RPT-60017-18001

FINAL STATUS SURVEY REPORT

for

Soil Areas Located
at the Winchester Engineering and Analytical Center
Winchester and Woburn, Massachusetts

Prepared for the
Food and Drug Administration

August 2018

Reviewed by:

Neil C. Kiely

North Wind Project Manager

8-16-18

Date

Elon Malkin

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WEAC Decommissioning Program Manager

Date

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Knoxville, TN 37931

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Acronyms and Abbreviations

AEC	Atomic Energy Commission
AF	Area Factor
ALARA	as low as reasonable achievable
ASG	Automated Science Group, Inc.
BF	branching fraction
CFR	Code of Federal Regulations
cm	centimeter
cm^2	square centimeters
COC	contaminant of concern
cpm	counts per minute
DCGL	Derived Concentration Guideline Level
DHEW	Department of Health, Education, and Welfare
DHHS	U.S. Department of Home Land Security
DOE	Department of Energy
dpm	disintegrations per minute
DQO	data quality objective
DSR	dose to source ratio
ECD	electron capture detector
EMC	elevated measure criteria
EPA	U.S. Environmental Protection Agency
FDA	Food and Drug Administration
FSS	Final Status Survey
FSSP	Final Status Survey Plan
FSSR	Final Status Survey Report
FUSRAP	Formerly Utilized Sites Remedial Action Program

g	gram
GPS	global positioning system
GWA	Ground Water Associates, Inc.
HPGe	high purity germanium
HSA	Historical Site Assessment
LBGR	lower boundary of the gray region
m	meter
m^2	square meters
m^3	cubic meters
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDA	minimum detectable activity
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MEI	maximally exposed individual
mrem/y	millirems per year
North Wind	North Wind Site Services, LLC
NRC	U.S. Nuclear Regulatory Commission
NRHL	Northeast Radiological Health Laboratory
OLIVER	Massachusetts Online Viewer
ORNL	Oak Ridge National Laboratory
pCi/g	picocuries per gram
PHS	Public Health Service
PMD	peak of the mean dose
QA	quality assurance
QC	quality control

RER	relative error ratio
RESRAD	residual radioactivity
RG	remediation goal
ROC	Radionuclide of Concern
RSO	Radiation Safety Officer
SOF	Sum of Faction
SOP	Standard Operating Procedure
SOR	Sum of Ratios
SU	Survey Unit
USGS	United States Geological Survey
WEAC	Winchester Engineering and Analytical Center
WRS	Wilcoxon Rank Sum
yd^3	cubic yards

1. INTRODUCTION

This Final Status Survey Report (FSSR) has been prepared by North Wind Site Services, LLC (North Wind) to fulfill the requirements of Contract HHSF223201710022C for the U.S. Department of Home Land Security (DHHS), Food and Drug Administration (FDA). Under this Contract, North Wind performed clean up actions at the Winchester Engineering and Analytical Center (WEAC), which is located in Woburn and Winchester, Massachusetts and is operated by the FDA. Following cleanup, this FSSR has been developed to document the post-clean up final radiological status of the land areas within the study area. This FSSR has been developed based upon the direction and guidance provided in several documents, the most relevant of which are provided in Table 1-1. Throughout this FSSR, references will be made to these documents.

1.1 Scope

This FSSR is specific to the assessment of radiological site conditions following the removal of radiologically contaminated soils resulting from past uranium milling and refinement processes performed for the Atomic Energy Commission (AEC) prior to 1961. WEAC is seeking official documentation that certain defined land areas which lie within the proposed footprint of a future laboratory facility are non-regulated in regards to their intended industrial use.

During the remediation phase of the project, North Wind removed found contamination until areas met the remediation goal (RG) for the site. A combination of gamma walkover surveys/scanning and soil sample analysis were used to determine that project RGs were met. One surface-contaminated article (e.g., an abandoned utility pipe) was found within one excavation area; this was surveyed and released *in situ* following guidance found in the North Wind procedures for the release of equipment and materials, along with guidance provided in the Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME) (NRC 2009). As the RG was evidentially achieved, survey units were subjected to the Final Status Survey (FSS) process, which was designed and implemented in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) protocols. Contaminated soils were shipped offsite to a permitted commercial facility. As the RG was achieved in each survey unit/area, North Wind performed additional characterization (e.g., extensive site trenching) to preclude the likelihood that additional buried contamination remains to be found on site.

