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January 31, 2020

Mr. John Hickman
U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Decommissioning, Uranium Recovery, and Waste Programs
Reactor Decommissioning Branch, Mail Stop: T8F5
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SUBJECT: INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE SUBSURFACE SOILS ASSOCIATED WITH THE SACRIFICIAL BARRIER AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS; DOCKET NOs. 50-295 and 50-304; RFTA 18-004; DCN: 5271-SR-07-0

Dear Mr. Hickman:

Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the attached report detailing the confirmatory survey activities of the sacrificial barrier subsurface soil at the Zion Nuclear Power Station in Zion, Illinois.

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

Sincerely,

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

NAA:tb

Attachment

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE SUBSURFACE SOILS ASSOCIATED WITH THE SACRIFICIAL BARRIER AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

N. A. Altic, CHP
and
J. D. Lee
ORISE

FINAL REPORT

Prepared for the
U.S. Nuclear Regulatory Commission

JANUARY 2020

NOTICES

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE SUBSURFACE SOILS ASSOCIATED WITH THE SACRIFICIAL BARRIER AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

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FINAL REPORT

JANUARY 2020

CONTENTS

FIGURES

TABLES

ACRONYMS

AA	alternate action
CFR	Code of Federal Regulations
Co-60	cobalt-60
cpm	counts per minute
Cs-137	cesium-137
DCGL	derived concentration guideline level
$DCGL_{BC}$	Base Case DCGL
$DCGL_{EMC}$	elevated measurement comparison DCGL
$DCGL_{Op}$	Operational DCGL
DOE	Department of Energy
DQO	data quality objective
DRP	discrete radioactive particle
DS	decision statement
Exelon	Exelon Generation Company
FSS	final status survey
GPS	global positioning system
H-3	tritium
HTD	hard-to-detect
LTP	license termination plan
µCi	microcuries
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MeV	mega electron volt
mrem/yr	millirem per year
NaI	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	picocuries per gram
PSQ	principal study question
Q	quantile
RA	radiological assessment
REAL	Radiological and Environmental Analytical Laboratory
ROC	radionuclide of concern
SOF	sum of fractions
Sr-90	strontium-90
SU	survey unit
TAP	total absorption peak
TEDE	total effective dose equivalent
ZNPS	Zion Nuclear Power Station
ZS	Zion*Solutions*, LLC

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE SUBSURFACE SOILS ASSOCIATED WITH THE SACRIFICIAL BARRIER AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities of subsurface soils associated with the sacrificial barrier at the Zion Nuclear Power Station (ZNPS). During the period of April 16–18, 2019 and July 15–19, 2019, ORISE performed an independent confirmatory survey consisting of gamma walkover surface scans and soil sampling.

During the April 2019 confirmatory survey, ORISE staff performed gamma surface scans that identified locations of elevated response distinguishable from localized background. As the survey progressed, the site requested that the U.S. Nuclear Regulatory Commission (NRC) suspend confirmatory survey activities while the site evaluated the anomalies. NRC agreed to the request, but did ask that ORISE analyze all collected confirmatory samples. A total of 16 judgmental soil samples were collected from 15 individual locations. Two samples were discrete radioactive particles (DRPs) that consisted solely of cobalt-60 (Co-60). One other sample location contained concrete-like debris contaminated with cesium-137 (Cs-137), and the surrounding soils exceeded a sum of fractions (SOF) of unity, based on the Operational derived concentration guideline level ($DCGL_{Op}$). All other radionuclides of concern (ROCs)—including strontium-90 (Sr-90) and nickel-63 (Ni-63)—were less than their respective $DCGL_{Op}$. All Sr-90 and tritium (H-3) concentrations were less than the analytical minimum detectable concentration (MDC).

In July of 2019, at the request of NRC, ORISE returned to the site to re-perform the previously planned and partially implemented confirmatory surveys. A total of 21 judgmental samples were collected from 19 individual locations. One sample, containing predominately Cs-137, exceeded the allowable SOF [unity] based on the $DCGL_{Op}$, but was less than the allowable limit when compared to the Base Case DCGL ($DCGL_{BC}$). Two samples contained DRPs that consisted solely of Co-60. All other results for gamma-emitting ROCs were less than the $DCGL_{Op}$. A subset of eight soil samples were selected based on the gamma spectrometry results and were analyzed for Sr-90, Ni-63, and H-3. Only Ni-63 was detected above the analytical MDC, but at concentrations less than 1% of the $DCGL_{Op}$. Based on the results of the July 2019 confirmatory survey, the study area does contain residual radioactivity, and the results of the survey are provided herein for NRC's evaluation.

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE SUBSURFACE SOILS ASSOCIATED WITH THE SACRIFICIAL BARRIER AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

1. INTRODUCTION

The Zion Nuclear Power Station (ZNPS) consisted of two reactors, Units 1 and 2, which operated commercially from 1973 to 1997 and 1974 to 1996, respectively. Cessation of nuclear operations was certified in 1998 after both reactor units were defueled and the fuel assemblies had been placed in the spent fuel pool. Both units were then placed in safe storage pending the commencement of site decommissioning and dismantlement. In 2010, the U.S. Nuclear Regulatory Commission (NRC) operating license was transferred from Exelon Generation Company (Exelon) to Zion*Solutions,* LLC (ZS) to allow the physical decommissioning process, which is expected to be completed within 10 years. The end-state and primary decommissioning objective at ZNPS is the transfer of all spent nuclear fuel to the independent spent fuel storage installation and to reduce residual radioactivity within structures and soils to levels below the criteria specified in 10 *Code of Federal Regulations* (CFR) 20.1402, permitting release of the site for unrestricted use. Upon successful completion of the decommissioning activities, control and responsibility for the site will be transferred back to Exelon and the independent spent fuel storage installation will be maintained under Exelon's Part 50 license (EC 2015).

As part of decommissioning, all above-grade structures, with a few exceptions, were demolished. Structures below the 588-foot elevation (referenced from mean sea level), consisting of primarily exterior subgrade walls and floors, remain. These basement structures were backfilled as part of the final site restoration. In order to demonstrate compliance with the release criteria in 10 CFR 20.1402, ZS implemented final status survey (FSS) activities of remaining basement structures, along with associated embedded piping and penetrations, buried piping, and remaining soil. FSS methodologies are outlined in Chapter 5 of ZS's license termination plan (LTP) (ZS 2018). FSS methods are based on those outlined in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). NRC issued license amendments 191 and 178 to approve ZS's LTP in September of 2018 (NRC 2018).

For this specific effort, ZS placed clean borrow over the original grade to "catch" materials, such as dust and debris generated and dispersed by demolition activities. This borrow layer is referred to as the sacrificial barrier. After demolition activities were concluded, ZS removed the sacrificial barrier plus other soils from the original grade, thus leaving an exposed subsurface layer that presumably had not been radiologically impacted by site operations. ZS performed high-density gamma walkover surveys of the exposed subsurface layer as part of a radiological assessment (RA). ZS committed to collecting volumetric subsurface samples after land restoration as part of the FSS. NRC requested that the Oak Ridge Institute for Science and Education (ORISE) perform a confirmatory survey of the exposed soils following the removal of the sacrificial barrier at ZNPS.

2. SITE DESCRIPTION

ZNPS is located in Lake County, Illinois, on the easternmost portion of the city of Zion. It is approximately 64 kilometers (40 miles) north of Chicago, Illinois, and 68 kilometers (42 miles) south of Milwaukee, Wisconsin. The owner-controlled site is composed of approximately 134 hectares (331 acres) and is situated between the northern and southern parts of Illinois Beach State Park on the western shore of Lake Michigan (EC 2015 and ZS 2018). Figure 2.1 provides an overview of ZNPS. The site and its surrounding environs is relatively flat, with the elevation of the developed portion of the site at approximately 591 feet above mean sea level. For reference, the elevation of Lake Michigan, which bounds the site on the east, is approximately 577.4 feet at low water level (ZS 2018).

The area within the security-restricted fence contained the principal components of the power plant, including the two containment vessels, the turbine, the crib house, and a waste water treatment facility. The site subdivided land areas into survey units (SUs), which are outlined in Figure 2.2.

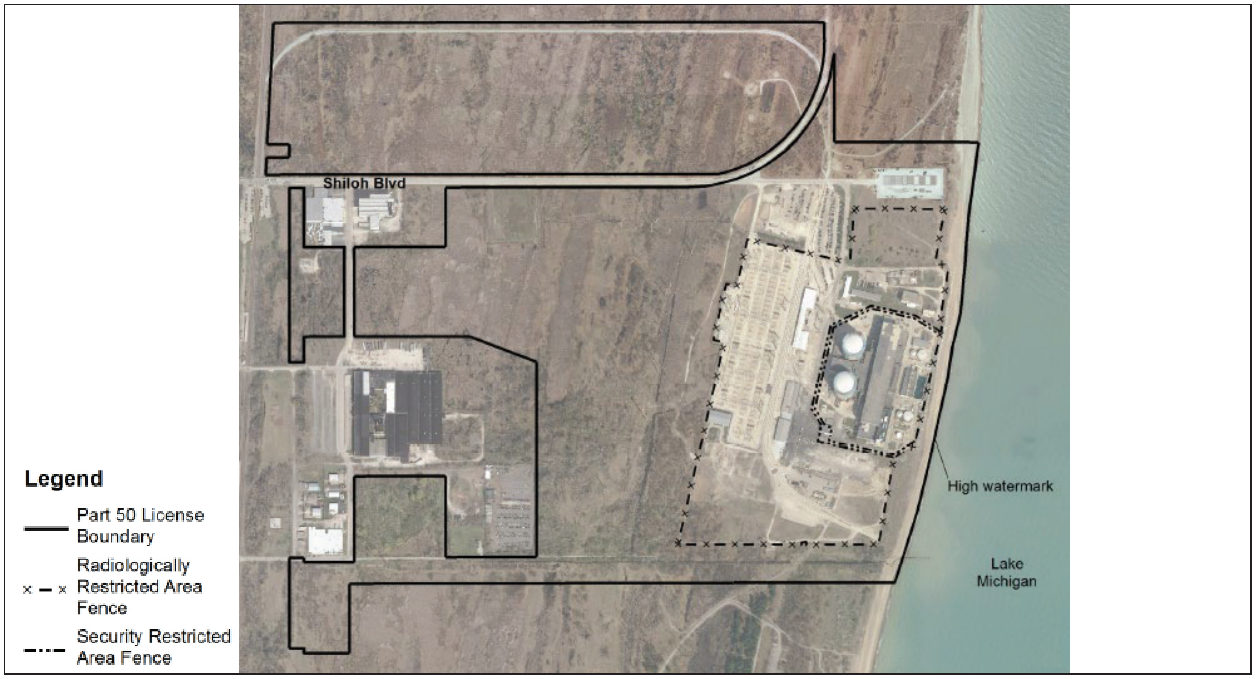

Figure 2.1. ZNPS Overview (Adapted from ZS 2018)

