CUA

THE CATHOLIC UNIVERSITY OF AMERICA

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April 5, 2016

License No. SUD-157

Docket No. 040-06329

Daniel Collins
Director, DNMS
United States Nuclear Regulatory Commission-Region I
2100 Renaissance Blvd. Suite 100
King of Prussia, PA 19406-2713

Dear Mr. Collins

In response to our recent correspondence and conversations, The Catholic University of America performed additional decommissioning surveys in Maloney Hall. The University closed Maloney Hall in 2014 for renovation and repurpose into a non-laboratory academic and administrative facility.

Enclosed please find the follow up radiation survey report performed by Ecology Services under the direction of CUA's RSO to support the release of referenced laboratory rooms in Maloney Hall. Please advise if the report meets your approval for the unrestricted use of Maloney Hall.

If you have any questions or need further information, please contact Mr. Mahmoud S. Haleem at 202-319-5206 or email Haleem@cua.edu.

Sincerely,

Mr. Louis Alar
Director, Environmental Health & Safety

Cc:

Mr. Mahmoud S. Haleem, Radiation Safety Officer
Dr. Aaron Barkatt, Chair, Radiation Safety Committee

Enclosure: Hard and electronic copy of the report

590584
NMSS/RGNI MATERIALS-002

Final Status Survey Report

The Catholic University of America
Maloney Hall Chemistry Building Rm 4, 7 & 213
620 Michigan Ave, N.E.
Washington, DC 20064

Prepared by:

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ECOLOGY
SERVICES, INC.

March 2016

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List of Acronyms

ALARA	As Low As Reasonably Achievable
CFR	Code of Federal Regulations
Ci	Curie
CUA	The Catholic University of America
DU	Depleted Uranium
DCGL	Derived Concentration Guideline Level
$DCGL_{EMC}$	Derived Concentration Guideline Level Elevated Measurement Comparison
DQO	Data Quality Objective
ESI	Ecology Services, Inc.
FSS	Final Status Survey
HSA	Historical Site Assessment
LBGR	Lower Bounds of the Gray Region
LSC	Liquid Scintillation Counter
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
mCi	millicuire
MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
NOC	Nuclide(s) of concern
NRC	Nuclear Regulatory Commission
NUREG	US Nuclear Regulatory Commission Regulation
PPE	Personal Protective Equipment
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RSO	Radiation Safety Officer
SN	Serial Number
Th-NAT	Natural Thorium
σ	Standard Deviation
TEDE	Total Effective Dose Equivalent
^{232}Th	Thorium-232
U-NAT	Natural Uranium
VSP	Visual Sample Plan

Executive Summary

The Catholic University of America (CUA), located at 620 Michigan Ave N.E, Washington, DC 20064, has terminated license activities in rooms 4, 7 and 213 of Maloney Hall under their Nuclear Regulatory Commission (NRC) Radioactive Materials Program License No. SUD-157. This report presents the methods, results, and conclusions of the Final Status Survey (FSS) that was conducted to determine whether these rooms are acceptable for unrestricted release in accordance with the NRC free release requirements.

It should be noted that the report is the second FSS report for these areas. The initial assumed natural forms of thorium and uranium for the building occupancy scenario. It was later determined with discussions with the NRC and CUA that only licensable forms of uranium exist and the areas are to be renovated. Data in the initial report will be used as characterization data for this FSS.

The release criteria, against which the survey findings were applied, was the Derived Concentration Guideline Level (DCGL). The DCGLs were calculated for a total effective dose equivalent (TEDE) of 25 mrem/yr using the computer code DandD Version 2.1 with default parameters. The only known possible contaminants were various forms of natural uranium (U-NAT; oxides, acetates and nitrates in solid and aqueous forms) as well as depleted uranium (DU). The calculated DCGL for U-NAT was 94 dpm/100cm^2 and 98 dpm/100cm^2 for DU. Each was calculated with the default of 10% maximum removable activity. Specifically U-NAT was selected as the most restrictive DCGL for this FSS.

The survey was conducted on February 15th-19th, 2016 for fixed and removable contamination. Results showed the following:

- The scanning surveys, static measurements, and wipe samples for removable contamination all showed that the survey units average was much less than the DCGL.
- All results were less than the DCGL.
- All results were less than the minimum detectable activity (MDA) except for one static measurement.

From the results it is concluded that rooms 4, 7 and 213 in Maloney Hall of The Catholic University of America, located at 620 Michigan Ave N.E, Washington, DC 20064, are acceptable for unrestricted release.

1.0 Introduction

1.1 General

The Catholic University of America (CUA), located at 620 Michigan Ave N.E, Washington, DC 20064, has terminated license activities in rooms 4, 7 and 213 of Maloney Hall. Although their Nuclear Regulatory Commission (NRC) Radioactive Materials Program License No. SUD-157 does not expire until September 30th, 2023 (See Attachment A), they have ceased licensed activities in these rooms. The final status survey (FSS) was conducted to determine whether the radioactive material usage and storage areas are acceptable for unrestricted release in accordance with the NRC unrestricted release requirements.

1.2 Site History

Maloney Hall is situated on the southeast edge of campus along Michigan Avenue N.E. and John McCormack Drive N.E. This facility is less than 3 air miles northeast of the White House, placing it in a highly dense region of residential and commercial properties. Maloney Hall is located in red below in Figure 1.1.

CUA began the operation with radioactive material (RAM) back in the 1950s. Although specific licensable activities subject to this FSS did not begin until 2013. Specifically for these three rooms sample preparation, analysis and storage was performed for natural uranium (U-NAT) and depleted uranium (DU) as specified in RAM License SUD-157. A review of their inventory records has allowed for the determination that room 213 also stored three sealed sources (Cobalt-57, Tin-119, and Samarium-151) that were determined to be intact and not leaking.

Figure 1.1 Maloney Hall of The Catholic University of America Campus[1]

[1] The Catholic University of America, "Campus Map", www.cua.edu/map, December 9th, 2014.

1.3 Purpose and Scope

Ecology Services, Inc. was contracted to perform a FSS in the radiological usage area to demonstrate that radiological conditions satisfy regulatory agency requirements for unrestricted release. These areas were surveyed on February 15th-19th, 2016.

The survey does not include environmental sampling exterior to the building (i.e., soil or vegetation) or other areas outside of the scope. Furthermore the three sealed sources mentioned above in Section 1.2 were not considered nuclides of concern (NOC) since there was no evidence that these sources have leaked. These sources are also part of a separate license at CUA and were considered out of scope. It should be noted that the use of a micro-rem exposure rate meter was used as a quality assurance measure and found no elevated readings.

1.4 Release Criterion

The release criterion, against which the survey findings were applied, is that specified by the NRC, Code of Federal Regulations (CFR), Title 10 Subtitle 20 Subpart E 1402, specifically:

> *A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA).*[2]

For removable and surficial contamination, the release criterion was translated into a derived concentration guideline level (DCGL) for the identified potential contaminants. The DCGL was calculated using default parameters with DandD Version 2.1. It was concluded that the calculation for a total effective dose equivalent (TEDE) for 25 mrem/yr (see Table 1 below) yielded 94 dpm/100cm^2 for U-NAT and 98 dpm/100cm^2 for DU with a maximum of 10% removable. It should be noted that the calculated DCGLs used the respective ratio of U-234, U-235 & U-238 found in DU and natural uranium.

The DCGL has been calculated to meet the ALARA TEDE requirement of 25 mrem/yr. It should be noted that the ALARA principle was further exercised as needed.

Table 1: DCGL for 25 mrem/yr TEDE per Isotope

Isotope	Half-life	Radiation Type	Total Activity (dpm/100cm^2)	Removable Activity (dpm/100cm^2)
U-NAT	4.5E9 years	α β γ	94	9.4
DU	4.5E9 years	α β γ	98	9.8

1.5 Study Boundaries

The FSS is restricted to the interior of the facility, and more specifically the three rooms within Maloney Hall.

[2] 10 CFR 20.1402: *Radiological criteria for unrestricted use.*, January 9th, 2016.

1.6 Decision Rule

The parameter of interest in determining whether the survey results satisfy the release criteria is that the mean value of the residual activity is less than the DCGL.

A typical survey unit will be evaluated using three methods, each being used to determine fixed or removable contamination levels which will be evaluated against the DCGL. Table 2 represents the methods that were used to determine fixed and/or removable contamination for each survey unit.

Table 2: Evaluation Methods	
Evaluation Methods	**Parameter Identified**
Scanning Surveys	Fixed and Removable Contamination
Static Measurements at selected points	Fixed and Removable Contamination
Wipe Sample Measurements	Removable Contamination

1.7 Management

A team of qualified personnel from ESI performed the survey; an organizational chart is shown in Figure 1.2. Lab personnel performed analytical services for gross radiation levels on wipes using approved standard operating procedures.

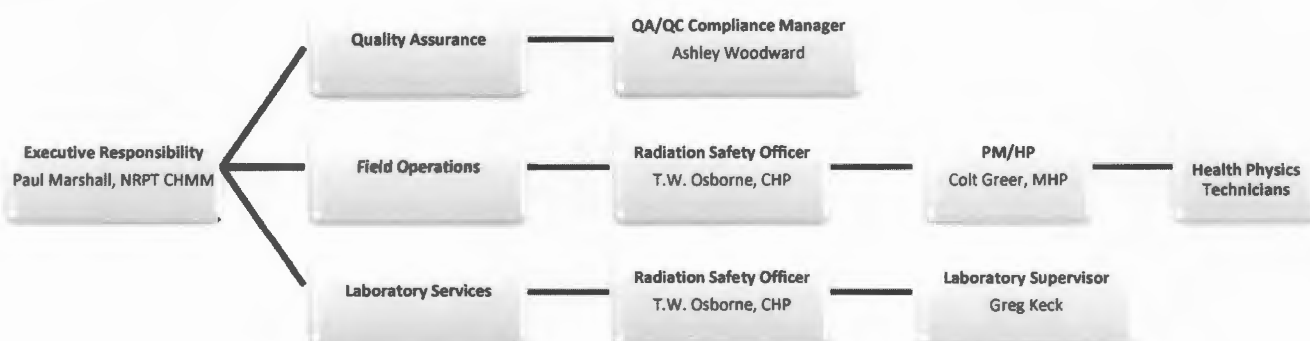


Figure 1.2 Ecology Services, Inc. Personnel

The following details the duties of the personnel performing services for this effort:

Project Manager (PM):

- Provides central leadership, direction, and management of the decommissioning process and Quality Assurance (QA) Program;
- Ensures project quality and primary responsibility for coordinating activities and resolution of concerns with the facility personnel;
- Provides overall project management and communication between regulatory staff and project personnel;
- Approves the project Quality Assurance Project Plan (QAPP) and project-specific implementing procedures;
- Ensures compliance with project plans and procedures by means of daily site inspections/surveillances;
- Ensures that project personnel are wearing personal radiation monitors and personal protective equipment (PPE) appropriate for the task;
- Identifies and maintains proper work area boundaries and signage;
- Ensures that materials and equipment are properly scanned before exiting a radiological control zone; and
- Stops unsatisfactory work.

Radiation Safety Officer (RSO):

- Has ultimate responsibility and authority for oversight of the project radiation protection program governing the technical aspects of work performed at the facility;
- Ensures that all project personnel are properly trained for their respective tasks;
- Ensures that radiological monitoring equipment is checked daily; and
- Manages the health physics technician(s) performing monitoring and characterization activities in support of the work.

Quality Assurance/Quality Control (QA/QC) Compliance Manager:

- Ensure that preparation and maintenance of the QA Program are responsive to NRC QA requirements;
- Implement NRC and the facility quality policies and define the direction of the QA Program with respect to these policies;
- Determine when conditions during decommissioning are not in compliance with the QA Program;
- Review and approve procedures implementing the requirements of the facility's QA Program; and
- Maintains required QA records.

Health Physics (HP) Technicians:

- Provide the requisite level of quality in work performed;
- Perform work safely and correctly the first time, and assure that reliability, performance, and customer satisfaction are maximized;
- Meet established requirement and recommend improvements in material and work process quality;
- Inform management of suspected unsafe or unacceptable quality conditions; and
- Stops work when it is known or suspected that work being performed could potentially result in an unsafe or unacceptable quality condition.

1.8 Training

Training of project personnel is commensurate with their experience, their responsibilities and the potential hazards to which they would be exposed. Records are maintained that show the employee's name, training date, type of training received, and other relevant information. Training includes, as applicable:

- General Employee Training, which consisted of a general orientation on site requirements and policies;
- Radiation worker training; and
- Job-specific training, which was performed as appropriate for individual jobs.

These records are available upon request.

2.0 Quality Assurance Project Plan

This Plan describes the results of the Data Quality Objectives (DQOs) Process conducted to develop quality assurance and quality control for the FSS of CUA. DQOs are developed in order to identify and implement sampling and analytical methodologies which limit the introduction of error into the analytical data [MARSSIM, Section 9.1].

The DQOs are qualitative and quantitative statements derived from the outputs of the DQO process that:

(1) Clarify the study objective;
(2) Define the most appropriate type of data to collect;
(3) Determine the most appropriate conditions for collecting the data; and
(4) Specify limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision.

The DQO Process ensures that:

a) The elements of the facility characterization and final status survey plans will be implemented in accordance with the approved procedures;
b) Surveys will be conducted by trained personnel using calibrated instrumentation;
c) The quality of the data collected will be adequate;
d) All phases of facility characterization and final survey data acquisition and evaluation will be properly reviewed, and oversight provided; and
e) Corrective actions, when identified, will be implemented in a timely manner and determined to be effective.

The above DQOs were incorporated into the survey planning and design shown below.

3.0 Survey Plan and Design

3.1 Statement of the Problem

CUA in Washington, DC has ceased licensable activities in Maloney Hall rooms 4, 7 & 213 entirely. These areas must comply with NRC requirements for unrestricted use in order to freely release them from license requirements.

To ensure the release criterion is met, all FSS work was conducted under the regulatory scope of the NRC Region 1, under the guidance of the following:

- US Nuclear Regulatory Commission Regulation (NUREG) 1727, *NMSS Decommissioning Standard Review Plan*
- NUREG 1757, Vol.2, *Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria*
- NUREG 1757, Vol.1, *Consolidated Decommissioning Guidance: Decommissioning Process for Materials Licensees*
- NUREG 1575, MARSSIM
- 10 CFR 20.1402, *Radiological criteria for unrestricted use*
- *DCMR Title 22, Chapter 22-B67*

3.2 Identification of the Decision

The decision is based on whether or not the survey unit satisfies the release criterion discussed previously in Section 1.4.

3.3 ALARA Consideration

In order to freely release restricted areas, a licensee must demonstrate that the release criteria have been met and must demonstrate whether it is feasible to further reduce the level of residual radioactivity to levels below those necessary to meet the release criteria (i.e. to levels that are ALARA). Additionally, explicit analyses do not have to be done for areas where no residual radioactivity distinguishable from background has been found. If residual radioactivity cannot be detected, it may be assumed that it has been reduced to levels that are ALARA.[3]

Furthermore, "Removal of loose residual radioactivity from buildings is almost always cost- effective except when very small quantities of radioactivity are involved. Therefore, loose residual radioactivity normally should be removed, and if it is removed, the analysis would not be needed."[3] However, "... screening levels developed by the NRC staff, the staff presumes, absent information to the contrary, that licensees or responsible parties that remediate building surfaces or soil to the generic screening levels do not need to demonstrate that these levels are ALARA."[3]

It should be noted that this selected DCGL is equivalent to the screening levels developed by the NRC. Additionally, remediation actions of general housekeeping have been performed as needed.

[3] NUREG-1727 Appendix D

3.4 Identify Inputs to the Decision

There are numerous aspects which need to be evaluated for this survey plan and design. They are listed below:

3.4.1 Historical Site Assessment

Information was gathered from a review of the historical site assessment (HSA) (Attachment B) as well as interviews with the current radiation safety officer (RSO). This has led to the conclusion that the survey units should not have any levels of contamination above DCGL prior to remediation. In fact, routine surveys (See Attachment C) as well as ESI's characterization survey had no measurements above minimal detectable concentrations (MDC) for instrumentation used.

3.4.2 Scoping and Characterization Surveys

Scoping surveys are conducted to provide preliminary data to support the HSA information needed to guide planning of characterization surveys, to identify radionuclide contaminants, to identify relative radionuclide ratios, and to identify the general levels and extent of contaminants.

Available radiological data on facilities, systems, and equipment are generally considered to be scoping data. Therefore the routine surveys performed (Attachment C) meet the requirements of scoping surveys.

Characterization surveys include facility and site sampling, monitoring, and analysis activities to determine the extent and nature of residual contamination. They provide the basis for planning decommissioning actions, and provide technical information to develop, evaluate, and select appropriate remediation techniques. They also provide information for radiation protection purposes and for characterizing waste. Additionally, characterization surveys can be performed so that they are commensurate with the FSS requirements and be used to determine the outcome of the FSS. ESI's survey in 2014 will be used as the characterization survey.

This report details the FSS which was performed to determine the outcome of each survey unit.

3.4.3 Building Surface Contamination

It can reasonably be assumed that the following existed for building surface contamination:

- The contamination on building surfaces (walls, floors, ceilings, etc.) is surficial and non-volumetric (ex. <10mm (0.4 in.)[4]);
- Contamination on surfaces is mostly fixed, with the fraction of loose contamination not to exceed 10 percent (generally accepted value) of the total surface activity;

[4] NUREG 1757 Vol. 1, Rev. 2

- The screening criteria will not be applied to surfaces such as buried structures (e.g., drainage or sewer pipes); such structures and buried surfaces will be treated on a case-by-case basis.

If the above information were to be concluded differently based on the results of the FSS, then ESI would take the necessary steps for re-evaluation.

3.4.4 Determination of Survey Units

Examination of past site operations along with site scoping and characterization surveys are used in the determination of survey units and their classification. Areas are determined to be either impacted or non-impacted.

Impacted Areas are areas that may have residual radioactivity from the licensed activities and are classified into one of three classes based on levels of residual radioactivity:

- Class 1: Impacted areas that, prior to remediation, are expected to have concentrations of residual radioactivity that exceed the DCGL.

