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September 3, 2021

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SUBJECT: **CONTRACT NO. DE-SC0014664**
INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS ASSESSING THE PRESENCE OF RESIDUAL RADIOACTIVITY AND RADIOACTIVE PARTICLES WITHIN SELECT LAND AREAS AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS
DOCKET NOs. 50-295 and 50-304; RFTA No. 18-004
DCN 5271-SR-09-0

Dear Ms. Conway:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the enclosed final report detailing the confirmatory survey activities to assess the presence of residual radioactivity and particles within land areas at the Zion Nuclear Power Station in Zion, Illinois.

U.S. Nuclear Regulatory Commission staff comments have been incorporated into this revised, final version. 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
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N. A. Altic, CHP
ORISE

FINAL REPORT

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SEPTEMBER 2021

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This document was prepared for the U.S. Nuclear Regulatory Commission by the Oak Ridge Institute for Science and Education (ORISE) through interagency agreement number 31310018N0014 with the U.S. Department of Energy (DOE). ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-SC0014664.

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FINAL REPORT

SEPTEMBER 2021

CONTENTS

FIGURES

TABLES

ACRONYMS

Am-241	americium-241
Ba-133	barium-133
CFR	Code of Federal Regulations
cm	centimeter(s)
Co-60	cobalt-60
Cm-244	curium-244
cpm	counts per minute
Cs-134	cesium-134
Cs-137	cesium-137
CSU	confirmatory survey unit
DCGL	derived concentration guideline level
DOE	U.S. Department of Energy
DQO	data quality objective
DTPA	Diethylenetriaminepentaacetic Acid
EDTA	Ethylenediaminetetraacetic Acid
Eu-152/154/155	Europium-152/154/155
Exelon	Exelon Generating Company
FSS	final status survey
GM	Geiger-Muller
GPS	global positioning system
HCL	Hydrochloric Acid
HDPE	high-density polyethylene
HTD	hard-to-detect
ID	unique identifier
IL	investigation level
ISFSI	independent spent fuel storage installation
L	liter
LTP	license termination plan
m^2	square meter(s)
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MeV	Mega electron Volt
µm	micrometer
mL	milliliter
NaI[Tl]	thallium-doped sodium iodide
Ni-63	nickel-63
NIST	National Institute of Standards and Technology
NORM	naturally occurring radioactive material
Np-237	neptunium-237
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocurie per gram
Pu-238	plutonium-238
Pu-239/240	plutonium-239/240

Pu-241	plutonium-241
Pu-242	plutonium-242
PVDF	Polyvinylidene difluoride
Q	quantile
Ra-228	radium-228
REAL	Radiological and Environmental Analytical Laboratory
RESL	Radiological and Environmental Sciences Laboratory
ROC	radionuclide of concern
RRA	radiologically restricted area
SPM	Survey Procedures Manual
Sr-90	strontium-90
SU	survey unit
TAP	total absorption peak
Th-228/232	thorium-228/232
TPU	total propagated uncertainity
U-233/234	uranium-233/234
VSP	Visual Sample Plan
ZNPS	Zion Nuclear Power Station
ZS	Zion*Solutions*, LLC

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1. INTRODUCTION

The Zion Nuclear Power Station (ZNPS) consisted of two reactors, Unit 1 and Unit 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 a spent-fuel pool. Both units then were 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 Generating Company (Exelon) to Zion*Solutions*, LLC (ZS) to allow the physical decommissioning process.

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 primarily of 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 Title 10 of the Code of Federal Regulations (10 CFR) 20.1402, ZS implemented final status survey (FSS) activities of remaining basement structures along with associated embedded piping, building penetrations, and buried piping. FSS activities for the soils has also been completed by ZS. FSS methodologies are outlined in Chapter 5 of ZS's license termination plan (LTP) (ZS 2018) and methods are based on those outlined in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000).

In April 2021, NRC staff requested that Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities within select land areas of the site. The focus of this limited confirmatory survey was to assess residual radioactivity levels and the presence of radioactive particles in specific areas of the site, including survey units (SUs) where concrete debris was stored after the licensee performed FSS. NRC will use the confirmatory survey data for their decision making, as described in Section 3.

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 (330 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 are 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).

Major decommissioning activities at ZNPS are now complete. As such, all above-grade structures have been removed and the associated excavations have been backfilled. Figure 2.1 provides recent satellite imagery depicting current site conditions. The former radiologically restricted area (RRA) boundary and former security restricted area are superimposed on Figure 2.1. The area within the former security restricted area fence contained the principal components of the power plant, including the two containment structures, the turbine building, auxiliary building, crib house, and waste-water treatment facility. The site subdivided land areas into FSS SUs.

Figure 2.1. ZNPS Overview (adapted from ZS 2018)

3. PROCEDURES

The ORISE and NRC (staff from Region III and headquarters) survey team performed visual inspections, measurements, and sampling activities at ZNPS. The primary objective of the confirmatory survey was to determine if radioactive particles were present within land areas selected by NRC staff. Based on the overall survey objective, a presence/absence sampling—also known as compliance sampling or acceptance testing—formed the basis of the survey design to determine if radioactive particles of cobalt-60 (Co-60) were present within land areas selected by NRC staff based

on past cobalt-60 particle releases. Also, the licensee's previous determination of the types and activity levels of radionuclides remaining on the site was taken into consideration. In summary, the presence/absence sampling approach involved subdividing each survey area into equally sized grids of 100 square meters (m^2) and selecting the appropriate number of grid cells for investigation. The number of grids that required investigation was dependent on the desired confidence and desired percentage of acceptable area (i.e., percentage of total area that does not contain a particle). This presence/absence survey was performed for a limited fraction of the site (i.e., approximately 3% of the total site area was covered by the random/systematic grid cells). The FSS SUs were further segregated (in addition to the MARSSIM classification) as either Group 1—areas not expected to contain Co-60 particles or Group 2—areas that may contain Co-60 particles. The SUs were delineated into three confirmatory survey units (CSUs) for the presence/absence evaluation. CSUs are depicted in Figure A.1 in Appendix A. Additional information related to the survey design and selection of the grid cell sample set is provided in Section 3.2.

Survey activities were conducted in accordance with the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual* (SPM) and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2016a and ORAU 2021a). Appendices C and D provide additional information regarding survey instrumentation and related processes discussed within this section.

3.1 REFERENCE SYSTEM

ORISE referenced confirmatory measurement/sampling locations to global positioning system (GPS) coordinates using the Illinois East state plane 1201 NAD 1983 (meters). Other prominent site features also were referenced. Measurement and sampling locations were documented on detailed survey maps.

3.2 MEASUREMENT/SAMPLING LOCATIONS

Visual Sample Plan (VSP), version 7.12a, was used to calculate the required number of samples. The survey design for the compliance sampling effort (Group 1 CSUs) was sufficient to demonstrate that 95% of the decision area was acceptable at the 95% confidence level. VSP planning inputs and outputs are presented in Figure 3.1. Grid cell locations for CSU 1 are presented in Appendix A, Figure A.2. Due to the systematic layout of the grid cells, VSP populated CSU 1 with 59 grid cells.

VSP placed grid cell 47 outside of the CSU 1 boundary. Rather than re-generating the grid cell layout, grid cell 47 was not surveyed.

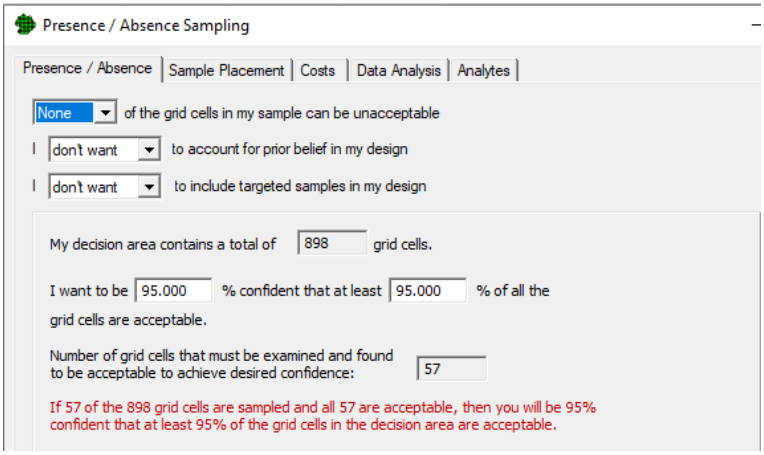

Figure 3.1. VSP Inputs for Presence/Absence Compliance Sampling (Group 1 CSUs)

The survey design for the acceptance sampling effort (Group 2 CSUs) was sufficient to demonstrate that 90% of the decision area was acceptable at the 95% confidence level, with no more than 2.5% (4) of the grid cells containing a particle. A lower threshold for grid cell acceptance, relative to compliance sampling (90% vs 95%), was selected based on the elevated potential for a particle and to optimize field survey resources. VSP planning inputs and outputs are presented in Figure 3.2. Grid cell locations for CSU 2 are presented in Appendix A, Figure A.3. Due to the systematic layout of the grid cells, VSP populated CSU 2 with 88 grid cells.

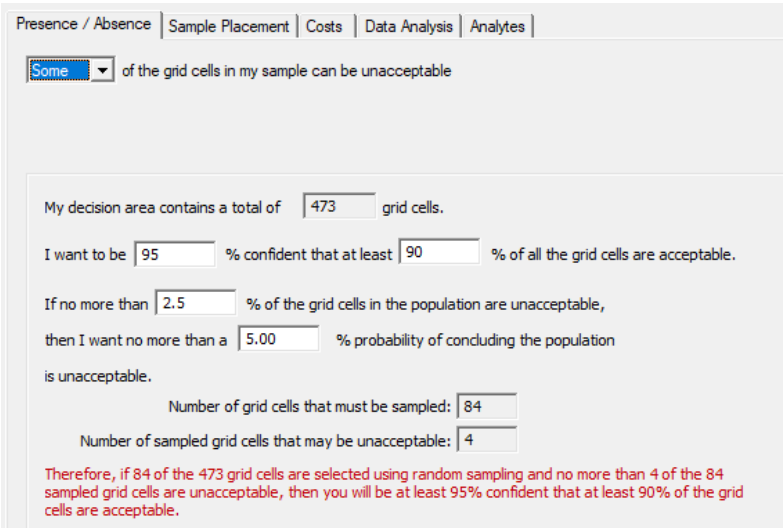

Figure 3.2. VSP Inputs for Presence/Absence Compliance Sampling (Group 2 CSUs)

CSU 3 consists of the switchyard, the majority of which was not accessible due to the presence of high-voltage electrical equipment. Rather than performing grid cell investigations, surveys were limited to gamma walkover scans of safely accessible areas and judgmental soil sampling, see additional information in Section 3.3 regarding confirmatory survey activities in CSU 3.

3.3 SURFACE SCANS

Surface scans were performed with Ludlum model 44-10 2-inch by 2-inch thallium-doped sodium iodide NaI[Tl], referred to as NaI, scintillation detectors coupled to Ludlum model 2221 ratemeter-scalers with audible indicators. Ratemeter-scalers also were coupled to GPS systems that enabled real-time gamma count rate and geo-referenced data capture. Scan data for each area investigated were not always electronically captured—NRC staff did not use GPS equipment, and the ORISE survey team experienced technical difficulties with the equipment. Scan data were electronically captured in approximately 80% of the investigated grid cells within CSU 1 and CSU 2. Locations of elevated response that were audibly distinguishable from localized background levels, suggesting the presence of residual contamination, were marked for further investigation. Scan coverage was high-density within the selected 10-m by 10-m grid cell, as the presence of a particle in the grid served as the basis for the presence/absence data assessment. Surface scans performed outside of the grid cells were less dense than those scans performed within the grid cells, such as those surveys performed in the southern portion of the site. For surveys in the switchyard, ORISE surveyors removed their GPS equipment due to safety concerns working in close proximity to the high-voltage equipment that covered most of the surface area of the switchyard. Although survey instrumentation functioned properly, overall scan survey coverage was limited in this area (less than 5% coverage of the total SU area), and was not uploaded for further analysis.

To maximize the particle scan sensitivity, surveys were performed with a slow scan speed (nominally 0.25 m/s). The detector height was not more than 7.5 cm (3 in) above the ground. Because the investigation level (IL) was defined as gamma count rates distinguishable from localized background, surveyors used headphones to aid in surveyor vigilance. The survey team paid attention to soil type while performing surface scans, as the land areas at Zion contained multiple soil types with varying background gamma radiation levels. Lead collimators were not used on the Ludlum 44-10 detectors by all surveyors or in all site areas. A wide range of discrete particles activities and radionuclide

compositions were found with and without collimators by several ORISE surveyors and NRC staff during this survey.

In addition to the particle presence/absence determination, identifying residual volumetric contamination also was a study objective. The surface scanning methodology for identifying Co-60 particles also provided sufficient sensitivity to identify volumetric contamination for the radionuclides of concern (ROCs) previously identified by the licensee, assuming an established ratio with gamma-emitting radionuclides (Tables 6-2 and 6-32 of the LTP; ZS 2018) that are detectable with the NaI detectors used in this survey. Appendix D provides additional information related to the scan sensitivity for volumetric contamination.

Additionally, low-density judgmental gamma scans were performed in areas identified by NRC staff. These additional areas were primarily FSS SUs within the former power-block, south of the former Unit 1 Containment Building, and also along the former haul road. The scan density of these surveys was limited based on the amount of time remaining due to environmental conditions.

3.4 INVESTIGATION OF ANOMALIES

Based on prior ORISE experience, a particle that is present near the land surface produces an obvious increase in audible detector response (e.g., a NaI detector response above 20,000 counts per minute [cpm]). However, consideration must be given to areas exhibiting a slight, but localized, increase in detector response relative to background. The general protocol for investigating these subtle anomalies, which may represent the presence of a particle at depth or of lower activity, was to remove the top layer of soil (nominally 5 cm), place it aside, and then re-scan the area. A sharp increase in detector response during the re-scan from the area where the top layer of soil was removed could indicate the presence of a particle, and, if so, the surveyor would continue the investigation. The total surface area of soil that was removed for the investigation depended on field conditions; however, a nominal area of approximately 200–300 cm^2 was generally sufficient.

A total of seven suspected particles were collected during this survey (two were collected by NRC staff; five were collected by the ORISE survey team). When a single particle was found by a surveyor during the survey, the surveyor looked for more particles in that immediate area (a radial distance of about 2 m from the particle location). Particles were isolated in the field, to the extent possible, and captured in a separate container. If no additional particles were found, the only action was to collect

the particle in the soil sample and then confirm the particle was within the soil sample container after collection.

Numerous other anomalies not associated with the presence of a particle, based on the field investigation, were flagged for potential judgmental sampling. These anomalies were suspected to be associated with the presence of naturally occurring radioactive material (NORM). Thirty-two of these flagged locations were sampled in accordance with Section 3.5.

3.5 SOIL SAMPLING

Volumetric surface soil samples were collected using hand trowels. A hammer and chisel were used, as needed, to break up the surface soil layer. All sampling equipment was decontaminated in the field after the collection of each sample to prevent cross-contamination. Prior to soil sampling, a static gamma radiation 1-minute count was performed, then the surface soil sample was collected at a depth of 0 to 15 cm, followed by a static gamma radiation measurement at the 15-cm depth. At the ORISE sampling locations, approximately 1 kilogram of soil was collected in either a 1 liter (L) high-density polyethylene (HDPE) bottle or a 6 millimeter thick poly re-sealable bag. NRC staff collected their samples in a 500 mL Marinelli container. After collection, samples were labeled with a unique identifier (ID). The sample ID format for ORISE-collected samples was 5271SNNNN, where 5271 is an ORISE-specific site code, S signifies a soil-related sample, and NNNN is a sequential sample number for the site code. NRC staff collected samples using a similar format of 5271-S-NNN. ORISE-collected samples were numbered in the 100 series; NRC-collected samples were numbered in the 200 series. The first ORISE sample collected was 5271S0112, and the first NRC staff collected sample was 5271-S-200. For ease of reference in this report, sample IDs are referred to without the "5271" or "-." For example, the first ORISE sample is referenced as S0112, and the first NRC sample is referenced as S200.

Derived concentration guideline levels (DCGLs), as approved in the LTP, are presented in Table 3.1. Soil DCGLs were defined only for select ROCs (cesium 134/137 [Cs-134/137], Co-60, nickel-63 [Ni-63], and strontium-90 [Sr-90]), and they take into account adjustments for an assumed level of radioactivity from “insignificant radionuclides” as per Table B.1 presented in Appendix B. The DCGLs in Table 3.1 are not applicable to total activity results for a particle due to the specific set of assumptions under which the DCGLs were developed.

