# SITE CLOSEOUT REPORT REV 2 –
# APPENDIX H ORISE VERIFICATION SURVEY

**U.S. DEPARTMENT OF ENERGY**

**HIGH FLUX BEAM REACTOR STACK (BLDG 705)**
**DECOMMISSIONING AND DEMOLITION (D&D)**
**BROOKHAVEN NATIONAL LABORATORY**
**UPTON, NY**
**CERCLIS NUMBER NY 789008975**

# APPENDIX H
# ORISE VERIFICATION SURVEY

OAK RIDGE INSTITUTE
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November 8, 2021

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**SUBJECT: CONTRACT NO. DE-SC0014664
INDEPENDENT VERIFICATION SURVEY SUMMARY AND RESULTS FOR THE BROOKHAVEN NATIONAL LABORATORY HIGH FLUX BEAM REACTOR STACK, UPTON, NEW YORK
DCN: 5356-SR-01-DRAFT**

Dear Ms. Gamba:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the enclosed draft report detailing the verification survey activities performed for the High Flux Beam Reactor Stack demolition project at the Brookhaven National Laboratory in Upton, New York.

Please feel free to contact me at 865.574.6273 or Erika Bailey at 865.576.6659 if you have any comments or concerns.

Sincerely,

Nick A. Altic, CHP
Health Physicist/Project Manager
ORISE

NAA:enb

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# INDEPENDENT VERIFICATION SURVEY SUMMARY AND RESULTS FOR THE BROOKHAVEN NATIONAL LABORATORY HIGH FLUX BEAM REACTOR STACK UPTON, NEW YORK

**E. N. Bailey**
**ORISE**

**Prepared for the**
**U.S. Department of Energy**
**and**
**U.S. Army Corps of Engineers**

**November 2021**

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OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

**Prepared by**

**E. N. Bailey**

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**NOVEMBER 2021**

**Prepared for the**
**U.S. Department of Energy**
**and**
**U.S. Army Corps of Engineers**

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## CONTENTS

## FIGURES



## TABLES

# ACRONYMS

| | |
|---|---|
| AA | alternative action |
| AEC | Atomic Energy Commission |
| ALARA | as low as reasonably achievable |
| Am-241 | americium-241 |
| AOC | areas of concern |
| BAO | Brookhaven Area Office |
| BNL | Brookhaven National Laboratory |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| cm | centimeter(s) |
| Co-60 | cobalt-60 |
| cpm | counts per minute |
| Cs-137 | cesium-137 |
| DCGL | derived concentration guideline level |
| DOE | U.S. Department of Energy |
| DQO | data quality objective |
| DS | decision statement |
| Eu-152 | europium-152 |
| Eu-154 | europium-154 |
| FSP | field-sampling plan |
| FSS | final status survey |
| GPS | global positioning system |
| H-3 | tritium |
| $H_0$ | null hypothesis |
| $H_A$ | alternative hypothesis |
| ha | hectares |
| HFBR | High Flux Beam Reactor |
| HTD | hard-to-detect |
| IV | independent verification |
| LBGR | lower bound of the gray region |
| $m^2$ | square meter(s) |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual |
| MeV | mega electron volt |
| MDC | minimum detectable concentration |
| mrem/yr | millirem per year |
| NaI[Tl] | thallium-doped sodium iodide |
| Ni-63 | nickel-63 |
| NIST | National Institute of Standards and Technology |
| NRC | U.S. Nuclear Regulatory Commission |
| ORAU | Oak Ridge Associated Universities |
| ORISE | Oak Ridge Institute for Science and Education |
| pCi/g | picocurie per gram |
| PSQs | principal study questions |
| Pu-238 | plutonium-238 |
| Pu-239 | plutonium-239 |
| Pu-240 | plutonium-240 |

| | |
|---|---|
| Q | quantile |
| RA | reference area |
| Ra-226 | radium-226 |
| RCRA | Resource Conservation and Recovery Act |
| REAL | Radiological and Environmental Analytical Laboratory |
| ROC | radionuclide of concern |
| ROD | Record of Decision |
| SOF | sum-of-fractions |
| SOR | sum-of-ratios |
| Sr-90 | strontium-90 |
| SU | survey unit |
| TAP | total absorption peak |
| TEDE | total effective dose equivalent |
| TPU | total propagated uncertainty |
| U-234 | uranium-234 |
| U-235 | uranium-235 |
| U-238 | uranium-238 |
| UBGR | upper bound of the gray region |
| USACE | U.S. Army Corps of Engineers |
| VSP | Visual Sample Plan |

# INDEPENDENT VERIFICATION SURVEY SUMMARY AND RESULTS FOR THE BROOKHAVEN NATIONAL LABORATORY HIGH FLUX BEAM REACTOR STACK UPTON, NEW YORK

## 1. INTRODUCTION

Brookhaven National Laboratory (BNL) is operated by the U.S. Department of Energy (DOE) and conducts research in various aspects of physical, biomedical, and environmental sciences. BNL was originally occupied by the U.S. Army as Camp Upton during both World Wars I and II. In 1947, the site was transferred to the Atomic Energy Commission (AEC). The AEC was resolved into the Energy Research and Development Administration, and later into the DOE Brookhaven Area Office (BAO).

In late 1989, BNL was included on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List. DOE entered into an agreement to establish the framework and schedule for characterizing, assessing, and remediating the site in accordance with CERCLA and the Resource Conservation and Recovery Act (RCRA) requirements. BNL generated the Response Strategy Document that identified various areas of concern (AOCs). The High Flux Beam Reactor (HFBR) is identified as AOC 31 and comprises the HFBR complex and waste loading area (BNL 2009).

The HFBR operated between 1965 and 1996 as a research reactor that generated neutrons for experiments in materials science, chemistry, biology, and physics. In late 1999, DOE announced the permanent shutdown of the reactor. As part of the planned remediation, Building 705 (the Stack) and associated systems and components (silencer, stormwater collection system) have been removed. Additional information regarding the remediation of the Stack is provided in Section 2. After removal of the stack and structures, the remaining subsurface portion was subject to a Final Status Survey (FSS). A field-sampling plan (FSP), outlining the FSS approach, was submitted to DOE/U.S. Army Corps of Engineers (USACE) (OFJV 2020). DOE staff requested that Oak Ridge Institute for Science and Education (ORISE) perform an independent verification (IV) survey of remaining surfaces associated with the Stack project. DOE/USACE will use the IV survey data for their evaluation of the FSS data relative to the project end-point criteria.

## 2. SITE DESCRIPTION

BNL is located in eastern Suffolk County on Long Island, approximately 60 miles east of New York City in the census-designated place of Upton, New York. The BNL property is approximately 2,100 hectares (ha) (5,300 acres) of primarily wooded land. Most facilities are located near the center of the property on approximately 700 ha (1,700 acres) of developed land. Figure 2.1 provides an overview of the location of BNL.

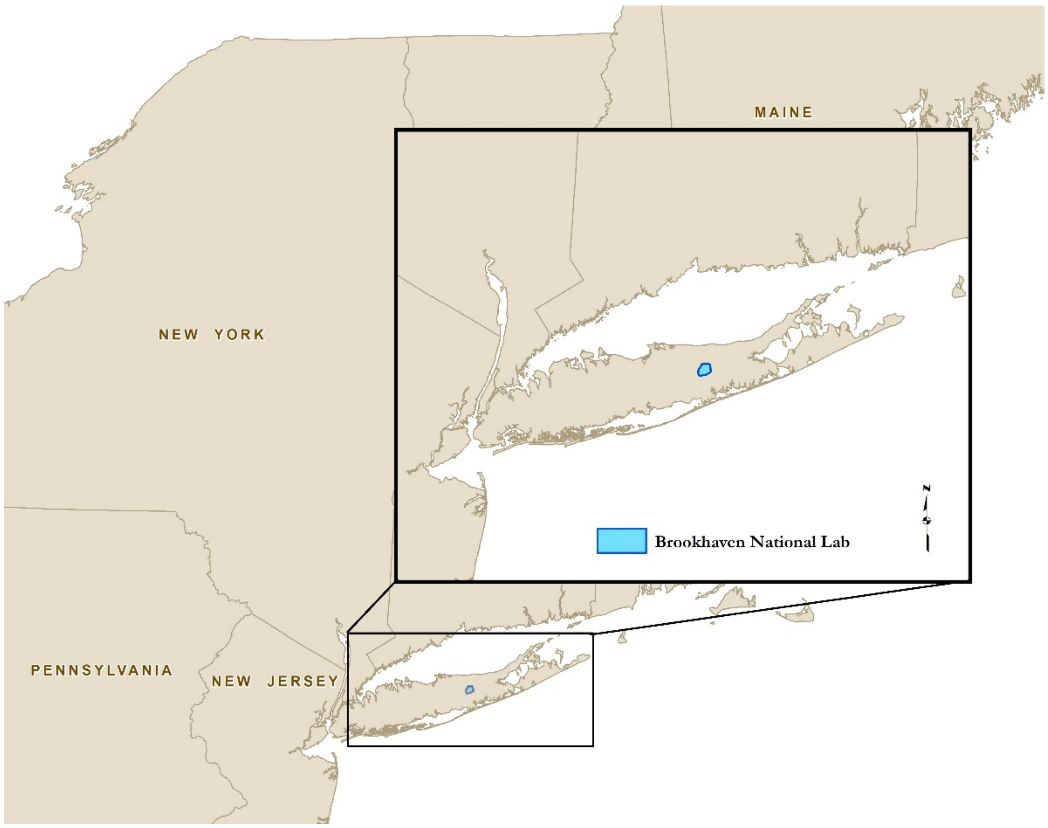


**Figure 2.1. Location of BNL**

The HFBR Complex is composed of multiple structures housing systems necessary for successful reactor operation and located centrally within the developed region of the site. Location of the HFBR Complex within the BNL property is presented in Figure 2.2.

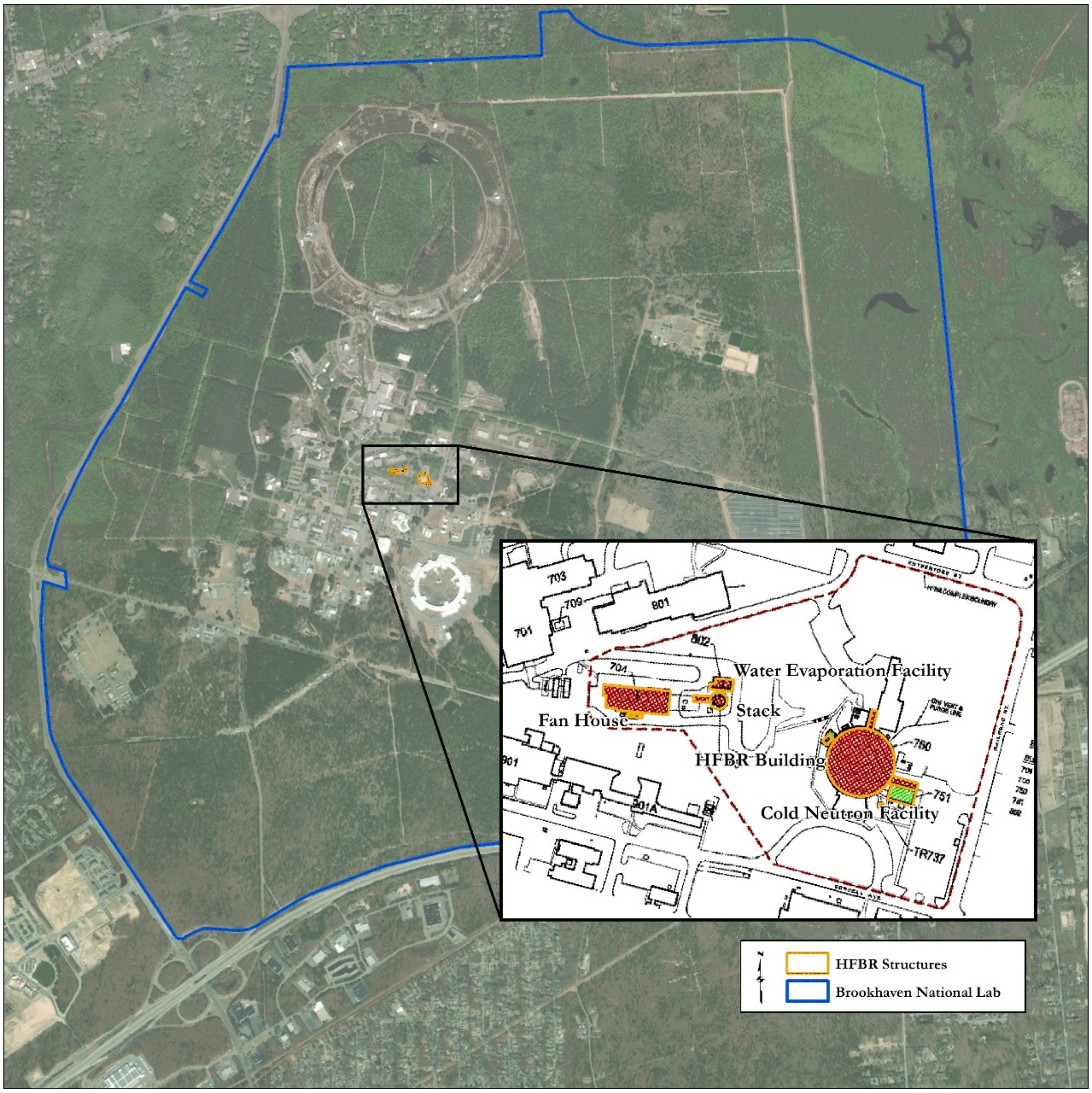


**Figure 2.2. Location of the HFBR Complex within BNL**

Building 705 was the 100-meter (m) tall exhaust Stack initially providing an elevated release point for the primary and secondary cooling air. The Stack rested atop a series of four octagonal slabs of reinforced concrete referred to as the pedestal. Each slab was 0.61 m thick and was 1.2 m larger in diameter than the slab above. The top of the pedestal was at ground level and had an exposed surface area of approximately 1,670 $m^2$. Three, 7.62 centimeter (cm) in diameter, stainless steel drain lines or "pipes" transect the pedestal. The drain lines penetrated the top two slabs in the southwest portion of the pedestal, exiting through the northwest side of the pedestal, approximately 1.17 m below ground surface, and connected with the stormwater collection system. The drain lines in the pedestal were grouted following FSS and IV data collection and soil was placed over the concrete pedestal.

Building 705 had an acoustic filter, the silencer, that was installed at the eastern end of the below ground duct connecting the former Fan House (Building 704) and the west side of the Stack (Building 705). All structures including the silencer, the concrete floor of the silencer, the drain line and sump, and contaminated underlying soils were removed prior to FSS activities.

The Stack stormwater collection system included a 550-gallon underground storage tank located northeast of Building 705 installed in April 2010. The tank was covered by a 6-foot by 10-foot reinforced concrete pad. There was a 7.62 cm drain line approximately 23 m long connecting the pedestal stormwater drains to the collection tank. Removal of the Stack stormwater collection system and removal of underlying contaminated soil happened prior to FSS activities. All SUs were backfilled to grade following FSS and IV data collection.

## 3. DATA QUALITY OBJECTIVES

The data quality objectives (DQOs) described herein are consistent with the *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA 2006) and provided a formalized method for planning radiation surveys, improving survey efficiency and effectiveness, and ensuring that the type, quality, and quantity of data collected were adequate for the intended decision applications. The seven steps in the DQO process were as follows:

1. State the problem
2. Identify the decision/objective
3. Identify inputs to the decision/objective
4. Define the study boundaries
5. Develop a decision rule
6. Specify limits on decision errors
7. Optimize the design for obtaining data

IV survey DQOs were originally presented in ORISE 2021 and are represented here for completeness.

## 3.1 State the Problem

The first step in the DQO process defined the problem that necessitated the study. After removal of the Stack and associated systems and components, residual radioactivity may remain following remedial actions. Data generated from independent verification survey activities will provide DOE/USACE with the information to determine if the remediated areas meet the release criteria for surface media (i.e., asphalt and concrete) and soils that are presented in the Record of Decision (ROD) and FSP. DOE directed that activities be coordinated through the USACE point of contact as they are responsible for managing project activities at BNL on behalf of DOE. USACE contracted FSS activities to a separate organization. FSS data assessment methods are outlined in the FSP. Objectives of the IV survey activities are to provide independent verification data for DOE/USACE's evaluation of the FSS results for the remaining areas associated with the HFBR Stack. Based on this, the problem statement is as follows:

> Independent verification survey activities are necessary to generate radiological data for DOE/USACE's assessment and evaluation of the accuracy and adequacy of FSS design, implementation, and results for demonstrating compliance with the release criteria.

## 3.2 Identify the Decision/Objective

The second step in the DQO process identified the principal study questions (PSQs) and alternative actions (AAs), developed decision statements (DSs), and organized multiple decisions, as appropriate. This second step is done by specifying AAs that could result from a "Yes" response to the PSQs and combining the PSQs and AAs into a DS. Given that the problem statement introduced in Section 3.1 is fairly broad, multiple PSQs arise. PSQs, AAs, and combined decision statements are presented in Table 3.1.

| Table 3.1. Independent Verification Survey Decision Process | |
|---|---|
| **Principal Study Questions** | **Alternative Actions** |
| **PSQ1:** Are IV results comparable with the FSS data for the areas investigated and are residual radioactivity concentrations below applicable volumetric limits? | **Yes:**<br>Compile IV data and report results to DOE/USACE for their decision making. Provide interpretation of IV field surveys and verify that: 1) IV surveys did not identify anomalous areas of residual radioactivity, 2) quantitative laboratory data satisfied the DOE-approved decommissioning criteria, 3) FSS survey units were classified in accordance with MARSSIM guidance, and 4) statistical examination/assessment conditions were met.<br>**No:**<br>Compile IV data and report results to DOE/USACE for their decision making. Provide interpretation of IV field surveys and verify that: 1) IV surveys identified anomalous areas of residual radioactivity, 2) quantitative field and laboratory data exceeded the DOE-approved decommissioning criteria, 3) FSS survey units were not classified in accordance with MARSSIM guidance, and 4) statistical examination/assessment conditions were not met. |
| **PSQ2:** Are surface activity levels of remaining structures less than the applicable limits? | **Yes:**<br>Compile IV data and report results to DOE/USACE for their decision making. Provide interpretation of IV field surveys and verify that: 1) IV surveys did not identify anomalous areas of residual radioactivity, 2) quantitative field data were less than the applicable surface activity limits, 3) FSS survey units were classified in accordance with MARSSIM guidance, and 4) statistical examination/assessment conditions were met.<br>**No:**<br>Compile IV data and report results to DOE/USACE for their decision making. Provide interpretation of IV field surveys and verify that: 1) IV surveys identified anomalous areas of residual radioactivity, 2) quantitative field data exceeded the applicable surface activity limits, 3) FSS survey units were not classified in accordance with MARSSIM guidance, and 4) statistical examination/assessment conditions were not met. |
| **Decision Statements** | |
| Determine if IV survey data agree with the FSS data for areas investigated and that residual radioactivity concentrations are below their respective limit.<br><br>Determine whether surface activity levels of remaining structures are below the applicable limits. | |

Typical IV survey designs would include verification of survey unit (SU) classification (i.e., the collected survey data either supports or refutes the SU classification). However, the FSP states that all SUs are currently a Class 1, the most conservative. Because the Class 1 designation is the most restrictive, it was unnecessary to evaluate whether a given SU should have received a higher classification.