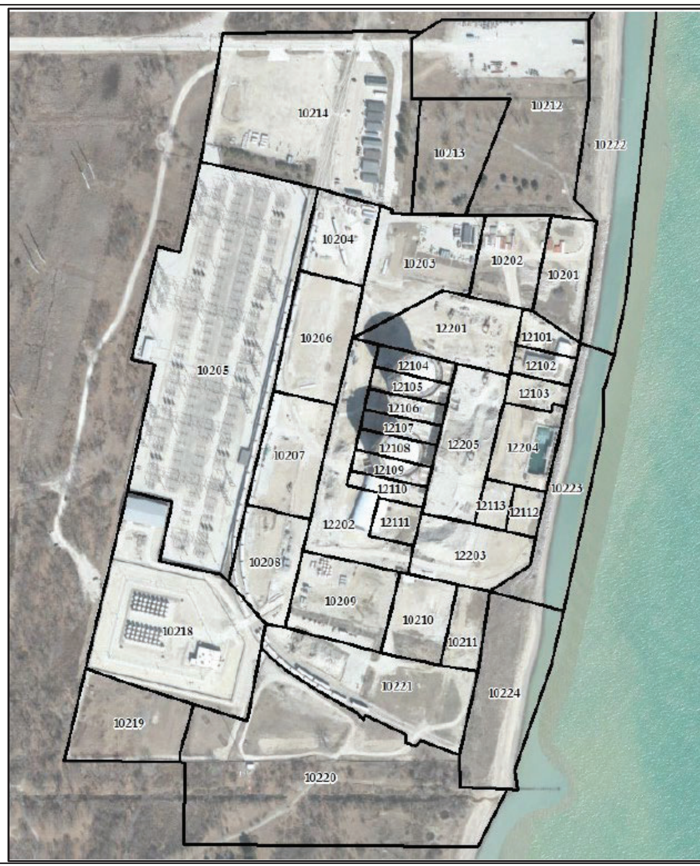

Figure 2.2. Overview of ZNPS Survey Units (Adapted from NRC 2019)

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 provide a formalized method for planning radiation surveys, improving survey efficiency and effectiveness, and ensuring that the type, quality, and quantity of data collected are adequate for the intended decision applications.

The seven steps of the DQO process are 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

Confirmatory survey DQOs were originally presented in ORISE 2019 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. NRC requested that ORISE perform confirmatory surveys at ZNPS. The objectives of the confirmatory survey activities were to provide NRC with independent confirmatory data for NRC's consideration in the evaluation of the site's RA results. The problem statement was formulated as follows:

> Confirmatory survey activities are necessary to generate independent radiological data for NRC's consideration in the evaluation of the RA survey 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 alternate actions (AAs), developed a decision statement (DS), and organized multiple decisions, as appropriate. This was done by specifying AAs that could result from a "Yes" response to the PSQ and combining the PSQ and AAs into a DS. Table 3.1 presents the confirmatory survey decision process.

Table 3.1. ZNPS Confirmatory Survey Decision Process	
Principal Study Question	**Alternate Actions**
Did confirmatory survey results identify residual radiological contamination in the subsurface soil associated with the sacrificial barrier land area?	**Yes:** Compile confirmatory data and report results to NRC for their decision making. Provide independent interpretation of confirmatory survey results that identified anomalous field or laboratory data and/or when sample population examination/assessment conditions have been met. **No:** Compile confirmatory data and report results to NRC for their decision making. Provide independent interpretation that confirmatory field surveys did not identify anomalous areas of residual radioactivity, that quantitative field and laboratory data satisfy the NRC-approved decommissioning criteria, and/or that sample population examination/assessment conditions have been met.
Decision Statement	
Confirmatory survey results did/did not identify anomalous results or other conditions, and the results were/were not below the NRC-approved endpoint criteria.	

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 would meet data requirements. For this effort, information inputs included the following:

- Site-generated RA data for the subject soil surfaces
- *Zion Station Restoration Project License Termination Plan* (ZS 2018)
- Subsurface soil derived concentration guideline levels (DCGLs) for radionuclides of concern (ROCs) plus respective scan and analytical minimum detectible concentrations (MDCs), which are discussed in subsection 3.3.1. Because the excavation surface is below the original grade and the areas will eventually be covered with fill, subsurface guidelines are used for this evaluation
- ORISE confirmatory direct gamma radiation scans
- ORISE soil sample analytical results

3.3.1 Radionuclides of Concern and Release Guidelines

The primary ROCs identified for ZNPS are beta-gamma emitters—fission and activation products listed in Table 3.2—resulting from reactor operations. ZS developed site-specific DCGLs that correspond to a residual radioactive contamination level, above background, which could result in a total effective dose equivalent (TEDE) of 25 millirem per year (mrem/yr) to an average member of the critical group. These DCGLs—defined in ZS's LTP as Base Case DCGLs ($DCGL_{BC}$s)—are radionuclide-specific and independently correspond to a TEDE of 25 mrem/yr for each source term. The initial suite of ROCs present at ZNPS has been reduced based on an insignificant dose contribution from a number of radionuclides. As such, the $DCGL_{BC}$s have been reduced to account for the dose from these insignificant radionuclides.

In order to ensure that the total dose from all site-related source terms—basement structures, soils, buried piping, and groundwater—is less than the NRC-approved release criteria, the $DCGL_{BC}$s are further reduced to Operational DCGLs ($DCGL_{Op}$s). The $DCGL_{Op}$s represent the expected dose from prior investigations and are used for remediation and FSS/RA design purposes. $DCGL_{BC}$s and $DCGL_{Op}$s for subsurface soil, accounting for insignificant dose contributors, are provided in Table 3.2. Note that ZS did not identify tritium (H-3) as a primary ROC; however, it was included as part of this study, as requested by NRC.

Table 3.2. ZNPS Subsurface Soil DCGLs[a] and Corresponding MDCs (pCi/g)

ROC	$DCGL_{BC}$	$DCGL_{Op}$	Nominal Scan MDC[b]	Analytical MDC[c]
Co-60	3.44	0.881	3 to 5	< 0.1
Cs-134	4.44	1.137	Unknown	< 0.1
Cs-137	7.75	1.984	6 to 8	< 0.1
Ni-63	763.02	195.333	HTD	<2
Sr-90	1.66	0.425	HTD	~0.2
H-3	-[d]	-[d]	HTD	<3

[a]Recreated from ZS 2018
[b]Approximated using the methods described in NRC 2000
[c]Based on observed analytical MDCs
[d]H-3 is not identified as a primary ROC; therefore, DCGLs are not available
pCi/g = picocuries per gram
MDC = minimum detectible concentration
HTD = hard-to-detect ROCs; scanning instrument not sensitive to these ROCs

Any detection suggesting the presence of residual contamination present after the sacrificial soils were removed may have resulted in some action. Because each individual $DCGL_{BC}$ represents a separate

radiological dose, the sum-of-fractions (SOF) approach must be used to evaluate the total dose from the SU and must demonstrate compliance with the dose limit. Typically, the SOF would be calculated with the average ROC concentration; however, since only judgmental samples were collected, the SOF was calculated for each sample using Equation 3-1.

$$SOF_{Sample} = \sum_{j=1}^{n} \frac{C_{sample,j}}{DCGL_j} \qquad \text{Eq. (3-1)}$$

Where:

$C_{sample,j}$ is the sample concentration of ROC "j"

$DCGL_{,j}$ is the $DCGL_{BC}/DCGL_{Op}$ for ROC "j"

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. Confirmatory surveys were conducted during two periods [site visits]: April 16–18, 2019, and July 15–19, 2019. Physical boundaries of the confirmatory activities were the SUs associated with the power block (see Figure 3.1) that contained the sacrificial barrier. Additional physical boundaries for the confirmatory activities depended on safe access considerations. The primary reason for not achieving 100% investigation of the subject area was standing water. The ORISE survey team was not permitted to access these areas because the depth of the water was unknown. All survey subunits associated with the power block are designated as a Class 1 by the site.