Table 1-1. Documents Supporting Development and Execution of the FSS

Document	Relationship	Comment
Decommissioning Plan for Soils Areas at the Winchester Engineering and Analytical Center (North Wind 2017).	Provides the scope and approach for the remediation effort and the RG.	Derived Concentration Guideline Level (DCGL) values are developed in Appendix B of the Decommissioning Plan.
Historical Site Assessment (HSA), Winchester Engineering and Analytical Center (WEAC 2017).	Provides the FSS study boundaries.	The HSA provides the boundaries of the potentially contaminated area and defines the potential contaminants of concern (COCs).
MARSSIM (NRC 2002).	Input and assessment design used to determine when the goal has been reached.	Provides recommended statistical basis for survey and assessment strategies to ensure that the remediation criteria have been achieved at a desired degree of confidence.
Final Status Survey Plan (FSSP) for Soils Areas at the Winchester Engineering and Analytical Center (North Wind 2018)	Provides the basis and approach to complete site FSS activities with respect to design and data quality objectives (DQOs)	The FSSP provides select DQOs, statistical design, and confidence levels designed to demonstrate attainment of clean up objectives (DCGLs).
Standard Operating Procedures (SOPs); a list of applicable SOPs is provided in Appendix A.	Generic and detailed “how to” documents.	SOPs provide detailed instructions on operating instrumentation, sample collection, survey technique, and completing records.

2. SITE DESCRIPTION AND HISTORY

The WEAC, which is located on the border of Woburn and Winchester, Massachusetts, started operation in 1952 under contract with the AEC's Division of Research and Development. The facility held AEC licenses from 1952 to 1959 when the facility was used to isolate uranium from ore. In 1959, the facility's mission changed to the monitoring of uranium, thorium, and radium from the effluents of uranium tailings from Grand Junction, Colorado. In 1960, AEC began cleanup operations, which included removing uranium processing equipment, decontaminating the facility, disposing of radioactive materials, and transporting 14 yards of low-grade uranium-bearing ore to a landfill in Woburn, Massachusetts.

In 1961, after AEC completed cleanup operations, the laboratory switched ownership to the Department of Health, Education, and Welfare's (DHEW's) Public Health Service (PHS), who established the Northeast Radiological Health Laboratory (NRHL). DHEW operated under AEC Byproduct Material License Number 20-8361-1 E64 and AEC Special Nuclear Material License Number SNM-688; neither license documents uranium burial. In 1961, DHEW PHS operations consisted of analyzing environmental samples.

In 1971, radiological health programs were transferred to the DHEW's FDA. The FDA took over operations at WEAC and tested radiopharmaceutical samples. Starting in 1973, FDA began monitoring foods for radioactivity and cleaning electron capture detectors (ECDs) for FDA field laboratories. In 1979, DHEW became the DHHS, under which the FDA currently operates. DHEW and DHHS have added multiple structures to the site, including warehouses and waste sheds. With the exception of the radioactive waste sheds, DHHS and DHEW have not used any of the outside buildings or grounds for the use, storage, processing, burial, or disposal of radioactive material. Prior to site remediation activities conducted in 2018, all above ground structures were removed from the study area.

Currently, the FDA WEAC is funded and anticipates building an additional laboratory testing facility to the north of the existing main building. In anticipation of this event, WEAC desires to formally document that this area has been cleaned and is ready for construction activities needed to support the facility expansion.

2.1 Previous Investigations and Site Activities

WEAC currently operates under U.S. Nuclear Regulatory Commission (NRC) Materials Possession License No. 20-08361-01 (2010 – present). WEAC is authorized to process radioactive materials in association with on-going testing and analytical measures of radionuclides in foods, pharmaceuticals, and environmental media. WEAC currently uses radiological material for research and development, as defined in 10 Code of Federal Regulations (CFR) 30.4, for laboratory studies in the development of radiochemical methods to detect radionuclides in foods and medical devices; for instrument development and calibration; and for education and training. Under DHEW or DHHS ownership, WEAC has not buried any radioactive material on site. Based on a review of historical operations at the site, it appears unlikely that post-1961 site activities contributed to the residual contamination encountered during the study area remediation conducted in 2018.

2.2 Previous Decommissioning Activities

WEAC started operation in 1952 under the AEC Division of Research and Development. The site was operated under AEC contract by the *American Cyanamid Company* from 1952 to 1954. *The National Lead Company* continued operations from 1954 to 1961. The facility held AEC licenses from 1952 to 1959 when the facility was used for uranium processing and analysis. The facility conducted analyses of

uranium ore, and the facility was also used in uranium pre-pilot and pilot plant work. The work involved the making of "yellowcake." Yellowcake (U_3O_8) is a solid product of the uranium milling process, which takes its name from its color and texture.

