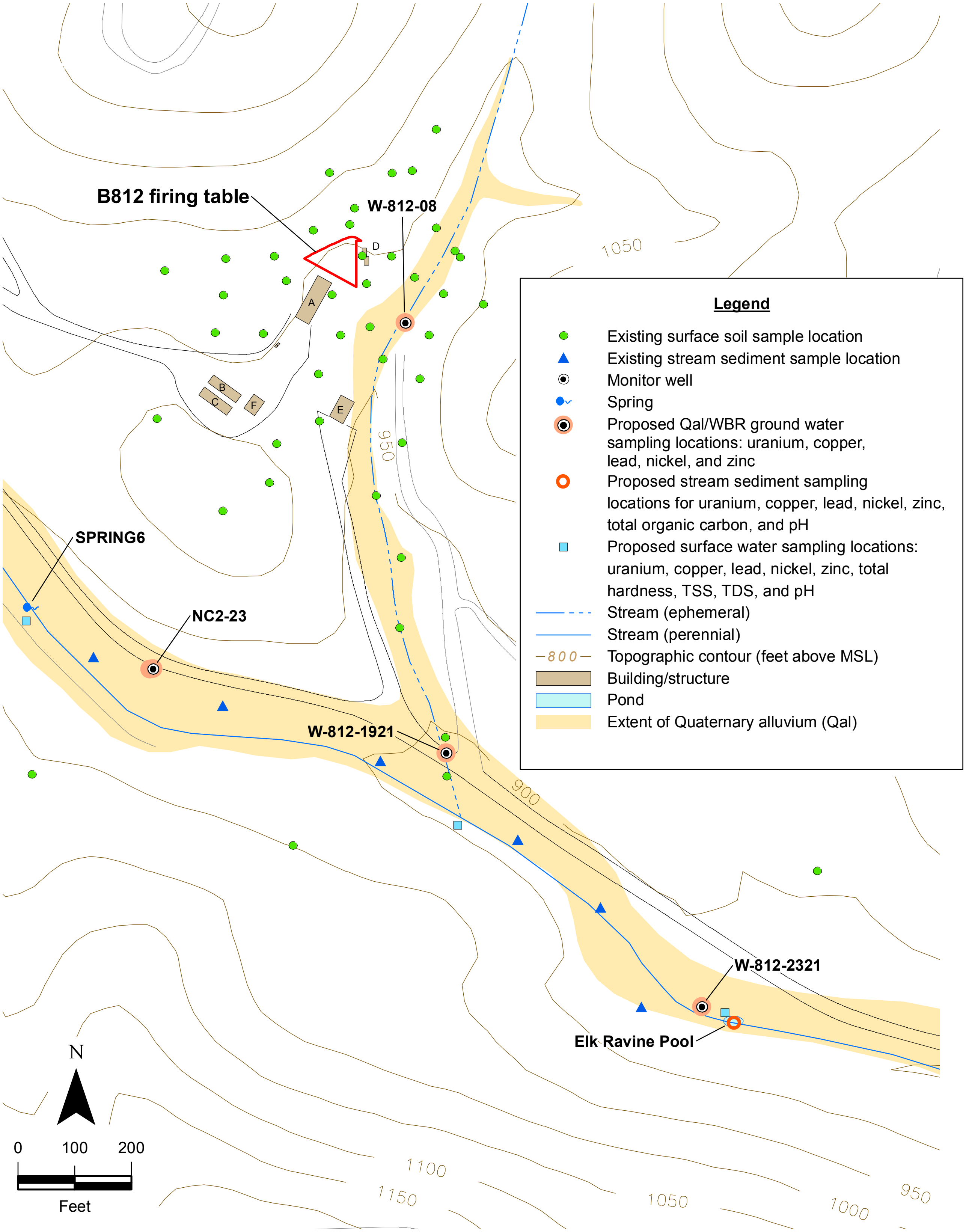

**Figure 8. Proposed sediment, surface water, and ground water sampling locations at the Building 812 Operable Unit.**

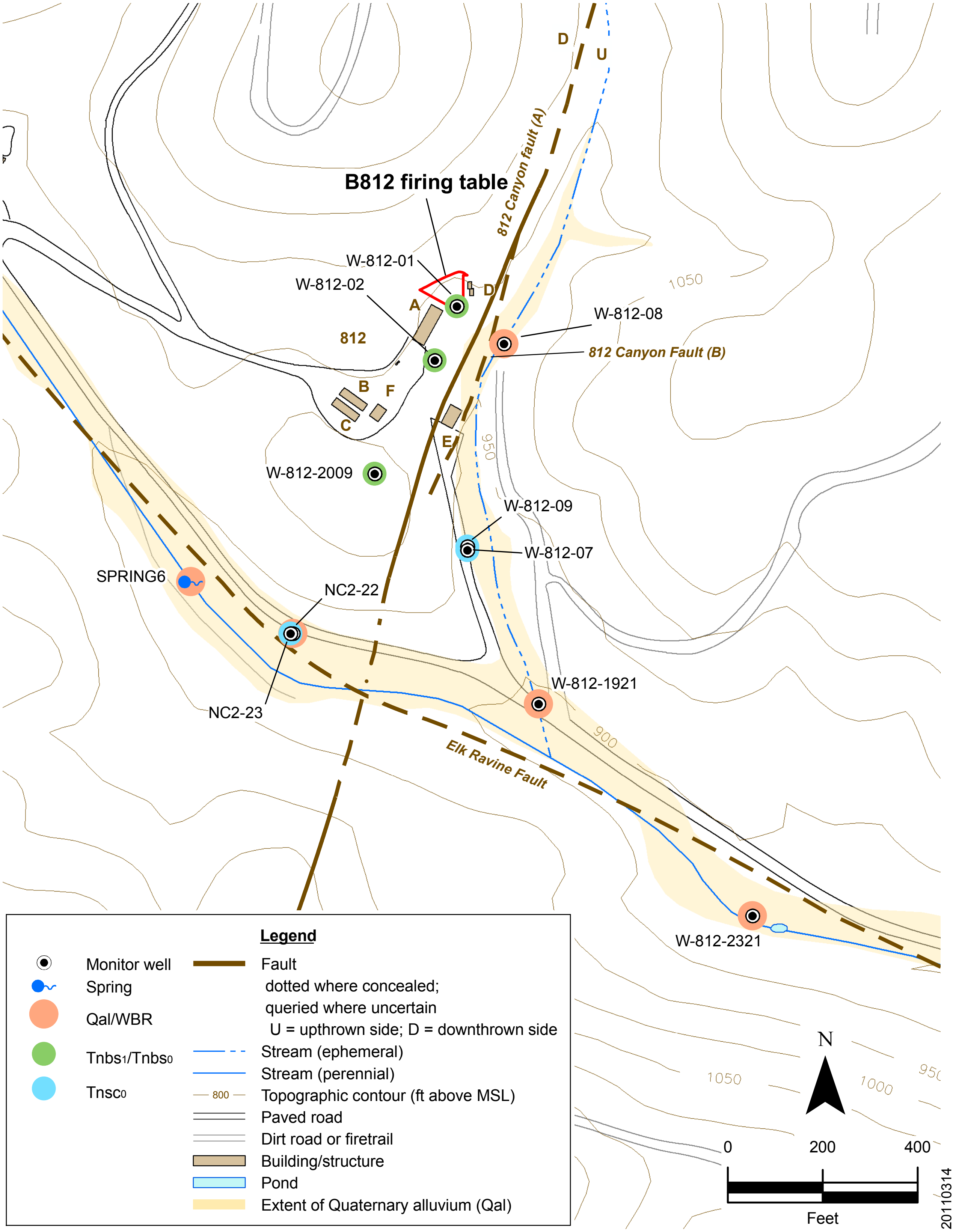

**Figure 9. Proposed ground water and surface water locations to be sampled for lithium and radium-226 at the Building 812 Operable Unit.**