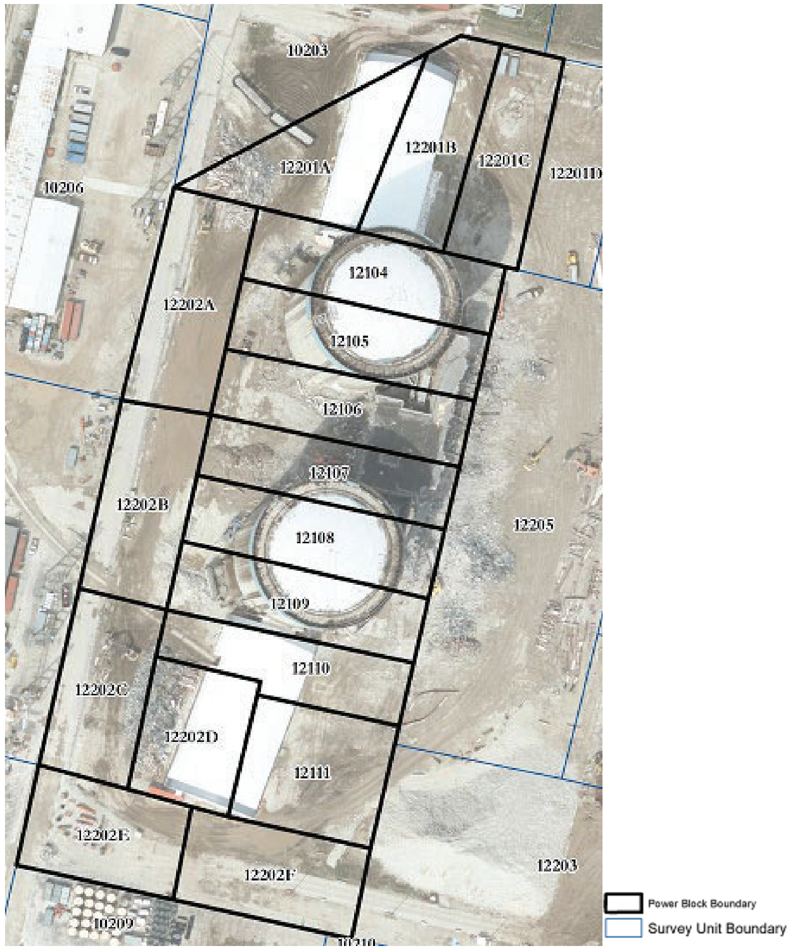

Figure 3.1. SUs Associated with the Power Block Subject to Confirmatory Surveys

3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specified appropriate population parameters (e.g., mean, median), evaluated action levels relative to the appropriate detection limits, and developed an "if…then…" decision rule statement. Decision rules for this survey were based on independent scan surveys and soil sample results.

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 (H_A). A significant subsurface soil source term was not expected; therefore, any positive detection may have required follow-up action, and, thus, a formal statistical comparison was unnecessary. Therefore, the null and alternative hypothesis were as follows:

H_0: Subsurface soils beneath the sacrificial layer do not contain residual ROC contamination
H_A: Subsurface soils beneath the sacrificial layer do contain residual ROC contamination

Rejection of the null hypothesis may not indicate that the area is unacceptable for release. The area of residual contamination also should be considered. Ultimately, NRC will assess the acceptability of any remaining hot spots identified during the confirmatory survey.

Qualitative parameters of interest included gamma walkover survey data collection over accessible soils (i.e., surface soils beneath the sacrificial barrier after it was removed). Locations with levels of radiation distinguishable from localized background—as determined in real time by the surveyor during direct gamma scans and/or based on post-processing of scan data—were marked for further investigation. For this study, the quantitative parameters of interest are individual soil sample concentrations and the associated analytical MDC. The decision rule was stated as follows:

> If ROC concentrations in confirmatory samples are reported less than analytical detection limits, then the subject area is presumed to be free of residual contamination. Otherwise, the subject area may be impacted by site operations and additional action may be required. Present results to NRC for their evaluation.

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 were controlled both during the confirmatory activities and during data quality assessments. As shown in Table 3.2, detector scan MDCs for gamma-emitting ROCs were expected to be above subsurface soil $DCGL_{Op}$s. Any anomalies above background identified while performing the surveys or subsequent data assessment were thoroughly investigated and discussed with NRC staff. Additionally, analytical MDCs were approximately 10% of the $DCGL_{Op}$—with the exception of strontium-90 (Sr-90), which was approximately 50% of the $DCGL_{Op}$, as indicated in Table 3.2.

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 survey areas specifically requested by NRC. Survey activities were conducted in accordance with the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual* and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2016a and currently ORAU 2019a).

4.1 Reference System

ORISE referenced confirmatory measurement/sampling locations using global positioning system (GPS) coordinates using Illinois East State Plane 1201 NAD 1983 (meters). Measurement and sampling locations were documented on detailed 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. Accessible areas associated with the power block SUs 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 marked for further investigation via volumetric sampling. Additionally, direct gamma scan data were processed and reviewed prior to leaving the site in order to identify any additional judgmental sampling locations.

4.3 Measurement/Sampling Locations

Random samples were not specifically required to assess the mean concentration—any single positive detection may have resulted in follow-up actions, but were proposed to achieve greater probability of detecting a location with a soil concentration greater than the DCGL, but less than the scan MDC. However, temporal boundaries prevented the collection of a random data set as planned. Therefore, as agreed upon by NRC, all samples/measurements were collected from judgmental locations. The

ORISE field team used all available time onsite to perform gamma walkovers and collect judgmental samples.

4.4 Soil Sampling

Soil sampling locations were judgmentally selected from the study area and collected following the removal of the sacrificial barrier. These samples will represent subsurface soil conditions after final backfill. Soil samples were collected from the exposed surface to a depth of 15 centimeters. A total of 37 samples were collected between the two site visits—16 samples in April and 21 samples in July. Four sample locations—two from the April 2019 site visit and two from the July 2019 site visit—exhibited indications of a discrete radioactive particle (DRP) versus volumetric contamination (i.e., the NaI detector response was highly localized). The presence of DRPs was confirmed at each location, and the particles were isolated while onsite. During the April site visit, the DRPs were isolated in the field prior to sample collection. The DRPs collected during the July site visit were isolated after the volumetric soil sample was collected. The DRPs were collected for confirmatory analysis in order to confirm the contaminants.

One-minute, static NaI counts were performed at each sample location pre- and post-sample collection. The static measurements were used to assess the potential for contamination at depth.

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* (currently ORAU 2019b). With exception of isolated particles, samples were homogenized and analyzed by high-resolution gamma spectrometry for gamma-emitting fission and activation products. Results for the volumetric soil samples were reported in units of picocuries per gram (pCi/g). The DRPs were reported in units of total activity—microcuries (µCi)—because a concentration value in pCi/g is not applicable to the DRP results.

Select soil samples also were analyzed for hard-to-detect (HTD) ROCs. As directed by NRC, all samples from the April 2019 sampling effort, excluding the DRPs and sample 5271S0045, and a

subset of eight samples from the July 2019 effort were selected for analysis of HTD ROCs. The selections were based primarily on the gamma spectrometry results. For the HTD analysis, REAL prepared samples utilizing wet chemistry and material oxidation. Samples then underwent separation and were analyzed for Sr-90, nickel-63 (Ni-63), and H-3 by low-background proportional or liquid scintillation counting, as applicable. All HTD analytes were reported in units of pCi/g.

Scan data were graphed in quantile (Q) plots and histograms for assessment. The Q plot is a graphical tool for assessing the distribution of a data set. In viewing the Q plots provided, the Y-axis represents ROC concentrations in units of counts per minute (cpm). 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, appears as a step function.

Soil sample analytical results were plotted using strip charts, often referred to as one-dimensional scatter plots.

6. FINDINGS AND RESULTS

The results of the confirmatory survey are discussed in the following subsections.

6.1 SURFACE SCANS

Figure 6.1 presents the overall Q plot for the scan data from each site visit. The sharp increase in the Q plot at the upper quantile is associated with the DRPs. As previously discussed, certain site conditions, such as excavations and/or standing water, rendered some areas inaccessible. The details of each site visit are discussed in the following subsections.

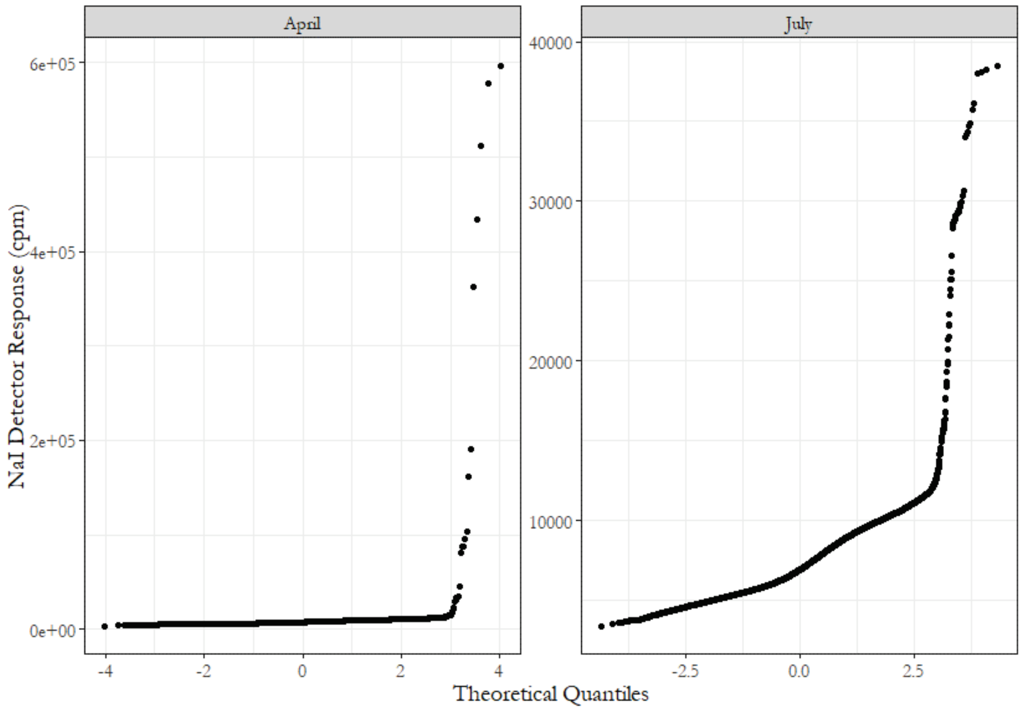

Figure 6.1 Q Plot of Gamma Walkover Data for April 2019 and July 2019 Confirmatory Surveys

