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November 26, 2019

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**SUBJECT: DOE Contract No. DE-SC0014664
INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR
THE GENERAL ATOMICS TRIGA REACTOR FACILITY BUILDING G21 AND
ASSOCIATED LAND AREA, SAN DIEGO, CALIFORNIA
DOCKET NOs. 05000089 AND 05000163; RFTA NO. 19-005;
DCN 5339-SR-01-0**

Dear Ms. Doell:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the enclosed final report, which describes the procedures and results of the confirmatory survey of the General Atomics TRIGA Reactor Facility and associated land area. The U.S. Nuclear Regulatory Commission's (NRC's) comments on the draft report have been addressed in the final version.

You may contact me at 865.576.6659 or Kaitlin Engel at 865.574.7008 if you have any questions or require additional information.

Sincerely,

Erika N. Bailey
Survey and Technical Projects Group Manager
ORISE

ENB:tlb

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SUMMARY AND RESULTS FOR THE
GENERAL ATOMICS TRIGA REACTOR
FACILITY BUILDING G21 AND ASSOCIATED
LAND AREA, SAN DIEGO, CALIFORNIA**

**K. M. Engel
ORISE**

FINAL REPORT

**Prepared for the
U.S. Nuclear Regulatory Commission**

NOVEMBER 2019

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**Prepared by
K. M. Engel
ORISE**

NOVEMBER 2019

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U.S. Nuclear Regulatory Commission**

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS
FOR THE GENERAL ATOMICS TRIGA REACTOR FACILITY BUILDING G21
AND ASSOCIATED LAND AREA, SAN DIEGO, CALIFORNIA

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FINAL REPORT

NOVEMBER 2019



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ACRONYMS

| | |
|----------------|---|
| AA | alternative action |
| cm | centimeter |
| cpm | counts per minute |
| DCGL | derived concentration guideline level |
| dpm | disintegrations per minute |
| DQO | data quality objective |
| DS | decision statement |
| EMC | elevated measurement comparison |
| EPA | U.S. Environmental Protection Agency |
| FSS | final status survey |
| FSSP | final status survey plan |
| GA | General Atomics |
| GPS | global positioning system |
| HTD | hard-to-detect |
| m ² | square meter |
| MDC | minimum detectable concentration |
| NaI | sodium iodide |
| NIST | National Institute of Science and Technology |
| NORM | naturally occurring radioactive material |
| NRC | U.S. Nuclear Regulatory Commission |
| ORAU | Oak Ridge Associated Universities |
| ORISE | Oak Ridge Institute for Science and Education |
| pCi/g | picocurie per gram |
| PSQ | principal study question |
| ROC | radionuclide of concern |
| SOF | sum of fraction |
| SU | survey unit |
| TAP | total absorption peak |
| TPU | total propagated uncertainty |
| TRF | TRIGA Reactor Facility |
| TRIGA | Training, Research, Isotopes, General Atomics |
| VSP | Visual Sample Plan |



**INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS
FOR THE GENERAL ATOMICS TRIGA REACTOR FACILITY BUILDING G21
AND ASSOCIATED LAND AREA, SAN DIEGO, CALIFORNIA**

EXECUTIVE SUMMARY

In 1997, General Atomics ceased all operations related to the Training, Research, Isotopes, General Atomics (TRIGA) reactor at its main site on the Torrey Pines mesa in San Diego, California. The facility is currently undergoing decontamination and decommissioning for unrestricted release of the reactor pools and remaining reactor rooms, as well as the related structures, systems, and components (GA 2019).

The Oak Ridge Institute for Science and Education (ORISE) performed independent assessment activities during the period of August 5–8, 2019. Confirmatory survey activities included gamma surface scans, gamma direct measurements, alpha-plus-beta scans, alpha-plus-beta direct measurements, smear sampling, and soil/volumetric sampling within Building G21 and associated land area, as applicable. The areas investigated included the following survey units (SUs): Mark I reactor pit, Mark F reactor pit and canal, Mark I reactor room (floor and lower walls), Mark F reactor room (floors and lower walls), the soil lab, mezzanine 1, mezzanine 2, TRIGA waste yard, TRIGA front yard, TRIGA back yard, and room 112, as well as a small section of the roof. The U.S. Nuclear Regulatory Commission (NRC) was aware that some SUs were still in the process of final status survey (FSS) during the time of the ORISE survey but requested that ORISE proceed with independent assessment.

Gamma and alpha-plus-beta scans identified multiple areas of elevated direct radiation both inside and outside of Building G21. Based on the results of scanning, 62 locations were selected for direct measurements and smear sampling. At 16 of these locations, smear samples were collected for hard-to-detect (HTD) radionuclide analysis. Two volumetric concrete samples were collected for analysis at locations identified by ORISE based on scan results. Additionally, the NRC selected two of the licensee's archived FSS samples that were of interest to the NRC and directed ORISE to conduct independent laboratory analyses. Nine locations were selected for judgmental soil sampling and an additional 12 random soil samples were collected from the TRIGA back yard.



Eleven direct measurements exceeded the 5,000 disintegration per minute (dpm)/100 square centimeters (cm²) screening value; however, all removable activity measurements were below the 1,000 dpm/100 cm² screening value. All smear samples collected for HTD analyses were below the analytical minimum detectable concentrations (MDCs). The two volumetric concrete samples collected from the ORISE-identified locations each had a sum-of-fraction (SOF) result greater than 1. Each sample had cesium-137 (Cs-137) concentrations that exceeded the screening value of 11 picocuries per gram (pCi/g). Additionally, strontium-90 (Sr-90) was identified in these two samples above the analytical MDC. No individual concentrations within the soil samples exceeded their respective screening levels for the site-identified radionuclides of concern (ROCs) and all SOFs were less than 1.

While results of the confirmatory survey support the licensee's classification of the SUs, as the locations that exceeded the screening values were in Class 1 areas, several key issues were identified: surface activity measurements exceeded the screening value in a SU that had already received FSS, several other locations on structural surfaces exhibited contamination that exceeded the applicable screening value, Sr-90 was identified in two volumetric samples when Sr-90 was not identified as a ROC, and elevated radiation levels were identified on the TRIGA building roof although it was not listed as a SU. Based on results of the August 5-8, 2019 confirmatory survey, certain survey units associated with Building G21 were found to contain residual radioactivity in excess of NRC-approved decommissioning criteria. As a result, the radiological conditions, at the time of the confirmatory survey, cannot be confirmed to meet the established decommissioning criteria. Survey results are provided herein for NRC's evaluation.



INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE GENERAL ATOMICS TRIGA REACTOR FACILITY BUILDING G21 AND ASSOCIATED LAND AREA, SAN DIEGO, CALIFORNIA

1. INTRODUCTION

General Atomics (GA, the licensee) developed the Training, Research, Isotopes, General Atomics (TRIGA) class of research reactor, which was designed to be used in both industrial and academic applications. Between 1957 and 1966, three TRIGA reactors were constructed at the GA main site on the Torrey Pines mesa, also known as the TRIGA Reactor Facility (TRF), in San Diego, California. The three reactors were the TRIGA Mark I, Mark F, and Mark III. The Mark III reactor was shut down in 1972, decommissioned, and its license was terminated. Therefore, the Mark III was not within the scope of this confirmatory survey (GA 2019). The pool-type TRIGA Mark I reactor was operational from 1958 until 1997. It was licensed to operate at a power level of 250 kilowatts and could be rapidly pulsed to power levels of over 1,000 megawatts (NRC 2018a). The pool-type TRIGA Mark F reactor was operational from 1960 until 1995 and was designed to provide controlled instantaneous pulses of intense neutron and gamma radiation (NRC 2018b).

In 1997, GA ceased all remaining TRIGA reactor operations at the Torrey Pines facility. All irradiated fuel, activated and contaminated hardware, startup neutron sources, and balance of plant components associated with the Mark I and Mark F reactors have been removed from the facility. The two reactors were located in building G21 and currently are undergoing decontamination and decommissioning, with the goal of unrestricted release of the Mark I and Mark F reactor pools, reactor rooms, and other impacted areas within building G21 that supported reactor operations, as well as several exterior areas adjacent to the G21 building. This will allow termination of GA's U.S. Nuclear Regulatory Commission (NRC) reactor licenses R-38 and R-67 (GA 2019).

The NRC requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities within the impacted areas of the GA TRIGA site.

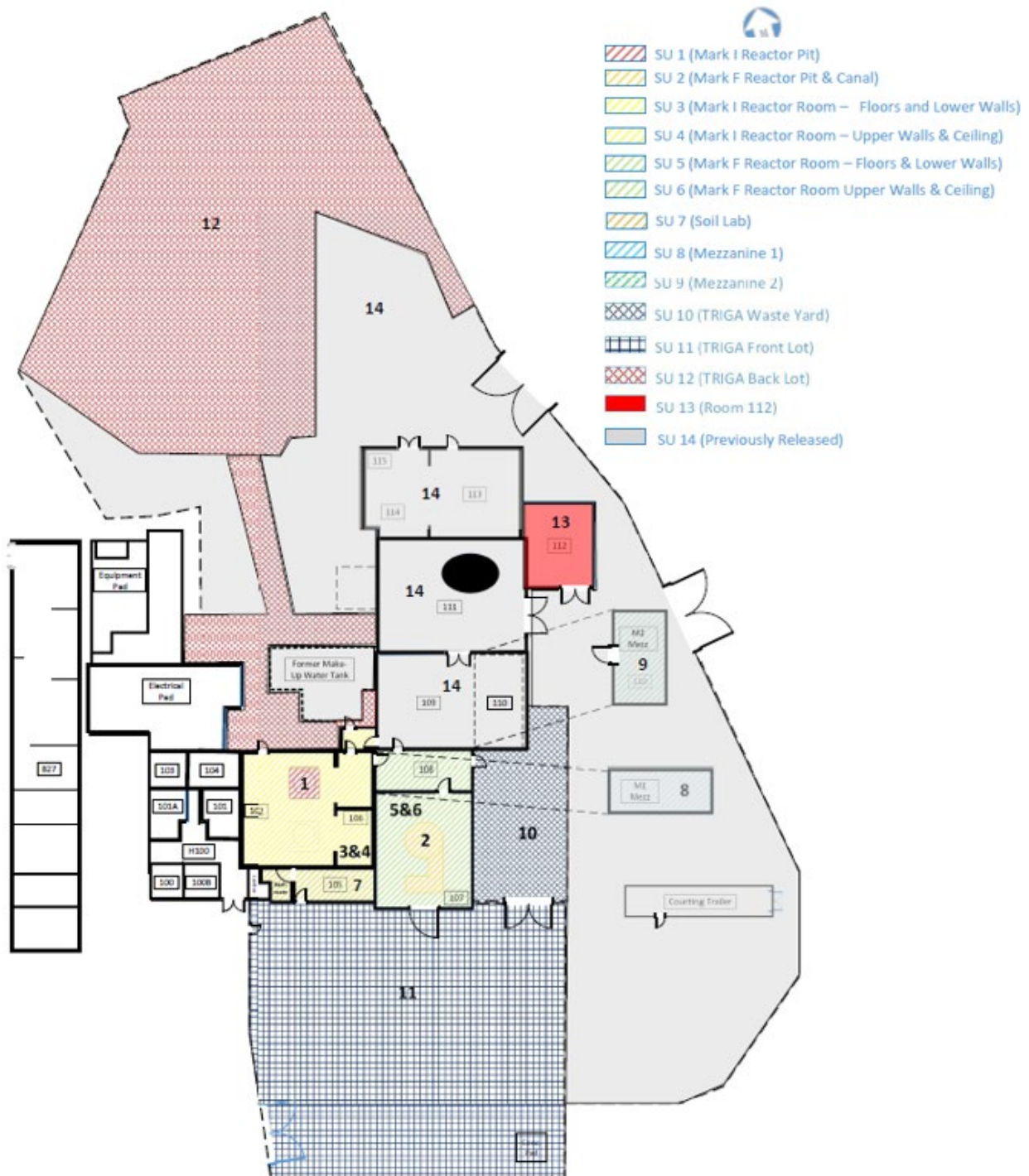


2. SITE DESCRIPTION

The TRIGA reactor facility is located 24 kilometers (15 miles) north of San Diego, California. Building G21 and the associated support facilities are located on a 120 hectare (295 acres) tract of land acquired by the General Dynamics Corporation (later General Atomics) from the city of San Diego in 1956. Figure 2.1 provides a site map of the TRF showing the delineation of the survey units (SUs) including the Mark I and Mark F reactor pits and impacted support rooms, as well as the associated land areas. There are 14 SUs associated with the TRF: nine Class 1 SUs, four Class 2 SUs, and one non-impacted SU (this area previously was approved for release) (GA 2019). Table 2.1 provides the SU descriptions and classifications.

| Table 2.1. TRIGA Building (G21) Survey Units and Classification (GA 2019) ^a | | | |
|--|---|---------------|------------------------|
| Survey Unit # | Description | Initial Class | Area (m ²) |
| 1 | Mark I Reactor Pit | 1 | 9.0 |
| 2 | Mark F Reactor Pit and Canal | 1 | 14.8 |
| 3 | Mark I Reactor Room (floors and lower walls) | 1 | 84.8 |
| 4 | Mark I Reactor Room (upper walls and ceiling) | 1 | 93.8 |
| 5 | Mark F Reactor Room (floors and lower walls) | 1 | 72.7 |
| 6 | Mark F Reactor Room (upper walls and ceiling) | 1 | 87.5 |
| 7 | Soil Lab | 1 | 27.4 |
| 8 | Mezzanine 1 | 1 | 23.6 |
| 9 | Mezzanine 2 | 2 | 30.6 |
| 10 | TRIGA Waste Yard | 1 | 117.7 |
| 11 | TRIGA Front Yard (asphalt) | 2 | 546 |
| 12 | TRIGA Back Yard (soil) | 2 | 886 |
| 13 | Room 112 | 2 | 36.47 |
| 14 | Non-Impacted Areas | Non-Impacted | 283.6 |

^a The roof was not listed as a SU in the *TRIGA Reactor Facility Final Status Survey Plan* (GA 2019).





3. DATA QUALITY OBJECTIVES

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

1. State the problem
2. Identify the decision
3. Identify inputs to the decision
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 defines the problem that necessitates the study. The licensee is requesting approval from the NRC for the unrestricted release of the TRIGA reactor pools, reactor rooms, and all impacted survey units noted in Table 2.1 that supported reactor operations. The NRC requested that ORISE perform confirmatory surveys to generate independent radiological data to assist the NRC in evaluating the licensee's final status survey (FSS) results. Therefore, the problem statement is as follows:

Confirmatory surveys are necessary to generate independent radiological data to assist the NRC with their assessment and determination of the adequacy of the FSS design, implementation, and results for demonstrating compliance with the release criteria.

3.2 IDENTIFY THE DECISION

The second step in the DQO process identifies the principal study questions (PSQs) and alternative actions (AAs), develops decision statements (DSs), and organizes multiple decisions, as appropriate. This was done by specifying AAs that could result from a "Yes" response to the PSQs and combining the PSQs and AAs into DSs. Table 3.1 presents the PSQs, AAs, and DSs for this survey effort.