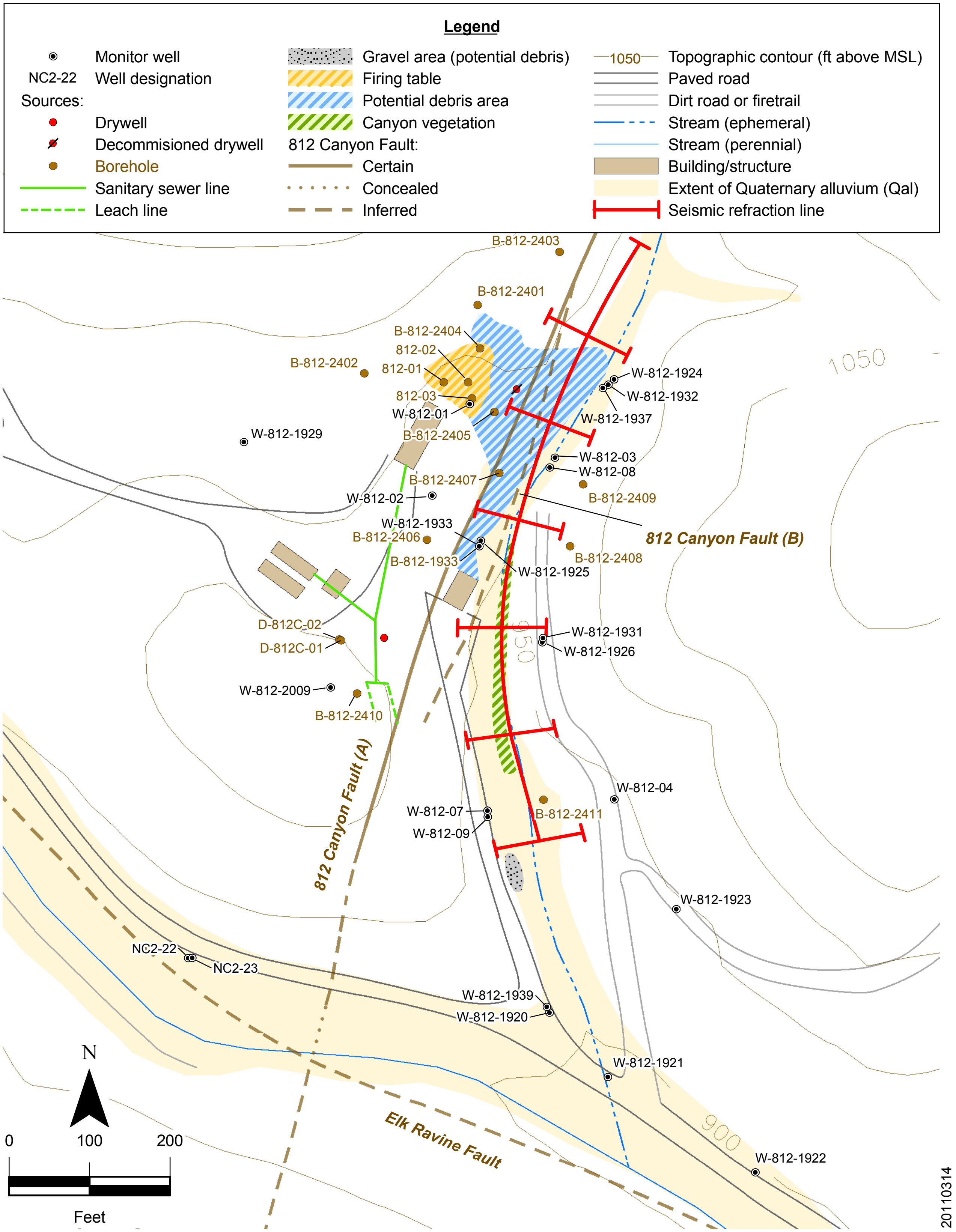

**Figure 10. Proposed locations of seismic refraction survey lines at the Building 812 Operable Unit.**

# Tables

# List of Tables

## Table 1. Data Quality Objectives for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit.

**Step 1. State the Problem.** ***Define the problem that necessitates the study and identify the planning/project team.***

**Problem:** Explosives experiments at the Building 812 firing table released depleted uranium to surface soil, subsurface soil, and ground water. Several metals have also been released to the environment from these experiments. Previous investigations identified the extent of uranium-238 and uranium-235 (principal uranium isotopes in depleted uranium) in surface and subsurface soil based on soil sampling and analysis. In August 2009, an independent panel of scientists from U.S. DOE EM-22 and Savannah River Site recommended that before selecting a final remedy for uranium in soil at Building 812, additional characterization be conducted to further constrain the extent of uranium-238 requiring remediation, and define site-specific uranium mineralogy, mobility, bioavailability, and grain size distribution. A screening-level human health and ecological risk assessment was also completed in April 2010 and identified the need to conduct additional characterization of metals and uranium in surface water, shallow ground water and sediment, and lithium and radium in ground water. Previous investigations have identified uranium-235 and uranium-238 in surface and subsurface soil at maximum activities of 0.95 and 93 picocuries per gram (pCi/g) (surface soil) and 110 and 22,630 pCi/g (subsurface soil), respectively. These investigations also identified metals in surface soil at maximum concentrations of 4,100 milligrams per kilograms (mg/kg) for copper, 150 mg/kg for lead, 540 mg/kg for nickel and 230 mg/kg for zinc. Chemicals in surface and subsurface soil exceed human health risk-based standards for industrial workers (U.S. Environmental Protection Agency Regional Screening Levels, and Preliminary Remediation Goals). Chemicals in surface water, shallow ground water, surface soil, and subsurface soil also exceed ecological screening levels.

**Planning Team**: The planning/project team consists of Michael Taffet, Tina Carlsen, Victor Madrid, Valerie Dibley, Leslie Ferry, and John Radyk. Michael Taffet, Victor Madrid, and John Radyk are California Professional Geologists and/or Certified Hydrogeologists.

**Step 2. Identify the Goal of the Study.** ***State how environmental data will be used in meeting objectives and solving the problem, identify study question and relevance, and alternative outcomes.***

The goals of these characterization activities are to:

1. Provide better definition of the lateral and vertical extent of uranium in subsurface soil in the Building 812 area.
2. Define the relationship between soil grain size and uranium activity in surface and subsurface soil.
3. Determine the chemical form of the uranium in soil as a means of determining its solubility and bioavailability.
4. Define the geometry of soil and decomposed bedrock that can be excavated with conventional equipment (is "rippable").
5. Determine the extent of phreatic vegetation within the Building 812 Canyon stream channel area.
6. Determine the uranium mass in local vegetation and invertebrates.
7. Further characterize uranium and metals concentrations in surface water, shallow ground water, and sediment, and the factors controlling bioavailability.
8. Conduct additional characterization of lithium and radium-226 in ground water.