- Class 2: Impacted areas that, prior to remediation, are not likely to have concentrations of residual radioactivity that exceed the DCGL.

- Class 3: Impacted areas that have a low probability of containing residual radioactivity, at a small fraction of the DCGL.

Non-Impacted Areas are areas without residual radioactivity from licensed activities. In the FSS, radiation surveys do not need to be conducted in non-impacted areas.

Table 3 displays the classification for the survey unit based on records, data and conservatism. It should be noted that upper walls and ceilings were considered non-impacted. These areas fell within the MARSSIM recommended survey unit area size for the appropriate classification for structures (i.e. Class 1 Floor Area ≤ 100 m^2).

Table 3: Survey Unit Classification

Survey Unit	Classification	Survey Unit Size (Floor area m^2)	Survey Unit Size m^2 (including lower walls <6')
Maloney Hall Room 4	Class 1	32.76	76.32
Maloney Hall Room 7	Class 1	66.37	76.05
Maloney Hall Room 213	Class 1	32.83	141.5

3.4.5 Appropriate DCGL Selection(s)

Radionuclide-specific DCGLs were used to demonstrate compliance with release criterion discussed in Section 1.4. MARSSIM [Section 4.3] provides three methods for determining DCGLs for sites with multiple radionuclides:

(1) Gross activity: The process of determining a site-specific DCGL based on the individual DCGL of each radionuclide present and their relative fraction of the total contributed activity.

(2) Unity Rule: The process of establishing radionuclide mixtures that yield a combined fractional concentration limit that is less than or equal to one.

(3) Use of the most conservative surface contamination DCGL from the mixture of radionuclides present.

Based upon the scoping information, the selection of method (3) was chosen for this FSS. Method (3) was used since each nuclide of concern is an alpha emitter with nearly identical detection efficiency.

3.4.6 Sample Number and Locations

The number of sample locations was determined using MARSSIM Section 5.5.2.3 with the aid of the characterization data and decision errors (see Section 3.4.8 below). This method determined the required number of samples to be 20.

Visual Sample Plan (VSP) software Version 7.0 can also be used to determine the number of samples (uses MARSSIM Section 5.5.2.3 methodology) and their locations. Class 1 areas use a non-parametric systematic triangular grid pattern with a random start sampling technique. VSP documentation describes the process and is shown in Attachment F.

The number of survey locations was determined during input of survey unit parameters via VSP, which is compliant with the MARSSIM Method. It should be noted however that VSP is only automatically compliant for survey units which meet the MARSSIM suggested survey unit size (which is true in this case) and if the MDC_{SCAN} requirements are met.

For this FSS it was determined that the $DCGL_{EMC}$ requirement was not met for the largest survey unit (Maloney Hall Room 7). Thus the appropriate number of samples required was determined using MARSSIM Section 5.5.2.4 to be 34 samples. This calculated value must be manually entered by the user in VSP so that the proper number of unbiased systematic samples are taken.

3.4.7 Selection, Calibration and Operation of Instrumentation

Proper selection and use of instrumentation ensures that sensitivities are sufficient to detect radionuclides as well as assuring the validity of the data. Instrument calibrations were performed annually with NIST traceable sources using approved procedures. Instrument operability was verified by performing daily background and check sources when in use.

For U-NAT (alpha (α), beta (β), gamma (γ) emitter) the assessment of fixed/total contamination can be performed with scintillators and/or gas operated detection systems. Based on probe areas, efficiencies and the DCGL, a zinc sulfide scintillator was selected as the best detection system for this isotope.

A windowless gas flow proportional counter will be used to quantify the levels of removable contamination. Based on the DCGL the counter will be set on the alpha region to meet the MDC requirements.

3.4.7.1 Scanning Surveys

Scanning surveys were performed to locate radiation anomalies indicating residual gross activity that may require further investigation or action. These surveys were performed prior to static measurement and sampling due to the low probability of identifying elevated counts on areas derived from grid spacing with these other methods. Scanning also provides the surveyor with regions where judgmental sampling may be performed and therefore must be done first.

The instruments having the lowest detection sensitivity were used for the scans wherever physical surface conditions and measurement locations permitted. Scanning speeds were approximately performed at 1/5 probe width per second. Audible features on the instrumentation were used to identify locations having elevated count rates.

Procedures are provided in MARSSIM for calculating scan Minimum Detectable Concentrations (MDCs) for particular survey instruments. More detail on signal detection theory and instrument response is provided in NUREG-1507, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*. These procedures were followed to obtain appropriate probability of a scan to find a predetermined level of activity. This calculation took into account site-specific factors such as background, scanning speed and surface efficiency.

Background was slightly variable depending on the surface types present throughout the survey units. As a means of conservatism, the determination of the MDC compliance with MARSSIM was done using the highest average background for a given instrument. It should be noted however that this variation in average background was from 1-3 counts during a 60 second integrated measurement. Therefore the same equation (See Equation 1 below) was used for determination of the probability to observe a single count. Additionally G in equation 1 was set to the $DCGL_{EMC}$ since the survey units were classified as Class 1 areas. This meets the MDC_{SCAN} requirements in MARSSIM.

$$Equation\ 1: \quad P(n \geq 1) = 1 - e^{\frac{-GEd}{60v}}$$

$$Where: G = DCGL\ (dpm)$$

$$E = Detector\ Efficiency\ (4pi)$$

$$d = Detector\ width\ in\ direction\ of\ scan\ (cm)$$

$$v = scan\ speed\ (cm/s)$$

The MDC_{SCAN} probability for the instrumentation selected was simulated with the use of plutonium-239 (alpha emitter). This alpha emitter is similar to U-NAT in regards to average alpha energies and is considered acceptable to use. Table 4 displays the input parameters used in Equation 1 above to determine the probability of observing 1 count.

Table 4: Alpha Scanning Probability to Observe a Single Count w/BKG 1-3 cpm									
Instrument Make/ Model	Probe	Active Area (cm^2)	Background (cpm)	G (dpm/ probe area)	Radio-Nuclide	Efficiency (4pi, $\varepsilon_i{}^*\varepsilon_s$)	d (cm)	v (cm/s)	P
Ludlum Model 12	43-90	125	1-3	275	^{239}Pu	10.79%	7	1.5	90.1%

Based on the scanning calculation, the activity equal to the DCGL yields 90% confidence with a scan speed of 1/5 probe width per second. This also meets the MARSSIM scan sensitivity requirement that the instrument used is capable of detecting the $DCGL_{EMC}$.

Once the surveyor observed a single count, he/she paused for 6 seconds. If another count was observed the surveyor then paused to take a 60 second integrated measurement. This was recorded on the scanning survey sheet. If the surveyor did not observe another count he/she continued scanning the surface area.

The 6 second pause was determined using Equation 2 below. This equation was used to determine the time interval needed to observe a specific level of activity.

$$Equation\ 2: \quad t = \frac{13{,}800}{CAE}$$

$$Where: C = Activity\ (dpm/100cm^2)$$

$$A = Area\ of\ probe\ (cm^2)$$

$$E = efficiency\ (4pi)$$

Solving the above Equation 2 with the $DCGL_{EMC}$ it was concluded that another count would be observed within 4.65 seconds (Table 5 below). Due to limitation of the survey instrument, the minimum observation with the scaler function was a 6 second count time. Therefore 6 seconds (or 171 dpm/100cm^2) was selected for a single measurement to appear. Areas which met this criteria were considered flagged and required a static 60 second integrated count to be recorded. It should be noted that most flagged measurements were false positives.

Table 5: Pause Time Determination After a Single Count While Scanning					
Instrument Make/ Model	Probe	Active Area, A (cm^2)	E (4pi, , $\varepsilon_i{}^*\varepsilon_s$)	C (dpm/100cm^2)	t (seconds)
Ludlum Model 12	43-90	125	10.79%	220	4.65
Ludlum Model 222	43-90	125	10.79%	171	6

Scanning was performed in the survey unit to detect areas of elevated concentrations. Scanning coverage fractions and scanning investigation levels for buildings are shown below in Table 6 (This table is based on MARSSIM Roadmap Table 5 and Table 5.8).

Table 6: Scanning Coverage Fractions and Investigation Levels

Class	Scanning Coverage Fraction	Flag scanning measurement result when:
1	100 percent coverage*	> $DCGL_{EMC}$
2	10 to 100 percent; systematic and judgmental	> DCGL or > MDC_{SCAN}
3	1 to 100 percent judgmental	> DCGL or > MDC_{SCAN}

*100% coverage of areas reasonably accessible given instrumentation and surfaces geometry.

3.4.7.2 Static Measurements

Static (direct) measurements were collected at systematic locations to supplement scanning surveys for the identification of small areas of elevated activity. Unbiased sample locations along with professional judgment were also used to identify locations for static measurements to further define the extent of residual radioactivity and to determine maximum radiation levels within the survey unit area. All direct measurement locations and results were documented.

Static measurements were taken on surfaces using the scaler function of the instruments for a count time of 60 seconds. Coverage fractions and investigation levels are listed below in Table 7.

Table 7: Static Coverage Fractions and Investigation Levels

Class	Static Coverage Fraction	Flag direct measurement result when:
1	Number of data points from statistical tests	> $DCGL_{EMC}$ OR > DCGL & statistical based parameters
2	Number of data points from statistical tests	> DCGL
3	Number of data points from statistical tests	> Some Fraction of the DCGL

The MDC_{STATIC} for the instrumentation selected was calculated for the same isotope described above for the MDC_{SCAN}, using the MARSSIM method (MARSSIM 6.7.1). Again due to variable background the highest average background was used to calculate the MDC_{STATIC} for conservatism. The results are shown in Table 8 below. It should be noted that each static sample location was analyzed for the specific background for that surface type to get the true calculated activity present (See Attachment D).

Table 8: Instrument MDC_{STATIC} (worst case)								
Instrument Make/Model	**Detector**	**Active Area (cm^2)**	**Serial Number**	**Background (cts)**	**L_D (net cts)**	**Radio-Nuclide**	**Efficiency (4π)**	**MDC_{STATIC} ($dpm/100cm^2$)**
Ludlum Model 2221	43-90	125	PR228907	3	11	^{239}Pu	10.79%	**82**

3.4.7.3 Removable Activity Measurements (Wipe Samples)

All wipe samples were analyzed using a Ludlum 2200 w/ EIC FP-2 (SN 16134) windowless gas flow proportional counter. Typical 2pi efficiencies for this model range from 45-55% for alphas. This is over 50% efficient due to backscatter of alphas. The MDA for this instrument is approximately 3-5 dpm which will meet the removable fraction of the DCGL.

3.4.8 Specify Limits on Decision Errors

For the purpose of the statistical evaluation of data, the null hypothesis (H_0) was adopted, (i.e. the survey unit exceeds the release criterion). This requires significant evidence that the residual radioactivity in the survey unit is less than the release criterion to reject H_0 (and pass the survey unit).

In this case, a Type I decision error occurs when the null hypothesis is rejected when it is true, and is referred to as a false positive error; denoted by alpha (α). A Type II decision error occurs when the null hypothesis is accepted when it is false. This is referred to as a false negative error; denoted by beta (β). A 95% confidence level is typically used with the acceptable decision error for α being 0.05 and β being 0.05. However since the characterization survey was planned to be used as a FSS and was later determined not to meet the future use requirement, the alpha and beta values were set at 0.025 for 97.5% confidence. Table 9 represents the decision error matrix for this FSS:

TABLE 9: DECISION ERRORS [MARSSIM APP D]			
H_0: The Residual Activity in the Survey Unit Exceeds the Release Criterion			
		Decision	
		Reject H_0 (Meets Release Criteria)	Accept H_0 (Exceeds Release Criterion)
True Condition of Survey Unit	Meets Release Criterion	(No decision error)	Incorrectly Fail to Release Survey Unit (Type II)
	Exceeds Release Criterion	Incorrectly Release Survey Unit (Type I)	(No decision error)

4.0 Specific Conduct of Survey

4.1 Area Classification

As discussed previously, the area classification was performed as shown in Table 3.

4.2 Scanning Surveys

All scanning surveys were performed using a zinc sulfide alpha scintillation probe (Ludlum Model 2221 with 43-90 SN 313977/PR228907 DOC 1/19/16). All scanning instrument detection limits (MDS_{SCAN}) met the recommended MARSSIM values. The scanning coverage was approximately 100% of the all accessible areas and lower wall (< 6') surfaces. Scanning surveys were performed prior to static and wipe measurements. Results are shown in Attachment D.

4.3 Static Surveys

The sample locations which were generated by VSP (V7.0), along with judgmental sample locations, were areas requiring static measurements. These measurements were performed with the same zinc sulfide probe used for scanning and were taken at each location prior to a wipe sample. Results of the static survey measurements are shown in Attachment E.

4.4 Wipe Surveys

Each identified static location and judgmental locations were wipe tested to further analyze the extent of contamination. As discussed, it was assumed that no more than 10% of the total contamination is removable. It should be noted that each wipe was taken as a representative surface area of $100cm^2$, if not it was noted. This was performed by wiping a total surface area of $100cm^2$ with moderate pressure with a dry numbered wipe (filter paper). Attachment F contains all wipe sample analysis reports using the windowless gas flow proportional counter.

4.5 Waste Management

Radioactive waste generated during standard operational activities were characterized and disposed of offsite at an appropriate approved licensed disposal facility.

5.0 Survey Findings, Results and Analysis

From the results described below, all measurements were much less than the DCGL. In fact all were less than MDC. Therefore the MARSSIM Sign Test is not warranted.

5.1 Scanning Surveys

As mentioned previously, the scanning method for alpha contamination is materially different than that of beta and gamma counting. Due to the restrictive DCGL the investigation level was set at the $DCGL_{EMC}$ (220 dpm/$100cm^2$) since each area was classified as a Class 1 area. This achieved 90% confidence of observing a single count with a 1/5 probe width per second scan speed.

Throughout the survey unit there were numerous single counts observed during scanning. This required the surveyor to pause for 6 seconds after each observed count. As mentioned previously the 6 second pause represented approximately 171 dpm/100cm^2. If another count was observed during this 6 second pause, the surveyor took a static measurement. Table 10 indicated the number of flagged, requiring a static measurement, locations in each survey unit. It should be noted that only one static, located in the sink of Maloney Hall Room 7, was greater than MDC_{STATIC}.

Table 10: Quantity of Flagged Scanning Measurements per Survey Unit	
Survey Unit	**Flagged Measurements**
Maloney Hall Room 4	11
Maloney Hall Room 7	33
Maloney Hall Room 213	8

For further detail of all scan results please see Attachment D. It should be noted on these scan sheets that each location where a pause occurred is represented with a dot. If a 60 second count was required the resulting number is indicated on the scan sheet (none of which were greater than MDC_{STATIC}).

5.2 Static Measurement Surveys

All static survey unit measurements were found to be well below the DCGL. In fact all were less than MDC_{STATIC} except one which was located in Room 7. It should be noted that this unbiased sample location (MH 7 – 11, Sink) was the same location identified while scanning. All data for this part is shown in Attachment E with the associated VSP generated sample identification.

5.3 Wipe Sample Analysis

All survey units wipe sample results were well below the DCGL. In fact all wipe samples were less than MDC (7.6 dpm). Specific results are located in Attachment F with the VSP generated sample ID.

5.4 MARSSIM Sign Tests

Even though the Sign Test was not warranted, it was performed in accordance with the guidance given in Section 8.3.2 of MARSSIM. Each measurement was subtracted from the action level to obtain n differences $d_i = AL - X_i$. Any difference of zero was discarded from consideration and the sample size reduced accordingly.

The test statistic S+ was calculated by counting the positive differences. S+ was then compared with the critical value k, which was obtained from Table I.3 in Appendix I of MARSSIM. If S+ > k, then the null hypothesis is rejected. For this survey plan the null hypothesis is that the survey units contain residual activity above the DCGL. These results are shown in Attachment G and all data met the specified level of confidence and was well below the DCGL.

5.5 Analysis of All Results

From all the results it can be determined that a proper number of unbiased samples were collected, revealing that the suggested release criterion has been successfully met. Furthermore, it was determined from the data collected that all of the assumptions were either conservative or true. As mentioned fifty-two scanning locations were flagged, requiring a static measurement. However only one of the fifty-two was found to be greater than MDC_{STATIC}. This one measurement identified to contain residual activity distinguishable from background was below the DCGL and ALARA goal.

Being conservative, this area of low level residual contamination does not preclude the release of this facility for unrestricted use if it is considered ALARA. Furthermore, this facility is considered ALARA based the items described in Section 3.3.

5.6 Records

All samples and original survey data have been archived at Ecology Services, Inc. main office, 9135 Guilford Road, Ste. 200, Columbia, MD, and will be held for three years or as requested.

6.0 Determination of Compliance with State and Federal Standards

Determination of compliance is conducted in two steps:

(1) *Review the measurement data to confirm that the survey units were properly classified.* All survey unit grids demonstrated no contamination above the DCGL, the areas were properly classified.

(2) *Determine whether the measurement results demonstrate that the survey units meet the radiological criteria for unrestricted use.* All survey units passed the MARSSIM Sign Test and were well below predetermined DCGL, meeting the radiological criteria for unrestricted use.

7.0 Conclusion

From the results it is concluded that rooms 4, 7 and 213 in Maloney Hall of The Catholic University of America, located at 620 Michigan Ave N.E, Washington, DC 20064, are acceptable for unrestricted release.

8.0 References

10 CFR 20, *Standards for Protection Against Radiation*, U.S. NRC, January, 2016.

10 CFR 30, *Rules of General Applicability to Domestic Licensing of Byproduct Material, October, 2008.*

ANSI/HPS N13.12, *American National Standard –Surface and Volume Radioactivity Standards for Clearance,* American National Standards Institute, Inc., 2013.

District of Columbia Municipal Regulations, Title 22 *Public Health and Medicine*, Chapter 22-B67 *Radiation: Administration and Enforcement*, December 2014.

ISO 7503-1, *Evaluation of surface contamination -- Part 1: Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters*, ISO, 1988.NUREG - 1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, DOD, DOE, EPA and US NRC, August, 2000.

NUREG - 1757, *Consolidated NMSS Decommissioning Guidance, Decommissioning Process for Materials Licensees*, Vol. 1&2, US NRC, September, 2002 & 2006.