Table 3.1. Confirmatory Survey Decision Process

| Principal Study Questions | Alternative Actions |
|---|--|
| PSQ1: Are residual radioactivity concentrations associated with the TRIGA Reactor Facility below applicable limits? | Yes: Compile confirmatory data and report results to the NRC for their decision making. Provide independent interpretation that confirmatory field surveys did not identify anomalous areas of residual radioactivity, that quantitative field and laboratory data satisfied the NRC-approved decommissioning criteria, and/or that statistical sample population examination/assessment conditions were met. No: Compile confirmatory data and report results to the NRC for their decision making. Provide independent interpretation of confirmatory survey results identifying any anomalous field or laboratory data and/or when statistical sample population examination/assessment conditions were not satisfied for the NRC's determination of the adequacy of the FSS data. |
| PSQ2: Do analytical results confirm the absence of fission and activation products not identified in the final status survey plan (FSSP), including hard-to-detect (HTD) radionuclides, within select confirmatory samples? | Yes: Provide analytical minimum detectable concentrations (MDCs) and the less-than-MDC results to the NRC. No: Provide analytical results to the NRC that include all identified radionuclides for their assessment and decision making. Provide independent interpretation of confirmatory sample analyses that identified anomalous results. |
| PSQ3: Do the confirmatory results support the classification of the FSS SUs? | Yes: Confirmatory results support the classification of the FSS SUs. Compile confirmatory survey data and present results to the NRC for their decision making. No: Confirmatory results do not support the classification of the FSS SUs. Summarize the discrepancies and provide technical comments to the NRC for their decision making. |
| Decision Statements | |
| Confirmatory survey results did/did not identify volumetric concentrations and/or surface activity levels that exceed the release criteria. Confirmatory survey results did/did not identify other fission and activation products and/or HTD radionuclides in select confirmatory samples. Confirmatory survey results do/do not agree with the FSS SU classification. | |



3.3 IDENTIFY INPUTS TO THE DECISION

The third step in the DQO process identifies both the information needed and the sources of this information, determines the basis for action levels, and identifies sampling and analytical methods to meet data requirements. For this effort, information inputs included the following:

- The site's FSSP (Note that, at the time of the confirmatory survey and ORISE reporting, the FSS was in progress; therefore, the FSS data/report were not available.)
- ORISE confirmatory survey results including:
 - Surface scans in the G21 building and SUs exterior to the building
 - Static direct measurements
 - Samples collected for determination of removable activity, including HTDs for select locations in the G21 building and on structural surfaces in SUs exterior to the building
 - ORISE volumetric sample analytical results
- Radionuclides of concern (ROCs) and their associated limits (discussed in Section 3.3.1)

3.3.1 Radionuclides of Concern and Release Criteria

The primary ROCs are beta-gamma emitters—fission and activation products resulting from reactor operation. Based on the historical site assessment, the licensee determined that the potential ROCs are cobalt-60 (Co-60), cesium-137 (Cs-137), europium-152 (Eu-152), and europium-154 (Eu-154) (GA 2019).

The radiological release criteria in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 20, “Standards for Protection Against Radiation,” Subpart E, “Radiological Criteria for License Termination,” for unrestricted use will be used for the TRF. In order to demonstrate compliance with the 25 millirem per year release criterion, the NRC approved the use of default screening values instead of site-specific derived concentration guideline levels (DCGL_{WS}) for soil and concrete (NRC 2017). Default screening values used for this site are from NUREG-1757, *Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria*, Vol. 2 (NRC 2006). For structural surfaces, the release limits from NRC Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors* (NRC 1974), as noted in GA’s decommissioning plan, will be implemented, hereafter also referred to as screening values for consistency (GA 1999). Based on the FSSP commitments, elevated measurement comparisons (i.e., DCGL_{EMC} or screening value

maximums) will not be implemented; therefore, the average screening values are treated as “not-to-exceed” threshold values (GA 2019).

Tables 3.2 and 3.3 provide the default screening values for the ROCs for surfaces and structures and concrete and soil, respectively. (Note that in Table 3.2 the maximum values are not applicable as individual FSS/confirmatory measurements will be compared to the average limit.) The SU is determined to meet the release criterion provided that all measurements are less than the screening values. Removable contamination measurements will be directly compared to the applicable screening values in table 3.2 (GA 2019).

| Table 3.2. Surfaces and Structures Screening Values (GA 1999) | | | |
|---|--|-----------------------------|-------------------------------|
| Radionuclides of Concern ^a | dpm/100 cm² ^b | | |
| | Average ^c | Maximum ^d | Removable ^e |
| U-nat, U-235, U-238, and associated decay products | 5,000 | 15,000 | 1,000 |
| Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129 | 100 | 300 | 20 |
| Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-133, I-131 | 1,000 | 3,000 | 200 |
| Beta/gamma emitters (nuclides with decay modes other than alpha), except Sr-90 and others noted above | 5,000 | 15,000 | 1,000 |

^a Where surface contamination by both alpha- and beta/gamma-emitting nuclides exists, the limits established for alpha- and beta/gamma-emitting nuclides should apply independently.

^b As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute (cpm) observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrument.

^c Measurements of average contaminant should not be averaged over more than 1 square meter (m²). For objects of less surface area, the average should be derived for each such object.

^d The maximum contamination level applies to an area of not more than 100 square centimeters (cm²).

^e The amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with a dry filter or a soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.



Table 3.3. Concrete and Soil Screening Values (GA 2019)

| Radionuclides of Concern | Screening Level for Unrestricted Release (pCi/g) ^b |
|--------------------------|---|
| Co-60 | 3.8 |
| Cs-137 | 11.0 |
| Eu-152 | 7.0 ^a |
| Eu-154 | 8.0 |

^a This value is lower than the value listed in NUREG-1757 (8.7 pCi/g) because of the memorandum of understanding between the Environmental Protection Agency (EPA) and the NRC.

^b For informational purposes, the screening level for Sr-90 listed in NUREG-1757 is 1.7 pCi/g.

The values in Table 3.3 represent surficial surface soil concentrations of individual radionuclides that would be deemed in compliance with the 25 millirem per year (mrem/yr) unrestricted release dose limit in 10 CFR 20. Therefore, for sites with multiple radionuclides present, radionuclide-specific results (i.e., volumetric samples) on a per sample basis must be evaluated using the SOF approach to assess the total dose and demonstrate compliance with the dose limit. SOF calculations are performed as follows:

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

Where C_j is the concentration of ROC “j” and $DCGL_{W,j}$ is the screening value for ROC “j”. Note that gross concentrations are considered here for conservatism. A result that does not exceed 1 (unity) ensures compliance with the 25 millirem per year (mrem/yr) unrestricted release dose limit.

3.4 DEFINE THE STUDY BOUNDARIES

The fourth step in the DQO process defines target populations and spatial boundaries, determines the timeframe for collecting data and making decisions, addresses practical constraints, and determines the smallest subpopulations, area, volume, and time for which separate decisions must be made.

Confirmatory survey activities took place in the G21 building and SUs exterior to the building listed in Table 2.1, except for the upper walls—above approximately 2.5 meters—and the ceilings in all structural SUs. The only SUs that did not receive some level of confirmatory surveys were SUs 4 and 6 because of time constraints with accessing the upper walls and ceilings along with the expectation of lower contamination potential. Additionally, per NRC’s request, ORISE scanned a small section

of the roof above the Mark F reactor room. Confirmatory survey activities were performed during the week of August 5, 2019, which constitutes the temporal boundary of the study.

3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specifies appropriate parameters (e.g., mean, median), confirms action levels were above detection limits, and develops an "if...then..." decision rule statement. The confirmatory survey focused on scanning to identify locations that could exceed the applicable screening values and/or analytical MDCs. With the exception of a limited random soil sample population generated for the TRIGA back yard (SU 12), all other locations selected for direct measurement or sampling were judgmentally selected.

Qualitative parameters of interest included the scan data collected across the accessible surfaces of SUs. For this study, the quantitative parameters of interest were individual sample concentrations (volumetric and removable), surface activity results (direct measurements), and the associated MDCs. The decision rules for each SU, as applicable, are stated below:

If the individual concentrations of ROCs in the volumetric samples are below an SOF of 1 (unity) and if individual surface activity measurements are below their respective screening values, then recommend acceptance; otherwise, provide technical comments/recommendations to the NRC for their decision making.

If other fission and activation products, including HTDs, are not positively identified in confirmatory samples, then provide the NRC with the analytical MDCs along with the less-than values; otherwise, summarize the results and present to the NRC along with technical recommendations, as necessary.

Since ORISE focused on scanning in SUs to identify locations that could exceed the applicable screening values and/or analytical MDCs, if all measurements or sample results are below their respective screening values, then recommend acceptance of SU classification; otherwise, provide technical comments/recommendations to the NRC for their decision making.

3.6 SPECIFY LIMITS ON DECISION ERRORS

The sixth step in the DQO process specifies the decision maker's limits on decision errors, which are then used to establish performance goals for the survey. Decision errors are controlled both during the confirmatory investigations and during data quality assessment. The *a priori* detector scan

MDCs were below the screening values for the site-identified ROCs for hand-held detectors (see Appendix D). The survey level of performance matched the planned level of performance (i.e. slow scan speed and surveyors paused liberally); therefore, contamination levels near the scan MDC would have been identified. Any anomalies above background identified while performing the surveys were thoroughly investigated and discussed with the NRC staff.

The FSS data were unavailable at the time of the field activities, and FSS activities had only been completed in SUs 8 and 9. Therefore, with the exception of SU 12, ORISE proceeded with scanning and the collection of judgmental only measurements and samples. The number of random samples collected in the TRIGA back yard (SU 12) during the confirmatory survey was based on developing a non-parametric confidence interval and were collected to provide the NRC with an unbiased estimate of the mean/median ROC concentrations.

3.7 OPTIMIZE THE DESIGN FOR OBTAINING DATA

The seventh step in the DQO process reviews the DQO outputs, develops data collection design alternatives, formulates mathematical expressions for each design, selects the sample size to satisfy DQOs, decides on the most resource-effective design of agreed alternatives, and documents requisite details. The confirmatory survey followed a graded approach, such that survey efforts concentrated on the areas with the highest potential for contamination.

Specific survey procedures are presented in Section 4.

4. PROCEDURES

The ORISE survey team conducted independent confirmatory survey activities, including surface scans, surface activity measurements, and sampling activities, within the accessible portions of the SUs noted previously, or as specifically requested by the NRC, during the period of August 5-8, 2019. Survey activities were in accordance with the project-specific confirmatory survey plan, the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual*, and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORISE 2019, ORAU 2016a, 2019a). Appendices C and D provide additional information regarding survey instrumentation and related processes discussed within this section.



4.1 REFERENCE SYSTEM

ORISE referenced outdoor confirmatory measurement/sampling locations to global positioning system (GPS) coordinates, specifically NAD 1983 (CORS96) State Plane California, and also noted the locations on field forms. Indoor measurement/sampling locations were documented on detailed survey maps. Other prominent site features also were referenced.

4.2 SURFACE SCANS

Surface scans of land areas and structural surfaces were performed with Ludlum model 44-10 5 cm by 5 cm sodium iodide (NaI) scintillation detectors coupled to Ludlum model 2221 ratemeter-scalers with audible indicators. For the land area surveys, ratemeter-scalers also were coupled to GPS systems that enabled real-time gamma count rate and spatial data capture.

Surface scans of structural surfaces were also performed with either Ludlum model 43-68 gas proportional hand-held detectors or Ludlum model 43-37 gas proportional floor monitors operated in alpha-plus-beta mode. Both detector types were coupled to Ludlum model 2221 ratemeter-scalers with audible indicators. Scans with the floor monitor were qualitative (scan MDCs not calculated), but ORISE's experience is that floor monitors are effective at, and efficient for, identifying low levels of surface contamination that can be quantitatively investigated using other hand-held instruments.

The Class 1 SUs received high-density scan coverage (i.e., up to 100% coverage); Class 2 SUs received medium-density scan coverage (at least 50% coverage). Locations of elevated direct radiation, suggesting the presence of residual contamination, were marked for further investigation.

Limited gamma scans were performed in a small section of SU 14, a previously released area within the facility, per the NRC's request, although no conclusions can be drawn. Time constraints did not allow ORISE to collect follow-up, quantitative surface activity measurements.

4.3 SURFACE ACTIVITY MEASUREMENTS

Alpha-plus-beta surface activity measurements were performed with Ludlum model 2221 ratemeter-scalers with audible output paired with Ludlum model 43-68 gas proportional detectors with 0.8 milligram per square centimeter (mg/cm²) thick Mylar windows for the beta-gamma emitting ROCs. For the purpose of converting counts per minute (cpm) to units of disintegrations per



minute per 100 cm² (dpm/100 cm²), detector efficiencies used assumed that Co-60 was the predominant radionuclide for the SUs inside the building and Cs-137 was assumed for exterior SUs, based on discussions at the site between the NRC, ORISE, and the licensee.

Direct measurement locations were determined based on the results of scanning in all SUs. Table 4.1 provides a summary of the number of direct measurements and samples collected in each SU.

Table 4.1. Number and Type of Measurements

| SU | Description | Number of Samples | | | |
|-----------------|---|--------------------------------|------------|------|----------|
| | | Direct Measurements/ Smears | HTD Smears | Soil | Concrete |
| 1 | Mark I Reactor Pit | 8 | 3 | 3 | 1 |
| 2 | Mark F Reactor Pit and Canal | 10 | 6 | 0 | 2 |
| 3 | Mark I Reactor Room (floors and lower walls) | 5 | 1 | 0 | 0 |
| 4 | Mark I Reactor Room (upper walls and ceiling) | -- ^a | -- | -- | -- |
| 5 | Mark F Reactor Room (floors and lower walls) | 9 | 3 | 0 | 0 |
| 6 | Mark F Reactor Room (upper walls and ceiling) | -- | -- | -- | -- |
| 7 | Soil Lab | 2 | 0 | 0 | 0 |
| 8 | Mezzanine 1 | 5 | 0 | 0 | 0 |
| 9 | Mezzanine 2 | 1 | 0 | 0 | 0 |
| 10 | TRIGA Waste Yard | 5 | 1 | 0 | 1 |
| 11 | TRIGA Front Yard | 5 | 0 | 1 | 0 |
| 12 | TRIGA Back Yard | 0 | 0 | 17 | 0 |
| 13 | Room 112 | 9 | 2 | 0 | 0 |
| 14 | Non-Impacted Areas | 0 | 0 | 0 | 0 |
| NA ^b | Roof | 3 | 0 | 0 | 0 |
| Total | | 62 | 16 | 21 | 4 |

^a "--" Indicates measurements not performed in SU.

^b The roof was not listed as a SU in the *TRIGA Reactor Facility Final Status Survey Plan* (GA 2019).

ORISE collected material-specific background measurements from the site-determined non-impacted reference area from materials that, to the extent possible, were of similar construction to the measurement surfaces. The background reference area was outdoors just outside the main



entrance to Building 27. These background measurements were used for correcting gross measurement counts for conversion to surface activity levels.¹

4.4 SURFACE REMOVABLE ACTIVITY MEASUREMENTS

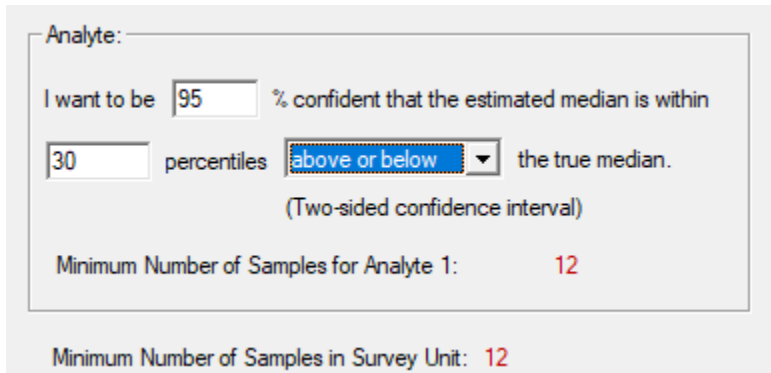
Dry smear samples, for determining removable gross alpha/beta activity levels, were collected from each direct measurement location, as applicable. Wet smears for the determination of removable tritium (H-3) and carbon-14 (C-14) were collected at judgmentally selected direct measurement locations, in an area adjacent to the dry smear sample location. See Table 4.1 for a summary. Figures A.1 through A.15 in Appendix A show measurement locations as applicable for each SU.

4.5 VOLUMETRIC SAMPLING

Nine judgmental soil samples were collected. Judgmental soil sample locations were determined based on indications noted during gamma scans, with the exception of soil sample S0021 in the TRIGA front yard (SU 11). SU 11 is mostly asphalt and concrete with a small strip of soil on the south end of the SU, which appeared to be a drainage area and a good location for a judgmental sample (S0021). Three judgmental soil samples were collected from the bottom of the Mark I reactor pit and five judgmental soil samples were collected from the TRIGA back yard (SU 12). Figures A.1 through A.15 show judgmental sample locations.