Table 3.1. ZNPS Surface Soil DCGLs (pCi/g)[a]		
Radionuclide	**Base Case**	**Operational**
Co-60	4.3E+00	1.1E+00
Cs-134	6.8E+00	1.7E+00
Cs-137	1.4E+01	3.6E+00
Ni-63	3.6E+03	9.1E+02
Sr-90	1.2E+01	3.1E+00

[a]Source: ZS 2018, Table 5-5 and Table 5-7

4. SAMPLE ANALYSIS AND DATA INTERPRETATION

ORISE-collected samples were transferred under chain of custody to the Radiological and Environmental Analytical Laboratory (REAL) in Oak Ridge, Tennessee, for analysis. NRC-collected samples were transferred under chain of custody to the Radiological and Environmental Sciences Laboratory (RESL) in Idaho Falls, Idaho, for analysis.

4.1 LABORATORY ANALYSIS

Analyses for samples submitted to REAL were performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2021b). Samples submitted to RESL were analyzed in accordance with RESL's *Analytical Procedures Manual* and analytical procedures contained in the following publications: Sill D.S., Sill C.W. 1994; Sill D.S., Bohrer S.E. 2000.

4.1.1 Sample Preparation

Samples collected to assess volumetric radionuclide concentrations were processed per standard laboratory protocols and procedures. Soil samples were dried, homogenized or crushed, as necessary, and packaged into calibrated geometries.

Laboratory staff manually segregated the suspected particle samples to isolate the sample portion exhibiting elevated, direct gamma radiation from the non-contaminated sample matrix. The contents of the sample container were emptied onto a white pan with elevated sides to minimize potential for material loss. A Ludlum model 44-9 Geiger-Muller (GM) probe and/or Ludlum model 44-10 collimated NaI detector were used to isolate the general area containing elevated activity. The

isolated material was then serially separated by half until only a small number of mono-layered particles were present. Staff then used standard office tape to trap the suspect particle(s) due to their highly mobile properties in the laboratory setting. REAL staff made a collective decision as to when a sufficient level of isolation was achieved. At the time, complete isolation was determined unnecessary in order to prevent contamination of laboratory facilities. All five particle samples analyzed by REAL were classified as "High Activity"[1] samples, as stated in the REAL Laboratory Manual, which require special handling protocols to protect laboratory infrastructure from potential contamination.

4.1.2 Sample Analysis

All samples were analyzed by high-resolution gamma spectrometry for ZNPS ROCs and select naturally occurring radionuclides. The isolated particles were analyzed in a calibrated point-source geometry. Based on the gamma spectrometry results, additional analyses were performed after discussion with NRC staff. RESL personnel performed similar techniques to isolate the europium-152 (Eu-152) and Eu-154-containing particle from sample S204A.

Select volumetric soil samples were analyzed for plutonium-238 (Pu-238), Pu-239/240, neptunium-237 (Np-237), americium-241 (Am-241), and curium-244 (Cm-244) by alpha spectrometry after chemical separation. The same select samples were analyzed for Sr-90 using a low background gas-flow proportional counter after chemical separation. Particle samples were analyzed for the same constituents after total dissolution. Appendix D provides additional information on the analyses performed, and Table D.1 provides a summary of the analyses by sample.

Analytical results for volumetric samples were reported in units of picocuries per gram (pCi/g) and pCi/sample for the particles.

4.2 DATA REPORTING AND PRESENTATION

Scan and soil sample data were graphed in quantile (Q) plots, Figure 5.1, and strip charts, Figure 5.5 respectively, for data assessment. The Q-plot is a graphical tool for assessing the distribution and variability of a data set(s). The Y-axis represents the gamma detector response in units of cpm for

[1] The term High Activity is defined as greater than 50 times the established background for the hand-held detector used to screen the sample. This term is only applicable to REAL procedures and is related to the determination of how the samples are processed to prevent cross-contamination.

scan data. The X-axis represents the data quantiles about the mean value. Values less than the mean are represented in the negative quantiles; 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. Data collected as part of this survey were archived by ORISE.

Select soil sample analytical results were plotted using strip charts, often referred to as one-dimensional scatter plots. The Y-axis is the soil sample radionuclide concentration in units of pCi/g. The X-axis of the strip chart is dimensionless.

5. FINDINGS AND RESULTS

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

5.1 SURFACE SCANS AND GRID CELL INVESTIGATION

Figure 5.1 presents a Q-plot summarizing the gamma walkover survey data collected during this confirmatory survey. The corresponding gamma walkover maps for CSU 1, CSU 2, CSU 3 perimeter, and the power-block are presented in Appendix A. Grid cells identified with the red hash mark in Figure A.4 and Figure A.5 were scanned; however, electronic scan data were not captured. The NaI detector response range, reported by the surveyor, are presented on the map for these grid cells. The gamma walkover maps are simply a tool to provide a qualitative overview of the gamma survey results. Decisions related to the presence of contamination were made in real time by the surveyor during the site visit. Scan results for each survey area are summarized in the following discussion. A portion of CSU 1 along the rock sea-wall was scanned with an uncollimated NaI detector due to the presence of vegetation that prevented lateral movement of the collimated detector. NaI detector response for the un-collimated survey is presented separately from the collimated scans.

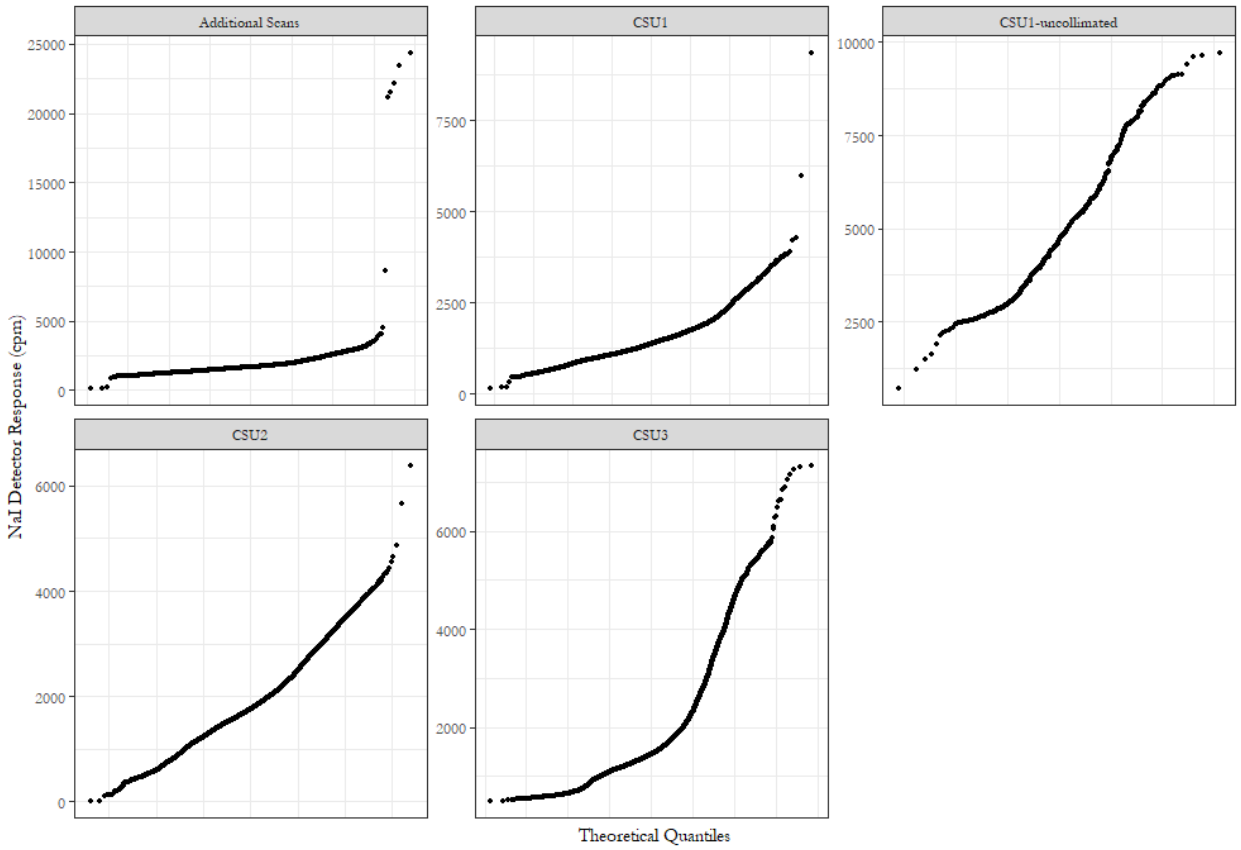

Figure 5.1. Q-Plot of Gamma Walkover Survey Data for Each Survey Area

5.1.1 CSU 1 Scan Summary

Field investigations conducted in CSU 1 were completed in 56 of the 57 required grids (Section 3.2 describes why one grid cell was not investigated). An overview of the gamma walkover surveys is provided in Figure A.4. Several grids were relocated due to their location in Lake Michigan. These grids were shifted west until they were in an accessible land area. Figure A.4 illustrates the approximate location of the relocated grids. Scan coverage objectives within CSU 1 grid cells were satisfied.

Two locations within CSU 1 were flagged for exhibiting elevated direct radiation consistent with the presence of a particle. Follow-up investigation included removing the surface material and isolating the material responsible for the direct gamma radiation levels. Suspected particles at these locations were collected (as S0124 and S204) based on the isolated nature of the direct gamma, reduction in direct gamma radiation to background levels after removal of the suspected particle, and the collected sample exhibiting elevated direct gamma radiation. Neither of these particles were from locations

within a planned survey grid cell. S204 was identified first in SU 12201B as a result of supplemental surveys performed by NRC staff, and S0124 was identified, also in SU 12201B, as a result of increased scan coverage in response to the first identified particle in SU 12201B. Additional scan coverage was performed around the location of S0124, and no anomalies were identified. Due to an issue with the hand-held GPS unit, the follow-up scans for each identified particle are not presented in Figure A.4. Table 5.1 in Section 5.2 provides additional information related to these samples collected from CSU 1. SUs from which the suspected particles were collected are also identified in Table 5.1.

Two locations from SU 10220C (S0127 and S0212) and one location each from SU 10222 (S0214) and SU 10224 (S0213) were flagged for follow-up investigation via judgmental sampling. These locations were not flagged based on suspicion of a particle, but, rather, an increase in NaI detector background count rate. GPS coordinates were not collected for S0212, S0213, and S0214; however, the approximate sample locations are shown in Figure A.9. Another two locations in SU 10223—along the east side of the silt fence, separating CSU 1 from the main plant area—were flagged for subsequent judgmental soil sampling. Samples (S0123 and S0130) were collected from these locations based on an increase in NaI detector background and were from the white clay-like soil. Additional samples of the same material were collected west of the silt fence based on similar NaI response characteristics; see Section 5.1.2 for additional discussion.

5.1.2 CSU 2 Scan Summary

All of the required 84 grid cells were investigated; an additional 4 grid cells were investigated based on the systematic grid cell layout, for a total of 88 grid cells investigated. An overview of the gamma walkover surveys for this CSU is provided in Figure A.5. Generally, higher NaI detector responses—relative to the other grid cells in this CSU—were observed in grid cells near the independent spent fuel storage installation (ISFSI). The ISFSI is known to store radioactive material; thus, elevated gamma radiation in this area was expected. Scan coverage objectives (i.e., high-density coverage, as described in Section 3.2) within the CSU 2 grid cells were met, with the exception of grid cell 84. Approximately 25% of grid cell 84 was blocked by the security fence. Rather than access the remaining area, scan coverage around the grid cell was expanded to account for the unassessed portion across the fence.

A total of five locations within CSU 2 were flagged for exhibiting elevated direct radiation consistent with the presence of a particle. There was not a consistent NaI detector response, relative to particle activity (see Section 5.2.2 for additional details related to particle analytical results), between the flagged locations due to a number of variables, including depth from land surface, activity, and radionuclide composition. Of the five locations flagged for additional investigation, three were located within the CSU 2 grid cells. These three suspect particles were collected from grid cells 09 (S0112A), 66 (S0120), and 88 (S0116) (Figure A.8). The additional two suspected particle locations were flagged during supplementary surface scans performed by NRC and ORISE staff. The fourth suspected particle was in SU 10204B (S203) near the northern portion of CSU 2; gamma scans related to this suspect particle were not electronically captured. The fifth suspected particle was collected from SU 12203A (S0126) during supplemental scans directed by NRC staff; scan data associated with this suspect particle are presented in Figure A.5. The portion of the scans that identified the particle was included in the CSU 2 boundary, which is the rationale for presenting this suspect particle in this report section.

At all five suspected particle locations in CSU 2, the surveyors were able to collect the discrete material exhibiting the elevated direct gamma radiation. As with the two suspected particles collected in CSU 1, once the material was removed from the soil, the direct gamma radiation levels were reduced to background levels and the sample produced all of the elevated direct gamma radiation. Table 5.1 in Section 5.2 provides additional information related to these samples collected from CSU 2. Scan coverage was expanded surrounding each suspect particle location with the exception of grid cell 09. This suspect particle was collected from approximately the center of the grid cell and, as such, additional coverage was unnecessary because the distance from the particle location to the grid cell boundary was greater than the radial distance of the extended survey coverage in response to the identification of discrete particle during this survey.

5.1.3 CSU 3 Scan Summary

Figure A.6 presents the gamma walkover survey results for the area outside of the switchyard boundary. These scans were conducted outside of CSU 3—as CSU 3 is defined as the area inside of the switchyard fences. However, these scans are presented along with CSU 3 results due to close spatial proximity. Scan density inside and surrounding the switchyard was low density and covered less than 10% of CSU 3. Due to safety concerns with the active electrical equipment, surveyors

entering the switchyard were advised not to bring GPS equipment inside; therefore, the scan data was not electronically captured. No suspected particles were identified within the CSU 3 boundary or within the exterior boundary scans. Three locations were flagged for follow-up investigation inside the switchyard via judgmental soil sampling. These locations were not selected based on the surveyors' determination of contamination, but were flagged to generate negative data. The flagged locations represent the highest relative direct gamma radiation within the area surveyed. Locations with the highest gamma levels have the highest potential for containing residual ROC concentrations. Sampling these locations provides data on the radionuclide mixture if residual contamination was present. Also, laboratory analysis of the samples can provide information to confirm whether residual ROC contamination is/is not present in areas of high gamma levels or possibly can be attributed to elevated background due to other radiation sources, such as NORM, or direct radiation from the ISFSI.

5.1.4 Scan Summary for Additional Areas Investigated

While the survey team was onsite, NRC staff directed additional scan coverage within SUs associated with the former power-block. A summary of these gamma walkover results is presented in Figure A.7. No suspected particles (with the exception of S0126, discussed in Section 5.1.2 above) were identified, and no additional areas were flagged for follow-up investigation via judgmental sampling. It is important to note that the additional gamma walkover scans were not performed with the same rigor as the investigations within CSU 1 and CSU 2. These additional surveys were not intended to satisfy the presence/absence survey design basis. Therefore, conclusions related to the presence of particles within the additional areas cannot be made with the same level of confidence as in CSU 1 and CSU 2.

5.2 ANALYTICAL RESULTS OF SUSPECTED PARTICLES

Analytical results for the suspected particles are discussed as a whole, rather than by individual CSU, based on the shared characteristics between the particles. A summary of results in terms of the presence/absence survey design by CSU is presented in Section 6. Locations of the suspected particles are indicated in Figure A.8.

5.2.1 Physical Description

A total of seven samples suspected of containing particles were collected at ZNPS during the April 2021 survey; five were returned to REAL. The remaining two suspected particle samples were transferred to RESL. Table 5.1 summarizes the field collection conditions of each of the suspected particles. For the purpose of this report, material was classified as a particle if the distribution of radioactivity within the sample did not match the conceptual site model under which the DCGLs were developed (i.e., widespread, uniformly distributed volumetric contamination).