NUREG - 1727, *NMSS Decommissioning Standard Review Plan: Appendix D, ALARA Analyses*, US NRC, September, 2000.

Visual Sample Plan, Batelle Memorial Institute, Version 7.0, © 2014.

Attachment A

NRC Radioactive Material License No. SUD-157

U.S. NUCLEAR REGULATORY COMMISSION

Amendment No. 15

MATERIALS LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and Title 10, Code of Federal Regulations, Chapter I, Parts 30, 31, 32, 33, 34, 35, 36, 39, 40, and 70, and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, acquire, possess, and transfer byproduct, source, and special nuclear material designated below; to use such material for the purpose(s) and at the place(s) designated below; to deliver or transfer such material to persons authorized to receive it in accordance with the regulations of the applicable Part(s). This license shall be deemed to contain the conditions specified in Section 183 of the Atomic Energy Act of 1954, as amended, and is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

Licensee	
	In accordance with the letter dated June 3, 2013,
1. The Catholic University of America Department of Environmental Health & Safety	3. License number SUD-157 is amended in its entirety to read as follows:
2. 620 Michigan Ave. N.E. Washington D.C. 20064	4. Expiration date September 30, 2023
	5. Docket No. 040-06329

6. Byproduct, source, and/or special nuclear material	7. Chemical and/or physical form	8. Maximum amount that licensee may possess at any one time under this license
A. Natural Uranium	A. Any	A. 10 kilograms
B. Depleted Uranium	B. Any	B. 10 kilograms
C. Natural Thorium	C. Any	C. 50 kilograms
D. Thorium 232	D. Any	D. 50 kilograms

9. Authorized use:

A. through D. Research and development in radioactive waste treatment technology; teaching and training of students.

CONDITIONS

10. Licensed material may be used or stored only at the licensee's facilities located at 620 Michigan Avenue, N.E., Washington D.C.

11. Licensed material shall be used by, or under the supervision of, individuals designated in writing, by the Radiation Safety Committee. The licensee shall maintain records of individuals designated as users for three years following the last use of licensed material by that individual.

12. The Radiation Safety Officer for this license is Mahmoud S. Haleem.

13. The licensee shall not use licensed material in or on human beings.

MATERIALS LICENSE SUPPLEMENTARY SHEET	License Number SUD-157
	Docket or Reference Number 040-06329
	Amendment No. 15

14. The licensee shall not use licensed material in field applications where it is released except as provided otherwise by specific condition of this license.

15. Notwithstanding the requirements of License Condition 17, the licensee is authorized to make program changes and changes to procedures specifically identified in the condition, which were previously approved by the U.S. Nuclear Regulatory Commission and incorporated into the license without prior Commission approval as long as:

    A. The proposed revision is documented, reviewed, and approved by the licensee's Radiation Safety Committee in accordance with established procedures prior to implementation.

    B. The revised program is in accordance with regulatory requirements, will not change the license conditions, and will not decrease the effectiveness of the Radiation Safety Program.

    C. The licensee's staff is trained in the revised procedures prior to implementation.

    D. The licensee's audit program evaluates the effectiveness of the change and its implementation.

16. The licensee is authorized to transport licensed material in accordance with the provisions of 10 CFR Part 71, "Packaging and Transportation of Radioactive Material."

17. Except as specifically provided otherwise in this license, the licensee shall conduct its program in accordance with the statements, representations, and procedures contained in the documents, including any enclosures, listed below. The U.S. Nuclear Regulatory Commission's regulations shall govern unless the statements, representations, and procedures in the licensee's application and correspondence are more restrictive than the regulations.

    A. Letter dated June 3, 2013 (ML13168A240)
    B. Letter dated September 12, 2013 (ML13262A201)

For the U.S. Nuclear Regulatory Commission

Date September 25, 2013

By Elizabeth Ullrich
Commercial and R&D Branch
Division of Nuclear Materials Safety
Region I
King of Prussia, Pennsylvania 19406
Wednesday, September 25, 2013 09:18:17

Attachment B

Historical Site Assessment

Historical Site Assessment Questionnaire

1. Was the site ever licensed for the manufacture, use, or distribution of radioactive materials under Agreement State Regulations, NRC licenses, or Armed Services permits or for the use of 91B material?

   No

2. Did the site ever have permits to dispose of or incinerate radioactive materials on-site? Is there evidence of such activities?

   No

3. Has the site ever had deep wells for injection or permits for such?

   No

4. Did the site ever have permits to perform research with radiation generating devices or radioactive materials except medical or dental x-ray machines?

   Yes

5. As a part of the site's RAM license, were there ever any Soil Moisture Density Gauges (AmBe, PuBe sources) or Radioactive Thickness Monitoring Gauges stored or disposed of on-site?

   No

6. Was the site used to create radioactive material(s) by activation?

   No

7. Were radioactive sources stored on-site?

   Yes, sealed sources such Co-57, Sn-119m and Sm-151

8. Is there evidence that the site was involved in the Manhattan Project or any Manhattan Engineering District (MED) activities (1942-1946)?

   No

9. Was the site ever involved in the support of nuclear weapons testing?

   No

10. Were any facilities on the site used as a weapons storage area? Was weapons maintenance ever performed at the site?

    No

11. Was there ever any decontamination, maintenance or storage of radioactively contaminated ships, vehicles or planes performed on-site?

    No

12. Is there any record of any aircraft accident at or near the site (e.g., DU counterbalances, thorium alloys, radium dials)?

    No

13. Was there ever any radiopharmaceutical manufacturing, storage, transfer or disposal on-site?

    No

14. Was animal research ever performed on-site?

    No

15. Were uranium, thorium or radium compounds (NORM) used in manufacturing, research or testing at the site, or were these compounds stored at the site? Yes.

16. Has the site ever been involved in the processing or production of NORM compounds or mining, milling, processing or production of uranium?
    No

17. Were coal or coal products used on-site? If yes, did combustion of these substances leave ash or ash residue on-site? If yes, are runoff or production ponds on-site?
    no

18. Was there ever any on-site disposal of material known to be high in NORM (e.g., monozite sands used in sandblasting)?
    No

19. Did the site process pipe from the oil and gas industries?
    No

20. Is there any reason to expect that the site might be contaminated with radioactive material (other than previously listed)?
    No

Surface Soil (0-15 cm depth)

- Were all sources used on-site encapsulated?
  No, Room 4 and 7 USED DEPLETED URANIUM.
- Were radiation sources used only in specific areas of the site?
  No
- Was surface soil re-graded or moved elsewhere for fill or construction purposes?
  No

Sub-Surface Soil

- Are there any areas of known or suspected surface soil contamination?
  No
- Is there a ground water plume without an identifiable source?
  No
- Is there potential for enhance mobility of radionuclides in the soil?
  No
- Is there evidence that the soil has been disturbed?
  No
- Is there evidence of subsurface disturbances?
  No
- Are surface structures present?
  Yes

Structures

- Were adjacent structures used for storage, maintenance or processing of radioactive materials?
  No
- Is a building or its addition or a new structure located on a former radioactive waste burial site or contaminated land?
  No
- Was the building constructed using contaminated material?
  No

- Does the potentially non-impacted portion of the building share a drainage system or ventilation system with a potentially contaminated area?
  No
- Is there evidence that previously identified areas of contamination were remediated by painting or similar methods of immobilizing contaminants?
  No

Surface Water

- Is surface water nearby?
  No
- Is the waste quantity particularly large?
  No
- Is the drainage area large?
  No
- Is rainfall heavy?
  No
- Is the infiltration rate low?
  UNKNOWN
- Are sources of contamination poorly contained or prone to runoff?
  No
- Is a runoff route well defined?

  Yes
- Has deposition of waste into surface water been observed?
  No
- Does analytical or circumstantial evidence suggest surface water contamination?
  No
- Is the site prone to flooding?
  No

Ground Water

- Are sources of contamination poorly contained?
  No
- Is the source likely to contaminate ground water?
  No
- Is the waste quantity particularly large?
  No
- Is rainfall heavy?
  No
- Is the infiltration rate high?
  Not applicable
- Is the site located in an area of karst terrain?
  No
- Is the subsurface highly permeable?
  Not applicable
- What is the distance from the surface to an aquifer?
  Unknown
- Are suspected contaminants highly mobile in ground water?
  no
- Does analytical or circumstantial evidence suggest ground water contamination?

Air **No**

- Were there observations of contaminant releases to the air?

No

- Does analytical or circumstantial evidence suggest a release to the air?
  No
- For radon exposure only, are there elevated amounts of radium (226Ra) in the soil or water that could act as a source of radon in the air?
  No
- Is there a prevailing wind and a propensity for windblown transport of contamination?
  No

Company Name: The Catholic University of America

Location – street address, city, county, state, geographic coordinates
620 Michigan Ave., N.E.
Washington, D.C. 20064

Topography – USGS 7.5 minute quadrangle or equivalent

Stratigraphy –

Environmental Setting –

1. Geology –
2. Hydrogeology –
3. Hydrology –
4. Meteorology

HSA Methodology –

1. Approach and Rationale
2. Boundaries of Site
3. Documents Reviewed
4. Property Inspections
5. Personnel Interviews

History and Current Usage –

1. History – years of operation, type of facility, description of operations, regulatory permits, licenses, waste handling procedures

   Labs 4 & 7 were used for three years.
   Lab 213 sealed sources were used, 33 years

2. Current Usage – type of facility, description of operations, probable source types and sizes, description of spills or releases (any known contamination please describe), waste manifests, radionuclide inventories, emergency or removal actions

   The whole Chemistry building is closed and the labs are not in use. Only sealed sources were removed and some glass jars containing depleted thorium and uranium oxides, nitrates and acetate were removed from lab 213. No historical records of such item indicate any usage of the materials.

3. Adjacent Land Usage – sensitive areas such as wetlands or preschools

Colt Greer

From:	Haleem, Mahmoud S. <HALEEM@cua.edu>
Sent:	Tuesday, September 29, 2015 10:18 AM
To:	Colt Greer (CGreer@EcologyServices.com); Greg Keck (gkeck@ecologyservices.com)
Cc:	pmarshall@ecologyservices.com; Alar, Louis P.
Subject:	CUA Decommissioning Report follow up

Good morning;

I just finished speaking with Mr. Todd Jackson, senior Health Physicist with NRC-Region I regarding the issue of the decommissioning report of not including The Thorium as a main factor of contributing to the public dose.
I based my conclusion on the following factors:

1. No one was authorized to use or made a request to use thorium isotope under the Source material license from the Chemistry department.
2. The Radioactive Material Inventory Record (RMIC) that dates back to 1980 did not include or show anyone from the Chemistry department that might made an acquisition of the thorium isotope under any of the licenses we have.
3. The two bottles containing a total of 27 grams of thorium oxide predate the source material license where the materials were acquired under the general license (CFR 20 Part 40.22).

Mr. Jackson has no issue if we decide to take thorium related calculations out of the decommissioning report since it will be justifiable with the above mentioned points. Let me know what you think of this course of action and get in touch with me through email or by telephone when you need more feedback or information. Your help into this is very much appreciated.

Thank you.

Mahmoud S. Haleem
Radiation Safety Officer (RSO) I Environmental Health and Safety
202.319.5206 I Haleem@cua.edu
Marist Annex I Washington, DC 20064

REASON. FAITH. SERVICE.
THE CATHOLIC UNIVERSITY OF AMERICA

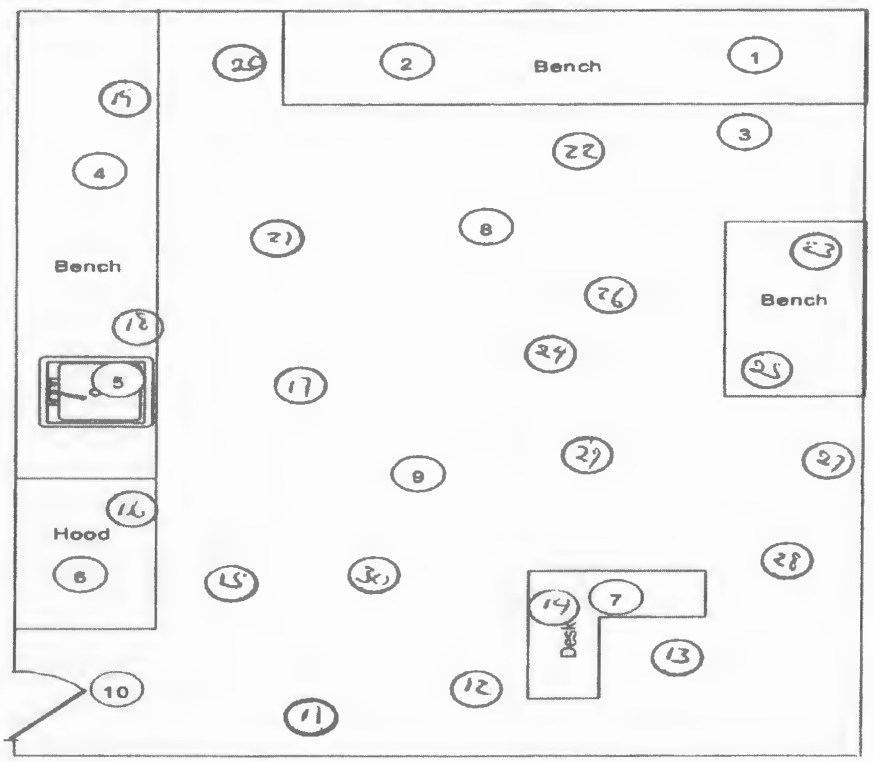
Attachment C

Latest Routine Scoping Survey Results

Radiation Safety Lab Survey	Catholic University of America	Independent Laboratory Survey Performed By
Reason: **Routine-Monthly**	Washington, DC	**RSO, Inc.**

Building	Room	Lab Type
Chemistry	4	

	Name	Phone No.	Date / Wipe No.
Authorized Investigator	Mahmoud S. Haleem	202-319-5206	Date: 7/23/2014
Surveyor	Evans, Herb	(301) 953-2482	Wipe No. 31-60



Radionuclides/Wipe Test Results (dpm/100 cm^2)

	H-3		I-125
	C-14	X	U
	S-35	X	Th
	P-32		

Wipe	H-3	C-14	P-32		α	β	γ
1	<100	<100	<100		<5	<50	<200
2							
3							
4							
5							
6							
7							
8							
9							
10							

Compliance Items:

	01. Lab Postings on Door		09. Absorbent Paper (Rad Areas Only)		17. Prohibition Eating, Drinking, Smoking
	02. Emergency Contact on Door		10. Adequate Storage of Licensed Material		18. Radiation Levels <2 mR/hr
	03. Signs And Labels -Room		11. Routine Use of Gloves		19. Removable >100 dpm
	04. -Source Container		12. Routine Use of Lab Coats		20. Lab Access Secured
	05. -Refrigerator / Freezer		13. Routine Use of Safety Glasses		21. Licensed Material Secured
	06. -LSC Vials		14. Adequate Personal Exposure Monitoring		22. Scan shows free of contamination
	07. -Waste Containers		15. Personnel Trained	X	Yes
	08. -Other Equipment		16. Adequate Waste Storage		No

Lab Survey Meters:	Calibration Current	Operational
Meter 1-	Meter 2-	Meter 3-

Survey Results: No Action Required - X Corrective Action Required - [ ] - Yes

Corrective Action Taken:

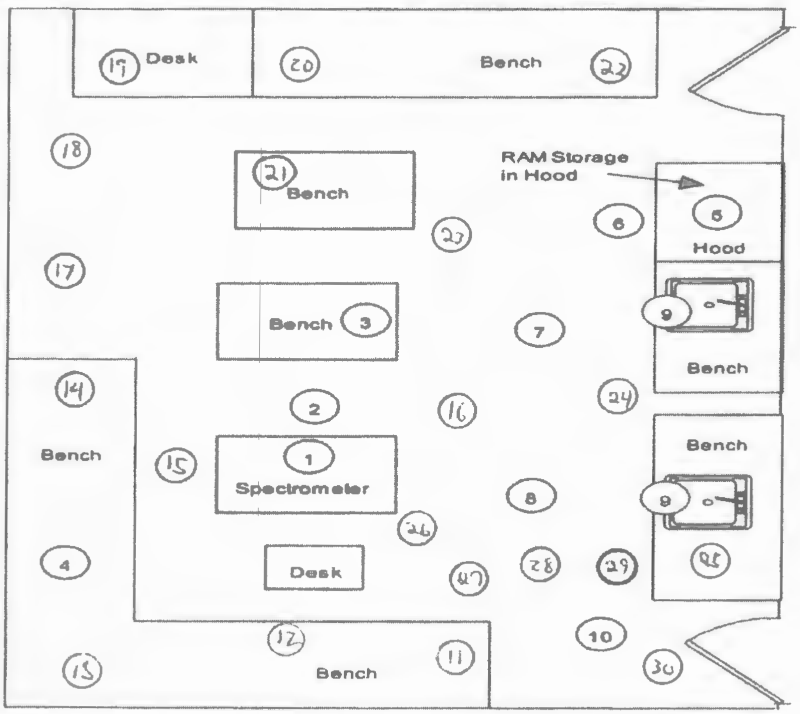
Person Contacted for Corrective Action: Date: Phone:

Remarks: Smears #11-30 are <100dpm/100cm2

Survey Meter Used for this Survey: Bicron surveyor M s/n A391L Cal Date: 10/25/2013

Radiation Safety Lab Survey	Catholic University of America	Independent Laboratory Survey Performed By		
Reason: **Routine-Monthly**	Washington, DC	**RSO, Inc.**		
		Building: **Chemistry**	Room: **7**	Lab Type:

	Name	Phone No.	Date / Wipe No.
Authorized Investigator	**Mahmoud S. Haleem**	**202-319-5206**	Date: **7/23/2014**
Surveyor	**Evans, Herb**	(301) 953-2482	Wipe No.: 1-30



Radionuclides/Wipe Test Results (dpm/100 cm^2)

	H-3		I-125
	C-14	X	U
	S-35	X	Th
	P-32		

Wipe	H-3	C-14	P-32		α	β	γ
1	<100	<100	<100		<5	<50	<200
2	↓	↓	↓		↓	↓	↓
3							
4							
5							
6							
7							
8							
9							
10	↓	↓	↓		↓	↓	↓

