August 1, 2013

Mr. Theodore Smith, Project Manager
U.S. Nuclear Regulatory Commission
Office of Federal and State Materials and Environmental Management Program
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SUBJECT: INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE FORD NUCLEAR REACTOR, REVISION 1, ANN ARBOR, MICHIGAN (DOCKET NO. 50-151; RFTA 12-008) DCN 5176-SR-01-1

Dear Mr. Smith:

Oak Ridge Associated Universities (ORAU) is pleased to provide the enclosed report that details the confirmatory survey activities that were performed during the period of December 4 through 6, 2012, at the University of Michigan's Ford Nuclear Reactor in Ann Arbor, Michigan. The survey activities were conducted in accordance with ORAU confirmatory and inspection plans provided to the U.S. Nuclear Regulatory Commission. Based on your comment, this revision of the final report incorporates a footnote in Table 7.4 as text in Sect. 7.5.

Please feel free to contact me via my information below, or Erika Bailey at 865.576.6659, if you have any questions or comments.

Sincerely,

Nick A. Altic
Health Physicist
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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE FORD NUCLEAR REACTOR, REVISION 1 ANN ARBOR, MICHIGAN

Nick Altic

Prepared for the
U.S. Nuclear Regulatory Commission

ORAU
OAK RIDGE ASSOCIATED UNIVERSITIES

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE FORD NUCLEAR REACTOR, REVISION 1
ANN ARBOR, MICHIGAN

Prepared by

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Prepared for the
U.S. Nuclear Regulatory Commission

FINAL REPORT

AUGUST 2013

Prepared by Oak Ridge Associated Universities under the Oak Ridge Institute of Science and Education contract, number DE-AC05-06OR23100, with the U.S. Department of Energy under interagency agreement (NRC FIN No. F-1244) between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

5176-SR-01-1

ORAU

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE FORD NUCLEAR REACTOR ANN ARBOR, MICHIGAN

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FINAL REPORT

AUGUST 2013

CONTENTS

TABLES

FIGURES

ACRONYMS

COC	contaminant of concern
cpm	counts per minute
CU	confirmatory unit
$DCGL_W$	derived concentration guideline level
DER	normalized absolute difference
dpm	disintegrations per minute
FNR	Ford Nuclear Reactor
FSS	final status surveys
FSSP	final status survey plan
IA	impacted areas
IEAV	Independent Environmental Assessment and Verification
ISM	integrated safety management
LBGR	lower bound of the gray region
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MeV	megaelectron volts
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
NRIP	NIST Radiochemistry Intercomparison Program
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
Q	quantile
SOF	sum of fractions
SU	survey unit
TAP	total absorption peak
UM	University of Michigan

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE FORD NUCLEAR REACTOR, REVISION 1 ANN ARBOR, MICHIGAN

1. INTRODUCTION

The Ford Nuclear Reactor (FNR) at the University of Michigan (UM) was a light-water cooled and moderated open-pool design reactor (UM 2012). It had a heterogeneous core composed of aluminum and enriched uranium-235 (UM 2006). The FNR went critical in 1957 and provided neutron and gamma irradiation services, neutron beam port experimental facilities, and training facilities for use by faculty, students, and researchers from UM, other universities, and industrial organizations. The FNR was operated by the Michigan Memorial Phoenix Project of UM under U.S. Nuclear Regulatory Commission (NRC) License R-28, Docket 50-2, until it was shut down in July 2003. The fuel was removed in December 2003.

CH2M HILL conducted the historical site assessment in 2003 to assess and detail the radiological status of the FNR. Results of radiological surveys showed that many potentially impacted areas were free of contamination, including a major portion of the FNR structure. However, non-routine occurrences, accidents, or spills between 1959 and 2001 contributed to the contamination of several systems and surfaces associated with the reactor (UM 2006).

At the NRC's request, Oak Ridge Associated Universities' (ORAU) Independent Environmental Assessment and Verification (IEAV) Program conducted in-process confirmatory survey activities at the FNR.

2. SITE DESCRIPTION

Located on the North Campus of UM at 2301 Bonisteel Boulevard, approximately 1.25 miles northeast of the central business district of Ann Arbor (Fig. A-1), the windowless FNR building is constructed of reinforced concrete with a brick veneer. The footprint of the FNR building is approximately 4,760 square feet (440 square meters) with a height near 69 ft. (21 m) and is conjoined with the Phoenix Memorial Laboratory. Though several services were interconnected, the two structures operated independently. The FNR facility was divided into five levels (UM 2006):

Basement (liquid cooling and waste systems), 1st Floor (beamport experimental area), 2nd Floor (maintenance and other support facilities and systems), 3rd Floor (reactor access and control), and the 4th Floor (cooling tower) (Figs. A-2 to A-6).

Results from the characterization surveys in 2006 identified contamination in the following areas (UM 2006):

- Basement
  - Floor drains
  - Sumps
  - Floor
- 1st Floor
  - Floor drain
  - Floor trench around the west and north pool walls
  - Storage ports in the west wall
- 3rd Floor
  - Floor drains
  - Floor near the pool
  - South wall above the pool
  - Room 3103

The extensive removal, disposition, and/or decontamination of these components, structures, and systems—as well as several others throughout the FNR—were performed during the remediation phase of the decommissioning process. Post-remediation sampling and routine surveys have been performed to confirm that volumetric and surface contamination are not present in/on the remaining FNR structures (UM 2012).

2.1 Confirmatory Units

The operational history for various areas of the facility resulted in different levels of potential exposure to residual radiological contamination. Therefore, different areas required different levels of survey coverage to determine if remaining residual radioactivity levels meet the NRC release criteria. UM has divided the FNR facility into multiple survey units (SUs) in accordance with the guidance in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000).

MARSSIM designates three category classifications for impacted areas (IAs), or areas that have some potential for containing contaminated material. Based on contamination potential, IAs are categorized as Class 1, 2, or 3. Descriptions for each classification for IAs are as follows:

Class 1: Buildings or land areas that have a significant potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys) that exceeds the expected derived concentration guideline level ($DCGL_W$)

Class 2: Buildings or land areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the $DCGL_W$

Class 3: Any impacted areas that are not expected to contain residual contamination, or are expected to contain levels of residual contamination at a small fraction of the $DCGL_W$

Non-impacted areas are areas that should not have the potential to contain contaminated materials.

For confirmatory purposes, ORAU grouped several of UM's finished final status surveys (FSS) SUs into three confirmatory units (CUs). All CUs were given a Class 1 designation. Two CUs were located in the basement and one was located on the third floor. UM had just begun FSS activities on the 1st or 2nd floors; therefore, ORAU could not perform confirmatory surveys of those areas. Instead, ORAU performed in-process surveys consisting of high- to medium density scans in the several areas that had not received FSS.

Located in the basement, CU 1 consisted of SUs B-1, B-2, B-4, B-5, B-6, and a portion of SU B-3. Also located in the basement, CU 2 consisted of a portion of SU B-3 and SU 1-13. CU 2 did not have a ceiling and was open to the first floor; this CU contained the bottom portion of the pool. CU 3 was located on the third floor and consisted of SUs 3-3, 3-4, 3-5, 3-6, 3-7, and 3-8.

3. APPLICABLE SITE GUIDELINES

The primary contaminants of concern (COCs) for the FNR are beta-gamma emitters—fission and activation products—resulting from reactor operation. Results from samples collected during remediation activities indicate that residual amounts of cobalt-60 (Co-60), silver-108m (Ag-108m), silver-110m (Ag-110m), and cesium-137 (Cs-137) may be present in construction materials and exposed surface soils (UM 2012). In addition, europium-152 (Eu-152) and carbon-14 (C-14) were detected in subsurface soil at concentrations below their respective default screening values.

Table 3.1 provides further detail regarding the respective contaminants and associated DCGLs (UM 2012).

Table 3.1. FNR Radiological Contaminants and Decommissioning Criteria

Radionuclide	Surface Soil DCGL (pCi/g)	Structure Surface DCGL (dpm/100cm^2)	
		Total	Removable
Co-60	3.8	7,050	705
Cs-137	11	28,000	2,800
Ag-108m	8.2	17,000	1,700
Ag-110m	4.92	10,200	1,020
C-14	N/A	N/A	N/A
Eu-152	N/A	N/A	N/A
Gross beta	N/A	5125	512

[a]N/A = not applicable or not present as a contaminant
[b]Includes short-lived daughter products present due to assumed ingrowth period of 20 years

4. OBJECTIVES

UM was still in the process of performing FSS at the time of the ORAU site visit. Therefore, ORAU performed in-process inspections in areas where UM was working during the visit and confirmatory surveys where FSS were completed. The objectives were to independently review contractor documentation and field data, evaluate UM's survey process, and generate independent radiological data to assist NRC in evaluating the adequacy and accuracy of UM's FSS results.

5. PROCEDURES

During the period December 4 through December 6, 2012, ORAU performed an in-process confirmatory survey of the FNR. The survey was in accordance with a plan dated November 30, 2012, and submitted to and approved by the NRC headquarters (ORAU 2012a). Survey activities were conducted in accordance with the ORAU/ORISE Survey Procedures and ORAU Quality Program Manuals (ORAU/ORISE 2013a and ORAU 2012b). This report summarizes the procedures and results of the survey.

5.1 DOCUMENT REVIEW

Prior to on-site activities, ORAU was tasked with reviewing the final status survey plan (FSSP) for the FNR provided by UM. The FSSP was reviewed for adequacy and appropriateness while taking MARSSIM guidance into account (NRC 2000).ORAU also reviewed UM's FSS data packages of the SUs listed in Section 2.1 to ensure that survey objectives stated in the FSSP were met.

5.2 REFERENCE SYSTEM

ORAU used specific X, Y coordinates from the southwest corner of the respective CU floor and lower left corner of walls.

5.3 SURFACE SCANS

Gamma scans were performed using sodium iodide (NaI) scintillation detectors coupled to ratemeter-scalers with audible indicators. Beta surface scans were performed using both large (floor monitor) and hand-held gas proportional detectors coupled to ratemeter-scalers with audible indicators. Both NaI and gas proportional detector/instrument combinations were connected to hand-held electronic data collectors equipped with real-time data-logging software to record instrument response during scans.

High-density scans were performed in all three CUs. Judgmental confirmatory surveys were also performed within portions of SUs where FSS activities had not been completed. Medium- to high-density scans were performed for judgmental scan locations. Judgmental scan locations were as follows:

- 1st Floor – Lower walls and floor of Room 1101
- 2nd Floor – Exhaust plenum and floor in Room 2111
- 3rd Floor – Lower walls and floor of Rooms 3110, 3109, and 3108, and Corridor 3101
- 4th Floor – Cooling tower floor, walls and support bracing

5.4 Surface Activity Measurements

Construction material-specific background measurements were collected for correcting gross activity measurements performed on structural SUs. Material-specific backgrounds were collected from the same area by both ORAU and the licensee. Direct measurements for total beta activity were performed at random locations in each CU (Figs. A-7 to A-9). The number of measurements performed was determined by the relative shift used by UM. No judgmental direct measurement locations were identified were collected. Smear samples to determine removable gross beta activity levels were collected from any direct measurement location that was above 10% of the $DCGL_W$.

Additionally, ten measurement locations were selected to correspond to licensee locations (i.e., side-by-side measurements) for direct data comparison. The direct measurements were performed using hand-held gas proportional detectors. Detectors were coupled to portable ratemeter-scalers.

5.5 Soil and Miscellaneous Material Sampling

Two judgmental surface soil samples were collected from the basement area (Fig. A-7). Soil sample 5176S0001 was collected from the cold sump drain line trench along the south wall. Soil sample 5176S0002 was collected from the hot sump trench area where it meets the east wall. Selected sample locations were based on the results of gamma scans and previously identified contamination.

In addition to the soil samples collected by the survey team, UM submitted five samples for an inter-laboratory comparison at NRC's request (Samples 5176S0003 through 5176S0007). ORAU also received five split samples from UM (Samples 5176S0008 through 5176S0012), in addition to the samples submitted for the inter-laboratory comparison.

6. SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples were returned to the ORAU/ORISE Radiological and Environmental Analysis Laboratory in Oak Ridge, Tennessee, for analysis and interpretation. Sample analyses were performed in accordance with the ORISE Laboratory Procedures Manual (ORAU/ORISE 2013b). Soil and miscellaneous roofing material samples were analyzed by solid-state gamma spectroscopy for gamma-emitting COCs. Analytical results were reported in units of picocuries per gram (pCi/g). Direct measurement data were converted to units of disintegrations per minute per 100 square centimeters (dpm/100 cm^2). The data generated were compared with the approved $DCGL_W$s established for the FNR.

7. FINDINGS AND RESULTS

The results for each of the verification activities are discussed below.

7.1 Document Review

The ORAU review of UM's FSSP indicated that an incorrect surface efficiency was used for calculating the total efficiency. Per the FSSP, a surface efficiency of 0.37 would be applied. In the absence of site-specific data, MARSSIM prescribes that a surface efficiency of 0.25 should be applied for beta emitters with a maximum energy between 0.15 and 0.4 megaelectron volt (MeV), and a surface efficiency of 0.5 should be applied for maximum beta energies above 0.4 MeV. UM opted to assign a surface efficiency of 0.25 to all beta emitters, which is a conservative approach. Other observations made during the confirmatory survey site visit are described below.

Table 7.1 provides a retrospective review of UM's FSS data packages for the 13 SUs in which confirmatory survey activities were performed. The FSS surface activity data reviewed was calculated with a surface efficiency of 0.25. For FSS planning, UM chose to set the lower bound of the gray region (LBGR) and expected contaminant variation at 50% and 30%, respectively, of the gross beta $DCGL_W$. The resulting relative shift (Δ/σ) is equal to 1.67, which translates to 17 direct measurement locations required for each survey unit (NRC 2000). A retrospective analysis of the FSS data shows that the mean surface activity and contaminant variability were less than the LBGR and expected variability used as planning inputs, meaning that more direct measurements were collected than required.