## 3.3 IDENTIFY INPUTS TO THE DECISION/OBJECTIVE

The third step in the DQO process identified both the information needed and the sources of this information, determined the basis for action levels, and identified sampling and analytical methods that will meet data requirements. For this effort, information inputs include the following:

- BNL FSP, FSS data, and project schedule.
- Site-specific volumetric cleanup limits and surface activity limits, further discussed in subsection 3.3.1.
- ORISE IV surface scans and surface activity data.
- ORISE volumetric sample and removable activity results.

### 3.3.1 Radionuclides of Concern and Release Guidelines

The primary radionuclides of concern (ROCs) for the soil and concrete associated with the HFBR Stack are the same as those specified in the Operable Unit I Record of Decision, namely cesium-137 (Cs-137), radium-226 (Ra-226), and strontium-90 (Sr-90) (BSA 2009). Additional ROCs were added based on characterization samples collected from the HFBR Stack and are provided in Table 3.2 (OFJV 2020). These additional ROCs were added because of fuel failures at the Brookhaven Graphite Research Reactor that released uranium oxides, which potentially adhered to the inside of the Stack (OFJV 2020).

Site-specific dose-based cleanup goals (i.e., derived concentration guideline levels [DCGLs]) for volumetric media were developed for remaining soil and concrete and are summarized in Table 3.2. The residential cleanup goals are based on a residential exposure scenario and represent a total effective dose equivalent (TEDE) of 15 millirem per year (mrem/yr). In addition to the residential cleanup goals, as low as reasonably achievable (ALARA) cleanup goals were also calculated—based on a TEDE of 10 mrem/yr—and are also presented in Table 3.2. FSS design objectives were based on satisfying the ALARA cleanup goals and these limits are applicable to surface and subsurface soil.

As outlined in the FSP, dose contributions from tritium (H-3) and nickel-63 (Ni-63) will be assessed if these radionuclides are detected in samples.

**Table 3.2. BNL HFBR Site-Specific Cleanup Goals for Soil and Concrete (pCi/g)[a]**

| ROC | Residential Cleanup Goal | ALARA Cleanup Goal | ROC | Residential Cleanup Goal | ALARA Cleanup Goal |
|---|---|---|---|---|---|
| H-3 | --[b] | --[b] | U-234 | --[c] | --[c] |
| Co-60 | 1,260 | 840 | U-235 | 4.6 | 3.1 |
| Eu-152 | 51 | 34 | U-238 | 4.7 | 3.1 |
| Eu-154 | 180 | 120 | Pu-238 | 57 | 38 |
| Ni-63 | --[b] | --[b] | Pu-239 | 35 | 23 |
| Sr-90 | 15 | 10 | Pu-240 | 35 | 23 |
| Cs-137 | 23 | 15 | Am-241 | 34 | 22 |
| Ra-226 | 5 | 3.3 | | | |

[a] Table was reproduced from values presented in OFJV 2020.
[b] Per OFJV 2020, if this ROC is identified above the detection limit, a dose assessment will be performed using analytical soil sample data.
[c] Per OFJV 2020, if the mean U-234 concentration in the survey unit exceeds the 95% upper confidence level of the reference area mean, a dose assessment will be performed using the survey unit data.

The unity rule applies to the release of land areas using the ALARA cleanup goals provided in Table 3.2. Sum-of-fractions (SOF) calculations are performed as follows:

$$SOF_{TOTAL} = \sum_{j=0}^{n} SOF_j = \sum_{j=0}^{n} \frac{C_j}{DCGL_{W,j}}$$

Where $C_j$ is the concentration of ROC "j" and $DCGL_{W,j}$ is the ALARA cleanup goal for ROC "j". Note that gross concentrations are considered here for conservatism.

The BNL Radiation Control Manual specifies surface contamination values for the unrestricted release of material, equipment, and property. These surface contamination limits stem from values specified in DOE Order 5400.5 (via DOE Order 458.1). Table 3.3 provides these values as presented in OFJV 2020.

| Table 3.3. BNL Radiation Control Manual Limits for Surface Contamination (dpm/100 $cm^2$)[a] | | | | | | | |
|---|---|---|---|---|---|---|---|
| **ROC** | **Total - Average** | **Total - Maximum** | **Removable** | **ROC** | **Total - Average** | **Total - Maximum** | **Removable** |
| H-3 | -- | -- | 10,000 | Ra-226 | 100 | 300 | 20 |
| Co-60 | 5,000 | 15,000 | 1,000 | U-235 | 5,000 | 15,000 | 1,000 |
| Eu-152 | 5,000 | 15,000 | 1,000 | U-238 | 5,000 | 15,000 | 1,000 |
| Eu-154 | 5,000 | 15,000 | 1,000 | Pu-238 | 100 | 300 | 20 |
| Ni-63 | 5,000 | 15,000 | 1,000 | Pu-239 | 100 | 300 | 20 |
| Sr-90 | 1,000 | 3,000 | 200 | Pu-240 | 100 | 300 | 20 |
| Cs-137 | 5,000 | 15,000 | 1,000 | Am-241 | 100 | 300 | 20 |

[a] Table was reproduced from values presented in OFJV 2020.

### 3.4 Define the Study Boundaries

The fourth step in the DQO process defined target populations and spatial boundaries, determined the timeframe for collecting data and making decisions, addressed practical constraints, and determined the smallest subpopulations, area, volume, and time for which separate decisions must be made. IV survey activities took place in all SUs identified in Table 3.4. Temporal boundaries included the overall project schedule and time-dependent funding constraints. The specific timing of on-site IV activities was dependent on the decommissioning contractor's and the overall project's schedule. IV activities were performed concurrently with FSS activities in order to meet the project's overall target completion date.

The site established a soil reference area (RA) to evaluate the background contributions of select radionuclides within the soil SUs, although ORISE is not certain if or how the RA data were used in FSS data assessments. ORISE performed a gamma walkover survey of the soil RA and collected three samples.

Additionally, ORISE collected static gamma measurements throughout the lengths of the three pipes transecting the pedestal.

Figure A.1 presented in Appendix A depicts the layout of the SUs within the land areas associated with the HFBR Stack demolition. As illustrated in Figure A.1, a portion of the silencer excavation (SU 7B) was inaccessible by foot due to safety concerns. Therefore, surveyors had to scan/sample this region from the basket of an aerial lift operated by the site.

| Table 3.4. HFBR Stack Structural and Land Area Survey Units[a] | | | | | |
|---|---|---|---|---|---|
| Survey Unit ID | Class | Description | Area ($m^2$)[b] | FSS Sample Media | Actual Number of FSS Samples |
| 7A | 1 | Exposed surface of concrete pedestal | 180 | Concrete | 5 – concrete<br><br>180 – SA measurements (planned) |
| 7B | 1 | Underlying soil under the silencer | 150 | Soil | 16 – 0 to 15.24 cm<br>16 – 15.24 to 30.48 cm<br>16 – 30.48 to 60.96 cm |
| 7C | 1 | Underlying soil of the stormwater collection system | 100 | Soil | 16 – 0 to15.24 cm<br>16 – 15.24 to 30.48 cm<br>16 – 30.48 to 60.96 cm |
| 7D | 1 | Waste container loading area | NP | Soil | 2 – asphalt<br>16 – 0 to15.24 cm<br>16 – 15.24 to 30.48 cm<br>15 – 30.48 to 60.96 cm |
| RAs | N/A | Concrete and soil reference areas | NP | Soil<br>Concrete | 16 – Soil<br>6 – Concrete |

[a]Source: OFJV 2020
[b]Areas are estimates
NP = not provided
RA = reference area
N/A = not applicable

### 3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specified appropriate population parameters (e.g., mean, median), developed action levels, confirmed detection limits are less than action levels, and developed an "if…then…" decision rule statement. Two PSQs were introduced in Table 3.1; therefore, two decision rules arose. The first PSQ relates to the degree to which the FSS data and IV data agree, whereas the second PSQ focuses on whether remaining structural surfaces satisfy surface activity limits. Decision rules addressing each PSQ are discussed below.

#### 3.5.1 PSQ1: FSS and Independent Verification Data Agreement

Evaluation of the IV and FSS data involves two comparisons: 1) comparison of the mean/median ROC concentrations in the IV volumetric samples to the FSS data mean/median and 2) comparison of the individual IV data points to a pass/fail criterion. Therefore, the parameter of interest is the mean/median ROC concentration in the study area. The ALARA cleanup goals will be used as the pass/fail criterion for individual samples.

The decision rule is stated as follows:

> If the IV ROC mean/median is within the allowable level of statistical uncertainty and each individual sample result is below single point pass/fail criterion, then the IV data are consistent with the FSS data; otherwise, perform further evaluation(s) and provide technical comments/recommendations to DOE/USACE for their evaluation and decision making.

Verification survey data are not intended to demonstrate compliance with the release criterion directly, but, rather, to support DOE/USACE staffs' determination that the FSS results are appropriate for the intended use. The general IV survey approach to support this determination focused on collecting systematic data from specific survey areas (SU 7B) and covering large areas of land with quantitative investigations (i.e., surface scans). Two types of verification samples were collected as part of this study: judgmental and random. Judgmental samples were collected based on on-site investigations, such as gamma walkover surveys, to evaluate discrete locations of contamination, and were compared to a single-point failure criterion. Random samples were collected to compare against the random/systematic FSS data set. When comparing independent data sets, it is important to establish an acceptable level of difference (i.e., the allowable level of statistical uncertainty). The intention of the comparison was to identify biases—either positive or negative—and evaluate whether the bias could result in the incorrect decision to release a SU when it does not meet the release criterion. Bias between the data sets may be either systematic (i.e., one data set is consistently higher than the other) or discrete. Details regarding the acceptable level of difference was dependent on numerous factors, which are discussed further in Section 3.6.1.

### 3.5.2 PSQ2: Surface Activity Levels

For the remaining structural surfaces, decision rules relate to the presence/absence of surface contamination above the applicable limits. Typical IV survey designs to address this PSQ would involve direct radiation scans and the collection of biased surface activity measurements at elevated locations identified during the scans. However, the low alpha surface activity limits presented scanning limitations. Therefore, to account for scanning limitations for alpha radiation, a presence/absence survey design was employed. The IV survey results are intended to demonstrate that a high percentage of the structural SU is less than the allowable surface activity limits with a high level of confidence. The formal statistical approach to presence/absence measurements is also known as compliance sampling. Each measurement has a binary outcome and is either: 1) acceptable—below the surface activity limits, or 2) unacceptable—above the surface activity limits. The compliance sampling approach required that all surfaces in the decision area be divided into non-overlapping, equal-size grid cells of specified size, one square meter for this project. A random number of grid cells were then selected for investigation. Surface activity measurements were then collected from each random grid cell and were assessed in terms of the binary outcome (i.e., either above or below the surface activity limits). The surface activity measurements were collected from the highest location identified during the scan of each investigated grid. As such, the parameter of interest for this decision is the magnitude of individual measurement results. The decision rule is stated as follows:

> If all surface activity measurements are below the applicable limits, then conclude that a high percentage of the SU is acceptable; otherwise, conclude a portion does not meet surface activity limits.

## 3.6 SPECIFY LIMITS ON DECISION ERRORS

The sixth step in the DQO process examined the consequences of making an incorrect decision and established bounds of decision errors. Decision errors are controlled during the survey design, on-site field investigations, and during the data assessment. Each order of decision error control is discussed in detail in the subsequent subsections.

### 3.6.1 Hypothesis Testing

The first order of control was related to the allowable difference between the FSS data and IV survey data. Hypothesis testing adopts a scientific approach where the survey data are used to select between the baseline condition (the null hypothesis, $H_0$) and an alternative condition (the alternative hypothesis, $H_A$). The null hypothesis, or the assumed base condition as stated, is normally based on which base condition carries the greatest risk, such as releasing a contaminated area or, alternatively, expending budgeted resources on investigations of potentially clean areas. The IV survey is the last step in the site survey and investigation process; as such, the procedures and processes used to generate the FSS data have received some level of prior review. Therefore, the null and alternative hypotheses are as follows:

> $H_0$: The IV ROC concentration (or surface activity) population mean/median ($\mu_{IV}$) is less than or equal to the FSS mean/median ($\mu_{FSS}$). Mathematically, the null hypothesis is stated as: $\mu_{IV} - \mu_{FSS} \leq 0$.
>
> $H_A$: The IV ROC concentration (or surface activity) population mean/median ($\mu_{IV}$) is greater than the FSS mean/median ($\mu_{FSS}$). Mathematically, the alternative hypothesis is stated as: $\mu_{IV} - \mu_{FSS} > 0$.

For the hypothesis testing, there were two types of decision errors to consider: Type I (typically designated as alpha, or $\alpha$) and Type II (typically designated as beta, or $\beta$). A Type I error occurs when the null hypothesis is rejected when it should not be, also known as a false positive, and reflects the confidence level in the decision (confidence is defined as $1 - \alpha$). A Type II error is incorrectly failing to reject the null hypothesis when it is false, also known as a false negative. The ability to reject the null hypothesis when it is false is known as the power of the test (power is defined as $1 - \beta$) and related to the magnitude of the difference between $\mu_{IV}$ and $\mu_{FSS}$ before there is sufficient evidence to reject the null hypothesis. The Type I error rate was set to 0.05; that is, there is a 5% chance of concluding the IV population mean is greater than the FSS population mean when it is actually not. The *a priori* Type II error rate will be no greater than 0.05; that is, there will be no greater than 5% chance of concluding the IV population mean is less than the FSS population mean when it is actually greater. The actual Type II error rate, and subsequent power achieved, is dependent on the number of samples collected and the concentration variability in the sample set.

The gray region is a term often associated with hypothesis testing where decision errors become significant. For this study, the width of the gray region is the range of SU mean concentrations where decision areas are important. The Type I error rate is specified at the lower bound of the gray region (LBGR) and the Type II region is defined at the upper bound of the gray region (UBGR). For typical *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) (DOE 2000) based surveys, the UBGR is set to the DCGL or action level. For this study, the UBGR is the difference in mean concentrations of the IV data and FSS data where we would reject the null hypothesis in favor of the alternate. The Type II error rate is specified at the UBGR. Therefore, when specifying the width of the gray region and value of the UBGR, one must also consider the cleanup goal. The width of the gray region must be less than the difference between the DCGL and expected FSS mean. Per the FSP, the expected FSS mean was 0.35 (specified in terms of unity); therefore, the width of the gray region shall be less than 0.65 (i.e., 1.00 – 0.35). For conservatism, the IV survey design accepted a gray region of 0.5. The LBGR was specified at a difference in mean concentrations of zero. Thus, the UBGR is 0.5.

The specific statistical test used to select between the null and alternative hypothesis was dependent on the distribution of the IV data. If the data are normally distributed, then a parametric test, such as the two-sample t-test, was the primary candidate. Non-parametric statistical tests, such as the Wilcoxon-Mann-Whitney test, do not consider the magnitude of individual results. However, comparing individual data points directly to the DCGL addresses this shortcoming of nonparametric tests.

The planned number of FSS concrete samples was not large enough for a formal statistical comparison. Therefore, IV decisions were based on the collection of judgmental samples at locations that had the highest potential for contamination. A similar survey approach was applied to the background RA, collecting IV samples at locations that were flagged during gamma walkover scans.

### 3.6.2 Presence/Absence Measurements

Required parameter inputs for the compliance sampling design are the desired percentage of the decision area that is acceptable, the confidence at which the decision area is deemed acceptable, and the relative probability that a targeted grid cell is unacceptable, relative to a randomly selected grid cell. For this effort, the survey design will be sufficient to demonstrate that 95% of the decision area was acceptable at the 95% confidence level.

### 3.6.3 Field and Analytical Minimum Detectable Concentrations

The second order of control was to optimize the verification field measurement and laboratory analytical minimum detectable concentrations (MDCs). Field scanning and analytical MDCs were minimized by following the procedures referenced in Sections 4 and 5, respectively. Detector scan MDCs for the primary gamma-emitting ROCs were expected to be below the soil ALARA DCGLs.

Any anomalies above background identified while performing the surveys or subsequent data assessment were thoroughly investigated.

The *a priori* detector scan MDCs for hand-held detectors are presented in Appendix D.

Additionally, analytical MDCs were less than 10% of the ALARA DCGL—with the exception of uranium-238 (U-238), the average analytical MDC was less than 50% of the ALARA DCGL, as indicated in Table B.3.

### 3.7 Optimize the Design for Obtaining Data

The seventh step in the DQO process was used to review DQO outputs, develop data collection design alternatives, formulate mathematical expressions for each design, select the sample size to satisfy DQOs, decide on the most resource-effective design of agreed alternatives, and document requisite details. Specific survey procedures are presented in Section 4.

## 4. PROCEDURES

The ORISE survey team performed visual inspections, measurements, and sampling activities within the accessible portions of all SUs during the periods of August 5–11, 2021, and August 30–September 3, 2021. Survey activities were conducted in accordance with the project-specific IV survey plan, the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual,* and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORISE 2021, ORAU 2016, ORAU 2021a). Appendices C and D provide additional information regarding survey instrumentation and related processes discussed within this section.

### 4.1 Reference System

ORISE referenced IV measurement/sampling locations to global positioning system (GPS) coordinates using the NAD 1983 State Plane New York Long Island FIPS 3104 (meters). Measurement and sampling locations were documented on field forms and survey maps.

### 4.2 Surface Scans

Ludlum model 44-10 2-inch by 2-inch thallium-doped sodium iodide (NaI[Tl]), hereafter referred to as NaI, detectors were used to evaluate direct gamma radiation levels for land areas and the concrete pedestal. Accessible areas associated with the survey areas were scanned with medium- to high-density coverage. All detectors were coupled to Ludlum Model 2221 ratemeter-scalers with audible indicators. Ratemeter-scalers also were coupled to hand-held GPS data-loggers to electronically record detector response concurrently with geospatial coordinates. Locations of elevated response that were audibly distinguishable from localized background levels, suggesting the presence of residual contamination, were flagged for further investigation and potential volumetric sampling. Portions of SUs 7B and 7D were inaccessible by foot due to safety concerns. Therefore, ORISE surveyors scanned/sampled these areas from the basket of an aerial lift operated by site personnel. When scanning from the lift, ORISE affixed the GPS unit to the railing of the basket but scanned all accessible areas around the basket. This is why there appear to be some small gaps on the gamma survey maps for these SUs.