Table 5.1. Field and Particle Collection Conditions

Sample ID	CSU	FSS Survey Unit	Approximate Depth (cm)	Sample Collection Notes
S0112A	2	10209E	<15	Sample was relatively easy to collect. Submitted to REAL for further analysis.
S0116	2	10220I	Surface	Sample required effort to isolate and collect. Submitted to REAL for further analysis.
S0120	2	12203D	Surface	Sample was easy to collect. Technican was able to scoop material with hand trowel. Submitted to REAL for further analysis.
S0124[a]	1	12201B	30	NaI response was near backgound levels. Sample was difficult to isolate and collect. Technican used a shovel to remove soil approximately 50 cm in diameter. Submitted to REAL for further analysis.
S0126[a]	2	12203A	Surface	Sample was easy to collect. Technican was able to scoop material with hand trowel. Submitted to REAL for further analysis.
S203A[a,b]	2	10204B	<15	Sample was relatively easy to isolate and collect. Submitted to RESL for further analysis.
S204A[a,b]	1	12201B	<15	Sample required effort to isolate and collect. Submitted to RESL for further analysis.

[a]Suspect particle was not collected from a CSU grid cell
[b]Sample collected by NRC staff

After the particle separation process was performed by REAL staff, as outlined in Section 4.1.1, it was determined that S0120 contained a collection of particles. Figure 5.2 provides a picture of S0120 prior to and during the preparation for radiochemical analysis. A single particle was isolated from sample S203A. Similar to S0120, upon further investigation by RESL, sample S203 was found to contain a collection of particles consistent in terms of physical characteristics to the particle isolated from S203A. Photographs of the collection of particles from soil sample S203 and the particle

isolated from sample S203A are provided in Figure 5.3. For discussion purposes in this report, the collection of particles isolated from S203 are hereafter referred to as S203B, which brings the total particle count to eight.

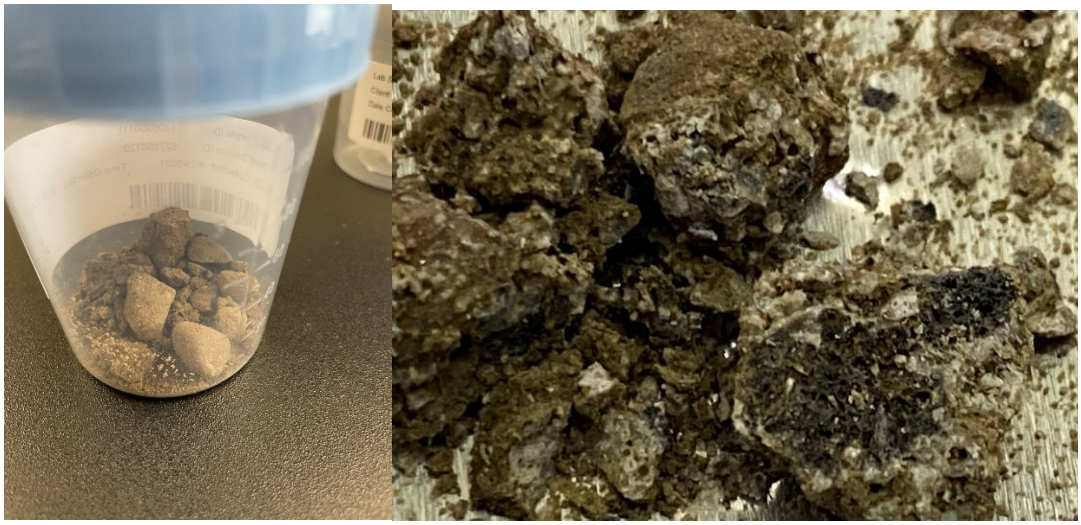

Figure 5.2. Sample S0120 Prior to (left) and During Laboratory Processing (right)

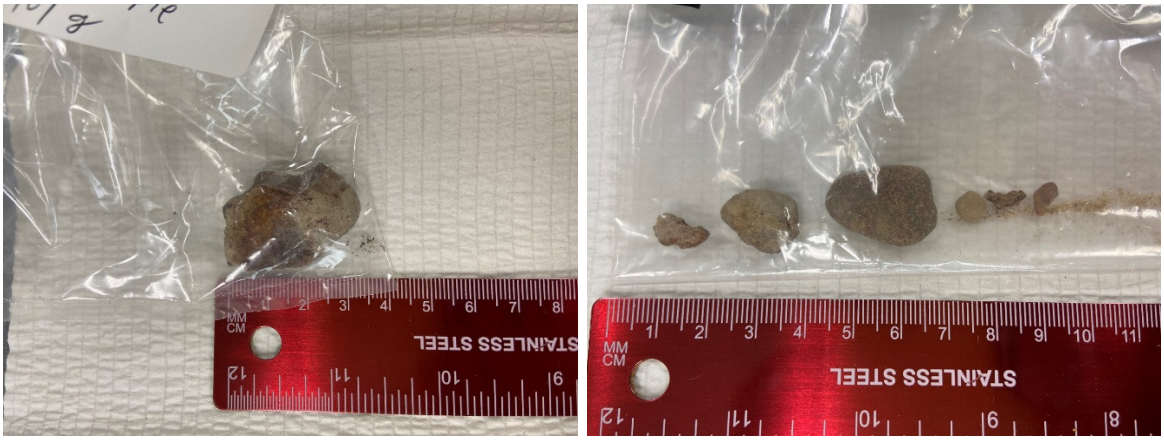

Figure 5.3. Particle Isolated from S203A (left) and Collection of Particles Isolated from S203 (right)

As part of the REAL separation approach for particles, once the material containing the elevated radioactivity was isolated, the material was fixed to a piece of tape. Figure 5.4 provides a picture of the isolated materials affixed to tape. Particles that were clearly visible are circled. Neither RESL nor REAL were able to provide quantitative measurements of the particle sizes. However, the circled particles were no larger than the size of a pencil tip. Also, neither RESL nor REAL can confirm that only one of the circled particles contained the radioactivity or that the radioactivity on the tape is

attributed to a visible particle, such as the ones circled in Figure 5.4, or invisible particles. There were many particle sizes, ranging from visible to invisible, adhered to the tape as viewed in a laboratory setting. Therefore, neither RESL nor REAL can make a determination on whether the radioactivity measured in the samples were from a single particle or multiple particles of respirable size. Additionally, REAL/RESL is unable to provide a quantitative assessment of the solubility of the particles. Appendix D provides additional information regarding the chemical dissolution process.

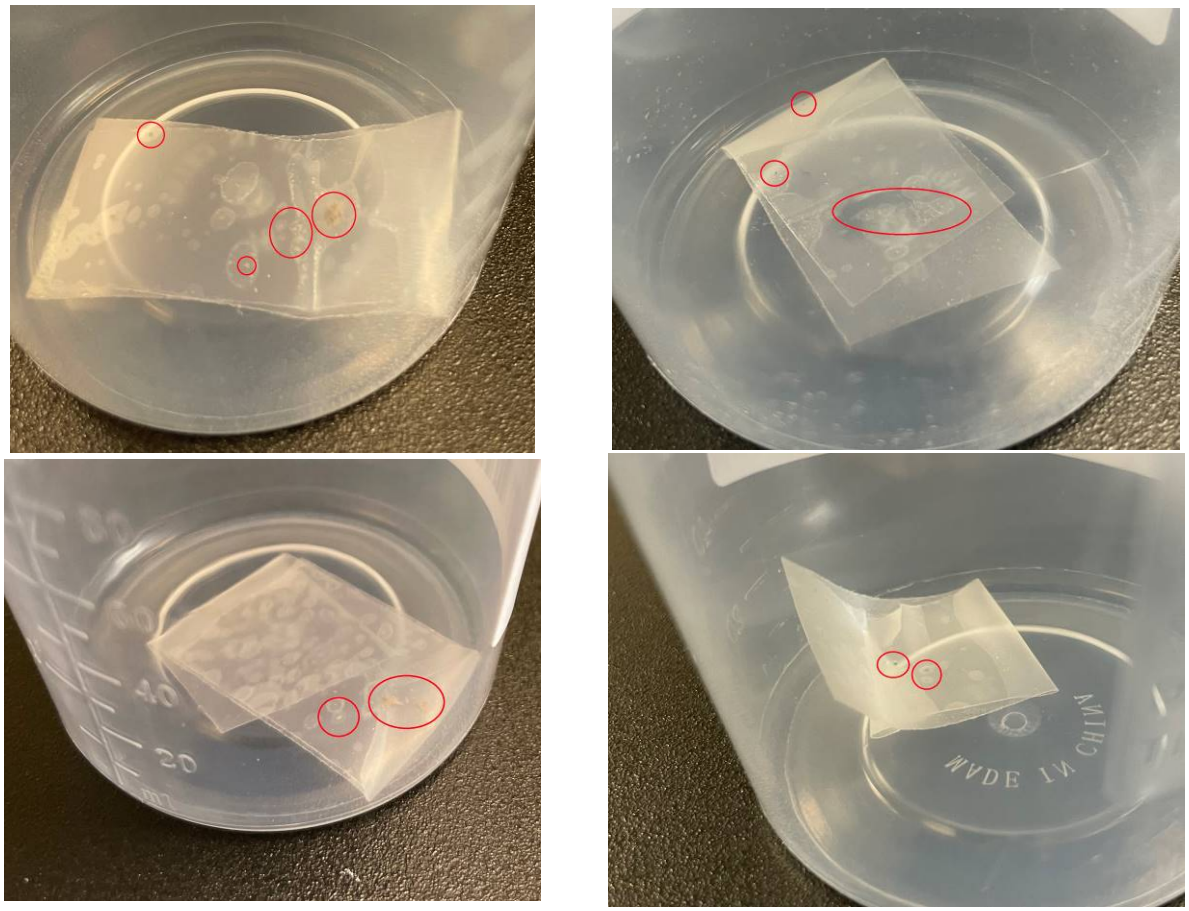

Figure 5.4. Pictures (left to right, top to bottom) of Particles in S0112A, S0116, S0124, S0126

5.2.2 Radionuclide Total Activity

Co-60 was the predominant radionuclide in the particles collected during previous confirmatory surveys (ORISE 2018, ORISE 2019, and ORISE 2020). Total radionuclide activities of the particles collected during this survey are summarized in Table 5.2. Appendix B, Table B.2 provides the analytical results for each particle along with the associated uncertainty. Two particles collected during this confirmatory survey (S0112A and S0116) were consistent with the previously collected

particles, both in terms of the constituent radionuclides and total activity. As presented in Table 5.1 particles S0112A and S0116 were collected from grid cells in CSU 2. Particle S0124 contained primarily Co-60; however, this particle also contained a small quantity (less than 1 pCi of total activity) of Pu-238 and Pu-239/240. Particle S0124 was identified in CSU 1 in response to expanded survey coverage and was not collected from a grid cell.

Table 5.2. Summary of Particle Total Activities (pCi)[a]

Sample	Am-241	Ba-133	Cm-244	Co-60	Cs-134	Cs-137	Eu-152	Eu-154	Eu-155	Np-237	Pu-238	Pu-239[b]	Sr-90
S0112A	0.040	10	0.000	**48400**	36	-27	-20	-40	27	0.000	0.000	0.059	-0.21
S0116	0.019	-8	0.038	**18400**	22	-4	-28	0	48	0.00	0.000	0.041	-0.34
S0120	0.033	**11**	0.011	**378**	11	0.6	**20000**	**1100**	13	-0.011	**0.043**	**0.063**	0.83
S0124	0.12	-300	0.06	**1508000**	1200	1000	-500	2000	-10	0.020	**0.14**	**0.079**	0.49
S0126	**79900**	-11	**14800**	**62**	12	**98900**	-70	**2920**	**838**	**3.9[c]**	**26188**	**7540**	**157043**
S204AEu	0.028	**1520**	-	**30000**	-	-	**344000**	**16200**	-	-0.028	-0.028	**16.6**	0.8

[a]Bolded values indicate the 95% uncertainty interval did not include zero
[b]Pu-239 value includes contributions from Pu-240
[c]Result is statistically positive, however, review of the alpha spectrum indicated that the alpha emissions were likely the result of Pu-242

Three particles (S0120, S0126 and S204A) contained radionuclides that were not consistent with the historical radionuclide contributions. The radionuclide makeup for particles S0126 and S204A/S0120 indicate different production sources within the plant. Particle S0120 and S204A contained Eu-152, Eu-154, and barium-133 (Ba-133) (Table 5.2)—all of which are neutron activation products typically found within the bioshield surrounding the reactor pressure vessel. In addition, RESL discovered through the use of high-resolution alpha spectrometry the presence of uranium-233 (U-233) in addition to naturally occurring U-234 in Sample S204AEu. RESL performed several theoretical neutron activation calculations that were consistent with the experimentally determined activity of the U-233, which is an activation product of natural thorium-232 (Th-232) contained in the bioshield concrete. Similarly, Pu-239/240 also was identified in S0120 and S204AEu and is suspected to result from neutron activation of U-238 in the bioshield concrete.

Particle S0126 contained a mixture of transuranics (Am-241, Cm-244, Pu-238, Np-237, and Pu-239/240) and fission products (Cs-137, Sr-90, Eu-154, and Eu-155). Results for particle S0126 presented in Table 5.2 indicate Np-237 is statistically positive, however, the alpha spectrum did not support the presence Np-237 alpha emissions. The alpha energy peaks in the observed spectrum are likely the result of pluntonium-242 (Pu-242). The presence of plutonium-241 (Pu-241) cannot be ruled out, however, the Pu-241 alpha yield is low and typically not observed via alpha spectrometry unless present in large activities. Plutonium-236 was used as a tracer to ensure no spectral overlap into the Np-237, Pu-241, or Pu-242 energy region. Based on the radionuclides present, the reactor fuel is the most likely source of particle S0126. Fission products other than those reported have the potential to be present in S0126, based on assumed burnup levels, average power levels, radioactive decay since shutdown, and other factors.

Particles S203A and S203B exhibited radionuclides unlike any other particle identified during this survey or previous surveys. Particle S203A contained elevated activities of Th-232, Th-228, and Ra-228 at 16,170 pCi; 23,900 pCi; and 37,000 pCi, respectively. Elevated activities of natural U-238 and U-234 at approximately 2,500 pCi/g also were reported in this sample. The elevated Ra-228 activity relative to Th-232 indicates that the material within the sample is not natural and the material has received some form of processing. RESL staff were able to determine an activity concentration of particle S203ATh (concentration values are not presented in this report). The activity concentration was used to estimate the total activity of the particles comprising S203B based on the total mass of the particles. Total activities for S203B and S203ATh are presented in Table 5.3. The origin of these samples could not be determined based on the available data.

Table 5.3. Summary of Thorium Particle Total Activities (pCi)[a]

Sample ID	Ra-228	Th-228	Th-230	Th-232	U-234	U-238
S203B[b]	**16800**	**10850**	**1180**	**7350**	**1170**	**1070**
5271-S-203ATh	**37000**	**23900**	**2600**	**16170**	**2570**	**2360**

[a]Bolded values indicate the 95% uncertainty interval did not include zero.
[b]Total activity of the particles was estimated based on the concentration of S203ATh and the sample mass of the particles (concentration values are not provided in this report).

5.3 RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Similar to the presentation of the particle analytical results in the previous section, analytical results for the volumetric soil samples are not presented in this report by CSU. As discussed in Section 5.1, none of the volumetric soil samples were collected based on the surveyor's suspicion of distributed

contamination (perhaps S0120 is an exception; however, the surveyor suspected the presence of a particle and not volumetric contamination). Thus, volumetric samples collected during this confirmatory survey fall into one of two groups. Samples in the first group were collected primarily to confirm the presence of NORM contributing to a slight increase in NaI detector background. Samples in the second group were collected to assess the residual radiological concentration of soils surrounding the suspected particles (suspected particles that the laboratory identified as containing volumetric contamination are reported in this group as well). Soil sample locations are provided in Figure A.9. Analytical results for each group are discussed in the following subsections.

5.3.1 Soil Samples Assessing the Presence of NORM

Radionuclide concentrations for individual soil samples discussed in this subsection are provided in Table B.3 in Appendix B. Figure 5.5 presents a strip chart of select radionuclide concentrations within the volumetric soil samples. Samples associated with the collection of suspected particles were removed from Figure 5.5 for better data visibility; see discussion in the next section for information related to these samples. As indicated by Figure 5.5, the radionuclides present in these samples are primarily attributable to NORM. Concentrations of NORM varied throughout the judgmental soil sample data set. Potassium-40 (K-40) exhibited the most variability; however, concentrations were consistent with soil samples collected during previous confirmatory surveys.