6.1.1 April 2019 Gamma Walkover Scans

In April 2019, ORISE staff performed gamma surface scans in portions of SUs 12102, 12104, 12105, 12106, 12107, and 12108. Overall, the gamma detector scan responses ranged from 3,400 to 600,000 cpm. A histogram of the scan data is provided in Figure A.2 in Appendix A. Note that all results above 17,000 cpm are combined in one bin to allow for better visibility of the lower count rate region of the distribution. Review of the histogram reveals a multi-modal distribution (i.e., multiple backgrounds). The ORISE field team noted multiple soil types, ranging from sand to clay, each with a different background. Note that the clay exhibited the highest background at approximately 10,000 cpm. Multiple backgrounds within each SU prevent the use of a fixed NaI action level to identify judgmental sampling locations, which is why ORISE based sampling decisions on an increase in detector response relative to localized background.

Detector response peaked at approximately 600,000 cpm, which resulted in the identification and collection of a DRP. This location is presented as 5271S0039 in Figure A.3. A second notable instance resulted in a detector response of approximately 100,000 cpm, which also resulted in the identification and collection of a DRP. This location is presented as 5271S0054 in Figure A.3.

6.1.2 July 2019 Gamma Walkover Scans

During the July 2019 confirmatory survey effort, ORISE performed gamma walkover scans of all area soils associated with the sacrificial barrier within the power block boundaries, including the SUs previously scanned in April 2019. Overall, the gamma detector scan responses ranged from approximately 3,500 to 40,000 cpm. A histogram of the scan data is provided in Figure A.5. Note that all results above 17,000 cpm are combined in one bin to allow for better visibility of the lower count rate region of the distribution. Review of the histogram reveals a multi-modal distribution similar to that of the April survey. The histogram for the July data appears more refined, as indicated by the sharper peak at approximately 6,000 cpm and the more defined curves. The increase in definition is due to a much larger data set for the July survey relative to the April survey.

Detector response peaked at approximately 40,000 cpm, which resulted in the identification and collection of a DRP. This location is presented as 5271S0056 in Figure A.6. A second notable instance resulted in a detector response of approximately 38,000 cpm, which also resulted in the identification of a DRP. This location is presented as 5271S0055 in Figure A.6.

6.2 SOIL SAMPLING

Soil sample locations for the April 2019 and July 2019 efforts are provided in Figures A.3 and A.6, respectively. Individual soil sample results are presented in Table B.1 in Appendix B. Details regarding the soil sample results for each site visit are discussed in the following subsections.

6.2.1 April 2019 Soil Sampling

A total of 16 samples were collected from 15 locations during the April 2019 survey, two of which were DRPs. Table 6.1 presents a summary of the analytical results for the soil samples collected during this effort. Cobalt-60 (Co-60) and cesium-137 (Cs-137) had concentrations above the analytical MDC in four and three of the 16 confirmatory samples, respectively. Co-60 concentrations in the confirmatory soil samples ranged from -0.013 to 3.69 pCi/g, while Cs-137 concentrations ranged from -0.031 to 1,672 pCi/g. The maximum observed concentrations for both Co-60 and Cs-137 were identified in sample 5271S0045, which was a piece of concrete-like debris collected from SU 12202. The results for 5271S0045 are approximate as the smallest calibrated geometry the laboratory utilizes for analysis still contained dead space. Sample 5271S0046 was the soil surrounding the debris

[5271S0045], and it was determined to have Co-60 and Cs-137 concentrations of 0.303 and 6.91 pCi/g, respectively.

Table 6.1. Summary of ROC Concentrations in Soil Samples Collected During the April 2019 Site Visit (pCi/g)

Parameter	Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	SOF_{Op}[a]	SOF_{BC}[a]
Min	-0.013	-0.035	-0.031	0.9	0.01	-1.7	0.07	0.02
Max	3.69[b]	0.040	1672[b]	3.8	0.20	-0.20	847	217

[a]The SOF does not include the fractional contribution from tritium; adjusted DCGLs are not presented in the site's LTP

[b]Sample result is approximate. Results are from 5271S0045

Thirteen of the samples were analyzed for Ni-63, Sr-90, and H-3. Sample 5271S0045 and the DRPs were not analyzed for HTD radionuclides. Five of the 13 samples had Ni-63 concentrations above the analytical MDC, with a maximum concentration of 3.8 pCi/g in sample 5271S0046. The Sr-90 and H-3 concentrations reported were less than the analytical MDC in the confirmatory samples.

Figure 6.2 presents a strip chart of the soil sample results from the April 2019 survey effort. Sample 5271S0045 was not included in the strip chart because the magnitude of the Co-60 and Cs-137 results were much higher than the rest of the samples. As indicated by the clustering of data points—with the exception of one data point for Co-60 and Cs-137, there is not a wide range of concentration values within the judgmental data set, indicating results are at or near background values. The SOF values exceeding unity are from the same sample, 5271S0046, which was the soil surrounding the concrete-like debris [5271S0045] collected in SU 12202.

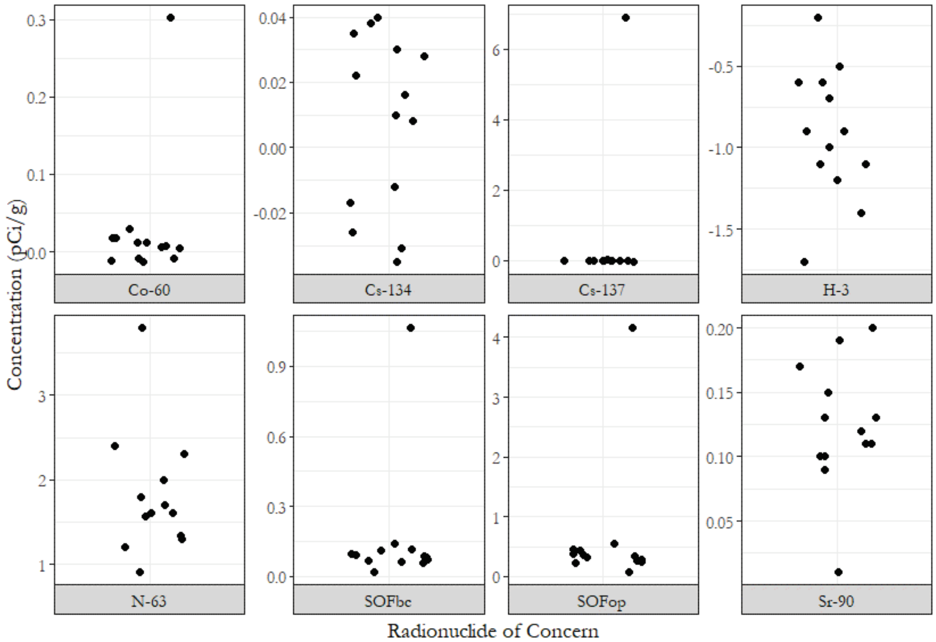

Figure 6.2. Strip Chart for the April 2019 Confirmatory Survey Soil Samples

Analytical results for the DRPs are presented in Table 6.2. Co-60 was the only ROC identified above the analytical MDC in these samples. Results were not compared to the DCGL or the elevated measurement comparison DCGL ($DCGL_{EMC}$) because the physical form of the sample does not match the conceptual site model.

Table 6.2. Radionuclide Activity of Discrete Particles from the April 2019 Site Visit

Sample ID	Survey Unit	ROC Activity and Uncertainty (µCi)								
		Co-60			Cs-134			Cs-137		
5271S0039	12106	1.757	±	0.094[a]	-1.20E-04	±	6.70E-04	6.90E-04	±	3.20E-04
5271S0054	12106	0.372	±	0.011	-3.0E-05	±	7.30E-04	2.40E-04	±	3.20E-04

[a]Uncertainties represent the total propagated uncertainty reported at the 95% confidence level

6.2.2 July 2019 Soil Sampling

A total of 21 samples were collected from 19 locations during the July 2019 survey, two of which were DRPs. Table 6.3 presents a summary of the soil sample results. Co-60 and Cs-137 were positively identified above analytical MDC in five and four of the 19 confirmatory samples, respectively. Co-60 concentrations in the confirmatory soil samples ranged from -0.016 to 0.511 pCi/g, while Cs-137 concentrations ranged from -0.030 to 1.70 pCi/g. The maximum observed concentration for both Co-60 and Cs-137 was identified in sample 5271S0073 from SU 12202A.