Compliance Items:

	01. Lab Postings on Door		09. Absorbent Paper (Rad Areas Only)		17. Prohibition Eating, Drinking, Smoking
	02. Emergency Contact on Door		10. Adequate Storage of Licensed Material		18. Radiation Levels <2 mR/hr
	03. Signs And Labels -Room		11. Routine Use of Gloves		19. Removable >100 dpm
	04. -Source Container		12. Routine Use of Lab Coats		20. Lab Access Secured
	05. -Refrigerator / Freezer		13. Routine Use of Safety Glasses		21. Licensed Material Secured
	06. -LSC Vials		14. Adequate Personal Exposure Monitoring		22. Scan shows free of contamination
	07. -Waste Containers		15. Personnel Trained	X	Yes
	08. -Other Equipment		16. Adequate Waste Storage		No

Lab Survey Meters:		Calibration Current		Operational
Meter 1-	Meter 2-		Meter 3-	

Survey Results: No Action Required - X Corrective Action Required - ☐ - Yes

Corrective Action Taken:

Person Contacted for Corrective Action: Date: Phone:

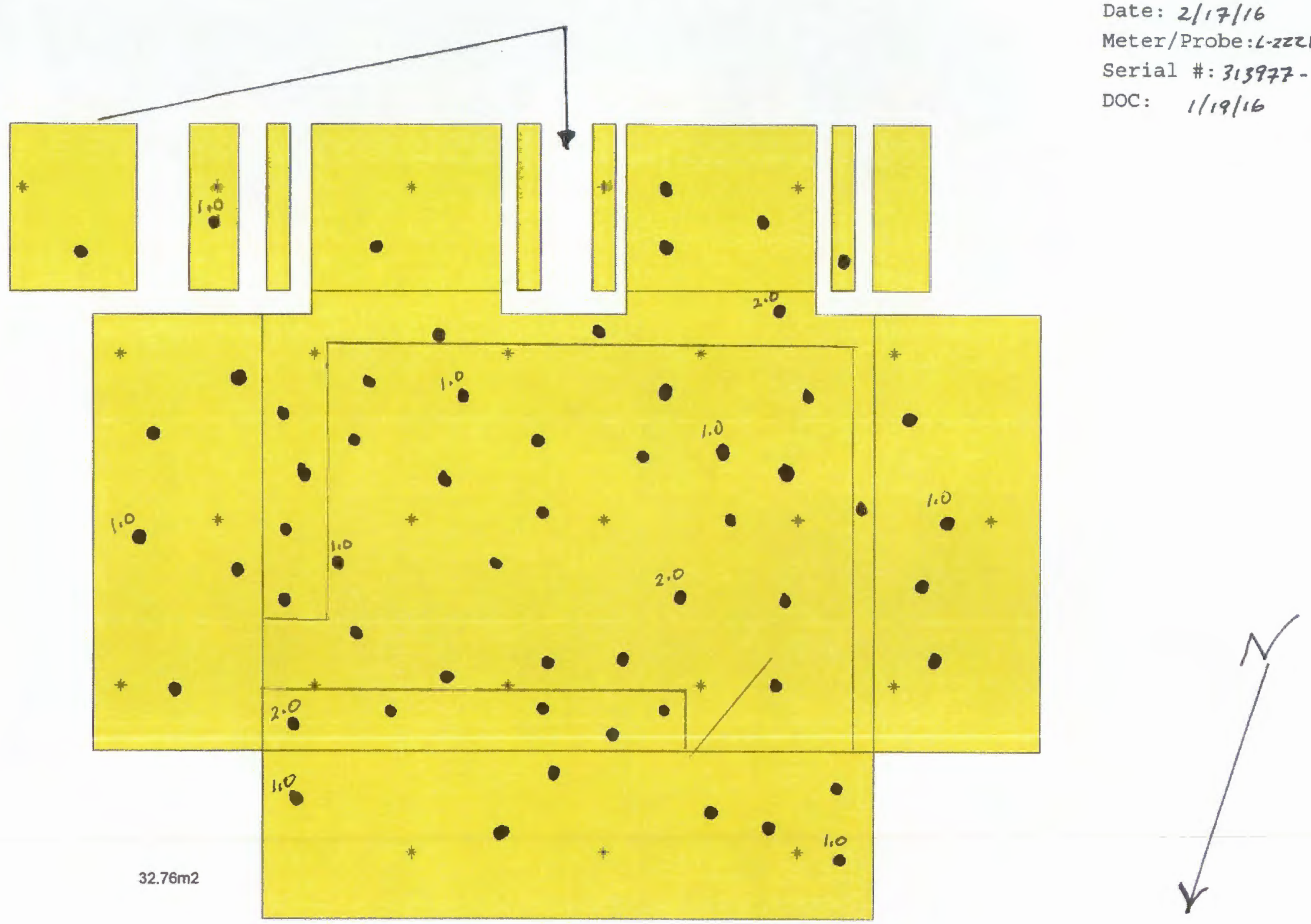
Remarks: Smears 11-30 are <100 dpm/100cm2

Survey Meter Used for this Survey: Bicron surveyor M s/n A391L Cal Date: 10/25/2013

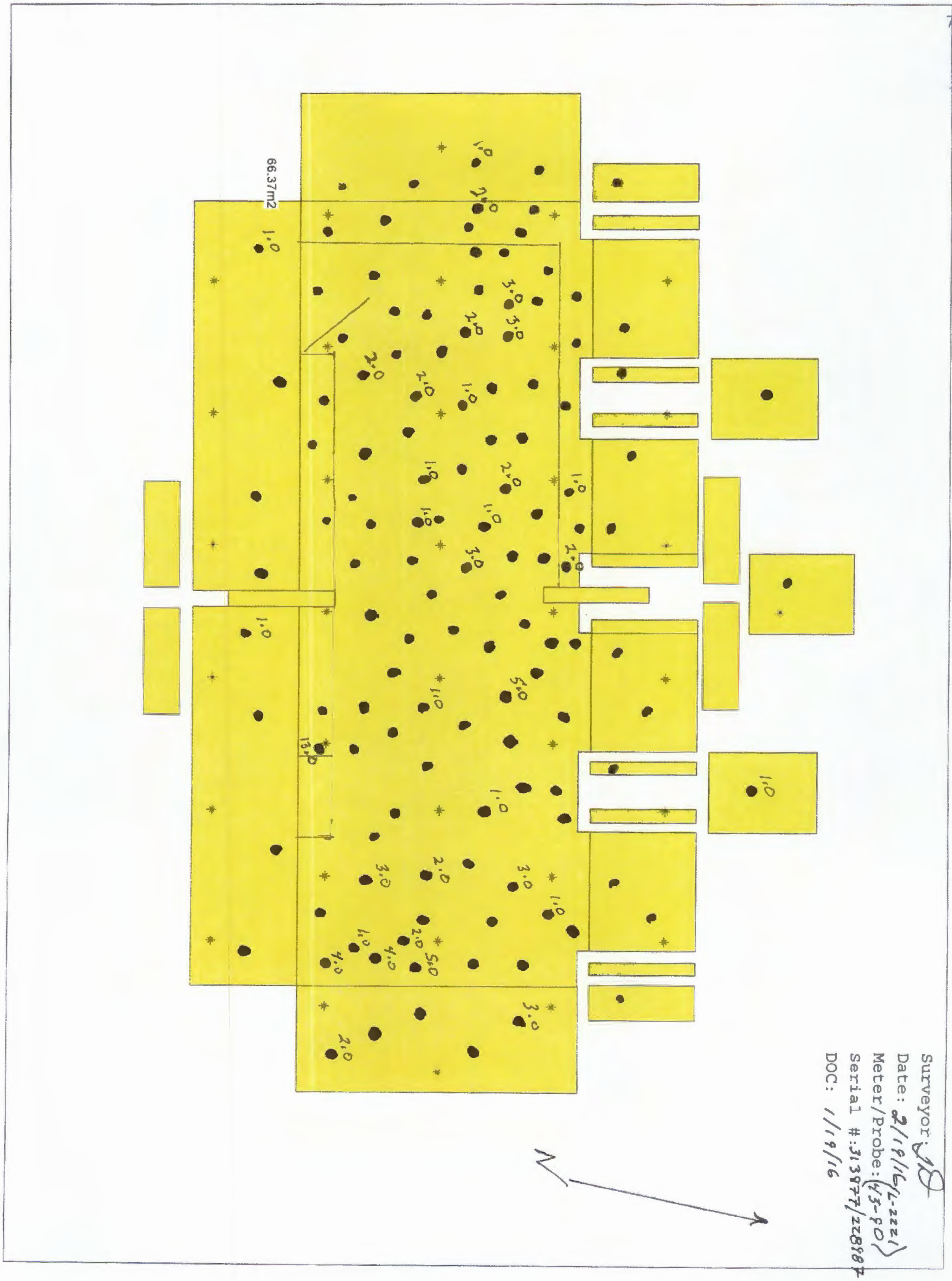
Attachment D

Scan Survey Results

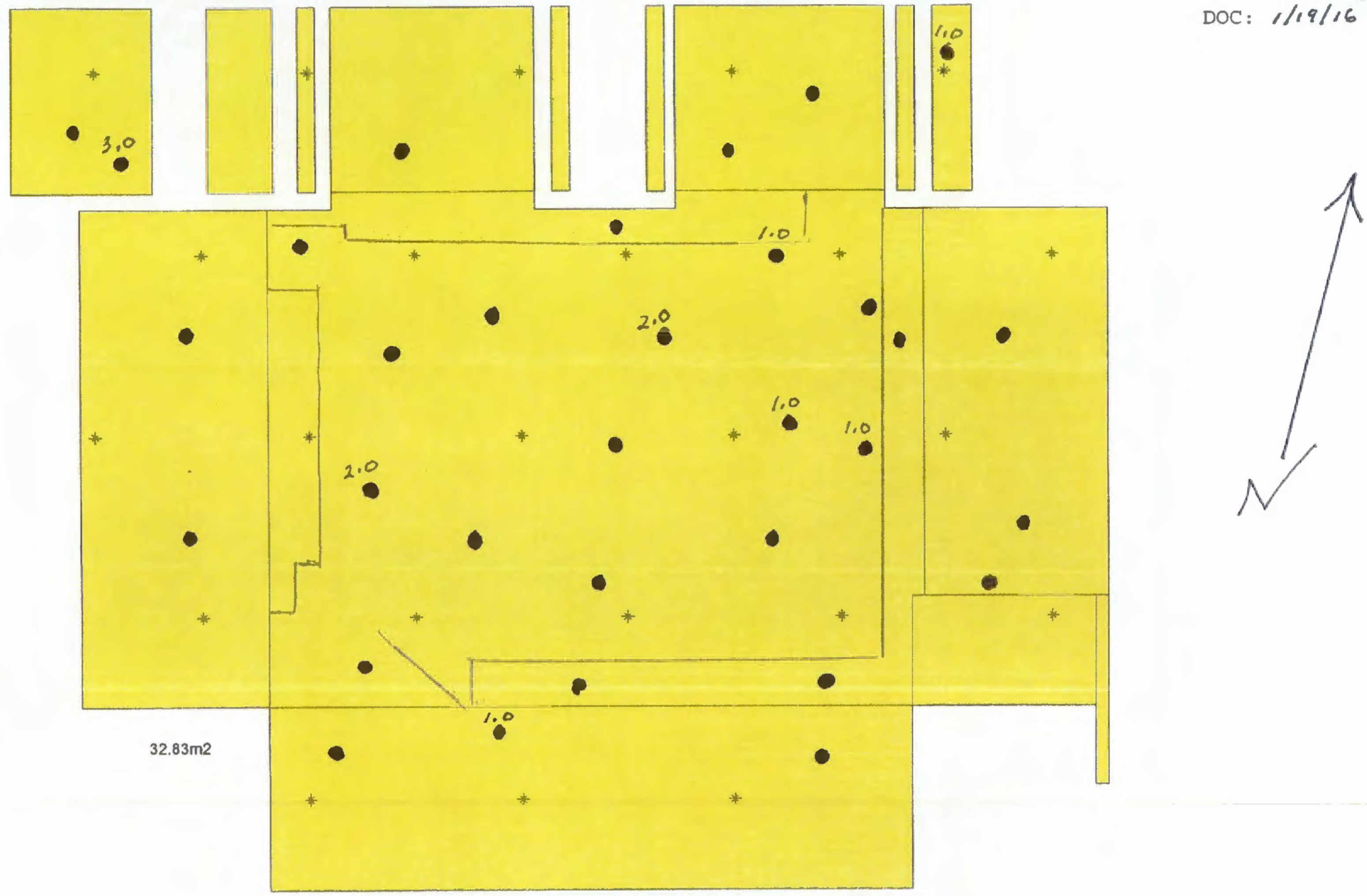
Km 004



Surveyor: [signature]
Date: 2/17/16
Meter/Probe: L-2221 - L-4390
Serial #: 313977 - 228987
DOC: 1/19/16


66.37m2
Surveyor:
Date:
Meter/Probe:
Serial #:
DOC:

Rm 213



Surveyor: [signature]
Date: 2/16/16
Meter/Probe: L-2221-L-4390
Serial #: 313977-228987
DOC: 1/19/16

Attachment E

Static Survey Results

The Catholic University of America

Main Campus

Location: Maloney Hall Room 4

Static Instrumentation Details

Rate Meter:	Ludlum-2221 S/N 313977	DOC:	January 19, 2016
Probe:	Ludlum 43-90 S/N PR228907	Background:	1-2 cpm
Probe Area:	125 cm^2	MDC_{STATIC}:	57-71 cpm
Efficiency:	10.79%	Survey Date:	2/17/16

Static Point	X Coordinate (in.)	Y Coordinate (in.)	Static Count (cts.)	Count Time (seconds)	Location	Alpha ~dpm/100cm^2	MDC (cts.)	BKG (cts.)	MDC dpm/100cm^2	Type
MH 4-1	63.5	-43.5	1	60	Brick	<MDC	12	2	71	Systematic
MH 4-2	146.1	-43.5	2	60	Hood	<MDC	9	1	57	Systematic
MH 4-3	228.7	-43.5	1	60	Brick	<MDC	12	2	71	Systematic
MH 4-4	-60.5	28.1	2	60	Drywall	<MDC	9	1	57	Systematic
MH 4-5	22.1	28.1	1	60	Tile	<MDC	12	2	71	Systematic
MH 4-6	104.8	28.1	2	60	Tile	<MDC	12	2	71	Systematic
MH 4-7	187.4	28.1	0	60	Tile	<MDC	12	2	71	Systematic
MH 4-8	270.1	28.1	2	60	Brick	<MDC	12	2	71	Systematic
MH 4-9	-19.2	99.7	2	60	Wood	<MDC	9	1	57	Systematic
MH 4-10	63.5	99.7	3	60	Tile	<MDC	12	2	71	Systematic
MH 4-11	146.1	99.7	2	60	Tile	<MDC	12	2	71	Systematic
MH 4-12	228.7	99.7	1	60	Tile	<MDC	12	2	71	Systematic
MH 4-13	311.4	99.7	2	60	Brick	<MDC	12	2	71	Systematic
MH 4-14	-60.5	171.2	0	60	Drywall	<MDC	9	1	57	Systematic
MH 4-15	22.1	171.2	1	60	Bench	<MDC	9	1	57	Systematic
MH 4-16	104.8	171.2	2	60	Tile	<MDC	12	2	71	Systematic
MH 4-17	187.4	171.2	0	60	Tile	<MDC	12	2	71	Systematic
MH 4-18	270.1	171.2	2	60	Brick	<MDC	12	2	71	Systematic
MH 4-19	-101.8	242.8	2	60	Brick	<MDC	12	2	71	Systematic
MH 4-20	-19.2	242.8	1	60	Brick	<MDC	12	2	71	Systematic
MH 4-21	63.5	242.8	1	60	Brick	<MDC	12	2	71	Systematic
MH 4-22	146.1	242.8	1	60	Brick	<MDC	12	2	71	Systematic
MH 4-23	228.7	242.8	2	60	Brick	<MDC	12	2	71	Systematic

The Catholic University of America

Main Campus

Location: Maloney Hall Room 7

Static Instrumentation Details

Rate Meter:	Ludlum-2221 S/N 313977	DOC:	January 19, 2016
Probe:	Ludlum 43-90 S/N PR228907	Background:	1-2 cpm
Probe Area:	125 cm^2	MDC_{STATIC}:	57-71 cpm
Efficiency:	10.79%	Survey Date:	2/19/16

Static Point	X Coordinate (in.)	Y Coordinate (in.)	Static Count (cts.)	Count Time (seconds)	Location	Alpha ~dpm/100cm^2	MDC (cts.)	BKG (cts.)	MDC dpm/100cm^2	Type
MH 7-1	53.3	-58.5	4	60	Metal	<MDC	9	1	57	Systematic
MH 7-2	142.3	-58.5	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-3	231.2	-58.5	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-4	320.2	-58.5	1	60	Brick	<MDC	12	2	71	Systematic
MH 7-5	409.1	-58.5	1	60	Hood	<MDC	9	1	57	Systematic
MH 7-6	498.1	-58.5	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-7	8.8	18.6	2	60	Bench	<MDC	9	1	57	Systematic
MH 7-8	97.8	18.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 7-9	186.7	18.6	3	60	Bench	<MDC	9	1	57	Systematic
MH 7-10	275.7	18.6	2	60	Wood	<MDC	9	1	57	Systematic
MH 7-11	364.7	18.6	13	60	Sink	89	9	1	57	Systematic
MH 7-12	453.6	18.6	3	60	Tile	<MDC	12	2	71	Systematic
MH 7-13	542.6	18.6	1	60	Brick	<MDC	12	2	71	Systematic
MH 7-14	-35.7	95.6	3	60	Brick	<MDC	12	2	71	Systematic
MH 7-15	53.3	95.6	2	60	Tile	<MDC	12	2	71	Systematic
MH 7-16	142.3	95.6	4	60	Tile	<MDC	12	2	71	Systematic
MH 7-17	231.2	95.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 7-18	320.2	95.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 7-19	409.1	95.6	3	60	Tile	<MDC	12	2	71	Systematic
MH 7-20	498.1	95.6	4	60	Tile	<MDC	12	2	71	Systematic
MH 7-21	587.1	95.6	3	60	Brick	<MDC	12	2	71	Systematic
MH 7-22	8.8	172.6	0	60	Bench	<MDC	9	1	57	Systematic
MH 7-23	97.8	172.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 7-24	186.7	172.6	2	60	Tile	<MDC	12	2	71	Systematic
MH 7-25	275.7	172.6	2	60	Tile	<MDC	12	2	71	Systematic
MH 7-26	364.7	172.6	3	60	Tile	<MDC	12	2	71	Systematic
MH 7-27	453.6	172.6	3	60	Tile	<MDC	12	2	71	Systematic
MH 7-28	542.6	172.6	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-29	53.3	249.7	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-30	142.3	249.7	1	60	Brick	<MDC	12	2	71	Systematic
MH 7-31	231.2	249.7	1	60	Brick	<MDC	12	2	71	Systematic
MH 7-32	320.2	249.7	1	60	Brick	<MDC	12	2	71	Systematic
MH 7-33	409.1	249.7	2	60	Brick	<MDC	12	2	71	Systematic
MH 7-34	498.1	249.7	3	60	Brick	<MDC	12	2	71	Systematic
MH 7-35	275.7	326.7	3	60	Glass	<MDC	9	1	57	Systematic