Table 7.1. Retrospective Analysis of FSS Data Packages					
ORAU Confirmatory Unit	UM SU	n Collected	Surface Activity (dpm/100 cm²)		Retrospective Δ/σ^{a}
			Mean	σ	
CU 1	B-1	22	287	247	20
CU 1	B-2	19	164	284	17
CU 1/CU 2	B-3	19	181	363	14
CU 1	B-4	26	-379	367	15
CU 1	B-5	19	-142	353	15
CU 1	B-6	18	93	285	18
CU 2	1-13	23	-164	1059	5.0
CU 3	3-3	17	857	335	13
CU 3	3-4	17	497	556	8.3
CU 3	3-5	18	528	490	9.4
CU 3	3-6	25	324	327	15
CU 3	3-7	20	294	437	11
CU 3	3-8	22	524	537	8.6

[a]Calculated by setting the LBGR at the SU mean surface activity.

7.2 Surface Scans

The gross count rates for beta and gamma radiation surface scan data for each ORAU CU and the corresponding UM SUs were prepared for report presentation using quantile (Q) plots. The Q-plots are presented in Appendix B. They are a graphical technique for determining if there is a common distribution in data sets. The advantage of the Q-plot is that population distributional aspects can be evaluated simultaneously. The detectable aspects include:

- Shifts in scale
- Changes in symmetry (skewness of the data)
- The presence of outliers

Q-plots were generated by uploading the scan data files into the U.S. Environmental Protection Agency's ProUCL software. In the Q-plots provided in Appendix B, the Y-axis represents observed count rates in counts per minute (cpm). The X-axis represents the data quantiles about the mean value. A normal distribution that is not skewed by outliers will appear as a straight line with the slope of the line subject to the degree of variability among the data population (i.e., a background radiation population). Values less than the mean are represented in the negative quantiles, and values greater than the mean are represented in the positive quantiles. The presence of more than one population—e.g., background radiation population and contamination—would display on a Q-plot as a step function. Small areas of localized contamination will appear on the Q-plot as outlier points in the upper right quadrant.

Instrument response for beta scans ranged from 3 to 805 gross cpm for the walls and 167 to 2,196 cpm for the floor over all areas investigated during confirmatory surveys. Instrument responses are low because data capture was initiated before the instrument was turned on; therefore, the instrument's increase to background was captured. Instrument response for gamma scans ranged from 1,054 to 28,393 gross cpm over all areas investigated during confirmatory surveys. Beta floor scans are reported separately from wall scans because different detectors were used. The detector for the beta floor scans had a much larger background reading than the detector used for beta wall scans. The ORAU survey team detected residual radioactivity in CU 3, outside of the doorway to Room 3103, while performing surface scans with hand-held gas proportional and NaI detectors. Even though the elevated area was small and below the action level, UM still remediated the area to background levels. Elevated instrument response for gamma scans for the floor and walls on the first floor is apparent by looking at the Q-plot; however, this elevated response is due to source storage area outside of the study boundary. No other areas of elevated activity were detected from surface scans.

7.3 SURFACE ACTIVITY MEASUREMENTS

Total surface activity levels for the three CUs are provided in Tables C-1 through C-3. The reported surface activities represent gross levels that have been corrected for background. Background measurements were collected from the lower pool monolith for concrete and the first floor men's restroom in the Phoenix Memorial Lab. These were the same area that UM collected their background measurements. Table 7.2 provides a summary of the confirmatory measurement data for each CU relative to FSS data of UM.

Table 7.2. Confirmatory Surface Activity Comparison								
Confirmatory Unit	Surface Activity (dpm/100 cm^2)							
	Min		Max		Mean		95% Confidence Interval of Mean	
	ORAU	UM	ORAU	UM	ORAU	UM	ORAU	UM
1	-370	-1,084	270	821	10	-10	-300 to 321	-808 to 789
2	-610	-1,511	300	3,596	-160	-85	-552 to 232	-1,853 to 1,682
3	-140	-870	610	1,875	187	488	-157 to 531	-447 to 1,423

The variation in the surface activity levels reported by UM was much larger than those determined by ORAU for all CUs. This large variation is most likely because the FSS instrumentation used by UM had a small efficiency; thus, a small change in background resulted in large change in surface activity. The mean surface activity reported by UM was within the 95% confidence interval of the mean reported by ORAU for each of the three CUs.

7.4 SURFACE ACTIVITY DATA COMPARISON

During the site visit ORAU collected side-by-side direct measurements with UM in SU 3-1, located in Corridor 3101, on the third floor. The instrument/detector combinations used were:

- ORAU—Ludlum Model 2221 ratemeter-scaler coupled to a Ludlum Model 43-68 gas proportional detector
- UM—Model 2360 data-logger coupled to a Ludlum Model 43-93 alpha/beta scintillation detector

The total efficiencies for the instrument and detector combinations were 7.36% for UM and 14% for ORAU. Geometry correction factors for ORAU and UM detectors used were 1.26 and 1.00, respectively. The results of the side-by-side measurements are shown in Table 7.3. The surface activity for the individual measurements reported by UM are all above zero, indicating that background may not be properly defined. However, it appears that UM under-estimated the background levels, which is conservative.

Table 7.3. Side-by-Side Beta Measurements for Survey Unit 3-1				
UM Location Code	Gross Counts (cpm)		Surface Activity (dpm/100 cm²)	
	ORAU	UM	ORAU	UM
FNR_3-1_C1_A_011	399	305	96	313
FNR_3-1_C1_C_012	384	399	11	1,698
FNR_3-1_C1_C_013	359	291	-130	231
FNR_3-1_C1_C_014	302	277	-450	41
FNR_3-1_W1_A_015	378	298	-23	217
FNR_3-1_C1_C_016	361	278	-120	326
FNR_3-1_F1_C_017	393	314	62	543
FNR_3-1_W1_A_018	412	297	170	204
FNR_3-1_C1_C_019	405	316	130	571
FNR_3-1_F1_C_022	415	293	190	258
	Mean:		-6	440

7.5 RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Individual sample results for the gamma-emitting fission/activation products that UM has identified as COCs are presented in Table 7.4. Samples 5176S0001 and 5176S0002 were collected from the drain line and hot sump soil trenches in the basement by the survey team during the December 2012 site visit. The remaining samples (5176S0008 through 5176S0012) presented in Table 7.4 were submitted as split samples to the ORAU/ORISE Radiological and Environmental Analysis Laboratory. These split samples were collected from the basement and first floor exposed soil areas—including the cold sump, hot sump, and trench between the cold sump and drain line. Sample results for 5176S0002 indicated the most notable detected concentrations of elevated COCs were for Ag-108m and Co-60; however, the levels were below the individual COC $DCGL_W$s.

Table 7.4. Radionuclide Concentrations in Soil (pCi/g)					
ORAU Sample ID	Ag-108M	Ag-110M	Cs-137	Co-60	SOF[a]
5176S0001[b]	0.53 ± 0.04[c]	-0.05 ± 0.02	0.05 ± 0.02	0.06 ± 0.02	0.08
5176S0002[d]	1.64 ± 0.12	-0.23 ± 0.06	0.45 ± 0.05	2.85 ± 0.19	0.99
5176S0008	0.00[e] ± 0.00	0.00 ± 0.01	0.00 ± 0.01	0.03 ± 0.02	0.01
5176S0009	0.01 ± 0.01	0.00 ± 0.01	-0.01 ± 0.02	0.17 ± 0.04	0.05
5176S0010	0.01 ± 0.01	-0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02	0.01
5176S0011	0.03 ± 0.01	-0.02 ± 0.02	0.00 ± 0.02	0.04 ± 0.02	0.01
5176S0012	0.22 ± 0.02	0.00 ± 0.01	0.21 ± 0.02	0.28 ± 0.03	0.12

[a]SOF = sum of fractions. Negative values were not included in the SOF calculations
[b]Collected from drain line soil trench
[c]Errors represent the total propagated uncertainties reported at the 95% confidence level
[d]Collected from hot sump soil trench
[e]Zero values are due to rounding

7.5.1 Inter-Laboratory Comparison

Five of UM's FSS soil samples (5176S0003 through -0007) were submitted to the ORAU/ORISE Radiological and Environmental Analysis Laboratory for an inter-lab comparison. Radionuclide concentrations determined by each laboratory are presented in Table C-4. The criterion used to evaluate the samples was the normalized absolute difference (DER). The DER is defined in the equation below (DOE 2012).

$$DER = \frac{|S - D|}{\sqrt{(CSU_S)^2 + (CSU_D)^2}} \leq 3$$

Where:

S = sample concentration
D = Duplicated sample concentration
CSU_S = 1 sigma uncertainty of the sample
CSU_D = 1 sigma uncertainty of the duplicate

If the DER is less than 3, the results are in agreement at the 99% confidence level. Sample 5176S0005 was the only sample that had a DER value of greater than 3, which was for Co-60 only. Results reported by both labs were below the Co-60 $DCGL_W$.

8. SUMMARY

At the NRC's request, ORAU conducted confirmatory surveys of the FNR during the period of December 4 through 6, 2012. The survey activities included visual inspections and measurement and sampling activities. Confirmatory activities also included the review and assessment of UM's project documentation and methodologies.

Surface scans identified elevated activity in two areas. The first area was on a wall outside of Room 3103 and the second area was in the southwest section on the first floor. The first area was remediated to background levels. However, the second area was due to gamma shine from a neighboring source storage area.

A retrospective analysis of UM's FSS data shows that for the SUs investigated by the ORAU survey team, UM met the survey requirements set forth in the FSSP. The total mean surface activity values were directly compared with the mean total surface activity reported by UM. Mean surface activity values determined by UM were within two standard deviations of the mean determined by ORAU. Additionally, all surface activity values were less than the corresponding gross beta $DCGL_W$. Laboratory analysis of the soil showed that COC concentrations were less than the respective $DCGL_W$ values. For the inter-lab comparison, the DER was above 3 for only one sample. However, since the sum of fractions (see Table C-5) for each of the soil samples was below 1, thus none of the samples would fail to meet release guidelines.

Based on the findings of the side-by-side direct measurements, and after discussion with the NRC and ORAU, UM decided to use a more appropriate source efficiency in their direct measurement calculations and changed their source efficiency from 0.37 to 0.25.