For the TRIGA back yard, Visual Sample Plan (VSP), version 7.10 was used to determine the number of samples required such that the estimated SU median was within 30 percentiles above or below the true SU median at the 95% confidence level (Figure 4.1). The 30 percentile interval provides a reasonable estimate of the median/mean, as data were expected to be less than the release limits given the Class 2 designation, and would generate an adequate sample size to minimize confirmatory survey decision errors. For this effort, based on the previously described planning inputs, 12 random samples were required; locations are depicted in Figure A.13. The target depth for soil samples was 0 to 15 cm. However, because of the extremely compacted and rocky soil, samples were collected as deep as possible, typically 0 to 8 cm using hand trowels. No additional depths were collected. Sampling equipment was rinsed and wiped after each sample to minimize the potential for cross-contamination.

¹ The construction material-specific backgrounds were considered appropriate for most confirmatory measurement surfaces with the exception of the reactor pits where the ambient background was lower because of subterranean shielding, resulting in mostly negative surface activity results.



Analyte:

I want to be % confident that the estimated median is within
 percentiles the true median.
(Two-sided confidence interval)

Minimum Number of Samples for Analyte 1: 12

Minimum Number of Samples in Survey Unit: 12

Figure 4.1 VSP Confirmatory Survey Planning Inputs

Two concrete samples were collected at ORISE judgmentally-selected locations based on the results of scans and direct measurements. One sample was collected from the Mark F reactor canal (SU 2) where fuel had been stored and the other was collected in the TRIGA waste yard (SU 10). The licensee collected both concrete samples per NRC's direction under general observation of ORISE; however, there was a delay in turning over sample custody to ORISE. Additionally, and prior to the confirmatory survey, the NRC had requested that the licensee save a split of all the FSS concrete samples that were collected in the Mark I and Mark F reactor pits. The NRC selected two samples: one each from the Mark I and Mark F reactor pits, and directed ORISE to conduct independent laboratory analysis.

5. SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and data collected on site were transferred to the ORISE facility for analysis and interpretation. Sample custody was transferred to the Radiological and Environmental Analytical Laboratory in Oak Ridge, Tennessee. Sample analyses were performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2019b). Volumetric samples were crushed and homogenized, and a portion was set aside before drying for future analyses before being analyzed by gamma spectrometry for gamma-emitting fission and activation products. For all soil samples, analytical results are reported for the site ROCs and other gamma-emitting naturally occurring radioactive material (NORM) (e.g., uranium, radium), for completeness. Volumetric sample results are reported in units of gross pCi/g. Smears were analyzed for gross alpha/beta activity, H-3, and C-14, and were reported in units of dpm/100 cm² and pCi/smear respectively. At the request of the NRC, Sr-90 analyses also was performed on the four concrete samples as well as four judgmental soil samples.



All scan results are presented as gross cpm. Total surface activity measurements are presented as net dpm/100 cm², with the appropriate material-specific background subtracted from the gross measurement.

6. FINDINGS AND RESULTS

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

Appendix A provides the gamma walkover and sample location figures and Appendix B provides data tables. Appendices C and D provide additional details regarding field and laboratory instrumentation, as well as additional information on calibration, quality assurance, survey and analytical procedures, and detection sensitivities.

6.1 SURFACE SCANS

Tables 6.1 provides a summary of the scanning survey data for each SU investigated.

Table 6.1. Summary of Scan Results

| SU | Description | Scan Ranges (cpm) | | |
|-----------------|--|-------------------|---------------------------|-------------------------------|
| | | NaI | Hand-Held Alpha-Plus-Beta | Floor Monitor Alpha-Plus-Beta |
| 1 | Mark I Reactor Pit | 19,000 to 30,000 | 350 to 800 | -- ^a |
| 2 | Mark F Reactor Pit and Canal | 9,000 to 25,000 | 200 to 55,000 | -- |
| 3 | Mark I Reactor Room (floors and lower walls) | 13,000 to 20,000 | 200 to 1,800 | 1,400 to 2,800 |
| 5 | Mark F Reactor Room (floors and lower walls) | 13,000 to 65,000 | 200 to 1,800 | 1,200 to 3,500 |
| 7 | Soil Lab | 11,000 to 17,000 | 300 to 750 | 1,200 to 2,000 |
| 8 | Mezzanine 1 | -- | 300 to 640 | 1,600 to 2,400 |
| 9 | Mezzanine 2 | -- | 200 to 600 | 800 to 1,200 |
| 10 | TRIGA Waste Yard | 10,000 to 31,000 | -- | 1,200 to 6,600 |
| 11 | TRIGA Front Yard | 7,600 to 31,000 | -- | 1,300 to 4,100 |
| 12 | TRIGA Back Yard | 9,200 to 25,000 | -- | -- |
| 13 | Room 112 | 14,000 to 22,000 | 250 to 700 | 1,400 to 3,000 |
| 14 | Non-Impacted Areas | 15,000 to 23,000 | -- | -- |
| NA ^b | Roof | 7,900 to 43,000 | 250 to 1,300 | -- |

^a "--" Indicates scan data not collected.

^b The roof was not listed as an SU in the *TRIGA Reactor Facility Final Status Survey Plan* (GA 2019).

Multiple locations were marked in the SUs for further investigation based on the observed surface scan results. Inside the G21 building, there were several areas of elevated direct alpha-plus-beta radiation identified, while there was minimal gamma radiation response at these locations. This was most notable in the Mark F reactor canal on both concrete surfaces and along a “track” near the entrance to the canal, which still contained a “seal” of unknown material. Similarly, one area on the roof had elevated alpha-plus-beta radiation levels on the side of a capped ventilation trunk, but no elevated gamma levels were noted for this location. One drain inside the building was identified as having elevated gamma radiation levels. The drain was located to the east of the Mark F reactor pit in a trench about one meter below a metal covering. The beta detector could not access the internal drain surfaces; therefore, elevated beta radiation levels inside of the drain could not be confirmed. Debris was noted in the elbow of the drain, but could not be reached. Outside of the G21 building, areas exhibiting elevated direct radiation were identified during both gamma and alpha-plus-beta scans. Figures A.9 through A.13 show exterior gamma scan results. It should be noted in Figure A.9 that an elevated gamma response is shown in the north section of the SU. This area was marked and further investigated; however, the elevated response could not be reproduced during follow-up investigations. Figure A.13 shows elevated gamma responses in an excavated area in the south section of the SU. These elevated responses occurred near concrete and rocks and may have been due to NORM in the rocks and concrete.

6.2 TOTAL AND REMOVABLE SURFACE ACTIVITY LEVELS

Table 6.2 provides a summary of the surface activity measurements collected both inside and outside the G21 building, and Tables B.1 through B.11, and B.15 in Appendix B provide individual measurement results for each SU. Table B.18 provides the construction material-specific background data for each detector type.

Five of the SUs investigated had direct measurements that exceeded the screening value for surfaces and structures, including SU 8 (mezzanine 1), which had already received FSS.

In the Mark F reactor canal (SU 2), multiple areas were identified as having elevated radiation levels during scanning; however, only a few were selected for direct measurements because of time constraints. The areas selected for the quantitative direct measurements represent a range of the observed detector responses (i.e., low, medium, high scanning count rates).

All removable activity was below the screening value. All removable H-3 and C-14 concentrations were below the respective analytical MDCs.

Table 6.2. Summary of Surface Activity Results

| SU | Description | No. of Locations that Exceed Screening Values | Gamma (cpm) | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|-----------------|--|---|-------------------|--------------------------------|-------------------------|---------|--------------|-------------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | | | dpm/100 cm ² | | pCi/sample | |
| 1 | Mark I Reactor Pit | 0 | 15,000 to 27,000 | -1,200 to -450 | 0 to 2 | 0 to 5 | -4.1 to 0.6 | -2.7 to 0.8 |
| 2 | Mark F Reactor Pit and Canal | 5 | 8,300 to 25,000 | -1,800 to 440,000 | 0 to 2 | 0 to 47 | -6.8 to 1.9 | -2.0 to 7.3 |
| 3 | Mark I Reactor Room (floors and lower walls) | 1 | 11,000 to 19,000 | -950 to 11,000 | 0 to 4 | 0 to 4 | -8.2 | -1.2 |
| 5 | Mark F Reactor Room (floors and lower walls) | 2 | 11,000 to 320,000 | -770 to 11,000 | 0 to 2 | 0 to 25 | -4.5 to -3.1 | 0.1 to 1.6 |
| 7 | Soil Lab | 0 | 16,000 to 17,000 | 570 to 650 | 0 to 2 | 0 | -- | -- |
| 8 | Mezzanine 1 | 2 | -- ^a | 2,700 to 16,000 | 0 to 2 | 0 to 13 | -- | -- |
| 9 | Mezzanine 2 | 0 | -- | -290 | 0 | 3 | -- | -- |
| 10 | TRIGA Waste Yard | 1 | 14,000 to 31,000 | 680 to 11,000 | 0 to 2 | 2 to 6 | -6.5 | 0.8 |
| 11 | TRIGA Front Yard | 0 | 17,000 to 35,000 | -330 to 1,900 | 0 | 0 to 3 | -- | -- |
| 12 | TRIGA Back Yard | -- | 13,000 to 20,000 | -- | -- | -- | -- | -- |
| 13 | Room 112 | 0 | 15,000 to 23,000 | -2,100 to 3,200 | 0 to 4 | 0 to 5 | -5.5 to 3.7 | 0.3 to 0.4 |
| NA ^b | Roof | 0 | 8,800 to 43,000 | 1,800 to 3,500 | -- | -- | -- | -- |

^a "--" Indicates measurement not collected.

^b The roof was not listed as an SU in the *TRIGA Reactor Facility Final Status Survey Plan* (GA 2019).

6.3 RADIONUCLIDE CONCENTRATIONS IN VOLUMETRIC SAMPLES

Tables 6.3 and 6.4 provide summaries of the results of the volumetric soil and concrete samples, respectively. Pre- and post-sampling measurement data and individual sample results for the various matrices are provided in Tables B.12 through B.17.

All ROC concentrations in soil samples were less than the respective screening levels and all SOFs were less than 1. For completeness, NORM concentrations also are reported for the soil samples. Sr-90—a pure beta emitter—was not identified by the licensee as a ROC; however, because the ORISE confirmatory survey alpha-plus-beta scans identified elevated beta radiation during scans without a corresponding increase in the gamma response in those same areas, some samples were selected for Sr-90 analyses.

The two volumetric concrete samples from ORISE-identified locations each had SOFs greater than 1 because of the Cs-137 concentration, which exceeded the screening level for both samples. The sample from outside of the G21 building (in SU 10, TRIGA waste yard, sample 5339M0002) had 114.0 pCi/g of Cs-137 and 6.40 pCi/g of Sr-90. The Co-60 concentration was less than 1 pCi/g. This sample agreed with the licensee's assumption that Cs-137 is the primary ROC in the SUs outside the G21 building. The sample from inside of the building (in SU 2, Mark F reactor canal, 5229M0001) had 26.5 pCi/g of Cs-137 and 0.49 pCi/g of Sr-90. The Co-60 concentration was less than 1 pCi/g. However, based on discussions at the site and for conservatism in calculating surface activity values, Co-60 is assumed as the predominant ROC inside the G21 building for ORISE calculations. Specifically, the gas proportional detector total efficiency associated with Co-60 is lower than that of Cs-137, resulting in a conservatively higher surface activity.

Table 6.3. Summary of Soil Sample Concentrations

| SU | Description | No. of Locations that Exceed Screening Values | Cs-137 | Co-60 | Eu-152 | Eu-154 | SOF |
|----|--------------------|---|-----------------|-----------------|-----------------|-----------------|--------------|
| | | | pCi/g | | | | |
| 1 | Mark I Reactor Pit | 0 | -0.022 to 0.012 | 0.042 to 0.130 | 0.394 to 3.19 | -0.083 to 0.14 | 0.07 to 0.50 |
| 11 | TRIGA Front Yard | 0 | 0.083 | 0.002 | -0.036 | -0.59 | 0.01 |
| 12 | TRIGA Back Yard | 0 | -0.014 to 0.933 | -0.033 to 0.021 | -0.069 to 0.062 | -0.54 to -0.045 | 0.00 to 0.08 |

Table 6.4. Summary of Concrete Concentrations

| SU | Description | No. of Locations that Exceed Screening Values | Cs-137 | Co-60 | Eu-152 | Eu-154 | SOF | Sr-90 |
|----|----------------------------|---|---------------|-----------------|----------------|----------------|-----------|--------------|
| | | | pCi/g | | | | | pCi/g |
| 1 | Mark I Reactor Pit | 0 | 0.025 | -0.039 | 0.06 | -0.56 | 0.01 | 0.07 |
| 2 | Mark F Reactor Pit & Canal | 1 | 0.127 to 26.5 | -0.011 to 0.211 | -0.03 to 0.043 | -0.36 to -0.12 | 0.02 to 2 | 0.04 to 0.49 |
| 10 | TRIGA Waste Yard | 1 | 114.0 | -0.041 | 0.07 | -0.33 | 10 | 6.40 |



7. SUMMARY

At the NRC's request, ORISE conducted confirmatory survey activities at the GA TRIGA Reactor Facility near San Diego, California, during the period of August 5–8, 2019. Confirmatory survey activities included gamma surface scans, gamma direct measurements, alpha-plus-beta scans, alpha-plus-beta direct measurements, smear sampling, and soil/volumetric sampling within the facility and associated land area, as applicable. The areas investigated included the Mark I reactor pit, Mark F reactor pit and canal, Mark I reactor room (floor and lower walls), Mark F reactor room (floors and lower walls), the soil lab, mezzanine 1, mezzanine 2, TRIGA waste yard, TRIGA front yard, TRIGA back yard, and room 112. Limited gamma scanning was performed in areas previously released within the facility. The NRC was aware that some SUs were still in the process of FSS during the time of the ORISE confirmatory survey activities but requested that ORISE proceed with independent assessment.

Gamma and alpha-plus-beta scans identified multiple areas of elevated direct radiation both inside and outside of the facility. Based on the results of scanning, 62 locations were selected for direct measurements and smear sampling. At 16 of these locations, smear samples were collected for HTD radionuclide analysis. Four volumetric samples were obtained for analysis. ORISE identified two locations for sampling based on scan results. The NRC selected the other two samples from the licensee's archived FSS samples that were of interest to the NRC and directed the ORISE confirmatory analysis. ORISE collected judgmental soil samples from nine locations and an additional 12 random soil samples were collected from the TRIGA back yard.

Eleven direct measurements exceeded the 5,000 dpm/100 cm² screening value; however, all removable activity was below the 1,000 dpm/100 cm² screening value. All removable H-3 and C-14 concentrations were below the analytical MDCs. The two volumetric concrete samples from ORISE-identified locations each had SOFs greater than 1. Each sample had Cs-137 concentrations that exceeded the screening value of 11 pCi/g. Sr-90 also was identified in these samples. No individual concentrations within the soil samples exceeded their respective screening levels and all SOFs were less than 1.



While results of the confirmatory survey support the overall classification of the SUs because locations that exceeded the screening values were in Class 1 areas, several key issues were identified:

- Surface activity measurements exceeded the screening value in a SU that had already received FSS;
- Several other locations on structural surfaces exhibited contamination greater than the applicable screening value;
- Sr-90 was identified in two volumetric concrete samples when Sr-90 was not included as an ROC, and
- Elevated radiation levels were identified on the roof although it was not listed as a SU.

ORISE was notified that additional remediation would be performed at the site based on these confirmatory findings. Based on the August 5 through 8, 2019 confirmatory survey and the REAL analytical results, all Building G21 and associated land areas investigated could not be confirmed to satisfy the applicable NRC decommissioning criteria for unrestricted use.



8. REFERENCES

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- ORISE 2019. *Project-Specific Plan for Confirmatory Survey Activities for the General Atomics TRIGA Reactor Facility Building G21 and Associated Land Area, San Diego, California*. Oak Ridge Institute for Science and Education. Oak Ridge, Tennessee. August.