A small diameter Ludlum model 44-159-1 cesium iodide (CsI) coupled to a model 2221 was used for investigation of the three drain lines embedded in the pedestal. Surface scans of the concrete pedestal were performed with a Ludlum model 43-37 gas-flow proportional floor monitor and Ludlum model 43-68 gas proportional hand-held detectors. Both detector types were coupled to Ludlum model 2221 ratemeter-scalers with audible indicators. The floor monitor was also coupled to a hand-held GPS data-logger to electronically record detector response concurrently with geospatial coordinates. Scan data from the floor monitor are qualitative (scan MDCs are not calculated), but ORISE experience is that floor monitors are effective at, and efficient for, identifying low levels of surface contamination. Locations identified with the floor monitor were quantitatively investigated using 43-68 gas proportional hand-held detectors. The floor monitor employed a 0.8 mg/cm$^2$ thick Mylar window and was operated in alpha-plus-beta mode. Beta-only and alpha-only scans were performed on the concrete pedestal using 43-68 gas proportional hand-held detectors with 3.8 and 0.8 mg/cm$^2$ thick Mylar windows, respectively. Beta-only scans were performed in only the grids selected for compliance sampling. Alpha-only scans were performed in all accessible grids. Each compliance grid received high-density scan coverage and the highest location within a grid was marked for subsequent surface activity measurements. The only grids that were not thoroughly assessed by ORISE were the grids ending in the number “1” on the western most edge of the pedestal. The remediation of the pedestal resulted in a sloped edge down into SU 7B with an elevated drop-off and no safety barrier. ORISE staff stayed several feet away from the western most edge.

During all scans, locations of elevated direct radiation, suggesting the presence of residual contamination, were marked for further investigation.

## 4.3 MEASUREMENT/SAMPLING LOCATIONS

Measurements/samples were collected from both randomly and judgmentally selected locations. The total number of judgmental measurements/samples was based on the findings during survey data collection. Visual Sample Plan (VSP), version 7, was used to assess the sample size required for decision making and to randomly place locations throughout SU 7B.

### 4.3.1 Volumetric Sampling Locations

In SU 7B, a randomly-selected soil sample data set was generated for a formal comparison of the mean/median ROC concentrations in the IV volumetric samples to the FSS data mean/median. VSP inputs required for the sample size calculation are the width of the gray region—where decision errors become significant, the desired Type I and Type II error rates, and the expected radionuclide variation. As presented in Section 3.6.1, the LBGR and UBGR was specified at 0 picocuries per gram (pCi/g) and 0.5 pCi/g, respectively, resulting in a gray region width of 0.5 pCi/g. The assumed standard deviation due to radionuclide variability is 0.35 pCi/g, as specified in the FSP. Both Type I and Type II errors were selected as 0.05. Based on the previously described inputs and assuming the population would be normally distributed, 12 soil samples were required in SU 7B. However, the required number of IV samples was increased to 16 to align with the number of FSS samples. Note that the total number of IV samples increased to 17 when using VSP to lay out the locations and complete the systematic grid in the SU.

Concrete sampling locations were judgmentally selected based on elevated responses during beta and gamma radiation scans; three locations were sampled.

Soil sample locations in the background RA were judgmentally selected based on direct gamma radiation scans; three locations were sampled. The background RA data is not being used for IV data assessment but is presented for completeness. Likewise, judgmental soil sample locations in all SUs were selected based on elevated responses during direct gamma radiation scans.

#### 4.3.2 Surface Activity Measurement Locations

The number of surface activity measurements for the concrete pedestal in SU 7A were dependent on the acceptable percentage of the SU area and the desired confidence level. The required sample size was determined to be 50 measurements based on the parameters specified in Section 3.6.2. Note that the total number of measurements was increased slightly to 56 measurements in order to complete the systematic grid in the SU.

#### 4.3.3 Piping Measurement Locations

Static gamma measurements were collected throughout the lengths of the three pipes transecting the pedestal in SU 7A using a Ludlum Model 44-159-1 CsI detector coupled to a Ludlum Model 2221 ratemeter-scaler. A few static measurements were also collected with a NaI detector although it would not fit through the entire length of any of the pipes. The count time for each static measurement was 1 minute. Pipe segments were measured at various 1-foot increments as the CsI detector was pulled through the pipes. Refer to Table B.6 for gross gamma count rates collected within the three pipes.

### 4.4 Soil Sampling

Surface soil sampling locations were randomly selected in SU 7B, as discussed in Section 4.3.1. In SU 7B, six locations were identified during surface scans with elevated direct gamma radiation levels distinguishable from background. Four of the locations were identified during gamma scans from the aerial lift. At each of these four locations, there was a rock or piece of concrete-like debris that was removed by the site staff. Following removal, ORISE collected post-remediation gamma scan data and determined that judgmental soil samples were not necessary as the material removed was the cause of the elevated count rates. The two remaining locations that were identified were within the trench box in SU 7B and judgmental samples 5356S0010 and 5356S0011 were collected at these locations for analysis.

In SU 7C, two locations were identified for judgmental sampling. One location was flagged during scans (5356S0024) and the second location (5356S0027) was suggested for sampling after post-processing the gamma walkover data.

In SU 7D, six locations were identified for judgmental sampling. Three locations were flagged during scans (5356S0023, 5356S0025, and 5356S0026) and the remaining three locations

(5356S0028, 5356S0029, and 5356S0030) were suggested for sampling after post-processing the gamma walkover data.

When coordinates were provided after post-processing gamma walkover data, the ORISE surveyor re-scanned the general area and collected the sample at the highest observed gamma count rate.

Prior to soil sampling, a 1-minute, static gamma radiation measurement was performed and then the surface soil sample was collected from a depth of 0 to 15 centimeters (cm) followed by a static gamma radiation measurement at the 15-cm depth.

Surface soil samples were collected using clean hand tools. All sampling equipment was rinsed in the field after the collection of each sample to prevent cross-contamination.

### 4.5 CONCRETE SAMPLING

Three judgmental concrete core samples (5356M0001, 5356M0002, and 5356M0003) were collected from the concrete pedestal in SU 7A. The core samples were collected using a coring machine operated by site staff. ORISE identified the locations and observed sample collection. Two, approximately 2-inch diameter cores were collected at each of the three locations and the coring barrel was rinsed with water in between sample locations. The cores were packaged by ORISE field staff by location indicating the top side of the cores. The ORISE laboratory staff processed the cores and analyzed only the top 2 inches of the each of the cores per location as one sample.

### 4.6 SURFACE REMOVABLE ACTIVITY MEASUREMENTS

Dry smear samples, for determining removable gross alpha/beta activity levels, were collected from each direct measurement location on the concrete pedestal in SU 7A. Wet smears for the determination of removable H-3 and Ni-63 were collected at judgmentally selected direct measurement locations in an area adjacent to the dry smear sample location; however, ORISE opted not to analyze these smears after reviewing the H-3 and Ni-63 results for the volumetric concrete samples. A dry smear was also collected within the south end of the western most "A" pipe in grid G3; the highest beta direct measurement associated with the pedestal was recorded over this pipe opening.

# 5. SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and data collected on site were transferred to the ORISE facility for analysis and interpretation. Sample custody was transferred to the Radiological and Environmental Analytical Laboratory (REAL) in Oak Ridge, Tennessee. Sample analyses were performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2021b). Soil and concrete samples were homogenized and sealed for a minimum of 27 days to allow ingrowth to provide Ra-226 concentrations via Pb-214. Samples were analyzed by gamma spectrometry for gamma-emitting fission and activation products. All soil and concrete samples were analyzed for Sr-90 and a select number of samples were analyzed for H-3 and Ni-63. Analytical results were reported in units of picocuries per gram (pCi/g).

Random soil sample results were graphed in quantile (Q) plots for assessment, and are discussed further in Section 6. The Q-plot is a graphical tool for assessing the distribution of a dataset. The Y-axis represents the ROC concentrations in units of pCi/g for sample data. The X-axis represents the data quantiles about the mean value. Values less than the mean are represented in the negative quantiles; the values greater than the mean are represented in the positive quantiles. A normal distribution that is not skewed by outliers (i.e., a background population) will appear as a straight line, with the slope of the line subject to the degree of variability among the data population. More than one distribution, such as background plus contamination or other outliers, will appear as a step function. Additionally, the FSS data were plotted along with the IV data to evaluate for biases. Biases—positive or negative—would be indicated by diverging data groupings.

# 6. FINDINGS AND RESULTS

The results of the IV survey activities are discussed in the following subsections.

## 6.1 SURFACE SCANS

Figure A.2 in Appendix A presents the gamma walkover data collected in the background RA selected by site staff. The gamma responses in the RA ranged from approximately 5,400 counts per minute (cpm) to 9,600 cpm. Figures A.3 through A.6 present the gamma walkover data collected for soil SUs 7B, 7C, and 7D. Two figures are presented for SU 7B including a pre-remediation figure (Figure A.3) and a post-remediation figure (Figure A.4). The highest location was noted on a piece of concrete-like debris. As noted in section 4.4, the count rates decreased following removal of the elevated rocks/concrete-like debris in SU 7B and post-remediation gamma scan files were collected. Overall, the gamma responses in the soil SUs ranged from approximately 2,700 cpm to 8,500 cpm after excluding the elevated pre-remediation "hotspots." Figure A.7 presents the gamma walkover data collected for the concrete pedestal in SU 7A. The gamma responses ranged from approximately 4,100 cpm to 12,100 cpm noting the highest location was associated with the south end of the western most "A" pipe. Elevated locations were also noted within and adjacent to the deepest remediation "trench" on the pedestal.

Figure A.8 presents the alpha-plus-beta data collected on the concrete pedestal with a floor monitor. The responses ranged from approximately 1,100 cpm to 2,700 cpm noting the highest locations were also associated with the south end of the western most "A" pipe and adjacent to the deepest remediation "trench" on the pedestal.

### 6.2 Piping Measurements

Refer to Table B.6 for gross gamma count rates collected within the three pipes transecting the pedestal. The gamma detectors were used solely as a qualitative means to identify elevated radiation levels in excess of background. The gamma levels in the middle pipe "B" and eastern most pipe "C" were unremarkable but the gamma levels in the south end of the western most pipe "A" increased dramatically as shown in Figure 6.1. The ORISE smear sample collected in grid G3 was collected from within the south end of the "A" pipe and the removable gross alpha and gross beta activity results were less than the respective analytical minimum detectable activity.

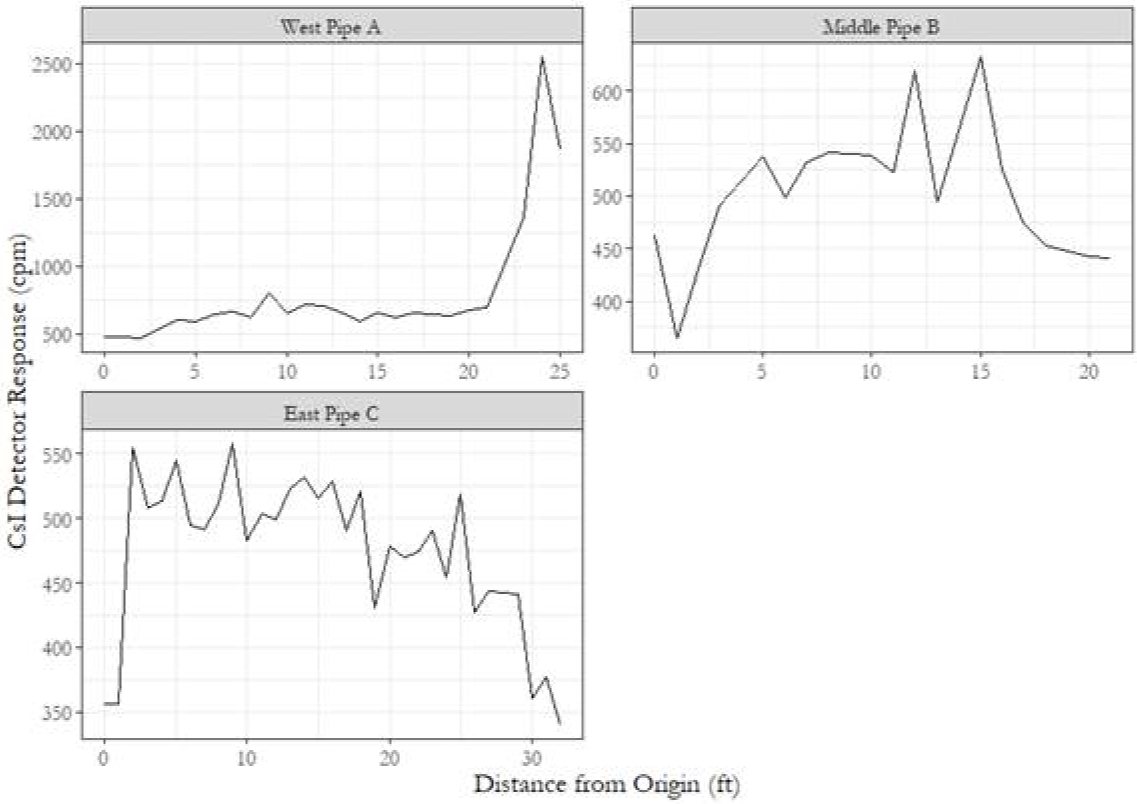


**Figure 6.1. CsI Detector Response in Piping**

## 6.3 Radionuclide Concentrations in Soil and Concrete Samples

Figure A.9 in Appendix A displays the locations for the background RA samples collected. Figures A.10 through A.11 display the locations for the soil and concrete samples collected. Sample coordinates and pre- and post-sample static gamma counts are presented in Tables B.1 and B.2 in Appendix B. Analytical results for individual soil samples and concrete samples are presented in Tables B.3 and Table B.4, respectively.

Table 6.1 summarizes the ROC concentrations of the randomly-collected soil samples in SU 7B. All random samples collected had a SOF value—based on the ALARA DCGLs—less than unity, which means that individual ROC concentrations were less than their respective ALARA DCGL. The random soil sample data set in SU 7B provides DOE/USACE with an unbiased estimate of the residual mean ROC concentration. The IV soil sample data set for SU 7B was collected for evaluation against the FSS data set, as described below.

| Table 6.1. Summary of Random Soil Sample Data in SU 7B | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Data for Statistical Comparison (pCi/g) | | | | | | | | | | | |
| | **Cs-137** | **Sr-90** | **Ra-226** | **Eu-152** | **Eu-154** | **U-235** | **U-238** | **Am-241** | **Co-60** | **H-3** | **Ni-63** | **SOF[a]** |
| Min | -0.0061 | -0.14 | 0.174 | -0.023 | -0.094 | -0.062 | 0.01 | -0.034 | -0.013 | -- | -- | 0.10 |
| Max | 0.808 | 0.27 | 0.339 | 0.039 | 0.023 | 0.078 | 0.59 | 0.005 | 0.0098 | -- | -- | 0.32 |
| Mean | 0.171 | 0.016 | 0.250 | 0.001 | -0.037 | 0.002 | 0.309 | -0.018 | -0.002 | -- | -- | 0.20 |
| Median | 0.059 | 0.020 | 0.233 | 0.002 | -0.032 | 0.001 | 0.290 | -0.020 | -0.002 | -- | -- | 0.20 |
| St Dev. | 0.016 | 0.010 | 0.016 | 0.000 | 0.000 | 0.011 | 0.050 | 0.001 | 0.000 | -- | -- | 0.06 |

[a]SOF was calculated using the ALARA DCGLs.

Figure 6.2 provides Q-Q plots of ROCs for the ORISE random IV data set and the FSS data set for SU 7B. Only sample concentrations for Cs-137 and Ra-226 were above the analytical MDCs in the IV random data set. However, based on current industry guidance, all reported concentrations greater than zero, even concentrations below the analytical MDCs, were included in the SOF calculations (noted as SOR, for sum-of-ratios in Figure 6.1). Additionally, negative values were treated as zeros in the ORISE assessment of both the IV and FSS data sets. Review of Figure 6.1 indicates that the ORISE data distributions are biased low—or have similar shape and central location, for all ROCs—with the exception of possibly Cs-137, U-238, and the SOR. The mean/median of these data sets were further evaluated with the Wilcoxon-Mann-Whitney test. The null hypothesis was not rejected for Cs-137 and the SOR, in other words there was not sufficient evidence to conclude the ORISE determined mean/median was greater than the mean/median of the FSS data. However, the null hypothesis was rejected for U-238 indicating the IV SU mean/median is greater than the FSS mean/median. Generally, a positive bias between IV survey data and FSS data is more of a concern than a negative bias. The reason for the positive bias in the U-238 concentrations was not determined. However, the individual U-238 results were compared directly to the ALARA DCGL and all values are less than the limit, and the average U-238 concentration is a factor of 10 less, so no additional assessment was necessary.