The Catholic University of America

Main Campus

Location: Maloney Hall Room 213

Static Instrumentation Details

Rate Meter:	Ludlum-2221 S/N 313977	DOC:	January 19, 2016
Probe:	Ludlum 43-90 S/N PR228907	Background:	1-2 cpm
Probe Area:	125 cm^2	MDC_{STATIC}:	57-71 cpm
Efficiency:	10.79%	Survey Date:	2/16/16

Static Point	X Coordinate (in.)	Y Coordinate (in.)	Static Count (cts.)	Count Time (seconds)	Location	Alpha ~dpm/100cm^2	MDC (cts.)	BKG (cts.)	MDC dpm/100cm^2	Type
MH 213-1	16	-36.3	3	60	Brick	<MDC	12	2	71	Systematic
MH 213-2	98.5	-36.3	1	60	Hood	<MDC	9	1	57	Systematic
MH 213-3	181	-36.3	2	60	Hood	<MDC	9	1	57	Systematic
MH 213-4	-25.2	35.1	3	60	Brick	<MDC	12	2	71	Systematic
MH 213-5	57.2	35.1	0	60	Tile	<MDC	12	2	71	Systematic
MH 213-6	139.7	35.1	2	60	Tile	<MDC	12	2	71	Systematic
MH 213-7	222.2	35.1	1	60	Tile	<MDC	12	2	71	Systematic
MH 213-8	304.7	35.1	2	60	Brick	<MDC	12	2	71	Systematic
MH 213-9	-66.5	106.6	2	60	Brick	<MDC	12	2	71	Systematic
MH 213-10	16	106.6	2	60	Tile	<MDC	12	2	71	Systematic
MH 213-11	98.5	106.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 213-12	181	106.6	1	60	Tile	<MDC	12	2	71	Systematic
MH 213-13	263.5	106.6	2	60	Brick	<MDC	12	2	71	Systematic
MH 213-14	-25.2	178	3	60	Brick	<MDC	12	2	71	Systematic
MH 213-15	57.2	178	1	60	Tile	<MDC	12	2	71	Systematic
MH 213-16	139.7	178	2	60	Tile	<MDC	12	2	71	Systematic
MH 213-17	222.2	178	2	60	Tile	<MDC	12	2	71	Systematic
MH 213-18	304.7	178	2	60	Brick	<MDC	12	2	71	Systematic
MH 213-19	-66.5	249.5	3	60	Brick	<MDC	12	2	71	Systematic
MH 213-20	16	249.5	1	60	Brick	<MDC	12	2	71	Systematic
MH 213-21	98.5	249.5	0	60	Glass	<MDC	9	1	57	Systematic
MH 213-22	181	249.5	0	60	Glass	<MDC	9	1	57	Systematic
MH 213-23	263.5	249.5	2	60	Brick	<MDC	12	2	71	Systematic

Attachment F

Wipe Sample Analysis Results

REPORT OF SAMPLE ANALYSIS

Rev 1.3

For:	Catholic University of America
Job:	Final Status Survey
Sample Type:	Numbered Dry Filter Wipe

Date:	29-Feb-16
By:	CG
Sample Date:	17-Feb-16
Counting Parameters:	Gross Alpha

Equipment Description:
Counter: Gas Proportional
Detector: EIC FP-2 GFPC

Input Background Data:

Background Cts	Ct Time (m)	Background CPM	% Error
1	2	0.50	196.00%

Input Efficiency Data:

Isotope	Gross Counts	Time (m)	DPM	Efficiency (4 Pi)	% Error
PU-239	10568	2	1.05E+04	50.17%	4.00%

MDA Calculation:

MDA (NET CPM)	MDA (DPM)	MDA (uCi)
3.8	7.6	3.434E-06

Sample Data: Note: A zero reading for DPM or pCi/gm values indicates only that the sample activity was less than the MDA.

Sequence Number	Sample ID	Gross Counts	Ct Time (m)	CF	Decay Factor	DPM/Sample	Error at 95% C.L.
1	MH 4 - 1	1	2	1	0.97	< MDA	N/A
2	MH 4 - 2	0	2	1	0.97	< MDA	N/A
3	MH 4 - 3	1	2	1	0.97	< MDA	N/A
4	MH 4 - 4	3	2	1	0.97	< MDA	N/A
5	MH 4 - 5	3	2	1	0.97	< MDA	N/A
6	MH 4 - 6	2	2	1	0.97	< MDA	N/A
7	MH 4 - 7	1	2	1	0.97	< MDA	N/A
8	MH 4 - 8	1	2	1	0.97	< MDA	N/A
9	MH 4 - 9	1	2	1	0.97	< MDA	N/A
10	MH 4 - 10	1	2	1	0.97	< MDA	N/A
11	MH 4 - 11	1	2	1	0.97	< MDA	N/A
12	MH 4 - 12	2	2	1	0.97	< MDA	N/A
13	MH 4 - 13	2	2	1	0.97	< MDA	N/A
14	MH 4 - 14	0	2	1	0.97	< MDA	N/A
15	MH 4 - 15	0	2	1	0.97	< MDA	N/A
16	MH 4 - 16	1	2	1	0.97	< MDA	N/A
17	MH 4 - 17	3	2	1	0.97	< MDA	N/A
18	MH 4 - 18	1	2	1	0.97	< MDA	N/A
19	MH 4 - 19	1	2	1	0.97	< MDA	N/A
20	MH 4 - 20	2	2	1	0.97	< MDA	N/A
21	MH 4 - 21	1	2	1	0.97	< MDA	N/A
22	MH 4 - 22	1	2	1	0.97	< MDA	N/A
23	MH 4 - 23	1	2	1	0.97	< MDA	N/A
	"Missed Activity"	9	2	1	0.97	8	

$$MDA(dpm) = \frac{4.65\sqrt{R_b/T_b} + 3}{T_b \cdot Efficiency}$$

Health Physicist

REPORT OF SAMPLE ANALYSIS

Rev 1.3

For:	Catholic University of America
Job:	Final Status Survey
Sample Type:	Numbered Dry Filter Wipe

Date:	29-Feb-16
By:	CG
Sample Date:	19-Feb-16
Counting Parameters:	Gross Alpha

Equipment Description:
Counter: Gas Proportional
Detector: EIC FP-2 GFPC

Input Background Data:

Background Cts	Ct Time (m)	Background CPM	% Error
1	2	0.50	196.00%

Input Efficiency Data:

Isotope	Gross Counts	Time (m)	DPM	Efficiency (4 Pi)	% Error
PU-239	10568	2	1.05E+04	50.17%	4.00%

MDA Calculation:

MDA (NET CPM)	MDA (DPM)	MDA (uCi)
3.8	7.6	3.434E-06

Sample Data: Note: A zero reading for DPM or pCi/gm values indicates only that the sample activity was less than the MDA.

Sequence Number	Sample ID	Gross Counts	Ct Time (m)	CF	Decay Factor	DPM/Sample	Error at 95% C.L.
1	MH 7 - 1	3	2	1	0.97	< MDA	N/A
2	MH 7 - 2	1	2	1	0.97	< MDA	N/A
3	MH 7 - 3	2	2	1	0.97	< MDA	N/A
4	MH 7 - 4	0	2	1	0.97	< MDA	N/A
5	MH 7 - 5	0	2	1	0.97	< MDA	N/A
6	MH 7 - 6	1	2	1	0.97	< MDA	N/A
7	MH 7 - 7	2	2	1	0.97	< MDA	N/A
8	MH 7 - 8	1	2	1	0.97	< MDA	N/A
9	MH 7 - 9	1	2	1	0.97	< MDA	N/A
10	MH 7 - 10	2	2	1	0.97	< MDA	N/A
11	MH 7 - 11	0	2	1	0.97	< MDA	N/A
12	MH 7 - 12	3	2	1	0.97	< MDA	N/A
13	MH 7 - 13	0	2	1	0.97	< MDA	N/A
14	MH 7 - 14	0	2	1	0.97	< MDA	N/A
15	MH 7 - 15	1	2	1	0.97	< MDA	N/A
16	MH 7 - 16	0	2	1	0.97	< MDA	N/A
17	MH 7 - 17	2	2	1	0.97	< MDA	N/A
18	MH 7 - 18	3	2	1	0.97	< MDA	N/A
19	MH 7 - 19	4	2	1	0.97	< MDA	N/A
20	MH 7 - 20	3	2	1	0.97	< MDA	N/A
21	MH 7 - 21	1	2	1	0.97	< MDA	N/A
22	MH 7 - 22	2	2	1	0.97	< MDA	N/A
23	MH 7 - 23	1	2	1	0.97	< MDA	N/A
24	MH 7 - 24	0	2	1	1.97	< MDA	N/A
25	MH 7 - 25	3	2	1	2.97	< MDA	N/A
26	MH 7 - 26	0	2	1	3.97	< MDA	N/A
27	MH 7 - 27	1	2	1	4.97	< MDA	N/A
28	MH 7 - 28	1	2	1	5.97	< MDA	N/A
29	MH 7 - 29	2	2	1	6.97	< MDA	N/A
30	MH 7 - 30	1	2	1	7.97	< MDA	N/A
31	MH 7 - 31	0	2	1	8.97	< MDA	N/A
32	MH 7 - 32	2	2	1	9.97	< MDA	N/A
33	MH 7 - 33	1	2	1	10.97	< MDA	N/A
34	MH 7 - 34	2	2	1	11.97	< MDA	N/A
35	MH 7 - 35	1	2	1	12.97	< MDA	N/A
	"Missed Activity"	9	2	1	0.97	8	

$$MDA(dpm) = \frac{4.65\sqrt{R_b/T_b} + 3}{T_b \cdot Efficiency}$$

Health Physicist

REPORT OF SAMPLE ANALYSIS

Rev 1.3

For:	Catholic University of America
Job:	Final Status Survey
Sample Type:	Numbered Dry Filter Wipe

Date:	29-Feb-16
By:	CG
Sample Date:	16-Feb-19
Counting Parameters:	Gross Alpha

Equipment Description:
Counter: Gas Proportional
Detector: EIC FP-2 GFPC

Input Background Data:

Background Cts	Ct Time (m)	Background CPM	% Error
1	2	0.50	196.00%

Input Efficiency Data:

Isotope	Gross Counts	Time (m)	DPM	Efficiency (4 Pi)	% Error
PU-239	10568	2	1.05E+04	50.17%	4.00%

MDA Calculation:

MDA (NET CPM)	MDA (DPM)	MDA (uCi)
3.8	7.6	3.434E-06

Sample Data: Note: A zero reading for DPM or pCi/gm values indicates only that the sample activity was less than the MDA.

Sequence Number	Sample ID	Gross Counts	Ct Time (m)	CF	Decay Factor	DPM/Sample	Error at 95% C.L.
1	MH 213 - 1	0	2	1	0.97	< MDA	N/A
2	MH 213 - 2	3	2	1	0.97	< MDA	N/A
3	MH 213 - 3	4	2	1	0.97	< MDA	N/A
4	MH 213 - 4	0	2	1	0.97	< MDA	N/A
5	MH 213 - 5	0	2	1	0.97	< MDA	N/A
6	MH 213 - 6	0	2	1	0.97	< MDA	N/A
7	MH 213 - 7	4	2	1	0.97	< MDA	N/A
8	MH 213 - 8	2	2	1	0.97	< MDA	N/A
9	MH 213 - 9	2	2	1	0.97	< MDA	N/A
10	MH 213 - 10	0	2	1	0.97	< MDA	N/A
11	MH 213 - 11	3	2	1	0.97	< MDA	N/A
12	MH 213 - 12	2	2	1	0.97	< MDA	N/A
13	MH 213 - 13	1	2	1	0.97	< MDA	N/A
14	MH 213 - 14	1	2	1	0.97	< MDA	N/A
15	MH 213 - 15	3	2	1	0.97	< MDA	N/A
16	MH 213 - 16	2	2	1	0.97	< MDA	N/A
17	MH 213 - 17	3	2	1	0.97	< MDA	N/A
18	MH 213 - 18	0	2	1	0.97	< MDA	N/A
19	MH 213 - 19	0	2	1	0.97	< MDA	N/A
20	MH 213 - 20	1	2	1	0.97	< MDA	N/A
21	MH 213 - 21	0	2	1	0.97	< MDA	N/A
22	MH 213 - 22	1	2	1	0.97	< MDA	N/A
23	MH 213 - 23	1	2	1	0.97	< MDA	N/A
	"Missed Activity"	9	2	1	0.97	8	

$$MDA(dpm) = \frac{4.65\sqrt{R_b / T_b} + 3}{T_b \cdot Efficiency}$$

Health Physicist

Attachment G

VSP Sampling Analysis Information

Catholic University

Maloney Hall Room 4

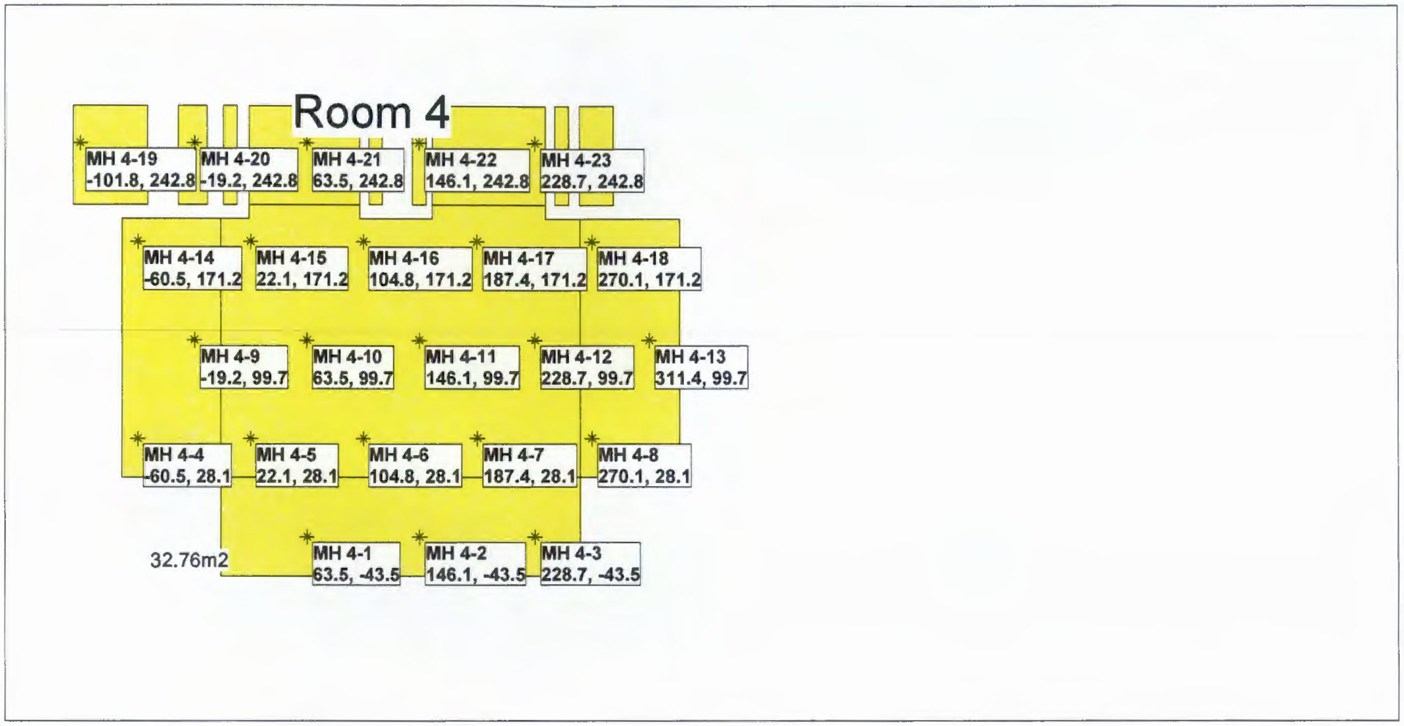
Systematic sampling locations for comparing a median with a fixed threshold (nonparametric - MARSSIM)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean or median to a fixed threshold
Type of Sampling Design	Nonparametric
Sample Placement (Location) in the Field	Systematic with a random start location
Working (Null) Hypothesis	The median(mean) value at the site exceeds the threshold
Formula for calculating number of sampling locations	Sign Test - MARSSIM version
Calculated total number of samples	20
Number of samples on map [a]	23
Number of selected sample areas [b]	1
Specified sampling area [c]	118301.80 in^2
Size of grid / Area of grid cell [d]	6.88706 feet / 41.077 ft^2
Grid pattern	Triangular
Total cost of sampling [e]	$0.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Size of grid / Area of grid cell gives the linear and square dimensions of the grid used to systematically place samples.
[e] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 18					
X Coord	Y Coord	Label	Value	Type	Historical
63.5	-43.5	MH 4-1	-7.4	Systematic	
146.1	-43.5	MH 4-2	7.4	Systematic	
228.7	-43.5	MH 4-3	-7.4	Systematic	
-60.5	28.1	MH 4-4	7.4	Systematic	
22.1	28.1	MH 4-5	-7.4	Systematic	
104.8	28.1	MH 4-6	0	Systematic	
187.4	28.1	MH 4-7	-14.8	Systematic	
270.1	28.1	MH 4-8	0	Systematic	
-19.2	99.7	MH 4-9	7.4	Systematic	
63.5	99.7	MH 4-10	7.4	Systematic	
146.1	99.7	MH 4-11	0	Systematic	
228.7	99.7	MH 4-12	-7.4	Systematic	

311.4	99.7	MH 4-13	0	Systematic	
-60.5	171.2	MH 4-14	-7.4	Systematic	
22.1	171.2	MH 4-15	0	Systematic	
104.8	171.2	MH 4-16	0	Systematic	
187.4	171.2	MH 4-17	-14.8	Systematic	
270.1	171.2	MH 4-18	0	Systematic	
-101.8	242.8	MH 4-19	0	Systematic	
-19.2	242.8	MH 4-20	-7.4	Systematic	
63.5	242.8	MH 4-21	-7.4	Systematic	
146.1	242.8	MH 4-22	-7.4	Systematic	
228.7	242.8	MH 4-23	0	Systematic	

Primary Sampling Objective

The primary purpose of sampling at this site is to compare a site median or mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the median(mean) value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the median(mean) value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative one, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach

A nonparametric systematic sampling approach with a random start was used to determine the number of samples and to specify sampling locations. A nonparametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that typical parametric assumptions may not be true.