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APPENDIX A
FIGURES

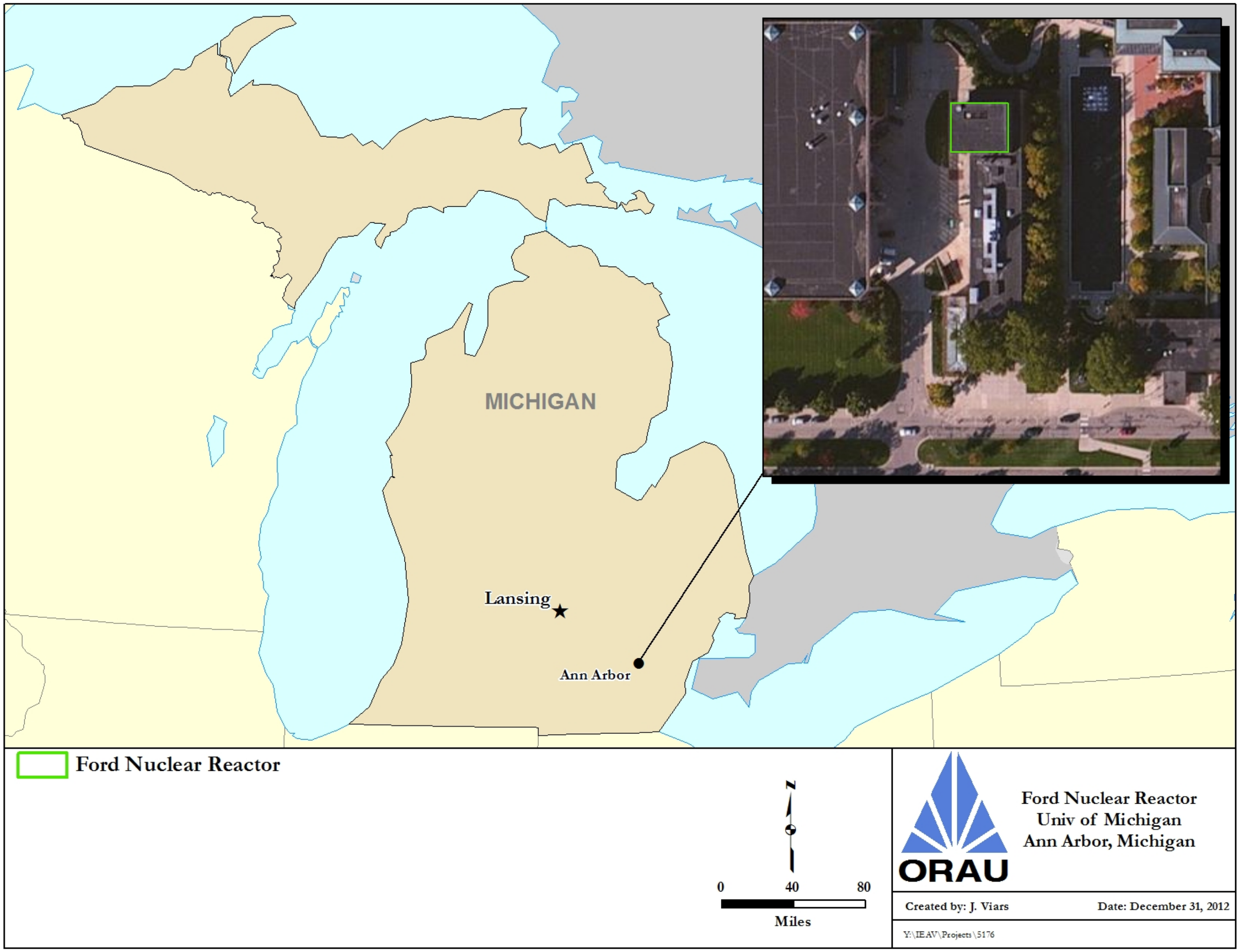

Fig. A-1. Location of the University of Michigan

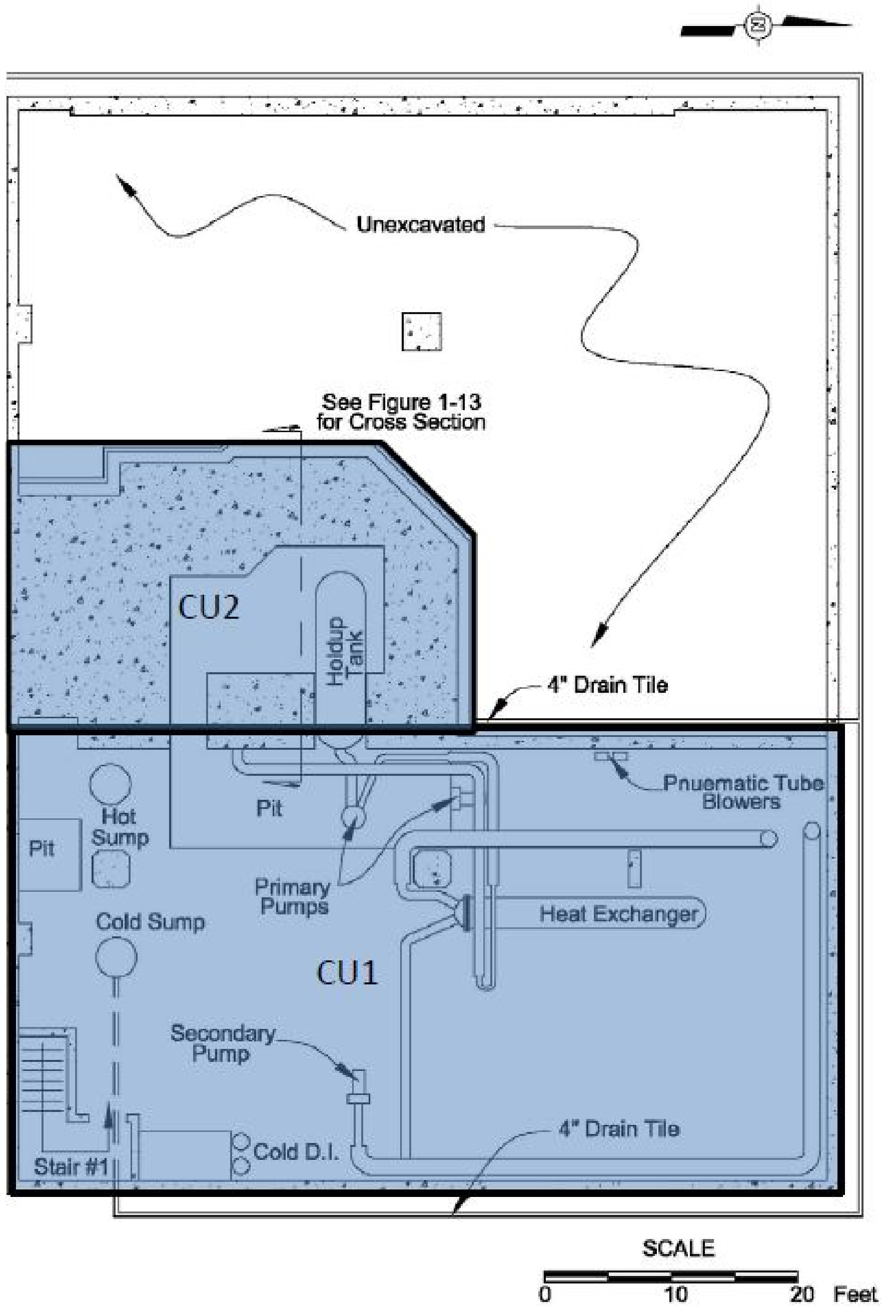

Figure provided by University of Michigan

Scan Coverage Percentage

Confirmatory Unit 1 (CU1) consists of Survey Units B-1, B-2, B-4, B-5 and B-6

- Beta floor, lower wall and ceiling scan coverage ~ 80%
- Gamma floor scan coverage ~ 80%
- Gamma lower wall scan coverage ~ 50%

Confirmatory Unit 2 (CU2) consists of a portion of Survey Unit B-3

- Beta floor, lower wall and ceiling scan coverage ~ 80%
- Gamma floor scan coverage ~ 80%
- Gamma lower wall scan coverage ~ 50%

ORAU

Ford Nuclear Reactor
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Ann Arbor, Michigan

Basement Scans and Confirmatory Units

Fig. A-2. Ford Nuclear Reactor, Basement Confirmatory Units and Scan Coverage

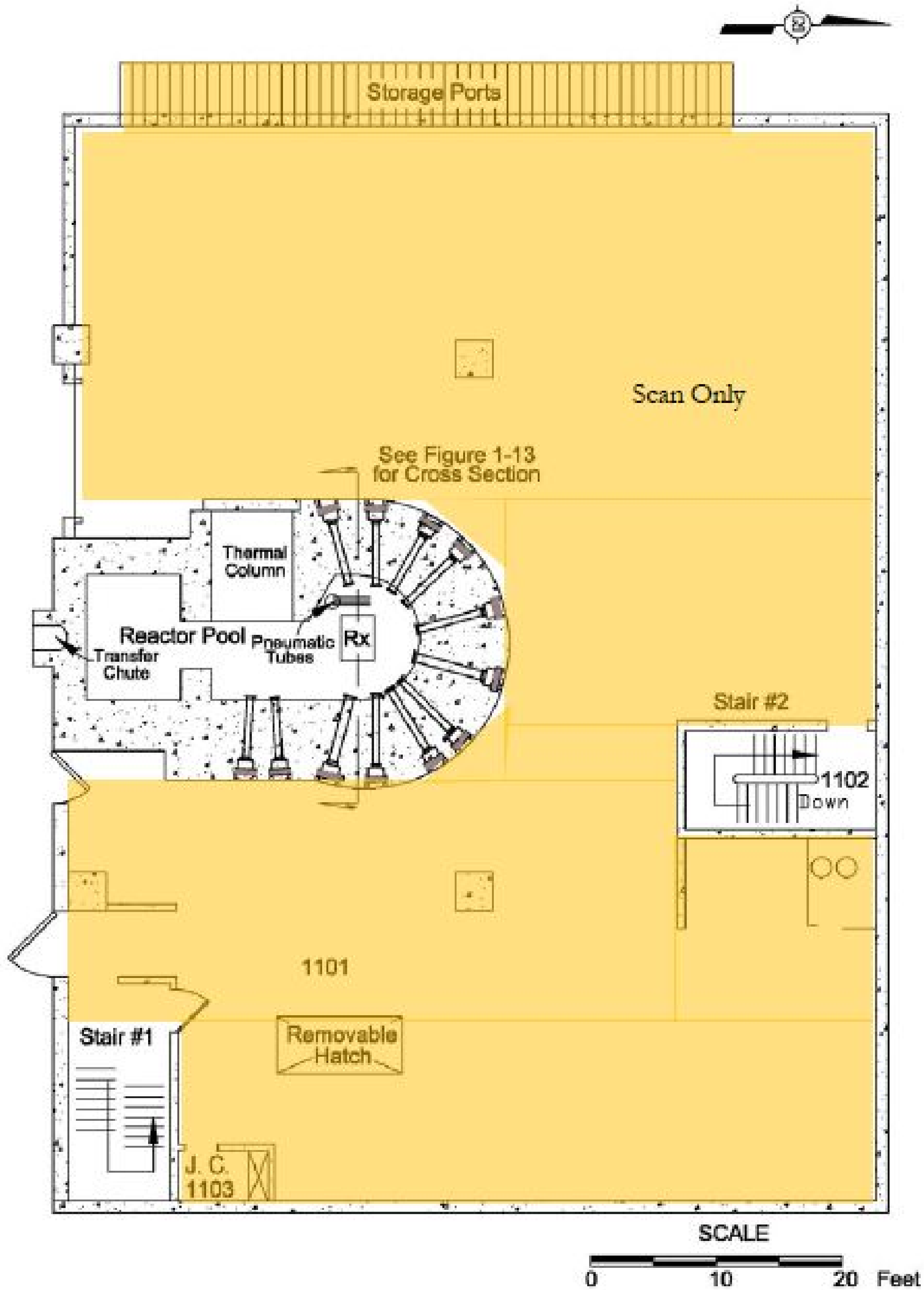

Figure provided by University of Michigan

Scan Coverage Percentage
Beta floor and lower wall scan coverage ~ 80%
Gamma floor scan coverage ~ 80%
Gamma lower wall scan coverage ~ 50%

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1st Floor Scan Coverage

Fig. A-3. Ford Nuclear Reactor, First Floor Scan Coverage

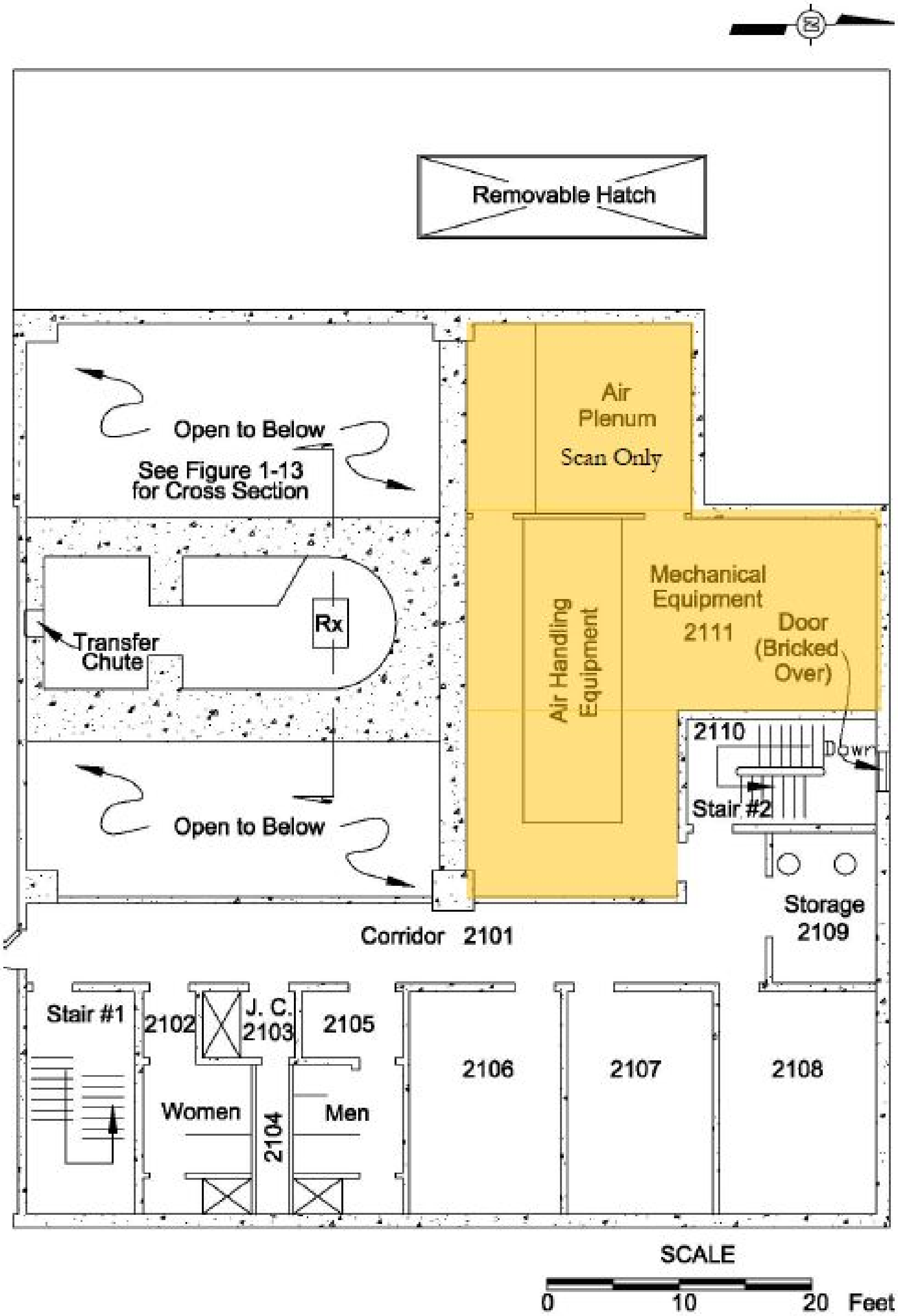

Figure provided by University of Michigan

Scan Coverage Percentage
Beta floor and exhaust plenum scan coverage ~ 80%
Gamma floor scan coverage ~ 80%

ORAU

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University of Michigan
Ann Arbor, Michigan