The following activities will be conducted to satisfy the goals: Drilling of boreholes, gamma radiation measurements within boreholes, and sampling and uranium analysis of soil from the boreholes.

1. Augering and drilling boreholes,
2. Gamma radiation measurements of soil and rock within boreholes to determine uranium-238 activity,
3. Sampling and analysis of subsurface soil from the boreholes for uranium isotopes,
4. Determination of correlation between uranium content and surface and subsurface soil grain size,
5. Determination of mineralogy of solid-phase uranium,

## Table 1. Data Quality Objectives for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit. (Continued)

**Step 2. Identify the Goal of the Study.** *State how environmental data will be used in meeting objectives and solving the problem, identify study question and relevance, and alternative outcomes. (Continued)*

6. Seismic refraction survey to define the geometry of valley fill alluvium and decomposed bedrock within Building 812 Canyon,
7. Determination of the areal extent of phreatic vegetation,
8. Analysis of uranium content in vegetation, and
9. Analysis of uranium content in invertebrates.
10. Sampling and analysis of surface water and shallow ground water samples for uranium, metals, pH, total hardness, total dissolved solids and total suspended solids.
11. Sampling and analysis of sediment for uranium, metals, total organic carbon, and pH.
12. Sampling and analysis of ground water samples for lithium and radium-226.

These characterization activity goals lead to the following study questions:

**What is the extent of uranium-238 in soil in the vicinity of Building 812?** Although, the extent of relevant uranium isotopes has previously been defined by sampling and analysis of uranium in soil samples, a refined and more discrete surface soil gamma radiation survey (described in a previous specific work plan [Energy Solutions, 2011]) will be performed to provide better definition of the extent of uranium-238 in surface soil and to locate hot spots and thus sampling locations for the soil uranium characterization activities outlined in this work plan. The additional boreholes and subsequent gamma radiation borehole measurements and subsurface soil sampling and analysis will enable better vertical definition of uranium isotopes in subsurface soil and rock. The seismic refraction survey will better define the 3-dimensional distribution of alluvium and decomposed bedrock that may contain elevated activities of uranium-238 and/or can be excavated.

**What is the relationship between uranium activity and soil grain size (diameter)?** To what degree, if any, is soil grain size diameter correlated with uranium content, i.e., does uranium preferentially occur in certain size fractions in surface and subsurface soil at the Building 812 firing table? Does the degree of correlation vary geographically and between surface and subsurface soil? Knowledge of the size fractionation of uranium in local soil will assist in formulating remedial alternatives for soil cleanup. If uranium is sequestered in particular size fractions, size fractionation may be effective in reducing the ultimate volume of soil that requires remediation by concentrating uranium-bearing soil of particular size fractions into a smaller volume. If grain size is found to not correlate with uranium content, then grain-size fractionation will not be included in the Feasibility Study remedial alternatives.

**What are the solid phases/minerals that contain the uranium in Building 812 soil?** The goal is to determine the uranium-bearing minerals that occur in the soil at Building 812 as a result of explosives experiments and subsequent weathering and diagenetic alteration. Uranium-bearing minerals have specific and documented solubilities and bioavailabilities. Mineral identification will define the ranges of solubility and bioavailability of residual uranium in surface and subsurface soil. Does the mineralogy vary spatially in the surface and subsurface soil at Building 812? Are there coatings on the uranium-bearing materials that might limit their solubility and bioavailability? This information will be used to define mobility parameters for ground water and surface water fate and transport modeling. It will also be used to define bioavailability in the human health and ecological risk assessments.

**What is the geometry of soil and decomposed bedrock that can be excavated with conventional excavation equipment (is "rippable")?** Knowledge of the geometry of Qal/WBR fill within the Building 812 Canyon will provide an upper limit on the volume of material there that may be contaminated with uranium, will guide the drilling program there, and set a limit on the maximum volume of soil there that may require cleanup.

**What is the extent of phreatic vegetation in the Building 812 channel?** This information will be used in the baseline ecological risk assessment (ERA) in determining if consuming phreatic vegetation represents a significant exposure route to terrestrial receptors.

## Table 1. Data Quality Objectives for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit. (Continued)

**Step 2. Identify the Goal of the Study.** *State how environmental data will be used in meeting objectives and solving the problem, identify study question and relevance, and alternative outcomes. (Continued)*

**To what level has uranium accumulated in local vegetation?** Is the concentration of uranium in representative local vegetation elevated relative to background and observed concentrations in adjacent soil? Are uranium concentrations in vegetation at levels predicted by bioaccumulation factors found in the literature? This information will be used in modeling uranium exposure to local deer mouse populations in the baseline ecological risk assessment.

**To what level has uranium accumulated in local soil invertebrates?** Is the concentration of uranium in representative local invertebrates elevated relative to background and observed concentrations in adjacent soil? Are uranium concentrations in soil invertebrates at levels predicted by bioaccumulation factors found in the literature? This information will be used in modeling uranium exposure to local rock wren populations in the baseline ecological risk assessment.

**What are the concentrations of uranium and metals in surface water, shallow ground water, and sediment and are they potentially bioavailable?** What is the concentration and aerial extent of uranium and metals in these media? Do they pose a significant ecological risk? Do the physical characteristics of the media suggest these chemicals to be bioavailable? These data will be used to determine current ecological hazard to terrestrial and aquatic assessment endpoints in the baseline ecological risk assessment.

**What are the concentrations of lithium and radium-226 in ground water?** Do they pose an unacceptable human health risk or hazard? These data will be used to determine current human health risk or hazard from these constituents in the human health baseline risk assessment.

**Step 3. Identify Information Inputs.** *Identify data & information needed to answer study questions.*

Data and information inputs include:

- Site background and historical information, including previous environmental investigation.
- Gamma radiation survey surface soil uranium-238 activity data.
- Borehole lithological logs.
- Borehole radiation survey uranium-238 activity data from measurement of thorium-234 and protactinium-234m gamma decay.
- Borehole soil analytical results for uranium isotopes.
- Uranium analytical results of sieved soil fractions from single surface and subsurface samples.
- SEM-EDS data to define uranium particles, morphologies, associated elements, and potential mineral families.
- Uranium analytical results from sequential extractions of single soil samples using progressively stronger leaching agents to define solid phase uranium.
- XRD data to define uranium minerals.
- Seismic refraction survey data to define "rippable" sediment geometry.
- Phreatic vegetation mapping data.
- Vegetation sample uranium analytical results.
- Invertebrate sample uranium analytical results.
- Surface soil and sediment sample analytical results for metals, uranium, and selected physical parameters.
- Surface water and shallow ground water sample analytical results for uranium, metals, and selected physical parameters.
- Ground water sample analytical results for lithium and radium-226
- Laboratory data validation.