Table 6.3. Summary of ROC Concentrations in Soil Samples Collected During the July 2019 Site Visit (pCi/g)

Parameter	Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	SOF_{Op}[a]	SOF_{BC}[a]
Min	-0.016	-0.043	-0.030	0.04	-0.020	-1.00	0.00	0.00
Max	0.511	0.041	1.70	1.68	0.11	0.6	1.45	0.37

[a]The SOF does not include the fractional contribution from tritium

Eight of the 21 samples were analyzed for HTDs. One of the eight samples had Ni-63 concentration above the analytical MDC, with a maximum concentration of 1.68 pCi/g in sample 5271S0073. The Sr-90 and H-3 concentrations reported were less than the analytical MDC in the confirmatory samples.

Figure 6.3 presents a strip chart of the soil sample results from the July survey effort. As indicated by the clustering of data points—with the exception of sample 5271S0073, there is not a wide range of concentration values within the judgmental data set, indicating results are at or near background values. Sample 5271S0073 exceeded an SOF of unity based on the $DCGL_{Op}$s; individual ROC concentrations were below their respective $DCGL_{Op}$. However, when these results were compared to the $DCGL_{BC}$, the resulting SOF was 0.37.

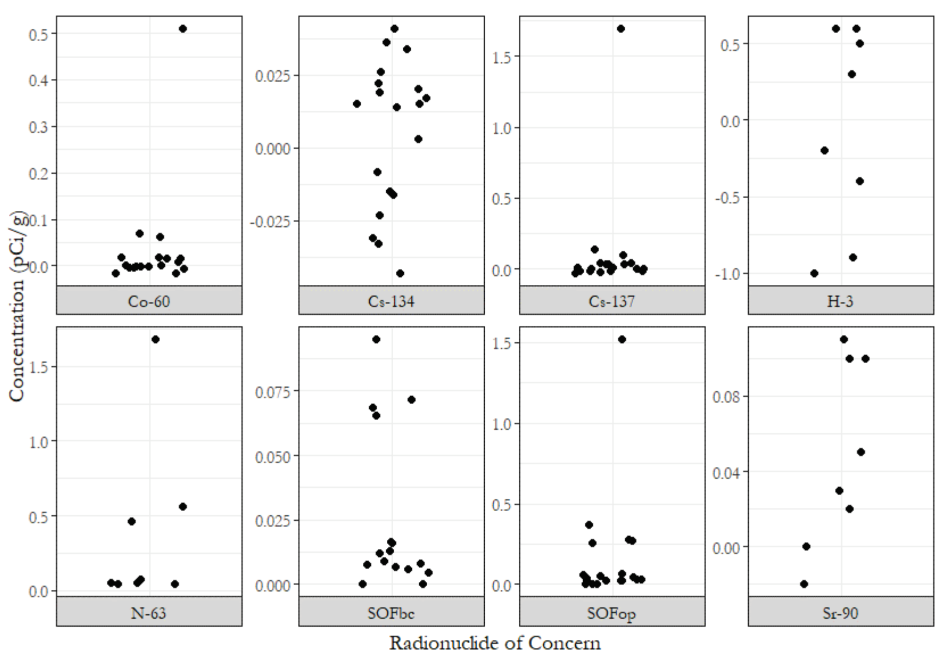

Figure 6.3. Strip Chart for the July 2019 Confirmatory Survey Soil Samples

DRPs from soil samples 5271S0055 and 5271S0056 were isolated and containerized prior to leaving the site. The DRPs were assigned their original same sample ID with an "A" appended to the end. Total activity results for the DRPs are presented in Table 6.4 below. Note that, as stated in Section 4.4, the DRPs collected during the April Site visit were isolated prior to sample collection, and, thus, were assigned a sample ID without the "A" designation.

Table 6.4. Radionuclide Activity of Discrete Particles from the July 2019 Site Visit

Sample ID	Survey Unit	ROC Activity and Uncertainty (µCi)								
		Co-60			Cs-134			Cs-137		
5271S0055A	12202D	0.259	±	0.013[a]	6.0E-05	±	2.00E-04	5.0E-05	±	1.30E-04
5271S0056A	12202F	0.450	±	0.023	-8.0E-05	±	3.60E-04	1.40E-04	±	1.40E-04

aUncertainties represent the total propagated uncertainty reported at the 95% confidence level

7. SUMMARY AND CONCLUSIONS

During the period of April 16–18, 2019, and July 15–19, 2019, ORISE performed independent confirmatory survey activities of subsurface soils associated with the sacrificial barrier at ZNPS. The confirmatory surveys consisted of gamma walkover scans and surface soil sampling (i.e., post removal of the sacrificial barrier). As a result of the gamma walkover surveys, a total of 37 locations between the two site visits were flagged for further investigation by soil sampling.

During the April 2019 site visit, a total of 16 samples were collected from 15 locations, two of which were DRPs with a total Co-60 activity of 0.372 and 1.757 µCi. After removal of the DRPs from the soil, the NaI detector response returned to background, indicating capture of all contamination. Concrete-like debris containing Cs-137 was identified at another location, and the surrounding soil exceeded the SOF allowance [unity] based on the $DCGL_{BC}$. All other samples were below the $DCGL_{Op}$ for selected ROCs. The site requested that NRC suspend confirmatory survey activities while the site evaluated the anomalies, to which NRC agreed. As a result, the entire power block was not surveyed as planned.

After the site completed their evaluation and corrective actions for the subject soils, NRC requested that ORISE return and re-perform the originally planned confirmatory survey activities. This site visit occurred in July 2019, during which a total of 21 soils samples were collected from 19 locations. Two

samples contained DRPs with a total Co-60 activity of 0.259 and 0.450 μCi. After removal of the DRPs from the soil, the NaI detector response returned to background, indicating capture of all contamination. One other sample exhibited an SOF greater than unity based on the $DCGL_{Op}$, but less than unity based on the $DCGL_{BC}$. All other individual ROC sample concentrations were either less than the analytical MDC or below the $DCGL_{Op}$. Based on the results of the July 2019 confirmatory survey, the study area contains residual radioactivity, and the results to the survey are provided herein for NRC's evaluation.