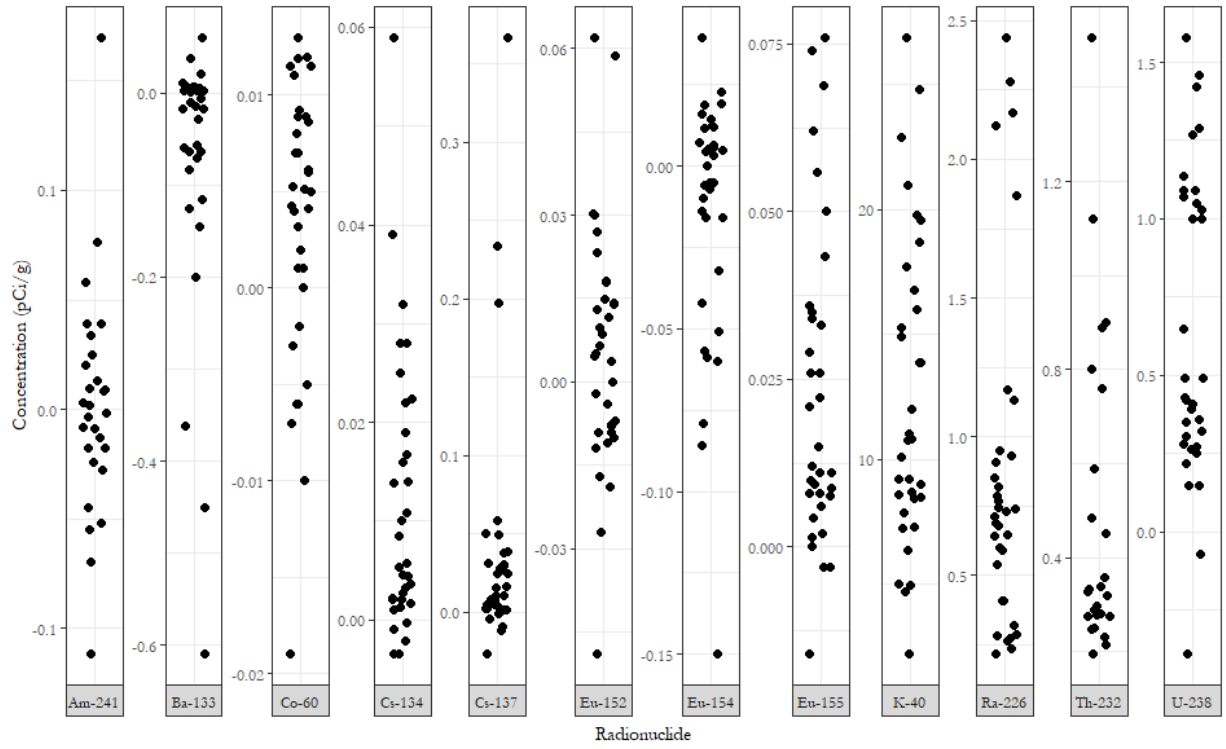

Figure 5.5. Strip Chart for Volumetric Soil Samples

As indicated in Figure 5.5, three samples (S0122, S0127, and S0212; the data points are not labeled on the plot) exhibited elevated concentrations of Cs-137 relative to the rest of the samples presented in the strip chart. The maximum Cs-137 concentration was 0.367 pCi/g. Select samples from this group—including S0122 and S0127—were also analyzed for hard-to-detect (HTD) radionuclides, and these results are summarized in Table 5.4. Co-60 and Cs-137 results also are presented in Table 5.4. Sample S0127 was collected in SU 10220C in CSU 1 (grid cell 21) and had statistically positive results for Am-241 and Pu-239/240 based on 95% uncertainty interval not including zero. Sample S0122 was collected inside of the security fence near the lake in CSU 2 and initially had a statistically positive result for Am-241, again based on 95% uncertainty interval not including zero. These samples (S0122 and S0127) were re-counted with a longer count time (2,000 minutes versus the initial 1,000-minute count) and the results were reassessed. Table B.4 summarizes the original and re-count results. Based on the subsequent re-analysis of sample S0122, the 95% uncertainty interval for Am-241 was found to include zero, indicating the radionuclide was not detected. The re-analysis of S0127 confirmed the statistically positive results for Am-241 and Pu-239/240.

Table 5.4. HTD Analysis of Soil Samples Assessing NORM (pCi/g)[a]								
Sample	**Co-60**	**Cs-137**	**Am-241**	**Cm-244**	**Np-237**	**Pu-238**	**Pu-239/240**	**Sr-90**
S0121	0.008	**0.0499**	-0.0089	0.0015	-0.0014	0.0000	0.0029	0.06
S0122	-0.002	**0.234**	-0.0016	0.0016	0.0001	0.0024	0.0024	0.07
S0127	-0.006	**0.367**	**0.0072**	-0.0016	0.0024	0.0008	**0.0154**	-0.04

[a]Bolded values indicate the 95% uncertainty interval did not include zero.

5.3.2 Soil Samples Associated with Suspected Particles

Analytical results for soil surrounding the particles are summarized in Table 5.5. The corresponding particle sample ID also is presented in Table 5.5. Radionuclide concentrations for individual soil samples discussed in this subsection are provided in Table B.3. The soil surrounding particle S0112A exhibited elevated concentrations of Co-60 and Cs-137. A dedicated sample representing the soil surrounding particles S0116 and S0124 was not collected. Particle S0124 was collected from a depth of approximately 30 cm below the surface. After the soil containing S0124 was removed, the surveyor could not determine which soil was originally surrounding the particle. HTD analyses for S0116 and S0124 were performed on the remaining soil after the REAL laboratory staff separated the particle from the small amount of soil collected—these results are presented as S0116A and S0124A in Table 5.5. Radionuclide concentrations in the soil surrounding the particles were largely unremarkable. Sample S0125 did not exhibit appreciable concentrations of transuranics and fission products, other than Cs-137, that were present in particle S0126.

Sample ID S204 represents the soil surrounding S204AEu and was collected after the particle sample was obtained. S204A represents the soil after the particle was removed in the laboratory. Slightly elevated concentrations of europium (Eu-152 and Eu-154) and Co-60 were identified in both samples (S204 and S204A) representing the soil surrounding particle S204AEu. Cs-137 was the only plant-derived radionuclide identified in sample S0121, which was the soil surrounding particle S0120.

Table 5.5. Radionuclide Concentrations in Soil Surrounding Particles (pCi/g)[a]

Soil Sample	Particle Sample	Am-241	Ba-133	Cm-244	Co-60	Cs-134	Cs-137	Eu-152	Eu-154	Eu-155	Np-237	Pu-238	Pu-239	Sr-90
S0112[b]	S0112A	0.003	-0.228	-0.0016	**0.039**	**0.025**	**0.134**	0.009	0.000	0.023	0.0000	0.0031	0.0031	-0.02
S0116A[c]	S0116	0.0016		-0.0016	-	-	-	-	-	-	0.0015	0.0030	0.0046	-0.01
S0121[d]	S0120	-0.0089	-0.056	0.0015	0.008	0.010	**0.0499**	0.013	-0.014	0.008	-0.0014	0.0000	0.0029	0.06
S0124A[c]	S0124	0.0000		0.0000	-	-	-	-	-	-	0.0000	0.0032	0.0049	**0.17**
S0125[d]	S0126	0.0016	-0.017	0.0000	0.001	-0.0010	**0.038**	0.000	0.012	0.033	0.0000	0.0015	0.0030	0.12
S204[b]	S204AEu	-	0.04	-	**0.020**	0.04	**0.024**	**0.089**	0.003	0.03	0.012	-	-0.0016	0.6
S204A[e]	S204AEu	-	0.013	-	**0.094**	0.0000	**0.051**	**0.60**	0.020	0.02	0.021	-	0.003	0.1

[a]Bolded values indicate the 95% uncertainty interval did not include zero.
[b]Sample mass was approximately 800 grams.
[c]Sample mass was less than 100 grams.
[d]Sample mass was approximately 450 grams.
[e]Sample mass was approximately 300 grams.

6. SUMMARY AND CONCLUSIONS

During the period of April 26–30, 2021, ORISE performed independent confirmatory survey activities of surface soils associated within select land areas at ZNPS. The primary goal of the survey was to identify and collect particles containing plant-derived radioactivity consistent with historically identified particles. Confirmatory surveys consisted of gamma walkover surface scans and soil sampling.

Based on gamma walkover scans and subsequent grid cell investigations, a total of seven samples were collected with the suspicion of containing particles. A total of 40 volumetric soil samples were collected during this confirmatory survey. Five of the 40 volumetric samples collected during the survey represented the soils surrounding five of the seven suspected particle locations (a total of eight particles were found from seven locations). The remaining 35 soil samples were collected to assess slightly elevated direct gamma radiation levels. These 35 samples were collected primarily to confirm the presence of elevated concentrations of NORM and/or generate negative data points.

Analytical results for the 35 soil samples collected to assess residual contamination were mostly consistent with background levels. One of these samples (S0127) located within SU 10220C (CSU 1) exhibited slightly elevated concentrations of Cs-137, Am-241, and Pu-239/240.

Subsequent laboratory analysis confirmed the presence of particles in all seven samples. Additionally, after processing by RESL, an eighth particle was found in soil sample S203 (described in this report

as S203B) consistent in physical appearance and radiological constituents to that of particle S203A. These two samples (S203 and S203B) contained elevated levels of thorium, uranium, and radium-228 (Ra-228), which are of unknown origin. Another sample (S0120) contained multiple particles of plant-derived radionuclides, namely Eu-152, Eu-154, Ba-133, and smaller activities of Pu-239/240. These radionuclide constituents are similar to those identified in a particle (S204) collected from SU 12201B. Regarding the two samples containing multiple particles (S0120 and S203B), a determination cannot be made as to whether this material originated as a unified matrix and was subsequently degraded by environmental or other external factors. Three of the eight confirmed particles (S0112A, S0116, and S0124) contained predominantly Co-60 and were consistent with historically identified particles at the ZNPS site during previous surveys conducted by the licensee and confirmatory surveys conducted by ORISE. Additionally, S0124 contained Pu-238 and Pu-239/240 with activities less than 1 pCi. Alpha spectrometry was not performed on the historical particles collected by ORISE; therefore, it is not possible to determine whether these transuranic activities fall within the typical activity range of historical particles. The fourth confirmed particle (S0126) contained transuranics and fission products; the fifth confirmed particle (S204AEu) contained a mix of neutron activation products and one transuranic (Pu-239). Based on the analytical results, there are four groups, related to the origin source, of particles present: (1) neutron activation of reactor corrosion products (e.g., Co-60, Ni-63, iron-55 [Fe-55]), (2) neutron activation of the reactor bioshield (e.g., Eu-152, Eu-154, Ba-133), (3) irradiated fuel fragment (e.g., transuranic and fission products), and (4) unknown (thorium isotopes).

The design basis for this confirmatory survey served to determine whether particles were present or absent from a specified proportion of the site at a high confidence level. A total of three confirmed particles were found in grid cells within CSU 2, and an additional particle was identified in CSU 2, but not within a grid cell. A total of two particles were found in CSU 1; however, the particles were not identified within a grid cell. From a technical survey design perspective, the number of particles identified and the locations from which they were identified were not significant such that one would reject the null hypothesis (that a high percentage of the investigated area does not contain particles). However, two particles contained radionuclide constituents that were unexpected, and two particles were identified (in relatively close proximity) in areas where particles were not expected. Additionally, because the survey planning objectives specify that a single particle identified in CSU 1 may be unacceptable, identification of two particles—even though not identified in a grid

cell—may be sufficient for additional evaluation by the NRC staff. At a minimum, when unexpected survey conditions arise, MARSSIM recommends that the data quality objectives (DQO) process be revisited. The results of the presence/absence survey in CSU 1 and CSU 2 should not be extrapolated to other areas of the site outside of the CSU boundary. Confirmatory survey results, herein, are provided to NRC staff for their evaluation and subsequent decision making.