## Table 1. Data Quality Objectives for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit. (Continued)

| **Step 4. Define the Boundaries of the Study.** *Specify the spatial & temporal limits, scale of inference.* |
|---|
| The limits of the study include the approximately 34-acre area around Building 812 previously defined as the extent of uranium-238 in excess of background in surface soil shown in Figure 5 of this work plan. Sampling units include surface and subsurface soil and decomposed bedrock within the 34-acre area to a maximum depth of 25 feet (ft) below grade. The study will focus on data collected from July 2011 to October 2012, although data collected from earlier investigation activities will also be considered. |
| **Step 5. Develop the Analytical Approach and Decision Analysis.** *Define the parameters of interest, specify the type of inference, and develop the logic for drawing conclusions from findings.* |
| The parameters of interest are uranium activities and concentrations from soils, soil invertebrates, vegetation, grain size separates, and sequential extractions, SEM-EDS images and spectra for uranium solids, XRD spectra for uranium minerals, selected metal concentrations/activities for sediment, surface water and ground water, and seismic refraction data. The data evaluation methods and logic for drawing conclusions are described in the individual characterization activity data analysis and reporting sections in Chapter 3 of this Work Plan. |
| **Step 6. Specify Performance or Acceptance Criteria.** *Develop performance criteria for new data being collected or acceptable criteria for existing data being considered for use.* |
| Statistically-derived limits on sampling design error are not quantifiable because sampling strategy based on professional judgment is being used. To minimize sampling error, samples will be collected using standard Site 300 methodologies outlined in the standard operating procedures, and in a manner consistent with previously collected data. To minimize analytical error, standard analytical methods will be used. Quantitation Limits for all individual analytical parameters are consistent with those used for all Site 300 soil and ground water studies.<br>New and existing data will be accepted if they are collected and analyzed according to the specifications of this Work Plan and are validated as described in the QAPP (LLNL, 1992). If modifications to the collection or analysis procedures described in this Work Plan are necessary, these changes will be evaluated for their impact on resulting data usability. Some of the proposed methods and analyses for these investigations are not covered in the QAPP and some do not have US EPA or other standard methods. These methods and analyses are standard for uranium geochemical research. The data collected will be considered quantitative and will be used to define the extent, occurrence, form, mobility and bioavailability of site-specific uranium. Additional performance or acceptance criteria are specified in activity-specific QA/QC sections in Chapter 3 of this Work Plan. |
| **Step 7. Develop the Plan for Obtaining Data.** *Select the resource-effective sampling and analysis plan that meets the performance criteria.* |
| The detailed plans for obtaining the required data are outlined in the individual characterization activity scope of work and methods sections in Chapter 3 of this Work Plan. |

**Table 2. Sampling and Analysis Plan Summary for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit.**

| Characterization Activity | Sampling Strategy | Description | Field Method (SOP Numbers) | Analytical Methods | Analytical Parameters |
|---|---|---|---|---|---|
| Subsurface Soil Uranium Characterization | Systematic sampling and hot spot | Boreholes will be augered by hand and drilled. Selected borehole intervals will be measured with a downhole High Purity Germanium (HPGe) detector to define uranium-238 ($^{238}$U) activity concentrations. Samples will be collected from borehole intervals that yielded elevated $^{238}$U activities from gamma radiation measurements and analyzed for uranium isotopes. | Field borehole logging (SOP 1.1, Borehole Sampling of Soil and Rock (SOP 1.2), Drilling (SOP 1.3), Well Site Core Handling (SOP 1.15) | Gamma spectroscopy (HPGe measurements); AS; ICP-MS | Uranium and Uranium Isotopes |
| Uranium Grain Size Distribution Analysis | Systematic sampling and hot spot | Samples of surface and subsurface soil will be subjected to sieve analysis supplemented by other grain size separation techniques. Resulting separates will be analyzed for uranium content. Scanning electron microscope- energy dispersive spectral analysis (SEM-EDS) will also be used to measure size of uranium-bearing fine particles. | Surface Soil Grab Sampling (SOP-1.12, SOP-4.14) and Borehole Sampling of Soil and Rock (SOP 1.2) | ASTM Method D6913; AS, ICP-MS, KPA UTOT | Uranium and Uranium Isotopes |
| Uranium Solid Phase Characterization | Systematic sampling and hot spot | Samples of surface and subsurface soil will be subjected to SEM-EDS, sequential extractions, and x-ray diffraction (XRD) to define uranium-bearing solid composition, morphology, size ranges, oxidation states, and other characteristics. | Surface Soil Grab Sampling (SOP-1.12, SOP-4.14) and Borehole Sampling of Soil and Rock (SOP 1.2) | AS, ICP-MS, KPA UTOT, and others | Uranium and Uranium Isotopes and miscellaneous x ray and electron spectra |
| Seismic Refraction Survey | Comprehensive | Seismic lines with geophones will be configured parallel and perpendicular to the Building 812 Canyon channel. A hammer and plate will be used to generate seismic waves that will be recorded on the geophone arrays. | Contractor SOP | Contractor Methods | Seismic P-wave velocities and arrival times |
| Surface water characterization for uranium, metals, and bioavailability | Systematic Sampling | Surface water sampling is planned for the late summer or early fall of 2011. Three surface water locations are proposed. The locations include 1) the current Spring 6 sampling location, 2) the confluence of the 812 drainage and Elk Ravine, and 3) the Elk Ravine pool. A single sampling event is planned for these constituents. These three locations will also be sampled for uranium isotopes during winter 2011-2012. All surface water sampling locations will be mapped using a global positioning system (GPS). | Surface Water Grab Sampling (SOP-2.5, SOP-4.14) | ICP-MS or AS; EPA Method 200.8; EPA Method 150.1; SM 2320.B, 2540.C, and 2540.D | Uranium and Uranium Isotopes; Copper, Lead, Nickel and Zinc; pH; Total Hardness, Total Dissolved Solids and Total Suspended Solids |
| Shallow ground water characterization for uranium and metals | Systematic Sampling | Shallow ground water sampling is planned for the late summer or early fall of 2011. All five wells screened in the shallow alluvium will be sampled (NC2-23, W-812-2321, W-812-1921, W-812-08 and W-812-1932). A single sampling event is planned. | Ground Water Grab Sampling (SOP-2.1 through SOP-2.4, SOP-2.7) | ICP-MS; EPA Method 200.8 | Uranium and Uranium Isotopes; Copper, Lead, Nickel and Zinc |
| Sediment characterization for uranium, metals, and bioavailability | Systematic Sampling | Sediment sampling is planned for the late summer or early fall of 2011. A sample will be collected from the pool within Elk Ravine southeast of the drainage confluence. The sediment sampling location will be mapped using a GPS. | Sediment Grab Sampling (SOP-1.12, SOP-4.14) | ICP-MS or AS; EPA Method 200.8; SM 9060; EPA Method 150.1 | Uranium and Uranium Isotopes; Copper, Lead, Nickel and Zinc; Total Organic Carbon; pH |
| Phreatic Vegetation Mapping | Comprehensive | Phreatic vegetation mapping within the Building 812 drainage is planned for the late summer or early fall of 2011. Phreatic species present will be identified to a minimum of genus level. | GPS Mapping (SOP-4.14) | Not applicable | Not Applicable |
| Uranium Uptake by Vegetation Characterization | Concentration Gradient | Vegetation sampling is planned for the spring of 2012. Ten locations spanning a uranium concentration gradient will be sampled. Final locations will be selected based on the results of the uranium surface soil characterization, planned for the summer of 2011. | Vegetation Grab Sampling (SOP-4.14) | ICP-MS | Uranium and Uranium Isotopes |
| Uranium Uptake by Soil Invertebrates Characterization | Concentration Gradient | Soil invertebrate sampling is planned for the spring of 2012. Ten locations spanning a uranium concentration gradient are planned. Final locations will be selected based on the results of the uranium surface soil characterization, planned for the summer of 2011. | Soil Invertebrate Pit trapping (SOP-4.14) | ICP-MS | Uranium and Uranium Isotopes |