Both parametric and non-parametric equations rely on assumptions about the population. Typically, however, non-parametric equations require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than if a non-parametric equation was used.

Locating the sample points over a systematic grid with a random start ensures spatial coverage of the site. Statistical analyses of systematically collected data are valid if a random start to the grid is used. One disadvantage of systematically collected samples is that spatial variability or patterns may not be discovered if the grid spacing is large relative to the spatial patterns.

Number of Total Samples: Calculation Equation and Inputs

The equation used to calculate the number of samples is based on a Sign test (see PNNL 13450 for discussion). For this site, the null hypothesis is rejected in favor of the alternative one if the median(mean) is sufficiently smaller than the threshold. The number of samples to collect is calculated so that if the inputs to the equation are true, the calculated number of samples will cause the null hypothesis to be rejected.

The formula used to calculate the number of samples is:

$$n = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(SignP - 0.5)^2}$$

where

$$SignP = \Phi\left(\frac{\Delta}{S_{total}}\right)$$

$\Phi(z)$ is the cumulative standard normal distribution on $(-\infty, z)$ (see PNNL-13450 for details),
n is the number of samples,
S_{total} is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site median(mean) is less than the threshold,
β is the acceptable probability of incorrectly concluding the site median(mean) exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

Note: MARSSIM suggests that the number of samples should be increased by at least 20% to account for missing or unusable data and uncertainty in the calculated value of n. VSP allows a user-supplied percent overage as discussed in MARSSIM (EPA 2000, p. 5-33).

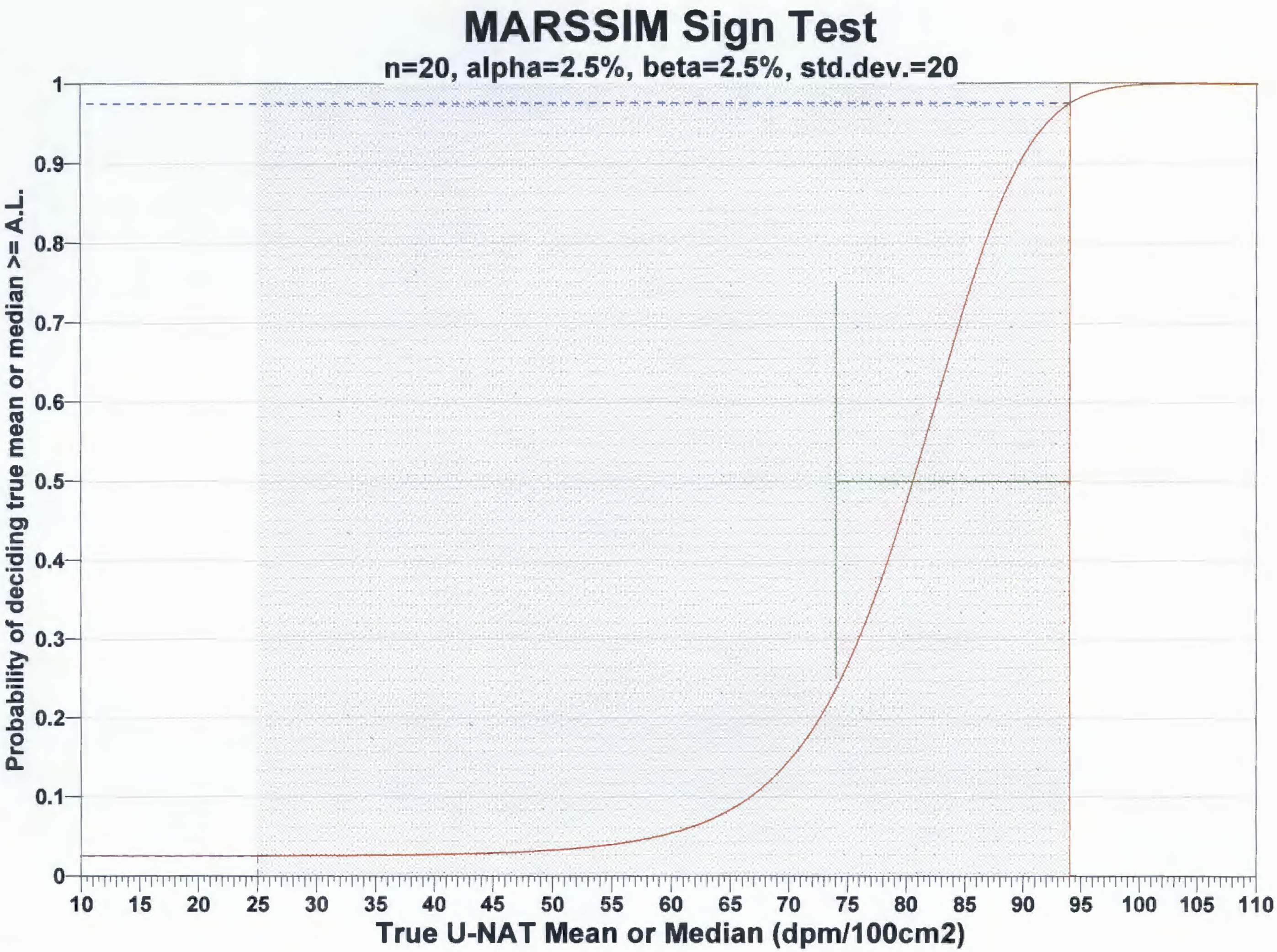
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n[a]	Parameter					
		S	**Δ**	**α**	**β**	**$Z_{1-\alpha}$**[b]	**$Z_{1-\beta}$**[c]
U-NAT	20	20 dpm/100cm2	69 dpm/100cm2	0.025	0.025	1.95996	1.95996

[a] The final number of samples has been increased by the MARSSIM Overage of 20%.
[b] This value is automatically calculated by VSP based upon the user defined value of α.
[c] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true median(mean) values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the computed sign test statistic is normally distributed,
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected probabilistically.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the gridded sample locations were selected based on a random start.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%),

probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level. The following table shows the results of this analysis.

Number of Samples							
AL=94		α=5		α=10		α=15	
		s=40	s=20	s=40	s=20	s=40	s=20
LBGR=90	β=5	377	100	299	80	251	66
	β=10	299	80	230	62	188	51
	β=15	251	66	188	51	150	40
LBGR=80	β=5	100	32	80	26	66	21
	β=10	80	26	62	20	51	16
	β=15	66	21	51	16	40	14
LBGR=70	β=5	50	20	39	16	33	14
	β=10	39	16	30	12	24	10
	β=15	33	14	24	10	20	9

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $0.00, which averages out to a per sample cost of $0.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**23 Samples**
Field collection costs		$0.00	$0.00
Analytical costs	$0.00	$0.00	$0.00
Sum of Field & Analytical costs		**$0.00**	**$0.00**
Fixed planning and validation costs			$0.00
Total cost			**$0.00**

Data Analysis for U-NAT
The following data points were entered by the user for analysis.

U-NAT (dpm/100cm2)										
Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	-14.8	-14.8	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4
10	0	0	0	0	0	0	0	0	0	7.4
20	7.4	7.4	7.4							

SUMMARY STATISTICS for U-NAT	
n	23
Min	-14.8
Max	7.4
Range	22.2
Mean	-2.5739
Median	0
Variance	42.856
StdDev	6.5464
Std Error	1.365
Skewness	-0.076664
Interquartile Range	7.4

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
-14.8	-14.8	-11.84	-7.4	0	0	7.4	7.4	7.4

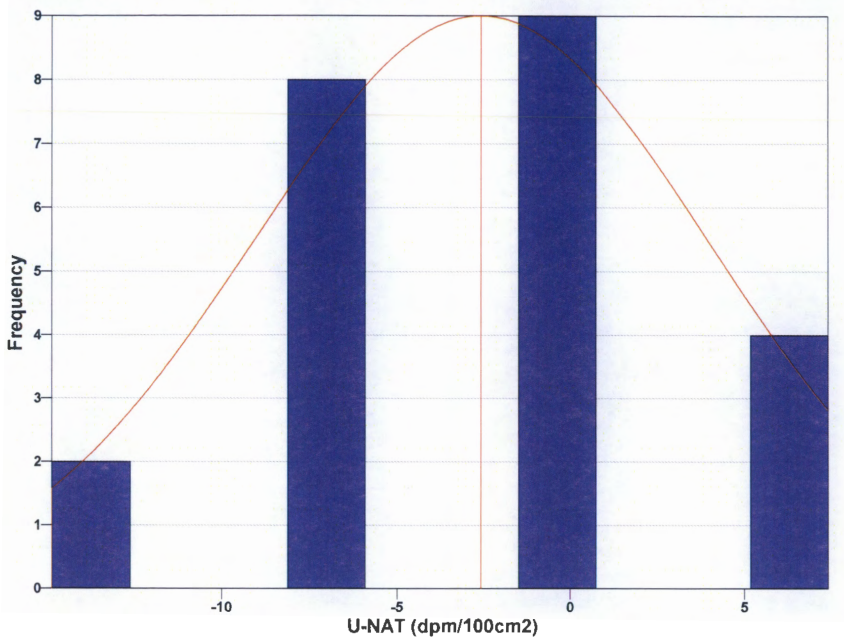
Data Plots
Three graphical displays of the data are shown below: the Histogram, the Box and Whiskers plot, and the Quantile-Quantile (Q-Q) plot.

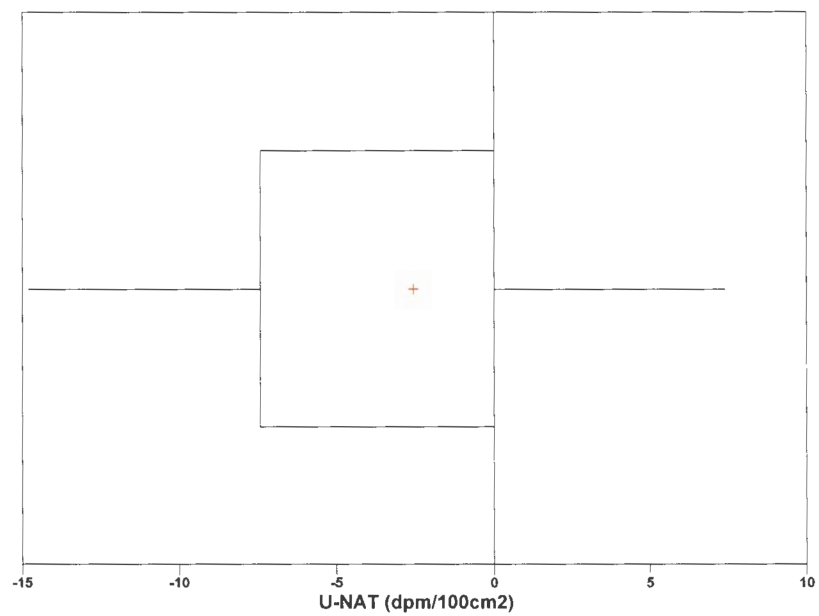
The Histogram is a plot of the fraction of the n observed data that fall within specified data "bins." A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

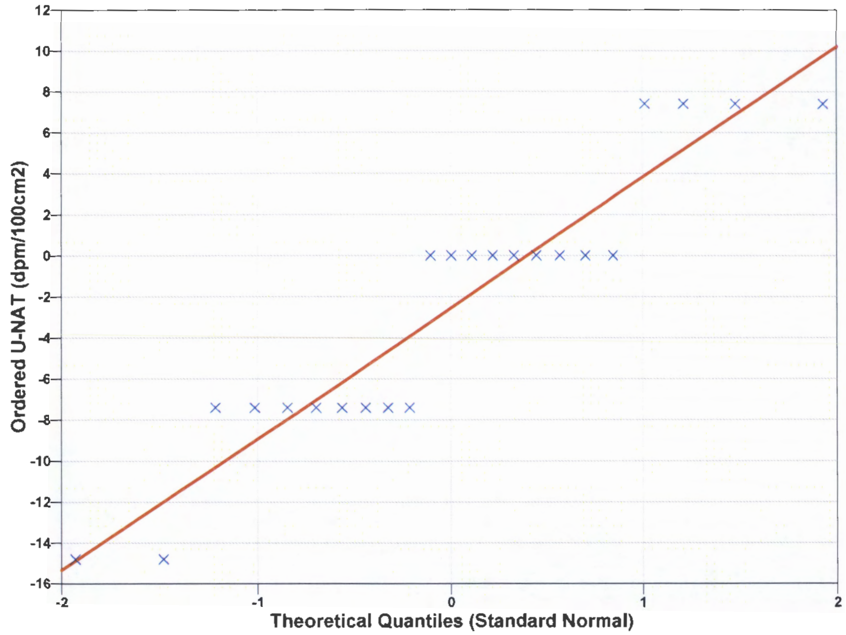
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the

box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these three plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests for U-NAT
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.8821
Shapiro-Wilk 5% Critical Value	0.914

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	-0.22997

95% Non-Parametric (Chebyshev) UCL	3.3761

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (3.376) may be a more accurate upper confidence limit on the true mean.

MARSSIM Sign Test
The Sign test was performed in accordance with the guidance given in section 8.3.2 of MARSSIM. Each measurement was subtracted from the action level to obtain n differences $d_i = AL - X_i$. Any differences of zero were discarded from consideration and the sample size was reduced accordingly. The test statistic S+ was calculated by counting the positive differences. S+ was then compared with the critical value k, which was obtained from Table I.3 in Appendix I of MARSSIM.

If $S+ > k$, then the null hypothesis is rejected.

MARSSIM SIGN TEST		
Test Statistic S+	**97.5% Critical Value**	**Null Hypothesis**
23	16	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, so conclude the site is clean.

Catholic University

Maloney Hall Room 7

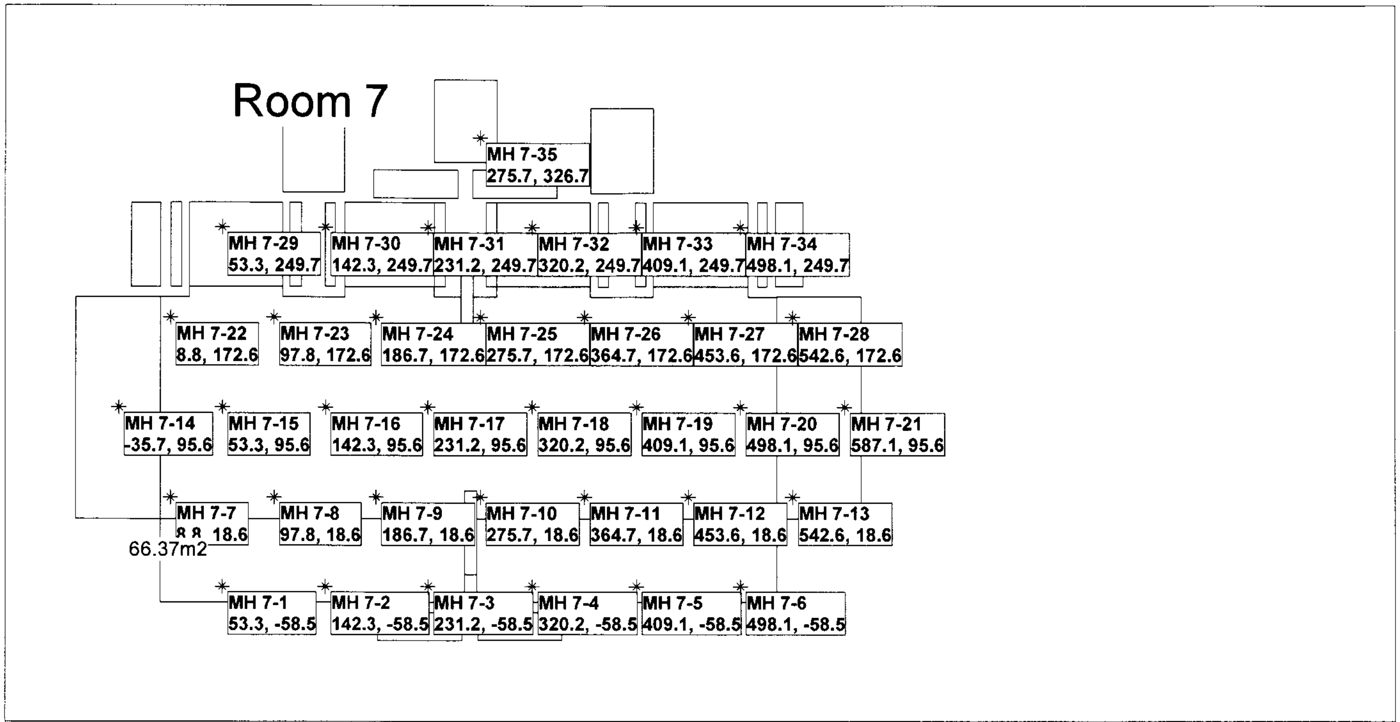
Systematic sampling locations for comparing a median with a fixed threshold (nonparametric - MARSSIM)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean or median to a fixed threshold
Type of Sampling Design	Nonparametric
Sample Placement (Location) in the Field	Systematic with a random start location
Working (Null) Hypothesis	The median(mean) value at the site exceeds the threshold
Formula for calculating number of sampling locations	Sign Test - MARSSIM version
Calculated total number of samples	32
Number of samples on map [a]	35
Number of selected sample areas [b]	1
Specified sampling area [c]	219317.79 in^2
Size of grid / Area of grid cell [d]	7.41336 feet / 47.595 ft^2
Grid pattern	Triangular
Total cost of sampling [e]	$0.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Size of grid / Area of grid cell gives the linear and square dimensions of the grid used to systematically place samples.
[e] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
53.3	-58.5	MH 7-1	22.2	Systematic	
142.3	-58.5	MH 7-2	0	Systematic	
231.2	-58.5	MH 7-3	0	Systematic	
320.2	-58.5	MH 7-4	-7.4	Systematic	
409.1	-58.5	MH 7-5	0	Systematic	
498.1	-58.5	MH 7-6	0	Systematic	
8.8	18.6	MH 7-7	7.4	Systematic	
97.8	18.6	MH 7-8	-7.4	Systematic	
186.7	18.6	MH 7-9	14.8	Systematic	
275.7	18.6	MH 7-10	7.4	Systematic	
364.7	18.6	MH 7-11	89	Systematic	
453.6	18.6	MH 7-12	7.4	Systematic	