Aerial photography taken by the Massachusetts Highway Department in 1954 is shown in Figure 2-1. It is clear from this image that AEC was actively using the grounds within the fenced portion of the property. There are also multiple buildings and structures that no longer exist. The concrete pads that are currently located on site are likely remnants of these old structures. There is also a building with a pitched roof that predates the pilot plant.

In 1959, the facility's mission changed to the monitoring of uranium, thorium, and radium in the effluents of uranium tailings. The AEC Division of Biology and Medicine had responsibility for the work at the facility. Effluent samples from a uranium pilot plant in Grand Junction, Colorado, were analyzed.

AEC began cleanup operations in 1960. AEC removed its uranium processing equipment and decontaminated the facility. AEC disposed of radioactive materials off-site and transported 14 cubic yards (yd^3) of low-grade uranium-bearing ore to a landfill in Woburn, Massachusetts.

In 1961, the operation of the laboratory switched from AEC to the DHEW's PHS. DHEW surveyed and accepted the facility, and a contaminated hood that was discovered during the survey was removed. DHEW PHS operated under Atomic Energy Byproduct Material License Number 20-8361-1 (E64) and Special Nuclear Material License Number SNM-688. According to Automated Science Group, Inc. (ASG) documentation, structures present on the grounds in 1961 included the Main Building, the Pilot Plant, the Solvent Shed, the Old Radioactive Waste Shed, and the Pipe Rack Shed.

DHEW PHS established the NRHL at the site in 1961. From 1961 to 1969, the laboratory provided laboratory quality control (QC) for cross-check samples, analyzed environmental samples for fallout radioactivity, and conducted some research and development. For a short time (i.e., 1969 to 1972), the U.S. Environmental Protection Agency (EPA) was a tenant and took over the environmental monitoring and QC activities. An aerial photograph of WEAC, taken in 1969 by the Massachusetts Highway Department, is provided as Figure 2-2.

In 1971, radiological health programs were transferred to the DHEW's FDA, which took over operations at WEAC and established its current mission. At that time, WEAC tested radiopharmaceuticals and validated methodologies for new radiopharmaceutical drug applications. Beginning in 1973, WEAC began monitoring foods for radioactivity. WEAC also cleaned ECDs and analyzed ECD swipes for the FDA's field laboratories. In 1979, DHEW became the DHHS, under which the FDA currently operates.

WEAC was reviewed by the Energy Research and Development Administration and its successor, the Department of Energy (DOE), for inclusion in the Formerly Utilized Sites Remedial Action Program (FUSRAP). In 1977, Oak Ridge National Laboratory (ORNL) conducted a preliminary radiological survey of the site and concluded that further radiation surveys were not warranted. In October 1979, the Woburn landfill was surveyed by ORNL and the Massachusetts Department of Public Health. In 1986, DOE concluded that because the site was adequately decontaminated and was being operated under an NRC license, it would be eliminated from consideration for inclusion in FUSRAP. In their FUSRAP elimination report, DOE reported that the use of areas at WEAC would not result in any measurable radiological hazard to site occupants or the general public because of previous AEC-related activities.

In 1991, radioactive "tailings" consisting of Radium-226 (Ra-226) and daughter products were found by an intern working with WEAC's Radiation Safety Officer (RSO) in the back of property near the gas tank storage area. The RSO supervised soil removal and shipment as low level waste to Barnwell, South Carolina.

Note: *Red arrow indicates former building with pitched roof constructed before the Pilot Plant.*

Figure 2-1. Aerial Photograph of WEAC in 1954.

Note: *Whole body Counting Room, Pilot Plant, Pipe Rack Shed, West Warehouse, and Old Radioactive Waste Shed visible.*

Figure 2-2. Aerial Photograph of WEAC in 1969.

In 1995, ASG prepared a Radiological Status Report of WEAC (ASG 1995) for the DOE's Hazardous Waste Remedial Action Program, managed by Martin Marietta Energy Systems, Inc. According to this report, no radioactivity above background was found in outdoor areas or outbuildings. However, this report did identify potential burial locations based on site history; one being under the eastern most warehouse, and the other being the area near the gas tank storage shed. The ASG survey reports that the evaluation of the outside areas of the site showed dose rates indistinguishable from background, suggesting the absence of undiscovered uranium burial areas. Other reports prepared by ASG include a Preliminary Decommissioning Plan and a Decommissioning Funding Plan. Aerial photographs taken in 1980 and 1996, respectively, are shown in Figure 2-3.