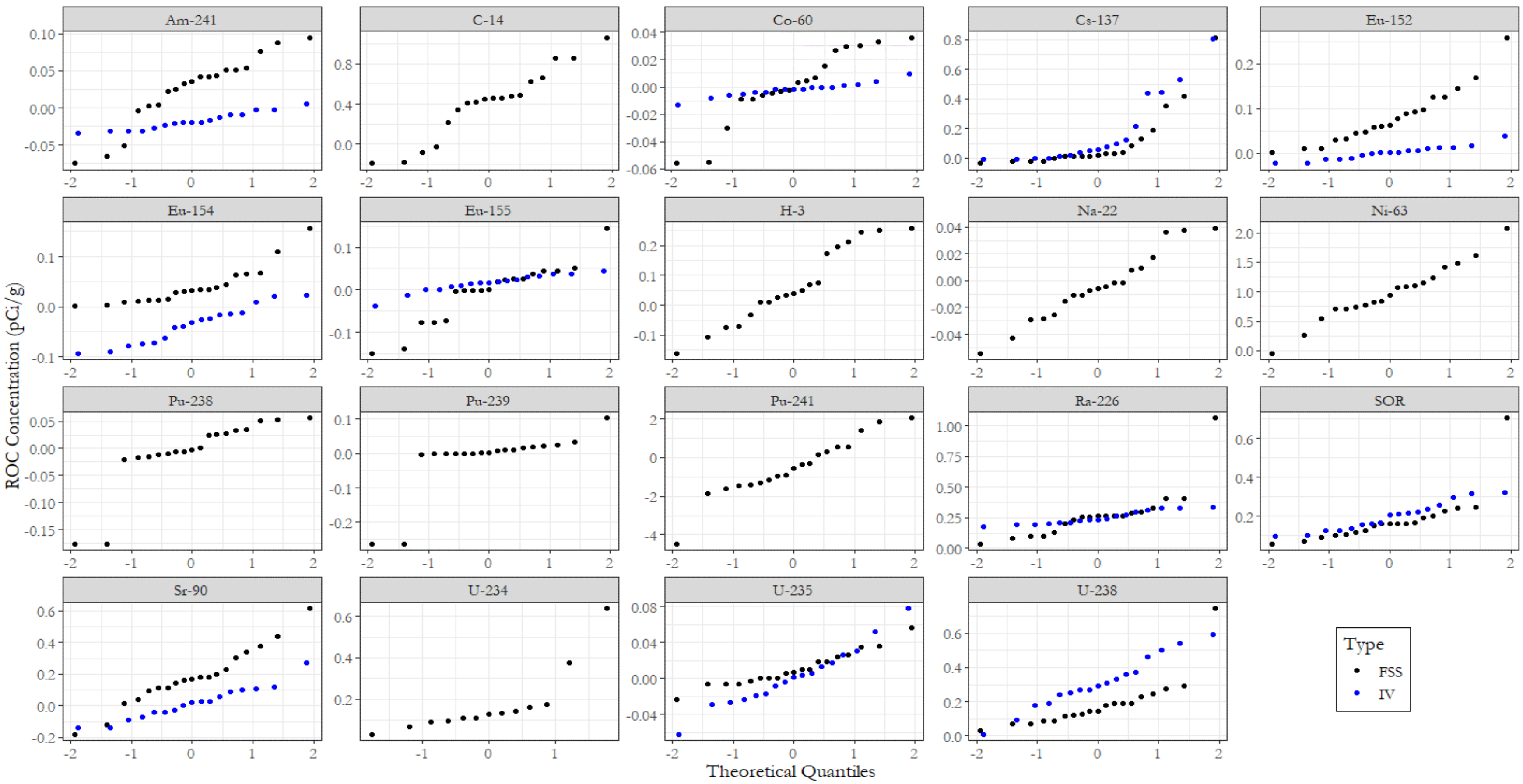


**Figure 6.2. Q-Q Plot for ORISE IV and FSS Soil Sample Results from SU 7B**

Table 6.2 summarizes the ROC concentrations of the judgmental soil samples collected in SUs 7B, 7C, and 7D. All judgmental soil samples collected had a SOF value less than unity—based on the ALARA DCGLs.

| Table 6.2. Summary of Judgmental Soil Sample Data (SUs 7B, 7C, and 7D) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Cs-137 | Sr-90 | Ra-226 | Eu-152 | Eu-154 | U-235 | U-238 | Am-241 | Co-60 | H-3 | Ni-63 | SOF[a,b] |
| Min | -0.019 | -0.10 | 0.25 | -0.024 | -0.202 | -0.09 | 0.15 | -0.052 | -0.006 | -0.6 | 0.53 | 0.19 |
| Max | 0.529 | 0.17 | 0.732 | 0.035 | 0.023 | 0.12 | 0.83 | 0.003 | 0.01 | 0.4 | 0.9 | 0.56 |

[a]The SOF calculation does not include the fractional contribution from H-3 or Ni-63 as they do not have a DCGL.
[b]SOF was calculated using the ALARA DCGLs.

Table 6.3 summarizes the ROC concentrations of the judgmental concrete samples collected in SU 7A. Two of the 3 concrete samples collected had a SOF greater than unity—based on the ALARA DCGLs. Additionally, all 3 samples contained H-3 which does not have an ALARA DCGL.

| Table 6.3. Summary of Judgmental Concrete Sample Data in SU 7A | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Cs-137 | Sr-90 | Ra-226 | Eu-152 | Eu-154 | U-235 | U-238 | Am-241 | Co-60 | H-3 | Ni-63 | SOF |
| Min | 0.004 | 0.04 | 0.379 | -0.08 | -0.046 | 0.00 | 0.38 | -0.045 | -0.01 | 59.5 | 0.5 | 0.35 |
| Max | 17.9 | 32.70 | 0.511 | 0.031 | 0.007 | 0.08 | 0.60 | -0.022 | 0.006 | 155.6 | 1.2 | 4.71 |

[a]The SOF calculation does not include the fractional contribution from H-3 or Ni-63 as they do not have a DCGL.
[b]SOF was calculated using the ALARA DCGLs.

## 6.4 TOTAL AND REMOVABLE SURFACE ACTIVITY LEVELS

Table B.5 in Appendix B provides individual measurement results for the concrete pedestal in SU 7A including the removable gross alpha/beta activity levels. ORISE collected concrete material-specific background data from the Building 610 concrete pad which was identified by BNL staff as being similar to the concrete pedestal. ORISE used the beta-only material-specific background in IV surface activity calculations, but found that the alpha-only background was too high (average of 19 cpm) and not representative of the alpha background for the concrete pedestal. ORISE opted to use an alpha background of zero in IV surface activity calculations for conservatism.

Figure 6.3 presents the alpha surface activity results for the concrete pedestal. All alpha surface activity values are less than the 100 dpm/100 $cm^2$ surface activity limit.

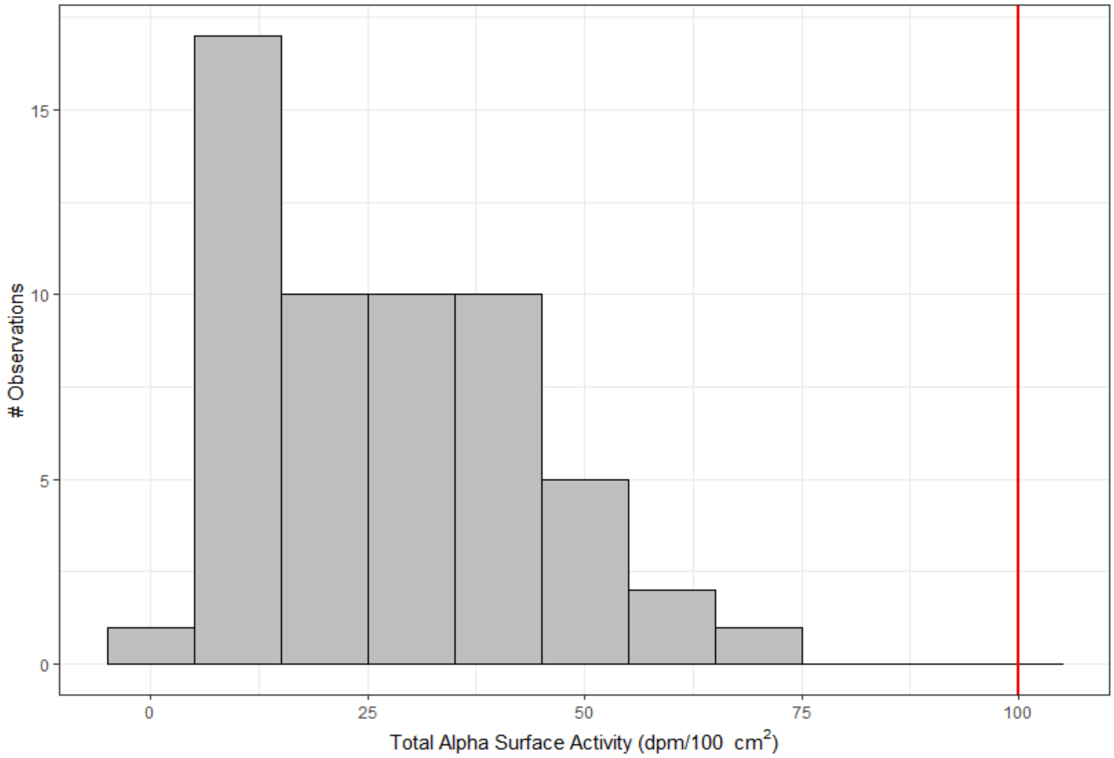


**Figure 6.3. ORISE IV Alpha Surface Activity Results from SU 7A**

Because ORISE does not have information on the respective fractional contribution of residual ROC contamination remaining in the concrete assumed for FSS data assessment, the beta-only surface activity values in Table B.5 are presented in two ways. The surface activity values are presented assuming all activity is from Cs-137 and then assuming all activity is from Sr-90. If all contamination is actually Cs-137, there are two results above the 5,000 dpm/100 cm$^2$ average Cs-137 limit; refer to Figure 6.4. Note: The figure only includes the measurements collected in randomly selected grids. However, both results are below the 15,000 dpm/100 cm$^2$ maximum Cs-137 limit. If all contamination is actually Sr-90 (i.e., higher total beta measurement efficiency than Cs-137), the results for the same two locations are still above the lower 1,000 dpm/100 cm$^2$ Sr-90 average limit, refer to Figure 6.5. Note: The figure only includes the measurements collected in randomly selected grids. However, only one of the locations is above the 3,000 dpm/100 cm$^2$ Sr-90 maximum limit. One location was in grid I4 and was one of the randomly selected grids for presence/absence measurements. The second location was a judgmental location in grid G3 over the south end of the western most "A" pipe and the contamination appeared to be inside the pipe. A concrete sample was collected from the location in grid I4 (5356M0003) and the fractional contribution in this sample is a mix of both Cs-137 and Sr-90.

Additionally, ORISE determined the fractional surface activity contributions from Sr-90 and Cs-137 based on FSS and IV volumetric concrete analytical results (Table 6.4). ORISE calculated the fractional activity from Cs-137 and Sr-90 at the two locations exceeding the average/maximum beta limit using Sr-90/Cs-137 ratios of 4.2 and 2. When compared to their respective limits, the Sr-90 results are still above the average limit in all instances but only above the maximum Sr-90 limit for the grid G3 location if assuming a Sr/Cs ratio of 4.2. However, as noted previously the elevated surface activity at this location is believed to be a result of contamination from within the "A" pipe and not from the concrete.

| **Table 6.4. Fractional Surface Activity** | | |
|---|---|---|
| Assuming Sr/Cs = 4.2 | | |
| Grid ID | ROC | Total Beta Activity ($dpm/100cm^2$) |
| I4 | Sr-90 | 1,892 |
| I4 | Cs-137 | 972 |
| G3 | Sr-90 | 3,396 |
| G3 | Cs-137 | 1,745 |
| Assuming Sr/Cs = 2 | | |
| Grid ID | ROC | Total Beta Activity ($dpm/100cm^2$) |
| I4 | Sr-90 | 1,562 |
| I4 | Cs-137 | 1,685 |
| G3 | Sr-90 | 2,803 |
| G3 | Cs-137 | 3,024 |

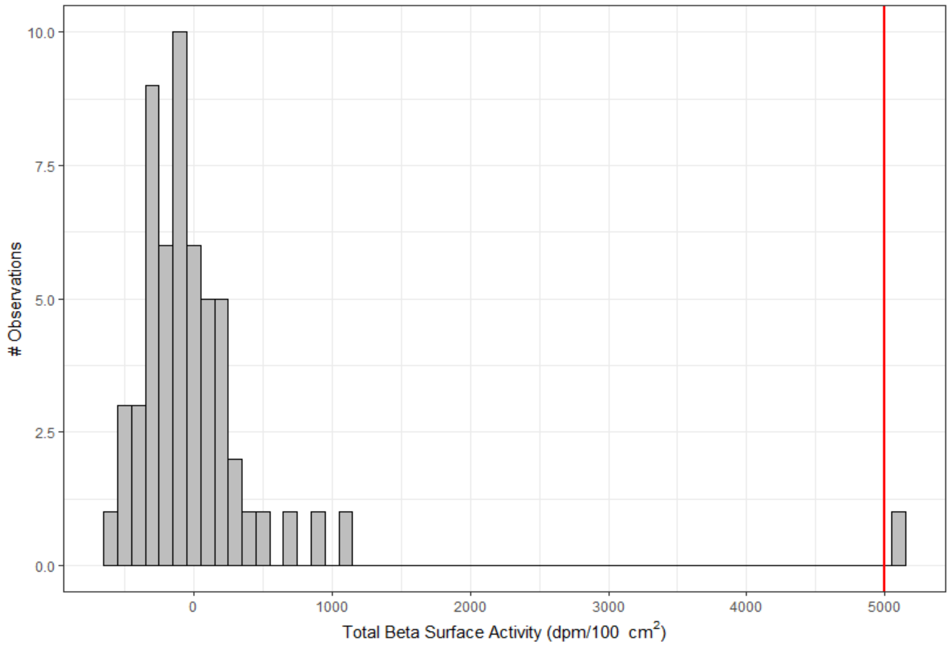


**Figure 6.4. ORISE Beta Surface Activity Results from SU 7A (assuming all is from Cs-137)**

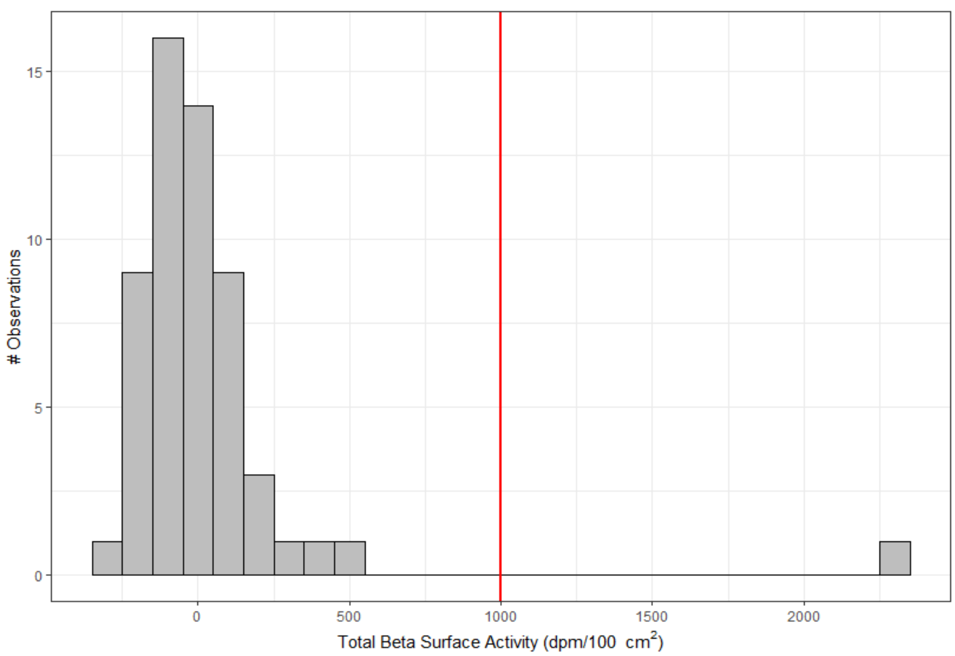


**Figure 6.5. ORISE Beta Surface Activity Results from SU 7A (assuming all is from Sr-90)**

All removable gross alpha and gross beta activity results were less than the respective analytical minimum detectable activity and below the removable surface contamination limits. As mentioned previously, ORISE opted not to analyze the wet smears collected for potential hard-to-detect (HTD) analysis after reviewing the H-3 and Ni-63 results for the volumetric concrete samples.

# 7. SUMMARY AND CONCLUSIONS

The ORISE survey team performed independent visual inspections, measurements, and sampling activities within the accessible portions of all SUs during the periods of August 5–11, 2021, and August 30–September 3, 2021. The verification activities consisted of gamma surface scans, gamma direct measurements, alpha-plus-beta scans, alpha and beta direct measurements, smear sampling, and soil/volumetric sampling.

In total, thirty soil samples were collected. Seventeen sample locations were randomly generated in SU 7B for a direct comparison against the FSS data. Additionally, 3 judgmental samples were collected from the background reference area and 10 judgmental samples were collected in the soil SUs. All random, background, and judgmental soil samples collected had a SOF value less than unity—based on the ALARA DCGLs. For SU 7B, the ORISE IV data distributions are biased low—or have similar shape and central location, for all ROCs—with the exception of U-238. Further evaluation via the Wilcoxon-Mann-Whitney test for U-238 concluded the null hypothesis was rejected for U-238 indicating the IV SU mean/median is greater than the FSS mean/median. The reason for the positive bias in the U-238 concentrations was not determined. However, the individual U-238 results were compared directly to the ALARA DCGL and all values are less than the limit, and the average U-238 concentration is a factor of 10 less, so no additional assessment was necessary.

Three judgmental concrete samples were collected from the concrete pedestal in SU 7A. Two of the 3 concrete samples had a SOF greater than unity—based on the ALARA DCGLs. Additionally, all 3 samples contained H-3 which does not have an ALARA DCGL.

For the IV surface activity measurements performed on the concrete pedestal in SU 7A, all alpha surface activity results were less than the 100 dpm/100 $cm^2$ surface activity limit. All removable gross alpha and gross beta activity results were less than the removable surface contamination limits. The beta-only surface activity values were assessed and presented in numerous ways with the assumptions noted in Section 6.4. ORISE suggests DOE/USACE staff's decisions regarding the IV measurements be made using the same fractional contributions for Sr-90 and Cs-137 as used for the FSS data assessment, if reasonable. Note that the surface activity measurement collected from Grid

G3 should not be included in the presence/absence data assessment as this location was judgmentally selected and not randomly selected.

Based on results of the independent verification activities, ORISE identified one issue that DOE/USACE should consider when evaluating the FSS data: the dose contribution from residual tritium and other radionuclides within the pedestal structure. All three IV volumetric samples collected from the pedestal exhibited elevated concentrations of tritium. Because there is no approved DCGL for tritium, evaluation of these data within specified DQOs of this survey is not possible. Additionally, two of the three volumetric concrete samples exhibited a SOF greater than 1, based on the ALARA cleanup goal. Moreover, one of the three volumetric concrete samples exhibited Sr-90 concentrations exceeding the residential cleanup goal. Discrete elevated areas of contamination exceeding the DCGL are typically evaluated with an elevated measurement comparison, however applicable area factors for all relevant radionuclides were not presented in the FSP.

ORISE did not identify any anomalous issues that would preclude the soil FSS data from demonstrating compliance with the release criterion.

# 8. REFERENCES

BNL 2009. *Remedial Design/Remedial Action Work Plan for the Decontamination and Dismantlement (D&D) of the Stack and Removal of HFBR Underground Utilities*. Brookhaven National Laboratory. Upton, New York; December 2009.

BSA 2009. *Final Record of Decision for Area of Concern 31, High Flux Beam Reactor*. Brookhaven Science Associates (BSA). Upton, NY. February.