**Table 2. Sampling and Analysis Plan Summary for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit. (Continued)**

| Characterization Activity | Sampling Strategy | Description | Field Method (SOP Numbers) | Analytical Methods | Analytical Parameters |
|---|---|---|---|---|---|
| Ground water characterization for Lithium and Radium-226 | Systematic Sampling | Ground water sampling is planned for the late summer or fall of 2011. Three wells monitoring the $Tnbs_1/Tnbs_0$ hydrostratigraphic unit (HSU) directly adjacent to or near the Building 812 firing table (W-812-01, W-812-02, and W-812-2009), three wells monitoring the Quaternary alluvium/weathered bedrock (Qal/WBR) HSU downgradient of the firing table (NC2-23, W-812-08 and W-812-1921), and three wells in the $Tnsc_0$ HSU downgradient of the firing table (NC2-22, W-812-07 and W-812-09) will be sampled (total of 9 wells). Spring 6 will also be sampled. | Ground Water Grab Sampling (SOP-2.1 through SOP-2.4, SOP-2.7) | EPA Methods 903 and 200.7 | Radium-226 and Lithium |

**Notes:**

**AS = Uranium isotope activities by alpha spectrometry.**
**ASTM = American Society for Testing and Materials.**
**EPA = U.S. Environmental Protection Agency.**
**GPS = Global positioning system.**
**HPGe = High purity germanium.**
**HSU = Hydrostratigraphic unit.**
**ICP-MS = Uranium isotope masses by inductively coupled mass spectrometry.**
**KPA UTOT = Total uranium concentration by kinetic phosphorescence.**
**SEM-EDS = Scanning electron microscopy-energy dispersive spectral analysis.**
**SOP = Standard Operating Procedure.**
**SM = Standard Methods.**
**TOC = Total organic carbon.**
**XRD = X-ray diffraction.**

## Table 3. Summary of Applicable Standard Operating Procedures (SOPs) for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit.

| SOP Number[a] | SOP Name[a] |
|---|---|
| ***Subsurface Soil*** | |
| SOP-1.1 | Field Borehole Logging |
| SOP-1.2 | Borehole Sampling of Unconsolidated Sediments and Rock |
| SOP-1.3 | Drilling |
| SOP-1.6 | Borehole Geophysical Logging |
| SOP-1.8 | Disposal of Investigation-Derived Wastes (Drill Cuttings, Core Samples, and Drilling Mud) |
| SOP 1.15 | Well Site Core Handling |
| ***Surface Soil/ Sediment*** | |
| SOP-1.12 | Surface Soil Sampling |
| ***Surface Water*** | |
| SOP-2.5 | Surface Water Sampling |
| ***Ground Water*** | |
| SOP-2.1 | Pre-sample Purging of Wells |
| SOP-2.2 | Field Measurements on Surface and Ground Waters |
| SOP-2.3 | Sampling Monitor Wells with Bladder Pumps, Electric Submersible Pumps, and Specific-Depth Grab Sampling Devices |
| SOP-2.4 | Sampling Monitor Wells with a Bailer |
| SOP-2.7 | Pre-sample Purging and Sampling of Low-Yielding Monitor Wells |
| ***Mapping*** | |
| SOP-4.14 | Mapping with the Trimble Pathfinder Pro XR GPS System |
| ***General Field*** | |
| SOP-4.1 | General Instructions for Field Personnel |
| SOP-4.2 | Sample Control and Documentation |
| SOP-4.3 | Sample Containers and Preservation |
| SOP-4.4 | Guide to Packaging and Shipping of Samples |
| SOP-4.5 | General Equipment Decontamination |
| SOP-4.8 | Calibration/Verification and Maintenance of Field Instruments Used in Measuring Parameters of Surface Water, Ground Water, and Soils |
| SOP-4.9 | Collection of Field QC Samples |
| ***Data Validation*** | |
| SOP-4.6 | Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories |
| ***Data Management*** | |
| SOP-4.10 | Records Management |
| SOP-4.18 | ERD Document Control |
| SOP-5.1 | Data Management Chain of Custody and Printed Analytical Result Receipt and Processing |
| SOP-5.3 | Data Management Electronic Analytical Result Receipt and Processing for Sample, Analysis, and QC Data |
| SOP-5.4 | Data Management Hand Entry of Analytical Results |
| SOP 5.8 | Field Logbook Control |
| SOP-5.10 | Data Management Receipt and Processing Lithology by Electronic Transfer |

[a] **From Goodrich and Lorega (2009).**

## Table 4. Summary of Applicable Laboratory Analytical Methods for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit.

| Analyte | Analytical Method | Reporting Limit |
|---|---|---|
| ***Ground Water/ Surface Water*** | | |
| Radionuclides | | |
| Radium-226 | EPA Method 903 | 0.25 pCi/L |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 6e-3 to 1e-1 pCi/L |
| $^{235}$U | | 2e-6 to 6e-4 pCi/L |
| $^{238}$U | | 3e-7 to 9e-5 pCi/L |
| Metals/Other Inorganics | | |
| Lithium | EPA Method 200.7 | 0.02 mg/L |
| Copper | EPA Method 200.8 | 0.005 mg/L |
| Lead | EPA Method 200.8 | 0.005 mg/L |
| Nickel | EPA Method 200.8 | 0.005 mg/L |
| Zinc | EPA Method 200.8 | 0.01 mg/L |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 2e-6 to 2e-4 mg/L |
| $^{235}$U | | 4e-9 to 1e-6 mg/L |
| $^{238}$U | | 7e-10 to 2e-7 mg/L |
| Total Hardness (as $CaCO_3$) | SM 2340.B | 1 mg/L |
| Total Dissolved Solids | SM 2540.C | 1 mg/L |
| Total Suspended Solids | SM 2540.D | 1 mg/L |
| pH | EPA Method 150.1 | 1-14 units |
| Bioassays | | |
| Water flea chronic 7-day test | EPA Method 1002 | NA |
| Algae 4-day growth | EPA Method 1003 | NA |
| | | |
| ***Sediment/ Subsurface Soil*** | | |
| Radionuclides | | |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 4e-3 pCi/g dry weight |
| $^{235}$U | | 2e-2 pCi/g dry weight |
| $^{238}$U | | 3e-1 pCi/g dry weight |
| Uranium isotopes | EPA Method 907 | |
| $^{238}$U | | 0.005 pCi/g dry weight |
| $^{234}$U | | 0.005 pCi/g dry weight |
| $^{235}$U | | 0.005 pCi/g dry weight |
| Copper | EPA Method 6010B | 5 mg/kg wet weight |
| Lead | EPA Method 6010B | 10 mg/kg wet weight |
| Nickel | EPA Method 6010B | 10 mg/kg wet weight |
| Zinc | EPA Method 6010B | 5 mg/kg wet weight |