8. REFERENCES

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APPENDIX A
FIGURES

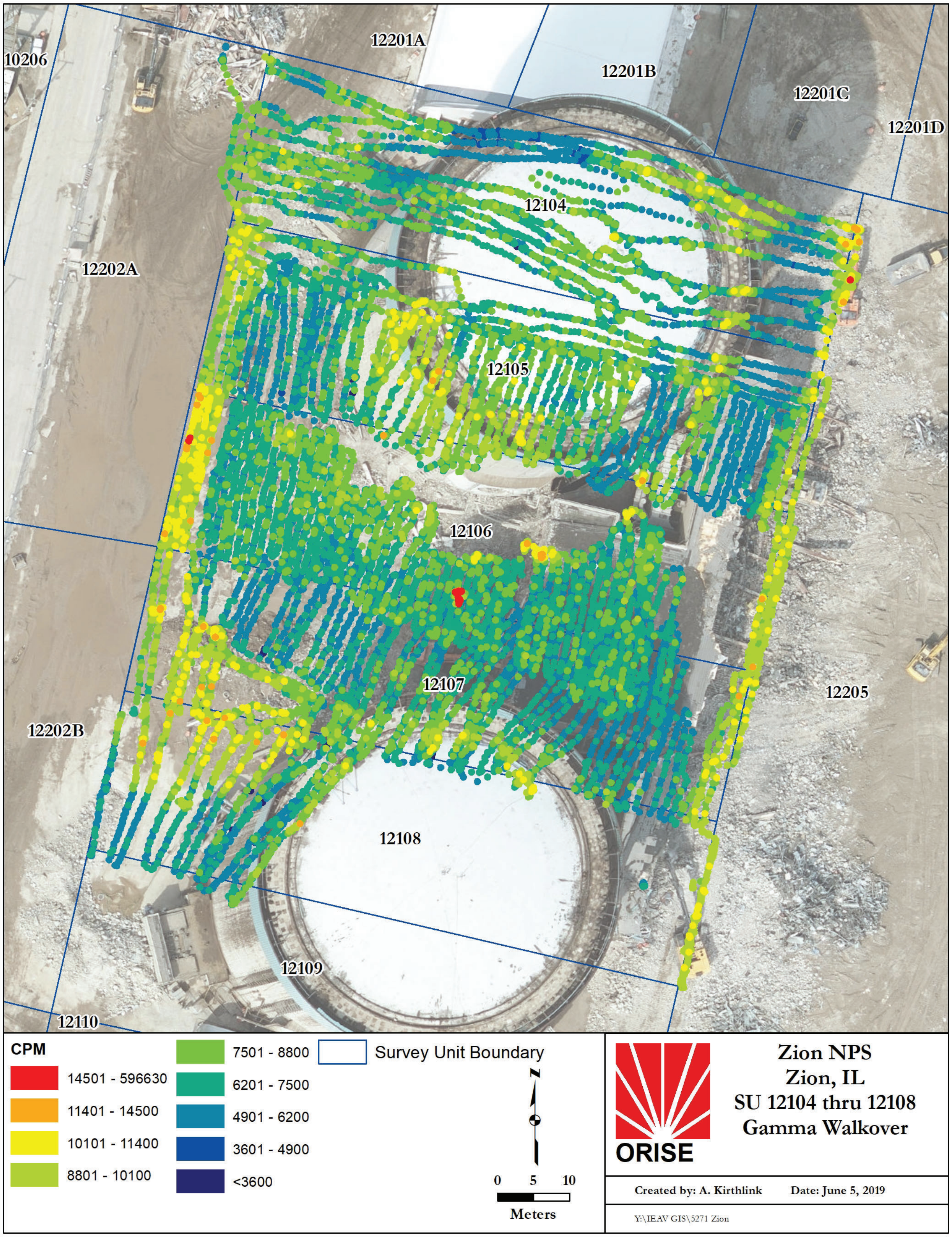

Figure A.1. Gamma Walkover Survey Performed During the April 2019 Site Visit

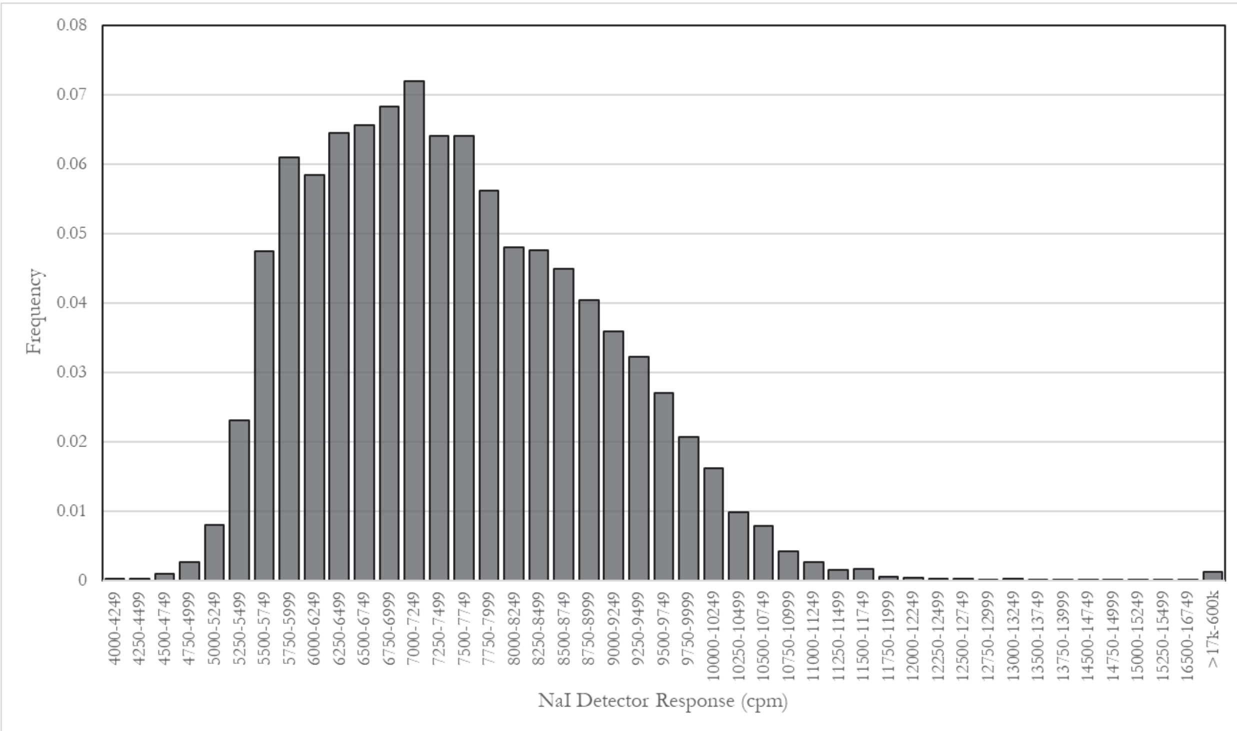

Figure A.2. Histogram of Scan Data from the April 2019 Site Visit

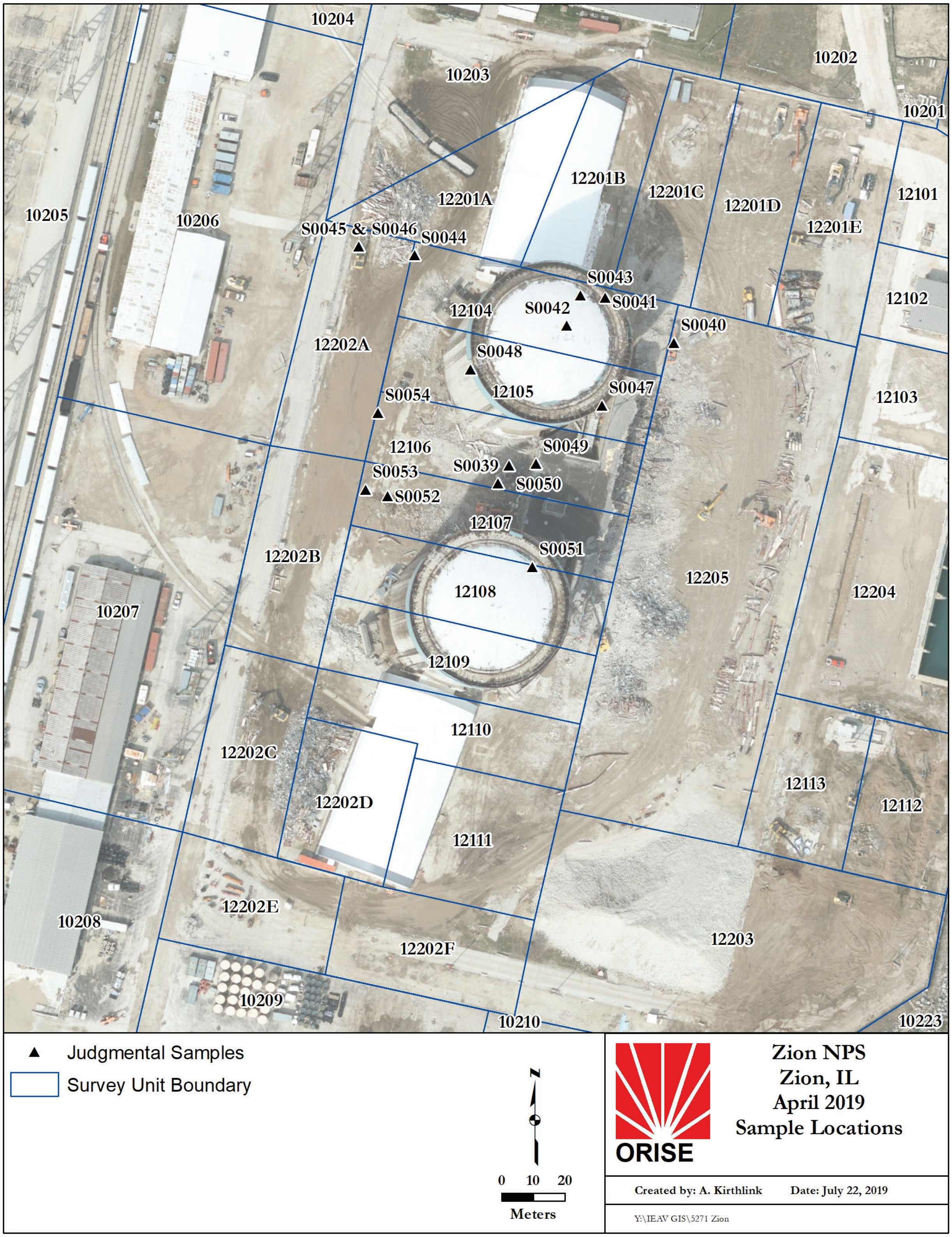

Figure A.3. Confirmatory Soil Sampling Locations from the April 2019 Site Visit

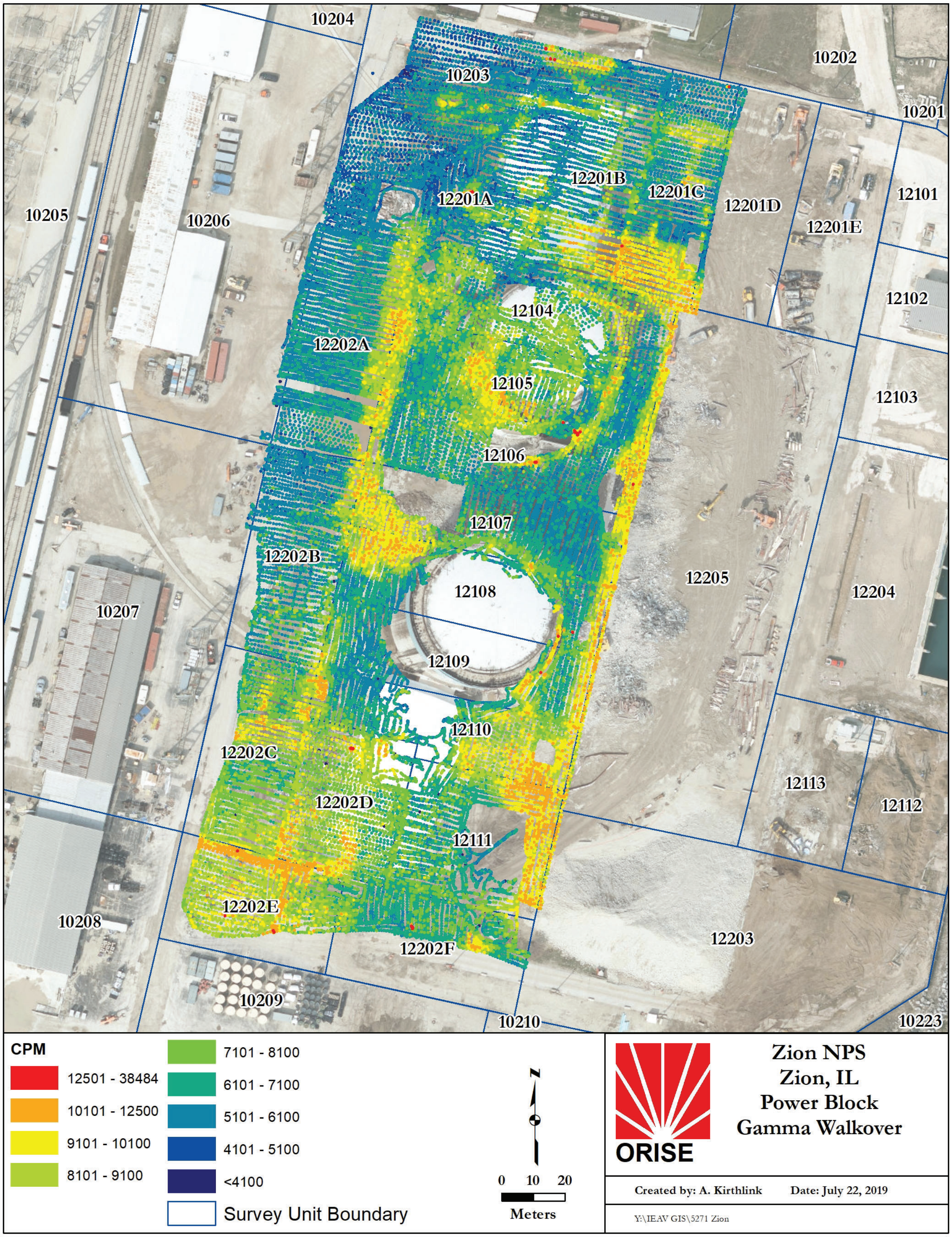

Figure A.4. Gamma Walkover Survey Performed During the July 2019 Site Visit

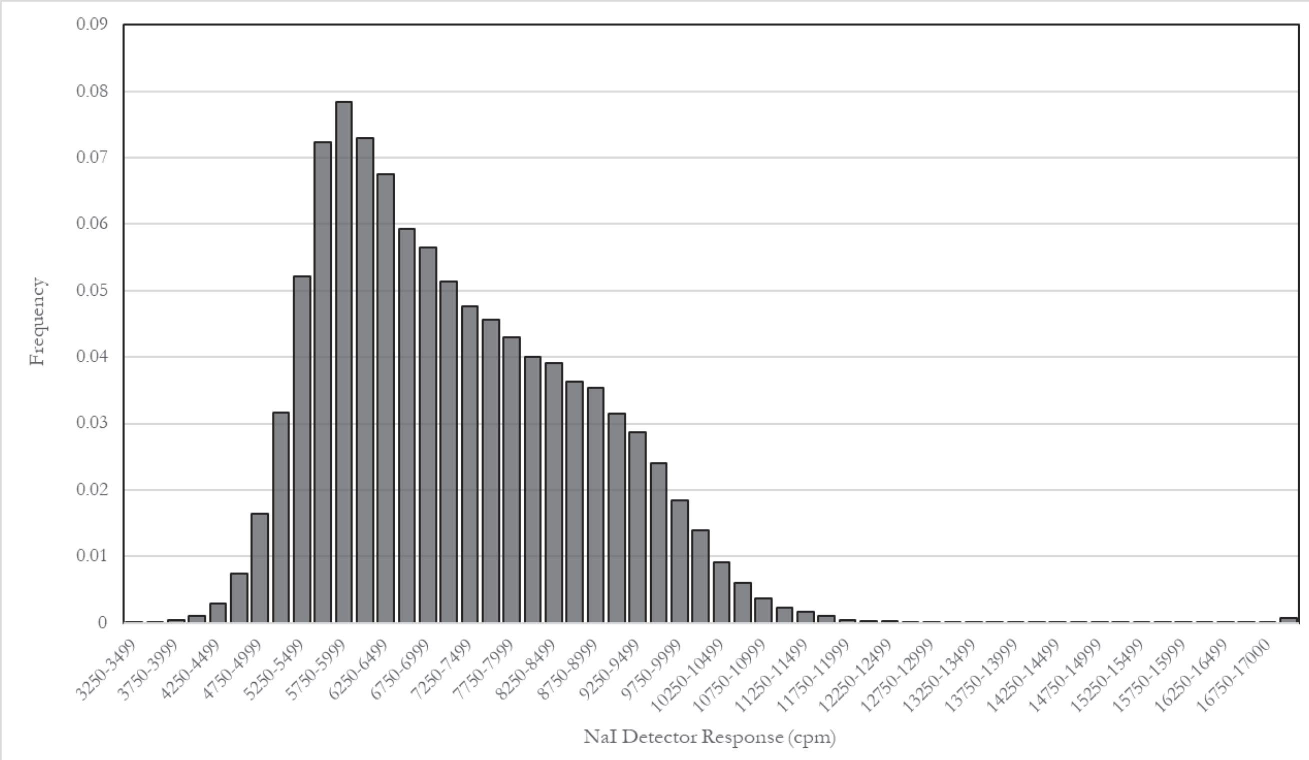

Figure A.5. Histogram of Scan Data from the July 2019 Site Visit

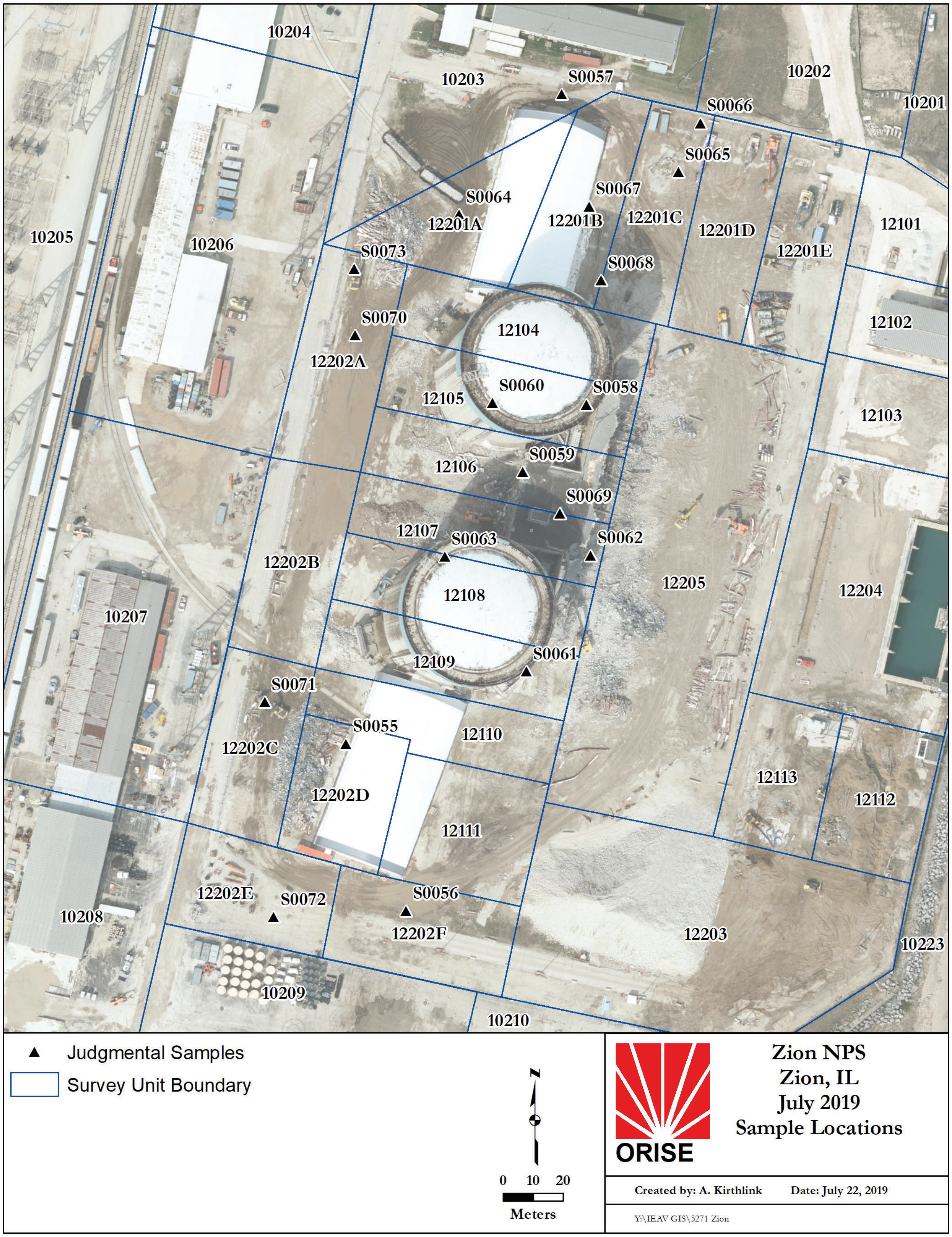

Figure A.6. Confirmatory Soil Sampling Locations from the July 2019 Site Visit

APPENDIX B
TABLES

Table B.1. Radionuclide Concentrations in Judgmental Confirmatory Soil Samples

Sample ID	Survey Unit	ROC Concentration and Uncertainty [a,b] (pCi/g)						SOF[c]	
		Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	Op	BC
April 2019 Site Visit									
5271S0040	12104	0.018 ± 0.025	0.016 ± 0.026	-0.010 ± 0.025	1.7 ± 1.1	0.01 ± 0.12	-1.7 ± 1.5	0.07	0.02
5271S0041	12104	-0.009 ± 0.022	-0.017 ± 0.013	0.004 ± 0.008	**2.3** ± 1.1	0.19 ± 0.13	-0.9 ± 1.7	0.46	0.12
5271S0042	12104	0.005 ± 0.026	0.022 ± 0.025	0.011 ± 0.018	1.34 ± 0.94	0.10 ± 0.12	-0.6 ± 1.2	0.27	0.07
5271S0043	12104	0.017 ± 0.021	0.028 ± 0.021	0.000 ± 0.018	**2.0** ± 1.1	0.11 ± 0.12	-0.9 ± 1.2	0.31	0.08
5271S0044	12104	0.012 ± 0.019	0.030 ± 0.020	**0.029** ± 0.011	1.56 ± 0.97	0.13 ± 0.13	-0.5 ± 1.0	0.37	0.09
5271S0045[d]	12202	**3.69** ± 0.26	-0.012 ± 0.065	**1,672** ± 94	-	-	-	847	217
5271S0046	12202	**0.303** ± 0.030	0.008 ± 0.016	**6.91** ± 0.41	**3.8** ± 1.1	0.13 ± 0.13	-0.2 ± 1.4	4.16	1.06
5271S0047	12105	-0.009 ± 0.023	-0.026 ± 0.015	-0.004 ± 0.012	1.2 ± 1.0	0.10 ± 0.12	-1.0 ± 1.2	0.24	0.06
5271S0048	12105	0.012 ± 0.021	0.040 ± 0.022	0.002 ± 0.011	1.6 ± 1.1	0.12 ± 0.12	-1.1 ± 1.2	0.34	0.09
5271S0049	12106	0.030 ± 0.024	0.038 ± 0.027	0.009 ± 0.007	1.3 ± 1.0	0.20 ± 0.13	-1.4 ± 1.2	0.55	0.14
5271S0050	12106	0.007 ± 0.020	-0.035 ± 0.016	0.009 ± 0.007	1.6 ± 1.1	0.11 ± 0.13	-1.1 ± 1.2	0.28	0.07
5271S0051	12107	-0.011 ± 0.029	0.035 ± 0.025	-0.031 ± 0.024	**1.8** ± 1.1	0.17 ± 0.13	-1.2 ± 1.1	0.44	0.11
5271S0052	12107	0.006 ± 0.025	-0.031 ± 0.018	0.001 ± 0.021	0.9 ± 1.0	0.09 ± 0.12	-0.7 ± 1.4	0.22	0.06
5271S0053	12107	-0.013 ± 0.024	0.010 ± 0.016	0.007 ± 0.019	**2.4** ± 1.1	0.15 ± 0.13	-0.6 ± 1.2	0.38	0.10
July 2019 Site Visit									
5271S0055	12202D	**0.062** ± 0.018	0.015 ± 0.019	**0.099** ± 0.019	0.46 ± 0.43	0.10 ± 0.11	0.6 ± 1.6	0.37	0.10
5271S0056	12202F	**0.069** ± 0.016	-0.008 ± 0.009	**0.138** ± 0.017	0.56 ± 0.43	0.05 ± 0.11	-0.4 ± 1.7	0.27	0.07
5271S0057	10203	0.001 ± 0.023	0.019 ± 0.025	-0.020 ± 0.017	-	-	-	0.02	0.00
5271S0058	12105	0.018 ± 0.024	0.017 ± 0.027	0.032 ± 0.013	-	-	-	0.05	0.01
5271S0059	12106	-0.016 ± 0.024	0.026 ± 0.026	-0.002 ± 0.018	0.04 ± 0.40	0.00 ± 0.10	-1.0 ± 1.3	0.02	0.01
5271S0060	12105	-0.001 ± 0.023	0.036 ± 0.025	-0.002 ± 0.019	-	-	-	0.03	0.01