542.6	18.6	MH 7-13	-7.4	Systematic	
-35.7	95.6	MH 7-14	7.4	Systematic	
53.3	95.6	MH 7-15	0	Systematic	
142.3	95.6	MH 7-16	14.8	Systematic	
231.2	95.6	MH 7-17	-7.4	Systematic	
320.2	95.6	MH 7-18	-7.4	Systematic	
409.1	95.6	MH 7-19	7.4	Systematic	
498.1	95.6	MH 7-20	14.8	Systematic	
587.1	95.6	MH 7-21	7.4	Systematic	
8.8	172.6	MH 7-22	-7.4	Systematic	
97.8	172.6	MH 7-23	-7.4	Systematic	
186.7	172.6	MH 7-24	0	Systematic	
275.7	172.6	MH 7-25	0	Systematic	
364.7	172.6	MH 7-26	7.4	Systematic	
453.6	172.6	MH 7-27	7.4	Systematic	
542.6	172.6	MH 7-28	0	Systematic	
53.3	249.7	MH 7-29	0	Systematic	
142.3	249.7	MH 7-30	-7.4	Systematic	
231.2	249.7	MH 7-31	-7.4	Systematic	
320.2	249.7	MH 7-32	-7.4	Systematic	
409.1	249.7	MH 7-33	0	Systematic	
498.1	249.7	MH 7-34	7.4	Systematic	
275.7	326.7	MH 7-35	14.8	Systematic	

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a site median or mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the median(mean) value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the median(mean) value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative one, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A nonparametric systematic sampling approach with a random start was used to determine the number of samples and to specify sampling locations. A nonparametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that typical parametric assumptions may not be true.

Both parametric and non-parametric equations rely on assumptions about the population. Typically, however, non-parametric equations require fewer assumptions

and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than if a non-parametric equation was used.

Locating the sample points over a systematic grid with a random start ensures spatial coverage of the site. Statistical analyses of systematically collected data are valid if a random start to the grid is used. One disadvantage of systematically collected samples is that spatial variability or patterns may not be discovered if the grid spacing is large relative to the spatial patterns.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Sign test (see PNNL 13450 for discussion). For this site, the null hypothesis is rejected in favor of the alternative one if the median(mean) is sufficiently smaller than the threshold. The number of samples to collect is calculated so that if the inputs to the equation are true, the calculated number of samples will cause the null hypothesis to be rejected.

The formula used to calculate the number of samples is:

$$n = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(SignP - 0.5)^2}$$

where

$$SignP = \Phi\left(\frac{\Delta}{S_{total}}\right)$$

$\Phi(z)$ is the cumulative standard normal distribution on $(-\infty,z)$ (see PNNL-13450 for details),
n is the number of samples,
S_{total} is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site median(mean) is less than the threshold,
β is the acceptable probability of incorrectly concluding the site median(mean) exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

Note: MARSSIM suggests that the number of samples should be increased by at least 20% to account for missing or unusable data and uncertainty in the calculated value of n. VSP allows a user-supplied percent overage as discussed in MARSSIM (EPA 2000, p. 5-33).

The values of these inputs that result in the calculated number of sampling locations are:

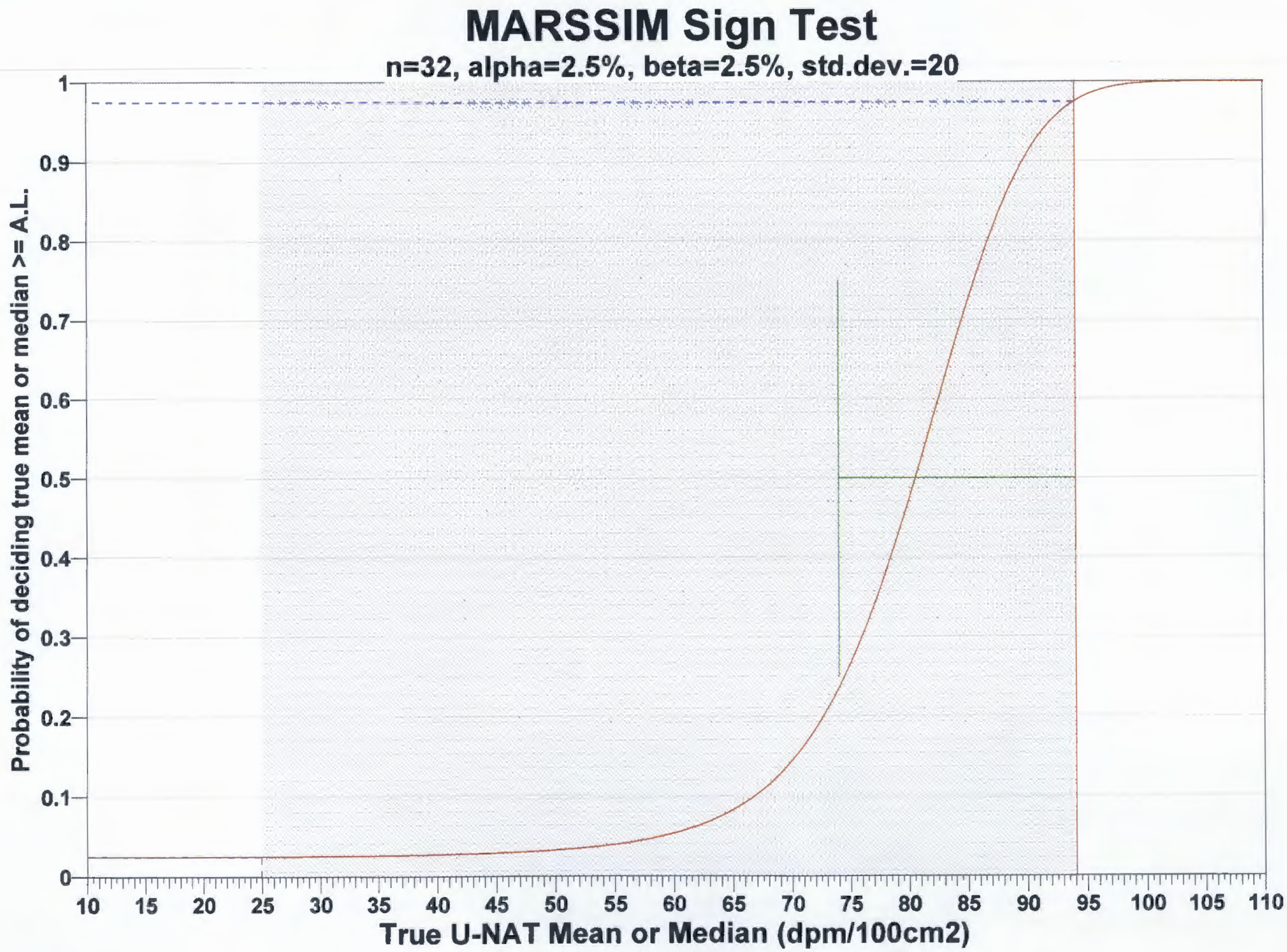
Analyte	n[a]	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [b]	$Z_{1-\beta}$ [c]
U-NAT	32	20 dpm/100cm2	69 dpm/100cm2	0.025	0.025	1.95996	1.95996

[a] The final number of samples has been increased by the MARSSIM Overage of 100%.
[b] This value is automatically calculated by VSP based upon the user defined value of α.
[c] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is

dirty on the vertical axis versus a range of possible true median(mean) values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the computed sign test statistic is normally distributed,
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected probabilistically.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the gridded sample locations were selected based on a random start.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level. The following table shows the results of this analysis.

Number of Samples							
AL=94		α=5		α=10		α=15	
		s=40	s=20	s=40	s=20	s=40	s=20
LBGR=90	β=5	628	166	498	132	418	110
	β=10	498	132	382	102	312	84
	β=15	418	110	312	84	250	66
LBGR=80	β=5	166	52	132	42	110	34
	β=10	132	42	102	32	84	26
	β=15	110	34	84	26	66	22
LBGR=70	β=5	82	32	64	26	54	22
	β=10	64	26	50	20	40	16
	β=15	54	22	40	16	32	14

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling

The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $0.00, which averages out to a per sample cost of $0.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	Per Analysis	Per Sample	35 Samples
Field collection costs		$0.00	$0.00

Analytical costs	$0.00	$0.00	$0.00
Sum of Field & Analytical costs		**$0.00**	**$0.00**
Fixed planning and validation costs			$0.00
Total cost			**$0.00**

Data Analysis for U-NAT
The following data points were entered by the user for analysis.

U-NAT (dpm/100cm2)										
Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4
10	0	0	0	0	0	0	0	0	0	0
20	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	14.8
30	14.8	14.8	14.8	22.2	89					

SUMMARY STATISTICS for U-NAT								
n	35							
Min	-7.4							
Max	89							
Range	96.4							
Mean	4.6571							
Median	0							
Variance	281.51							
StdDev	16.778							
Std Error	2.836							
Skewness	3.9046							
Interquartile Range	14.8							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
-7.4	-7.4	-7.4	-7.4	0	7.4	14.8	35.56	89

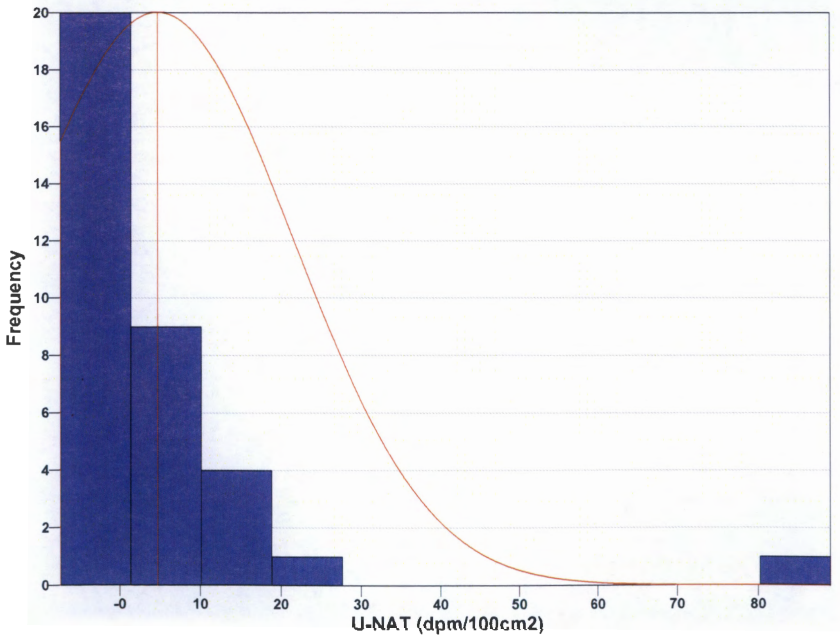
Data Plots

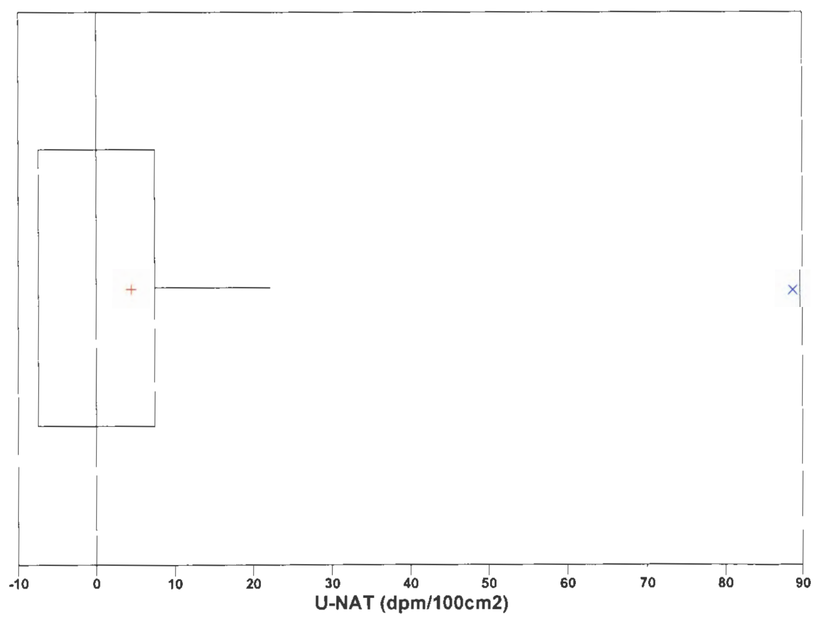
Three graphical displays of the data are shown below: the Histogram, the Box and Whiskers plot, and the Quantile-Quantile (Q-Q) plot.

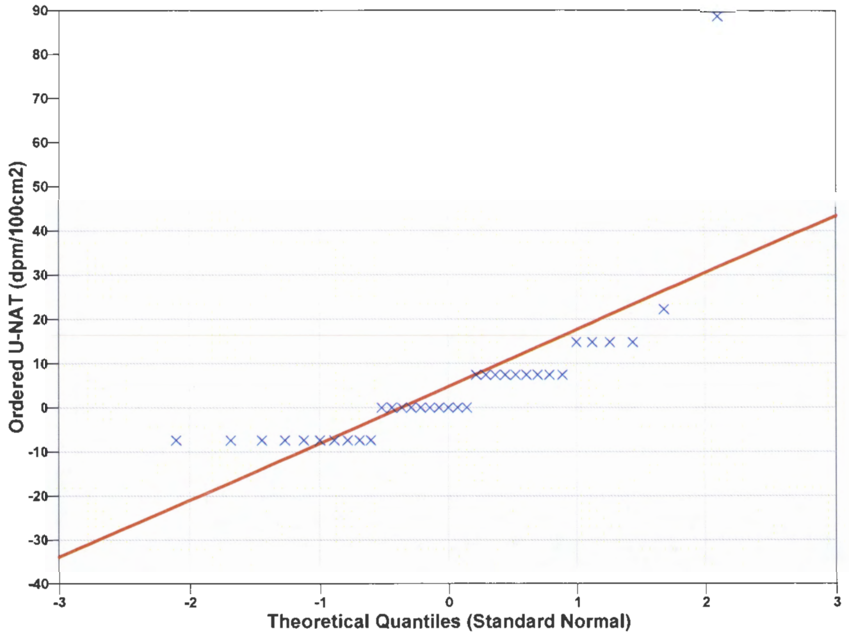
The Histogram is a plot of the fraction of the n observed data that fall within specified data "bins." A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these three plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests for U-NAT
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.5958
Shapiro-Wilk 5% Critical Value	0.934

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	9.4527

95% Non-Parametric (Chebyshev) UCL	17.019

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (17.02) may be a more accurate upper confidence limit on the true mean.

MARSSIM Sign Test
The Sign test was performed in accordance with the guidance given in section 8.3.2 of MARSSIM. Each measurement was subtracted from the action level to obtain *n* differences $d_i = AL - X_i$. Any differences of zero were discarded from consideration and the sample size was reduced accordingly. The test statistic S+ was calculated by counting the positive differences. S+ was then compared with the critical value *k*, which was obtained from Table I.3 in Appendix I of MARSSIM.

If $S+ > k$, then the null hypothesis is rejected.

MARSSIM SIGN TEST		
Test Statistic S+	**97.5% Critical Value**	**Null Hypothesis**
35	23	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, so conclude the site is clean.

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Software and documentation available at http://vsp.pnnl.gov

* - The report contents may have been modified or reformatted by end-user of software.