DOE 2000. *Multi-Agency Radiation Site Survey and Investigation Manual (MARSSIM), Revision 1*. DOE/EH-0624, Rev. 1. U.S. Department of Energy. Washington, D.C. August 2000.

EPA 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process*. EPA QA/G-4. U.S. Environmental Protection Agency. Washington, D.C. February.

NRC 2020. *Minimum Detectable Concentrations with Typical Radiation Survey for Instruments for Various Contaminants and Field Conditions, Revision 1*. U.S. Nuclear Regulatory Commission. Washington, D.C. August.

OFJV 2020. *Final Field Sampling Plan, U.S. Department of Energy, High Flux Beam Reactor Stack (BLDG 705) Demolition and Decommissioning Area of Concern 31, Revision 1*. Olgoonik/FPM JV, LLC (OFJV). Oneida, NY. December.

OFJV 2021. Email from D. Ours, OFJV to N. Altic, ORISE. RE: BNL verification survey. Received July 21, 2021.

ORAU 2016. *ORAU Radiological and Environmental Survey Procedures Manual*. Oak Ridge Associated Universities. Oak Ridge, Tennessee. November 10.

ORAU 2020a. *ORAU Health and Safety Manual*. Oak Ridge Associated Universities. Oak Ridge, Tennessee. October 29.

ORAU 2020b. *ORAU Radiation Protection Manual*. Oak Ridge Associated Universities. Oak Ridge, Tennessee. November 17.

ORAU 2021a. *ORAU Environmental Services and Radiation Training Quality Program Manual*. Oak Ridge Associated Universities. Oak Ridge, Tennessee. July 28.

ORAU 2021b. *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual*. Oak Ridge Associated Universities. Oak Ridge, Tennessee. April 30.

ORISE 2021. *Project-Specific Plan for Independent Verification Survey Activities Associated with the Brookhaven National Laboratory High Flux Beam Reactor Stack, Upton, New York*. Oak Ridge Institute for Science and Education. Oak Ridge, Tennessee. August 3.