5271S0061	12109	0.001 ± 0.025	-0.043 ± 0.018	-0.011 ± 0.022	-	-	-	0.00	0.00

Table B.1. Radionuclide Concentrations in Judgmental Confirmatory Soil Samples

Sample ID	Survey Unit	ROC Concentration and Uncertainty [a,b] (pCi/g)						SOF[c]	
		Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	Op	BC
5271S0062	12107	-0.004 ± 0.005	-0.033 ± 0.018	-0.016 ± 0.020	-	-	-	0.00	0.00
5271S0063	12108	-0.004 ± 0.026	-0.023 ± 0.014	**0.043** ± 0.014	0.05 ± 0.42	0.11 ± 0.11	-0.9 ± 1.2	0.28	0.07
5271S0064	12201A	0.017 ± 0.025	0.041 ± 0.026	0.013 ± 0.014	-	-	-	0.06	0.02
5271S0065	12201C	0.016 ± 0.021	0.020 ± 0.023	-0.014 ± 0.018	-	-	-	0.04	0.01
5271S0066	12201C	0.009 ± 0.015	0.015 ± 0.016	0.008 ± 0.009	-	-	-	0.03	0.01
5271S0067	12201B	-0.007 ± 0.023	-0.016 ± 0.014	0.035 ± 0.012	0.05 ± 0.41	0.02 ± 0.10	0.3 ± 1.3	0.06	0.02
5271S0068	12201C	-0.001 ± 0.031	0.034 ± 0.021	-0.030 ± 0.030	-	-	-	0.03	0.01
5271S0069	12106	-0.003 ± 0.007	-0.015 ± 0.014	0.041 ± 0.013	0.04 ± 0.41	0.10 ± 0.11	-0.2 ± 1.5	0.26	0.07
5271S0070	12202A	0.016 ± 0.016	0.014 ± 0.015	0.034 ± 0.011	0.07 ± 0.40	-0.020 ± 0.086	0.5 ± 1.3	0.05	0.01
5271S0071	12202C	-0.016 ± 0.034	0.022 ± 0.034	0.005 ± 0.028	-	0.03 ± 0.10	-	0.09	0.02
5271S0072	12202E	0.001 ± 0.023	-0.031 ± 0.017	-0.018 ± 0.020	-	-	-	0.00	0.00
5271S0073	12202A	**0.511** ± 0.046	0.003 ± 0.020	**1.70** ± 0.11	**1.68** ± 0.46	-	0.6 ± 1.6	1.45	0.37

[a]Uncertainties represent the total propagated uncertainties reported at the 95% confidence level
[b]Bolded values indicate the result was above the analytical MDC
[c]The SOF calculation does not include the fractional contribution from tritium
[d]Sample result is approximate

APPENDIX C
SURVEY AND ANALYTICAL PROCEDURES

C.1. PROJECT HEALTH AND SAFETY

The Oak Ridge Institute of 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*, and (ORAU 2014, ORAU 2016a, and ORAU 2016b). 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 2016a) 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.

C.2. CALIBRATION AND QUALITY ASSURANCE

Calibration of all field instrumentation was based on standards/sources traceable to the 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 2016a)
- *ORAU Environmental Services and Radiation Training Quality Program Manual* (currently ORAU 2019a)
- *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (currently ORAU 2019b)

The procedures contained in these manuals were developed to meet the requirements of U.S. Department of Energy (DOE) Order 414.1D and the NRC *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

C.3. SURVEY PROCEDURES

C.3.1 Surface Scans

Scans for elevated gamma radiation were performed by passing the detector slowly over the surface. The distance between the detector and surface was maintained at a minimum. The sodium iodide (NaI) scintillation detectors were used solely as a qualitative means to identify elevated radiation levels in excess of background. Identifications of elevated radiation levels that could exceed the localized background were determined based on an increase in the audible signal from the indicating instrument and/or were identified after post-processing the scan data while the team was still at the site.