## Table 4. Summary of Applicable Laboratory Analytical Methods for the Proposed Characterization Activities at the LLNL Site 300 Building 812 Operable Unit. (Continued)

| Analyte | Analytical Method | Reporting Limit |
|---|---|---|
| ***Sediment/ Subsurface Soil (continued)*** | | |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 0.013 mg/kg dry weight |
| $^{235}$U | | 0.01 mg/kg dry weight |
| $^{238}$U | | 0.1 mg/kg dry weight |
| Total Organic Carbon | EPA Method 9060 | 1 mg/kg wet weight |
| pH | EPA Method 9045 | 1-14 units |
| Percent moisture | EPA Method 3550 | 0.1% |
| ***Vegetation and Aquatic/Soil Invertebrates*** | | |
| Radionuclides | | |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 3e$^{-7}$ to 3e$^{-6}$ pCi/g dry weight |
| $^{235}$U | | 2e$^{-5}$ to 2e$^{-4}$ pCi/g dry weight |
| $^{238}$U | | 2e$^{-3}$ to 2e$^{-2}$ pCi/g dry weight |
| Metals/Other Inorganics | | |
| Uranium isotopes | ICP-MS | |
| $^{234}$U | | 1e$^{-6}$ to 1e$^{-5}$ mg/kg dry weight |
| $^{235}$U | | 1e$^{-5}$ to 1e$^{-4}$ mg/kg dry weight |
| $^{238}$U | | 1e$^{-3}$ to 1e$^{-2}$ mg/kg dry weight |

**Notes:**

**AS = Uranium isotopes by alpha spectroscopy.**
**ASTM = American Society for Testing and Materials.**
**EPA = U.S. Environmental Protection Agency.**
**ICP-MS = Uranium isotopes by mass spectrometry.**
**mg/kg = Milligrams/kilogram.**
**Mg/L = Milligrams/Liter.**
**NA = Not applicable.**
**pCi/g = Picocuries/gram.**
**pCi/L = Picocuries/Liter.**
**SM = Standard Methods.**
**TBD = To be determined.**
**$^{234}$U = Uranium-234.**
**$^{235}$U = Uranium-235.**
**$^{238}$U = Uranium-238.**

# Appendix A

# Sample Control and Documentation

# Appendix A

# A-1. Sample Control and Documentation

## A-1.1. Field Logbooks

A complete record of all samples and sampling events will be maintained by making entries into field logbook(s). Field logbooks are bound volumes with consecutively numbered pages. The Data Management Team (DMT) assigns each logbook a unique code and issues the logbooks upon request. A list of issued logbooks and their locations is maintained by the DMT. Logbooks are returned to the DMT at project completion.

The Environmental Restoration Department (ERD) Standard Operating Procedure (SOP) 4.2 "Sample Control and Documentation" describes how entries in the sampling field logbooks reflect the sampling event as accurately as possible and includes the following information:

- Date and time of sampling.
- Sample identification (ID) code.
- Method of sample collection, including preservation techniques, size or volume, description of the matrix of the sample, and any deviations or anomalies noted.
- Requested analyses and analytical laboratory performing the analyses.
- Results of associated field measurements.
- Calibration information pertaining to field instruments used for the sampling event.
- ID of field personnel performing the work.
- ID of field equipment (model number, serial number).
- Special notes of other activities in the area which may have an impact on analytical results.

Specific field data collection forms might be used during sampling activities. Each data collection form used during sampling becomes a controlled document. The document control number is derived from the logbook code and the logbook page number that was used to document that sampling event and is recorded on specific field forms including chain-of-custody forms.

## A-1.2. Chain-of-Custody (CoC) Records

As stated in Draft ERD SOP 4.2: Sample Control and Documentation, the primary objective of using CoC documents is to create an accurate written record that can be used to trace the possession and handling of the sample from the moment of its collection through analysis and receipt of analytical data.

### A-1.2.1. Issuance and Archival of CoC Records

- Blank CoC forms are obtained from DMT.
- Electronic COCs are produced from information in the Sampling Plan generated from the Sample Planning and Chain-of-Custody Tracking (SPACT) application in the Taurus Environmental Information Management System (TEIMS).

- Completed CoC records are archived by DMT.

### A-1.2.2. Required Documentation

Each CoC document will be completed using waterproof ink and contain the following information:

- Document control number.
- Sample matrix. Sample matrix codes are listed on the Sampling Plan or in the TEIMS by opening the "Data Team" page, then using the "QBF" link to access the "SAMPMATRIX" Table.
- Name of sampler and employer.
- Requested analysis code.
- Number and type of container(s).
- Sample ID and sample date and time.
- Area from which the sample originated.
- Name of the analytical laboratory where the samples are to be sent as designated by the Sampling Plan.
- Requester name: This is the organization for which the samples are being collected.
- Additional information/instructions or remarks. The remarks section should also indicate whether field filtration and/or preservation has been performed, or if it is required upon receipt at the lab.

## A-1.3. Sample Identification Labels

Detailed instructions are found in ERD SOP 4.2 "Sample Control and Documentation". ID labels are to be used when tagging or labeling sample containers. The sampling personnel may fill out sample container labels after collecting samples or prior to collecting samples at each location. Waterproof ink will be used on the label.

### A-1.3.1. Issuance and Archival

Sample labels may be obtained from the analytical laboratory where the samples are to be sent for analysis. The field personnel will have an adequate stock of labels on hand at all times. Labels are not archived and are destroyed with sample disposal at the laboratory.

### A-1.3.2. Required Documentation

The Sample ID Label will include the following information:

- Sample ID. The sample ID can be composed of various factors such as location, sample type, etc. If a new location is to be sampled, the DMT will approve all new sample IDs.
- Project name.
- Sample date. The date when the sample was collected.
- Sample time. Time is recorded according to the 24-hour clock (e.g., 1:00 a.m. = 0100 hour, 3:00 p.m. = 1500 hours).
- Samplers' initials. The initials of personnel conducting the sampling.
- Preservation method. The nature, concentrations and volume of any preservative

added to the sample should be indicated.

- Comments. Any additional information such as hold times or special turnaround times should be provided in the comments section.
- Requested analysis. The type of analysis to be performed on the sample.

Sample identification methodology is described in SOP 1.1 "Field Borehole Logging", Section 6.4.35, Sample Identification (ID). Included in the ID is the depth at the top of the sampling interval, which is given in feet and tenths of feet.

### A-1.4. Records Management

ERD SOP 4.10 "Records Management" applies to recorded information, in any format, that is created, received, or needed to document ERD work activities. The procedure describes the identification, creation, maintenance, retention, and disposition of records created or received within the ERD and will be followed throughout the course of this Work Plan.

## A-2. Sample Container and Preservation

Table A-1 summarizes the container types, volume and holding times. The samples will be collected as specified in this Work Plan. Samples for metals shall be refrigerated and analyzed as soon as possible. Samples submitted for radiological analyses do not need to be preserved by refrigeration.

Samples requiring refrigeration at 4 □C will be protected from getting wet. Samples will be immediately placed in an ice chest containing either Blue Ice packs (in air-tight plastic bags), or bagged or loose ice cubes. A temperature blank will always be included in the ice chests so that the laboratory can check the temperature of the cooler at the time of sample receipt. If samples are not submitted to the laboratory daily, ice chests will be checked periodically, and thawed ice replaced. Sample preservation methods will be noted as appropriate in the sampling logbook, on the sample label, and on the CoC document.

## A-3. Shipping

All samples will be shipped off site according to the ERD SOP 4.4 "Guide to Packaging and Shipping of Samples".