# APPENDIX A: FIGURES

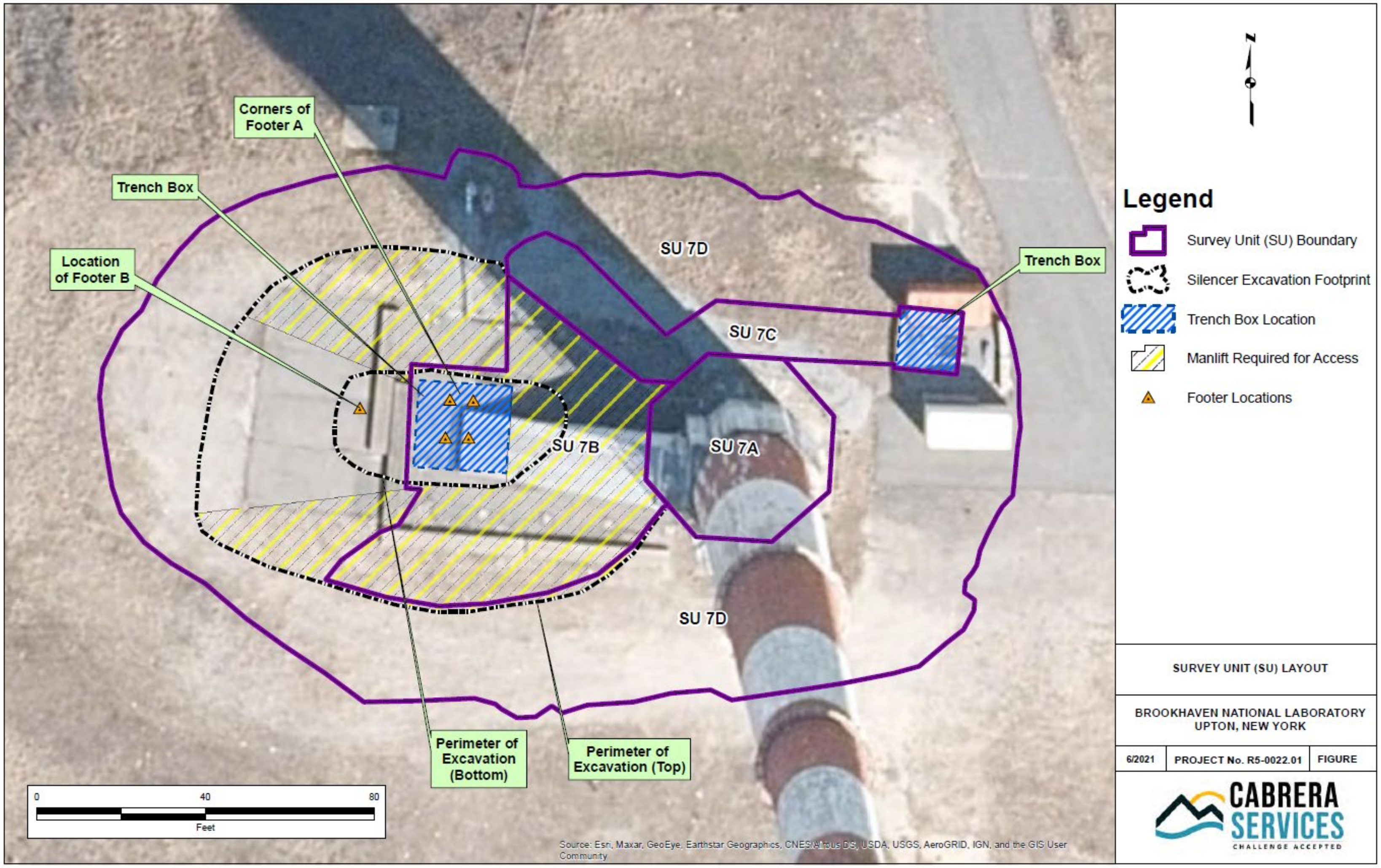


**Figure A.1. Survey Unit Layout for the HFBR Stack Demolition (OFJV 2021)**


**Figure A.2. Gamma Walkover Data for the Background Reference Area**

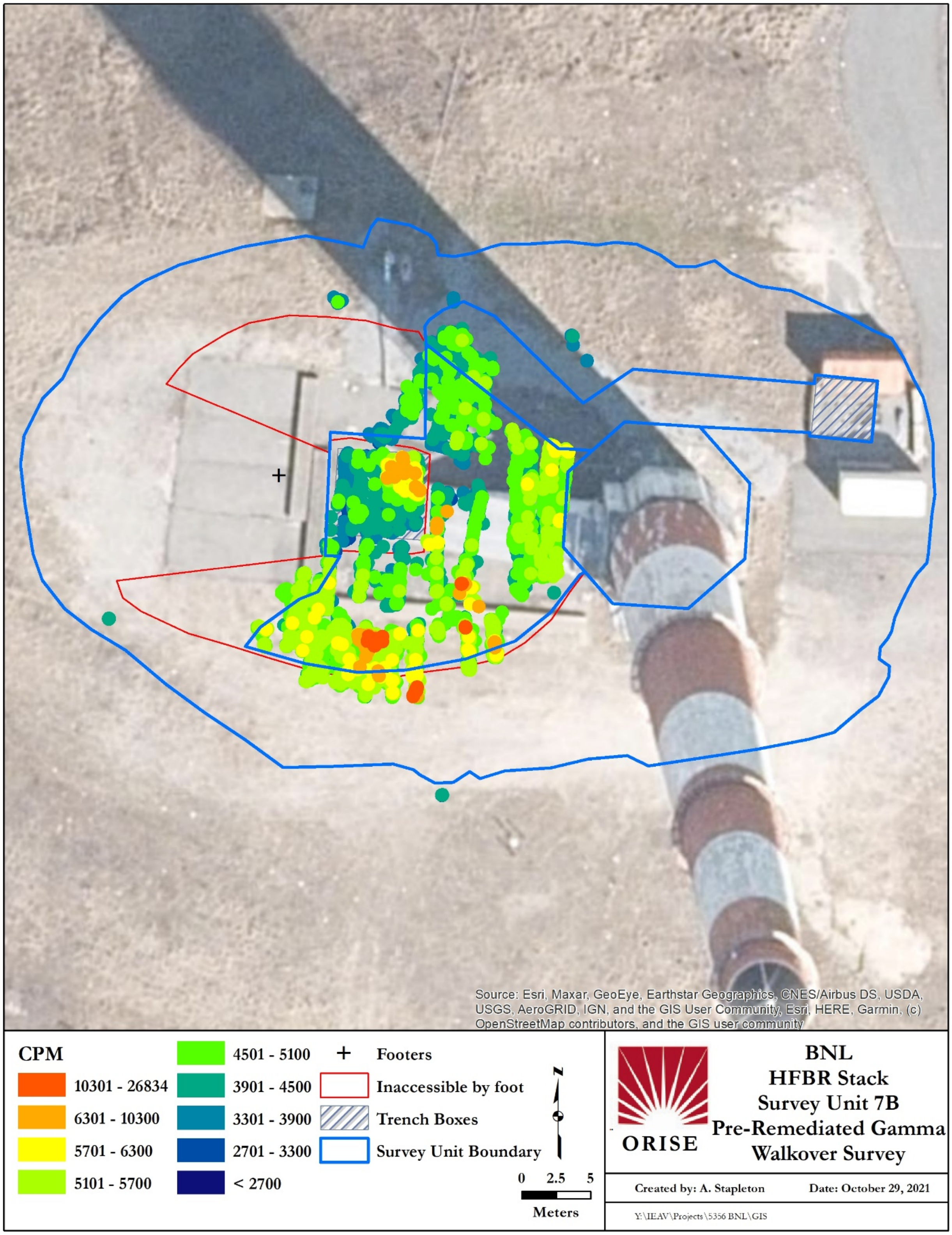


**Figure A.3. Gamma Walkover Data for Survey Unit 7B (Pre-Remediation)**

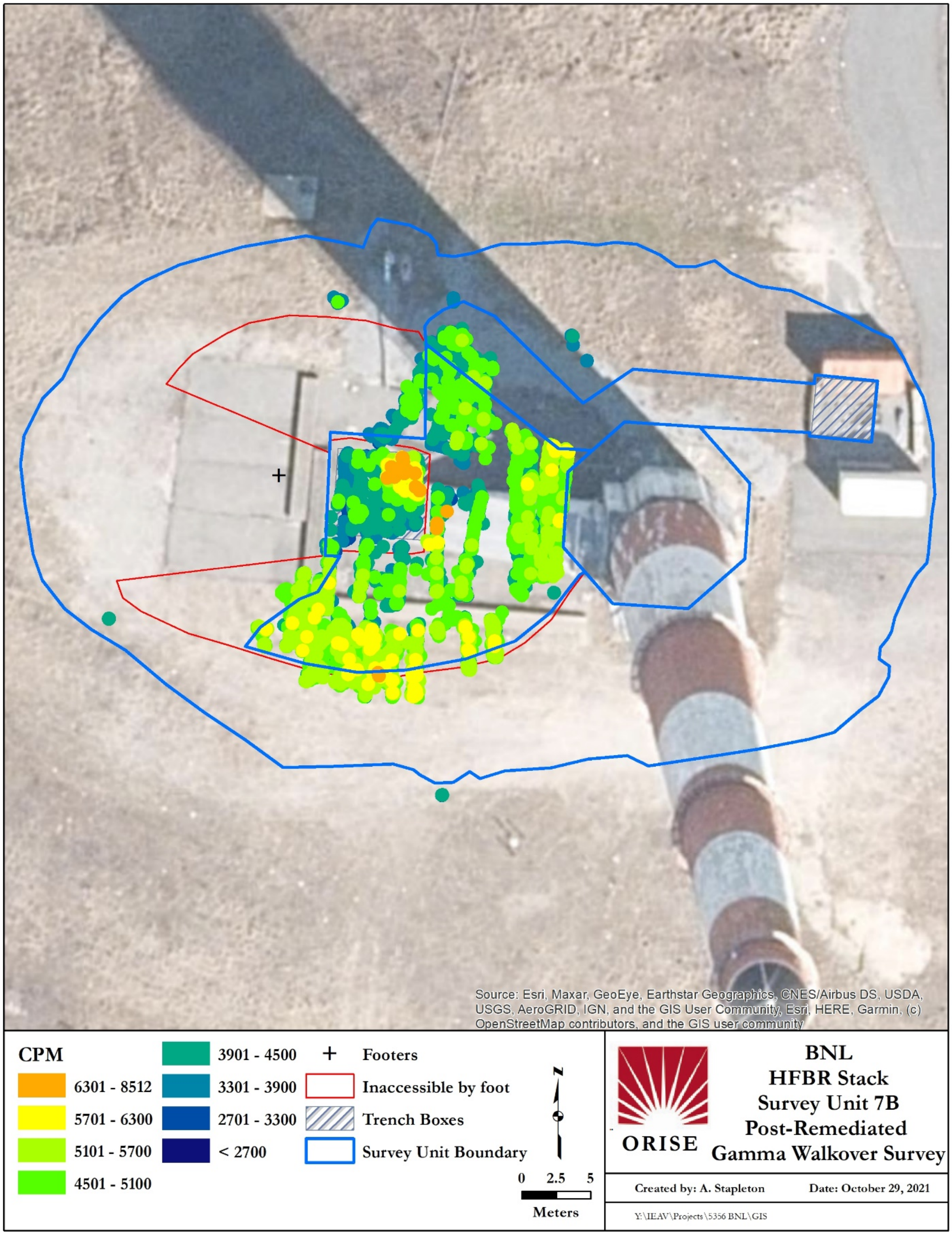


**Figure A.4. Gamma Walkover Data for Survey Unit 7B (Post-Remediation)**

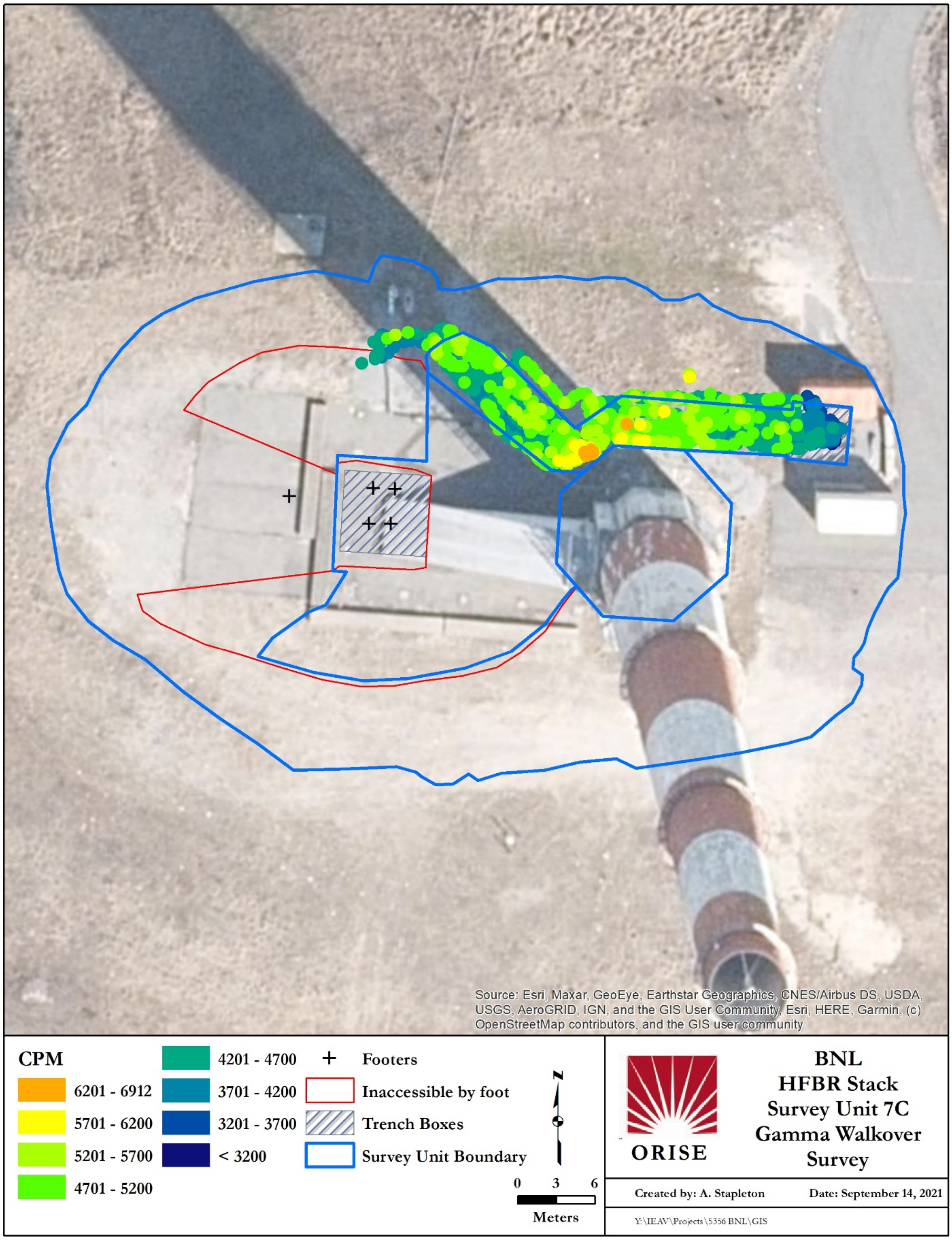


**Figure A.5. Gamma Walkover Data for Survey Unit 7C**


**Figure A.6. Gamma Walkover Data for Survey Unit 7D**

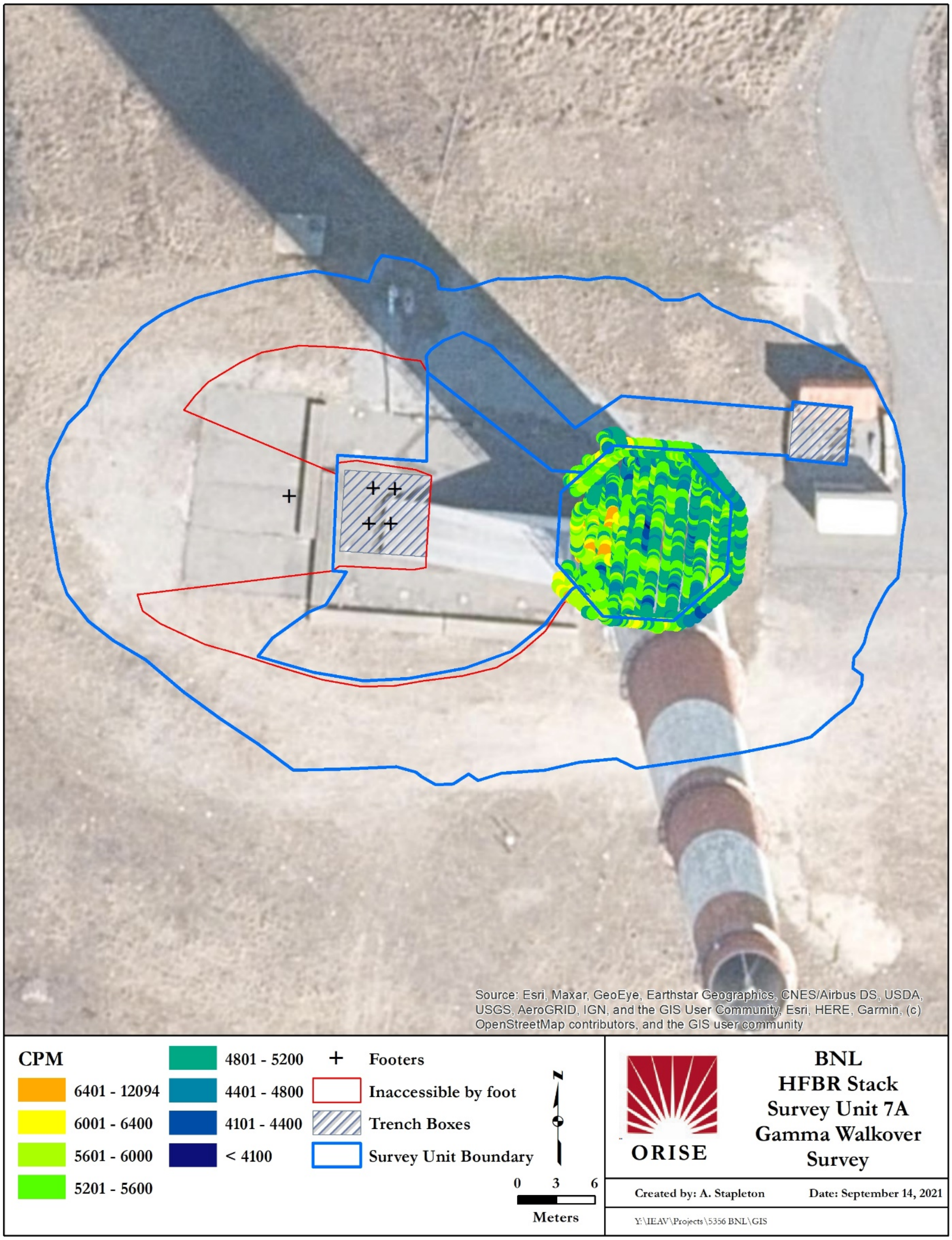


**Figure A.7. Gamma Walkover Data for Survey Unit 7A**

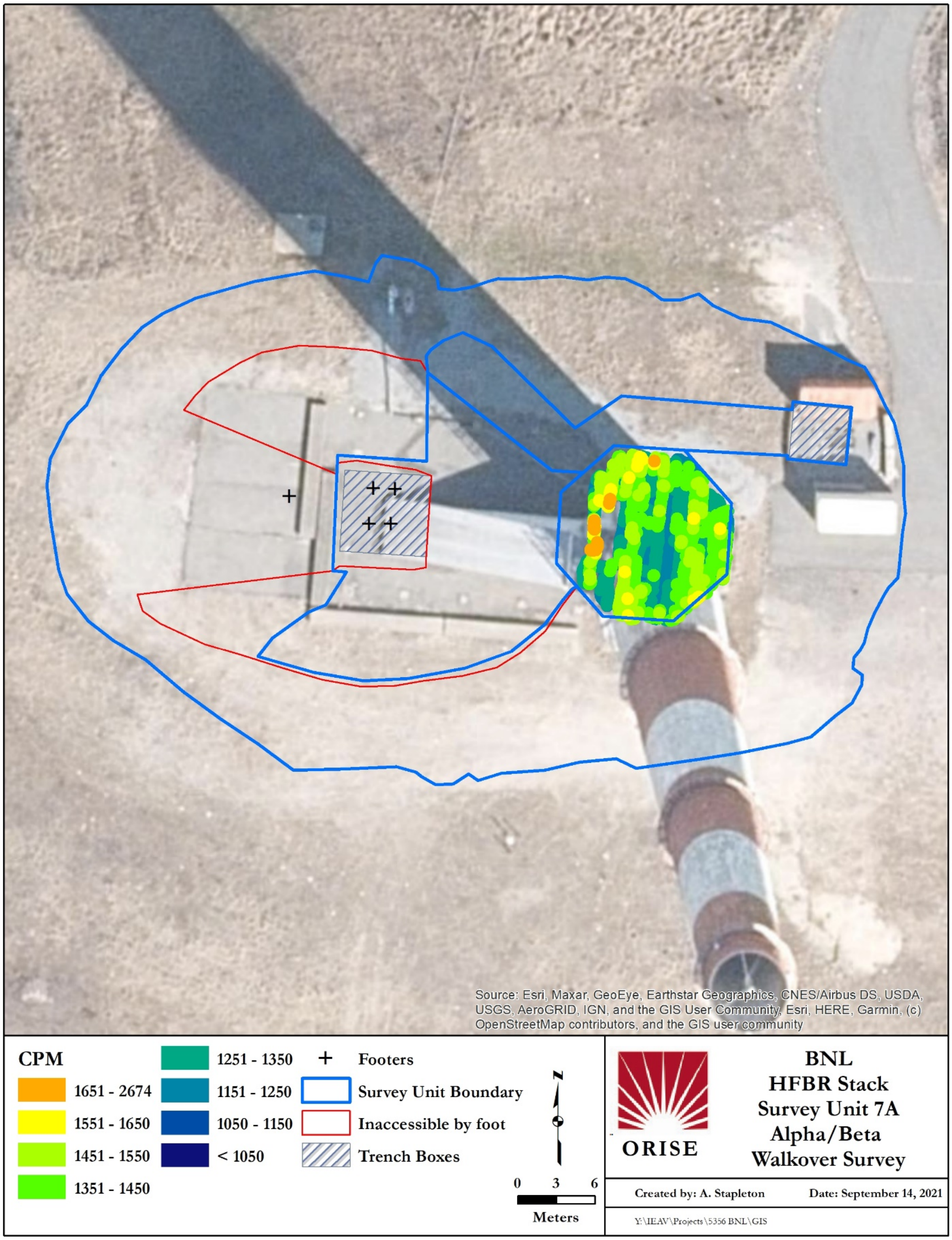


**Figure A.8. Alpha-plus-Beta Walkover Data for Survey Unit 7A**


**Figure A.9. Background Reference Area Soil Sample Locations**

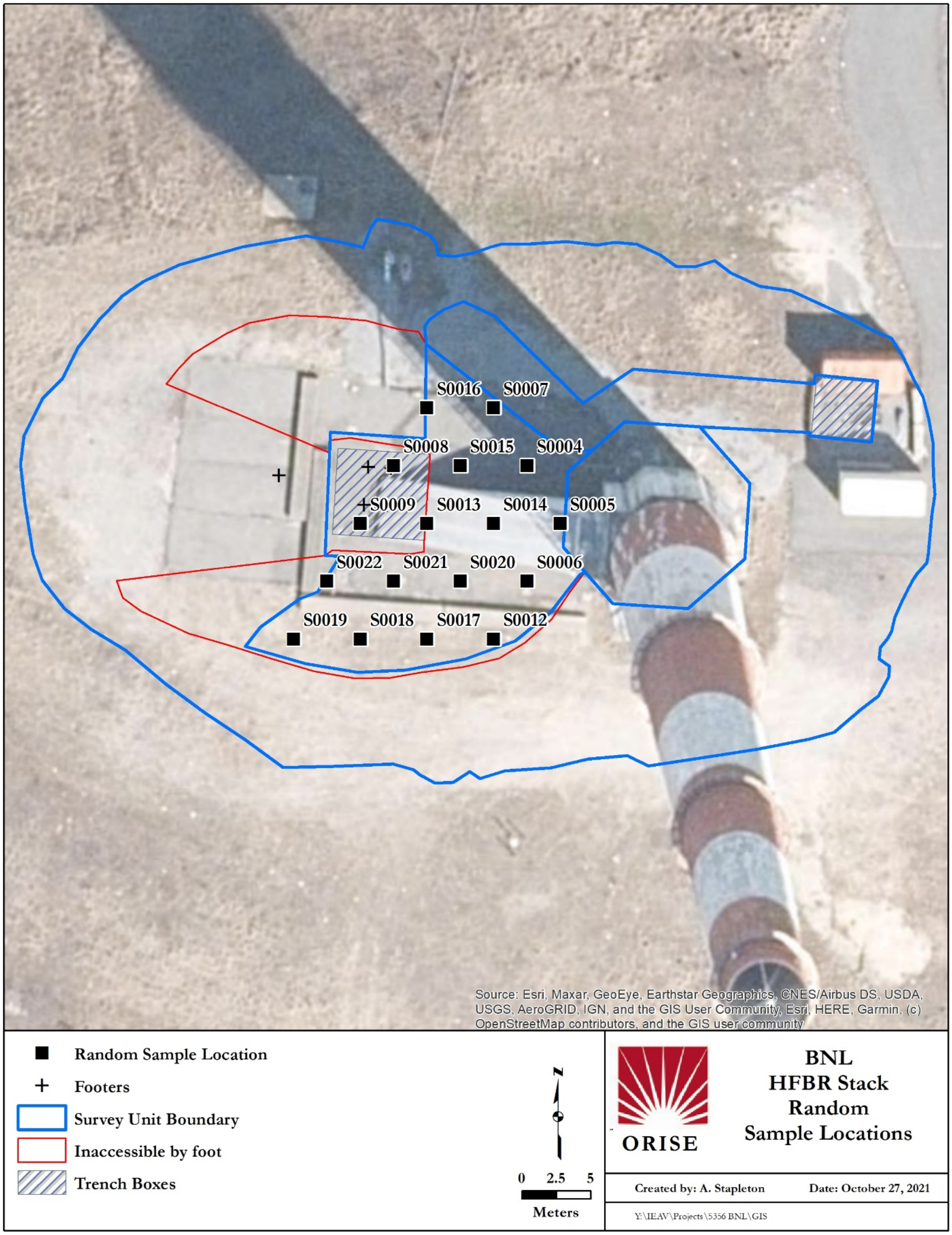


**Figure A.10. Random Soil Sample Locations for Survey Unit 7B**

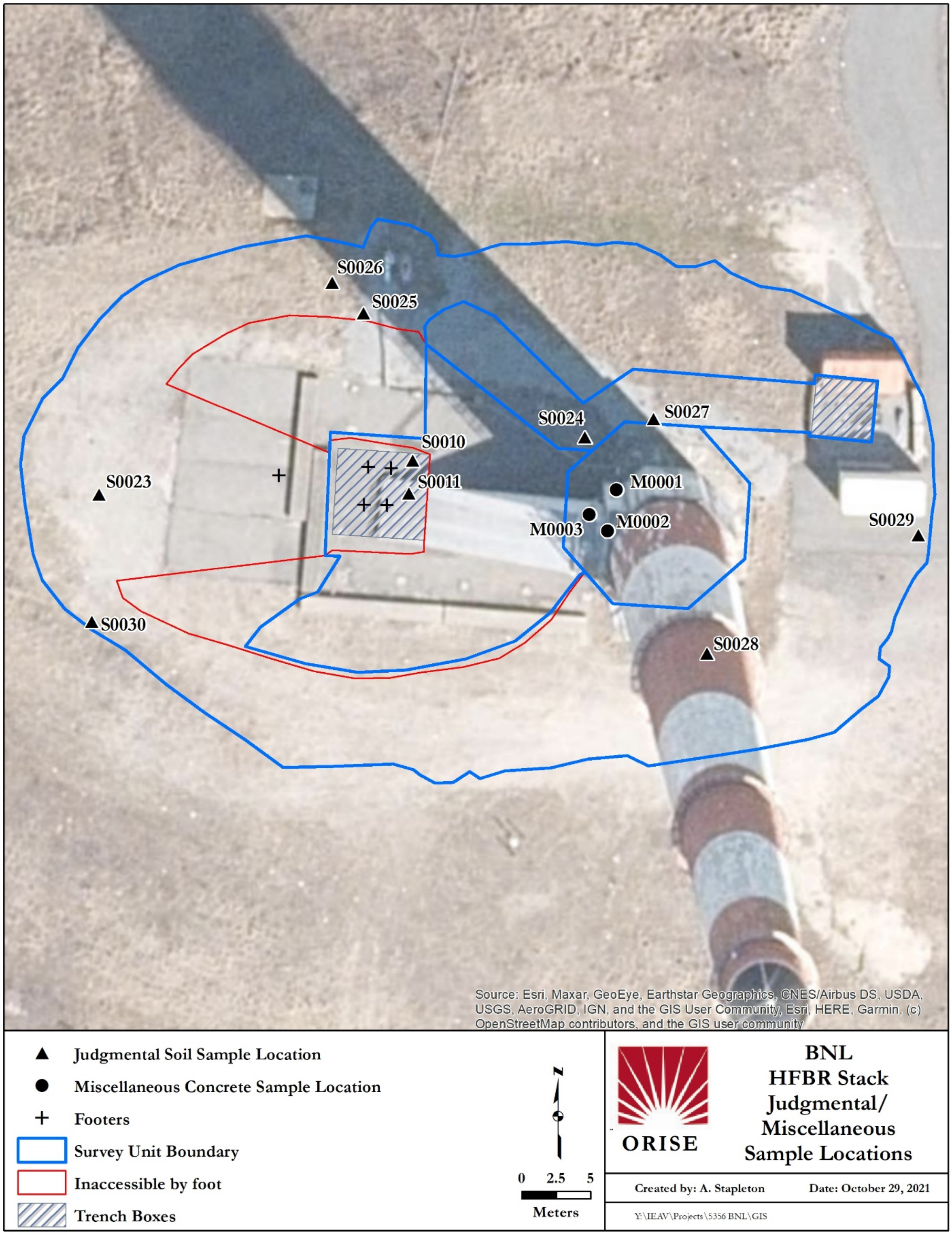


**Figure A.11. Judgmental Soil and Concrete Sample Locations**

# APPENDIX B: DATA TABLES

| Table B.1. Surface Soil Sample Locations and Gamma Measurements | | | | |
|---|---|---|---|---|
| Sample ID | Coordinates (m) | | Gamma Measurement (cpm) | |
| | Easting | Northing | Pre-Sample | Post-Sample |
| **Background Reference Area (Judgmental Samples)** | | | | |
| 5356S0001 | 397335 | 77655 | 7,200 | 8,100 |
| 5356S0002 | 397340 | 77658 | 6,800 | 7,500 |
| 5356S0003 | 397333 | 77671 | 7,400 | 8,300 |
| **Survey Unit 7B (Random Samples)** | | | | |
| 5356S0004 | 394746 | 78787 | 4,500 | 4,300 |
| 5356S0005 | 394748 | 78783 | 4,700 | 4,800 |
| 5356S0006 | 394746 | 78778 | 4,700 | 4,500 |
| 5356S0007 | 394743 | 78791 | 4,600 | 5,300 |
| 5356S0008 | 394736 | 78787 | 4,900 | 4,900 |
| 5356S0009 | 394733 | 78783 | 4,700 | 5,200 |
| 5356S0012 | 394743 | 78774 | 5,200 | 5,900 |
| 5356S0013 | 394738 | 78783 | 5,200 | 6,100 |
| 5356S0014 | 394743 | 78783 | 4,500 | 4,500 |
| 5356S0015 | 394741 | 78787 | 4,200 | 4,200 |
| 5356S0016 | 394738 | 78791 | 4,100 | 4,400 |
| 5356S0017 | 394738 | 78774 | 4,600 | 5,000 |
| 5356S0018 | 394733 | 78774 | 4,500 | 4,700 |
| 5356S0019 | 394729 | 78774 | 4,400 | 4,800 |
| 5356S0020 | 394741 | 78778 | 4,200 | 4,600 |
| 5356S0021 | 394736 | 78778 | 4,100 | 4,500 |
| 5356S0022 | 394731 | 78778 | 4,600 | 4,800 |
| **Survey Unit 7B (Judgmental Samples)** | | | | |
| 5356S0010 | 394737 | 78787 | 6,700 | 6,900 |
| 5356S0011 | 394737 | 78785 | 6,500 | 7,000 |
| **Survey Unit 7C (Judgmental Samples)** | | | | |
| 5356S0024 | 394751 | 78785 | 6,000 | 6,100 |
| 5356S0027 | 394755 | 78789 | 6,400 | 6,500 |
| **Survey Unit 7D (Judgmental Samples)** | | | | |
| 5356S0023 | 394714 | 78785 | 6,300 | 7,200 |
| 5356S0025 | 394734 | 78798 | 4,800 | 5,100 |
| 5356S0026 | 394731 | 78800 | 6,500 | 7,500 |
| 5356S0028 | 394759 | 78773 | 5,400 | 5,300 |
| 5356S0029 | 394774 | 78782 | 6,400 | 6,400 |
| 5356S0030 | 394714 | 78774 | 6,100 | 6,700 |

| Table B.2. Surface Concrete Sample Locations and Gamma Measurements in SU 7A | | | | |
|---|---|---|---|---|
| Sample ID | Coordinates (m) | | Gamma Measurement (cpm) | |
| | Easting | Northing | Pre-Sample | Post-Sample |
| 5356M0001 | 394752 | 78785 | 9,700 | 10,000 |
| 5356M0002 | 394751 | 78782 | 7,000 | 6,800 |
| 5356M0003 | 394750 | 78783 | 8,700 | 7,100 |