C.3.2 Soil Sampling

Soil samples (approximately 0.5 kilogram each) were collected by ORISE personnel using a clean garden trowel 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. Where applicable, discrete particles exhibiting elevated radioactivity were isolated and containerized separately from the original sample volume prior to leaving the site.

C.4. RADIOLOGICAL ANALYSIS

C.4.1 Gamma Spectroscopy

Samples were analyzed as received homogenized, and/or crushed as necessary, and a dry portion sealed into an appropriate volume Marinelli beaker or container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined and the samples 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 radionuclides and the typical associated minimum detectable concentrations (MDCs) for 1-hour count times are presented in Table C.1.

Table C.1. Typical MDCs Total Absorption Peaks

Radionuclide	TAP (MeV)[a]	MDC (pCi/g)
Co-60	1.332	0.06
Cs-134	0.795	0.06
Cs-137	0.662	0.05

[a]MeV = mega electron volt

C.4.2 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 then removed by running the slurry via anion exchange chromatography. Nickel was then separated from the slurry using a nickel selective resin cartridge. The purified nickel was then eluted off of the column with a dilute nitric acid solution. Ni-63 activity was then determined via liquid scintillation counting. The typical MDC for a 1-gram sample and 60-minute count time using this procedure is 1.8 picocuries per gram (pCi/g).

C.4.3 Radioactive Strontium Analysis

Strontium-90 (Sr-90) concentrations were quantified by total sample dissolution followed by radiochemical separation and counted on a low background 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 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 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 0.4-0.6 pCi/g for a 1 gram sample.

C.4.4 H-3 Analysis

Tritium (H-3) analysis for the soil samples was performed using a material oxidizer and counted by liquid scintillation. The material oxidizer combusts samples in a stream of oxygen gas and passes the products (including CO_2 and H_2O vapor), through a series of catalysts. The 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 3–5 pCi/g.

C.4.5 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.

APPENDIX D
MAJOR INSTRUMENTATION

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

D.1. SCANNING AND MEASUREMENT INSTRUMENT/ DETECTOR COMBINATIONS

D.1.1 Gamma

Ludlum NaI 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)

D.2. LABORATORY ANALYTICAL INSTRUMENTATION

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

High-Purity, Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-45200-5
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-30P4
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

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

Liquid Scintillation Counter
Perkin Elmer Tricarb 5110TR
(Perkin Elmer, Waltham, Massachusetts)