2nd Floor Scan Coverage

Fig. A-4. Ford Nuclear Reactor, Second Floor Scan Coverage

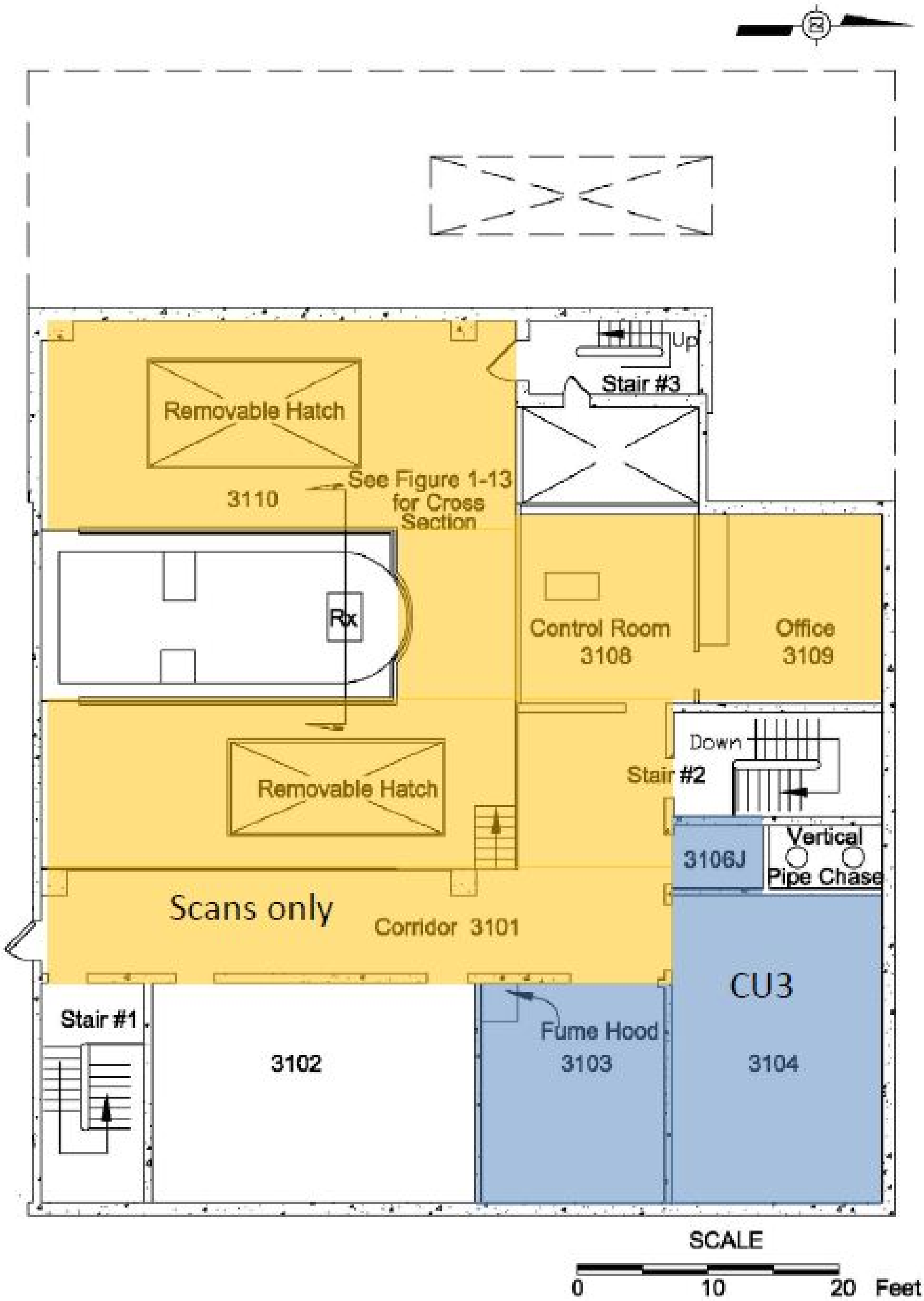

Figure provided by University of Michigan

Scan Coverage Percentage

Confirmatory Unit 3 (CU3) consists of Survey Units 3-3, 3-4, 3-5. 3-6, 3-7 and 3-8 (in Rooms 3103, 3104 and 3105J)

Beta floor and lower wall scan coverage ~ 80%

Gamma floor scan coverage ~ 80%

Gamma lower wall scan coverage ~ 50%

Remaining Areas

Beta floor and lower wall scan coverage ~ 80%

Gamma floor scan coverage ~ 80%

Gamma lower wall scan coverage ~ 50%

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Ann Arbor, Michigan

3rd Floor Scan Coverage

Fig. A-5. Ford Nuclear Reactor, Third Floor Scan Coverage

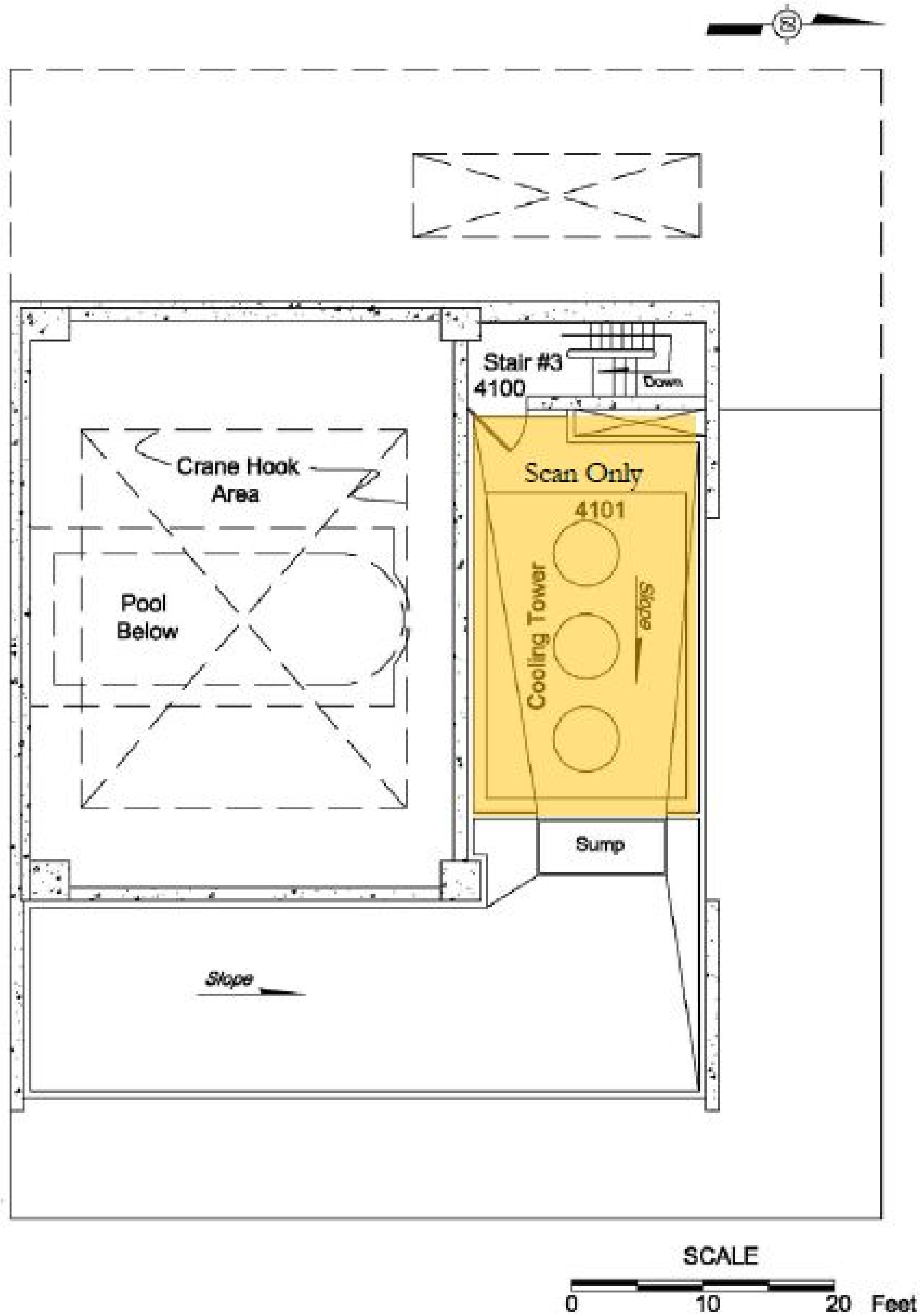

Figure provided by University of Michigan

Scan Coverage Percentage
Cooling Tower

Beta floor and tresses scan coverage ~ 80%
Gamma floor scan coverage ~ 80%
Gamma tresses scan coverage ~ 50%

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Ann Arbor, Michigan

Cooling Tower Scan Coverage

Fig. A-6. Ford Nuclear Reactor, Cooling Tower Scan Coverage

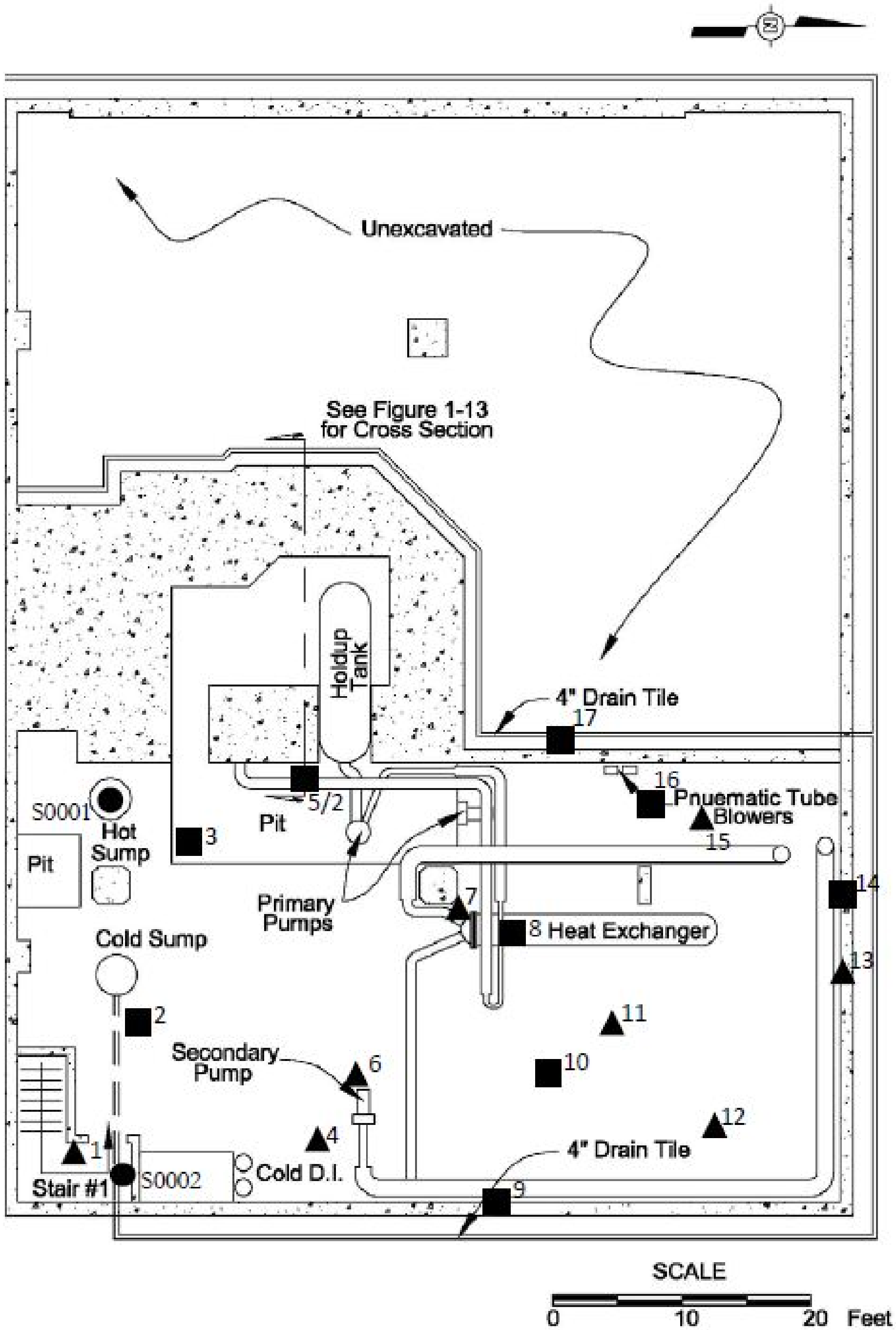

Figure provided by University of Michigan

Direct Measurement and Soil Sample Locations

- ■ #Direct Measurement/#Smear – Lower Walls and Floor
- ▲ #Direct Measurement/#Smear – Upper Walls and Ceiling
- ● S000# Soil Sample Location

Ford Nuclear Reactor
University of Michigan
Ann Arbor, Michigan

CU 1 Direct Measurement and Soil Sample Locations

Fig. A-7. Ford Nuclear Reactor, Confirmatory Unit 1 Direct Measurement and Soil Sample Locations