Properly identified sample containers will be placed inside Ziploc®-type storage bags, sealed, and then placed in picnic-cooler-type containers. Samples to be shipped will be packed with sufficient incombustible, absorbent cushioning material to minimize the possibility of sample container breakage. Samples that require refrigeration during shipping should be packed with a sufficient number of Blue Ice packs to keep the samples preserved. Temperature blanks will accompany all samples that require temperature preservation (4°C). They consist of a 250-milliliter (ml) poly container or equivalent filled with water. It will be noted in the Remarks section of the COC that a temperature blank has been included in the sample shipment. The receiving laboratory will measure these blanks and record the temperature on their sample receipt log.

## Table A-1. Sample Container Types, Volume, and Holding Times.

| Requested Analysis | Description | Method | Sample Type | Required Volume | Container Type | Preservation Method | Hold Time |
|---|---|---|---|---|---|---|---|
| AS:UISO | Uranium Isotopes | AS | Soil | 250g | Glass wide-mouth or brass/steel tube with Teflon coated lids. | None | 6 mo. |
| MS:UISO | Isotopic Uranium | ICPMS | Soil | 8 oz. | Glass wide-mouth or brass/steel tube with Teflon coated lids. | None | 6 mo. |
| TTLCMETALS | TTLC Metals | Various | Soil | 8 oz. | Glass wide-mouth or brass/steel tube with Teflon coated lids. | Cool, 4 deg. C | 6 mo. (except Hg) |
| AS:UISO | Uranium Isotopes | AS | AQ | 2 liters | Poly | Lab filtered | 6 mo. |
| MS:UISO | Uranium Isotopes | ICPMS | AQ | 250 ml. | Poly | Field filtered | 6 mo. |
| Dissolved Metals (DWMETALS, E200.7Li) | DWMTALS, Lithium | EPA 200.8<br>EPA 200.7 | AQ | 1 Liter, 1 Liter | Poly | Cool, 4 deg. C Lab filtered & preserved | 6 mo. |
| RA226, RA228 | Radium Isotopes | EPA 903, EPA 904 | AQ | 1 Liter, 1 Liter | Poly | Lab filtered and preserved | 6 mo. |
| pH | Water Quality Indicator, pH | EPA 150.1 | AQ | 250 mL | Poly | Cool, 4 deg. C | 12 hr. |
| Total Hardness | Total Hardness | SM 2340B | AQ | 500 mL | Poly | Cool, 4 deg. C | 24 hr. |

## Table A-1. Sample Container Types, Volume, and Holding Times. (Continued)

| Requested Analysis | Description | Method | Sample Type | Required Volume | Container Type | Preservation Method | Hold Time |
|---|---|---|---|---|---|---|---|
| TDS | Total Dissolved Solids | EPA 160.1 | AQ | 500 mL | Poly | Cool, 4 deg. C | 7 day |
| TSS | Total Suspended Solids | EPA 160.2 | AQ | 1 Liter | Poly | Cool, 4 deg. C | 7 day |

**Notes:**

| | |
|---|---|
| AS = | Alpha spectroscopy. |
| deg. C = | Degrees Celsius. |
| g = | Gram. |
| Hg = | Mercury. |
| ICPMS = | Inductively coupled plasma mass spectrometry. |
| Li = | Lithium. |
| MS = | Mass Spectrometry. |
| mL = | Milliliter. |
| mo. = | Month. |
| oz. = | Ounce. |
| RA = | Radium. |
| TDS = | Total dissolved solids. |
| TSS = | Total suspended solids. |
| TTLC = | Total threshold limit concentration. |
| TOC = | Total organic carbon. |
| UISO = | Uranium isotopes. |

# Appendix B

# Quality Assurance/Quality Control

# Appendix B

## B-1. Quality Assurance/Quality Control

### B-1.1. Quality Assurance Chain-of-Custody (CoC) Practices

For each sample collected in the field, sampling personnel will follow the practices described in Appendix A, including the use of field logbooks, CoC procedures and documentation, and a standard identification label to accompany each sample at all times. The CoC form will accompany the samples through the sampling and analysis process. When samples change custody, the relinquishing and the receiving parties sign the CoC document.

### B-1.2. Quality Assurance Performance Criteria

All sampling and analysis activities will be performed in accordance with the quality assurance (QA)/quality control (QC) practices described in this Work Plan and related procedures. Contract Analytical Laboratories (CALs) selected to perform analytical tests will possess a National Environmental Laboratory Accreditation Program (NELAP) certification for the state of California and participate in pre-award and annual United States (U.S.) Department of Energy (DOE) Consolidated Audit Program (CAP) audits. NELAP requirements do not fully encompass DOE requirements. In cases, where DOE-specific requirements differ from NELAP requirements, DOE requirements will supersede and shall be met by the CALs. All analytical laboratories, including onsite laboratories, must use methods and procedures functionally equivalent to the methods and procedures used the EPA Contract Laboratory Program and the California Department of Toxic Substances Control (DTSC) Certified Laboratory Program.

### B-1.3. Quality Assurance /Quality Control Practices

The QA/QC practices to be followed during the execution of this plan are summarized in this section. Adherence to these practices will produce data capable of withstanding scientific and legal scrutiny.

#### B-1.3.1. Field QA/QC

Field QA/QC is ensured by following uniform procedures for sample collection, handling, CoC, and shipping, and by evaluating QC samples collected in the field. QC samples shall be collected and identified in accordance with SOP 4.9 “Collection of Field QC Samples”. Field samples used to assess QA/QC for this work plan includes:

- Trip blanks. Trip blanks are provided by the CAL and will be submitted with each CoC.
- Rinsates (equipment blanks). Equipment blanks are analyzed to determine the effectiveness of the decontamination process and will be collected prior to inserting equipment downhole in a new investigative area.
- Field Blanks. A field blank is poured at the sampling location to identify contamination that may occur during the sample collection process.
- Collocated Samples. One collocated sample per 10 samples will be randomly

collected. The 10 will be divided into 5% interlaboratory and 5% intralaboratory collocated samples. When collocated samples are collected, processed, and analyzed by the same organization, they provide intra-laboratory precision information for the entire measurement system including sample acquisition, homogeneity, handling, shipping, storage, preparation and analysis. When collected, processed, and analyzed by different organizations, these QC checks provide inter-laboratory precision information for the entire measurement system. These field QC samples are required and their purpose defined in the Environmental Restoration Department (ERD) Quality Assurance Project Plan (QAPP).

### B-1.3.2. Laboratory QA/QC Practices

The Quality Systems for Analytical Services (QSAS) establishes a single, integrated QA program for providers of analytical laboratories supporting the U.S. DOE operations. The QSAS provides specific technical requirements and clarification for implementation of DOE requirements and is based on EPA's NELAP. It also incorporates EPA's Performance Approach. The QSAS is incorporated into contract vehicles or agreements and is the basis for qualification of laboratories providing services to DOE. This section summarizes laboratory practices that ensure analytical QA/QC.

#### *B-1.3.2.1. General Laboratory Controls*

In addition to instrument calibration and the analysis of QC samples, the CAL that performs the analyses must implement the following analytical controls:

- Reagents and solvents will have certified compositions.
- Reagent storage environment and duration will meet the manufacturers' guidelines.
- Laboratory equipment will be calibrated/standardized following the referenced procedures for the methods used and shall be documented.
- Volumetric measurements will be made with certified glassware.
- Data reduction computations will be independently checked.
- Qualified personnel will perform laboratory analyses using approved methods.
- QA/QC requirements and guidelines specified in the selected analytical methods will be followed.