APPENDIX A: FIGURES

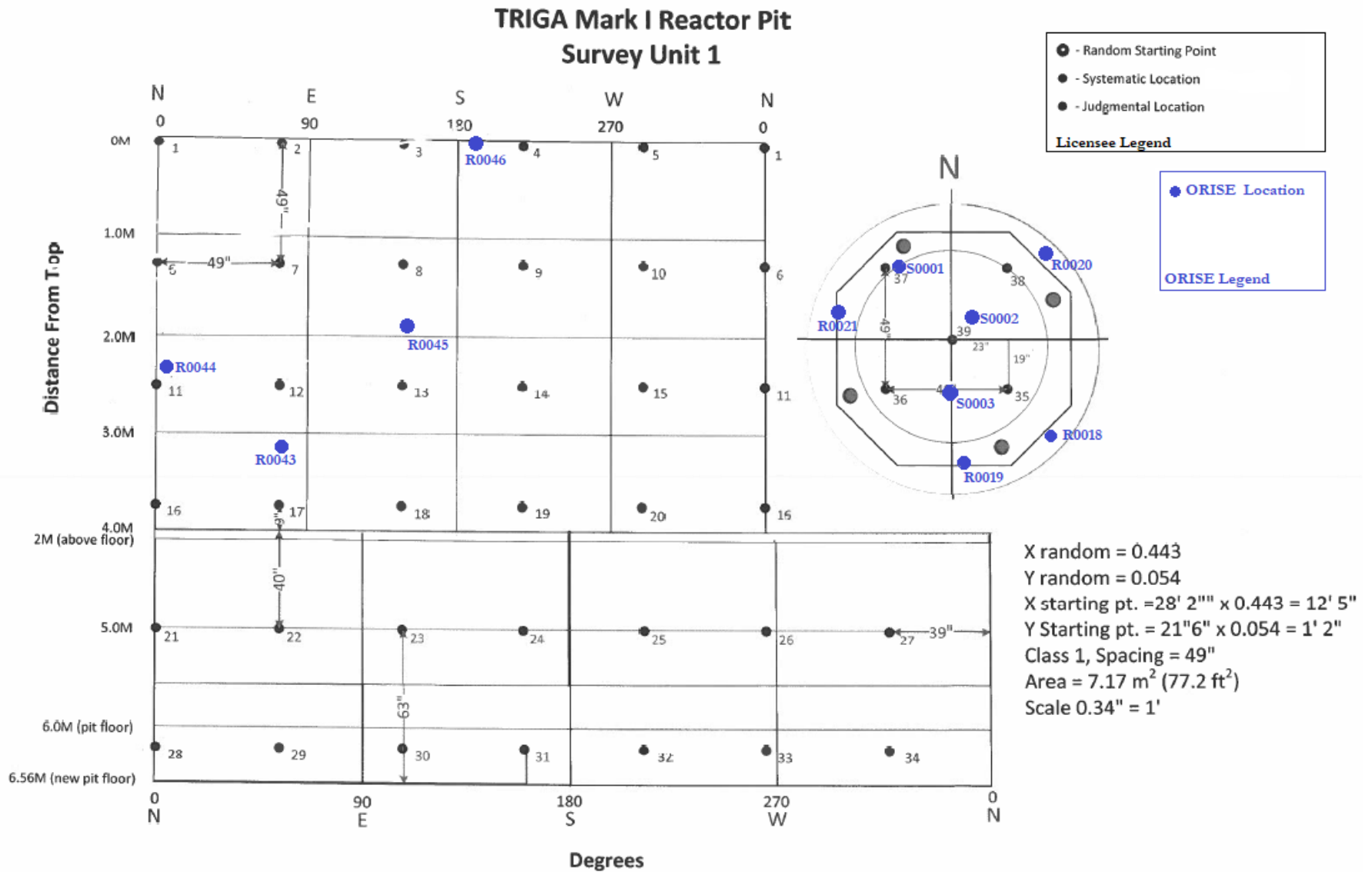


Figure A.1. SU 1 Mark I Reactor Pit Survey Locations

TRIGA Mark F Reactor Pit & Canal Survey Unit 2

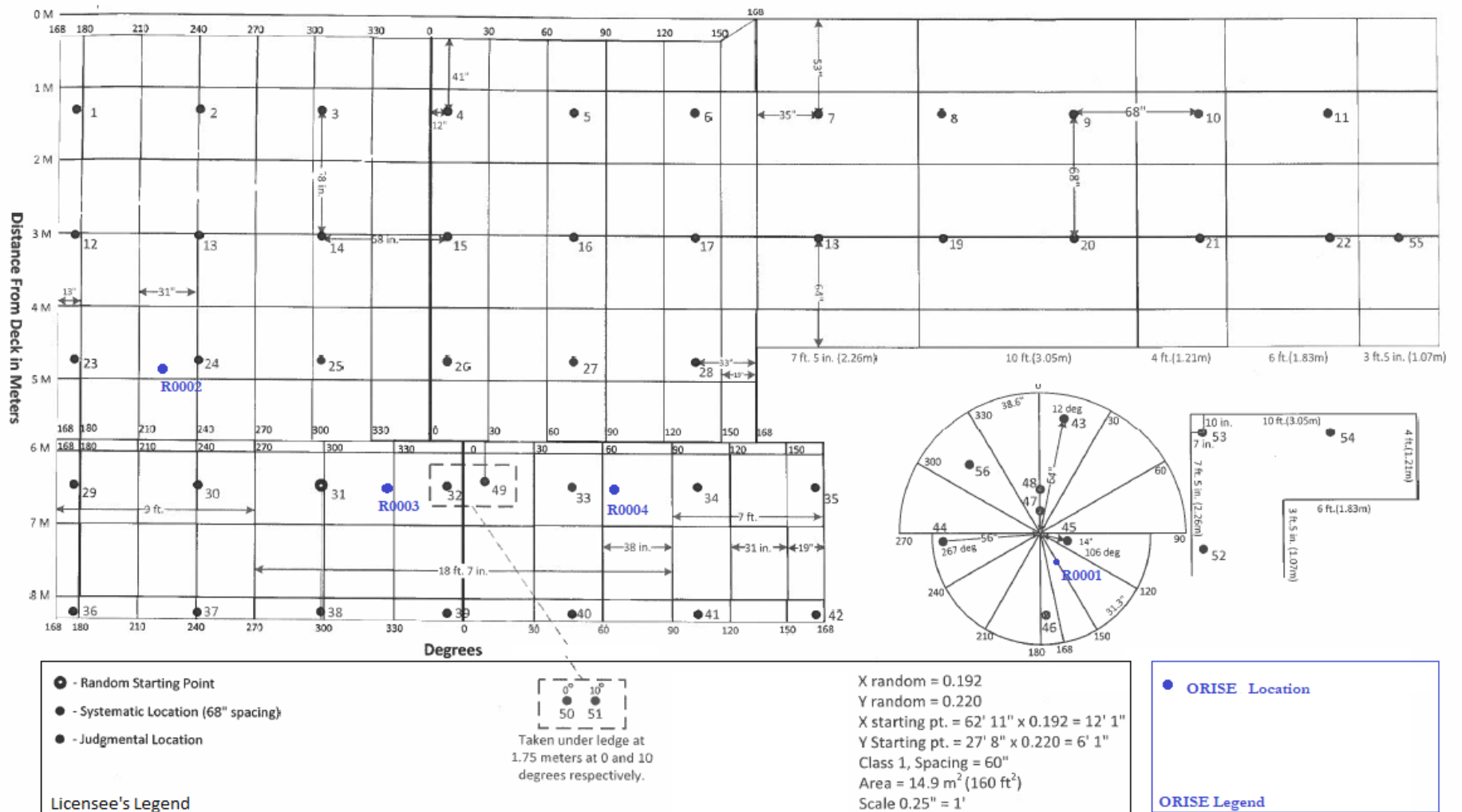


Figure A.2. SU 2 Mark F Reactor Pit Survey Locations

TRIGA Mark F Reactor Pit & Canal Survey Unit 2

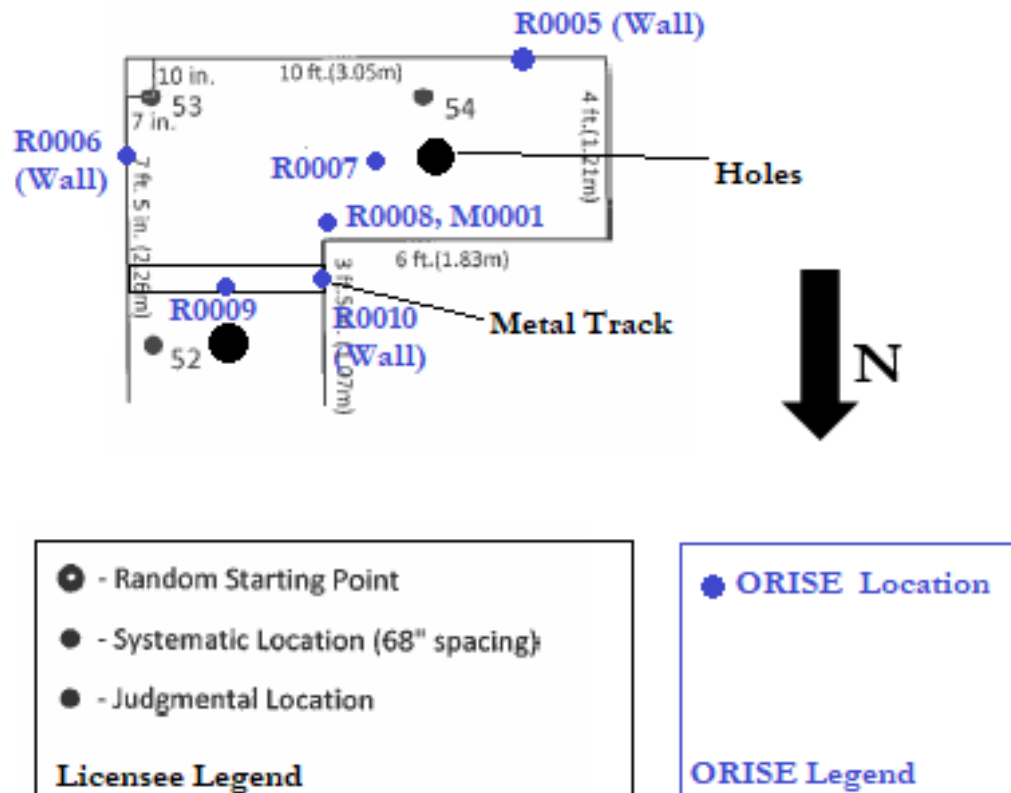


Figure A.3. SU 2 Mark F Reactor Pit Canal Survey Locations

TRIGA Mark I Reactor Room – Surfaces & Structures Below Two Meters Survey Unit 3

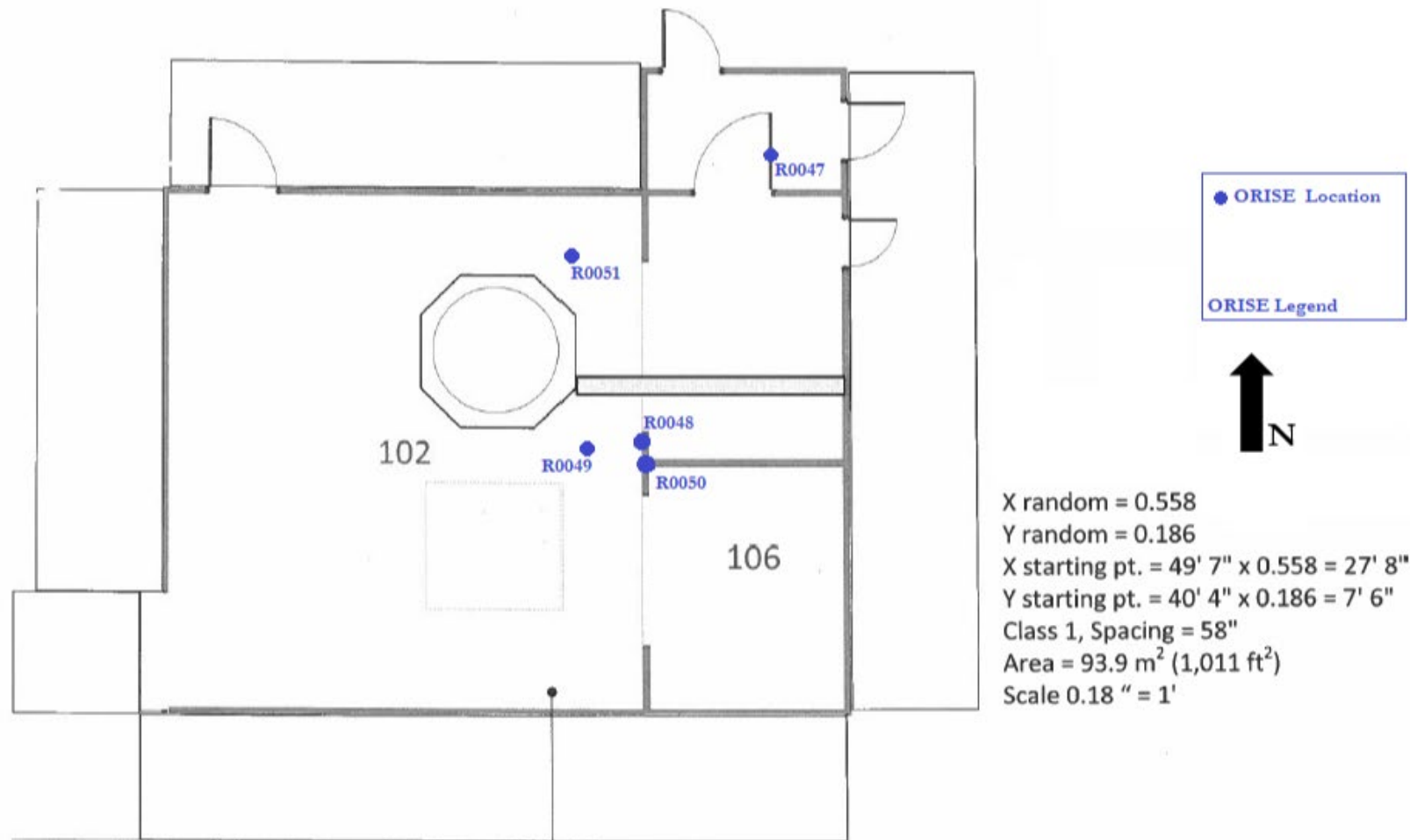


Figure A.4. SU 3 Mark I Reactor Room (floors and lower walls) Survey Locations



Figure A.5. SU 5 Mark F Reactor Room (floors and lower walls) Survey Locations

TRIGA Soil Lab – Surfaces & Structures Below Two Meters Survey Unit 7