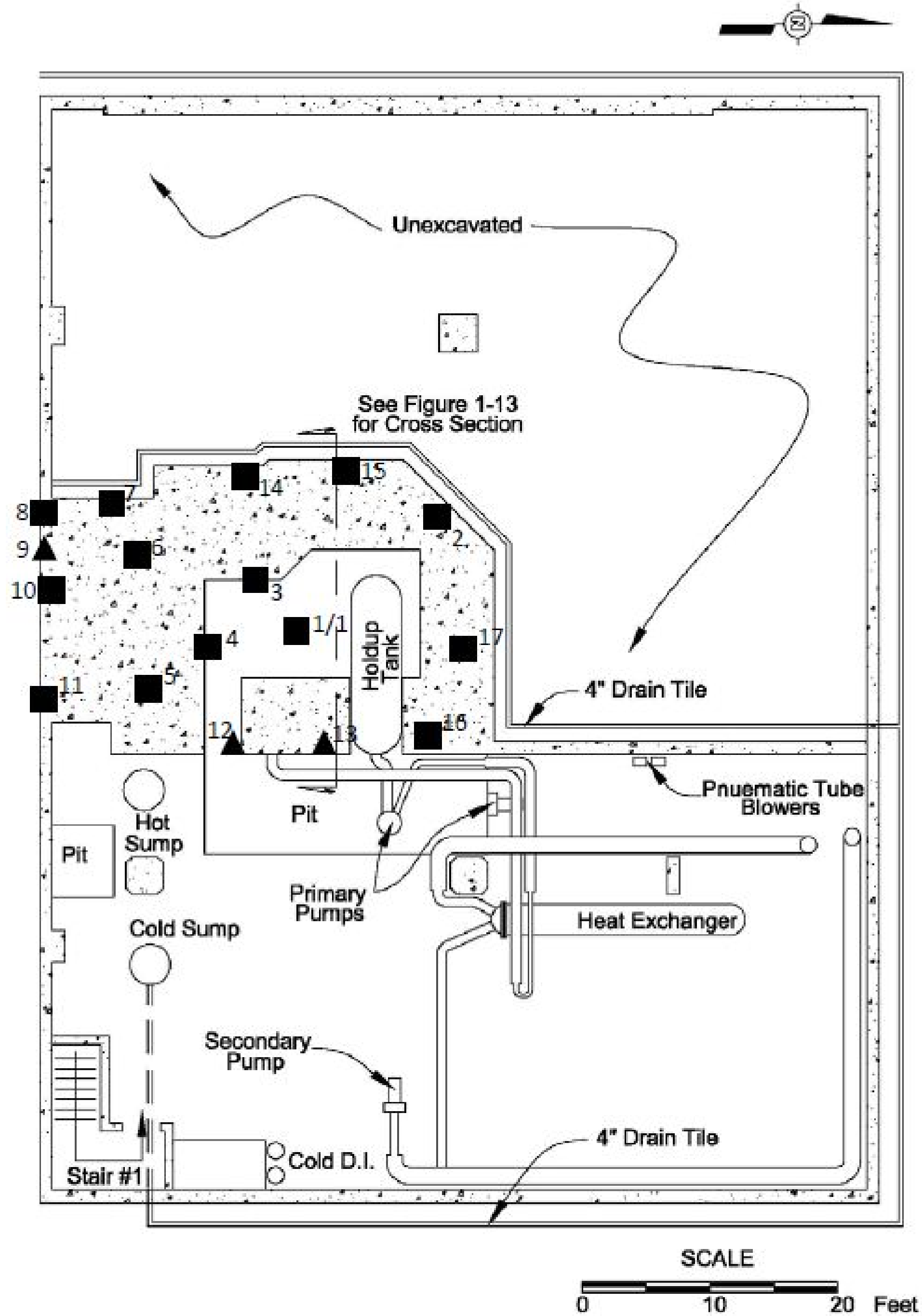

Figure provided by University of Michigan

Direct Measurement Locations

■ #Direct Measurement/#Smear – Lower Walls and Floor

▲ #Direct Measurement/#Smear – Upper Walls and Ceiling

Ford Nuclear Reactor
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Ann Arbor, Michigan

CU 2 Direct
Measurement Locations

Fig. A-8. Ford Nuclear Reactor, Confirmatory Unit 2 Direct Measurement Locations

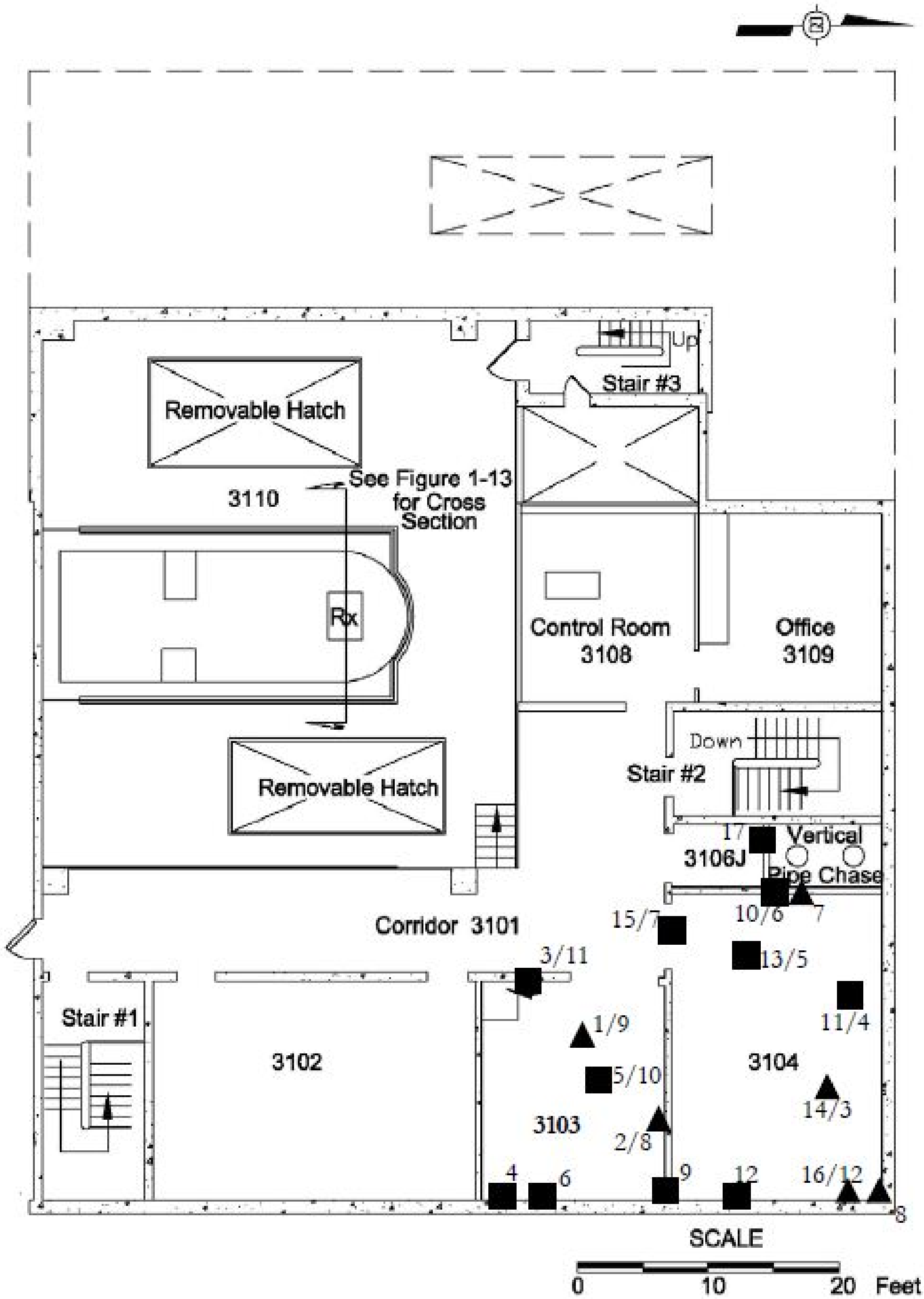


Figure provided by University of Michigan

Direct Measurement Locations

■ #Direct Measurement/#Smear – Lower Walls and Floor

▲ #Direct Measurement/#Smear – Upper Walls and Ceiling

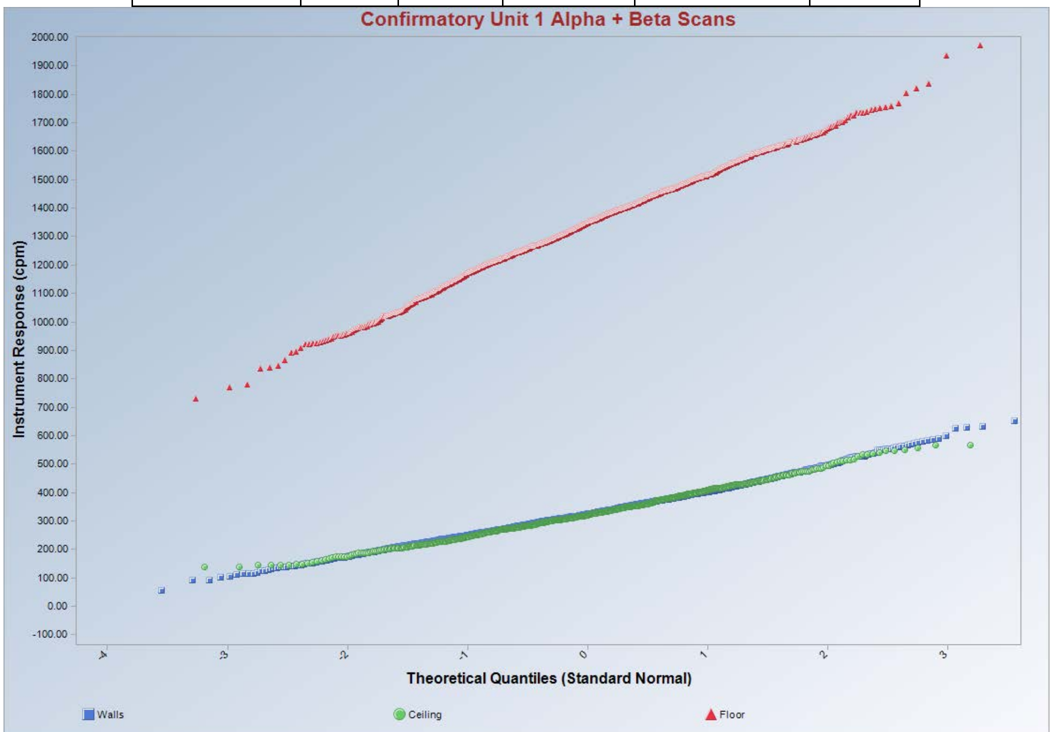
Ford Nuclear Reactor
University of Michigan
Ann Arbor, Michigan

CU 3 Direct Measurement Locations

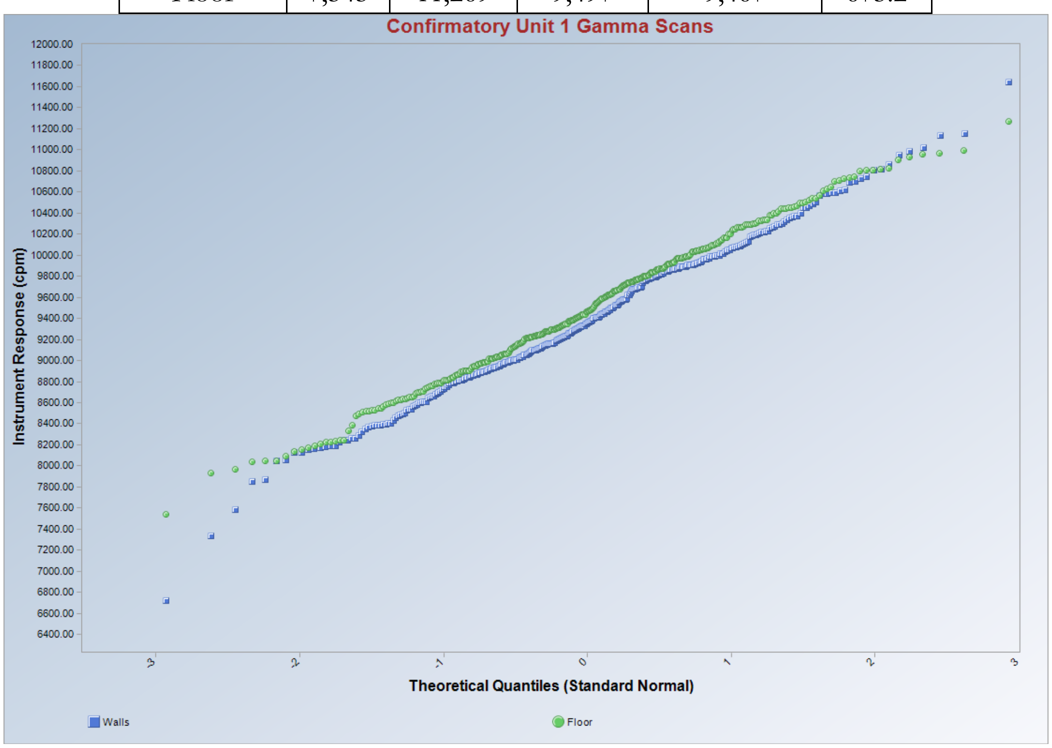
Fig. A-9. Ford Nuclear Reactor, Confirmatory Unit 3 Direct Measurement Locations

APPENDIX B
SCAN RESULTS

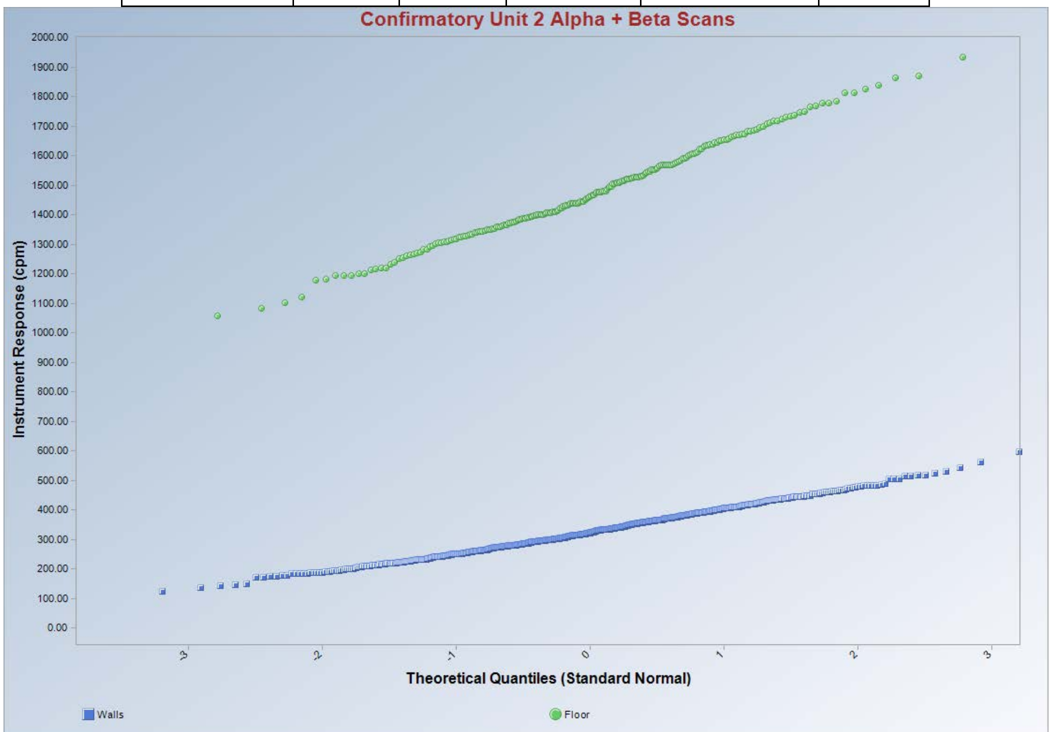
Confirmatory Unit 1 Beta Scan Summary Statistics					
Surface	**Min**	**Max**	**Mean**	**Median**	**SD**
Walls	57	654	328	325	78.86
Ceiling	138	568	326	321	79.48
Floor	732	1,975	1,343	1,351	179.7