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APPENDIX A: FIGURES

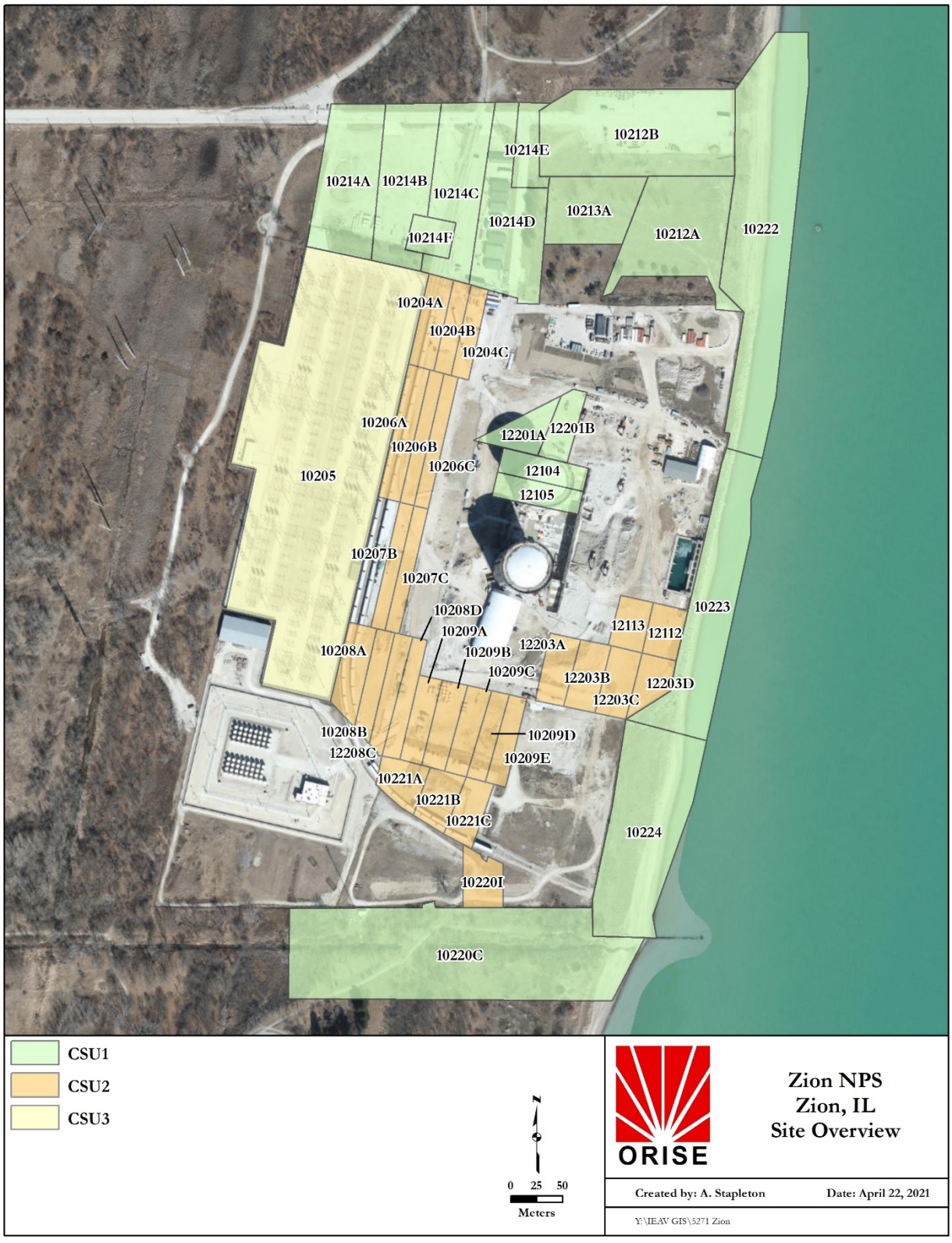

Figure A.1. Overview of CSUs for this Confirmatory Survey

Figure A.2. CSU 1 Grid Cell Locations

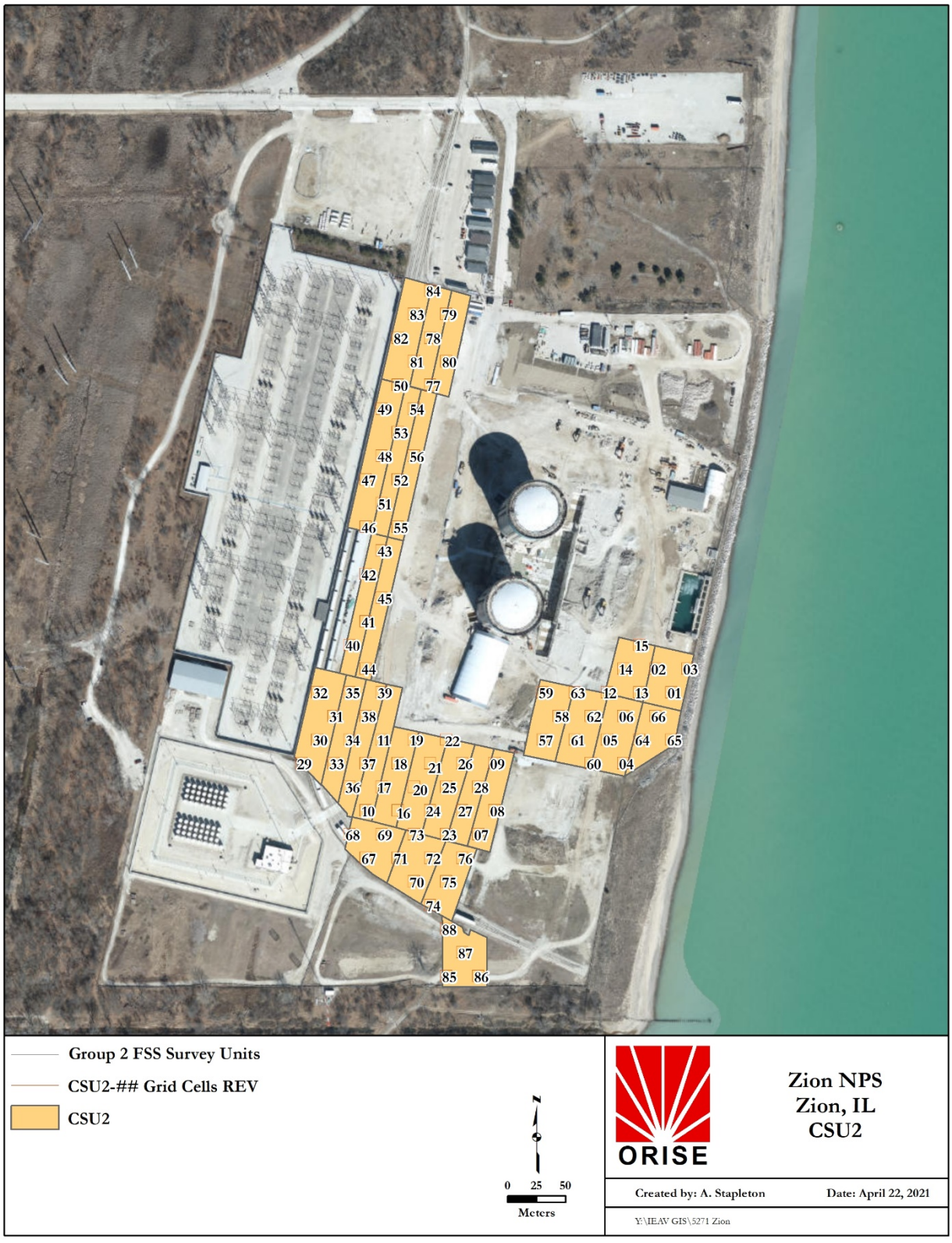

Figure A.3. CSU 2 Grid Cell Locations

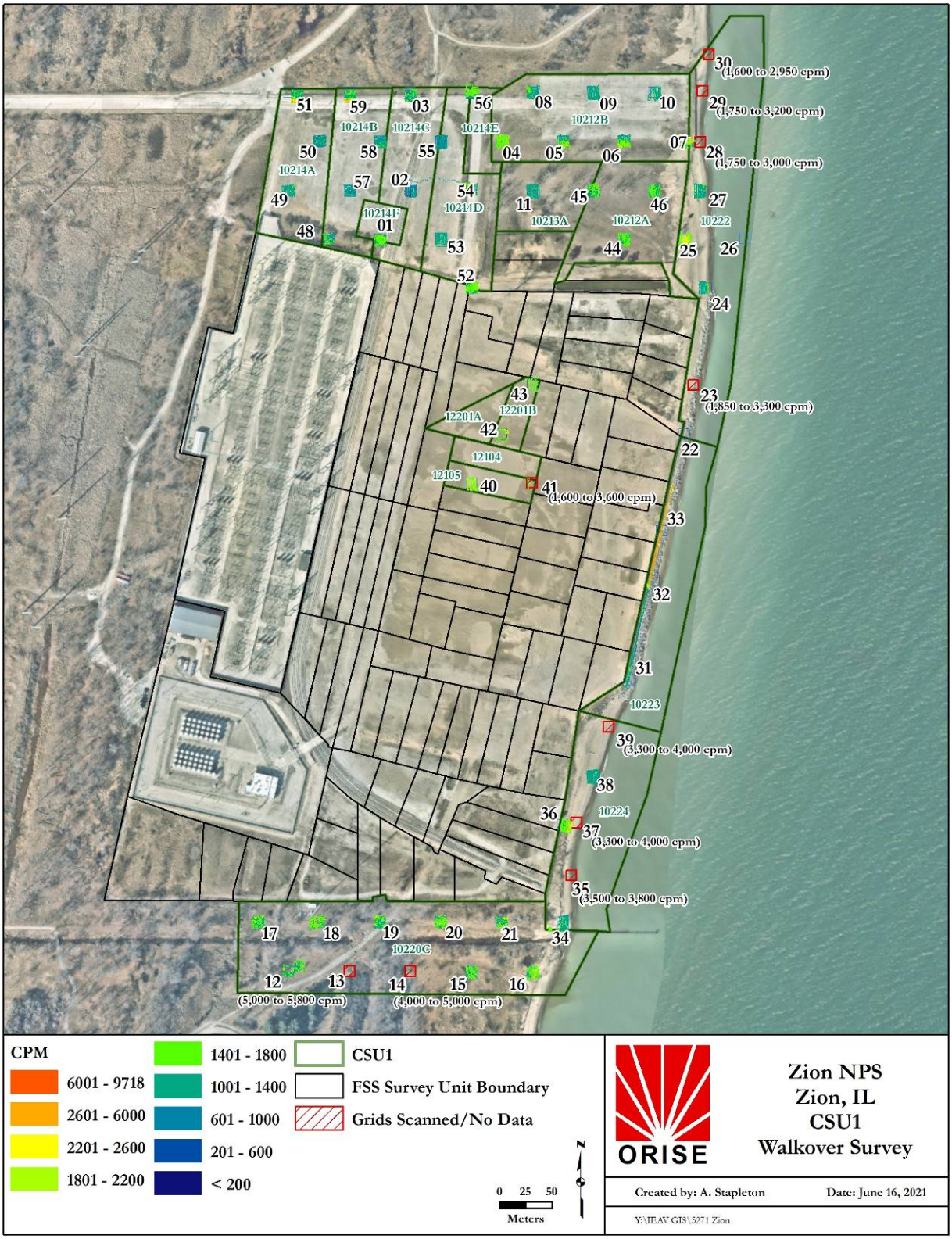

Figure A.4. CSU 1 Gamma Walkover Survey of Grid Cells

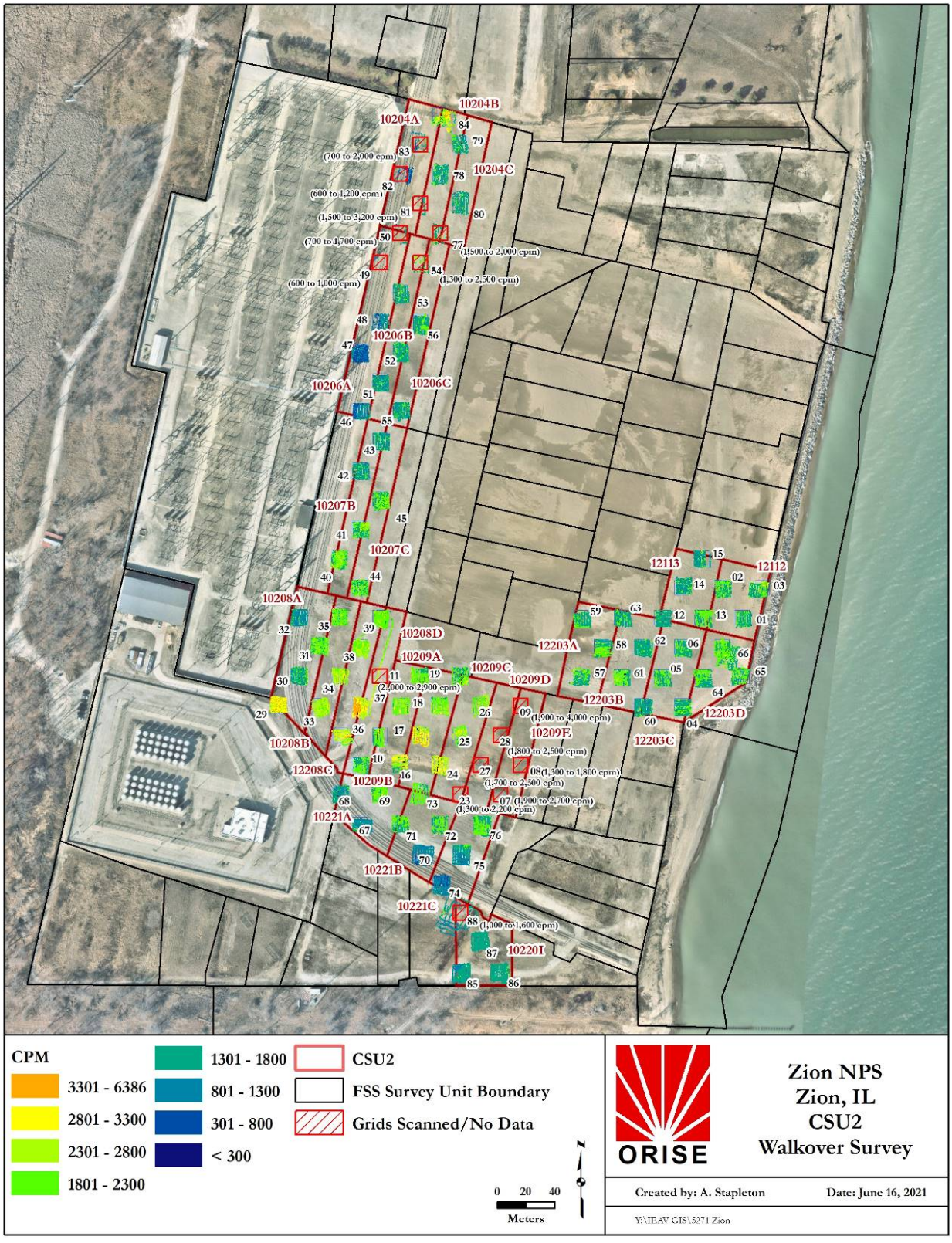

Figure A.5. CSU 2 Gamma Walkover Survey of Grid Cells

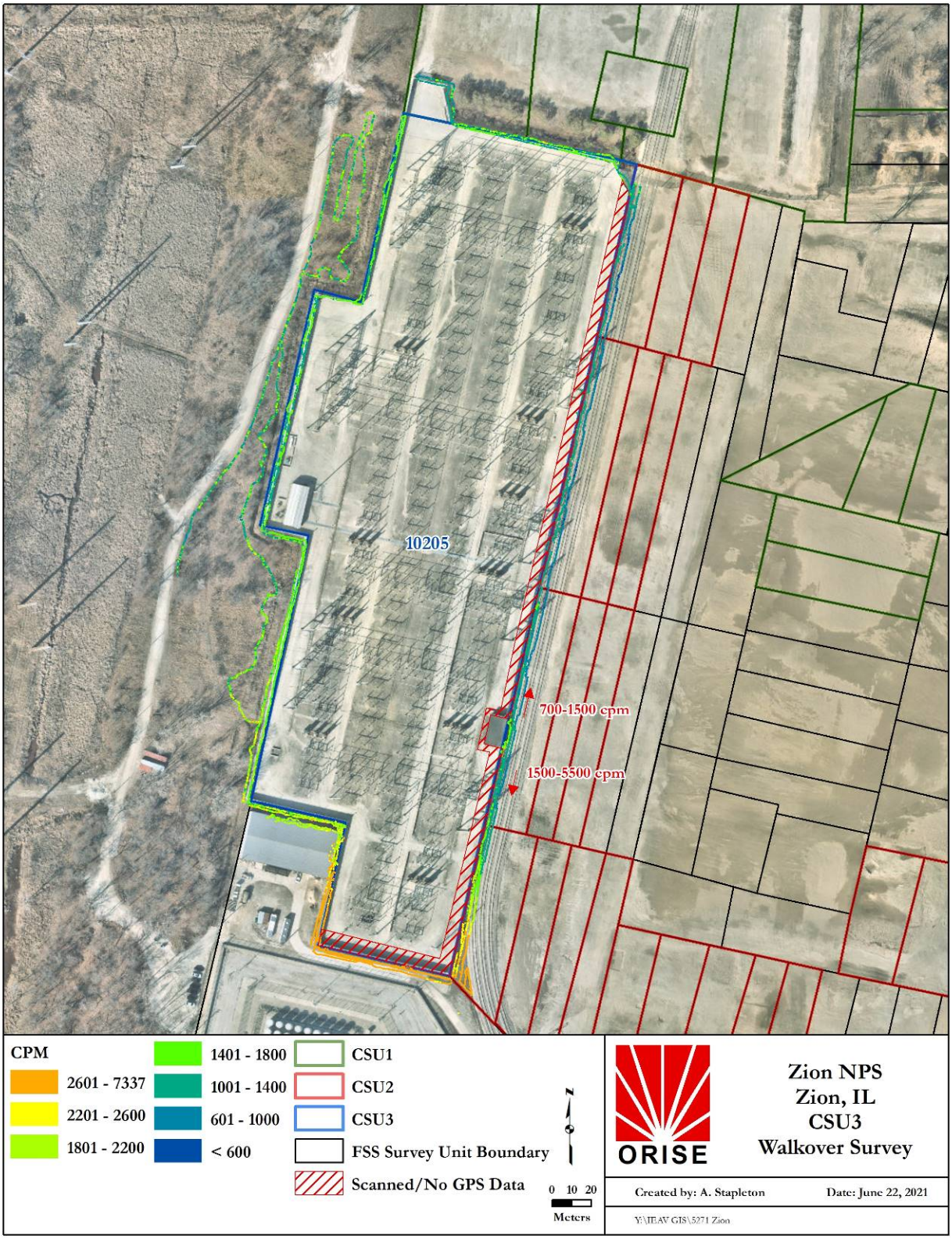

Figure A.6. CSU 3 Gamma Walkover Survey

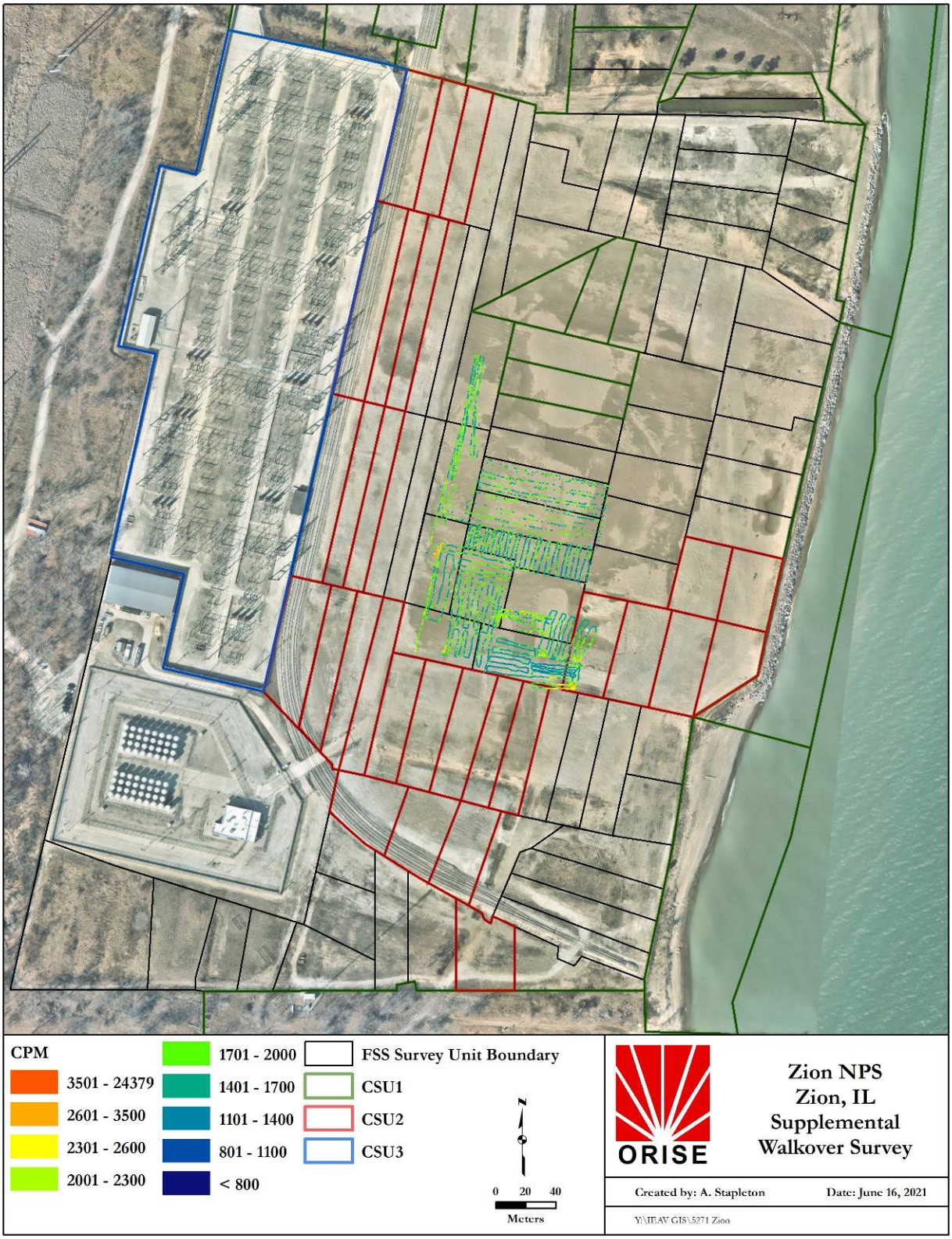

Figure A.7. Gamma Walkover Survey of Additional Areas Directed by NRC Staff

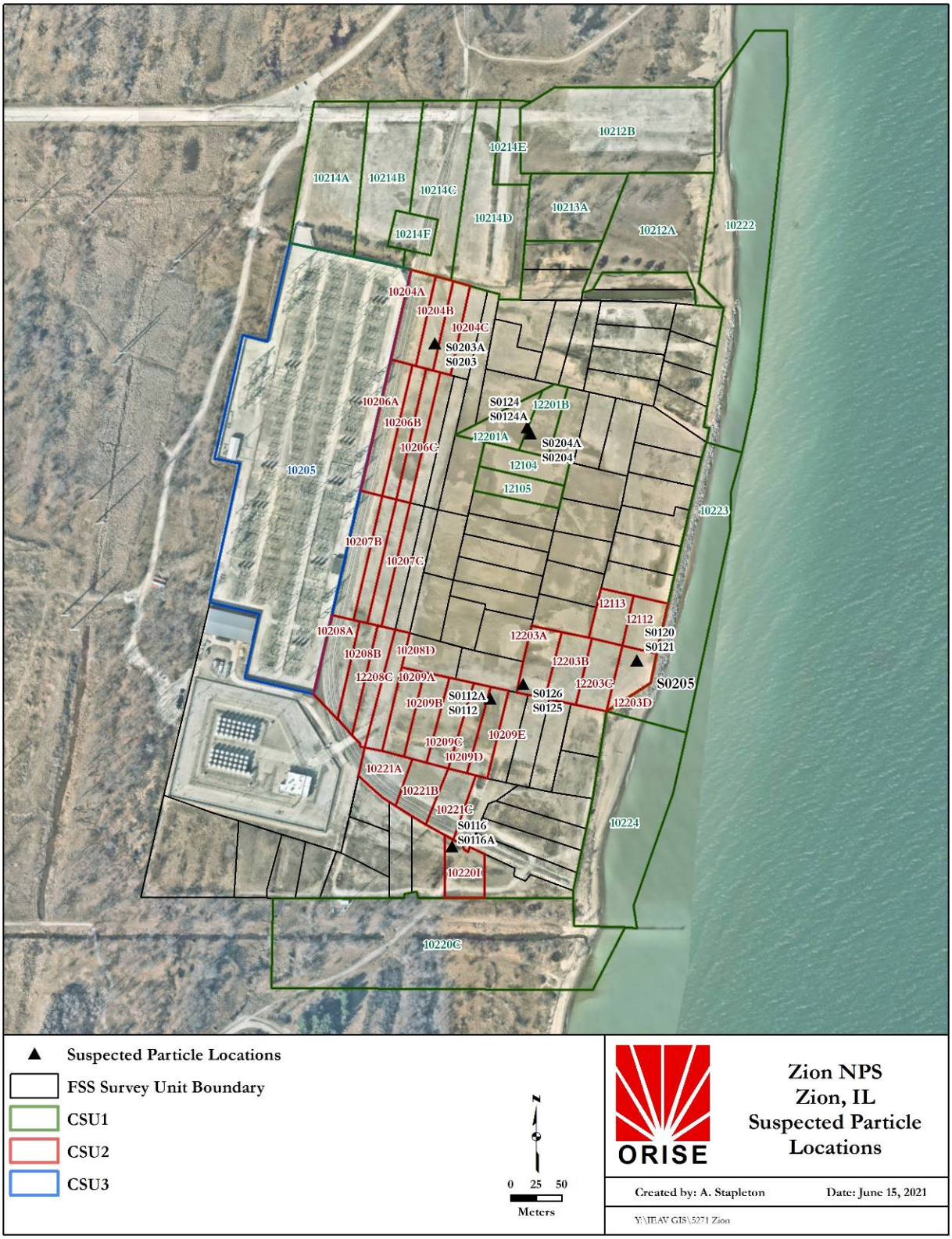

Figure A.8. Suspected Particle Locations

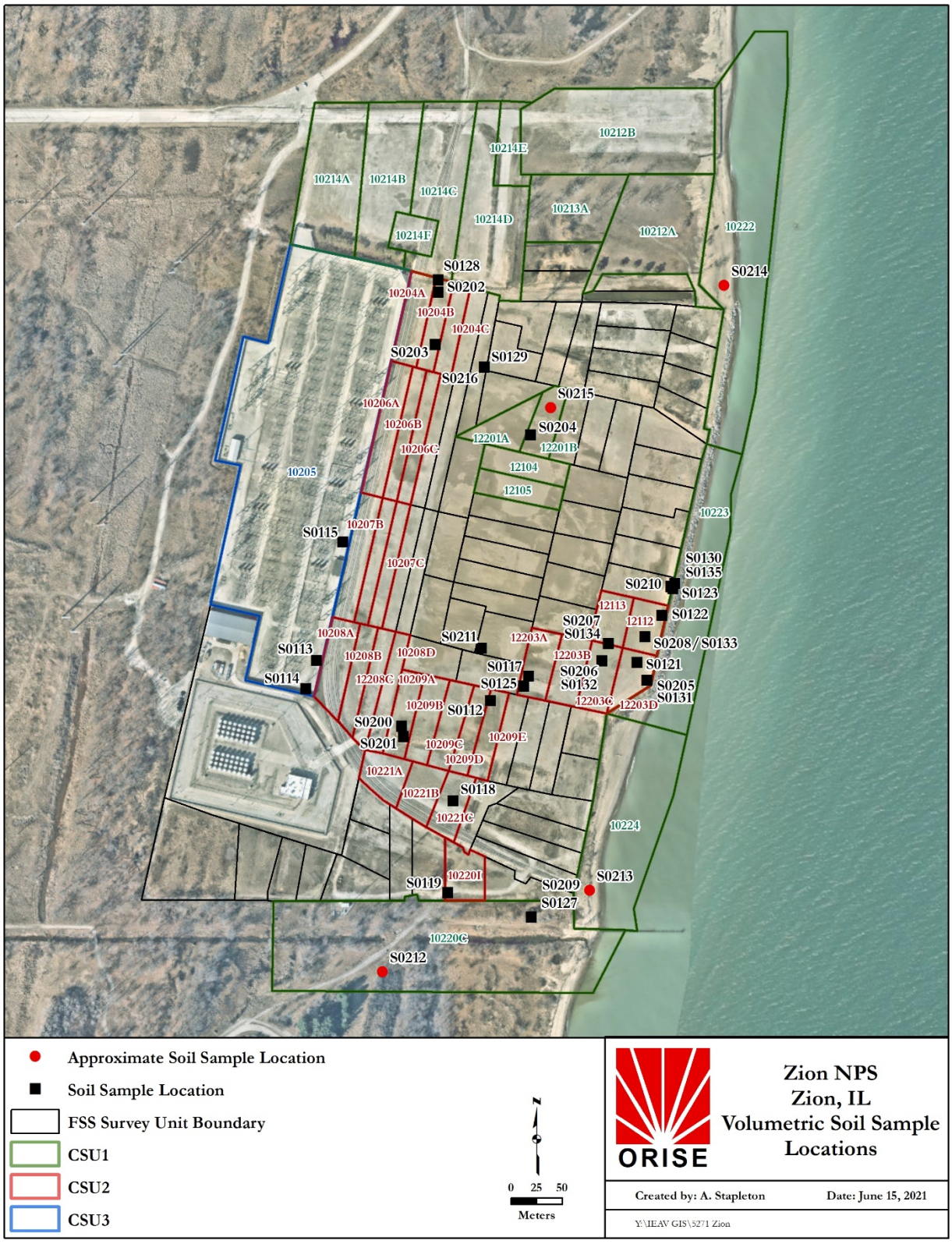

Figure A.9. Judgmental Volumetric Soil Sample Locations

APPENDIX B: DATA TABLES

Table B.1. Percent Inventory of Potential Radionuclides at ZNPS[a]					
Radionuclide	**Containment**	**Auxiliary**	**Radionuclide**	**Containment**	**Auxiliary**
Ag-108m	0.282	0.017	H-3	0.074	0.174
Am-241	0.007	0.001	Ni-59	0.156	0.498
Am-243	0.000	0.001	Ni-63	26.275	23.480
C-14	0.008	0.044	Nb-94	0.178	0.013
Cm-243	0.001	0.000	Np-237	0.000	0.000
Cm-244	0.001	0.000	Pu-238	0.001	0.001
Co-60	4.675	0.908	Pu-239	0.000	0.001
Cs-134	0.008	0.010	Pu-240	0.000	0.001
Cs-137	67.582	74.597	Pu-241	0.007	0.028
Eu-152	0.436	0.017	Sb-125	0.025	0.017
Eu-154	0.058	0.009	Sr-90	0.027	0.051
Eu-155	0.018	0.008	Tc-99	0.008	0.016
Fe-55	0.174	0.106	Total	100	100

[a]Source: ZS 2018, Table 6-2

Table B.2. Radionuclide Activity of Particles (pCi/sample) [a,b,c]

Sample ID	Sample Collector	Ag-108m	Am-241	Ba-133	Cm-244	Co-60	Cs-134	Cs-137	Eu-152	Eu-154	Eu-155	Fe-55	Ni-63	Nb-94	Np-237	Pu-238	Pu-239[d]	Sb-125	Sr-90	Ra-228	Th-228	Th-230	Th-232	U-233	U-234	U-235	U-238[e]
5271S0112A	ORISE	16 ± 36	0.040 ± 0.079	10 ± 45	0.000 ± 0.039	**48400 ± 2900**	36 ± 82	-27 ± 64	-20 ± 100	-40 ± 230	27 ± 50			54 ± 83	0.000 ± 0.039	0.000 ± 0.078	0.059 ± 0.087	40 ± 110	-0.21 ± 0.58							40 ± 130	-240 ± 310