These requirements are standard in a certified laboratory and will be verified during the laboratory inspection and validation process.

#### *B-1.3.2.2. Laboratory QA/QC*

A summary of QC sample results shall be provided for each sample and shall include the following:

- Method blank results and reporting limits, matrix units, batch number, date/time of analysis, instrument identification (ID) number, analyst ID, and method code.
- Surrogate or tracer yield recoveries, if applicable.
- Sample duplicate results, and relative percent difference (%RPD), if applicable.
- Matrix spike, matrix spike duplicate recoveries and %RPDs, batch number, date/time of analysis, instrument ID number, analyst ID, matrix, method code, and sample

result when indicated by the method.

- Laboratory control sample (recoveries, batch number, date/time of analysis, instrument ID, analyst ID, matrix, and method code.
- QC control limits for laboratory control samples, matrix spike/matrix spike duplicates, surrogate, and tracer yield recoveries, and %RPDs.

In addition, the CAL shall provide upon request all supporting documentation used to generate reported results, including, but not limited to:

- Initial instrument calibration data.
- Continuing calibration data.
- Retention time window determinations.
- Method detection limit determinations.
- Gas chromatography/mass spectrophometry (GC/MS) tune data.
- Laboratory QC control charts.

The following minimum corrective action (provided in the Statement of Work for each laboratory) is required to be taken by the laboratory when the QA/QC fails.

The Subcontractor shall perform at a minimum the QC analyses listed in Table B-1, as well as all other required and suggested QC sample analyses specified by the EPA Methodology.

When field QA/QC fails, as determined during the Environmental Restoration Department (ERD) data validation process, the course of action taken is decided at that time and may include, requesting a re-analysis, re-sampling, or appropriately qualifying the data in accordance with SOP 4.6: Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories.

Analytical laboratories are also required to follow any additional QC steps required by the analytical method in the event of a QC failure.

All sampling will be conducted in accordance with the Livermore Site and Site 300 Quality Assurance Project Plan (QAPP) (Dibley 1999). Sample preparation and analysis conducted by the analytical laboratories will follow QA requirements specified in the Livermore Site and Site 300 QAPP (Dibley 1999). All offsite contract analytical laboratories shall use methods and procedures functionally equivalent to the methods and procedures defined in the EPA Contract Laboratory Program and the California DTSC Certified Laboratory Program. Offsite ontract analytical laboratories must maintain a California Department of Health Services (DHS) Environmental Laboratory Accreditation Program certification for analytical tests for which the DHS offers certification. Although there are no EPA protocols for uranium mass analysis by inductively-coupled mass spectrometry (ICPMS), the LLNL onsite laboratory performing these state-of-the-art analyses follows good lab practice, participates in the State's Environmental Laboratory Accreditation Program (ELAP)), and DOE's Mixed Analyte Performance Program (MAPEP). The laboratory is ISO17025 accredited and maintains that certification through the Forensic Science Center.

## B-1.4. Precision, Accuracy, Representativeness, Comparability, and Completeness

Analytical data will be evaluated according to the precision, accuracy, representativeness, comparability, and completeness parameters to have a level of assurance of the quality of the measurement data. These parameters are necessary when considering the usefulness of a set of data for interpretation. The definitions provided are established in the approved ERD QAPP.

### B-1.4.1. Precision

Precision is determined by the degree of agreement between duplicate analyses of the same parameter in a given sample. It is an indicator of how well a laboratory can reproduce its work under a given set of conditions. Precision is expressed as %RPD and is determined by the laboratory by the analysis of matrix spike duplicates, sample duplicates, or laboratory control samples duplicates. The %RPD is compared to set control limits to determine acceptability. The ERD also assesses precision by the analysis of intralaboratory and interlaboratory collocated samples.

Field audits, and checklists will be performed on a routine basis. These audits will document the use (or nonuse) of uniform sampling methods and of handling and shipping procedures.

### B-1.4.2. Accuracy

The analytical laboratories analyze QC samples to assess precision and accuracy. Accuracy is defined by the degree of agreement between measured value and true or known value. It is a measure of the bias in the measurement system. The laboratories assess accuracy, expressed as percent recovery (%RCV), by the analysis of matrix spikes and laboratory control samples. The %RCV is compared to set control limits to determine acceptability.

### B-1.4.3. Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition. Representativeness is a qualitative term that determines whether in situ and other measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and phenomenon measured or studied. ERD uses sampling techniques and EPA prescribed sample preservation to ensure that the samples are representative of the media of interest.

### B-1.4.4. Comparability

Comparability is the measure of the confidence with which one data set or method can be compared to another. Standard techniques are used to collect and analyze representative samples to ensure comparable results.

### B-1.4.5. Completeness

The ERD Annual QA Report summarizes completeness by determining the completeness of the data set in terms of the number of valid results obtained for the number of analyses planned. The ERD completeness objective is 90%.

## B-1.5. Data Review, Validation and Verification

Data will be reviewed by the QC Chemist upon receipt from the analytical laboratory. During this review, the chemist will verify and validate the data in accordance with the ERD QAPP and ERD SOP 4.6 “Validation and Verification of Radiological and Nonradiological Data Generated by Analytical Laboratories”.

## Table B-1. Minimum Corrective Requirements.

| QC Sample Type | QC Failure Corrective Action |
|---|---|
| **Organic Analysis** | |
| **Method Blanks** | **Follow method specified actions if analytes are detected in the method blank greater than the calculated MDL.** |
| **Matrix Spikes** | **If percent recovery is outside of control limits, perform method specific corrective actions.** |
| **Matrix Spike Duplicate** | **If relative percent difference is outside of control limits perform, method specific corrective actions.** |
| **Laboratory Control Samples** | **If percent recovery is outside control limits, reanalyze sample batch for the analytes in question.** |
| **Surrogates** | **If percent recovery is less than the lower acceptance limit, reanalyze sample.** |
| **Trip Blanks, Field Blanks** | **If analytes detected in associated samples, analyze all associated trip and field blanks.** |
| **Inorganic Analysis** | |
| **Method Blanks** | **Analyte detections in the method blank and instrument blank are unacceptable. If analytes are detected in the blank and in the samples, re-digest/reanalyze samples or, upon approval from the LLNL project managers, implement method specified actions.** |
| **Matrix Spikes** | **If percent recovery is less than 30, perform a post-digestion spike LLNL samples to check for matrix interferences.** |
| **Matrix Spike Duplicate** | **If relative percent difference is outside of control limits perform method specific corrective actions.** |
| **Laboratory Control Samples** | **If percent recovery is outside control limits, reanalyze sample batch.** |
| **Radiological Analysis** | |
| **Method Blanks** | **Follow method specified actions if analytes are detected in the method blank above the Minimum Detection Activity (MDA).** |
| **Matrix Spikes** | **If percent recovery is outside of control limits, perform method specific corrective actions.** |
| **Matrix Spike Duplicate** | **If relative percent difference is outside of control limits perform, method specific corrective actions.** |
| **Laboratory Control Samples** | **If percent recovery is outside control limits, reanalyze sample batch.** |
| **Tracer Yields** | **If percent recovery is less than the lower acceptance limit, reanalyze sample batch.** |

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