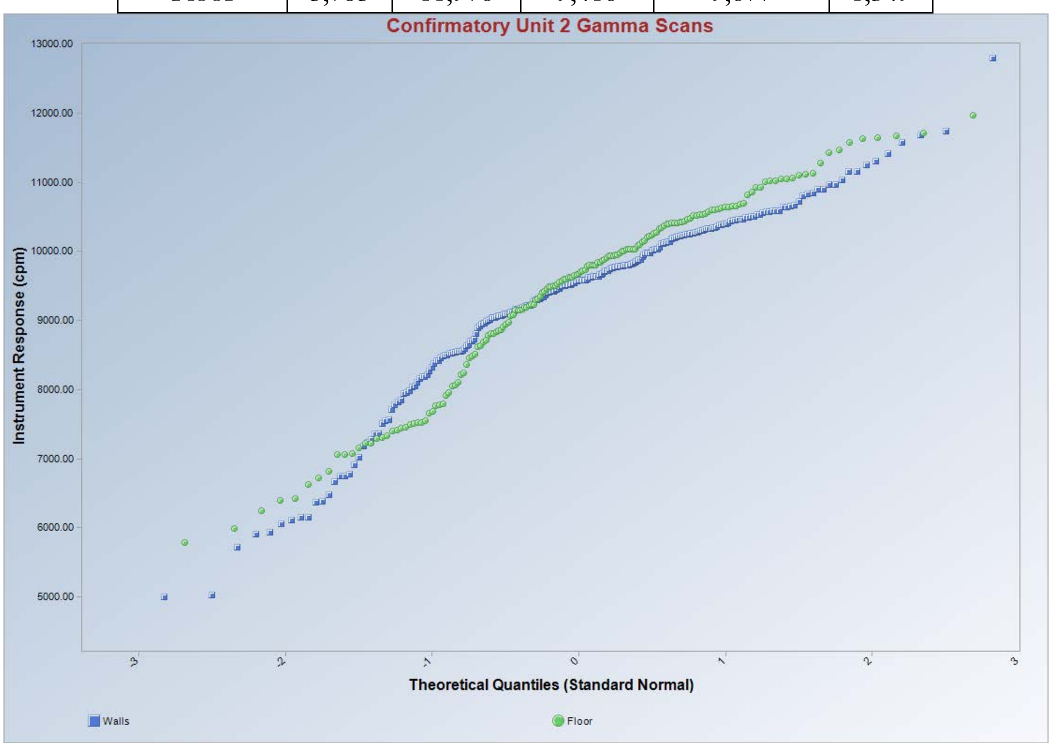
Confirmatory Unit 1 Gamma Scan Summary Statistics					
Surface	**Min**	**Max**	**Mean**	**Median**	**SD**
Walls	6,725	11,647	9,393	9,360	700.1
Floor	7,545	11,269	9,497	9,467	675.2



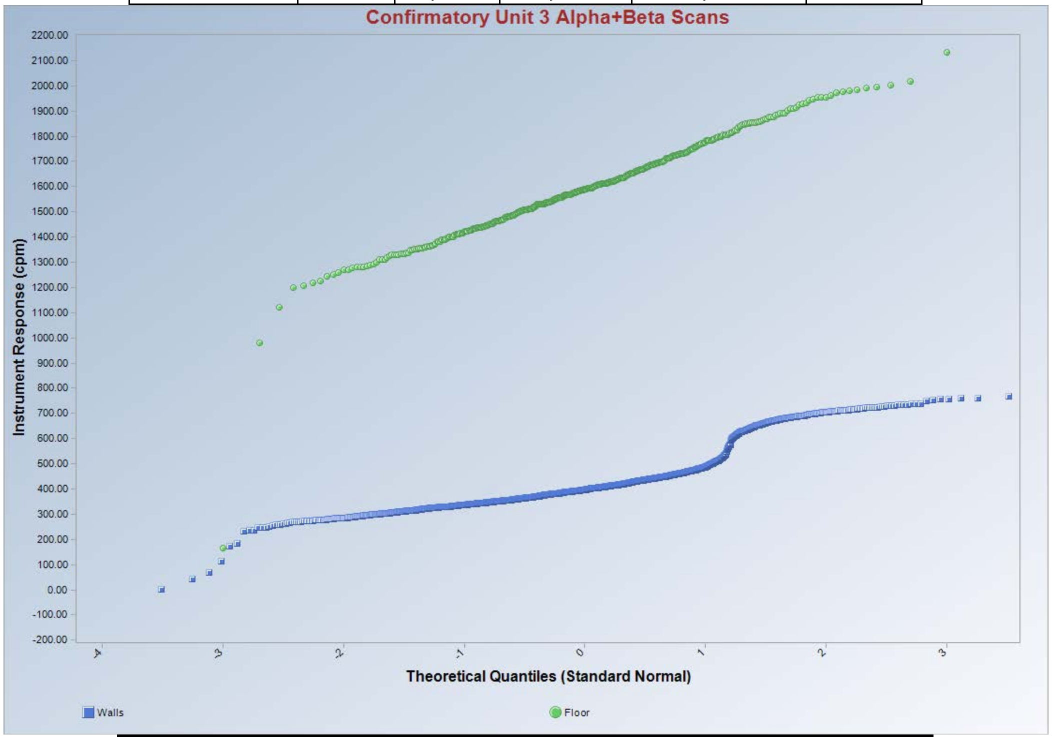
Confirmatory Unit 2 Beta Scan Summary Statistics					
Surface	**Min**	**Max**	**Mean**	**Median**	**SD**
Walls	125	599	327.8	324.5	74.57
Floor	1,057	1,932	1,476	1,463	164.9



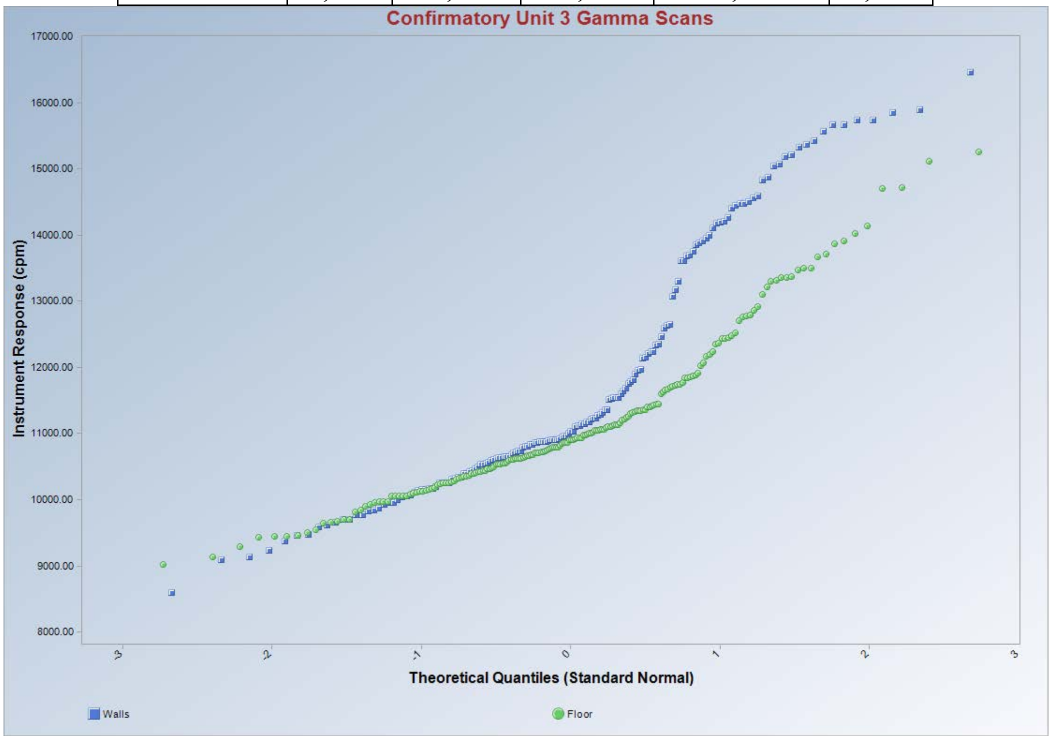
Confirmatory Unit 2 Gamma Scan Summary Statistics					
Surface	**Min**	**Max**	**Mean**	**Median**	**SD**
Walls	4,998	12,803	9,353	9,578	1,231
Floor	5,785	11,976	9,416	9,677	1,349



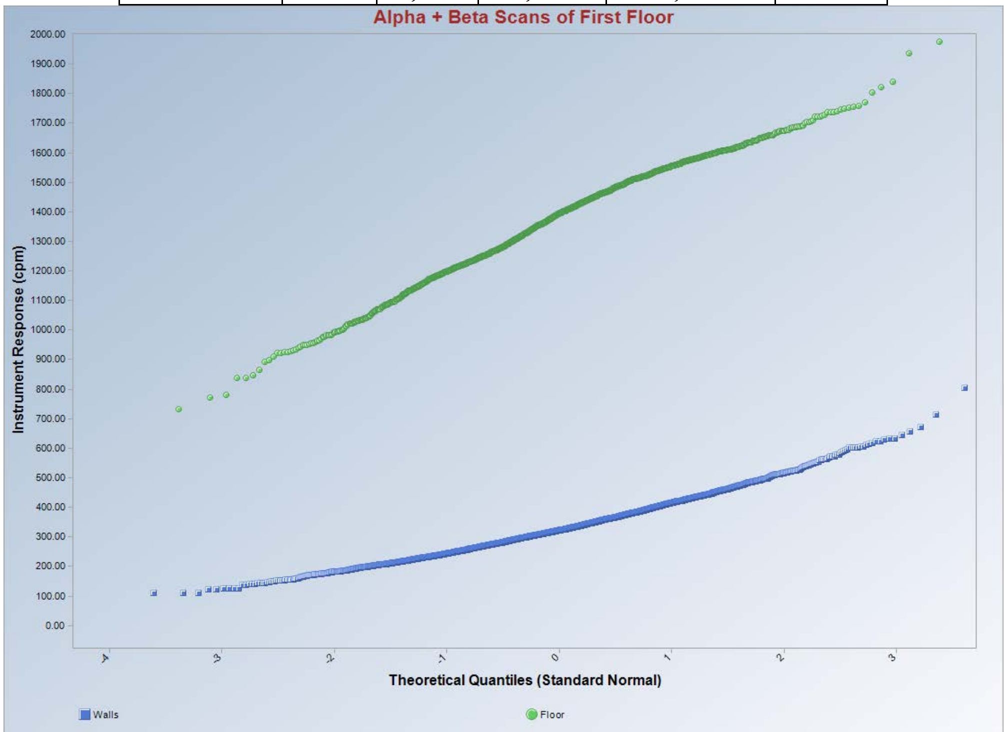
Confirmatory Unit 3 Beta Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	3	768	422.4	397	105.9
Floor	167	2,133	1,592	1,590	186.3



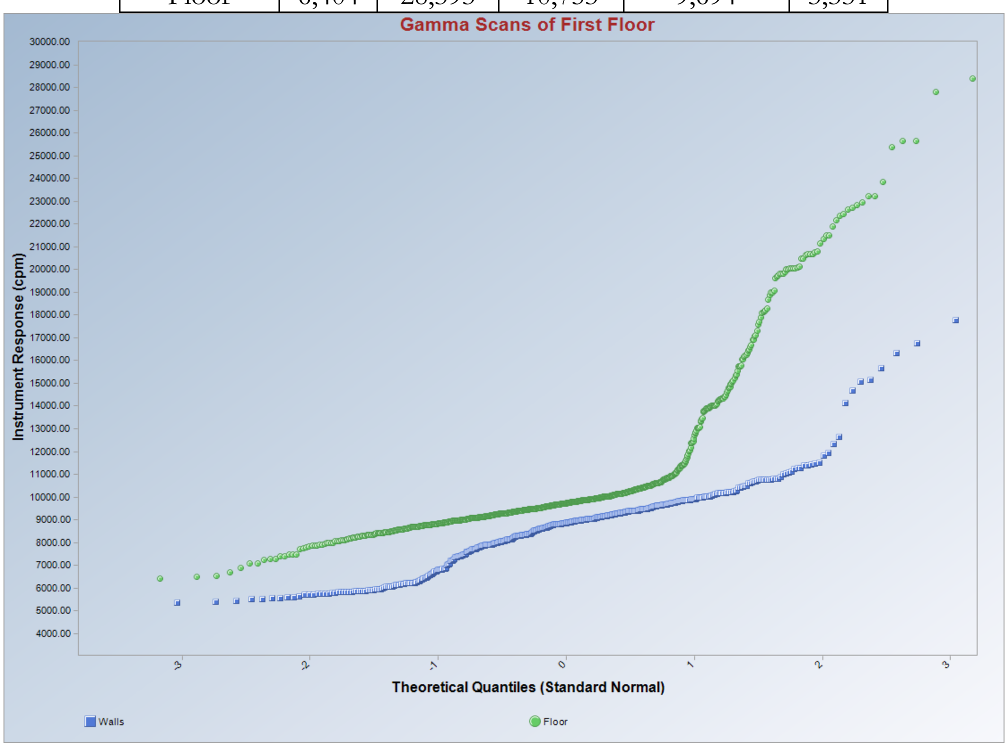
Confirmatory Unit 3 Gamma Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	8,604	16,462	11,739	11,029	1,851
Floor	9,019	15,255	11,169	10,909	1,203