5271S0116	ORISE	0 ± 21	0.019 ± 0.038	-8 ± 25	0.038 ± 0.053	**18400 ± 1100**	22 ± 44	-4 ± 31	-28 ± 59	0 ± 150	48 ± 48			**47 ± 45**	0.00 ± 0.04	0.000 ± 0.056	0.041 ± 0.056	5 ± 66	-0.34 ± 0.57							-24 ± 94	-470 ± 440
5271S0120	ORISE	-1.8 ± 6	0.033 ± 0.037	**11 ± 4.1**	0.011 ± 0.022	**378 ± 27**	11 ± 12	0.6 ± 1.7	**20000 ± 1200**	**1100 ± 130**	13 ± 14			-502 ± 57	-0.011 ± 0.06895	**0.043 ± 0.041**	**0.063 ± 0.051**	-3 ± 12	0.83 ± 2.21							-66 ± 28	-48 ± 61
5271S0124	ORISE	-90 ± 620	0.12 ± 0.12	-300 ± 780	0.06 ± 0.10	**1508000 ± 91000**	1200 ± 1500	1000 ± 1100	-500 ± 1800	2000 ± 5400	-10 ± 860			-800 ± 1500	0.020 ± 0.039	**0.14 ± 0.10**	**0.079 ± 0.078**	-200 ± 1900	0.49 ± 0.62							800 ± 2200	900 ± 4790
5271S0126	ORISE	18 ± 54	**79900 ± 8700**	-11 ± 50	**14800 ± 2100**	**62 ± 14**	12 ± 17	**98900 ± 5900**	-70 ± 120	**2920 ± 400**	**838 ± 94**			0.2 ± 5.4	3.9[f] ± 3.4	**26188 ± 1862**	**7540 ± 551**	-10 ± 160	**157043 ± 4110**							80 ± 120	-470000 ± 110000
S203B[g]	NRC																			**16800 ± 1500**	**10850 ± 630**	**1180 ± 120**	**7350 ± 420**		**1170 ± 120**		**1070 ± 110**
5271-S-203ATh[h]	NRC																			**37000 ± 2300**	**23900 ± 1400**	**2600 ± 260**	**16170 ± 920**		**2570 ± 250**		**2360 ± 230**
5271-S-204AEu[i]	NRC		0.028 ± 0.037	**1520 ± 100**		**30000 ± 4000**			**344000 ± 27000**	**16200 ± 2100**		**111 ± 24**	**27 ± 8**		-0.028 ± 0.037	-0.028 ± 0.037	**16.6 ± 1.6**		0.8 ± 3.1					**1.29 ± 0.37**	**2.2 ± 0.6**		**1.62 ± 0.37**

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

[b]Bold values indicate that the 95% uncertainty interval does not include zero

[c]RESL analytical results for alpha emitting radionuclides in NRC samples were determined by total dissolution followed by alpha spectrometry

[d]Results include contribution from Pu-240

[e]U-238 was determined by Th-234 for ORISE samples

[f]Result is statistically positive, however, review of the alpha spectrum indicated that the alpha emissions were likely the result of Pu-242

[g]Sample S203B was separated from sample 5271-S-203

[h]Sample 5271-S204ATh was separated from sample 5271-S-203A

[i]Sample 5271-S204AEu was separated from sample 5271-S-204A

Table B.3. Radionuclide Concentration in Volumetric Soil Samples (pCi/g) [a,b,c]

Sample ID	Sample Collector	Ag-108m	Am-241	Am-241/Pu-238	Ba-133	Co-60	Cs-134[d]	Cs-137	Cm-244	Eu-152	Eu-154	Eu-155	K-40	Nb-94	Np-237[e]	Pu-238	Pu-239[f]	Ra-226	Ra-228[g]	Sb-125	Sr-90	Th-228[h]	Th-230	Th-232	U-234	U-235	U-238[i]
5271S0112	ORISE	-0.002 ± 0.013	0.003 ± 0.013		-0.228 ± 0.064	**0.039 ± 0.023**	**0.025 ± 0.020**	**0.134 ± 0.024**	-0.0016 ± 0.0092	0.009 ± 0.042	0.000 ± 0.052	0.023 ± 0.032	**8.62 ± 0.84**	-0.015 ± 0.016	0.0000 ± 0.0043	0.0031 ± 0.0043	0.0031 ± 0.0043	**0.64 ± 0.25**	**0.322 ± 0.096**	0.006 ± 0.038	-0.02 ± 0.14	**0.341 ± 0.037**				**0.069 ± 0.058**	**0.4 ± 0.29**
5271S0113	ORISE	0.003 ± 0.011	0.025 ± 0.051		-0.083 ± 0.021	0.011 ± 0.016	-0.0003 ± 0.0052	**0.016 ± 0.015**		-0.017 ± 0.033	-0.042 ± 0.050	0.026 ± 0.040	**7.88 ± 0.69**	0.003 ± 0.013	-0.007 ± 0.022			**0.73 ± 0.26**	**0.358 ± 0.076**	0.010 ± 0.035		**0.273 ± 0.028**				**0.089 ± 0.087**	-0.39 ± 0.48
5271S0114	ORISE	0.004 ± 0.010	-0.002 ± 0.027		-0.006 ± 0.010	-0.005 ± 0.016	0.0022 ± 0.0039	-0.009 ± 0.013		**0.030 ± 0.028**	-0.016 ± 0.040	-0.003 ± 0.023	**4.96 ± 0.48**	0.004 ± 0.011	-0.009 ± 0.020			**0.41 ± 0.21**	**0.231 ± 0.058**	-0.014 ± 0.032		**0.207 ± 0.023**				0.005 ± 0.057	**0.28 ± 0.23**
5271S0115	ORISE	0.0011 ± 0.0093	-0.018 ± 0.020		-0.029 ± 0.013	-0.006 ± 0.019	-0.0035 ± 0.0045	0.001 ± 0.012		-0.010 ± 0.032	-0.057 ± 0.069	0.006 ± 0.022	**8.71 ± 0.75**	-0.001 ± 0.014	0.003 ± 0.018			**0.60 ± 0.22**	**0.194 ± 0.067**	0.003 ± 0.031		**0.251 ± 0.026**				-0.016 ± 0.053	0.15 ± 0.21
5271S0117	ORISE	-0.003 ± 0.016	-0.052 ± 0.039		-0.45 ± 0.11	-0.010 ± 0.028	0.0036 ± 0.0087	0.002 ± 0.026		-0.019 ± 0.052	-0.15 ± 0.11	**0.062 ± 0.048**	**19.8 ± 1.6**	0.009 ± 0.021	-0.023 ± 0.031			**1.87 ± 0.39**	**0.76 ± 0.14**	-0.032 ± 0.051		**0.701 ± 0.059**				0.10 ± 0.10	**1.27 ± 0.47**
5271S0118	ORISE	0.000 ± 0.010	0.013 ± 0.049		-0.059 ± 0.022	0.001 ± 0.013	-0.0021 ± 0.0044	**0.0080 ± 0.0059**		-0.012 ± 0.029	-0.006 ± 0.036	0.021 ± 0.036	**8.47 ± 0.72**	0.006 ± 0.012	0.011 ± 0.021			**0.59 ± 0.27**	**0.25 ± 0.063**	-0.017 ± 0.032		**0.270 ± 0.053**				0.069 ± 0.077	0.15 ± 0.41
5271S0119	ORISE	-0.001 ± 0.013	-0.045 ± 0.040		-0.362 ± 0.066	-0.003 ± 0.019	**0.028 ± 0.020**	-0.004 ± 0.017		-0.011 ± 0.039	-0.086 ± 0.076	0.035 ± 0.038	**13.9 ± 1.0**	0.003 ± 0.017	-0.004 ± 0.017			**0.95 ± 0.30**	**0.484 ± 0.051**	-0.016 ± 0.042		**0.464 ± 0.038**				0.072 ± 0.076	**0.49 ± 0.31**
5271S0120	ORISE	-0.13 ± 0.43	0.0024 ± 0.0027		**0.80 ± 0.30**	**27.4 ± 1.9**	0.80 ± 0.88	0.04 ± 0.12	0.0008 ± 0.0016	**1449 ± 84**	**79.5 ± 9.5**	0.9 ± 1.0	**18.1 ± 2.7**	-36.4 ± 4.2	-0.0008 ± 0.0050	**0.0031 ± 0.0030**	**0.0046 ± 0.0037**	1.5 ± 7.4	-19 ± 3.8	-0.22 ± 0.84	0.06 ± 0.16	0.47 ± 0.63				-4.8 ± 2.0	-3.5 ± 4.4
5271S0121	ORISE	0.0009 ± 0.0095	-0.0089 ± 0.0092		-0.056 ± 0.021	0.008 ± 0.017	0.010 ± 0.017	**0.0499 ± 0.0099**	0.0015 ± 0.0096	0.013 ± 0.034	-0.014 ± 0.037	0.008 ± 0.039	**9.01 ± 0.75**	-0.003 ± 0.014	-0.0014 ± 0.0028	0.0000 ± 0.0028	0.0029 ± 0.0056	**0.71 ± 0.29**	**0.28 ± 0.073**	-0.003 ± 0.037	0.06 ± 0.15	**0.272 ± 0.030**				0.006 ± 0.093	0.43 ± 0.44
5271S0122	ORISE	-0.009 ± 0.014	-0.0016 ± 0.0050		-0.116 ± 0.042	-0.002 ± 0.022	**0.025 ± 0.021**	**0.234 ± 0.037**	0.0016 ± 0.0059	-0.009 ± 0.044	-0.079 ± 0.090	0.015 ± 0.034	**12.0 ± 1.1**	-0.008 ± 0.018	-0.0001 ± 0.0003	0.0024 ± 0.0027	0.0024 ± 0.006	**0.747 ± 0.081**	**0.327 ± 0.096**	0.019 ± 0.041	0.07 ± 0.14	**0.405 ± 0.040**				0.053 ± 0.087	**0.65 ± 0.33**
5271S0123	ORISE	-0.005 ± 0.019	-0.112 ± 0.056		-0.064 ± 0.022	0.013 ± 0.028	**0.039 ± 0.029**	-0.012 ± 0.024		-0.002 ± 0.016	-0.005 ± 0.063	0.034 ± 0.053	**26.9 ± 1.9**	0.005 ± 0.023	0.017 ± 0.036			**2.28 ± 0.50**	**0.9 ± 0.12**	0.004 ± 0.057		**0.959 ± 0.068**				**0.17 ± 0.11**	**1.05 ± 0.45**
5271S0125	ORISE	0.006 ± 0.012	0.0016 ± 0.0031		-0.017 ± 0.016	0.001 ± 0.022	-0.0010 ± 0.0065	**0.038 ± 0.018**	0.0000 ± 0.0031	0.000 ± 0.040	0.012 ± 0.054	0.033 ± 0.033	**10.07 ± 0.88**	-0.0035 ± 0.0095	0.0000 ± 0.0030	0.0015 ± 0.0030	0.0030 ± 0.0073	**0.82 ± 0.32**	**0.332 ± 0.084**	-0.027 ± 0.038	0.12 ± 0.15	**0.336 ± 0.034**				0.010 ± 0.075	**0.49 ± 0.28**
5271S0127	ORISE	0.016 ± 0.022	**0.0072 ± 0.0047**		-0.070 ± 0.035	-0.006 ± 0.031	0.0013 ± 0.0090	**0.367 ± 0.055**	-0.0016 ± 0.0031	-0.009 ± 0.061	-0.059 ± 0.094	0.011 ± 0.068	**10.8 ± 1.1**	**0.034 ± 0.021**	0.0024 ± 0.0048	0.0008 ± 0.0016	**0.0154 ± 0.0089**	**1.17 ± 0.49**	**0.45 ± 0.12**	0.021 ± 0.068	-0.04 ± 0.13	**0.424 ± 0.049**				0.02 ± 0.15	0.41 ± 0.79
5271S0128	ORISE	-0.017 ± 0.016	-0.013 ± 0.039		-0.064 ± 0.020	0.000 ± 0.024	**0.028 ± 0.024**	-0.027 ± 0.018		0.027 ± 0.046	-0.060 ± 0.066	0.010 ± 0.031	**22.9 ± 1.6**	0.002 ± 0.016	0.003 ± 0.031			**2.17 ± 0.37**	**0.89 ± 0.13**	0.009 ± 0.046		**0.781 ± 0.055**				-0.015 ± 0.094	**1.42 ± 0.51**
5271S0129	ORISE	0.001 ± 0.015	-0.018 ± 0.068		-0.145 ± 0.035	0.002 ± 0.022	**0.022 ± 0.013**	0.002 ± 0.013		-0.008 ± 0.035	-0.005 ± 0.052	0.050 ± 0.054	**16.8 ± 1.3**	-0.002 ± 0.019	-0.007 ± 0.030			**1.13 ± 0.38**	**0.59 ± 0.1**	-0.035 ± 0.046		**0.530 ± 0.044**				**0.13 ± 0.11**	0.35 ± 0.63
5271S0130	ORISE	-0.008 ± 0.017	-0.070 ± 0.083		-0.200 ± 0.044	0.004 ± 0.025	-0.0034 ± 0.0079	-0.001 ± 0.017		0.005 ± 0.050	-0.016 ± 0.065	**0.076 ± 0.063**	**24.8 ± 1.7**	-0.009 ± 0.021	0.015 ± 0.035			**2.12 ± 0.46**	**1.12 ± 0.15**	0.019 ± 0.052		**1.005 ± 0.069**				**0.15 ± 0.13**	**1.09 ± 0.78**
5271S0131	ORISE	-0.0042 ± 0.0097	-0.024 ± 0.029		-0.010 ± 0.011	0.007 ± 0.016	0.014 ± 0.014	**0.027 ± 0.012**		-0.007 ± 0.028	-0.032 ± 0.037	0.002 ± 0.030	**11.05 ± 0.86**	0.003 ± 0.012	-0.015 ± 0.019			**0.54 ± 0.22**	**0.276 ± 0.065**	0.005 ± 0.029		**0.236 ± 0.024**				0.018 ± 0.054	**0.22 ± 0.20**
5271S0132	ORISE	-0.008 ± 0.011	-0.008 ± 0.026		-0.015 ± 0.016	0.005 ± 0.021	**0.019 ± 0.018**	**0.030 ± 0.012**		-0.004 ± 0.038	-0.051 ± 0.050	-0.016 ± 0.032	**9.19 ± 0.88**	-0.012 ± 0.019	0.003 ± 0.023			**0.64 ± 0.26**	**0.288 ± 0.089**	0.014 ± 0.034		**0.281 ± 0.032**				0.068 ± 0.076	0.25 ± 0.26
5271S0133	ORISE	-0.004 ± 0.011	0.009 ± 0.028		-0.017 ± 0.013	0.007 ± 0.016	0.002 ± 0.016	**0.049 ± 0.015**		0.015 ± 0.033	-0.007 ± 0.041	0.008 ± 0.032	**10.79 ± 0.87**	-0.012 ± 0.014	0.009 ± 0.022			**0.41 ± 0.20**	**0.298 ± 0.032**	-0.003 ± 0.033		**0.288 ± 0.028**				**0.068 ± 0.065**	-0.07 ± 0.23
5271S0134	ORISE	-0.0011 ± 0.0075	-0.028 ± 0.021		-0.125 ± 0.037	-0.007 ± 0.016	0.016 ± 0.017	**0.031 ± 0.016**		-0.027 ± 0.035	-0.010 ± 0.045	-0.003 ± 0.025	**8.59 ± 0.70**	0.004 ± 0.014	0.002 ± 0.019			**0.69 ± 0.23**	**0.248 ± 0.071**	0.011 ± 0.031		**0.237 ± 0.026**				0.034 ± 0.062	**0.42 ± 0.22**
5271S0135	ORISE	-0.003 ± 0.017	-0.055 ± 0.042		-0.61 ± 0.12	-0.019 ± 0.031	**0.059 ± 0.028**	0.005 ± 0.021		-0.049 ± 0.058	0.016 ± 0.080	**0.074 ± 0.052**	**21.0 ± 1.6**	0.000 ± 0.023	-0.020 ± 0.034			**2.44 ± 0.43**	**0.8 ± 0.15**	-0.009 ± 0.054		**0.766 ± 0.063**				0.08 ± 0.11	**1.07 ± 0.47**
5271S0116A	ORISE		0.0016 ± 0.0031						-0.0016 ± 0.0031						0.0015 ± 0.0030	0.0030 ± 0.0042	0.0046 ± 0.0052				-0.01 ± 0.14					
5271S0124A	ORISE		0.0000 ± 0.0047						0.0000 ± 0.0033						0.0000 ± 0.0032	0.0032 ± 0.0045	0.0049 ± 0.0055				**0.17 ± 0.16**					
5271-S-200	NRC	0.008 ± 0.016	0.04 ± 0.09		0.006 ± 0.007	0.004 ± 0.004	0.014 ± 0.020	0.008 ± 0.010		0.02 ± 0.04	0.02 ± 0.04	0.06 ± 0.10	**14.9 ± 1.7**		0.005 ± 0.008			**0.68 ± 0.08**		-0.014 ± 0.020						**1.1 ± 0.6**
5271-S-201	NRC	0.001 ± 0.005	0.08 ± 0.15		0.04 ± 0.06	**0.009 ± 0.006**	0.002 ± 0.004	**0.025 ± 0.006**		0.018 ± 0.027	0.005 ± 0.015	0.03 ± 0.04	**16.0 ± 1.9**		0.06 ± 0.12			**0.77 ± 0.08**		0.03 ± 0.06						**1.6 ± 0.5**
5271-S-202	NRC	0.002 ± 0.012	0.04 ± 0.04		0.020 ± 0.031	0.012 ± 0.020	0.008 ± 0.014	0.010 ± 0.011		0.03 ± 0.06	0.019 ± 0.037	0.04 ± 0.06	**19.6 ± 2.9**		0.010 ± 0.018			**0.74 ± 0.11**		0.022 ± 0.027						**1.3 ± 0.8**
5271-S-203	NRC	0.009 ± 0.015	0.010 ± 0.196		0.02 ± 0.04	0.007 ± 0.009	0.003 ± 0.014	0.03 ± 0.04		0.009 ± 0.110	1 ± 2	1 ± 2	**7.9 ± 0.9**		0.01 ± 0.05			**1.31 ± 0.13**		0.04 ± 0.08						**6.6 ± 2.7**
5271-S-203A	NRC	0.004 ± 0.020	0.07 ± 0.18		0.012 ± 0.020	0.014 ± 0.020	-0.012 ± 0.025	0.02 ± 0.04		0.04 ± 0.06	0.02 ± 0.09	0.4 ± 0.8	**9.7 ± 0.7**		0.003 ± 0.019			**0.44 ± 0.07**		0.004 ± 0.034						**5.1 ± 3.6**
5271-S-204	NRC	0.0019 ± 0.0025		0.0016 ± 0.0022	0.04 ± 0.08	**0.020 ± 0.005**	0.04 ± 0.06	**0.024 ± 0.006**		**0.089 ± 0.023**	0.003 ± 0.010	0.03 ± 0.04	**14.0 ± 1.6**		0.012 ± 0.014	-0.0016 ± 0.0022		**0.52 ± 0.06**	**0.21 ± 0.02**	-0.006 ± 0.012	0.6 ± 0.6	**0.192 ± 0.019**	**0.254 ± 0.025**	**0.214 ± 0.021**	**0.238 ± 0.023**		**0.260 ± 0.025**
5271-S-204A	NRC	0.01 ± 0.02		-0.0016 ± 0.0022	0.013 ± 0.016	**0.094 ± 0.026**	0.0000 ± 0.0204	**0.051 ± 0.021**		**0.60 ± 0.08**	0.020 ± 0.037	0.02 ± 0.05	**13.3 ± 1.0**		0.021 ± 0.025	0.003 ± 0.004		**0.51 ± 0.09**	**0.24 ± 0.02**	0.05 ± 0.10	0.1 ± 0.6	**0.211 ± 0.021**	**0.256 ± 0.025**	**0.240 ± 0.024**	**0.300 ± 0.029**		**0.273 ± 0.027**
5271-S-205	NRC	0.0007 ± 0.0013	0.03 ± 0.08		0.009 ± 0.016	0.012 ± 0.020	0.005 ± 0.016	0.008 ± 0.014		0.06 ± 0.06	0.004 ± 0.024	0.07 ± 0.12	**18.7 ± 1.3**		0.005 ± 0.011			**0.91 ± 0.11**		0.017 ± 0.022						**1.0 ± 0.7**
5271-S-206	NRC	0.0013 ± 0.0033		-0.0015 ± 0.0022	0.0008 ± 0.0046	0.005 ± 0.010	0.03 ± 0.04	**0.024 ± 0.005**		0.012 ± 0.029	0.005 ± 0.015	0.009 ± 0.020	**7.3 ± 0.8**		0.011 ± 0.016	-0.0015 ± 0.0022		**0.28 ± 0.04**	**0.275 ± 0.027**	0.009 ± 0.018		**0.290 ± 0.028**	**0.338 ± 0.033**	**0.275 ± 0.027**	**0.309 ± 0.030**		**0.304 ± 0.030**
5271-S-207	NRC	0.003 ± 0.006		0.0015 ± 0.0022	0.004 ± 0.006	0.009 ± 0.016	0.005 ± 0.006	**0.058 ± 0.007**		0.06 ± 0.12	0.006 ± 0.014	0.008 ± 0.010	**6.4 ± 0.8**		0.005 ± 0.005	0.005 ± 0.006		**0.273 ± 0.027**	**0.3369 ± 0.033**	0.004 ± 0.011	**1.0 ± 0.7**	**0.322 ± 0.032**	**0.40 ± 0.04**	**0.337 ± 0.033**	**0.39 ± 0.04**		**0.39 ± 0.04**
5271-S-208	NRC	0.002 ± 0.004		-0.0015 ± 0.0020	0.002 ± 0.007	0.012 ± 0.020	0.003 ± 0.010	**0.039 ± 0.009**		0.006 ± 0.018	0.005 ± 0.014	0.02 ± 0.04	**8.4 ± 1.0**		0.006 ± 0.008	0.003 ± 0.004		**0.26 ± 0.04**	**0.28 ± 0.03**	0.02 ± 0.04		**0.298 ± 0.029**	**0.385 ± 0.038**	**0.277 ± 0.027**	**0.310 ± 0.030**		**0.265 ± 0.026**
5271-S-209	NRC	0.00010 ± 0.00400	0.02 ± 0.09		0.003 ± 0.007	0.006 ± 0.012	0.017 ± 0.020	**0.028 ± 0.006**		0.01 ± 0.04	0.012 ± 0.018	0.04 ± 0.08	**17.7 ± 2.1**		0.009 ± 0.009			**0.79 ± 0.08**		-0.010 ± 0.033						**1.0 ± 0.6**
5271-S-210	NRC	0.002 ± 0.005	0.17 ± 0.20		0.002 ± 0.015	0.012 ± 0.014	0.022 ± 0.023	0.004 ± 0.006		0.02 ± 0.09	0.012 ± 0.018	0.011 ± 0.022	**13.9 ± 2.8**		0.02 ± 0.04			**0.93 ± 0.13**		0.02 ± 0.04						**1.5 ± 0.5**
5271-S-211	NRC	0.004 ± 0.004		-0.0015 ± 0.0022	0.010 ± 0.015	0.009 ± 0.018	0.004 ± 0.008	**0.015 ± 0.007**		0.004 ± 0.007	0.007 ± 0.016	0.00000 ± 0.01537	**7.2 ± 1.1**		0.006 ± 0.009	0.005 ± 0.006		**0.22 ± 0.04**	**0.32 ± 0.03**	0.04 ± 0.08	0.6 ± 0.6	**0.315 ± 0.031**	**0.42 ± 0.04**	**0.318 ± 0.031**	**0.338 ± 0.033**		**0.359 ± 0.035**
5271-S-212	NRC	0.0030 ± 0.0037		0.003 ± 0.004	0.06 ± 0.12	0.004 ± 0.005	0.011 ± 0.012	**0.197 ± 0.017**		-0.008 ± 0.015	0.003 ± 0.020	0.009 ± 0.030	**4.7 ± 0.4**		0.015 ± 0.016	0.003 ± 0.004		**0.32 ± 0.04**	**0.21 ± 0.02**	0.03 ± 0.04	0.5 ± 0.6	**0.219 ± 0.022**	**0.356 ± 0.035**	**0.215 ± 0.021**	**0.230 ± 0.023**		**0.251 ± 0.025**
5271-S-213	NRC	0.0010 ± 0.0029		0.003 ± 0.004	0.004 ± 0.005	0.005 ± 0.010	0.003 ± 0.007	0.011 ± 0.020		0.010 ± 0.018	0.0002 ± 0.0134	0.004 ± 0.011	**2.20 ± 0.33**		0.01 ± 0.02	0.006 ± 0.008		**0.65 ± 0.05**	**1.51 ± 0.15**	0.003 ± 0.010	0.3 ± 0.6	**1.37 ± 0.13**	**1.28 ± 0.13**	**1.51 ± 0.15**	**1.41 ± 0.14**		**1.13 ± 0.11**
5271-S-214	NRC	0.0018 ± 0.0031	0.003 ± 0.008		0.0018 ± 0.0034	0.006 ± 0.008	0.001 ± 0.006	0.004 ± 0.008		0.005 ± 0.007	0.02 ± 0.04	0.001 ± 0.009	**5.0 ± 0.6**		0.01 ± 0.04			**0.236 ± 0.023**		0.010 ± 0.011						**0.27 ± 0.20**
5271-S-215	NRC	0.003 ± 0.007	-0.004 ± 0.019		0.007 ± 0.012	0.003 ± 0.007	0.006 ± 0.010	0.002 ± 0.006		0.009 ± 0.016	0.04 ± 0.06	0.03 ± 0.04	**15.3 ± 1.7**		0.005 ± 0.008			**0.85 ± 0.07**		0.007 ± 0.015						**1.0 ± 0.5**
5271-S-216	NRC	0.004 ± 0.004	0.06 ± 0.06		0.005 ± 0.010	0.009 ± 0.016	0.002 ± 0.014	**0.030 ± 0.006**		0.014 ± 0.027	0.014 ± 0.016	0.012 ± 0.022	**9.2 ± 0.7**		0.018 ± 0.020			**0.29 ± 0.05**		0.008 ± 0.013						**0.32 ± 0.31**

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

[b]Bold values indicate that the 95% uncertainty interval does not include zero

[c]RESL analytical results for alpha emitting radionuclides in NRC samples were determined by total dissolution followed by alpha spectrometry

[d]The gamma spectrometry software did not identify Cs-134 in any sample nor did it identify any of the 3 major gamma lines (604, 795, or 569 keV). The reported values are a force fit calculation based on the keyline energy of 795 keV. Further inspection by REAL staff verified that there are no peaks related to Cs134 present in the gamma spectra of these samples.

[e]For ORISE samples that received gamma spectrometry, Np-237 was determined by Pa-233

[f]Results include contribution from Pu-240

[g]Ra-228 was determined by Ac-228 for ORISE samples

[h]Th-228 was determined by Pb-212 for ORISE samples

[i]U-238 was determined by Th-234 for ORISE samples

Table B.4. Alpha Recount of Select Samples (pCi/g)[a,b]																	
Sample	Count	Am-241			Cm-244			Pu-238			Pu-239/240			Np-237			
		Result		TPU	Result		TPU	Result		TPU	Result		TPU	Result		TPU	
S0120[c]	original	0.0000	±	0.0031	0.0047	±	0.0069	-0.0015	±	0.0051	**0.0060**	**±**	**0.0059**	-0.0106	±	0.0099	
	re-count	0.0024	±	0.0027	0.0008	±	0.0016	**0.0031**	**±**	**0.0030**	**0.0046**	**±**	**0.0037**	-0.0008	±	0.0050	
S0122	original	**0.0096**	**±**	**0.0089**	0.0000	±	0.0031	0.0030	±	0.0059	0.0045	±	0.0051	-0.0015	±	0.0030	
	re-count	-0.0016	±	0.0050	0.0016	±	0.0059	0.0024	±	0.0027	0.0024	±	0.0060	0.0001	±	0.0003	
S0127	original	**0.0085**	**±**	**0.0075**	0.0017	±	0.0033	0.0016	±	0.0055	**0.0113**	**±**	**0.0084**	0.0016	±	0.0032	
	re-count	**0.0072**	**±**	**0.0047**	-0.0016	±	0.0031	0.0008	±	0.0016	**0.0154**	**±**	**0.0089**	0.0024	±	0.0048	

[a]Uncertainties represent the total propagated uncertainty reported at the 95% confidence level.
[b]Bold values indicate that the 95% uncertainty interval does not include zero.
[c]S0120 is classified as a particle; results presented in this table were converted to total activity by multiplying the sample concentration by sample mass.
TPU = Total propagated uncertainty

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 his 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)

C.1.2 ALPHA, BETA, GAMMA

Ludlum Pancake-type, Halogen Quenched Geiger-Muller Probe Model 44-9
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)

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-7
CANBERRA/Tennelec Model No: ERVDS-30-25195
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)

(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector-11
EG&G ORTEC Model No. GMX-45-76-CW-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)

High-Purity, Intrinsic Detector-10
EG&G ORTEC Model No. GEM-MX5970-76-S/CDG-SV-76
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)

APPENDIX D: SURVEY AND ANALYTICAL PROCEDURES

D.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* (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 daily pre-job briefing of the survey areas was completed with site staff and 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.

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 2016a)
- *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 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

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 thallium-doped sodium iodide (NaI[Tl]) scintillation detectors were used solely as a qualitative means to identify elevated radiation levels in excess of background. 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.

For the measurement of soils where volumetric derived concentration guideline levels (DCGLs) were applicable, the confirmatory survey considered the gross gamma $DCGL_{Op}$ (3.4 pCi/g) used for final status survey (FSS) planning purposes. However, the scan survey also measured for the presence of particles in areas investigated, which was the limiting scan survey requirement. Using the scan minimum detectable concentration (MDC) calculation approach outlined in NUREG-1507, the *a priori* confirmatory scan sensitivity was evaluated. The calculation used the following inputs:

- Index of sensitivity = 1.38
- Observation interval = 2 seconds (based on a source diameter of 0.25 m^2 and 0.25 m/s surveyor velocity)
- Detector background = 7,500 counts per minute (cpm) (this value varies considerably across the site; collimator use on the detector reduced this value by a factor of 2 or 3)
- Surveyor efficiency = 0.75
- Radionuclide of concern (ROC) fraction = 0.05 for Co-60; 0.95 for Cs-137

Based on the above inputs, the scan MDC for cobalt-60 (Co-60) and cesium-137 (Cs-137) was 1.7 picocuries per gram (pCi/g) and 3.4 pCi/g, respectively, when a collimator was not used. The corresponding gross scan MDC was 3.2 pCi/g, which was below the gross $DCGL_{Op}$. The corresponding minimum detectable count rate for the surveyor ($MDCR_{Surveyor}$) was 750 counts per minute (cpm). The $MDCR_{Surveyor}$ served as the gamma investigation level (IL). If a judgmental sample was collected in response to exceedance of the gamma IL, the surveyor further bound the area contributing to the elevated detector response. The approximate size of the elevated area was noted on the appropriate field form. Use of collimators reduced the background count rate of the detector, and, depending on the actual background count rate during scan surveys, the gross scan MDC was reduced to below the $DCGL_{Op}$. Again, the scan protocol for particles was used in all survey units, with the measurement goal of detecting less than 1 microcurie (μCi)of Co-60 at the soil surface and to a depth of 6 inches. Note that the survey design basis was focused on detecting Co-60 particles; therefore, scan sensitivities for the particles containing constituents other than Co-60 were not evaluated during the survey planning or reporting. Scan sensitivities presented in this section met the goals outlined in data quality objectives (DQO) Step 6 (i.e., scan MDC less than the $DCGL_{Op}$ for volumetric contamination and less than 1 μCi for a particle).

D.3.2 SOIL SAMPLING

Surface soil samples (approximately 1 kilogram each) were collected by ORISE personnel using a clean garden trowel to transfer soil into a new sample container. All containers were labeled and security sealed in accordance with ORISE procedures. ORISE staff hand delivered the samples under chain-of-custody to the ORISE laboratory for analysis.

D.4. RADIOLOGICAL ANALYSIS

Table D.1. provides an analysis matrix for each sample collected as part of this confirmatory survey.

Table D.1 ORISE Laboratory Analysis Matrix by Sample ID				
Sample ID	**Sample Matrix**	**Gamma Spectrometry**	**Alpha Spectrometry**	**Sr-90 Analysis**
5271S0112	Volumetric	✓	✓	✓
5271S0113	Volumetric	✓		
5271S0114	Volumetric	✓		
5271S0115	Volumetric	✓		
5271S0116A	Volumetric		✓	✓
5271S0124A	Volumetric		✓	✓
5271S0117	Volumetric	✓		
5271S0118	Volumetric	✓		
5271S0119	Volumetric	✓		
5271S0120	Volumetric	✓	✓	✓
5271S0121	Volumetric	✓	✓	✓
5271S0122	Volumetric	✓	✓	✓
5271S0123	Volumetric	✓		
5271S0125	Volumetric	✓	✓	✓
5271S0127	Volumetric	✓	✓	✓
5271S0128	Volumetric	✓		
5271S0129	Volumetric	✓		
5271S0130	Volumetric	✓		
5271S0131	Volumetric	✓		
5271S0132	Volumetric	✓		
5271S0133	Volumetric	✓		
5271S0134	Volumetric	✓		
5271S0135	Volumetric	✓		
5271S0112A	Particle	✓	✓	✓
5271S0116	Particle	✓	✓	✓
5271S0124	Particle	✓	✓	✓
5271S0126	Particle	✓	✓	✓

D.4.1 GAMMA SPECTROSCOPY

Volumetric samples were 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. Net material weights were determined, and the samples were counted using intrinsic, high-purity, germanium detectors coupled to a pulse-height analyzer system.

Particle samples were treated with the general procedure discussed in Section 4.1.1 to isolate the activity source: The contents of each sample container were emptied onto a white pan with elevated sides to minimize potential for inadvertent loss of material. A Ludlum model 44-9 GM probe and/or Ludlum model 44-10 collimated sodium iodide detector were used to isolate the general area containing elevated activity based upon detector response. The isolated material was then serially separated by half until only a small number of mono-layered particles (not necessarily all particles) were present. A member of the team then used standard Scotch tape to fix the suspect particles. This approach allows the placement of the particle(s) in a point source geometry without attenuation from other sample materials. This also minimizes the amount of material that would subsequently be used for chemical separation. Due to the particulate size and elevated responses by the hand-held instrumentation, ORISE's Radiological and Environmental Analytical Laboratory (REAL) performed Gamma spectroscopy utilizing a point source calibration at 11 cm above a high-purity germanium (HPGe) detector.

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 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 MDCs for a 1-hour count time are presented in Table D.2.

Table D.2. Typical MDCs and TAPs for ROCs		
Radionuclide[a]	**TAP (MeV)[b]**	**MDC (pCi/g)[c]**
Ag-108m	0.433	0.03
Am-241	0.059	0.10
Ba-133	0.356	0.04
Co-60	1.332	0.04
Cs-134	0.795	0.05
Cs-137	0.662	0.04
Eu-152	0.344	0.09
Eu-154	0.723	0.17
Eu-155	0.105	0.10
K-40	1.460	0.54
Nb-94	0.871	0.04
Np-237 by Pa-233	0.311	0.06
Ra-226	0.186	0.68
Sb-125	0.427	0.09
Th-232 byAc-228	0.911	0.15
U-235	0.063	0.21
U-238	0.143	0.87

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

D.4.2 PARTICLE DISSOLUTION

The four particle samples were all treated with the following dissolution procedure. Each sample attached to tape was placed into individually labeled 250mL Erlenmeyer flasks. A combination of concentrated acids (nitric, sulfuric, and perchloric) and a small amount of sodium bisulfate were added to each flask. This mixture was heated and refluxed until the organic tape component was destroyed and then a clear pyrosulfate fusion formed and no particles were visible to lab staff (i.e., no special equipment was used). Samples 14063S0115 and 14063S0117 required 2 and 3 days, respectively, for complete dissolution.

Each sample was dissolved with 4M hydrochloric acid (HCL) and filtered through a 0.45 micron (μm), 25-mm diameter polyvinylidene diflouride (PVDF) filter. Each filter was retained and verified "clean" by gamma scans using HPGe detectors, HP260 B/G, and alpha scintillator probes. Finally

each sample was diluted to 100 milliliters (mL) except for particle sample S0124, which was diluted to 200 mL.

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 0.4-0.6 pCi/g for a 1-gram sample.

D.4.4 ALPHA SPECTROMETRY

Volumetric samples were dissolved by a combination of potassium hydrogen fluoride and pyrosulfate fusions. Particle samples were previously subjected to a pyrosulfate dissolution as described in D.4.2, and a measured quantity of the total dilution was treated with an additional pyrosulfate fusion in a new glass beaker. The fusion cakes were dissolved, and all alpha emitters were co-precipitated on barium sulfate. The barium sulfate was re-dissolved, and the contaminants of concern were separated from the other actinides by extraction chromatography utilizing Eichrom Technologies resins, co-precipitated with cerium fluoride, and analyzed using passivated implanted planar silicon detectors, alpha spectrometers, and multichannel analyzers. The alpha spectroscopy detector system calculated an MDC for each individual isotope per sample based on the detector background, counting efficiency, chemical yield, and sample quantity. The typical MDC for samples with a quantity of 1 (total or grams) is approximately 0.01 pCi/sample or pCi/g.

D.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, count times, and contributions from other

radionuclides in samples, the detection limits differed from sample to sample and instrument to instrument.