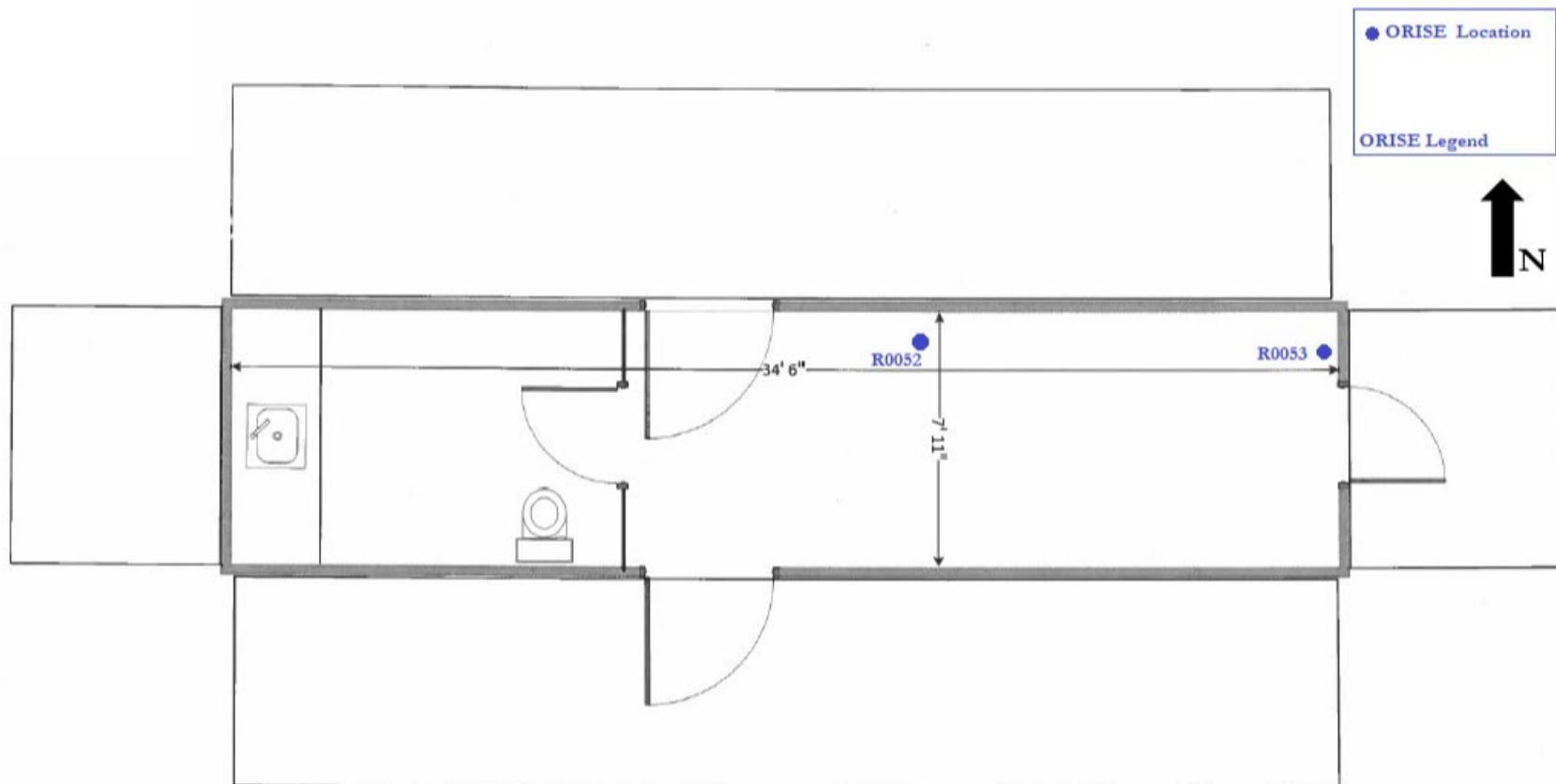


Figure A.6. SU 7 Soil Lab Survey Locations

- - Random Starting Point
- - Systematic Location (68" spacing)
- - Judgmental Location

Licensee Legend

ORISE Location

ORISE Legend

Figure A.7. SU 8 Mezzanine 1 Survey Locations

TRIGA Mezzanine 2 – Surfaces & Structures Below Two Meters Survey Unit 9



Figure A.8. SU 9 Mezzanine 2 Survey Locations



Figure A.9. SU 10 TRIGA Waste Yard Gamma Walkover Map with Survey Locations



Figure A.10. SU 10 TRIGA Waste Yard Alpha-Plus-Beta Walkover Map with Survey Locations

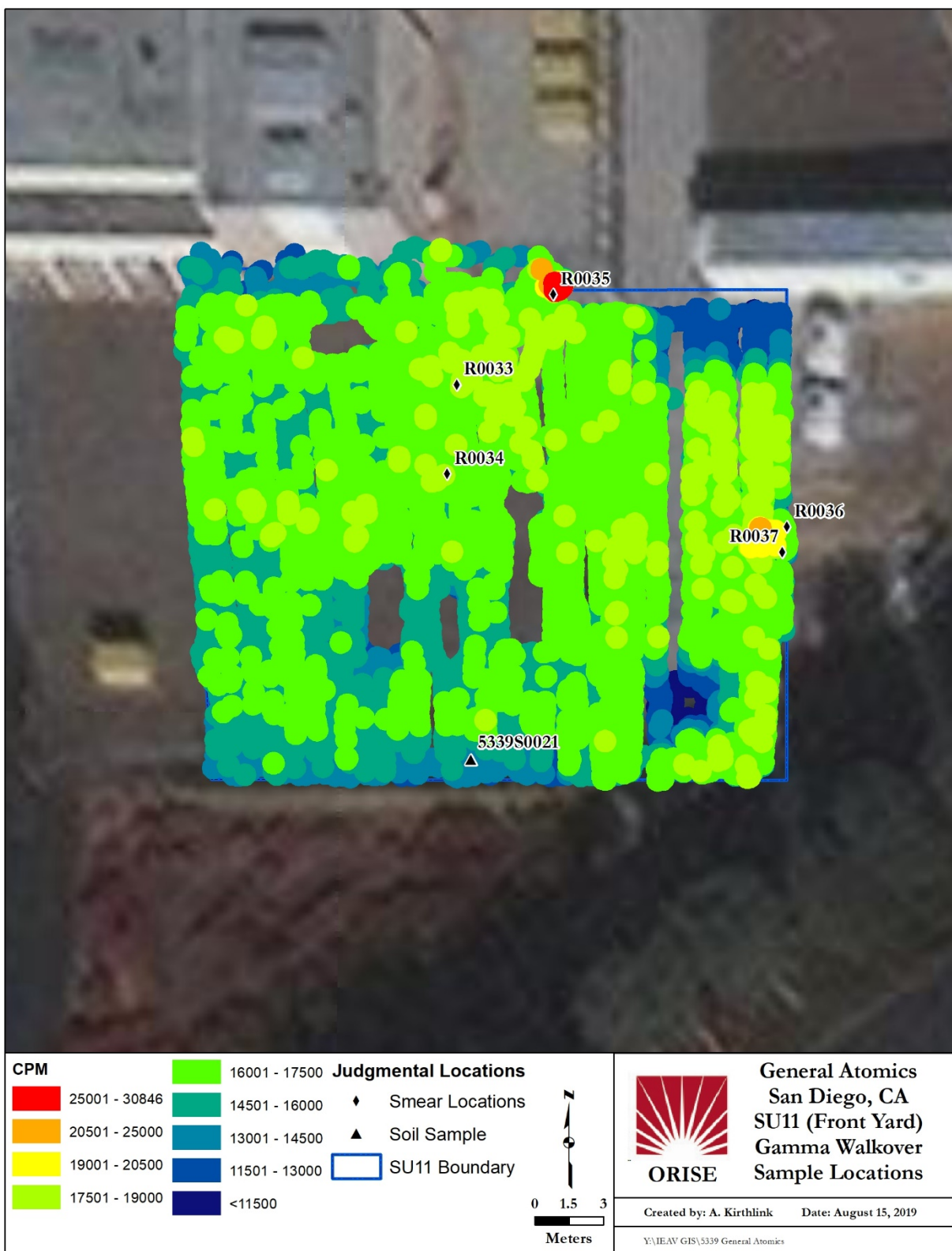


Figure A.11. SU 11 TRIGA Front Yard Gamma Walkover Map with Survey Locations

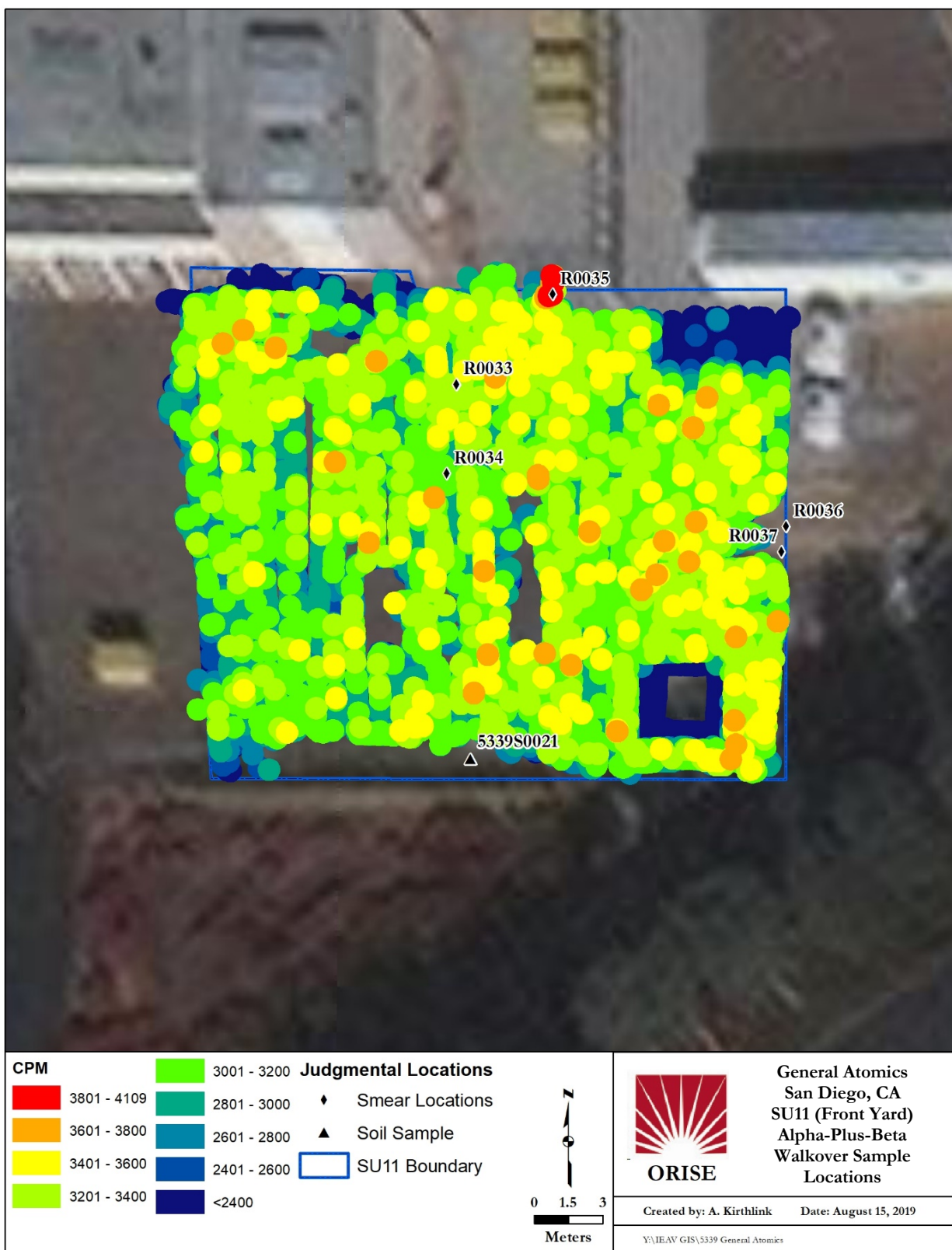


Figure A.12. SU 11 TRIGA Front Yard Alpha-Plus-Beta Walkover Map with Survey Locations

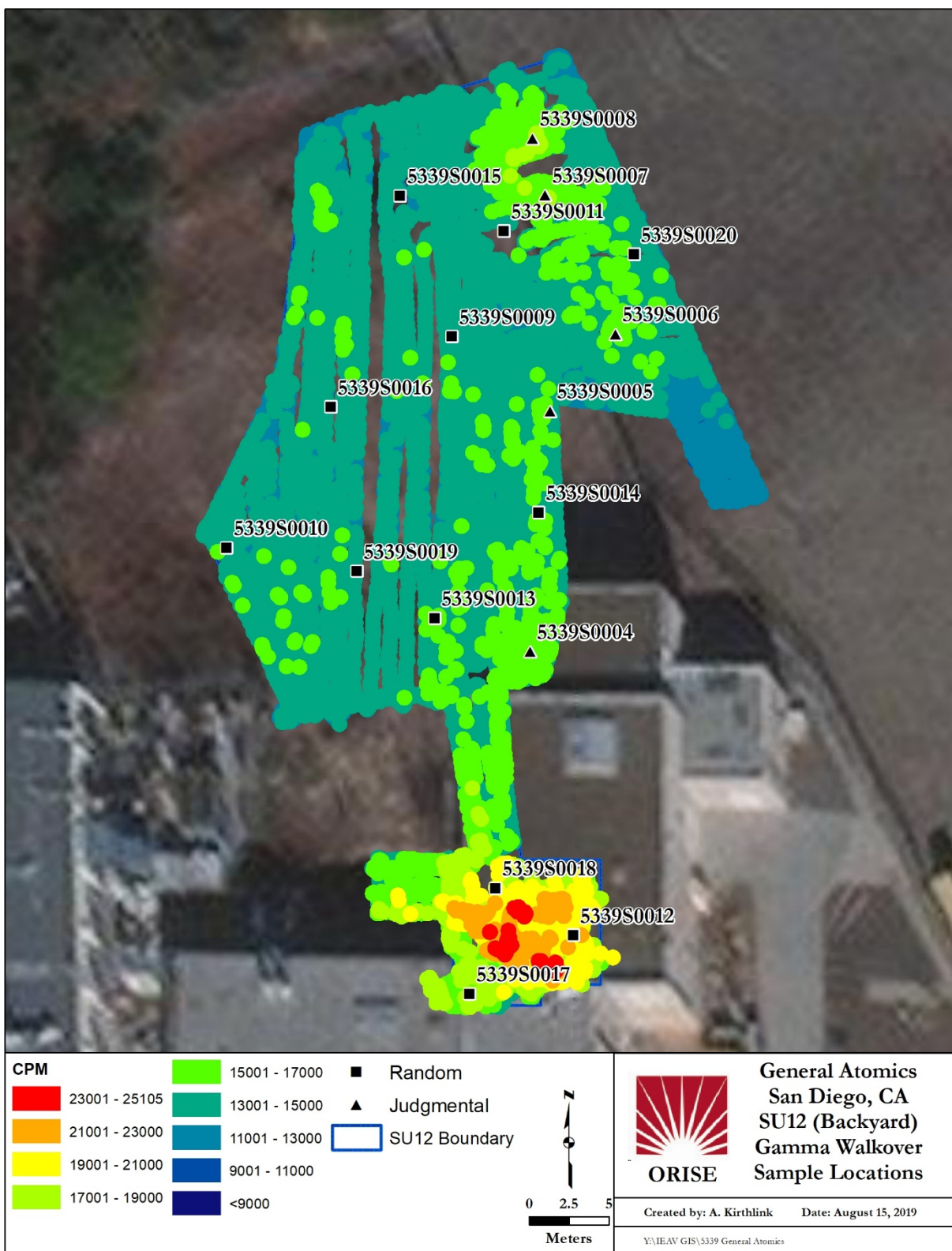


Figure A.13. SU 12 TRIGA Back Yard Gamma Survey Map with Survey Locations

TRIGA Room 112 – Surfaces & Structures Below Two Meters Survey Unit 13

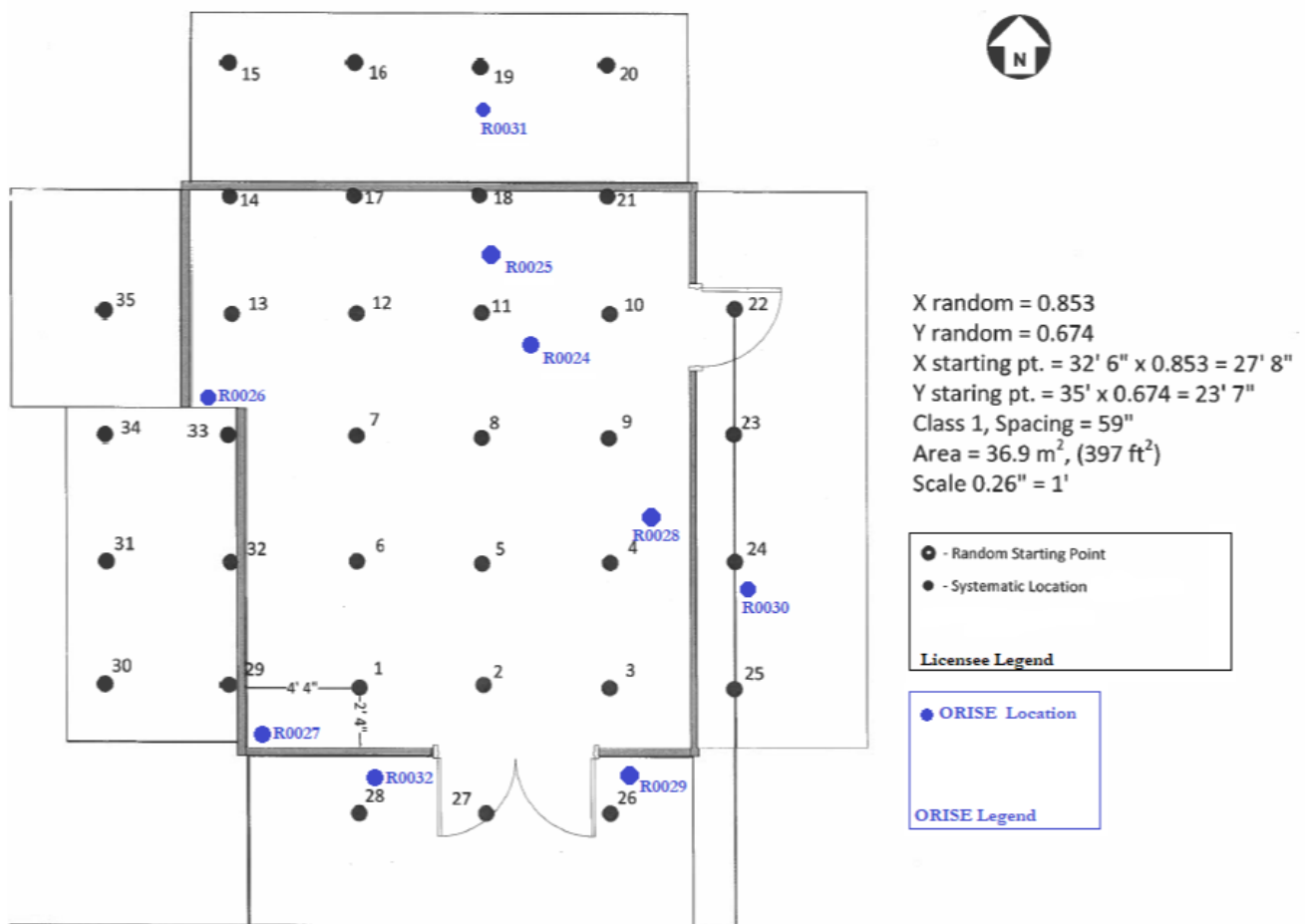


Figure A.14. SU 13 Room 112 Survey Locations

TRIGA – Mark I & Mark F Roof

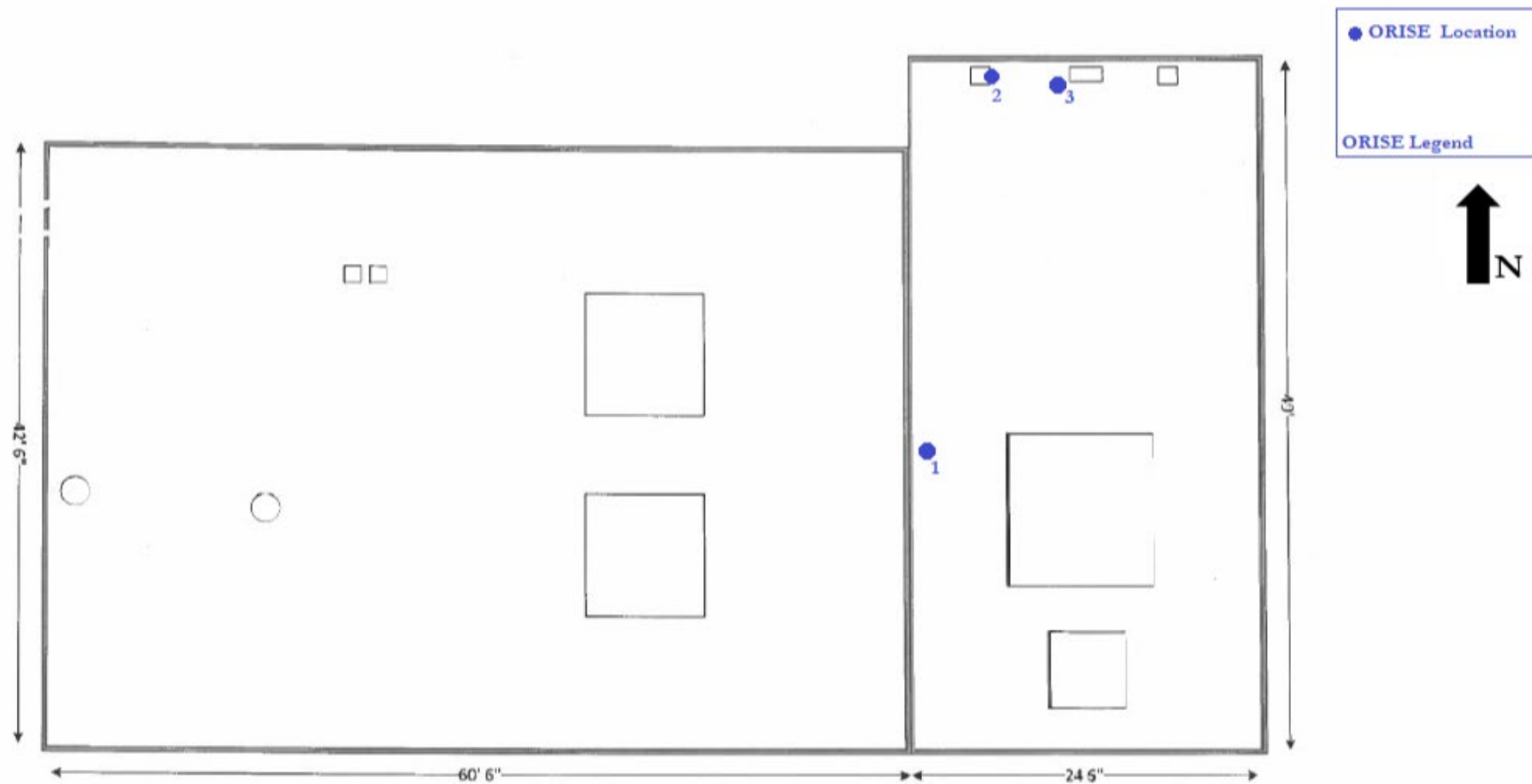


Figure A.15. Mark I and Mark F Roof (only a small area of Mark F was scanned)

APPENDIX B: DATA TABLES

| Table B.1. SU 1 Mark I Reactor Pit Measurement Locations, Gamma Measurements, and Surface Activity Levels | | | | | | | | |
|---|----------|-------------------------------|--------|--------------------------------|-------------------------|------|------------|------|
| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
| | | | cpm | dpm/100 cm ² | Alpha | Beta | H-3 | C-14 |
| | | | | | dpm/100 cm ² | | pCi/sample | |
| 5339R0018 | Concrete | South/SW Sidewall | 26,000 | -560 | 0 | 3 | -4.1 | -2.7 |
| 5339R0018a | Concrete | South/SW Sidewall | -- | -- | -- | -- | -4.1 | -2.7 |
| 5339R0019 | Concrete | South Sidewall | 27,000 | -590 | 0 | 5 | 0.6 | -2.2 |
| 5339R0020 | Concrete | NE Sidewall | 26,000 | -450 | 0 | 2 | -- | -- |
| 5339R0021 | Concrete | West Sidewall | 25,000 | -740 | 0 | 0 | -- | -- |
| 5339R0043 | Concrete | NE Cylinder, Between 12 & 17 | 22,000 | -1,100 | 2 | 0 | -2.7 | 0.8 |
| 5339R0044 | Concrete | North Cylinder, Near 11 | 22,000 | -1,200 | 2 | 0 | -- | -- |
| 5339R0045 | Concrete | SE Cylinder, Between 8 & 13 | 21,000 | -1,100 | 2 | 0 | -- | -- |
| 5339R0046 | Concrete | South Cylinder, Between 3 & 4 | 15,000 | -1,200 | 0 | 0 | -- | -- |
| Minimum | | | 15,000 | -1,200 | 0 | 0 | -4.1 | -2.7 |
| Maximum | | | 27,000 | -450 | 2 | 5 | 0.6 | 0.8 |

Table B.2. SU 2 Mark F Reactor Pit and Canal Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|----------------|----------|-----------------------|--------|--------------------------------|-------------------------|-----------------------|------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | pCi/sample | | |
| 5339R0001 | Concrete | Floor | 25,000 | 360 | 0 | 0 | -2.2 | -0.9 |
| 5339R0002 | Concrete | SE Wall | 20,000 | -1,800 | 2 | 3 | -1.4 | 1.5 |
| 5339R0003 | Concrete | NW Wall | 23,000 | -690 | 0 | 0 | 0.0 | 1.5 |
| 5339R0004 | Concrete | N Wall | 25,000 | -110 | 0 | 2 | 0.0 | -2.0 |
| 5339R0005 | Concrete | Canal S Wall | 10,000 | 2,700 | 0 | 5 | -6.8 | -1.0 |
| 5339R0006 | Concrete | Canal E Wall | 11,000 | 12,000 | 0 | 3 | -- | -- |
| 5339R0007 | Concrete | Canal Floor | 14,000 | 23,000 | 0 | 0 | -- | -- |
| 5339R0008 | Concrete | Canal Floor | 14,000 | 440,000 | 0 | 15^a | 1.9 | 7.3 |
| 5339R0009 | Metal | Canal Track Floor | 13,000 | 410,000 | 0 | 47 | -- | -- |
| 5339R0010 | Metal | Canal Track West Side | 8,300 | 35,000 | 0 | 0 | -- | -- |
| Minimum | | | 8,300 | -1,800 | 0 | 0 | -6.8 | -2.0 |
| Maximum | | | 25,000 | 440,000 | 2 | 47 | 1.9 | 7.3 |

^a Bolded values are greater than the analytical MDC.

| Table B.3. SU 3 Mark I Reactor Room Measurement Locations, Gamma Measurements, and Surface Activity Levels | | | | | | | | |
|--|----------|------------------------|--------|--------------------------------|-------------------------|------|------------|------|
| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
| | | | cpm | dpm/100 cm ² | Alpha | Beta | H-3 | C-14 |
| | | | | | dpm/100 cm ² | | pCi/sample | |
| 5339R0047 | Metal | NE Door | 11,000 | 2,900 | 4 | 4 | -- | -- |
| 5339R0048 | Concrete | Wall Between 102 & 106 | 19,000 | 11,000 | 0 | 3 | -8.2 | -1.2 |
| 5339R0049 | Concrete | Floor | 16,000 | -300 | 0 | 0 | -- | -- |
| 5339R0050 | Concrete | Wall Between 102 & 106 | 16,000 | -580 | 0 | 0 | -- | -- |
| 5339R0051 | Concrete | Floor | 16,000 | -950 | 0 | 2 | -- | -- |
| Minimum | | | 11,000 | -950 | 0 | 0 | -- | -- |
| Maximum | | | 19,000 | 11,000 | 4 | 4 | -8.2 | -1.2 |

| Table B.4. SU 5 Mark F Reactor Room Measurement Locations, Gamma Measurements, and Surface Activity Levels | | | | | | | | |
|--|---------------|-----------------|---------|--------------------------------|-------------------------|-----------------------|------------|------|
| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
| | | | cpm | dpm/100 cm ² | Alpha | Beta | H-3 | C-14 |
| | | | | | dpm/100 cm ² | | pCi/sample | |
| 5339R0011 | Concrete | Floor SE Corner | 20,000 | 3,100 | 0 | 2 | -3.6 | 1.6 |
| 5339R0012 | Concrete | South Wall | 17,000 | 2,000 | 0 | 5 | -- | -- |
| 5339R0013 | Metal | South Door | 11,000 | 11,000 | 0 | 25^a | -- | -- |
| 5339R0014 | Concrete | West Wall | 14,000 | -770 | 0 | 0 | -- | -- |
| 5339R0015 | Concrete | West Wall | 13,000 | -120 | 0 | 3 | -- | -- |
| 5339R0016 | Concrete | East Wall | 14,000 | 1,600 | 0 | 2 | -- | -- |
| 5339R0017 | Concrete/Tile | Floor SW Corner | 14,000 | 3,800 | 0 | 0 | -- | -- |
| 5339R0022 | Concrete | East Trench | 130,000 | 7,100 | 2 | 0 | -3.1 | 1.3 |
| 5339R0023 | Metal Drain | East Trench | 320,000 | -- | 0 | 0 | -4.5 | 0.1 |
| Minimum | | | 11,000 | -770 | 0 | 0 | -4.5 | 0.1 |
| Maximum | | | 320,000 | 11,000 | 2 | 5 | -3.1 | 1.6 |

^a Bolded values are greater than the analytical MDC.

Table B.5. SU 7 Soil Lab Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|----------------|--------------------|----------|--------|--------------------------------|-------------------------|------|------------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | | pCi/sample | |
| 5339R0052 | Laminate Over Tile | Floor | 16,000 | 650 | 0 | 0 | -- | -- |
| 5339R0053 | Laminate Over Tile | Floor | 17,000 | 570 | 2 | 0 | -- | -- |
| Minimum | | | 16,000 | 570 | 0 | 0 | -- | -- |
| Maximum | | | 17,000 | 650 | 2 | 0 | -- | -- |

Table B.6. SU 8 M1 Mezzanine Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|----------------|--------------|--------------------|-------|--------------------------------|-------------------------|------|------------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | | pCi/sample | |
| 5339R0054 | Cinder Block | West Window Ledge | -- | 6,200 | 0 | 0 | -- | -- |
| 5339R0055 | Cinder Block | West Wall | -- | 2,900 | 2 | 9 | -- | -- |
| 5339R0056 | Cinder Block | South Window Ledge | -- | 2,700 | 0 | 13 | -- | -- |
| 5339R0057 | Concrete | NW Corner of Floor | -- | 3,600 | 0 | 3 | -- | -- |
| 5339R0058 | Concrete | Floor | -- | 16,000 | 2 | 8 | -- | -- |
| Minimum | | | -- | 2,700 | 0 | 0 | -- | -- |
| Maximum | | | -- | 16,000 | 2 | 13 | -- | -- |

Table B.7. SU 9 M2 Mezzanine Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|-----------|--------------|-----------|-------|--------------------------------|-------------------------|------------|-----|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | pCi/sample | | |
| 5339R0059 | Cinder Block | East Wall | -- | -290 | 0 | 3 | -- | -- |
| Minimum | | | -- | -- | -- | -- | -- | -- |
| Maximum | | | -- | -- | -- | -- | -- | -- |

Table B.8. SU 10 TRIGA Waste Yard Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location (E, N) (ft) | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|-----------|----------|----------------------|--------|--------------------------------|-------------------------|------------|------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | pCi/sample | | |
| 5339R0038 | Concrete | 6259749, 1907389 | 31,000 | 11,000 | 0 | 2 | -6.5 | 0.8 |
| 5339R0039 | Concrete | 6259749, 1907393 | 19,000 | 680 | 0 | 6 | -- | -- |
| 5339R0040 | Concrete | 6259747, 1907396 | 17,000 | 3,800 | 2 | 4 | -- | -- |
| 5339R0041 | Concrete | 6259749, 1907392 | 16,000 | 4,200 | 0 | 2 | -- | -- |
| 5339R0042 | Concrete | 6259749, 1907387 | 14,000 | 4,100 | 0 | 5 | -- | -- |
| Minimum | | | 14,000 | 680 | 0 | 2 | -- | -- |
| Maximum | | | 31,000 | 11,000 | 2 | 6 | -6.5 | 0.8 |

| Table B.9. SU 11 TRIGA Front Yard Measurement Locations, Gamma Measurements, and Surface Activity Levels | | | | | | | | |
|--|----------|-------------------------|--------|--------------------------------|-------------------------|------|------------|------|
| Sample ID | Material | Coordinates (E, N) (ft) | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
| | | | cpm | dpm/100 cm ² | Alpha | Beta | H-3 | C-14 |
| | | | | | dpm/100 cm ² | | pCi/sample | |
| 5339R0033 | Asphalt | 6259719, 1907371 | 17,000 | -330 | 0 | 3 | -- | -- |
| 5339R0034 | Asphalt | 6259718, 1907358 | 17,000 | 1 | 0 | 0 | -- | -- |
| 5339R0035 | Asphalt | 6259736, 1907382 | 35,000 | 1,900 | 0 | 0 | -- | -- |
| 5339R0036 | Asphalt | 6259767, 1907351 | 20,000 | -170 | 0 | 0 | -- | -- |
| 5339R0037 | Asphalt | 6259766, 1907347 | 19,000 | -290 | 0 | 0 | -- | -- |
| Minimum | | | 17,000 | -330 | 0 | 0 | -- | -- |
| Maximum | | | 35,000 | 1,900 | 0 | 3 | -- | -- |

Table B.10. SU 13 Room 112 Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|-----------|--------------|------------|--------|--------------------------------|-------------------------|------|------------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | | pCi/sample | |
| 5339R0024 | Concrete | Floor | 16,000 | 1,500 | 0 | 5 | -5.5 | 0.4 |
| 5339R0025 | Concrete | Floor | 16,000 | -2,100 | 4 | 0 | -- | -- |
| 5339R0026 | Concrete | Floor | 23,000 | -1,100 | 0 | 0 | -- | -- |
| 5339R0027 | Concrete | Floor | 20,000 | -1,200 | 0 | 0 | -- | -- |
| 5339R0028 | Concrete | Floor | 16,000 | 3,200 | 0 | 0 | 3.7 | 0.3 |
| 5339R0029 | Cinder Block | South Wall | 16,000 | 100 | 2 | 0 | -- | -- |
| 5339R0030 | Cinder Block | East Wall | 15,000 | -2 | 0 | 0 | -- | -- |
| 5339R0031 | Cinder Block | North Wall | 15,000 | -210 | 0 | 3 | -- | -- |
| 5339R0032 | Cinder Block | South Wall | 18,000 | 100 | 0 | 5 | -- | -- |
| Minimum | | | 15,000 | -2,100 | 0 | 0 | -5.5 | 0.3 |
| Maximum | | | 23,000 | 3,200 | 4 | 5 | 3.7 | 0.4 |

Table B.11. Roof Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample Loc. | Material | Location | Gamma | Total Alpha-Plus-Beta Activity | Removable Activity | | | |
|-------------|----------------|--|--------|--------------------------------|-------------------------|------|------------|------|
| | | | | | Alpha | Beta | H-3 | C-14 |
| | | | cpm | dpm/100 cm ² | dpm/100 cm ² | | pCi/sample | |
| 1 | Rocks/ Roof | Near West Edge over Mark F Reactor Room | 43,000 | 3,500 | -- | -- | -- | -- |
| 2 | Metal | East Side of West Trunk over Mark F Reactor Room | 8,800 | 1,800 | -- | -- | -- | -- |
| 3 | Rocks/ Roof | To the West of the Middle Trunk over Mark F Reactor Room | 17,000 | 2,600 | -- | -- | -- | -- |
| Minimum | | | 8,800 | 1,800 | -- | -- | -- | -- |
| Maximum | | | 43,000 | 3,500 | -- | -- | -- | -- |

| Table B.12. Mark I Pit (SU 1), Front Yard (SU 11), and Back Yard (SU 12) Soil Sample Locations and Gamma Measurements | | | | | |
|---|------------------|----------|--------------------|-------------|--------|
| Sample ID | Coordinates (ft) | | Area | Gamma (cpm) | |
| | Easting | Northing | | Pre | Post |
| Random Locations | | | | | |
| 5339S0009 | 6259682 | 1907572 | Back Yard | 14,000 | 16,000 |
| 5339S0010 | 6259636 | 1907529 | Back Yard | 14,000 | 17,000 |
| 5339S0011 | 6259693 | 1907594 | Back Yard | 14,000 | 17,000 |
| 5339S0012 | 6259707 | 1907449 | Back Yard | 20,000 | 20,000 |
| 5339S0013 | 6259679 | 1907514 | Back Yard | 14,000 | 17,000 |
| 5339S0014 | 6259700 | 1907536 | Back Yard | 15,000 | 19,000 |
| 5339S0015 | 6259672 | 1907601 | Back Yard | 13,000 | 15,000 |
| 5339S0016 | 6259657 | 1907558 | Back Yard | 13,000 | 15,000 |
| 5339S0017 | 6259686 | 1907437 | Back Yard | 18,000 | 20,000 |
| 5339S0018 | 6259677 | 1907454 | Back Yard | 16,000 | 18,000 |
| 5339S0019 | 6259663 | 1907524 | Back Yard | 15,000 | 16,000 |
| 5339S0020 | 6259720 | 1907589 | Back Yard | 14,000 | 17,000 |
| Mean | | | | 15,000 | 17,000 |
| Minimum | | | | 13,000 | 15,000 |
| Maximum | | | | 20,000 | 20,000 |
| Judgmental Locations | | | | | |
| 5339S0001 | -- | -- | Mark I Reactor Pit | 29,000 | 29,000 |
| 5339S0002 | -- | -- | Mark I Reactor Pit | 29,000 | 29,000 |
| 5339S0003 | -- | -- | Mark I Reactor Pit | 27,000 | 27,000 |
| 5339S0004 | 6259695 | 1907507 | Back Yard | 15,000 | 19,000 |
| 5339S0005 | 6259698 | 1907559 | Back Yard | 14,000 | 18,000 |
| 5339S0006 | 6259712 | 1907575 | Back Yard | 16,000 | 18,000 |
| 5339S0007 | 6259698 | 1907604 | Back Yard | 17,000 | 20,000 |
| 5339S0008 | 6259696 | 1907615 | Back Yard | 17,000 | 19,000 |
| 5339S0021 | 6259719 | 1907321 | Front Yard | 14,000 | 18,000 |
| Minimum | | | | 14,000 | 18,000 |
| Maximum | | | | 29,000 | 29,000 |

Table B.13. Mark I Pit (SU 1), Front Yard (SU 11), and Back Yard (SU 12) Soil Sample Concentrations

| Sample ID | Cs-137 (pCi/g) | | | Co-60 (pCi/g) | | | Eu-152 (pCi/g) | | | Eu-154 (pCi/g) | | | SOF | Sr-90 (pCi/g) | | |
|------------------|--------------------------|-------|-------|---------------|------------------|------------------|----------------|-------|-------|----------------|-------|-------|------|---------------|-----|-----|
| | Conc. | TPU | MDC | Conc. | TPU ^a | MDC ^b | Conc. | TPU | MDC | Conc. | TPU | MDC | | Conc. | TPU | MDC |
| Random Locations | | | | | | | | | | | | | | | | |
| 5339S0009 | 0.933^c | 0.079 | 0.046 | -0.005 | 0.028 | 0.058 | -0.037 | 0.062 | 0.147 | -0.36 | 0.15 | 0.27 | 0.08 | -- | -- | -- |
| 5339S0010 | -0.012 | 0.022 | 0.046 | 0.010 | 0.024 | 0.052 | 0.062 | 0.052 | 0.129 | -0.50 | 0.16 | 0.21 | 0.01 | -- | -- | -- |
| 5339S0011 | 0.041 | 0.020 | 0.043 | -0.033 | 0.036 | 0.065 | -0.012 | 0.065 | 0.143 | -0.46 | 0.16 | 0.25 | 0.00 | -- | -- | -- |
| 5339S0012 | 0.088 | 0.021 | 0.034 | -0.004 | 0.023 | 0.046 | -0.006 | 0.053 | 0.126 | -0.215 | 0.098 | 0.192 | 0.01 | -- | -- | -- |
| 5339S0013 | -0.004 | 0.033 | 0.069 | -0.019 | 0.037 | 0.071 | -0.049 | 0.070 | 0.151 | -0.46 | 0.18 | 0.30 | 0.00 | -- | -- | -- |
| 5339S0014 | 0.066 | 0.017 | 0.030 | -0.005 | 0.016 | 0.047 | 0.012 | 0.050 | 0.118 | -0.29 | 0.10 | 0.19 | 0.01 | -- | -- | -- |
| 5339S0015 | 0.131 | 0.023 | 0.035 | 0.007 | 0.024 | 0.051 | -0.016 | 0.051 | 0.118 | -0.42 | 0.13 | 0.21 | 0.01 | -- | -- | -- |
| 5339S0016 | 0.216 | 0.031 | 0.043 | 0.009 | 0.021 | 0.054 | -0.041 | 0.063 | 0.136 | -0.38 | 0.15 | 0.24 | 0.02 | -- | -- | -- |
| 5339S0017 | 0.069 | 0.017 | 0.031 | 0.019 | 0.023 | 0.051 | -0.041 | 0.050 | 0.114 | -0.28 | 0.10 | 0.19 | 0.01 | -- | -- | -- |
| 5339S0018 | 0.077 | 0.025 | 0.048 | 0.019 | 0.033 | 0.072 | -0.069 | 0.068 | 0.142 | -0.24 | 0.13 | 0.29 | 0.01 | -- | -- | -- |
| 5339S0019 | 0.017 | 0.015 | 0.035 | 0.001 | 0.027 | 0.055 | -0.013 | 0.056 | 0.130 | -0.31 | 0.11 | 0.22 | 0.00 | -- | -- | -- |
| 5339S0020 | 0.016 | 0.026 | 0.065 | 0.021 | 0.032 | 0.071 | 0.003 | 0.067 | 0.149 | -0.54 | 0.18 | 0.28 | 0.01 | -- | -- | -- |
| Mean | 0.1 | -- | -- | 0.002 | -- | -- | -0.02 | -- | -- | -0.37 | -- | -- | 0.02 | -- | -- | -- |
| Minimum | -0.012 | -- | -- | -0.033 | -- | -- | -0.069 | -- | -- | -0.54 | -- | -- | 0.00 | -- | -- | -- |
| Maximum | 0.216 | -- | -- | 0.021 | -- | -- | 0.062 | -- | -- | -0.215 | -- | -- | 0.08 | -- | -- | -- |

Table B.13. Mark I Pit (SU 1), Front Yard (SU 11), and Back Yard (SU 12) Soil Sample Concentrations

| Sample ID | Cs-137 (pCi/g) | | | Co-60 (pCi/g) | | | Eu-152 (pCi/g) | | | Eu-154 (pCi/g) | | | SOF | Sr-90 (pCi/g) | | |
|----------------------|----------------|-------|-------|---------------|------------------|------------------|----------------|-------|-------|----------------|-------|-------|------|---------------|------|------|
| | Conc. | TPU | MDC | Conc. | TPU ^a | MDC ^b | Conc. | TPU | MDC | Conc. | TPU | MDC | | Conc. | TPU | MDC |
| Judgmental Locations | | | | | | | | | | | | | | | | |
| 5339S0001 | -0.003 | 0.028 | 0.059 | 0.042 | 0.030 | 0.072 | 0.394 | 0.057 | 0.083 | -0.38 | 0.15 | 0.28 | 0.07 | -- | -- | -- |
| 5339S0002 | 0.012 | 0.024 | 0.058 | 0.130 | 0.030 | 0.052 | 3.19 | 0.21 | 0.14 | 0.100 | 0.066 | 0.279 | 0.50 | -- | -- | -- |
| 5339S0003 | -0.022 | 0.034 | 0.070 | 0.085 | 0.030 | 0.057 | 1.81 | 0.14 | 0.12 | 0.04 | 0.12 | 0.34 | 0.29 | -- | -- | -- |
| 5339S0004 | 0.019 | 0.012 | 0.044 | 0.011 | 0.029 | 0.065 | -0.028 | 0.070 | 0.152 | -0.045 | 0.095 | 0.305 | 0.00 | 0.04 | 0.16 | 0.28 |
| 5339S0005 | -0.014 | 0.023 | 0.050 | 0.007 | 0.025 | 0.054 | 0.021 | 0.054 | 0.129 | -0.28 | 0.12 | 0.22 | 0.00 | -- | -- | -- |
| 5339S0006 | 0.264 | 0.021 | 0.047 | 0.004 | 0.028 | 0.056 | 0.029 | 0.056 | 0.128 | -0.26 | 0.11 | 0.24 | 0.03 | 0.15 | 0.15 | 0.26 |
| 5339S0007 | 0.171 | 0.025 | 0.032 | -0.013 | 0.026 | 0.050 | -0.032 | 0.052 | 0.120 | -0.28 | 0.10 | 0.20 | 0.02 | 0.27 | 0.18 | 0.28 |
| 5339S0008 | 0.235 | 0.032 | 0.038 | -0.021 | 0.016 | 0.062 | 0.034 | 0.061 | 0.147 | -0.44 | 0.16 | 0.24 | 0.03 | 0.16 | 0.16 | 0.27 |
| 5339S0021 | 0.083 | 0.018 | 0.041 | 0.002 | 0.027 | 0.057 | -0.036 | 0.057 | 0.130 | -0.59 | 0.16 | 0.23 | 0.01 | -- | -- | -- |
| Minimum | -0.022 | -- | -- | -0.021 | -- | -- | -0.036 | -- | -- | -0.59 | -- | -- | 0.00 | 0.04 | -- | -- |
| Maximum | 0.264 | -- | -- | 0.13 | -- | -- | 3.19 | -- | -- | 0.1 | -- | -- | 0.50 | 0.27 | -- | -- |

^a Uncertainties are based on total propagated uncertainties at the 95% confidence level.

^b MDC = minimum detectable concentration.

^c Bolded values are greater than the analytical MDC.

Table B.14. Mark I Pit (SU 1), Front Yard (SU 11), and Back Yard (SU 12) Soil Sample NORM Concentrations