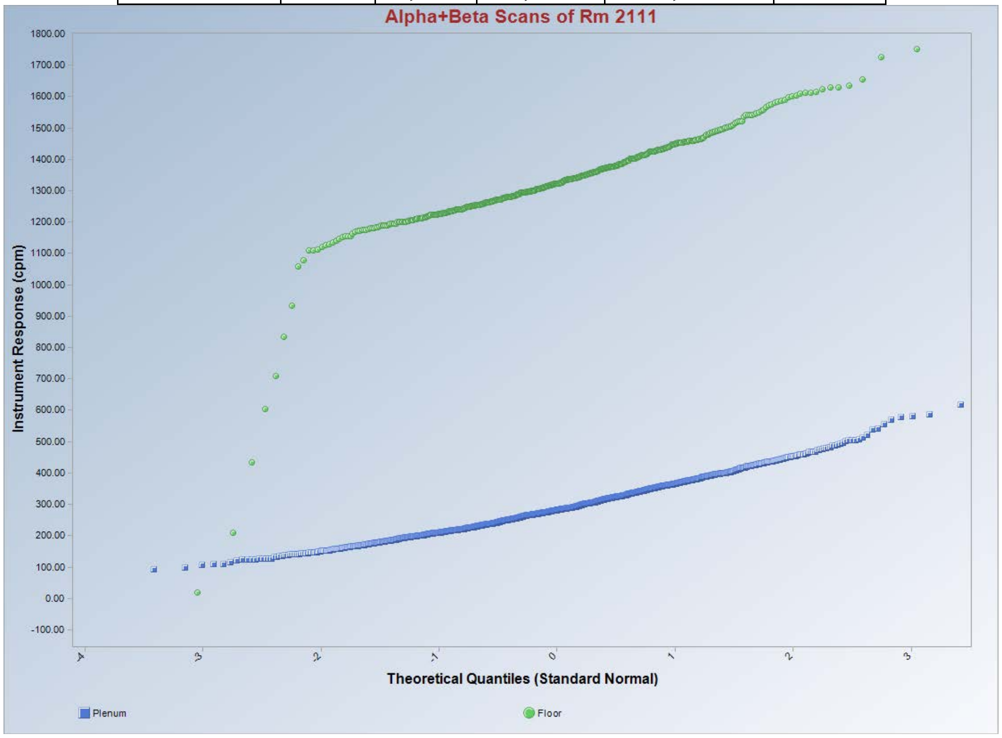
First Floor Beta Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	110	805	329.9	323	85.14
Floor	732	1,975	1,372	1,388	176.7



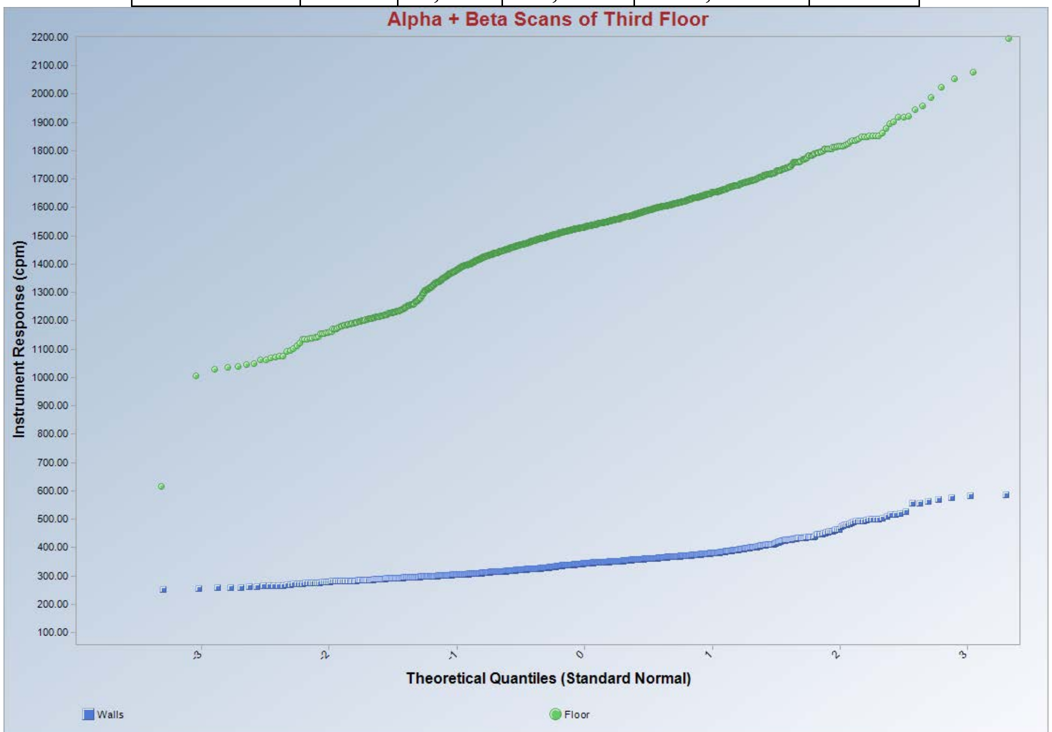
First Floor Gamma Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	5,354	17,795	8,623	8,816	1,734
Floor	6,404	28,393	10,753	9,694	3,331



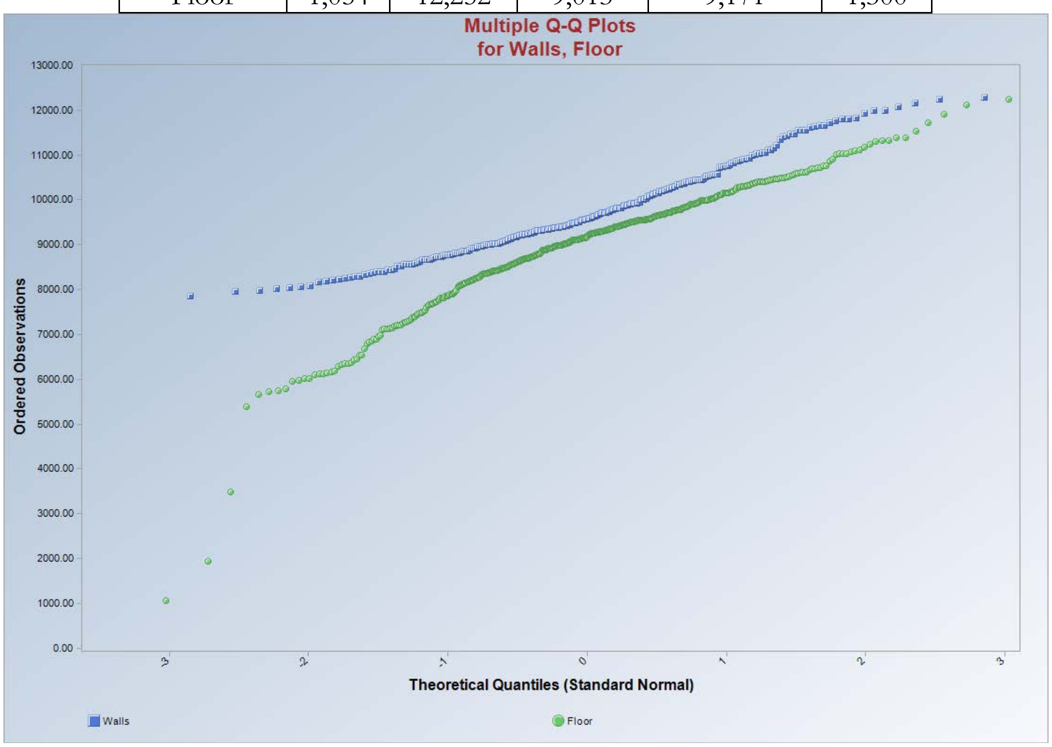
Rm 2111 Beta Scan Summary Statistics					
Surface	**Min**	**Max**	**Mean**	**Median**	**SD**
Plenum	92	619	288	282	77.5
Floor	19	1,751	1,327	1,322	146.6



Third Floor Beta Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	252	586	347.1	344	45.63
Floor	616	2,196	1,517	1,531	158.5

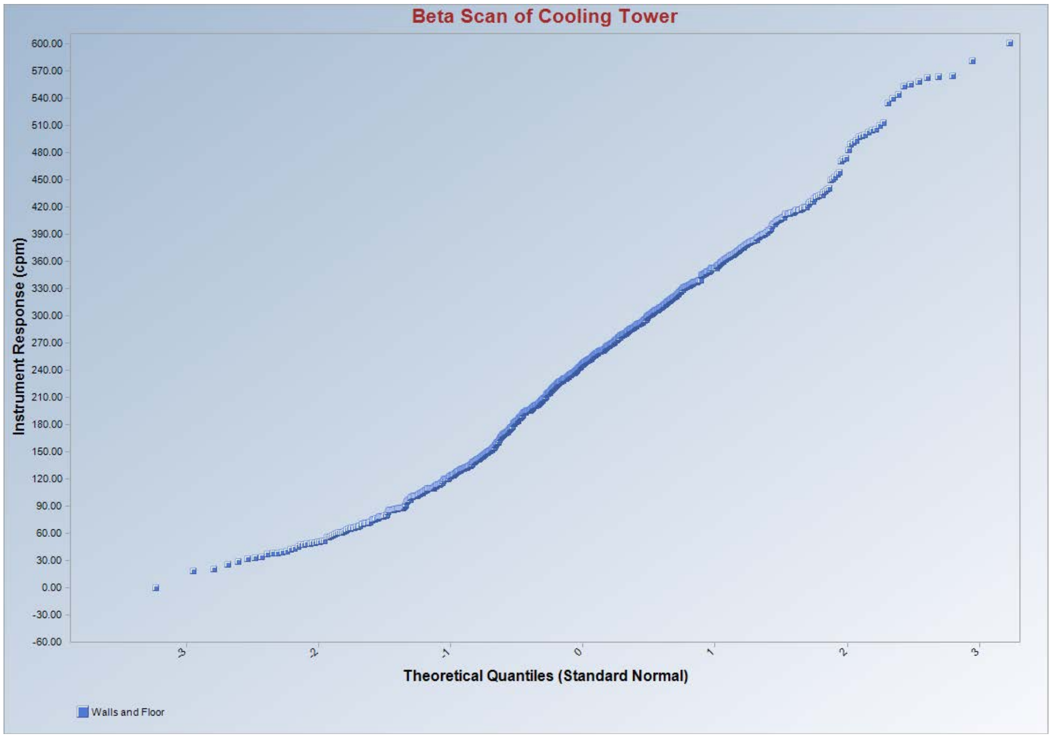


Third Floor Gamma Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Walls	7,862	12,289	9,732	9,576	969.1
Floor	1,054	12,252	9,013	9,171	1,300

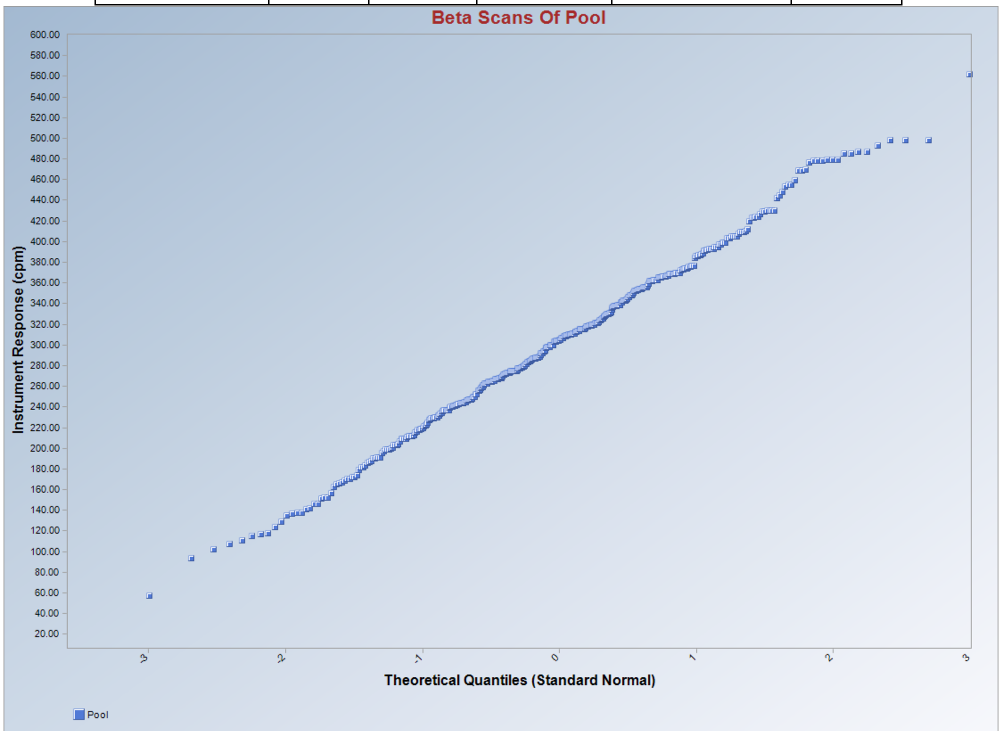


Cooling Tower Beta Scan Summary Statistics[a]					
Surface	Min	Max	Mean	Median	SD
Walls and Floor	0	601	243.8	247	109.4