**Table B.3. Verification Surface Soil Sample Concentrations**

| Sample ID | Cs-137 (pCi/g) | | | Sr-90 (pCi/g) | | | Ra-226 (pCi/g) | | | Eu-152 (pCi/g) | | | Eu-154 (pCi/g) | | | U-235 (pCi/g) | | | U-238 (pCi/g) | | | Am-241 (pCi/g) | | | Co-60 (pCi/g) | | | H-3 (pCi/g) | | | Ni-63 (pCi/g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conc.[a] | TPU[b] | MDC[c] | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | SOF |
| **Background Reference Area (Judgmental Samples)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5356S0001 | **0.191** | 0.026 | 0.033 | -0.09 | 0.15 | 0.30 | **0.610** | 0.062 | 0.075 | -0.029 | 0.043 | 0.093 | -0.015 | 0.053 | 0.166 | 0.086 | 0.092 | 0.220 | **0.750** | 0.360 | 0.730 | -0.054 | 0.032 | 0.075 | -0.003 | 0.018 | 0.038 | -- | -- | -- | -- | -- | -- | 0.47 |
| 5356S0002 | **0.184** | 0.029 | 0.035 | 0.08 | 0.18 | 0.32 | **0.545** | 0.099 | 0.070 | -0.008 | 0.035 | 0.082 | -0.021 | 0.031 | 0.118 | 0.004 | 0.096 | 0.225 | 0.09 | 0.53 | 1.27 | -0.010 | 0.062 | 0.154 | -0.008 | 0.014 | 0.026 | -- | -- | -- | -- | -- | -- | 0.22 |
| 5356S0003 | **0.118** | 0.023 | 0.041 | -0.06 | 0.16 | 0.31 | **0.652** | 0.060 | 0.075 | -0.005 | 0.039 | 0.085 | -0.005 | 0.041 | 0.169 | 0.051 | 0.090 | 0.213 | 0.79 | 0.41 | 0.86 | -0.022 | 0.031 | 0.088 | 0.002 | 0.016 | 0.033 | -- | -- | -- | -- | -- | -- | 0.48 |
| **Survey Unit 7B (Random Samples)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5356S0004 | -0.001 | 0.013 | 0.029 | -0.04 | 0.17 | 0.32 | **0.174** | 0.032 | 0.051 | -0.023 | 0.029 | 0.062 | -0.039 | 0.054 | 0.120 | 0.004 | 0.061 | 0.143 | 0.25 | 0.14 | 0.47 | -0.002 | 0.013 | 0.048 | -0.005 | 0.012 | 0.034 | -- | -- | -- | -- | -- | -- | 0.13 |
| 5356S0005 | **0.038** | 0.014 | 0.026 | 0.11 | 0.20 | 0.34 | **0.195** | 0.046 | 0.062 | -0.005 | 0.027 | 0.064 | -0.073 | 0.045 | 0.085 | -0.062 | 0.072 | 0.162 | 0.27 | 0.38 | 0.90 | -0.021 | 0.044 | 0.106 | 0.004 | 0.012 | 0.028 | -- | -- | -- | -- | -- | -- | 0.16 |
| 5356S0006 | 0.015 | 0.010 | 0.022 | 0.00 | 0.20 | 0.37 | **0.212** | 0.030 | 0.047 | 0.002 | 0.024 | 0.055 | -0.024 | 0.037 | 0.104 | 0.001 | 0.055 | 0.133 | 0.31 | 0.24 | 0.54 | -0.020 | 0.019 | 0.054 | -0.002 | 0.012 | 0.023 | -- | -- | -- | -- | -- | -- | 0.17 |
| 5356S0007 | 0.016 | 0.013 | 0.029 | 0.03 | 0.20 | 0.35 | **0.226** | 0.036 | 0.057 | 0.017 | 0.029 | 0.070 | -0.091 | 0.078 | 0.145 | -0.029 | 0.063 | 0.146 | 0.09 | 0.21 | 0.51 | 0.005 | 0.021 | 0.052 | 0.000 | 0.010 | 0.031 | -- | -- | -- | -- | -- | -- | 0.10 |
| 5356S0008 | **0.124** | 0.019 | 0.022 | 0.10 | 0.18 | 0.31 | **0.339** | 0.065 | 0.058 | 0.010 | 0.029 | 0.071 | -0.032 | 0.033 | 0.106 | -0.017 | 0.077 | 0.178 | 0.54 | 0.45 | 1.11 | -0.009 | 0.050 | 0.123 | -0.002 | 0.013 | 0.026 | -- | -- | -- | -- | -- | -- | 0.30 |
| 5356S0009 | **0.095** | 0.016 | 0.021 | 0.02 | 0.18 | 0.33 | **0.310** | 0.061 | 0.057 | 0.001 | 0.028 | 0.067 | -0.041 | 0.039 | 0.094 | 0.026 | 0.076 | 0.179 | 0.33 | 0.43 | 1.00 | -0.002 | 0.049 | 0.121 | 0.0012 | 0.0075 | 0.0253 | -- | -- | -- | -- | -- | -- | 0.22 |
| 5356S0012 | **0.808** | 0.067 | 0.025 | 0.09 | 0.28 | 0.49 | **0.238** | 0.038 | 0.059 | 0.013 | 0.037 | 0.084 | -0.014 | 0.044 | 0.134 | -0.008 | 0.057 | 0.139 | 0.27 | 0.23 | 0.51 | -0.024 | 0.022 | 0.053 | 0.000 | 0.014 | 0.031 | -- | -- | -- | -- | -- | -- | 0.22 |
| 5356S0013 | **0.531** | 0.059 | 0.027 | -0.09 | 0.25 | 0.47 | **0.232** | 0.050 | 0.059 | 0.002 | 0.031 | 0.074 | -0.079 | 0.059 | 0.111 | 0.078 | 0.078 | 0.188 | 0.59 | 0.43 | 0.94 | -0.027 | 0.047 | 0.114 | 0.002 | 0.012 | 0.025 | -- | -- | -- | -- | -- | -- | 0.32 |
| 5356S0014 | **0.052** | 0.016 | 0.029 | -0.14 | 0.26 | 0.49 | **0.191** | 0.028 | 0.043 | 0.012 | 0.029 | 0.068 | -0.075 | 0.051 | 0.113 | 0.013 | 0.056 | 0.133 | 0.18 | 0.20 | 0.47 | -0.009 | 0.020 | 0.049 | -0.002 | 0.015 | 0.029 | -- | -- | -- | -- | -- | -- | 0.12 |
| 5356S0015 | -0.0061 | 0.0073 | 0.0250 | 0.12 | 0.27 | 0.48 | **0.267** | 0.055 | 0.059 | 0.039 | 0.031 | 0.077 | 0.023 | 0.034 | 0.109 | -0.027 | 0.076 | 0.175 | 0.01 | 0.41 | 1.00 | -0.020 | 0.048 | 0.118 | 0.000 | 0.012 | 0.026 | -- | -- | -- | -- | -- | -- | 0.10 |
| 5356S0016 | -0.005 | 0.012 | 0.031 | -0.04 | 0.26 | 0.47 | **0.233** | 0.040 | 0.063 | -0.014 | 0.033 | 0.073 | -0.017 | 0.054 | 0.132 | 0.052 | 0.063 | 0.147 | 0.36 | 0.26 | 0.56 | -0.034 | 0.024 | 0.056 | -0.004 | 0.017 | 0.034 | -- | -- | -- | -- | -- | -- | 0.20 |
| 5356S0017 | **0.438** | 0.050 | 0.021 | 0.06 | 0.28 | 0.49 | **0.269** | 0.057 | 0.065 | -0.001 | 0.029 | 0.069 | -0.013 | 0.031 | 0.112 | -0.019 | 0.080 | 0.185 | 0.29 | 0.43 | 1.02 | -0.031 | 0.048 | 0.117 | 0.0098 | 0.0099 | 0.0251 | -- | -- | -- | -- | -- | -- | 0.21 |
| 5356S0018 | **0.059** | 0.013 | 0.026 | -0.07 | 0.22 | 0.40 | **0.295** | 0.039 | 0.053 | 0.005 | 0.033 | 0.075 | 0.021 | 0.039 | 0.130 | -0.004 | 0.066 | 0.155 | 0.50 | 0.28 | 0.59 | -0.013 | 0.024 | 0.058 | -0.006 | 0.018 | 0.035 | -- | -- | -- | -- | -- | -- | 0.25 |
| 5356S0019 | **0.078** | 0.020 | 0.036 | 0.03 | 0.21 | 0.38 | **0.329** | 0.065 | 0.063 | -0.013 | 0.030 | 0.070 | 0.009 | 0.031 | 0.116 | 0.018 | 0.082 | 0.193 | 0.37 | 0.45 | 1.04 | -0.031 | 0.044 | 0.121 | -0.004 | 0.011 | 0.022 | -- | -- | -- | -- | -- | -- | 0.23 |
| 5356S0020 | **0.215** | 0.029 | 0.033 | -0.14 | 0.23 | 0.45 | **0.199** | 0.034 | 0.054 | 0.005 | 0.030 | 0.070 | -0.063 | 0.053 | 0.116 | 0.006 | 0.056 | 0.145 | 0.24 | 0.24 | 0.54 | -0.017 | 0.022 | 0.052 | -0.002 | 0.013 | 0.027 | -- | -- | -- | -- | -- | -- | 0.15 |
| 5356S0021 | -0.0012 | 0.0092 | 0.0233 | -0.03 | 0.24 | 0.45 | **0.206** | 0.047 | 0.058 | -0.011 | 0.028 | 0.065 | -0.026 | 0.041 | 0.112 | -0.024 | 0.073 | 0.169 | 0.19 | 0.41 | 0.97 | -0.020 | 0.047 | 0.113 | -0.008 | 0.013 | 0.024 | -- | -- | -- | -- | -- | -- | 0.12 |
| 5356S0022 | **0.446** | 0.045 | 0.032 | 0.27 | 0.24 | 0.40 | **0.330** | 0.051 | 0.085 | -0.022 | 0.039 | 0.085 | -0.094 | 0.089 | 0.165 | 0.031 | 0.074 | 0.176 | 0.46 | 0.28 | 0.59 | -0.031 | 0.026 | 0.061 | -0.013 | 0.018 | 0.031 | -- | -- | -- | -- | -- | -- | 0.32 |
| **Survey Unit 7B (Judgmental Samples)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5356S0010 | **0.411** | 0.046 | 0.053 | 0.17 | 0.19 | 0.32 | **0.732** | 0.072 | 0.087 | -0.002 | 0.049 | 0.110 | -0.027 | 0.067 | 0.189 | 0.07 | 0.10 | 0.24 | **0.83** | 0.39 | 0.80 | -0.024 | 0.035 | 0.084 | 0.010 | 0.018 | 0.041 | -0.3 | 1.4 | 2.4 | 0.80 | 0.79 | 1.32 | 0.56 |
| 5356S0011 | **0.529** | 0.048 | 0.040 | 0.06 | 0.18 | 0.31 | **0.663** | 0.058 | 0.073 | -0.022 | 0.039 | 0.085 | -0.023 | 0.042 | 0.142 | 0.058 | 0.083 | 0.196 | 0.64 | 0.37 | 0.80 | -0.010 | 0.030 | 0.082 | 0.009 | 0.015 | 0.032 | -- | -- | -- | -- | -- | -- | 0.47 |
| **Survey Unit 7C (Judgmental Samples)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5356S0024 | **0.270** | 0.035 | 0.030 | 0.04 | 0.30 | 0.53 | **0.285** | 0.058 | 0.062 | 0.035 | 0.030 | 0.074 | 0.023 | 0.030 | 0.100 | 0.015 | 0.059 | 0.143 | 0.44 | 0.44 | 1.00 | -0.035 | 0.044 | 0.118 | 0.004 | 0.011 | 0.025 | 0.4 | 1.1 | 1.8 | 0.86 | 0.70 | 1.16 | 0.26 |
| 5356S0027 | 0.0021 | 0.0099 | 0.0247 | -0.08 | 0.30 | 0.56 | **0.250** | 0.037 | 0.055 | -0.024 | 0.033 | 0.069 | -0.027 | 0.044 | 0.124 | 0.067 | 0.063 | 0.155 | 0.36 | 0.23 | 0.51 | -0.022 | 0.019 | 0.051 | 0.010 | 0.015 | 0.034 | -0.06 | 0.91 | 1.60 | 0.59 | 0.63 | 1.05 | 0.21 |
| **Survey Unit 7D (Judgmental Samples)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5356S0023 | **0.0281** | 0.0096 | 0.0260 | -0.06 | 0.28 | 0.53 | **0.479** | 0.052 | 0.067 | 0.027 | 0.039 | 0.091 | -0.202 | 0.094 | 0.151 | -0.086 | 0.082 | 0.186 | **0.73** | 0.33 | 0.65 | -0.043 | 0.029 | 0.067 | -0.001 | 0.019 | 0.040 | -- | -- | -- | -- | -- | -- | 0.38 |
| 5356S0025 | 0.003 | 0.015 | 0.032 | -0.10 | 0.27 | 0.50 | **0.271** | 0.039 | 0.055 | 0.014 | 0.030 | 0.071 | -0.019 | 0.029 | 0.135 | 0.119 | 0.062 | 0.139 | 0.21 | 0.23 | 0.54 | -0.006 | 0.023 | 0.056 | -0.006 | 0.018 | 0.033 | -- | -- | -- | -- | -- | -- | 0.19 |
| 5356S0026 | -0.019 | 0.013 | 0.026 | 0.11 | 0.30 | 0.53 | **0.428** | 0.077 | 0.054 | 0.018 | 0.032 | 0.078 | -0.029 | 0.047 | 0.127 | -0.022 | 0.084 | 0.195 | 0.43 | 0.51 | 1.19 | -0.033 | 0.053 | 0.130 | -0.001 | 0.012 | 0.024 | -0.6 | 1.1 | 1.9 | 0.90 | 0.76 | 1.26 | 0.28 |
| 5356S0028 | **0.316** | 0.039 | 0.028 | 0.15 | 0.27 | 0.46 | **0.296** | 0.059 | 0.058 | 0.005 | 0.029 | 0.069 | 0.019 | 0.026 | 0.099 | 0.117 | 0.075 | 0.184 | 0.15 | 0.40 | 0.95 | 0.003 | 0.046 | 0.115 | -0.005 | 0.013 | 0.026 | -- | -- | -- | -- | -- | -- | 0.21 |
| 5356S0029 | 0.022 | 0.016 | 0.037 | 0.05 | 0.27 | 0.48 | **0.490** | 0.050 | 0.063 | -0.014 | 0.037 | 0.081 | -0.015 | 0.051 | 0.161 | 0.087 | 0.075 | 0.180 | 0.41 | 0.25 | 0.55 | -0.019 | 0.024 | 0.058 | 0.000 | 0.018 | 0.037 | -0.1 | 1.5 | 2.6 | 0.53 | 0.77 | 1.30 | 0.32 |
| 5356S0030 | **0.308** | 0.039 | 0.033 | 0.03 | 0.27 | 0.49 | **0.375** | 0.072 | 0.065 | -0.015 | 0.034 | 0.079 | -0.052 | 0.043 | 0.109 | 0.053 | 0.086 | 0.205 | 0.54 | 0.49 | 1.12 | -0.052 | 0.054 | 0.129 | 0.000 | 0.013 | 0.027 | -- | -- | -- | -- | -- | -- | 0.33 |

[a] Results greater than MDC are bolded.

[b] Uncertainties are based on total propagated uncertainties at the 95% confidence level.

[c] MDC = minimum detectable concentration.

**Table B.4. Verification Surface Concrete Sample Concentrations in SU 7A**

| Sample ID | Cs-137 (pCi/g) | | | Sr-90 (pCi/g) | | | Ra-226 (pCi/g) | | | Eu-152 (pCi/g) | | | Eu-154 (pCi/g) | | | U-235 (pCi/g) | | | U-238 (pCi/g) | | | Am-241 (pCi/g) | | | Co-60 (pCi/g) | | | H-3 (pCi/g) | | | Ni-63 (pCi/g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conc.[a] | TPU[b] | MDC[c] | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | SOF |
| 5356M0001 | **4.39** | 0.36 | 0.04 | **5.10** | 0.57 | 0.46 | **0.511** | 0.062 | 0.103 | 0.031 | 0.06 | 0.135 | 0.006 | 0.062 | 0.165 | 0.080 | 0.096 | 0.229 | 0.48 | 0.31 | 0.67 | -0.045 | 0.030 | 0.070 | 0.006 | 0.017 | 0.038 | **155.6** | 7.4 | 2.9 | 0.7 | 1.2 | 2.0 | **1.14** |
| 5356M0002 | 0.004 | 0.015 | 0.035 | 0.04 | 0.26 | 0.46 | **0.493** | 0.056 | 0.077 | 0.007 | 0.037 | 0.089 | 0.007 | 0.041 | 0.134 | 0.002 | 0.071 | 0.224 | 0.60 | 0.52 | 1.18 | -0.022 | 0.044 | 0.118 | -0.004 | 0.017 | 0.034 | **69.9** | 4.2 | 2.7 | 1.2 | 1.1 | 1.9 | 0.35 |
| 5356M0003 | **17.9** | 1.9 | 0.1 | **32.7** | 1.6 | 0.5 | **0.379** | 0.099 | 0.212 | -0.08 | 0.12 | 0.27 | -0.046 | 0.068 | 0.194 | 0.03 | 0.18 | 0.42 | 0.38 | 0.55 | 1.37 | -0.027 | 0.058 | 0.141 | -0.010 | 0.021 | 0.040 | **59.5** | 3.9 | 2.8 | 0.5 | 1.1 | 1.9 | **4.71** |

[a] Results greater than MDC are bolded.

[b] Uncertainties are based on total propagated uncertainties at the 95% confidence level.

[c] MDC = minimum detectable concentration.

| Table B.5. Concrete Pedestal Direct Measurement Locations and Surface Activity Levels | | | | | |
|---|---|---|---|---|---|
| Grid ID | Total Alpha Activity | Total Beta Activity (assuming all activity is from Cs-137) | Total Beta Activity (assuming all activity is from Sr-90) | Removable Activity[a] | |
| | | | | Alpha | Beta |
| | dpm/100 cm² | dpm/100 cm² | dpm/100 cm² | dpm/100 cm² | |
| L1 | 14 | -290 | -140 | -1 | 4 |
| L9 | 14 | -300 | -140 | -1 | 2 |
| H9 | 14 | -190 | -89 | 4 | 0 |
| I14 | 51 | -370 | -170 | -1 | 1 |
| O6 | 29 | -150 | -70 | -1 | 0 |
| G4 | 36 | 690 | 320 | 2 | 2 |
| J7 | 29 | 150 | 70 | -1 | 3 |
| J13 | 14 | 230 | 110 | -1 | 2 |
| B11 | 51 | 42 | 19 | -1 | -2 |
| E16 | 51 | -270 | -120 | -1 | -2 |
| N6 | 7 | 220 | 100 | -1 | 1 |
| O11 | 43 | -110 | -50 | -1 | 3 |
| G9 | 22 | 350 | 160 | 2 | -2 |
| K7 | 22 | -300 | -140 | -1 | 0 |
| J12 | 22 | -280 | -130 | -1 | 3 |
| F10 | 29 | -370 | -170 | -1 | -4 |
| G13 | 22 | 460 | 140 | 4 | 0 |
| O7 | 51 | -92 | -43 | -1 | 1 |
| K1 | 43 | -50 | -23 | -1 | 3 |
| M4 | 58 | -330 | -150 | -1 | 0 |
| B12 | 72 | -25 | -12 | -1 | -2 |
| G5 | 14 | 950 | 440 | -1 | -2 |
| M13 | 29 | 230 | 100 | -1 | 1 |
| C6 | 29 | 17 | 8 | -1 | 1 |
| L14 | 14 | -230 | -100 | -1 | -4 |
| C9 | 51 | -92 | -43 | -1 | 4 |
| L5 | 29 | -75 | -35 | 2 | -3 |
| F8 | 7 | -110 | -50 | -1 | 2 |
| E11 | 14 | 200 | 93 | 2 | 4 |
| C8 | 36 | -190 | -89 | -1 | 0 |
| P8 | 0 | -230 | -100 | -1 | 2 |
| F16 | 22 | -330 | -150 | -1 | 1 |
| L11 | 43 | 33 | 15 | -1 | 0 |
| K5 | 14 | -58 | -27 | -1 | 0 |
| H7 | 36 | 25 | 12 | -1 | 0 |
| O8 | 43 | -420 | -190 | -1 | 1 |
| E7 | 29 | 58 | 27 | -1 | 1 |

| Table B.5. Concrete Pedestal Direct Measurement Locations and Surface Activity Levels | | | | | |
|---|---|---|---|---|---|
| Grid ID | Total Alpha Activity | Total Beta Activity (assuming all activity is from Cs-137) | Total Beta Activity (assuming all activity is from Sr-90) | Removable Activity[a] | |
| | | | | Alpha | Beta |
| | dpm/100 cm² | dpm/100 cm² | dpm/100 cm² | dpm/100 cm² | |
| I4 | 29 | 5,100 | 2,300 | -1 | 4 |
| P9 | 36 | -530 | -240 | 2 | -3 |
| F12 | 22 | -490 | -230 | -1 | 0 |
| H5 | 29 | 1,100 | 510 | 2 | 4 |
| L4 | 22 | 130 | 62 | -1 | 2 |
| C7 | 58 | -120 | -54 | -1 | -2 |
| G14 | 14 | 280 | 130 | 2 | 0 |
| H15 | 22 | 120 | 54 | 4 | 7 |
| I3 | 14 | 210 | 97 | -1 | -4 |
| L6 | 22 | -310 | -140 | -1 | -2 |
| E5 | 14 | -120 | -54 | -1 | 1 |
| G16 | 22 | -340 | -160 | -1 | -2 |
| H14 | 43 | -170 | -77 | -1 | 2 |
| D13 | 14 | 380 | 170 | 2 | 6 |
| D5 | 14 | 92 | 43 | -1 | -2 |
| B9 | 7 | -580 | -270 | -1 | -2 |
| J8 | 36 | -460 | -210 | -1 | -2 |
| E6 | 29 | -25 | -12 | -1 | 1 |
| I13 | 14 | -84 | -39 | -1 | -2 |
| **Minimum** | 0 | -580 | -270 | -1 | -4 |
| **Maximum** | 72 | 5,100 | 2,300 | 4 | 7 |
| G3[b] | 22 | 9,100 | 4,200 | -1 | 7 |

[a]Results greater than the analytical minimum detectable activity are bolded (none).
[b]Judgmental measurement location.

| Table B.6. IV Gamma Measurements in SU 7A Pedestal Piping | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| West Pipe "A" | | | Middle Pipe "B" | | | East Pipe "C" | | |
| Loc.[a] | CsI Gross Count (cpm) | NaI Gross Count (cpm) | Loc. | CsI Gross Count (cpm) | NaI Gross Count (cpm) | Loc. | CsI Gross Count (cpm) | NaI Gross Count (cpm) |
| 0 | 481 | 4,336 | 0 | 463 | 3,377 | 0 | 356 | 2,909 |
| 1 | 475 | | 1 | 364 | 3,746 | 1 | 356 | 3,481 |
| 2 | 461 | | 2 | 430 | 4,820 | 2 | 555 | 4,979 |
| 3 | 539 | | 3 | 490 | 5,237 | 3 | 508 | 4,838 |
| 4 | 596 | | 5 | 538 | 5,117 | 4 | 513 | 4,951 |
| 5 | 586 | | 6 | 498 | | 5 | 545 | 4,911 |
| 6 | 641 | | 7 | 532 | | 6 | 495 | 4,745 |
| 7 | 663 | | 8 | 541 | | 7 | 492 | 5,031 |
| 8 | 619 | | 10 | 539 | | 8 | 511 | 4,780 |
| 9 | 794 | | 11 | 523 | | 9 | 558 | 4,985 |
| 10 | 652 | | 12 | 619 | | 10 | 483 | 4,996 |
| 11 | 716 | | 13 | 494 | | 11 | 503 | 4,701 |
| 12 | 707 | | 15 | 632 | | 12 | 499 | |
| 13 | 653 | | 16 | 526 | | 13 | 523 | |
| 14 | 591 | | 17 | 474 | | 14 | 532 | |
| 15 | 657 | | 18 | 453 | | 15 | 516 | |
| 16 | 627 | | 20 | 443 | 3,948 | 16 | 529 | |
| 17 | 653 | | 21 | 441 | 3,800 | 17 | 490 | |
| 18 | 638 | | | | | 18 | 521 | |
| 19 | 634 | | | | | 19 | 430 | |
| 20 | 675 | | | | | 20 | 478 | |
| 21 | 699 | | | | | 21 | 470 | |
| 22 | 1,033 | | | | | 22 | 474 | |
| 23 | 1,359 | | | | | 23 | 490 | |
| 24 | 2,543 | | | | | 24 | 454 | |
| 25 | 1,859 | 25,085 | | | | 25 | 519 | |
| | | | | | | 26 | 427 | |
| | | | | | | 27 | 443 | |
| | | | | | | 28 | 442 | |
| | | | | | | 29 | 441 | |
| | | | | | | 30 | 361 | |
| | | | | | | 31 | 377 | |
| | | | | | | 32 | 340 | 4,131 |

[a]The location refers to the distance in feet from the North end of each pipe.

**APPENDIX C: MAJOR INSTRUMENTATION**

## C.1. SCANNING AND MEASUREMENT INSTRUMENT/ DETECTOR COMBINATIONS

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or their employer.

### C.1.1 GAMMA

Ludlum NaI[Tl] Scintillation Detector Model 44-10, Crystal: 5.1 cm × 5.1 cm
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Trimble Geo 7X
(Trimble Navigation Limited, Sunnyvale, CA)

Ludlum CsI Scintillation Detector Model 44-159-1, Crystal: 1.8 cm × 1.8 cm
coupled to: Ludlum Ratemeter-scaler Model 2221

### C.1.2 ALPHA-PLUS-BETA

Ludlum Gas-flow Proportional Detector Model 43-68, 126 $cm^2$ physical area, both 0.8 and 3.8 $mg/cm^2$ Mylar windows
(Ludlum Measurements, Inc., Sweetwater, Texas)
coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)

Ludlum Gas-flow Proportional Detector Model 43-37, 584 $cm^2$ physical area, 0.8 $mg/cm^2$ Mylar window
(Ludlum Measurements, Inc., Sweetwater, Texas)
coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Trimble Geo 7X
(Trimble Navigation Limited, Sunnyvale, CA)

## C.2. LABORATORY ANALYTICAL INSTRUMENTATION

Low-Background Gas Proportional Counter
Series 5 XLB
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Apex Alpha/Beta Software
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Extended Range Intrinsic Detector

CANBERRA/Tennelec Model No: ERVDS30-25195
Canberra Lynx ® Multichannel Analyzer
Canberra Apex Gamma Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Cryo-Cycle II Hybrid Cryostat
(Canberra, Meriden, Connecticut
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
Ametek/ORTEC Model No. GMX45-76-CW-S
Canberra Lynx ® Multichannel Analyzer
Canberra Apex Gamma Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Cryo-Cycle II Hybrid Cryostat
(Canberra, Meriden, Connecticut
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
Ametek/ ORTEC Model No. CDG-SV-76/GEM-MX5970-S
Canberra Lynx ® Multichannel Analyzer
Canberra Apex Gamma Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Cryo-Cycle II Hybrid Cryostat
(Canberra, Meriden, Connecticut
Dell Workstation
(Canberra, Meriden, Connecticut)

Liquid Scintillation Counter
Perkin Elmer Tricarb 5110TR
(Perkin Elmer, Waltham, Massachusetts)
Used in conjunction with:
Quantasmart Software
(Perkin Elmer, Waltham, Massachusetts)

# APPENDIX D: SURVEY AND ANALYTICAL PROCEDURES

## D.1. PROJECT HEALTH AND SAFETY

The Oak Ridge Institute for Science and Education (ORISE) performed all survey activities in accordance with the *Oak Ridge Associated Universities (ORAU) Radiation Protection Manual*, the *ORAU Radiological and Environmental Survey Procedures Manual,* and the *ORAU Health and Safety Manual* (ORAU 2020b, ORAU 2016, and ORAU 2020a). Prior to on-site activities, a Work-Specific Hazard Checklist was completed for the project and discussed with field personnel. The planned activities were thoroughly discussed with site personnel prior to implementation to identify hazards present. Additionally, prior to performing work, a pre-job briefing and walk down of the survey areas were completed with field personnel to identify hazards present and discuss safety concerns. Should ORISE have identified a hazard not covered in ORAU 2016 or the project's Work-Specific Hazard Checklist for the planned survey and sampling procedures, work would not have been initiated or continued until the hazard was addressed by an appropriate job hazard analysis and hazard controls.

## D.2. CALIBRATION AND QUALITY ASSURANCE

Calibration of all field instrumentation was based on standards/sources traceable to National Institute of Standards and Technology (NIST).

Field survey activities were conducted in accordance with procedures from the following documents:

- *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2016)
- *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2021a)
- *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2021b)

The procedures contained in these manuals were developed to meet the requirements of U.S. Department of Energy (DOE) Order 414.1D and U.S. Nuclear Regulatory Commission's (NRC's) *Quality Assurance Manual for the Office of Nuclear Material Safety and Safeguards*, and contain measures to assess processes during their performance.

Quality control procedures include

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.

- Participation in Mixed-Analyte Performance Evaluation Program and Intercomparison Testing Program laboratory quality assurance programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

## D.3. SURVEY PROCEDURES

### D.3.1 SURFACE SCANS

Gamma scans were performed using Ludlum model 44-10 2-inch by 2-inch thallium-doped sodium iodide (NaI[Tl]) detectors. Alpha-plus-beta scans were performed using either the large-area (floor monitor) or hand-held gas proportional detectors with a physical detector area of 584 $cm^2$ or 126 $cm^2$, respectively. Scans for elevated radiation were performed by passing the detector slowly over the surface. The distance between the detectors and surface was maintained at a minimum. Identification of elevated radiation levels that could exceed the localized background were determined based on an increase in the audible signal from the indicating instrument or were identified after post-processing the scan data while the team was still at the site. The NaI gamma detectors were used solely as a qualitative means to identify elevated radiation levels in excess of background. However, for reference, NUREG-1507, Table 6-6, provides NaI scintillation detector scan minimum detectable concentrations (MDCs) for Common Radiological Contaminants (NRC 2020). For Cs-137, the scan MDC is 5.5 pCi/g, 2.8 pCi/g for Co-60, and 2.1 pCi/g for Ra-226. A specific scan MDC for the floor monitor was not determined as the instrument was used solely as a qualitative means to identify elevated radiation levels in excess of background. Identifications of elevated radiation levels that could exceed the background were determined based on an increase in the audible signal from the indicating instrument and quantitatively investigated using other hand-held instruments.

Surface scan MDCs for the hand-held gas proportional detectors were estimated using the approach described in NUREG-1507 (NRC 2020). The scan MDC is a function of many variables, including a 2-second observation interval; a specified level of performance at the first scanning state of 95% true positive and 25% false positive rate, which yields a d' value of 2.32 (NUREG-1507, Table 6-1); and a surveyor efficiency of 0.5. For the structural surfaces, the primary radionuclides of concern are

Cs-137 and Sr-90. As such the total efficiencies for beta are 0.095 for Cs-137 and 0.205 for Sr-90. The scan MDC was calculated using the following equation:

$$Scan\ MDC = \frac{d' \times \sqrt{C_b \times (i/60)} \times (60/i)}{\sqrt{p} \times \varepsilon_t \times \frac{Probe\ Area}{100\ cm^2}}$$

Where:

d' = index of sensitivity

$C_b$ = background (cpm)

$i$ = observation interval (sec)

p = surveyor efficiency

$\varepsilon_t$ = total efficiency

The scan MDC for surveys if assuming all activity is Cs-137 is 2,800 disintegrations per minute (dpm)/100 $cm^2$ and 1,300 dpm/100 $cm^2$ if assuming all activity is Sr-90, both based on the site specific beta instrument background for concrete of 342 cpm for the hand-held gas proportional detector.

### D.3.2 Surface Activity Measurements

Measurements of gross alpha and gross beta surface activity levels were performed using hand-held gas proportional detectors coupled to portable ratemeter-scalers. Count rates, which were integrated over 1 minute with the detector held in a static position, were converted to activity levels by dividing the count rate by the total static efficiency and correcting for the physical area of the detector plus background. The MDC for static surface activity measurements was calculated using the following equation:

$$MDC = \frac{3 + (4.65\sqrt{B})}{TG\varepsilon_{tot}}$$

Where:

B = background in time interval, T (1 min)

T = count time (min) used for field instruments

$\varepsilon_{tot}$ = total efficiency = $\varepsilon_i \times \varepsilon_s$ (instrument efficiency × source efficiency)

G = geometry correction factor (1.26)

The static MDC if assuming all activity is Cs-137 is 740 dpm/100 $cm^2$ and 340 dpm/100 $cm^2$ if assuming all activity is Sr-90, based on the site specific beta instrument background for concrete of 342 cpm.

The static MDC for alpha measurements is 22 dpm/100 $cm^2$ assuming a concrete background of 0 cpm.

### D.3.3 REMOVABLE ACTIVITY SAMPLING

Smear sampling for removable gross alpha and gross beta contamination were obtained from all direct measurement locations on the concrete pedestal. Smears for potential hard-to-detect (HTD) radionuclide analysis were obtained from a smaller portion of measurement locations. Removable activity samples were collected using numbered filter paper disks. Moderate pressure was applied to the smear and approximately 100 $cm^2$ of the surface was wiped. Dry smears for gross alpha and beta analysis were placed in labeled envelopes. Smears for HTD analysis were first wetted with deionized water before the surface was wiped. Wet smears were placed in glass vials with deionized water. Locations and other pertinent data were recorded and all samples were transferred under chain-of-custody. Note: None of the smears collected for potential HTD analysis were analyzed after the review of the H-3 and Ni-63 concentrations in the volumetric concrete core samples.

### D.3.4 SOIL SAMPLING

Soil samples (approximately 0.5 kilogram each from 0 to 15 centimeters) were collected by ORISE personnel using a clean hand tool to transfer soil into a new sample container. The container was then labeled and security sealed in accordance with ORISE procedures. ORISE shipped samples under chain-of-custody to the ORISE laboratory for analysis.

## D.4. RADIOLOGICAL ANALYSIS

### D.4.1 GROSS ALPHA/BETA

Smears were counted on a low-background proportional counter for gross alpha and beta activity. The minimum detectable activity achieved was 13 dpm/100 $cm^2$ for alpha and 14 dpm/100 $cm^2$ for beta.

### D.4.2 GAMMA SPECTROSCOPY

Samples were analyzed as received and homogenized or crushed, as necessary, and a dry portion sealed in a size-appropriate Marinelli beaker or container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. The samples were sealed for a minimum of 27 days to allow ingrowth to provide Ra-226 via Pb-214. Net material weights were determined, and the samples were counted using intrinsic, high-purity, germanium detectors coupled to a pulse-height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using computer capabilities inherent in the analyzer system. All total absorption peaks (TAPs) associated with the radionuclides of concern (ROCs) were reviewed for consistency of activity. Spectra also were reviewed for other identifiable TAPs. TAPs used for determining the activities of the radionuclides and the typical associated minimum detectable concentrations (MDCs) for a 1-hour count time are presented in Table D.1.

**Table D.1. Typical MDCs Total Absorption Peak**

| Radionuclide | TAP (MeV)[a] | MDC (pCi/g) |
|---|---|---|
| Am-241 | 0.0595 | 0.11 |
| Co-60 | 1.332 | 0.06 |
| Cs-137 | 0.662 | 0.05 |
| Eu-152 | 0.344 | 0.10 |
| Eu-154 | 0.723 | 0.15 |
| Eu-155 | 0.105 | 0.10 |
| Ra-226 by Pb-214 | 0.351 | 0.08 |
| U-238 by Th-234 | 0.063 | 0.75 |
| U-235 | 0.143 | 0.05 |

[a]Spectra also were reviewed for other identifiable TAPs.
[b]MeV = mega electron volt
[c]picocurie per gram

### D.4.3 Radioactive Strontium Analysis

Strontium-90 (Sr-90) concentrations were quantified by total sample dissolution followed by radiochemical separation, and were counted on a low-background gas proportional counter. Samples were homogenized and dissolved by a combination of potassium hydrogen fluoride and pyrosulfate fusions. The fusion cakes were dissolved, and strontium was co-precipitated on lead sulfate. The sulfate-salt complex was dissolved in ethylenediaminetetraacetic acid (EDTA) at a pH of 8.0. The strontium was separated from residual calcium and lead by re-precipitating strontium sulfate from EDTA at a pH of 4.0. Strontium was separated from barium by complexing the strontium in diethylenetriaminepentaacetic acid (DTPA) while precipitating barium as barium chromate. The strontium was ultimately converted to strontium carbonate and counted on a low-background gas proportional counter. The typical MDC for a 60-minute count time using this procedure is 0.4 pCi/g for a 1-gram sample.

### D.4.4 H-3 Analysis

Tritium (H-3) analysis for the soil samples was performed using a biological material oxidizer, and counted by liquid scintillation. The biological material oxidizer combusts samples in a stream of oxygen gas and passes the products (including carbon dioxide and water vapor), through a series of catalysts. H-3 is carried by water and is captured in a trapping scintillation cocktail specific to water. The typical MDC for H-3 for a 60-minute count time using this procedure is 4.5 pCi/g.

### D.4.5 Ni-63 Analysis

Soil samples were spiked with a nickel (Ni) and cobalt carrier and digested with a mixture of nitric and hydrochloric acids. Unwanted elements, such as iron and cobalt, were removed via anion exchange chromatography. Nickel was then further separated from the potential interfering elements using a nickel selective resin cartridge and buffered ammonium citrate. The purified nickel was eluted off of the column with a dilute nitric acid solution. Ni-63 activity was determined via liquid scintillation counting. The typical MDC for a 1-gram sample and 60-minute count time using this procedure is 2.0 pCi/g.

### D.4.6 DETECTION LIMITS

Detection limits, referred to as MDCs, were based on a 95% confidence level. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differed from sample to sample and instrument to instrument.