| Sample ID | K-40 (pCi/g) | | | Ra-226 by Pb-214 (pCi/g) | | | U-238 by Th-234 (pCi/g) | | | Th-232 by Ac-228 (pCi/g) | | |
|-----------------------------|-------------------------|------------------|------------------|--------------------------|-------|-------|-------------------------|------|------|--------------------------|------|------|
| | Conc. | TPU ^a | MDC ^b | Conc. ^c | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC |
| Random Locations | | | | | | | | | | | | |
| 5339S0009 | 19.4^d | 1.6 | 0.5 | 0.877 | 0.079 | 0.079 | 1.42 | 0.51 | 0.89 | 1.16 | 0.15 | 0.16 |
| 5339S0010 | 21.1 | 1.6 | 0.7 | 0.826 | 0.072 | 0.078 | 1.86 | 0.83 | 1.60 | 1.41 | 0.15 | 0.15 |
| 5339S0011 | 19.9 | 1.6 | 0.6 | 0.847 | 0.078 | 0.074 | 1.30 | 0.47 | 0.81 | 1.10 | 0.16 | 0.18 |
| 5339S0012 | 16.3 | 1.3 | 0.7 | 0.606 | 0.062 | 0.070 | 1.14 | 0.74 | 1.59 | 1.08 | 0.14 | 0.15 |
| 5339S0013 | 25.1 | 1.9 | 0.7 | 1.008 | 0.090 | 0.088 | 2.16 | 0.77 | 1.38 | 1.59 | 0.19 | 0.19 |
| 5339S0014 | 21.3 | 1.6 | 0.6 | 0.963 | 0.078 | 0.076 | 0.79 | 0.63 | 1.42 | 1.43 | 0.15 | 0.13 |
| 5339S0015 | 20.0 | 1.5 | 0.7 | 0.754 | 0.068 | 0.072 | 1.26 | 0.83 | 1.79 | 1.03 | 0.13 | 0.14 |
| 5339S0016 | 19.4 | 1.6 | 0.6 | 0.750 | 0.071 | 0.073 | 1.16 | 0.43 | 0.75 | 1.00 | 0.14 | 0.16 |
| 5339S0017 | 20.5 | 1.5 | 0.6 | 1.211 | 0.087 | 0.082 | 1.40 | 0.69 | 1.39 | 1.44 | 0.15 | 0.13 |
| 5339S0018 | 21.6 | 1.7 | 0.6 | 1.023 | 0.088 | 0.084 | 1.15 | 0.47 | 0.88 | 1.62 | 0.19 | 0.18 |
| 5339S0019 | 23.8 | 1.8 | 0.8 | 0.985 | 0.083 | 0.086 | 1.47 | 0.87 | 1.85 | 1.70 | 0.18 | 0.16 |
| 5339S0020 | 20.9 | 1.6 | 0.6 | 0.971 | 0.083 | 0.077 | 1.06 | 0.43 | 0.81 | 1.42 | 0.17 | 0.17 |
| Mean | 20.9 | -- | -- | 0.902 | -- | -- | 1.35 | -- | -- | 1.33 | -- | -- |
| Minimum | 16.3 | -- | -- | 0.606 | -- | -- | 0.79 | -- | -- | 1.00 | -- | -- |
| Maximum | 25.1 | -- | -- | 1.211 | -- | -- | 2.16 | -- | -- | 1.70 | -- | -- |
| Judgmental Locations | | | | | | | | | | | | |
| 5339S0001 | 18.0 | 1.4 | 0.6 | 0.838 | 0.073 | 0.074 | 1.10 | 0.41 | 0.73 | 1.30 | 0.16 | 0.16 |
| 5339S0002 | 20.8 | 1.6 | 0.9 | 0.874 | 0.085 | 0.118 | 1.52 | 0.91 | 1.97 | 1.35 | 0.17 | 0.24 |
| 5339S0003 | 18.1 | 1.5 | 0.6 | 0.850 | 0.081 | 0.097 | 1.28 | 0.51 | 0.97 | 1.22 | 0.18 | 0.25 |
| 5339S0004 | 23.8 | 1.9 | 0.6 | 0.997 | 0.092 | 0.095 | 1.55 | 0.59 | 1.09 | 1.44 | 0.20 | 0.25 |
| 5339S0005 | 23.6 | 1.7 | 0.7 | 0.917 | 0.076 | 0.077 | 1.93 | 0.89 | 1.74 | 1.69 | 0.17 | 0.17 |
| 5339S0006 | 18.5 | 1.5 | 0.6 | 0.769 | 0.067 | 0.067 | 1.06 | 0.38 | 0.67 | 1.09 | 0.14 | 0.15 |
| 5339S0007 | 18.4 | 1.4 | 0.7 | 0.734 | 0.066 | 0.081 | 1.09 | 0.74 | 1.61 | 1.25 | 0.14 | 0.15 |
| 5339S0008 | 19.0 | 1.5 | 0.8 | 0.997 | 0.084 | 0.079 | 1.35 | 0.85 | 1.83 | 1.69 | 0.18 | 0.17 |
| 5339S0021 | 23.0 | 1.7 | 0.8 | 0.889 | 0.077 | 0.093 | 2.51 | 0.99 | 1.79 | 1.53 | 0.17 | 0.15 |
| Minimum | 18 | -- | -- | 0.734 | -- | -- | 1.06 | -- | -- | 1.09 | -- | -- |
| Maximum | 23.8 | -- | -- | 0.997 | -- | -- | 2.51 | -- | -- | 1.69 | -- | -- |

^a Uncertainties are based on total propagated uncertainties at the 95% confidence level.

^b MDC = minimum detectable concentration.

^c Ra-226 values are estimated only. The Pb-214 progeny did not have sufficient ingrowth to achieve equilibrium.

^d Bolded values are greater than the analytical MDC.

Table B.15. Concrete Measurement Locations, Gamma Measurements, and Surface Activity Levels

| Sample ID | Area | Material | Location (E, N) (ft) | Gamma | | Total Alpha-Plus-Beta Activity | |
|-----------|--------------------------|----------|-------------------------|------------|-------------|--------------------------------|-------------------------|
| | | | | Pre-Sample | Post-Sample | Pre-Sample | Post-Sample |
| | | | | cpm | cpm | dpm/100 cm ² | dpm/100 cm ² |
| 5339M0001 | Mark F Reactor Pit Canal | Concrete | Floor | 14,000 | -- | 440,000 ^a | -430 |
| -- | Mark F Reactor Pit Canal | Concrete | N of M0001 | -- | -- | -- | 180,000 |
| -- | Mark F Reactor Pit Canal | Concrete | S of M0001 | -- | -- | -- | 200,000 |
| 5339M0002 | Waste Yard | Concrete | 6259749, 1907389 | 31,000 | 17,000 | 11,000 | 1,900 |
| -- | Waste Yard | Concrete | Beside M0002 | -- | 21,000 | -- | 3,800 |
| 5339M0003 | Mark I Reactor Pit | Concrete | Site Loc. 19 | -- | -- | -- | -- |
| 5339M0004 | Mark F Reactor Pit | Concrete | Site Loc. 25 | -- | -- | -- | -- |

^a For completeness an alpha-only measurement was collected prior to sample collection and the result was 13 counts per minute (gross).

Table B.16. Concrete Sample Concentrations

| Sample ID | Cs-137 (pCi/g) | | | Co-60 (pCi/g) | | | Eu-152 (pCi/g) | | | EU-154 (pCi/g) | | | SOF | Sr-90 (pCi/g) | | |
|-----------|-------------------------|------------------|------------------|---------------|-------|-------|----------------|-------|-------|----------------|------|------|------|---------------|------|------|
| | Conc. | TPU ^a | MDC ^b | Conc. | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC | | Conc. | TPU | MDC |
| 5339M0001 | 26.5^c | 1.5 | 0.1 | 0.211 | 0.053 | 0.081 | -0.03 | 0.20 | 0.44 | -0.36 | 0.21 | 0.44 | 2 | 0.49 | 0.22 | 0.32 |
| 5339M0002 | 114.0 | 6.5 | 0.3 | -0.041 | 0.061 | 0.111 | 0.07 | 0.39 | 0.85 | -0.33 | 0.24 | 0.47 | 10 | 6.40 | 0.54 | 0.33 |
| 5339M0003 | 0.025 | 0.031 | 0.074 | -0.039 | 0.055 | 0.103 | 0.06 | 0.11 | 0.27 | -0.56 | 0.21 | 0.42 | 0.01 | 0.07 | 0.16 | 0.28 |
| 5339M0004 | 0.127 | 0.032 | 0.055 | -0.011 | 0.046 | 0.094 | 0.043 | 0.097 | 0.233 | -0.12 | 0.16 | 0.39 | 0.02 | 0.04 | 0.17 | 0.29 |

^a Uncertainties are based on total propagated uncertainties at the 95% confidence level.

^b MDC = minimum detectable concentration.

^c Bolded values are greater than the analytical MDC.

Table B.17. Concrete Sample NORM Concentrations

| Sample ID | K-40 (pCi/g) | | | Ra-226 by Pb-214 (pCi/g) | | | U-238 by Th-234 (pCi/g) | | | Th-232 by Ac-228 (pCi/g) | | |
|-----------|-------------------------|------------------|------------------|--------------------------|-------|-------|-------------------------|------|------|--------------------------|------|------|
| | Conc. | TPU ^a | MDC ^b | Conc. ^c | TPU | MDC | Conc. | TPU | MDC | Conc. | TPU | MDC |
| 5339M0001 | 18.8^d | 1.8 | 1.3 | 0.859 | 0.083 | 0.294 | 0.87 | 0.66 | 1.47 | 1.08 | 0.21 | 0.31 |
| 5339M0002 | 16.2 | 1.7 | 1.5 | 0.77 | 0.21 | 0.46 | 0.97 | 0.75 | 1.69 | 0.90 | 0.19 | 0.30 |
| 5339M0003 | 19.3 | 1.9 | 2.4 | 1.12 | 0.14 | 0.23 | 1.39 | 0.80 | 1.68 | 1.47 | 0.25 | 0.39 |
| 5339M0004 | 7.0 | 1.2 | 2.1 | 0.193 | 0.089 | 0.199 | 0.68 | 0.58 | 1.29 | 0.37 | 0.16 | 0.33 |

^a Uncertainties are based on total propagated uncertainties at the 95% confidence level.

^b MDC = minimum detectable concentration.

^c Ra-226 values are estimated only. The Pb-214 progeny did not have sufficient ingrowth to achieve equilibrium.

^d Bolded values are greater than the analytical MDC.

| Table B.18. Material Specific Backgrounds ^a | | | | | |
|--|---------------------------|------------------------|-------------------|-------------------|-------------------|
| Ludlum Model 43-68 Gas Proportional Detector | | | | | |
| # | Poured Unpainted Concrete | Unpainted Cinder Block | Metal | Asphalt | Ambient Air |
| | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) |
| 1 | 688 | 489 | 293 | 911 | 334 |
| 2 | 649 | 510 | 276 | 885 | 351 |
| 3 | 749 | 507 | 290 | 894 | 331 |
| 4 | 731 | 491 | 307 | 877 | 299 |
| 5 | 704 | 519 | 281 | 887 | 322 |
| 6 | 756 | 539 | 261 | 928 | 317 |
| 7 | 732 | 462 | 282 | 880 | 329 |
| 8 | 712 | 461 | 251 | 949 | 327 |
| 9 | 725 | 519 | 283 | 951 | 335 |
| 10 | 729 | 456 | 286 | 936 | 322 |
| Mean | 720 | 500 | 280 | 910 | 330 |
| Ludlum Model 44-10 Scintillation Detector | | | | | |
| # | Poured Unpainted Concrete | Unpainted Cinder Block | Metal | Asphalt | Ambient Air |
| | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) | Measurement (cpm) |
| 1 | 13,937 | 11,954 | 8,581 | 16,058 | -- |
| 2 | 13,575 | 12,756 | 8,248 | 16,206 | -- |
| 3 | 14,246 | 12,142 | 8,342 | 15,957 | -- |
| 4 | 14,408 | 12,433 | 8,407 | 15,999 | -- |
| 5 | 13,883 | 11,889 | 8,733 | 16,249 | -- |
| 6 | 14,635 | 11,425 | 8,618 | 16,222 | -- |
| 7 | 14,059 | 11,556 | 8,925 | 16,113 | -- |
| 8 | 14,348 | 11,534 | 8,501 | 15,657 | -- |
| 9 | 14,707 | 11,476 | 8,578 | 15,642 | -- |
| 10 | 14,021 | 11,721 | 8,928 | 16,144 | -- |
| Mean | 14,000 | 12,000 | 8,600 | 16,000 | -- |

^a The site determined background reference area was outdoors just outside the main entrance to Building 27.

APPENDIX C: 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.

C.1. SCANNING AND MEASUREMENT INSTRUMENT/ DETECTOR COMBINATIONS

C.1.1 GAMMA

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

C.1.2 ALPHA-PLUS-BETA

Ludlum Gas-flow Proportional Detector Model 43-68, 126 cm² physical area, 0.8 mg/cm² Mylar window
(Ludlum Measurements, Inc., Sweetwater, Texas)
coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)

Ludlum Gas-flow Proportional Detector Model 43-37, 584 cm² physical area, 0.8 mg/cm² Mylar window
(Ludlum Measurements, Inc., Sweetwater, Texas)
coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)

C.2. LABORATORY ANALYTICAL INSTRUMENTATION

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

High-Purity, Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:

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

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

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

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

APPENDIX D: SURVEY AND ANALYTICAL PROCEDURES

D.1. PROJECT HEALTH AND SAFETY

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 walk down of the survey areas were completed with field personnel to identify hazards present and discuss safety concerns. Should ORISE have identified a hazard not covered in 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.

D.2. CALIBRATION AND QUALITY ASSURANCE

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

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

- *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2016a)
- *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2019b)
- *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2019a)

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

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment

operation is within acceptable statistical fluctuations

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

D.3. SURVEY PROCEDURES

D.3.1 SURFACE SCANS

Gamma scans were performed using a hand-held sodium iodide (NaI) scintillation detector with a 5 centimeter (cm) by 5 cm crystal. Alpha-plus-beta scans were performed using either the large-area (floor monitor) or hand-held gas proportional detector with a 0.8 mg/cm² window with a physical detector area of 584 cm² or 126 cm², respectively. Scans for elevated radiation were performed by passing the detector slowly over the surface. The distance between the detector and surface was maintained at a minimum. NUREG-1507, Table 6.4, provides NaI Scintillation Detector Scan MDCs for Common Radiological Contaminants (NRC 1998). For cesium-137 (Cs-137), the scan minimum detectable concentration (MDC) is 6.4 picocuries per gram (pCi/g) and, for cobalt-60 (Co-60), the MDC is 3.4 pCi/g. A specific scan MDC for the floor monitor was not determined as the instrument was used solely as a qualitative means to identify elevated radiation levels in excess of background. Identifications of elevated radiation levels that could exceed the background were determined based on an increase in the audible signal from the indicating instrument and quantitatively investigated using other hand-held instruments.

Surface scan MDCs for the hand-held gas proportional detectors were estimated using the approach described in NUREG-1507 (NRC 1998). The scan MDC is a function of many variables, including a 2-second observation interval; a specified level of performance at the first scanning state of 95% true positive and 25% false positive rate, which yields a d' value of 2.32 (NUREG-1507, Table 6.1); and a surveyor efficiency of 0.5. For survey units inside the building, the predominant radionuclide is assumed to be Co-60 and outside of the building, Cs-137. As such the total weighted efficiencies for beta are 0.10 for inside the building and 0.22 for outside the building. The scan MDC was calculated using the following equation:

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

Where:

d' = index of sensitivity

C_b = background (cpm)

i = observation interval (sec)

p = surveyor efficiency

ϵ_t = total efficiency

The scan MDC for surveys inside the building was 2,700 disintegrations per minute (dpm)/100 cm² and 1,200 dpm/100 cm² outside the building, both based on a nominal instrument background of 330 cpm for the hand-held gas proportional detector.

D.3.2 SURFACE ACTIVITY MEASUREMENTS

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

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

Where:

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

T = count time (min) used for field instruments

ϵ_{tot} = total efficiency = $\epsilon_i \times \epsilon_s$ (instrument efficiency \times source efficiency)

G = geometry correction factor (1.26)

The static MDC for inside the building was 720 dpm/100 cm² and 320 dpm/100 cm² outside the

building, both based on a nominal instrument background of 330 cpm.

D.3.3 REMOVABLE ACTIVITY SAMPLING

Smear sampling for removable gross alpha and gross beta contamination as well as for hard-to-detect (HTD) radionuclides were obtained from independent confirmatory measurement locations. Removable activity samples were collected using numbered filter paper disks. Moderate pressure was applied to the smear and approximately 100 cm² of the surface was wiped. Dry smears for gross alpha and beta analysis were placed in labeled envelopes. Smears for HTD analysis were first wetted with deionized water before the surface was wiped. Wet smears were placed in glass vials with deionized water. Locations and other pertinent data were recorded and all samples were transferred under chain-of-custody.

D.3.4 SOIL SAMPLING

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

D.4. RADIOLOGICAL ANALYSIS

D.4.1 GROSS ALPHA/BETA

Smears were counted on a low-background proportional counter for gross alpha and beta activity. The minimum detectable activity of the procedures is approximately 11 dpm/100 cm² for alpha and 14 dpm/100 cm² for beta.

D.4.2 GAMMA SPECTROSCOPY

Samples were analyzed as received, mixed, crushed, and/or homogenized as necessary, and a portion sealed in an appropriately sized Marinelli beaker. The quantity placed in the beaker was chosen to reproduce a calibrated counting geometry. Net material weights were determined, and the samples were counted using intrinsic, high-purity, germanium detectors coupled to a pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using computer capabilities inherent in the analyzer system. All total

absorption peaks (TAPs) associated with the radionuclides of interest were reviewed for consistency of activity. Spectra also were reviewed for other identifiable TAPs.

| Table D.1. Typical MDCs Total Absorption Peak | | |
|---|------------------------|-------------|
| Radionuclide | TAP (MeV) ^a | MDC (pCi/g) |
| Co-60 | 1.332 | 0.06 |
| Cs-137 | 0.662 | 0.05 |
| Eu-152 | 0.344 | 0.10 |
| Eu-154 | 0.723 | 0.15 |

D.4.3 H-3 AND C-14 ANALYSIS

Smear samples were placed into a scintillation cocktail without sample preparation and counted in a liquid scintillation analyzer. Tritium (H-3) and carbon-14 (C-14) values were calculated using the known efficiency in the appropriate energy region.

D.4.4 DETECTION LIMITS

Detection limits, referred to as MDCs, were based on 95% confidence level. 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.