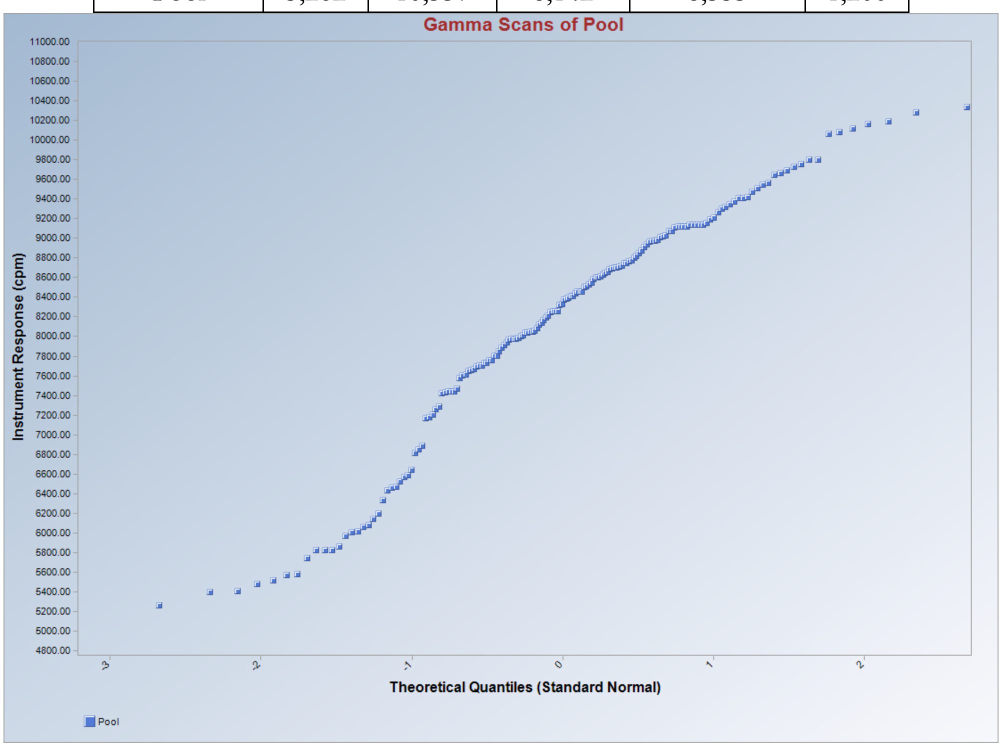
[a]Technician also performed gamma scans of this area but due to an electronic issue the data was not recorded. No contamination was identified by the technician. Scans could not be redone due to time constraints.



Pool Beta Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Pool	57	562	303.1	305	83.66



Pool Gamma Scan Summary Statistics					
Surface	Min	Max	Mean	Median	SD
Pool	5,262	10,337	8,142	8,353	1,200



APPENDIX C
TABLES

Table C-1. Confirmatory Unit 1 Surface Activity			
Location	Surface	Gross	Total Surface Activity (dpm/100 cm^2)
1	Ceiling	321	-200
2	Floor	380	130
3	Floor	376	110
4	Ceiling	335	-120
5	Floor	405	270[a]
6	Ceiling	343	-79
7	Ceiling	357	0
8	Floor	385	160
9	Wall 3	375	100
10	Floor	374	96
11	Ceiling	341	-91
12	Ceiling	365	45
13	Ceiling	390	190
14	Wall 2	291	-370
15	Ceiling	338	-110
16	Floor	364	40
17	Wall 1	358	6
Mean			10

[a]Removable surface activity was -2 dpm/100 cm^2

Table C-2. Confirmatory Unit 2 Surface Activity			
Location	Surface	Gross	Total Surface Activity (dpm/100 cm^2)
1	Floor	435	300[a]
2	Floor	352	-170
3	Floor	360	-120
4	Floor	380	-11
5	Floor	400	100
6	Floor	327	-310
7	Floor	331	-290
8	Wall 4	341	-230
9	Wall 4	321	-350
10	Wall 4	333	-280
11	Wall 4	364	-100
12	Wall 3	342	-230
13	Wall 3	344	-220
14	Floor	368	-79
15	Wall 1	366	-91
16	Wall 3	376	-34
17	Floor	274	-610
Mean			-160

[a]Removable activity was -1 dpm/100 cm^2

Table C-3. Confirmatory Unit 3 Surface Activity				
Location	Surface	Gross	Surface Activity (dpm/100 cm^2)	
			Total	Removable
1	Ceiling	395	220	2
2	Ceiling	415	330	1
3	Wall 1	464	610	-3
4	Wall 3	373	91	—[a]
5	Floor	393	200	—
6	Wall 3	376	110	—
7	Wall 1	372	85	—
8	Wall 2	381	140	—
9	Wall 4	386	160	—
10	Wall 1	409	290	-3
11	Floor	398	230	-4
12	Wall 3	333	-140	—
13	Floor	416	330	-1
14	Ceiling	412	310	2
15	Wall 4	406	280	-3
16	Wall 3	351	-34	—
17	Wall 2	680	-40	-1
Mean			187	

[a]Smear sample for removable activity was not collected

Table C-4. Inter-Laboratory Comparison of Soil Samples															
Sample ID		Ag-108m (pCi/g)						DER[a]	Ag-110m (pCi/g)						DER
ORAU	UM	ORAU			UM				ORAU			UM			
5176S0003	FNR-SOIL-2-007	0.02	±	0.01[b]	0.0305	±	0.0146[c]	*1.2*	0.02	±	0.02	0.00928	±	0.0182	*0.8*
5176S0004	FNR-SOIL-2-008	0.92	±	0.07	0.889	±	0.0354	*0.8*	-0.02	±	0.03	0.00871	±	0.0289	*1.4*
5176S0005	FNR-SOIL-2-009	0.02	±	0.02	0.0169	±	0.00947	*0.3*	-0.02	±	0.03	0.00357	±	0.0111	*1.4*
5176S0006	FNR-SOIL-2-013	0.02	±	0.02	-0.00280	±	0.0166	*1.7*	-0.02	±	0.03	-0.00303	±	0.0196	*0.9*
5176S0007	FNR-SOIL-2-014	0.00	±	0.02	0.0182	±	0.0196	*1.3*	0.00	±	0.02	0.00580	±	0.0262	*0.3*
Sample ID		Co-60 (pCi/g)						DER	Cs-137 (pCi/g)						DER
ORAU	UM	ORAU			UM				ORAU			UM			
5176S0003	FNR-SOIL-2-007	0.03	±	0.02	0.0383	±	0.0252	*0.5*	0.00	±	0.02	-0.00607	±	0.0202	*0.4*
5176S0004	FNR-SOIL-2-008	0.37	±	0.04	0.313	±	0.0403	*2.0*	0.05	±	0.02	0.0123	±	0.0341	*1.9*
5176S0005	FNR-SOIL-2-009	1.79	±	0.12	1.54	±	0.0602	*3.6*	-0.01	±	0.03	0.000233	±	0.0125	*0.6*
5176S0006	FNR-SOIL-2-013	0.30	±	0.04	0.282	±	0.0383	*0.6*	0.00	±	0.02	-0.0146	±	0.0227	*0.9*
5176S0007	FNR-SOIL-2-014	0.45	±	0.05	0.374	±	0.0488	*2.1*	0.01	±	0.02	0.000816	±	0.0277	*0.5*

[a]DER = normalized absolute difference (refer to page 11 for explanation). A DER less than 3, indicates that the results are in agreement at the 99% confidence level.
[b]Errors represent the total propagated uncertainties at the 95% confidence level
[c]Errors are reported at the 95% confidence level

Table C-5. SOFs for Soil Samples Submitted for Inter-Laboratory Comparison			
Sample ID		**SOF[a]**	
ORAU	**UM**	**ORAU**	**UM**
5176S0003	FNR-SOIL-2-007	0.01	0.02
5176S0004	FNR-SOIL-2-008	0.21	0.19
5176S0005	FNR-SOIL-2-009	0.47	0.41
5176S0006	FNR-SOIL-2-013	0.08	0.07
5176S0007	FNR-SOIL-2-014	0.12	0.10

[a]Negative values were not included in the SOF calculation

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 ORAU SCANNING AND MEASUREMENT INSTRUMENT/DETECTOR COMBINATIONS

D.1.1 GAMMA

Ludlum NaI Scintillation Detector Model 44-10, Crystal: 5.1 cm × 5.1 cm
(Ludlum Measurements, Inc., Sweetwater, TX)
coupled to:
Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, TX)
coupled to:
Trimble Data Logger (Trimble Navigation Limited, Sunnyvale, CA)

D.1.2 BETA

Ludlum Gas Proportional Detector Model 43-68, 126 cm^2 physical area
coupled to:
Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, TX)
coupled to:
Trimble Data Logger (Trimble Navigation Limited, Sunnyvale, CA)

Ludlum Gas Proportional Detector Model 43-37, 582 cm^2 physical area
coupled to:
Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, TX)
coupled to:
Trimble Data Logger (Trimble Navigation Limited, Sunnyvale, CA)

D.2 ORAU LABORATORY ANALYTICAL INSTRUMENTATION

High-Purity, Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195
(Canberra, Meriden, CT)
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, CT)

High-Purity, Intrinsic Detector
Model No. GMX-45200-5
CANBERRA Model No: GC4020
(Canberra, Meriden, CT)
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, CT)

APPENDIX E
SURVEY AND ANALYTICAL PROCEDURES

E.1 PROJECT HEALTH AND SAFETY

The proposed survey and sampling procedures were evaluated to ensure that any hazards inherent to the procedures themselves were addressed in current job hazard analyses. All survey activities performed by ORAU were conducted in accordance with ORAU health and safety and radiation protection procedures (ORAU 2012c; ORAU/ORISE 2011).

Pre-survey activities included the evaluation and identification of potential health and safety issues. Survey work was performed per the ORAU generic health and safety plans and a site-specific Integrated Safety Management (ISM) pre-job hazard checklist.

E.2 CALIBRATION AND QUALITY ASSURANCE

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

Field survey activities were conducted in accordance with procedures from the following Independent Environmental Assessment and Verification Program documents:

- Survey Procedures Manual (ORAU/ORISE 2013a)
- Laboratory Procedures Manual (ORAU/ORISE 2013b)
- Quality Program Manual (ORAU 2012b)

The procedures contained in these manuals were developed to meet the requirements of U.S. Department of Energy Order 414.1D.

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations
- Training and certification of all individuals performing procedures
- Periodic internal audits

E.3 SURVEY PROCEDURES

E.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. Specific scan minimum detectable concentration (MDCs) for the scintillation detectors (NaI and CsI) were not determined as the instruments were used solely as a qualitative means to identify elevated gamma radiation levels in excess of background. Identifications of elevated radiation levels that could exceed the site criteria were determined based on an increase in the audible signal from the indicating instrument.

Beta scans were performed using small, hand-held gas proportional detectors with a 0.8 mg/cm^{-2} window. Identification of elevated radiation levels was based on increases in the audible signal from the indicating instrument. Beta surface scan MDCs were estimated using the approach described in NUREG-1507 (NRC 1998). The scan MDC is a function of many variables, including the background level. Additional parameters selected for the calculation of scan MDCs included a two-second observation interval, a specified level of performance at the first scanning stage of 90% true positive and 25% false positive rate, which yields a d' value of 1.96 (NUREG-1507, Table 6.1), and a surveyor efficiency of 0.5. The beta total weighted efficiency was 0.14. The average concrete background for the detectors was around 390 counts per minute (cpm). The minimum detectable count rate (MDCR) and scan MDC was calculated as:

$$B_i = (390)(2\ s)(1\ min/60\ s) = 13\ counts$$

$$MDCR = (1.96)(13\ counts)^{1/2}[(60\ s/min)/2s] = 212\ cpm$$

$$MDCR_{surveyor} = 212/(0.5)^{1/2} = 300\ cpm$$

$$Scan\ MDC = (300)/(0.14*1.26) = 1{,}700\ dpm/100\ cm^2$$

E.3.2 SURFACE ACTIVITY MEASUREMENTS

Measurements of gross beta surface activity levels were performed using hand-held gas proportional detectors coupled to portable ratemeter-scalers. Count rates (cpm), which were integrated over one minute with the detector held in a static position, were converted to activity levels ($dpm/100\ cm^2$) by dividing the count rate by the total static efficiency ($\varepsilon_i \times \varepsilon_s$) and correcting for the physical area of the detector. The gross beta efficiency was 0.14 (calibrated with Tc-99). ORAU determined construction material-specific background for each surface type encountered for determining net count rates. However, the material-specific background was used for the sole purpose of determining an *a prior* static MDC. The *a priori* MDC for beta activity is given by:

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

Where:

B	=	background
ε_{tot}	=	total efficiency
G	=	geometry correction factor (1.26)

The *a priori* static MDC for concrete at the FNR was 540 dpm/100 cm^2.

E.3.3 SOIL SAMPLING

Approximately 0.5 to 1 kg of soil was collected at each sample location. Collected samples were placed in a plastic bag, sealed, and labeled in accordance with ORAU/ORISE survey procedures. The judgmental soil samples were collected as individual samples from areas of elevated gamma radiation based on gamma scans.

E.4 RADIOLOGICAL ANALYSIS

E.4.1 GAMMA SPECTROSCOPY

Samples of soil were dried, mixed, crushed, and/or homogenized as necessary, and a portion sealed in a 0.5-liter Marinelli beaker or other appropriate container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights and volumes were determined and the samples counted using intrinsic 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) that were associated with the radionuclides of concern were reviewed for consistency of activity. TAPs used for determining the activities of the radionuclides of concern and the typical associated MDCs for a four-hour count time were as follows.

Radionuclide	TAP[a] (MeV)	MDC (pCi/g)
Co-60	1.173	0.06
Cs-137	0.662	0.05
Ag-108m	0.434	0.04
Ag-110m	0.658	0.04

[a]Spectra were also reviewed for other identifiable TAPs that would not be expected at this site.

E.5 UNCERTAINTIES

The uncertainties associated with the analytical data presented in the tables of this report represent the total propagated uncertainties for that data. These uncertainties were calculated based on both the gross sample count levels and the associated background count levels.

E.6 DETECTION LIMITS

Detection limits, referred to as MDCs, were based on 95% confidence level via NUREG-1507 method. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument.