OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

January 28, 2020

Mr. John Hickman
U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Decommissioning, Uranium Recovery, and Waste Programs
Reactor Decommissioning Branch
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Rockville, MD 20852

SUBJECT: DOE Contract No. DE-SC0014664
INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR SELECT PENETRATIONS AND EMBEDDED PIPING IN THE CONTAINMENT AND AUXILIARY BUILDINGS AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS
DOCKET NOs. 50-295 and 50-304; RFTA NO. 18-004; DCN 5271-SR-04-0

Dear Mr. Hickman:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the enclosed report detailing the independent confirmatory survey activities associated with select penetrations in the Containment and Auxiliary Buildings at the Zion Nuclear Power Station in Zion, Illinois. This report provides the summary and results of ORISE on-site activities performed during the period of June 4–7, 2018.

You may contact me at 865.574.6273 or Erika Bailey at 865.576.6659 if you have any questions.

Sincerely,

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

NAA:tb

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N. A. Altic, CHP
ORISE

FINAL REPORT

Prepared for the
U.S. Nuclear Regulatory Commission

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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 under DOE contract number DE-SC0014664.

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FINAL REPORT

JANUARY 2020

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ACRONYMS

AA	alternate action
AF	area factor
Bkg	background
cpm	counts per minute
CsI	cesium iodide
DCGL	derived concentration guideline level
$DCGL_{BC}$	Base Case DCGL
$DCGL_{EMC}$	elevated measurement comparison DCGL
$DCGL_{GROSS}$	gross activity DCGL
$DCGL_{Op}$	Operational DCGL
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DQO	data quality objective
DS	decision statement
EPA	U.S. Environmental Protection Agency
Exelon	Exelon Generation Company
FSS	final status survey
HS	hot spot
LTP	license termination plan
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
mL	milliliter
mrem/yr	millirem per year
NaI	sodium iodide
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
pCi/m^2	picocuries per square meter
PPE	personal protective equipment
PSQ	principal study question
ROC	radionuclide of concern
SOF	sum of fractions
SU	survey unit
TAP	total absorption peak
TEDE	total effective dose equivalent
VSP	Visual Sample Plan
WWTF	Waste Water Treatment Facility
ZNPS	Zion Nuclear Power Station
ZS	Zion*Solutions*, LLC

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR SELECT PENETRATIONS AND EMBEDDED PIPING IN THE CONTAINMENT AND AUXILIARY BUILDINGS AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities of select remaining embedded piping and penetrations at the Zion Nuclear Power Station (ZNPS). The survey activities were conducted during the period of June 4–7, 2018, and included gamma surface scans, direct gamma measurements, and miscellaneous sampling. Direct gamma measurements were collected at randomly selected locations inside the Unit 1 and Unit 2 Containment penetrations and were compared with the corresponding FSS measurement.

None of the piping/penetration interior direct measurements exceeded the most restrictive Base Case derived concentration guideline level ($DCGL_{BC}$) in any of the areas investigated as part of the confirmatory survey. A cloth wipe of the penetration P035 interior identified the presence of Am-241, which was deselected from the final status survey (FSS) analysis based on an insignificant dose contribution. The Am-241 activity on the wipe, which represents the removable radionuclide of concern (ROC) portion, was at least an order of magnitude less than the more predominant gamma-emitters, Cs-137 and Co-60.

The confirmatory survey did not generate sufficient evidence to conclude that the FSS and confirmatory measurements were statistically different. The difference in the sodium iodide (NaI) detector response profile for one measurement pair in penetration P323 may be explained by loose debris containing contamination that was present inside of the penetration during FSS, but was not present during the confirmatory survey. However, additional evaluation is not recommended given the low magnitude of the confirmatory survey measurements relative to the $DCGL_{BC}$.

The results of the confirmatory surveys conducted by ORISE did not identify any issues that would preclude the FSS data from demonstrating compliance with the release criteria.

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR SELECT PENETRATIONS AND EMBEDDED PIPING IN THE CONTAINMENT AND AUXILIARY BUILDINGS AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS

1. INTRODUCTION

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

ZS's decommissioning commitments were that, all above-grade structures, with minor exceptions, would be demolished. Structures below the 588-foot elevation (referenced from mean sea level), consisting of primarily exterior subgrade walls and floors, would remain. These basement structures would be backfilled as part of the final site restoration. In order to demonstrate compliance with the release criteria in 10 CFR 20.1402, ZS would implement a final status survey (FSS) of remaining basement structures along with associated embedded piping and penetrations, buried piping, and surface and subsurface soil. FSS methodologies are outlined in Chapter 5 of ZS's license termination plan (LTP) (ZS 2018a). NRC issued license amendments 178 and 191 to approve ZS's LTP in September of 2018 (NRC 2018a). The primary FSS method for basement structure survey units (SUs) was *in situ* gamma measurements using a portable, high-resolution gamma spectrometer. FSS methods were based on methods outlined in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000).

NRC requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities of select remaining penetrations and embedded piping in the Containment and Auxiliary Buildings at ZNPS. This report summarizes the confirmatory survey activities and results for these areas.

2. SITE DESCRIPTION

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

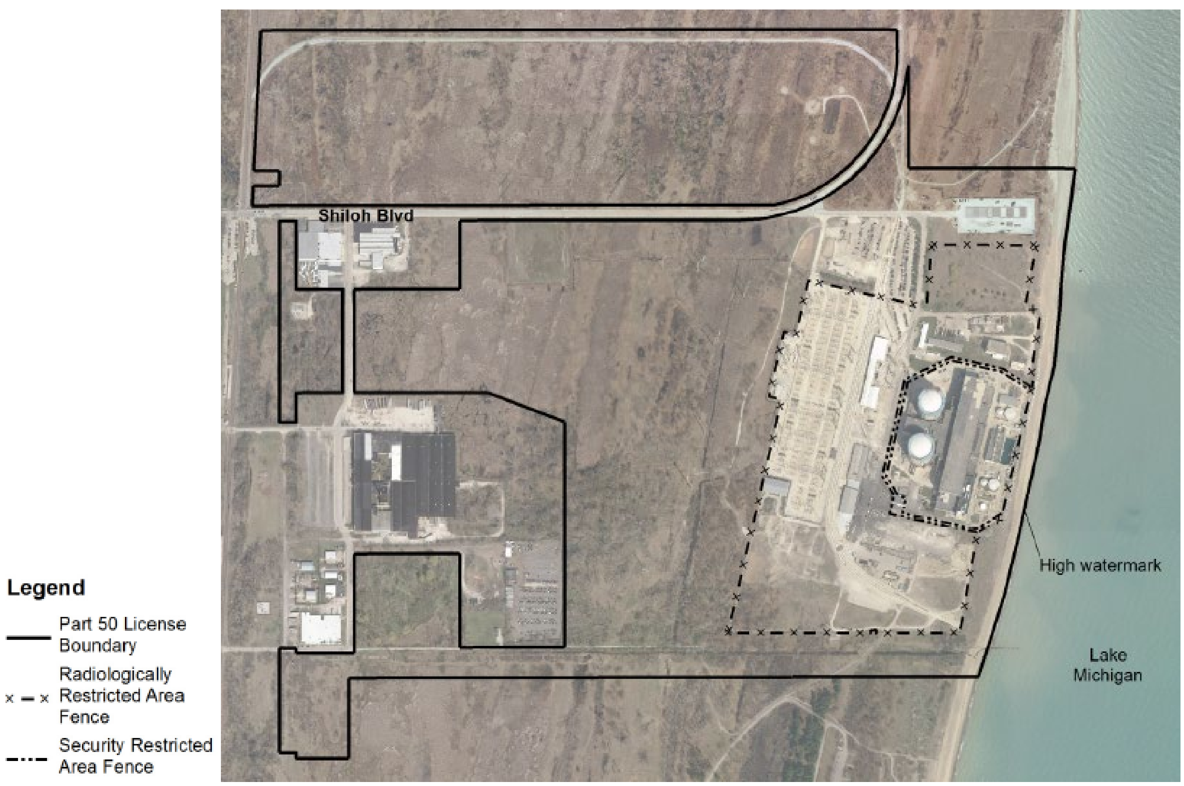

Figure 2.1. ZNPS Overview (adapted from ZS 2018a)

2.1 Unit 1 and 2 Containment Building Penetrations and Embedded Piping

The Containment Buildings housed the reactor pressure vessels and consist of a steel liner with interior and exterior concrete several feet thick. In both Containment Building basements, all concrete from the interior of the steel liner from the 565-foot to the 588-foot elevation was removed. The Containment Buildings contained multiple penetrations ranging from 6 to 50 inches in diameter and 4 to 52 feet in length (ZS 2018b). The only embedded piping remaining in each Containment Building is the 1.5-inch diameter in-core sump drain pipe.

2.2 Auxiliary Building Penetrations

The Auxiliary Building housed various support systems for both reactors, such as residual heat removal and reactor letdown systems. The Auxiliary Building basement consists of wall and floor structures below the 588-foot elevation. Auxiliary Building structures above the 588-foot elevation were demolished, leaving the basement open to the environment at the time of the confirmatory activities. The Auxiliary Building contained multiple penetrations ranging from 2.5 to 36 inches in diameter all with a length of 3 feet (ZS 2018b).

Figure 2.2 displays the licensed area with the Containment and Auxiliary Buildings indicated.

Figure 2.2. ZNPS Containment and Auxiliary Buildings (Google Earth)

3. DATA QUALITY OBJECTIVES

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

The seven steps of the DQO process are as follows:

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

3.1 STATE THE PROBLEM

The first step in the DQO process defined the problem that necessitated the study, identified the planning team, and examined the project budget and schedule. Prior to the confirmatory site visit, ZS was in the process of dismantling remaining structures and remediating remaining land areas. As part of this process, ZS conducted an FSS to demonstrate compliance with NRC's license termination criteria specified in 10 CFR 20.1402. To this end, NRC staff requested that ORISE perform confirmatory surveys of the penetrations and embedded piping in the Containment Buildings and Auxiliary Building to provide independent confirmatory data for NRC's consideration in their evaluation of the FSS. The problem statement was formulated as follows:

> Confirmatory surveys are necessary to generate independent radiological data for NRC's consideration in the evaluation of the FSS design, implementation, and results for demonstrating compliance with the release criteria.

3.2 IDENTIFY THE DECISION/OBJECTIVE

The second step in the DQO process identified the principal study questions (PSQs) and alternate actions (AAs), developed a decision statement (DS), and organized multiple decisions, as appropriate. This was done by specifying AAs that could result from a "yes" response to the PSQ and combining the PSQ and AAs into a DS. Table 3.1 presents the confirmatory survey decision process.

Table 3.1. FSS Confirmatory Survey Decision Process

Principal Study Question	Alternate Actions
Are the FSS measurements of penetrations and embedded piping equivalent to the ORISE independent confirmatory measurements?	**Yes:** Confirmatory survey results indicate that FSS measurements of penetrations and embedded piping are equivalent to the ORISE measurements; therefore, compile confirmatory survey data and present the results to NRC. **No:** Confirmatory survey results indicate that there is a positive statistical bias in the ORISE confirmatory measurements relative to the FSS measurements; therefore, summarize the discrepancies and provide technical comments to NRC.
Decision Statement	
The FSS results for penetrations and embedded piping are/are not equivalent to the ORISE confirmatory survey measurements.	

3.3 IDENTIFY INPUTS TO THE DECISION/OBJECTIVE

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

- FSS data for Unit 1 Containment, Unit 2 Containment, and the Auxiliary Building penetrations
- ZS derived concentration guideline levels (DCGLs), discussed in subsection 3.3.1
- ORISE confirmatory survey results, including surface radiation scans and direct surface activity measurements

3.3.1 Radionuclides of Concern and Release Guidelines

The primary radionuclides of concern (ROCs) identified for the ZNPS are beta-gamma emitters—fission and activation products—resulting from reactor operations. At ZNPS, there are four distinct source terms: basement structures, soils, buried piping, and groundwater. Furthermore, basement structures are composed of four structural source terms: surfaces, embedded piping, penetrations, and fill. ZS has developed site-specific DCGLs that correspond to a residual radioactive contamination level, above background, which could result in a total effective dose equivalent (TEDE) of 25 millirem per year (mrem/yr) to an average member of the critical group. These DCGLs—defined in ZS's LTP as Base Case DCGLs ($DCGL_{BC}$s)—are radionuclide-specific and independently correspond to a TEDE of 25 mrem/yr for each source term. In order to ensure that the total dose from all source terms is less than the NRC-approved release criteria, the $DCGL_{BC}$s are further reduced to Operational DCGLs ($DCGL_{Op}$s). The $DCGL_{Op}$s are scaled to an expected dose from prior investigations and are used for remediation and FSS design purposes. The initial suite of ROCs present at ZNPS was reduced based on an insignificant dose contribution from a number of radionuclides. The $DCGL_{BC}$s and $DCGL_{Op}$s, accounting for insignificant dose contributors, for embedded piping and penetrations—excluding fill material, are presented in Tables 3.2 and 3.3, respectively.

Table 3.2. ZS Embedded Piping DCGLs[a]

ROC	Auxiliary Bldg. Basement Embedded Floor Drains	Turbine Bldg. Basement Embedded Floor Drains	Unit 1 Containment In-Core Sump Embedded Drain Pipe	Unit 2 Containment In-Core Sump Embedded Drain Pipe	Unit 1 & Unit 2 Steam Tunnel Embedded Floor Drains	Unit 1 Tendon Tunnel Embedded Floor Drains	Unit 2 Tendon Tunnel Embedded Floor Drains
Base Case DCGLs (pCi/m²)							
H-3	N/A	N/A	8.28E+09		N/A	1.61E+10	
Co-60	7.33E+09	6.31E+09	5.47E+09		4.07E+10	1.06E+10	
Ni-63	2.78E+11	1.96E+11	1.40E+11		1.26E+12	2.72E+11	
Cs-134	5.10E+09	1.43E+09	1.05E+09		9.22E+09	2.04E+09	
Cs-137	2.68E+09	1.89E+09	1.37E+09		1.22E+10	2.67E+09	
Sr-90	2.41E+08	6.94E+07	4.98E+07		4.48E+08	9.70E+07	
Eu-152	N/A	N/A	1.28E+10		N/A	2.48E+10	
Eu-154	N/A	N/A	1.11E+10		N/A	2.16E+10	
Operational DCGLs (pCi/m²)							
H-3	N/A	N/A	6.62E+08	6.62E+08	N/A	3.22E+08	3.22E+08
Co-60	7.33E+09	2.52E+08	4.38E+08	4.38E+08	1.63E+09	2.12E+08	2.12E+08

Table 3.2. ZS Embedded Piping DCGLs[a]							
ROC	Auxiliary Bldg. Basement Embedded Floor Drains	Turbine Bldg. Basement Embedded Floor Drains	Unit 1 Containment In-Core Sump Embedded Drain Pipe	Unit 2 Containment In-Core Sump Embedded Drain Pipe	Unit 1 & Unit 2 Steam Tunnel Embedded Floor Drains	Unit 1 Tendon Tunnel Embedded Floor Drains	Unit 2 Tendon Tunnel Embedded Floor Drains
Cs-134	5.10E+09	5.72E+07	8.40E+07	8.40E+07	3.69E+08	4.08E+07	4.08E+07
Cs-137	2.68E+09	7.56E+07	1.10E+08	1.10E+08	4.88E+08	5.34E+07	5.34E+07
Ni-63	2.78E+11	7.84E+09	1.12E+10	1.12E+10	5.04E+10	5.44E+09	5.44E+09
Sr-90	2.41E+08	2.78E+06	3.98E+06	3.98E+06	1.79E+07	1.94E+06	1.94E+06
Eu-152	N/A	N/A	1.02E+09	1.02E+09	N/A	4.96E+08	4.96E+08
Eu-154	N/A	N/A	8.88E+08	8.88E+08	N/A	4.32E+08	4.32E+08

[a]Recreated from ZS 2018a.
pCi/m^2 = picocuries per square meter
ROC = radionuclide of concern

Table 3.3. ZS Penetration DCGLs[a]						
ROC	Auxiliary Building	Unit 1 & Unit 2 Containment	SFP/Transfer Canal	Turbine Building	Crib House/ Forebay[b]	WWTF[b]
Base Case DCGLs (pCi/m^2)						
H-3	3.99E+09	3.42E+09	4.84E+16	3.23E+09	N/A	N/A
Co-60	8.82E+07	2.26E+09	4.45E+08	1.76E+09	N/A	N/A
Cs-134	3.28E+08	4.32E+08	7.48E+08	4.00E+08	N/A	N/A
Cs-137	6.17E+08	5.66E+08	1.46E+09	5.29E+08	N/A	N/A
Ni-63	6.79E+10	5.78E+10	1.86E+14	5.48E+10	N/A	N/A
Sr-90	2.41E+07	2.06E+07	9.26E+10	1.94E+07	N/A	N/A
Eu-152	3.29E+08	5.26E+09	9.44E+08	4.06E+09	N/A	N/A
Eu-154	2.33E+08	4.58E+09	8.53E+08	3.58E+09	N/A	N/A
Operational DCGLs (pCi/m^2)						
H-3	3.14E+08	2.33E+08	1.13E+16	2.58E+08	N/A	N/A
Co-60	6.95E+06	1.54E+08	1.04E+08	1.41E+08	N/A	N/A
Cs-134	2.58E+07	2.94E+07	1.74E+08	3.20E+07	N/A	N/A
Cs-137	4.86E+07	3.85E+07	3.40E+08	4.23E+07	N/A	N/A
Ni-63	5.35E+09	3.93E+09	4.33E+13	4.38E+09	N/A	N/A
Sr-90	1.90E+06	1.40E+06	2.16E+10	1.55E+06	N/A	N/A
Eu-152	2.59E+07	3.58E+08	2.20E+08	3.25E+08	N/A	N/A
Eu-154	1.84E+07	3.11E+08	1.99E+08	2.86E+08	N/A	N/A

[a]Recreated from ZS 2018a.
[b]The Base Case and Operational DCGLs are not applicable because of the small surface area of penetrations present. The corresponding DCGLs for basement surfaces will apply.
pCi/m^2 = picocuries per square meter
ROC = radionuclide of concern
WWTF = Waste Water Treatment Facility

Because each of the individual $DCGL_{BC}$s represents a separate radiological dose, the sum-of-fractions (SOF) approach must be used to evaluate the total dose from the SU and demonstrate compliance with the dose limit. SOF calculations were performed as follows:

$$SOF = \sum_{j=1}^{n} \frac{\mathrm{C_{mean,j}}}{\mathrm{DCGL_{BC,j}}} + \frac{\left(C_{Elv,j} - C_{mean,j}\right)}{\left(DCGL_{BC,j} \times AF_j\right)}$$

Where:

> $C_{mean,j}$ is the mean concentration of ROC "j"
> $C_{Elv,j}$ is an elevated area of ROC "j"
> $DCGL_{BC,j}$ is the Base Case DCGL for ROC "j"
> $AF_{,j}$ is the area factor for ROC "j"

It is important to note that AFs—as described by MARSSIM—are only applicable to soils. However, the $DCGL_{BC}$s for basement structures are scaled by area to account for elevated radioactivity. In this case, the AF in the equation above is equal to the SU surface area divided by the surface area of the elevated "hot spot" (HS) ($AF = SU_{SA}/HS_{SA}$). For soils, the quantity ($DCGL_{BC,j} \times AF_j$) is referred to as the elevated measurement comparison, denoted by $DCGL_{EMC}$. Note that gross concentrations are considered here for conservatism.

3.4 Define the Study Boundaries

The fourth step in the DQO process defined target populations and spatial boundaries, determined the timeframe for collecting data and making decisions, addressed practical constraints, and determined the smallest subpopulations, area, volume, and time for which separate decisions must be made. Confirmatory surveys were performed on select penetrations and embedded piping in the Containment and Auxiliary buildings during the period of June 4–7, 2018. Penetrations selected for confirmatory survey were based on the highest FSS SOF results of penetrations that will remain. Table 3.4 lists SUs that were initially selected for confirmatory survey. Each SU listed in Table 3.4 corresponds to the smallest subpopulation where decisions are made.

Table 3.4. Penetrations Selected for Confirmatory Survey					
Unit 1 Containment		Unit 2 Containment		Auxiliary	
P035	Recirculating Sump Suction	P235	Recirculating Sump Suction	A011	Waste Disposal
P036	Cavity Flood Sump Suction	P236	Cavity Flood Sump Suction	A023	Waste Disposal
P037	Cavity Flood Sump Suction	P237	Cavity Flood Sump Suction		
P123	Recirculating Sump Suction	P323	Recirculating Sump Suction		
P124	Recirculating Sump Suction	P324	Recirculating Sump Suction		
P125[a]	In-Core Sump Discharge Pipe	P325[a,b]	In-Core Sump Discharge Pipe		

[a]Classified as embedded piping and, thus, DCGLs in Table 3.2 apply.
[b]This piping was removed during remediation and was not available for confirmatory survey.

3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specified appropriate population parameters (e.g., mean, median), confirmed action levels were above detection limits, and developed an "if…then…" decision rule statement. Decision rules for this survey were based on independent scan surveys and randomly and judgmentally selected surface activity measurements to determine whether there is a potential low relative statistical bias between the FSS and confirmatory data sets. FSS measurements consisted of surface activity measurements collected at 1-foot intervals throughout the length of the penetration. The FSS measurements were performed using sodium iodide (NaI) scintillation detectors calibrated to Cs-137 gamma rays[1]. Radionuclide-specific surface activity values—in units of picocuries per square meter (pCi/m^2)—were calculated using the gross surface activity and the expected ROC activity contributions from the LTP.

For the Containment Building penetrations, ORISE collected co-located surface activity measurements to assess whether the confirmatory measurements and FSS measurements were from the same population distribution. FSS measurements in both of the Containment Buildings' penetrations were performed using a 3-inch by 3-inch NaI detector, whereas the confirmatory measurements were collected with a 2-inch by 2-inch NaI detector. FSS measurements were reported as a gross value, uncorrected for background. The difference in detector volumes precluded a direct comparison of the gross response, as the relative response between the two detectors is dependent on the energy of the measured photons. Additionally, the FSS measurements were converted to units of total activity concentration and reported as a gross value, uncorrected for background. This prevented a direct comparison of the measurements reported in units of pCi/m^2.

[1] The gamma rays are from the Cs-137 daughter, Ba-137m

Therefore, the data sets were normalized, pooled and rank-transformed prior to analysis. Thus, the parameter of interest is the mean difference of ranks between the confirmatory measurements and the FSS data sets.

Figure 3.1 presents an example FSS surface activity profile along the length of penetration P324 in the Unit 2 Containment Building. The peaks indicate the presence of relatively localized deposits of residual contamination. Additionally, judgmental confirmatory measurements were collected at these locations—if not randomly selected—for comparison directly to the $DCGL_{BC}$.

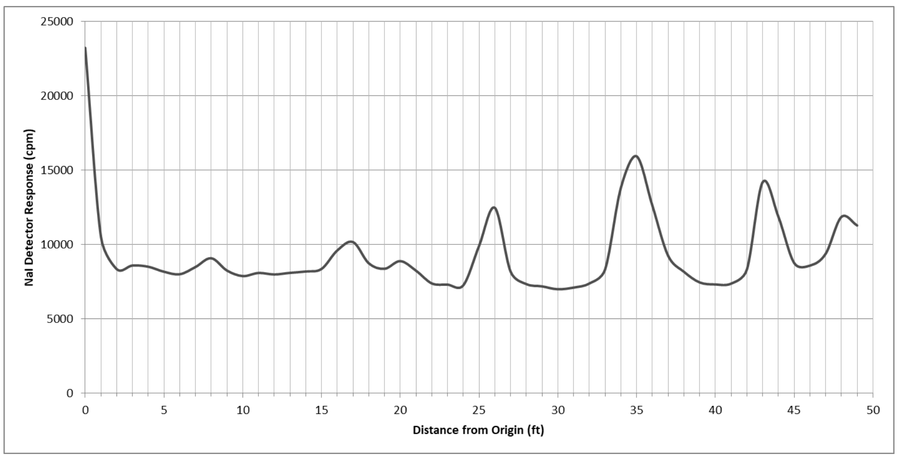

Figure 3.1. FSS Surface Activity Length Profile for Penetration P324 in the Unit 2 Containment Building

FSS data assessment was performed by converting gross instrument counts to disintegrations per minute (dpm) using the efficiency factor determined with the Cs-137 calibration standard. The total dpm value was then "divided" among other gamma-emitting ROCs based on the abundance fractions determined from characterization. The divided activity values were then converted into units of pCi/m^2 based on the surface area of a 1-foot length of penetration/pipe. This process is analogous to the gross activity DCGL ($DCGL_{GROSS}$), which is often implemented in typical MARSSIM-based structural FSS, except in reverse. Typically, when developing a $DCGL_{GROSS}$, individual DCGLs are weighted by the ROC abundance. Individual measurements then can be compared to the $DCGL_{GROSS}$ by an efficiency factor that accounts for the relative abundances. For confirmatory survey data evaluation, individual results were compared to the gamma-emitting ROC with the lowest $DCGL_{BC}$.

Based on the previous discussion, the decision rule is stated as follows:

> If the confirmatory survey data and FSS data are in agreement and all measurements are below the lowest $DCGL_{BC}$ for gamma-emitters, then conclude that the FSS data are acceptable for demonstrating compliance with the release criterion; otherwise, perform further evaluation(s) and provide technical comments/recommendations to the NRC for their evaluation and decision making.

3.6 SPECIFY LIMITS ON DECISION ERRORS

The sixth step in the DQO process examined the consequences of making an incorrect decision and established bounds on decision errors. Decision errors were controlled during the survey design, on-site field investigations, and during the data assessment. There were two orders of control, each discussed in the following subsections.

3.6.1 Hypothesis Testing

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

> H_0: The mean confirmatory measurement population ranks (R_{CU}) were less than or equal to the FSS mean population ranks (R_{FSS}). Mathematically, the null hypothesis was stated as: $R_{CU} - R_{FSS} \leq 0$.
>
> H_A: The mean confirmatory measurement population ranks were greater than the FSS mean population ranks. Mathematically, the alternative hypothesis was stated as: $R_{CU} - R_{FSS} > 0$.

For the hypothesis testing, two types of decision errors were considered: Type I (typically designated as alpha or α) and Type II (typically designated as beta or β). A Type I error occurs when the null hypothesis is rejected when it should not be rejected, also known as a false positive, and reflects the confidence level in the decision. A Type II error is incorrectly failing to reject the null hypothesis when the alternative hypothesis is true. This is also known as a false negative.

Decision errors were controlled both during field activities and during data quality assessment and were based on two orders of control. The Type I error rate was set to α=0.05, that is, there is a 5% chance of incorrectly rejecting the null hypothesis. The power of the statistical test, or the probability of the test to correctly reject the null hypothesis when it is false, is denoted as the quantity (1 - β). Typically, a prospective power is defined by selecting a Type II error rate that is acceptable while not requiring an overly burdensome sample size. The prospective Type II error rate was no greater than 0.1, that is, there is no greater than a 10% chance of concluding the confirmatory population mean is less than the FSS population mean when it is actually greater. The actual Type II error rate, and subsequent power, achieved is dependent on the number of samples collected and the concentration variability in the sample set.

3.6.2 Field and Analytical MDCs

The second order of control was to optimize minimum detectable concentrations (MDCs) with respect to ORISE sample count times for both field and laboratory measurements. Measurement MDCs were, at a minimum, equal to 50% of the guidelines presented in Tables 3.2 and 3.3.

3.7 Optimize the Design for Obtaining Data

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

4. PROCEDURES

The ORISE survey team conducted independent confirmatory survey activities, including gamma surface scans, direct gamma measurements, and miscellaneous sampling activities within the accessible survey areas specifically requested by NRC. Survey activities were conducted in accordance with the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual* and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2016a and ORAU 2018).

4.1 Reference System

Penetrations were segmented into 1-foot sections corresponding to measurements performed by ZS. ORISE referenced confirmatory measurements in terms of the number of 1-foot segments from the origin. For the Containment Buildings, the origin of penetrations was the termination of the specific penetration on the Auxiliary Building side. For example, Location 0 corresponds to the beginning of the first 1-foot penetration segment from the Auxiliary Building moving toward the Containment Buildings. The embedded piping and penetrations measured in the Unit 1 Containment and Auxiliary Buildings, respectively, were referenced in a similar manner. For these two areas, the detector was fully inserted into the penetration/embedded piping from the access point. Select 1-foot segments were measured as the detector was withdrawn.

4.2 Surface Scans

Cesium iodide (CsI) and NaI pipe detectors were used to evaluate direct gamma radiation levels on interior penetration surfaces. All detectors were coupled to Ludlum Model 2221 ratemeter-scalers with audible indicators. Locations of elevated response that were audibly distinguishable from background levels, suggesting the presence of residual contamination, were further investigated with a follow-up, static gamma measurement.

4.3 Surface Activity Measurements

Surface activity measurements were collected from both randomly and judgmentally selected locations. Visual Sample Plan (VSP), Version 7.9, was used to determine the number of random co-located measurements to meet the DQOs specified in the previous section. Figure 4.1 provides the VSP inputs to determine the number of measurements. As indicated in Figure 4.1, 28 measurements were required; thus, 28 1-foot penetration segments were randomly selected for measurement. For the Unit 1 Containment in-core sump discharge embedded piping, the detector was fully inserted into the piping from access points on the 565-foot Elevation and Under-vessel Area. Every other 1-foot pipe segment was measured as the detector was withdrawn, for a total of 13 measurements. Because of the small relative length (approximately 3 feet) of the penetrations in the Auxiliary Building, the entire portion of the penetrations was measured in 1-foot segments, for a total of three measurements in each penetration.

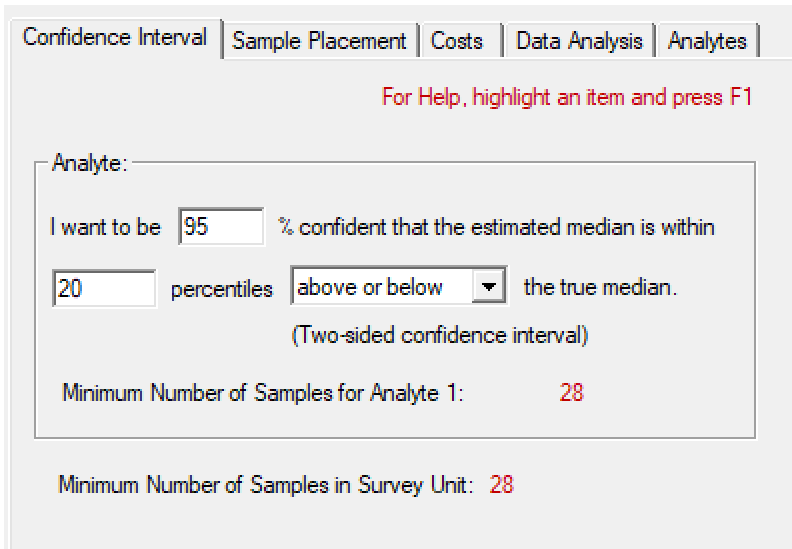

Figure 4.1. Sample Size Determination Using VSP

Static surface activity measurements were collected using either a Ludlum Model 44-157 NaI pipe detector or a Ludlum Model 44-159-1 CsI detector, depending on the length of the penetration. All detectors were coupled to Ludlum Model 2221 ratemeter-scalers. The count time for each static measurement was 1 minute. Detectors were calibrated to a Cs-137 standard in a manner that accounts for varying pipe diameter, and measurements were collected with the detector on the bottom on the penetration/pipe. The choice of Cs-137 as a calibration standard is conservative, because of the low efficiency of the scintillation detector relative to other gamma-emitting ROCs. The calibration methodology is discussed further in Appendix C.

4.4 MISCELLANEOUS SAMPLING

A miscellaneous sample of residual material was collected from penetration P035 in Unit 1 Containment. The sample was collected by wiping a cloth over the bottom portion of the penetration interior totaling approximately 0.25 m^2.

5. SAMPLE ANALYSIS AND DATA INTERPRETATION

Data and the miscellaneous sample collected on site were transferred to the ORISE facility for analysis and interpretation. Sample custody was transferred to the Radiological and Environmental Analytical Laboratory in Oak Ridge, Tennessee. Sample analyses were performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2017). The miscellaneous sample was analyzed by high-resolution gamma spectrometry for gamma emitting Cs-134/137, Co-60, and Eu-152/154 and by alpha spectrometry for Am-241 after chemical separation. Laboratory results were reported in units of pCi/sample. Direct surface activity measurements were reported in units of pCi/m^2. For consistency with the FSS measurements, surface activity measurements were not corrected for background contributions.

Both data sets were normalized based on the median and interquartile range (IQR) according to the following formula:

$$X_{i,nrm} = \frac{X_i - \mu_{1/2}}{IQR}$$

Where:

X_i = the i^{th} measurement in each data set

$\mu_{1/2}$ = the sample median

IQR = interquartile range for the data set, defined as the difference between the 75^{th} and 25^{th} quartile

After each data set was normalized, the results were pooled and ranked in ascending order. The mean difference between confirmatory and FSS sample ranks was evaluated using the two-sample Student's t-test. Results for the t-test were generated using ProUCL, version 5.1.

6. FINDINGS AND RESULTS

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

6.1 UNIT 1 CONTAINMENT

6.1.1 Surface Scans

Overall surface scans in the Unit 1 Containment penetrations ranged from approximately 2,500 counts per minute (cpm) to 260,000 cpm, the highest of which was observed in P123, a reactor recirculating sump suction penetration. Scan ranges by penetration are summarized in Table 6.1.

Table 6.1. Summary of Unit 1 Penetration Scan Range

Penetration	Scan Range (cpm)[a]		
P035	3,000	to	25,000
P036	2,500	to	20,000
P037	2,500	to	25,000
P123	3,900	to	260,000
P124	2,700	to	95,000

[a]Ludlum Detector Model 44-157 used

6.1.2 Surface Activity Measurements

Individual surface activity measurements are presented in Table B.1 in Appendix B. Table 6.2 presents a summary of the confirmatory measurements collected in Unit 1 Containment penetrations.

Table 6.2. Summary of Confirmatory Measurements in Unit 1 Penetrations[a]

Penetration	Parameter (pCi/m²)				
	Average	Median	SD	Min	Max
P035	9.70E+05	7.84E+05	8.08E+05	6.79E+05	5.05E+06
P036	9.08E+05	7.77E+05	7.38E+05	4.12E+05	4.64E+06
P037	9.47E+05	7.93E+05	8.34E+05	6.38E+05	5.17E+06
P123	2.34E+07	1.07E+07	2.52E+07	1.29E+06	7.34E+07
P124	8.11E+06	7.71E+06	6.67E+06	9.63E+05	2.28E+07

[a]Ludlum Detector Model 44-157 used

The maximum surface activity measurement was collected from penetration P123 at 7.34E+07 pCi/m^2, which is a small fraction of the Cs-134 $DCGL_{BC}$ at 17% (7.34E+07 pCi/m^2 /4.32E+08 pCi/m^2). Cs-134 has the lowest $DCGL_{BC}$ of all the gamma-emitters listed in Table 3.3; therefore, a change in the assigned gamma-emitting ROC mix would not result in an exceedance of the respective $DCGL_{BC}$.

Individual surface activity measurements for the Unit 1 in-core sump discharge embedded piping are presented in Table B.2. Results were compared directly to the $DCGL_{BC}$ for Cs-134. The maximum measurement collected was 2.77E+07 pCi/m^2, which is approximately 3% of the $DCGL_{BC}$ (2.77E+07 pCi/m^2 /1.05E+09 pCi/m^2).

6.1.3 Comparison of FSS and Confirmatory Data Sets

Raw detector responses (in units of cpm) for the paired measurements were plotted to examine the NaI response profile of each penetration. The plots for Unit 1 Containment penetrations are presented in Figure A.1 in Appendix A. Review of Figure A.1 indicates that the measurement pairs trend similarly between the FSS and confirmatory measurements throughout the length of the penetration (i.e., when the ORISE measurement indicates elevated activity, the FSS measurement is elevated in the same manner relative to other locations in the penetration).

Table 6.3 presents a summary of the Student's t-test performed on measurements collected in Unit 1 Containment penetrations. There was not sufficient evidence to reject the null hypothesis for any of the penetrations investigated. Individual measurements used for the Student's t-test are presented in Table B.3.

Table 6.3. Student's t-Test Summary for Unit 1 Penetrations

Penetration	t	T	p-val	Result
P035	0.390	1.674	0.35	p-val > 0.05: Fail to reject the null
P036	-0.718	1.674	0.76	p-val > 0.05: Fail to reject the null
P037	0.016	1.674	0.49	p-val > 0.05: Fail to reject the null
P123	-1.218	1.674	0.89	p-val > 0.05: Fail to reject the null
P124	-1.218	1.674	0.89	p-val > 0.05: Fail to reject the null

t = t-test statistic
T = critical value
p-val = p-value; probability of $t \leq T$

6.1.4 ROC Activity in the Swipe Sample

The swipe sample collected from penetration P035 in Unit 1 Containment was initially analyzed by gamma spectrometry, and the analysis revealed the presence of Am-241. Subsequent analysis via alpha spectrometry confirmed the presence of Am-241. Cm-244 also was noted as present in the sample (Cm follows the Am chemistry during the laboratory sample preparation process); however, since Cm was not anticipated, the sample was not processed to account for the slight difference in chemistry compared to Am. Therefore, the Cm-244 activity was not officially reported by the laboratory; although, the laboratory noted that the Cm-244 activity is expected to be approximately one-third of the Am-241 activity. The results for the miscellaneous sample swipe are presented in Table 6.4.

Table 6.4. ROC Activity in Miscellaneous Sample 5271M0038 Swipe[a]

ROC	Concentration (pCi/Sample)[b]
Am-241	154 ± 24
Co-60	17,890 ± 970
Cs-134[b]	20 ± 52
Cs-137	3,870 ± 270
Eu-152	736 ± 83
Eu-154[c]	190 ± 190
Cm-244[d]	NR

[a]An area totaling approximately 0.25 m² was wiped.
[b]Uncertainties represent the total propagated uncertainty reported at the 95% confidence level.
[c]ROC activity was not present above the analytical MDC.
[d]Cm-244 was identified, but value was not officially reported by the laboratory.
NR = not reported

6.2 Unit 2 Containment

6.2.1 Surface Scans

Overall surface scans in Unit 2 Containment penetrations ranged from approximately 2,500 cpm to 15,000 cpm, the highest of which was observed in P324, a reactor recirculating sump suction penetration. Scan ranges by penetration are summarized in Table 6.5.

Table 6.5. Summary of Unit 2 Penetration Scan Range	
Penetration	Scan Range (cpm)[a]
P235	2,500 to 10,000
P236	2,500 to 9,000
P237	2,500 to 8,000
P323	3,000 to 10,000
P324	3,000 to 15,000

[a]Ludlum detector Model 44-157 used

6.2.2 Surface Activity Measurements

Individual surface activity measurements are presented in Table B.4. Table 6.6 presents a summary of the confirmatory measurements collected in Unit 2 Containment penetrations.

Table 6.6. Summary of Confirmatory Measurements in Unit 2 Penetrations[a]

Penetration	Parameter (pCi/m²)				
	Average	Median	SD	Min	Max
P235	7.67E+05	7.03E+05	2.68E+05	6.26E+05	2.10E+06
P236	7.41E+05	6.88E+05	2.46E+05	6.06E+05	1.96E+06
P237	7.22E+05	6.55E+05	2.26E+05	5.89E+05	1.83E+06
P323	1.14E+06	1.02E+06	4.34E+05	7.53E+05	2.53E+06
P324	1.01E+06	8.85E+05	3.00E+05	7.10E+05	1.99E+06

[a]Ludlum detector Model 44-157 used

The maximum surface activity measurement was a judgmental (Table B.4) measurement collected from penetration P324 at 3.26E+06 pCi/m^2, which is less than 1% of the Cs-134 $DCGL_{BC}$ (3.26E+06 pCi/m^2 /4.32E+08 pCi/m^2). Cs-134 has the lowest $DCGL_{BC}$ of all the gamma-emitters listed in Table 3.4; therefore, a change in the assigned gamma-emitting ROC mix would not result in an exceedance of their respective $DCGL_{BC}$.

6.2.3 Comparison of FSS and Confirmatory Data Sets

As with the penetrations in Unit 1 Containment, the Unit 2 Containment raw detector responses (in units of cpm) for the paired measurements were plotted to examine the NaI response profile of each penetration. These plots for the Unit 2 Containment penetrations are presented in Figure A.2. Review of Figure A.2 indicates that the measurement pairs trend similarly between the FSS and confirmatory measurements throughout the length of the penetration, with the exception of P323. The confirmatory measurement data set is missing a peak at Location 1 that is present in the FSS data set. The survey team noted what appeared to be loose concrete rubble in several of the penetrations. A possible explanation for the missing peak in the P323 data set is that loose concrete rubble containing contamination inside penetration P323 was removed prior to the confirmatory survey.

Table 6.7 presents a summary of the Student's t-test performed on measurements collected in Unit 2 Containment penetrations. There was not sufficient evidence to reject the null hypothesis for any of the penetrations investigated. Individual measurement pairs used for the Student's t-test test are presented in Table B.5.

Table 6.7. Student's t-Test Summary for Unit 2 Penetrations

Penetration	t	T	p-val	Result
P235	-0.751	1.674	0.772	p-val > 0.05: Fail to reject the null
P236	0.049	1.674	0.481	p-val > 0.05: Fail to reject the null
P237	-0.57	1.674	0.714	p-val > 0.05: Fail to reject the null
P323	-0.8	1.674	0.786	p-val > 0.05: Fail to reject the null
P324	-0.244	1.674	0.596	p-val > 0.05: Fail to reject the null

t = t-test statistic
T = critical value
p-val = p-value; probability of t ≤ T

6.3 AUXILIARY BUILDING

Surface scans were not performed in the investigated Auxiliary Building penetrations A011 and A023 because the static measurements covered the entire penetration. Table 6.8 presents the Auxiliary Building penetration measurements. Because of the small sample size, the confirmatory measurements were not compared to the FSS measurements, but, rather, were compared directly to the $DCGL_{BC}$. The maximum measurement was collected from penetration A011 and was approximately 4% of the Cs-137 $DCGL_{BC}$ (2.57E+07 pCi/m^2 /6.17E+08 pCi/m^2). Assuming that the predominant gamma-emitting ROC is Co-60, which has the lowest $DCGL_{BC}$ of gamma-emitting ROCs in Table 3.3 instead of Cs-137, the max result is approximately 30% of the $DCGL_{BC}$ (2.57E+07 pCi/m^2 /8.82E+07 pCi/m^2).

Table 6.8. Confirmatory Measurements in the Auxiliary Building					
A011[a]			A023[b]		
Location[c]	Gross Count (cpm)	Gross Surface Activity (pCi/m^2)	Location	Gross Count (cpm)	Gross Surface Activity (pCi/m^2)
0	6,957	2.09E+07	0	20,421	5.17E+06
1	8,546	2.57E+07	1	36,759	9.30E+06
2	6,041	1.81E+07	2	34,129	8.63E+06

[a]Ludlum detector Model 44-159-1 used
[b]Ludlum detector Model 44-157 used
[c]Location refers to the 1-foot pipe segment referenced from the origin, which was the furthest point in the piping accessed from the Auxiliary Building.

7. SUMMARY AND CONCLUSIONS

At NRC's request, ORISE conducted confirmatory survey activities at ZNPS during the period of June 4–7, 2018. The survey activities included gamma surface scans, direct gamma measurements, and miscellaneous sampling. None of the piping/penetration interior direct measurements exceeded the most restrictive $DCGL_{BC}$ in any of the areas investigated as part of the confirmatory survey. A cloth wipe of the penetration P035 interior identified the presence of Am-241, which was deselected from FSS analysis based on an insignificant dose contribution. The Am-241 activity on the wipe, which represents the removable ROC portion, was at least an order of magnitude less than the more predominant gamma-emitters, Cs-137 and Co-60.

For the paired measurements, there was not sufficient evidence to reject the null hypothesis for all investigated Unit 1 and Unit 2 containment penetrations, except for P323 in Unit 2 Containment. Thus, since the sample ranks are not statistically different, it is concluded that the confirmatory and FSS measurements were drawn from the same population distribution. The difference in the NaI response profile for Location 1 in penetration P323 may be explained by loose debris containing contamination that was present inside of the penetration during FSS, but was not present during the confirmatory survey. However, additional evaluation is not recommended given the low magnitude of the confirmatory survey measurements relative to the $DCGL_{BC}$.

The results of the confirmatory surveys conducted by ORISE did not identify issues that would preclude the FSS data from demonstrating compliance with the release criteria.

8. REFERENCES

EC 2015. *The Future of Zion*. Webpage: http://www.exeloncorp.com/locations/power-plants/zion-station. Exelon Corporation. Chicago, Illinois. Accessed June 30, 2015.

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

NRC 2000. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).* NUREG-1575; Revision 1. U.S. Nuclear Regulatory Commission. Washington, D.C. August.

NRC 2018. *Letter from J.B. Hickman, USNRC, to J. Sauger, Energy Solutions, RE: Zion Nuclear Power Station, Units 1 and 2 – Issuance of Amendments 191 and 178 for the Licenses to Approve the License Termination Plan.* September 28.

ORAU 2014. *ORAU Radiation Protection Manual.* Oak Ridge Associated Universities. Oak Ridge, Tennessee. October.

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

ORAU 2016b. *ORAU Health and Safety Manual.* Oak Ridge Associated Universities. Oak Ridge, Tennessee. January.

ORAU 2017. *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual.* Oak Ridge Associated Universities. Oak Ridge, Tennessee. August 24.

ORAU 2018. *ORAU Environmental Services and Radiation Training Quality Program Manual.* Oak Ridge Associated Universities. Oak Ridge, Tennessee. July 20.

ZS 2018a. *Zion Station Restoration Project License Termination Plan, Rev. 2*. Zion*Solutions*, LLC. Chicago, Illinois. February 7.

ZS 2018b. *Letter from D. Wojtkowiak, ZionSolutions to J. Hickman, NRC, RE: Summary of Embedded Piping and Penetrations for Unit 1 Containment, Unit 2 Containment, Auxiliary Building and the Turbine Building.* May 16.

APPENDIX A: FIGURES

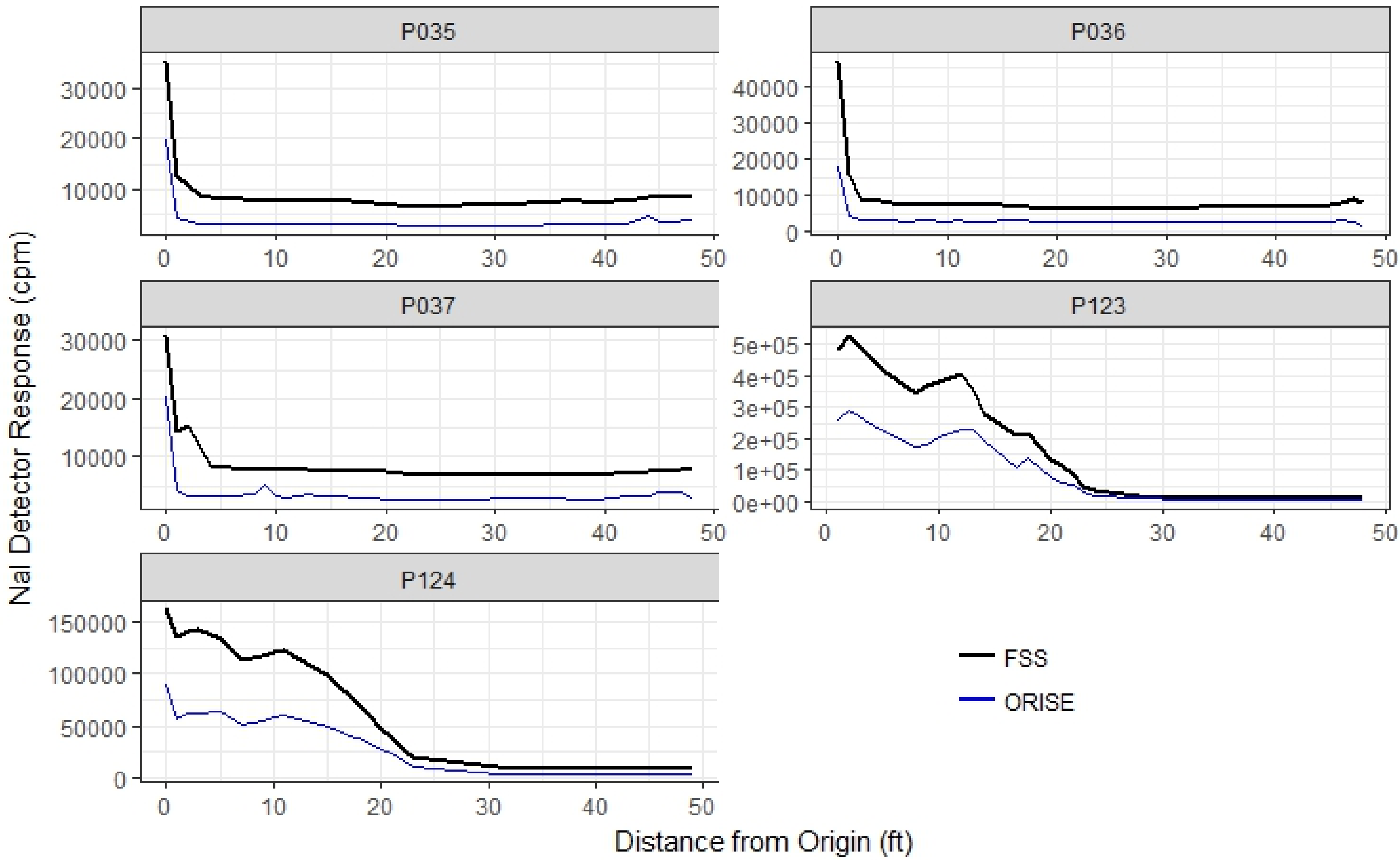

Figure A.1. Unit 1 Penetration NaI Response Profile

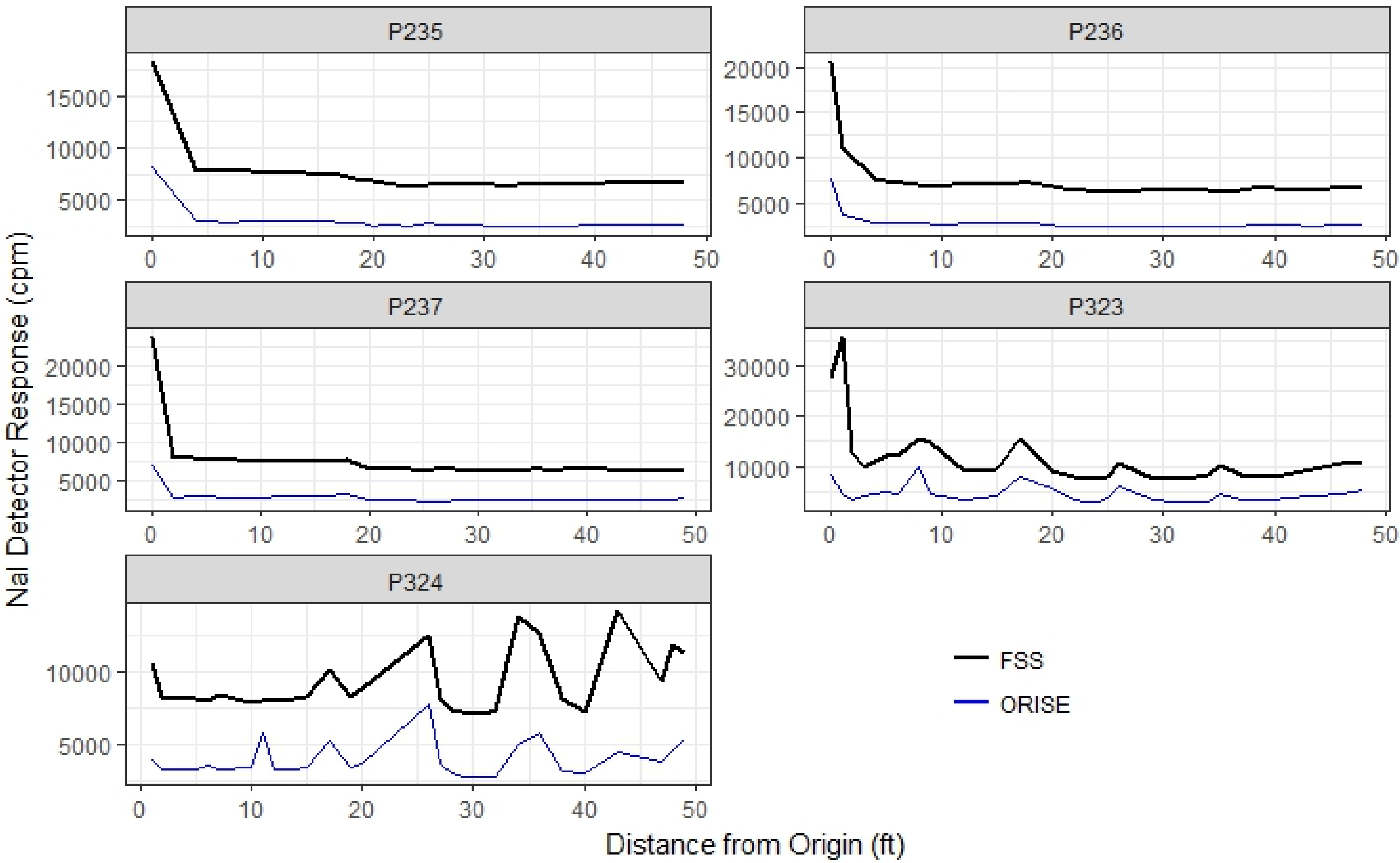

Figure A.2. Unit 2 Penetration NaI Response Profile

APPENDIX B: DATA TABLES

Table B.1. Confirmatory Measurements in Unit 1 Penetrations[a]														
P035			P036			P037			P123			P124		
Loc.[b]	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)
0	19,681	5.05E+06	0	18,090	4.64E+06	0	20,174	5.17E+06	1	261,720	6.71E+07	0	88,938	2.28E+07
1	4,277	1.10E+06	1	4,228	1.08E+06	1	4,121	1.06E+06	2	286,327	7.34E+07	1	56,290	1.44E+07
3	3,081	7.90E+05	2	3,179	8.15E+05	2	3,210	8.23E+05	5	221,934	5.69E+07	2	62,337	1.60E+07
4	3,198	8.20E+05	4	3,225	8.27E+05	4	3,151	8.08E+05	8	172,891	4.43E+07	3	61,751	1.58E+07
6	3,018	7.74E+05	5	3,202	8.21E+05	5	3,131	8.03E+05	9	180,581	4.63E+07	5	64,397	1.65E+07
7	3,071	7.88E+05	6	3,038	7.79E+05	6	3,144	8.06E+05	10	204,430	5.24E+07	7	51,462	1.32E+07
10	3,324	8.52E+05	8	3,233	8.29E+05	8	3,499	8.97E+05	12	231,571	5.94E+07	9	54,467	1.40E+07
11	3,245	8.32E+05	10	3,043	7.80E+05	9	3,271	8.39E+05	13	229,697	5.89E+07	10	58,168	1.49E+07
17	3,296	8.45E+05	11	3,193	8.19E+05	10	3,080	7.90E+05	14	191,506	4.91E+07	11	60,098	1.54E+07
19	2,994	7.68E+05	12	3,096	7.94E+05	11	3,039	7.79E+05	17	107,018	2.74E+07	15	50,267	1.29E+07
23	2,647	6.79E+05	14	3,024	7.75E+05	13	3,468	8.89E+05	18	141,016	3.62E+07	16	45,956	1.18E+07
25	2,697	6.92E+05	15	3,132	8.03E+05	14	3,108	7.97E+05	20	79,916	2.05E+07	17	40,794	1.05E+07
27	2,761	7.08E+05	20	3,068	7.87E+05	19	2,849	7.31E+05	21	62,427	1.60E+07	18	38,639	9.91E+06
28	2,682	6.88E+05	21	2,844	7.29E+05	20	2,608	6.69E+05	22	55,485	1.42E+07	19	32,940	8.45E+06
29	2,779	7.13E+05	24	2,807	7.20E+05	23	2,489	6.38E+05	23	27,689	7.10E+06	20	27,189	6.97E+06
30	2,819	7.23E+05	27	2,940	7.54E+05	26	2,610	6.69E+05	24	16,049	4.12E+06	21	23,047	5.91E+06
31	2,938	7.53E+05	28	2,955	7.58E+05	27	2,686	6.89E+05	28	9,760	2.50E+06	22	16,579	4.25E+06
33	2,795	7.17E+05	33	2,894	7.42E+05	32	2,765	7.09E+05	32	5,811	1.49E+06	23	11,543	2.96E+06
36	3,047	7.81E+05	35	2,880	7.39E+05	34	2,777	7.12E+05	34	8,604	2.21E+06	31	4,458	1.14E+06
37	3,030	7.77E+05	36	2,855	7.32E+05	35	2,854	7.32E+05	37	6,638	1.70E+06	36	4,073	1.04E+06
38	3,003	7.70E+05	39	2,814	7.22E+05	38	2,708	6.94E+05	39	5,224	1.34E+06	37	3,855	9.89E+05
39	3,042	7.80E+05	40	2,813	7.21E+05	39	2,707	6.94E+05	40	5,753	1.48E+06	39	4,144	1.06E+06
41	3,309	8.49E+05	42	2,880	7.39E+05	41	2,967	7.61E+05	42	6,051	1.55E+06	40	4,321	1.11E+06

Table B.1. (continued) Confirmatory Measurements in Unit 1 Penetrations[a]														
P035			**P036**			**P037**			**P123**			**P124**		
Loc.[b]	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**	**Loc.**	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**	**Loc.**	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**	**Loc.**	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**	**Loc.**	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**
42	3,311	8.49E+05	43	2,927	7.51E+05	42	3,242	8.31E+05	43	8,102	2.08E+06	43	4,335	1.11E+06
44	4,588	1.18E+06	45	3,085	7.91E+05	44	3,324	8.52E+05	45	5,850	1.50E+06	46	3,980	1.02E+06
45	3,623	9.29E+05	46	3,157	8.10E+05	45	3,724	9.55E+05	46	5,019	1.29E+06	47	3,755	9.63E+05
46	3,726	9.56E+05	47	2,926	7.50E+05	47	3,802	9.75E+05	47	5,547	1.42E+06	48	3,837	9.84E+05
48	3,951	1.01E+06	48	1,607	4.12E+05	48	2,840	7.28E+05	48	7,598	1.95E+06	49	3,893	9.98E+05
												13[c]	62,764	1.61E+07

[a]Ludlum detector Model 44-157 used.
[b]Location refers to the 1-foot pipe segment referenced from the origin, which is the termination of the penetration on the Auxiliary Building side.
[c]Judgmental measurement.
Loc. = Location

Table B.2. Unit 1 In-Core Sump Discharge Embedded Piping Confirmatory Measurements[a]		
Location[b]	**Gross Count (cpm)**	**Gross Surface Activity (pCi/m²)**
Measured from 565' Elevation		
0	3228	1.04E+07
2	1098	3.55E+06
4	853	2.76E+06
6	808	2.61E+06
8	738	2.39E+06
10	612	1.98E+06
12	518	1.67E+06
14	677	2.19E+06
16	729	2.36E+06
18	1204	3.89E+06
20	1588	5.13E+06
Measured from UV Area		
0	8558	2.77E+07
1	6255	2.02E+07

[a]Ludlum detector Model 44-159-1 used

[b]Location refers to the 1-foot pipe segment referenced from the origin, which was the furthest point in the piping accessed from the specified location.

Table B.3. Measurement Data Used for Student's t-Test in Unit 1 Containment																				
P035							P036							P037						
Loc.	FSS			ORISE			Loc.	FSS			ORISE			Loc.	FSS			ORISE		
	cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R
0	35,400	21.645	55	19,681	35.216	56	0	46,900	27.898	55	18,090	51.308	56	0	30,900	26.438	55	20,174	31.469	56
1	12,800	3.988	54	4,277	2.581	52	1	16,000	6.060	54	4,228	4.078	53	1	14,300	7.574	53	4,121	1.892	52
3	8,690	0.777	47	3,081	0.047	31	2	9,380	1.382	52	3,179	0.504	42	2	15,200	8.597	54	3,210	0.214	37
4	8,450	0.590	45	3,198	0.294	36	4	8,510	0.767	50	3,225	0.661	48	4	8,240	0.688	46	3,151	0.105	34
6	7,920	0.176	34	3,018	-0.087	22	5	8,250	0.583	46	3,202	0.583	45	5	8,490	0.972	49	3,131	0.068	31
7	8,180	0.379	37	3,071	0.025	30	6	7,770	0.244	39	3,038	0.024	29	6	8,010	0.426	45	3,144	0.092	32
10	7,780	0.066	32	3,324	0.561	44	8	7,580	0.110	33	3,233	0.688	49	8	7,720	0.097	33	3,499	0.746	48
11	7,980	0.223	35	3,245	0.394	38	10	7,600	0.124	34	3,043	0.041	30	9	7,830	0.222	38.5	3,271	0.326	42
17	7,670	-0.020	28	3,296	0.502	39	11	7,500	0.053	31	3,193	0.552	43	10	7,800	0.188	35	3,080	-0.026	28
19	7,220	-0.371	15	2,994	-0.138	19	12	7,350	-0.053	27	3,096	0.221	37	11	7,820	0.210	36	3,039	-0.101	25
23	6,570	-0.879	1	2,647	-0.873	2	14	7,560	0.095	32	3,024	-0.024	28	13	7,830	0.222	38.5	3,468	0.689	47
25	6,760	-0.730	5	2,697	-0.767	4	15	7,310	-0.081	26	3,132	0.344	40	14	7,560	-0.085	26	3,108	0.026	29
27	6,830	-0.676	8	2,761	-0.631	9	20	6,630	-0.562	9	3,068	0.126	35	19	7,670	0.040	30	2,849	-0.451	19
28	6,800	-0.699	7	2,682	-0.799	3	21	6,680	-0.527	10	2,844	-0.637	6	20	7,490	-0.165	24	2,608	-0.895	3
29	6,790	-0.707	6	2,779	-0.593	10	24	6,440	-0.696	5	2,807	-0.763	2	23	6,900	-0.835	6	2,489	-1.115	1
30	6,960	-0.574	11	2,819	-0.508	14	27	6,730	-0.491	13	2,940	-0.310	22	26	6,720	-1.040	2	2,610	-0.892	5
31	7,030	-0.520	13	2,938	-0.256	16	28	6,600	-0.583	8	2,955	-0.259	23	27	6,850	-0.892	4	2,686	-0.752	10
33	7,380	-0.246	17	2,795	-0.559	12	33	6,800	-0.442	15	2,894	-0.467	14	32	7,080	-0.631	14	2,765	-0.606	15
36	7,590	-0.082	23	3,047	-0.025	27	35	6,940	-0.343	20	2,880	-0.514	11.5	34	6,950	-0.778	8	2,777	-0.584	16
37	7,650	-0.035	26	3,030	-0.061	24	36	6,870	-0.392	17	2,855	-0.600	7	35	7,070	-0.642	13	2,854	-0.442	20
38	7,540	-0.121	20	3,003	-0.119	21	39	6,820	-0.428	16	2,814	-0.739	4	38	6,940	-0.790	7	2,708	-0.711	12
39	7,490	-0.160	18	3,042	-0.036	25	40	7,070	-0.251	24	2,813	-0.743	3	39	6,960	-0.767	9	2,707	-0.713	11
41	7,880	0.145	33	3,309	0.530	42	42	6,960	-0.329	21	2,880	-0.514	11.5	41	7,230	-0.460	18	2,967	-0.234	23
42	7,720	0.020	29	3,311	0.534	43	43	7,280	-0.102	25	2,927	-0.354	19	42	7,290	-0.392	21	3,242	0.273	41
44	8,350	0.512	40	4,588	3.239	53	45	7,750	0.230	38	3,085	0.184	36	44	7,380	-0.290	22	3,324	0.424	44
45	8,360	0.520	41	3,623	1.195	49	46	8,240	0.576	44	3,157	0.429	41	45	7,600	-0.040	27	3,724	1.161	50
46	8,550	0.668	46	3,726	1.413	50	47	9,290	1.318	51	2,926	-0.358	18	47	7,840	0.233	40	3,802	1.304	51
48	8,990	1.012	48	3,951	1.890	51	48	8,310	0.625	47	1,607	-4.852	1	48	7,990	0.403	43	2,840	-0.468	17

Loc. = Location
Adj. Meas. = Adjusted Measurement
R = Rank

Table B.3. (continued) Measurement Data Used for Student's t-Test in Unit 1 Containment													
P123							P124						
Loc.	FSS			ORISE			Loc.	FSS			ORISE		
	cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R
1	479,101	1.217	54	261,720	1.206	53	0	162,181	0.991	55	88,938	1.140	56
2	526,958	1.358	56	286,327	1.340	55	1	134,469	0.739	52	56,290	0.508	41
5	414,485	1.028	50	221,934	0.988	48	2	140,482	0.793	53	62,337	0.625	48
8	341,986	0.815	42	172,891	0.719	40	3	142,018	0.807	54	61,751	0.614	46
9	364,683	0.881	45	180,581	0.761	41	5	132,897	0.724	51	64,397	0.665	50
10	382,545	0.934	47	204,430	0.892	46	7	113,921	0.552	43	51,462	0.414	38
12	401,693	0.990	49	231,571	1.041	52	9	116,654	0.576	44	54,467	0.472	40
13	358,186	0.862	44	229,697	1.030	51	10	120,771	0.614	47	58,168	0.544	42
14	278,439	0.628	39	191,506	0.821	43	11	122,955	0.634	49	60,098	0.582	45
17	211,777	0.432	36	107,018	0.358	35	15	99,666	0.422	39	50,267	0.391	37
18	218,737	0.453	37	141,016	0.545	38	16	87,455	0.311	36	45,956	0.308	35
20	130,937	0.195	33	79,916	0.210	34	17	81,059	0.253	34	40,794	0.208	33
21	114,604	0.147	32	62,427	0.114	31	18	70,213	0.154	31	38,639	0.166	32
22	83,459	0.055	29	55,485	0.076	30	19	58,052	0.043	29	32,940	0.056	30
23	45,926	-0.055	28	27,689	-0.076	27	20	48,516	-0.043	28	27,189	-0.056	27
24	35,893	-0.085	26	16,049	-0.140	22	21	39,051	-0.129	26	23,047	-0.136	25
28	17,545	-0.138	23	9,760	-0.174	12	22	27,807	-0.232	24	16,579	-0.261	23
32	14,501	-0.147	21	5,811	-0.196	5	23	20,407	-0.299	22	11,543	-0.359	21
34	19,739	-0.132	25	8,604	-0.181	11	31	10,519	-0.389	20	4,458	-0.496	10
37	13,026	-0.152	17	6,638	-0.191	8	36	9,827	-0.395	18	4,073	-0.503	6
39	12,057	-0.155	14	5,224	-0.199	2	37	9,546	-0.398	16	3,855	-0.507	3
40	12,460	-0.153	16	5,753	-0.196	4	39	9,817	-0.395	17	4,144	-0.502	7
42	13,498	-0.150	18	6,051	-0.195	7	40	9,420	-0.399	15	4,321	-0.498	8
43	18,757	-0.135	24	8,102	-0.183	10	43	10,061	-0.393	19	4,335	-0.498	9
45	11,732	-0.156	13	5,850	-0.196	6	46	9,079	-0.402	14	3,980	-0.505	5
46	12,157	-0.154	15	5,019	-0.200	1	47	8,810	-0.405	11	3,755	-0.509	1
47	14,346	-0.148	20	5,547	-0.197	3	48	9,072	-0.402	13	3,837	-0.508	2
48	13,510	-0.150	19	7,598	-0.186	9	49	8,928	-0.404	12	3,893	-0.507	4

Loc. = Location
Adj. Meas. = Adjusted Measurement
R = Rank

Table B.4. Confirmatory Measurements in Unit 2 Penetrations[a]														
P235			P236			P237			P323			P324		
Loc.[b]	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)
0	8,203	2.10E+06	0	7,630	1.96E+06	0	7,142	1.83E+06	0	8,269	2.12E+06	1	3,925	1.01E+06
4	3,074	7.88E+05	1	3,606	9.25E+05	2	2,907	7.45E+05	1	4,335	1.11E+06	2	3,303	8.47E+05
5	3,017	7.74E+05	4	2,968	7.61E+05	4	3,017	7.74E+05	2	3,530	9.05E+05	5	3,317	8.51E+05
7	2,955	7.58E+05	5	2,969	7.61E+05	8	2,951	7.57E+05	3	3,999	1.03E+06	6	3,573	9.16E+05
9	3,082	7.90E+05	8	2,772	7.11E+05	9	2,834	7.27E+05	5	5,086	1.30E+06	7	3,325	8.53E+05
10	3,068	7.87E+05	10	2,697	6.92E+05	13	3,025	7.76E+05	6	4,406	1.13E+06	10	3,463	8.88E+05
12	3,100	7.95E+05	11	2,716	6.96E+05	16	3,016	7.73E+05	8	9,883	2.53E+06	11	5,752	1.48E+06
14	3,035	7.78E+05	12	2,893	7.42E+05	18	3,290	8.44E+05	9	4,355	1.12E+06	12	3,349	8.59E+05
15	3,039	7.79E+05	13	2,846	7.30E+05	20	2,664	6.83E+05	12	3,521	9.03E+05	13	3,241	8.31E+05
16	3,031	7.77E+05	14	2,864	7.34E+05	22	2,500	6.41E+05	15	4,025	1.03E+06	14	3,332	8.54E+05
17	2,839	7.28E+05	15	2,956	7.58E+05	24	2,540	6.51E+05	17	7,786	2.00E+06	15	3,383	8.68E+05
19	2,929	7.51E+05	16	2,808	7.20E+05	25	2,297	5.89E+05	20	5,508	1.41E+06	17	5,321	1.36E+06
20	2,576	6.61E+05	17	2,791	7.16E+05	26	2,415	6.19E+05	22	3,404	8.73E+05	19	3,438	8.82E+05
21	2,738	7.02E+05	18	2,817	7.22E+05	27	2,440	6.26E+05	23	3,133	8.03E+05	20	3,625	9.30E+05
22	2,659	6.82E+05	21	2,548	6.53E+05	28	2,484	6.37E+05	24	3,063	7.85E+05	26	7,776	1.99E+06
23	2,504	6.42E+05	25	2,363	6.06E+05	29	2,496	6.40E+05	25	3,942	1.01E+06	27	3,683	9.44E+05
25	2,969	7.61E+05	28	2,509	6.43E+05	30	2,512	6.44E+05	26	5,916	1.52E+06	28	2,962	7.60E+05
26	2,615	6.71E+05	29	2,461	6.31E+05	33	2,488	6.38E+05	29	3,214	8.24E+05	29	2,805	7.19E+05
29	2,714	6.96E+05	34	2,500	6.41E+05	34	2,526	6.48E+05	31	2,936	7.53E+05	31	2,767	7.10E+05
31	2,442	6.26E+05	35	2,520	6.46E+05	35	2,495	6.40E+05	32	3,127	8.02E+05	32	2,811	7.21E+05
32	2,515	6.45E+05	37	2,472	6.34E+05	36	2,566	6.58E+05	34	3,103	7.96E+05	34	4,940	1.27E+06
33	2,586	6.63E+05	38	2,624	6.73E+05	37	2,544	6.52E+05	35	4,412	1.13E+06	36	5,769	1.48E+06
37	2,545	6.53E+05	39	2,605	6.68E+05	38	2,469	6.33E+05	37	3,450	8.85E+05	38	3,201	8.21E+05
40	2,632	6.75E+05	40	2,558	6.56E+05	42	2,622	6.72E+05	39	3,445	8.83E+05	40	2,983	7.65E+05

Table B.4. (continued) Confirmatory Measurements in Unit 2 Penetrations[a]														
P235			P236			P237			P323			P324		
Loc.[b]	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)	Loc.	Gross Count (cpm)	Gross Surface Activity (pCi/m²)
41	2,692	6.90E+05	41	2,591	6.64E+05	43	2,600	6.67E+05	40	3,531	9.06E+05	43	4,505	1.16E+06
42	2,670	6.85E+05	44	2,513	6.44E+05	45	2,699	6.92E+05	41	3,655	9.37E+05	47	3,845	9.86E+05
47	2,746	7.04E+05	45	2,664	6.83E+05	48	2,528	6.48E+05	46	4,410	1.13E+06	48	4,581	1.17E+06
48	2,720	6.98E+05	48	2,669	6.84E+05	49	2,793	7.16E+05	48	5,188	1.33E+06	49	5,426	1.39E+06
						17[c]	3,203	8.21E+05	44[c]	7,630	1.96E+06	35[c]	12,708	3.26E+06

[a]Ludlum detector Model 44-157 used.
[b]Location refers to the 1-foot pipe segment referenced from the origin, which is the termination of the penetration on the Auxiliary Building side.
[c]Judgmental measurement.
Loc. = Location

Table B.5. Measurement Data Used for Student's t-Test in Unit 2 Containment																				
P235							P236							P237						
Loc.	FSS			ORISE			Loc.	FSS			ORISE			Loc.	FSS			ORISE		
	cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R
0	18,286	10.718	55	8,203	13.167	56	0	20,623	20.830	56	7,630	14.878	55	0	23,766	16.553	56	7,142	11.657	55
4	7,835	0.980	52	3,074	0.800	46	1	11,036	6.348	54	3,606	2.776	53	2	8,148	1.564	53	2,907	0.895	43
5	7,886	1.028	53	3,017	0.663	39	4	7,778	1.427	52	2,968	0.857	49	4	7,969	1.393	52	3,017	1.174	49
7	7,807	0.954	51	2,955	0.514	35	5	7,562	1.100	51	2,969	0.860	50	8	7,714	1.148	47	2,951	1.006	45
9	7,903	1.044	54	3,082	0.820	48	8	7,078	0.369	36	2,772	0.268	32	9	7,441	0.886	42	2,834	0.709	41
10	7,680	0.836	49	3,068	0.786	45	10	6,938	0.158	31	2,697	0.042	29	13	7,458	0.902	44	3,025	1.194	50
12	7,651	0.809	47	3,100	0.863	50	11	7,098	0.400	38	2,716	0.099	30	16	7,594	1.033	46	3,016	1.172	48
14	7,603	0.764	44	3,035	0.706	41	12	7,164	0.499	42	2,893	0.632	47	18	7,774	1.205	51	3,290	1.868	54
15	7,473	0.643	38	3,039	0.716	43	13	7,035	0.304	33	2,846	0.490	41	20	6,577	0.057	34	2,664	0.277	38
16	7,549	0.714	42	3,031	0.697	40	14	7,077	0.368	35	2,864	0.544	44	22	6,519	0.001	29	2,500	-0.140	11
17	7,463	0.634	37	2,839	0.234	33	15	7,143	0.468	40	2,956	0.821	48	24	6,533	0.014	30	2,540	-0.038	25
19	6,976	0.180	32	2,929	0.451	34	16	7,181	0.525	43	2,808	0.376	37	25	6,348	-0.163	7	2,297	-0.656	1
20	6,815	0.030	31	2,576	-0.400	5	17	7,245	0.622	46	2,791	0.325	34	26	6,517	-0.001	28	2,415	-0.356	2
21	6,669	-0.106	21	2,738	-0.010	27	18	7,225	0.591	45	2,817	0.403	39	27	6,544	0.025	31	2,440	-0.292	3
22	6,562	-0.206	15	2,659	-0.200	16	21	6,583	-0.378	17	2,548	-0.406	16	28	6,571	0.051	33	2,484	-0.180	5
23	6,385	-0.371	7	2,504	-0.574	2	25	6,302	-0.803	2	2,363	-0.962	1	29	6,410	-0.104	16.5	2,496	-0.150	9
25	6,452	-0.308	9	2,969	0.547	36	28	6,410	-0.640	5	2,509	-0.523	10	30	6,410	-0.104	16.5	2,512	-0.109	15
26	6,697	-0.080	24	2,615	-0.306	10	29	6,427	-0.614	8	2,461	-0.668	4	33	6,367	-0.145	10	2,488	-0.170	6
29	6,577	-0.192	17	2,714	-0.068	25	34	6,499	-0.505	12	2,500	-0.550	9	34	6,397	-0.116	13	2,526	-0.074	19
31	6,553	-0.214	14	2,442	-0.723	1	35	6,320	-0.776	3	2,520	-0.490	13	35	6,475	-0.041	24	2,495	-0.152	8
32	6,431	-0.328	8	2,515	-0.547	3	37	6,415	-0.632	7	2,472	-0.635	6	36	6,443	-0.072	20	2,566	0.028	32
33	6,464	-0.297	11	2,586	-0.376	6	38	6,618	-0.326	20	2,624	-0.177	25	37	6,401	-0.112	14	2,544	-0.028	27
37	6,680	-0.096	22.5	2,545	-0.475	4	39	6,729	-0.158	26	2,605	-0.235	23	38	6,581	0.060	35	2,469	-0.219	4
40	6,492	-0.271	12	2,632	-0.265	13	40	6,646	-0.283	21	2,558	-0.376	18	42	6,485	-0.032	26	2,622	0.170	37
41	6,645	-0.129	19	2,692	-0.121	20	41	6,511	-0.487	14	2,591	-0.277	22	43	6,417	-0.097	18	2,600	0.114	36
42	6,680	-0.096	22.5	2,670	-0.174	18	44	6,526	-0.465	15	2,513	-0.511	11	45	6,448	-0.067	22	2,699	0.366	39
47	6,789	0.006	29	2,746	0.010	30	45	6,710	-0.187	24	2,664	-0.057	27	48	6,386	-0.127	12	2,528	-0.069	21
48	6,777	-0.006	28	2,720	-0.053	26	48	6,592	-0.365	19	2,669	-0.042	28	49	6,466	-0.050	23	2,793	0.605	40

Loc. = Location
Adj. Meas. = Adjusted Measurement
R = Rank

Table B.5. (continued) Measurement Data Used for Student's t-Test in Unit 2 Containment													
P323							P324						
Loc.	FSS			ORISE			Loc.	FSS			ORISE		
	cpm	Adj. Meas.	R	cpm	Adj. Meas.	R		cpm	Adj. Meas.	R	cpm	Adj. Meas.	R
0	27,627	4.485	55	8,269	2.859	53	1	10,502	0.923	44	3,925	0.363	39
1	35,806	6.483	56	4,335	0.242	34	2	8,335	0.033	30	3,303	-0.113	15
2	12,965	0.904	46	3,530	-0.293	18	5	8,161	-0.039	24.5	3,317	-0.102	17
3	9,929	0.162	32	3,999	0.019	29	6	7,993	-0.108	16	3,573	0.094	34
5	12,027	0.675	42	5,086	0.742	44	7	8,477	0.091	33	3,325	-0.096	18
6	12,091	0.690	43	4,406	0.290	36	10	7,868	-0.159	13	3,463	0.010	29
8	15,367	1.491	50	9,883	3.933	54	11	8,078	-0.073	21	5,752	1.763	51
9	14,843	1.363	49	4,355	0.256	35	12	7,976	-0.115	14	3,349	-0.078	20
12	9,180	-0.021	27	3,521	-0.299	17	13	8,087	-0.069	22	3,241	-0.160	12
15	9,349	0.021	30	4,025	0.036	31	14	8,175	-0.033	27	3,332	-0.091	19
17	15,584	1.544	51	7,786	2.538	52	15	8,350	0.039	31	3,383	-0.052	23
20	9,055	-0.051	26	5,508	1.023	47	17	10,152	0.779	41	5,321	1.433	47
22	7,949	-0.321	16	3,404	-0.377	11	19	8,359	0.043	32	3,438	-0.010	28
23	7,656	-0.393	10	3,133	-0.557	5	20	8,875	0.255	37	3,625	0.134	35
24	7,437	-0.446	7	3,063	-0.604	2	26	12,457	1.726	50	7,776	3.313	56
25	8,127	-0.278	21	3,942	-0.019	28	27	8,170	-0.035	26	3,683	0.178	36
26	10,502	0.302	39	5,916	1.294	48	28	7,331	-0.380	7	2,962	-0.374	8
29	7,740	-0.372	12	3,214	-0.503	6	29	7,175	-0.444	5	2,805	-0.494	2
31	7,486	-0.434	8	2,936	-0.688	1	31	7,094	-0.477	4	2,767	-0.524	1
32	7,493	-0.433	9	3,127	-0.561	4	32	7,372	-0.363	9	2,811	-0.490	3
34	8,199	-0.260	23	3,103	-0.577	3	34	13,792	2.275	54	4,940	1.141	45
35	10,211	0.231	33	4,412	0.294	38	36	12,604	1.787	53	5,769	1.776	52
37	8,271	-0.243	24	3,450	-0.346	14	38	8,161	-0.039	24.5	3,201	-0.191	11
39	7,893	-0.335	15	3,445	-0.350	13	40	7,305	-0.390	6	2,983	-0.358	10
40	8,078	-0.290	20	3,531	-0.292	19	43	14,172	2.431	55	4,505	0.808	42
41	8,177	-0.266	22	3,655	-0.210	25	47	9,366	0.456	40	3,845	0.302	38
46	10,537	0.311	40	4,410	0.292	37	48	11,841	1.473	48	4,581	0.866	43
48	11,036	0.433	41	5,188	0.810	45	49	11,270	1.239	46	5,426	1.513	49

Loc. = Location
Adj. Meas. = Adjusted Measurement
R = Rank

APPENDIX C: SURVEY AND ANALYTICAL PROCEDURES

C.1. PROJECT HEALTH AND SAFETY

The Oak Ridge Institute for Science and Education (ORISE) performed all survey activities in accordance with the *Oak Ridge Associated Universities (ORAU) Radiation Protection Manual*, the *ORAU Health and Safety Manual*, and the *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2014, ORAU 2016b, and ORAU 2016a). Prior to on-site activities, a work-specific hazard checklist was completed for the project and discussed with field personnel. The planned activities were thoroughly discussed with site personnel prior to implementation to identify hazards present. Additionally, prior to performing work, a pre-job briefing and walkdown of the survey areas were completed with field personnel to identify hazards present and discuss safety concerns. Should ORISE have identified a hazard not covered in the *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2016a) or the project's work-specific hazard checklist for the planned survey and sampling procedures, work would not have been initiated or continued until the hazard was addressed by an appropriate job hazard analysis and hazard controls.

C.2. QUALITY ASSURANCE

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

- ORAU Radiological and Environmental Survey Procedures Manual (ORAU 2016a)
- ORAU Radiological and Environmental Analytical Laboratory Procedures Manual (ORAU 2017)
- ORAU Environmental Services and Radiation Training Quality Program Manual (ORAU 2018)

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

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.
- Participation in Mixed-Analyte Performance Evaluation Program and Intercomparison Testing Program laboratory quality assurance programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

C.3 PIPE DETECTOR CALIBRATION

Efficiency factors representing the total gamma-emitting radionuclide of concern (ROC) activity for the sodium iodide (NaI)/cesium iodide (CsI) detector were determined based on the diameter of the measured penetration. Calibration of all field instrumentation was based on standards/sources traceable to the National Institute of Standards and Technology (NIST). A Cs-137 line source, approximately 30 centimeters (cm) in length, was used for the efficiency determination of each detector. The calibration source was continuously rotated around the detector at constant speed using a motorized jig during measurement acquisition. Rotating the source simulates a large-area source distributed over a cylindrical geometry. Based on the length of the calibration standard, the area represented by each static measurement will be the surface area of a 1-foot long segment of pipe/penetration. Figure C.1 depicts the calibration geometry from the top down (looking into the penetration).

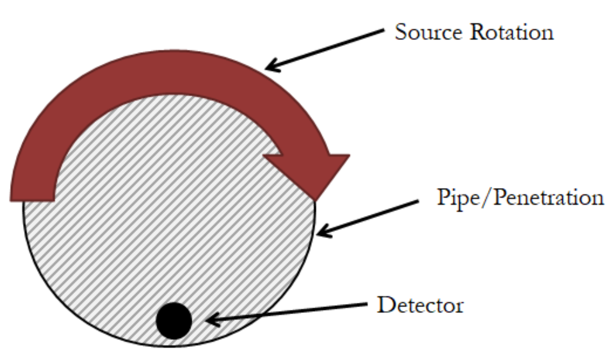

Figure C.1. Detector Calibration Geometry

Direct measurements were converted to surface activity units by:

$$\left(\frac{pCi}{100\ cm^2}\right) = \frac{R_{gross}}{\varepsilon \times G} \times \left(\frac{1\ pCi}{2.22\ dpm}\right) \qquad \text{(Equation C-1)}$$

Where

pCi = picocurie

cm^2 = square centimeter

R_{gross} = the gross static measurement count rate, uncorrected for background

ε = detector efficiency

G = Source area modification factor representing the surface area of a 1-linear-foot section of the penetration, which is 0.56 m^2 for a 23-inch diameter penetration. The detector field of view covers significantly more than this area. Previous ORISE pipe detector calibrations demonstrate that approximately 90% of the detector response to a point source (relative to the source centered with the detector midpoint) occurs within 15 cm from the detector midpoint.

dpm = disintegrations per minute

The static minimum detectable concentration (MDC) in units of pCi/square meter (m^2) was calculated by

$$MDC\left(\frac{pCi}{100\ cm^2}\right) = \frac{3+4.65\sqrt{Bkg}}{\varepsilon \times G} \times \left(\frac{1\ pCi}{2.22\ dpm}\right) \qquad \text{(Equation C-2)}$$

Where

Bkg = Background count rate, which is assumed to be 4,000 counts per minute (cpm)

Factors ε and G in Equation C-2 are the same as presented in Equation C-1. A summary of efficiency factors and corresponding MDCs for varying penetration/pipe diameters are presented in Table C.1.

Table C.1. Detector Efficiency and MDC Summary					
Duct Diameter (in)	**Bkg (cpm)[a]**	**ε**	**G (m^2)**	**MDC (pCi/m^2)**	**Comment**
NaI Detector - Model 44-157					
6	9,750	1.22E-02	0.15	1.17E+05	Applies to Aux waste disposal penetration A023
23	9,750	3.14E-03	0.56	1.19E+05	Applies to penetrations in the cavity flood sump and rx recirc sump
CsI Detector - Model 44-159-1					
1.5	750	3.82E-03	0.04	4.21E+05	Applies to in-core discharge embedded piping
1.97	750	3.13E-03	0.05	3.92E+05	Applies to Aux waste disposal penetration A011

[a]Background taken as typical value from manufacturer manual. Site-specific values were not determined; however this value is a conservative estimate.

C.4 Radiological Sample Analysis

Miscellaneous sample 5271M0038 contained multiple matrices, including the cloth wipe, some debris-residue material, some type of rubber/silicone seal, and a personal protective equipment (PPE) glove that was used to obtain the sample. The entire sample was analyzed by gamma spectrometry in a 250 milliliter (mL) marinelli beaker, and multiple radionuclides were identified, including, but not limited to, Am-241. To further determine where the radionuclides were concentrated within the sample, the sample was split into four different portions and placed into corresponding smaller gamma spectrometry calibrated geometries containers. The cloth wipe was cut into two pieces and each piece was placed in its own container and labeled, respectively, "swipe 1" and "swipe 2." The debris-residue was put into one container and labeled "residue 1." The glove and seal were placed into another container and labeled "glove-seal." Each container then was counted via gamma spectroscopy. The container labeled "swipe 1" was identified to contain the Am-241. While the other three containers were identified to have other minor residual contamination, Am-241 was not identified in these three containers.

C.4.1 Gamma Spectroscopy

Samples were counted using intrinsic, high-purity, germanium detectors coupled to a pulse-height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the 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 ROCs and the associated MDCs for a 1-hour count time are presented in Table C.2. Gamma spectrometry values reported in this document were based on the initial count of the sample in the 250 mL marinelli beaker. It was noted that only one portion of the swipe contained Am-241, and that same portion contained the majority of the gamma activity.

Table C.2. MDCs and Total Absorption Peak

Radionuclide	TAP (MeV)[a]	MDC (pCi/sample)
Co-60	1.332	60
Cs-134	0.795	109
Cs-137	0.662	90
Eu-152	0.344	151
Eu-154	0.723	400

[a] mega electron volt

C.4.2 Americium-241 Analysis by Alpha Spectrometry

The swipe portion that contained Am-241 was placed in a 250-mL platinum dish and the dish was placed into a muffle furnace, which was slowly ramped up to 900ºC. The remaining residue was first acid extracted with 1M HCL to remove elemental iron. This liquid fraction was held back to later return to the fused sample. The remaining solid residue was returned to the platinum dish and fused by a fluoride-pyrosulfate fusion. The sample was completely dissolved. The fusion cake was dissolved in 500 mL of 2M HCL with heat. The initial 1M HCL extraction was added back to the sample. The sample was diluted to 1000 mL with 1M HCL; 100 mL of the sample was used for Am-241 analysis, including a duplicate. Because of anticipated activity levels of 15–20 pCi/100 mL, the sample was spiked with Am-243 at similar levels. Analysis proceeded with no deviations. In addition to Am-241, Cm-244 was identified in the sample; however, the value determined by the software is an estimated value (biased low). Accurate analysis of the curium isotopes requires minor procedural changes to eliminate the low bias.

APPENDIX D: MAJOR INSTRUMENTATION

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

D.1 SCANNING AND MEASUREMENT INSTRUMENT/DETECTOR COMBINATIONS

D.1.1 Gamma

Ludlum NaI Scintillation Detector Model 44-157, Crystal: 5.1 cm × 5.1 cm
coupled to: Ludlum Ratemeter-scaler Model 2221

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

D.2 LABORATORY ANALYTICAL INSTRUMENTATION

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

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-45200-5
Used in conjunction with:
Lead Shield Model G-11
Lead Shield Model SPG-16-K8
(Nuclear Data)
Multichannel Analyzer
Canberra's Gamma Software
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-30P4
Used in conjunction with:
Lead Shield Model G-11
Lead Shield Model SPG-16-K8
(Nuclear Data)
Multichannel Analyzer
Canberra's Gamma Software
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. CDG-SV-76/GEM-MX5970-S
Used in conjunction with:
Lead Shield Model G-11
Lead Shield Model SPG-16-K8
(Nuclear Data)
Multichannel Analyzer
Canberra's Gamma Software
Dell Workstation
(Canberra, Meriden, Connecticut)

CANBERRA Alpha Analyst™ Integrated Alpha Spectrometer System with
A450-18AM Alpha Passivated Implanted Planar Silicon detectors
Used in conjunction with:
CANBERRA Apex-Alpha software v.1.2.0.56