Catholic University

Maloney Hall Room 213

Systematic sampling locations for comparing a median with a fixed threshold (nonparametric - MARSSIM)

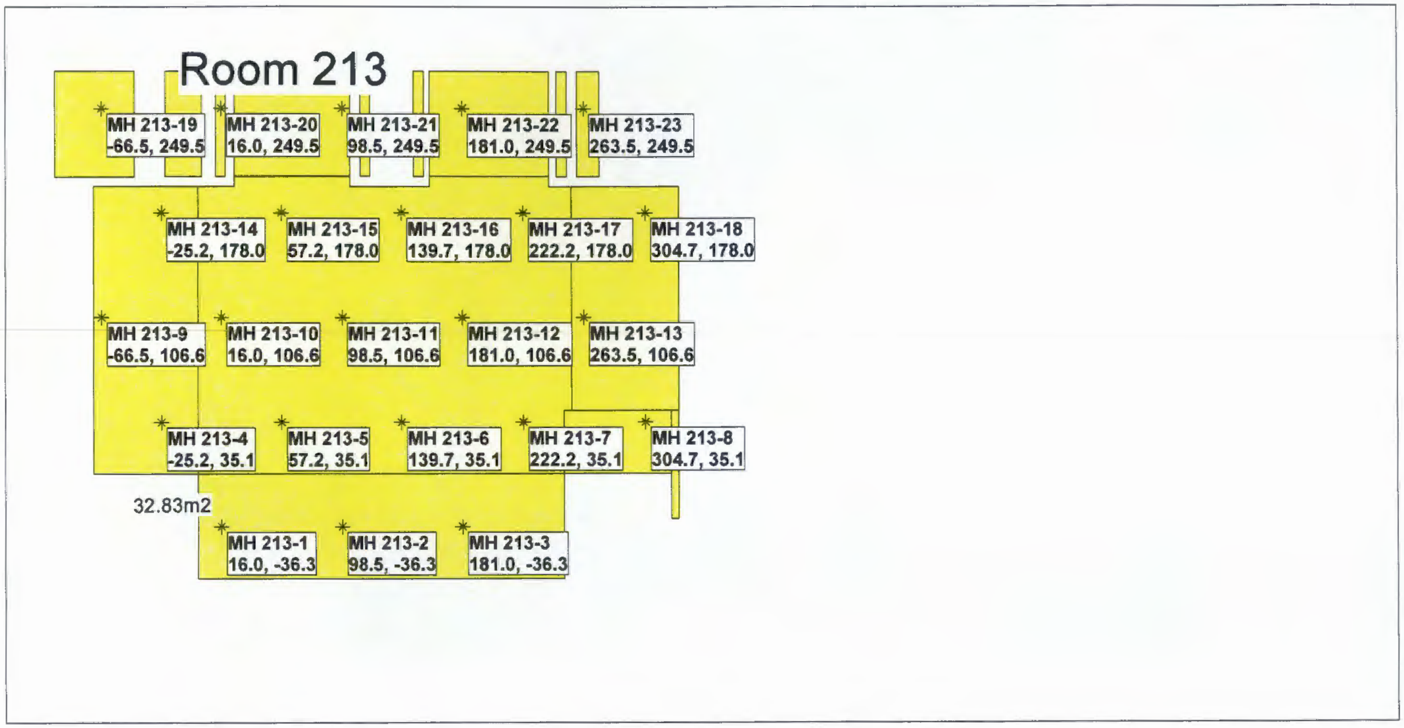
Summary

This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean or median to a fixed threshold
Type of Sampling Design	Nonparametric
Sample Placement (Location) in the Field	Systematic with a random start location
Working (Null) Hypothesis	The median(mean) value at the site exceeds the threshold
Formula for calculating number of sampling locations	Sign Test - MARSSIM version
Calculated total number of samples	20
Number of samples on map [a]	23
Number of selected sample areas [b]	1
Specified sampling area [c]	117871.84 in^2
Size of grid / Area of grid cell [d]	6.87454 feet / 40.9277 ft^2
Grid pattern	Triangular
Total cost of sampling [e]	$0.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Size of grid / Area of grid cell gives the linear and square dimensions of the grid used to systematically place samples.
[e] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
16.0	-36.3	MH 213-1	7.4	Systematic	
98.5	-36.3	MH 213-2	0	Systematic	
181.0	-36.3	MH 213-3	7.4	Systematic	
-25.2	35.1	MH 213-4	7.4	Systematic	
57.2	35.1	MH 213-5	-14.8	Systematic	
139.7	35.1	MH 213-6	0	Systematic	
222.2	35.1	MH 213-7	-7.4	Systematic	
304.7	35.1	MH 213-8	0	Systematic	
-66.5	106.6	MH 213-9	0	Systematic	
16.0	106.6	MH 213-10	0	Systematic	
98.5	106.6	MH 213-11	-7.4	Systematic	
181.0	106.6	MH 213-12	-7.4	Systematic	

263.5	106.6	MH 213-13	0	Systematic	
-25.2	178.0	MH 213-14	7.4	Systematic	
57.2	178.0	MH 213-15	-7.4	Systematic	
139.7	178.0	MH 213-16	0	Systematic	
222.2	178.0	MH 213-17	0	Systematic	
304.7	178.0	MH 213-18	0	Systematic	
-66.5	249.5	MH 213-19	7.4	Systematic	
16.0	249.5	MH 213-20	-7.4	Systematic	
98.5	249.5	MH 213-21	-7.4	Systematic	
181.0	249.5	MH 213-22	-7.4	Systematic	
263.5	249.5	MH 213-23	0	Systematic	

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a site median or mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the median(mean) value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the median(mean) value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative one, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A nonparametric systematic sampling approach with a random start was used to determine the number of samples and to specify sampling locations. A nonparametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that typical parametric assumptions may not be true.

Both parametric and non-parametric equations rely on assumptions about the population. Typically, however, non-parametric equations require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than if a non-parametric equation was used.

Locating the sample points over a systematic grid with a random start ensures spatial coverage of the site. Statistical analyses of systematically collected data are valid if a random start to the grid is used. One disadvantage of systematically collected samples is that spatial variability or patterns may not be discovered if the grid spacing is large relative to the spatial patterns.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Sign test (see PNNL 13450 for discussion). For this site, the null hypothesis is rejected in favor of the alternative one if the median(mean) is sufficiently smaller than the threshold. The number of samples to collect is calculated so that if the inputs to the equation are true, the calculated number of samples will cause the null hypothesis to be rejected.

The formula used to calculate the number of samples is:

$$n = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(SignP - 0.5)^2}$$

where

$$SignP = \Phi\left(\frac{\Delta}{S_{total}}\right)$$

$\Phi(z)$ is the cumulative standard normal distribution on $(-\infty,z)$ (see PNNL-13450 for details),
n is the number of samples,
S_{total} is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site median(mean) is less than the threshold,
β is the acceptable probability of incorrectly concluding the site median(mean) exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

Note: MARSSIM suggests that the number of samples should be increased by at least 20% to account for missing or unusable data and uncertainty in the calculated value of n. VSP allows a user-supplied percent overage as discussed in MARSSIM (EPA 2000, p. 5-33).

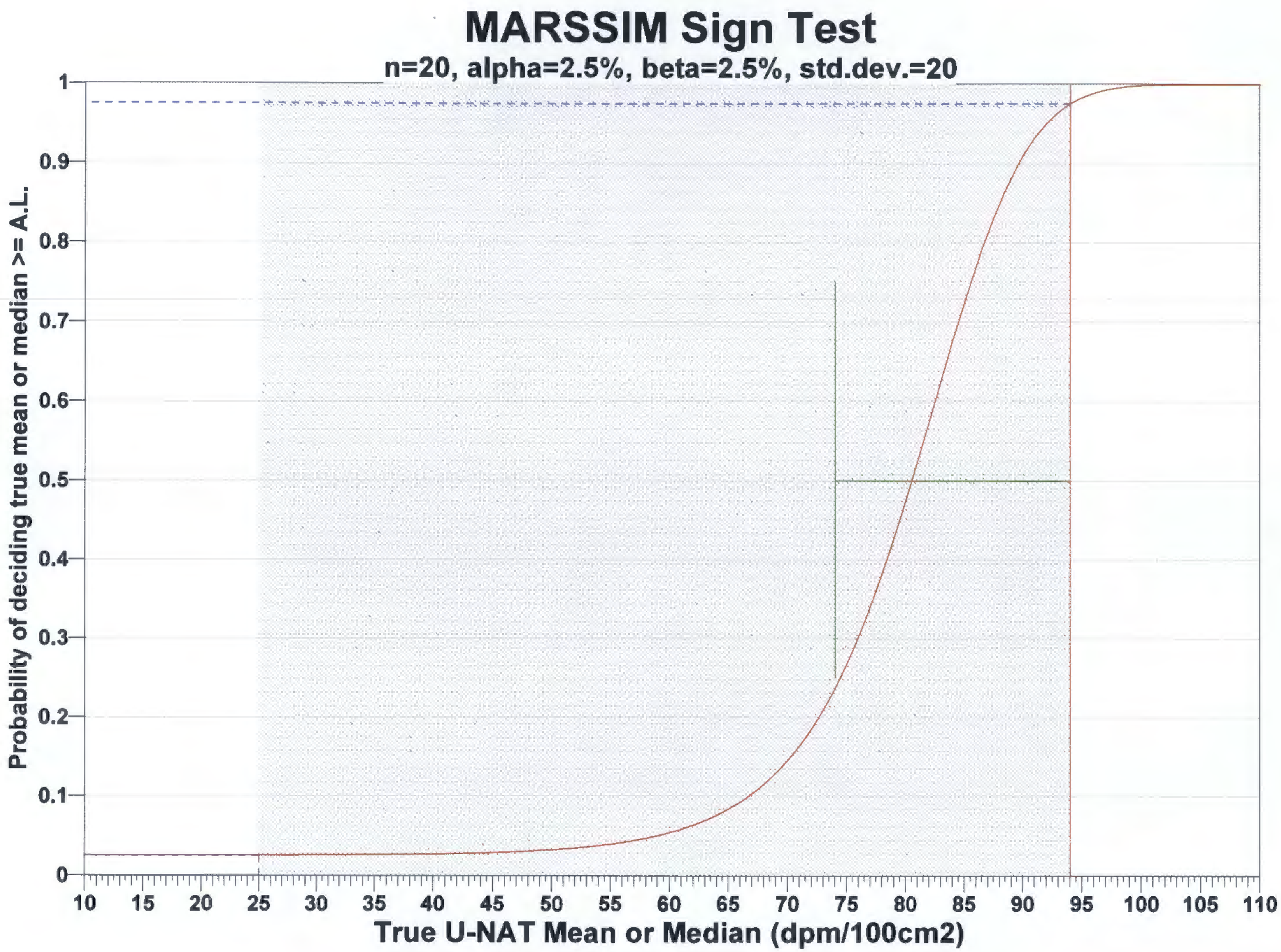
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n[a]	Parameter					
		S	**Δ**	**α**	**β**	**$Z_{1-\alpha}$** [b]	**$Z_{1-\beta}$** [c]
U-NAT	20	20 dpm/100cm2	69 dpm/100cm2	0.025	0.025	1.95996	1.95996

[a] The final number of samples has been increased by the MARSSIM Overage of 20%.
[b] This value is automatically calculated by VSP based upon the user defined value of α.
[c] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true median(mean) values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:
1. the computed sign test statistic is normally distributed,
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected probabilistically.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the gridded sample locations were selected based on a random start.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%),

probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level. The following table shows the results of this analysis.

Number of Samples							
AL=94		α=5		α=10		α=15	
		s=40	s=20	s=40	s=20	s=40	s=20
LBGR=90	β=5	377	100	299	80	251	66
	β=10	299	80	230	62	188	51
	β=15	251	66	188	51	150	40
LBGR=80	β=5	100	32	80	26	66	21
	β=10	80	26	62	20	51	16
	β=15	66	21	51	16	40	14
LBGR=70	β=5	50	20	39	16	33	14
	β=10	39	16	30	12	24	10
	β=15	33	14	24	10	20	9

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $0.00, which averages out to a per sample cost of $0.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**23 Samples**
Field collection costs		$0.00	$0.00
Analytical costs	$0.00	$0.00	$0.00
Sum of Field & Analytical costs		**$0.00**	**$0.00**
Fixed planning and validation costs			$0.00
Total cost			**$0.00**

Data Analysis for U-NAT
The following data points were entered by the user for analysis.

U-NAT (dpm/100cm2)										
Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	-14.8	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	0	0
10	0	0	0	0	0	0	0	0	7.4	7.4
20	7.4	7.4	7.4							

SUMMARY STATISTICS for U-NAT								
n	23							
Min	-14.8							
Max	7.4							
Range	22.2							
Mean	-1.287							
Median	0							
Variance	38.094							
StdDev	6.172							
Std Error	1.287							
Skewness	-0.16252							
Interquartile Range	7.4							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
-14.8	-13.32	-7.4	-7.4	0	0	7.4	7.4	7.4

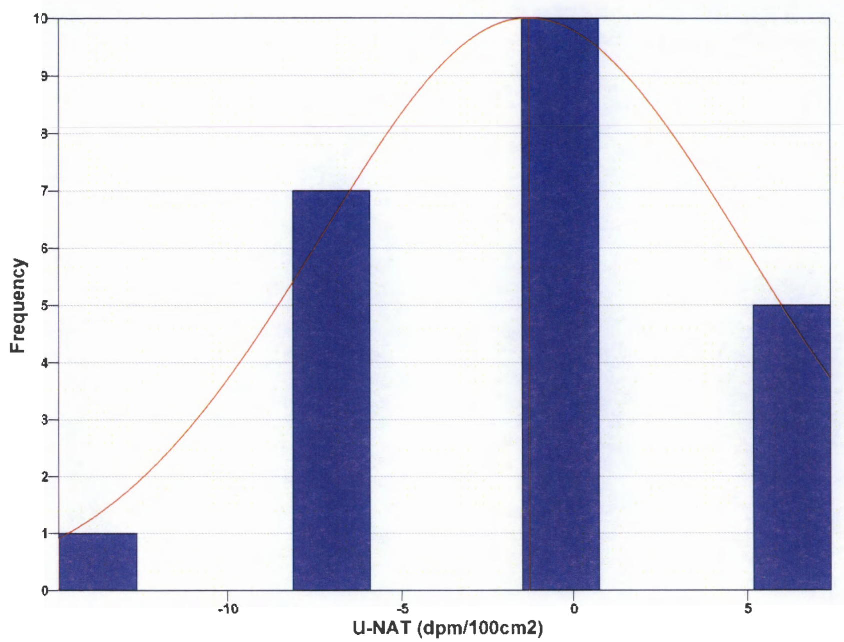
Data Plots
Three graphical displays of the data are shown below: the Histogram, the Box and Whiskers plot, and the Quantile-Quantile (Q-Q) plot.

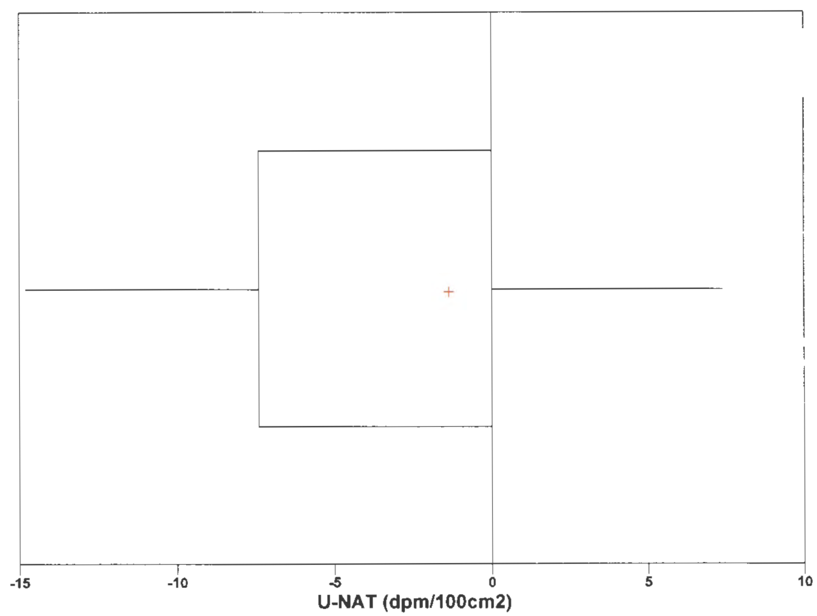
The Histogram is a plot of the fraction of the n observed data that fall within specified data "bins." A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

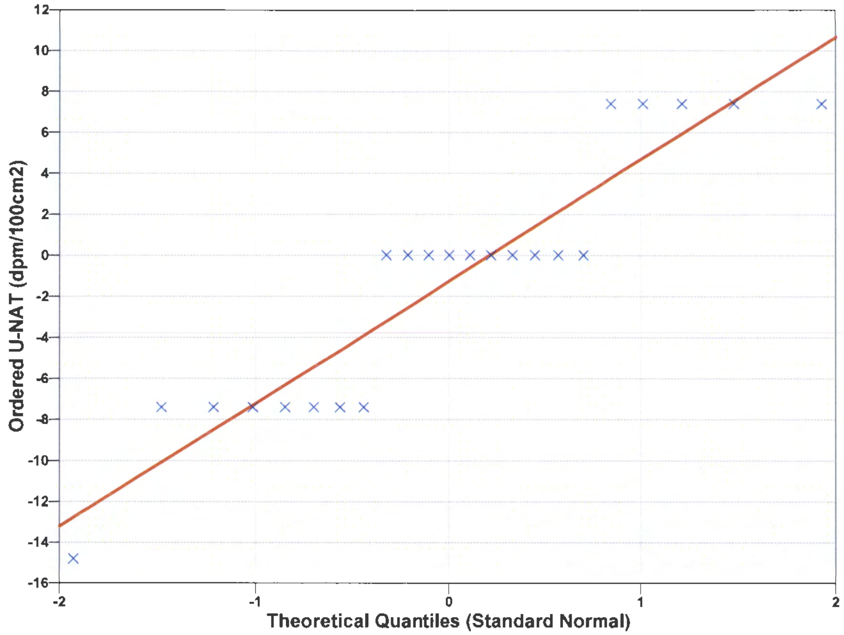
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the

box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The pth quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these three plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests for U-NAT
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.8695
Shapiro-Wilk 5% Critical Value	0.914

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	0.92293

95% Non-Parametric (Chebyshev) UCL	4.3228

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (4.323) may be a more accurate upper confidence limit on the true mean.

MARSSIM Sign Test

The Sign test was performed in accordance with the guidance given in section 8.3.2 of MARSSIM. Each measurement was subtracted from the action level to obtain *n* differences $d_i = AL - X_i$. Any differences of zero were discarded from consideration and the sample size was reduced accordingly. The test statistic S+ was calculated by counting the positive differences. S+ was then compared with the critical value *k*, which was obtained from Table I.3 in Appendix I of MARSSIM.

If $S+ > k$, then the null hypothesis is rejected.

MARSSIM SIGN TEST		
Test Statistic S+	**97.5% Critical Value**	**Null Hypothesis**
23	16	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, so conclude the site is clean.

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