2.3 Impacted Areas

Based on historical documents and aerial photography, AEC's operations involving uranium processing have only been conducted within the gated area. This is likely to contain residual contamination at levels greater than the site DCGL values. Thus, the impacted area is considered to include areas north of the main facility building, inside the gated area (see Figure 2-4).

2.4 Non-Impacted Areas

Based on historical documents and aerial photography, AEC's operations involving uranium processing have only been conducted north of the main facility building, within the gated area. Additionally, areas outside the gated area are considered to be non-impacted (see Figure 2-4).

2.5 Potentially Contaminated Media within the Study Area

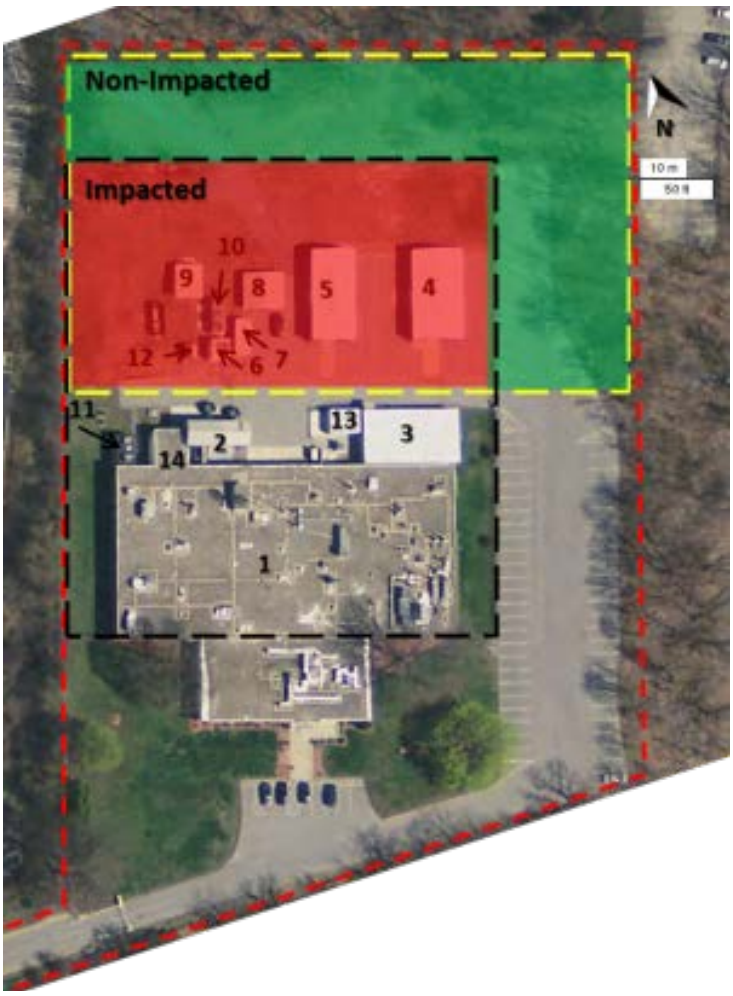
The decontamination and post-decontamination RG assessment is limited to soils and potentially contaminated debris located within the future building footprint of the laboratory expansion. Contaminated media under assessment is thus essentially limited to soil and buried debris. However, surfaces of buried utilities (i.e., water or gas lines) found within contaminated soils are also considered potentially impacted. Since the majority of soil coverings (e.g., asphalt and concrete) were placed on gravel that was placed over potentially contaminated soil, these materials were considered "suspect-clean" during remediation. Suspect clean materials were carefully removed from the underlying surfaces, sampled, and once confirmatory analysis was provided, dispositioned as non-impacted normal construction debris.

2.6 Prior On-site Burials

During remediation, two small (< 150 m^2) burial sites were encountered. Extensive trenching was performed across the study area down to a depth of 4 feet; no evidence of additional burial areas were found.

Note: *Both warehouses and Annex visible in 1980 (left), Hazardous Waste Shed visible in 1996 (right). Downloaded from the Massachusetts Office of Geographic Information (MassGIS) Online Viewer (OLIVER).*

Figure 2-3. Aerial Photographs of WEAC Taken in 1980 and 1996.



Note: *Green shaded area indicates non-impacted area, red shaded area indicates impacted area, yellow broken outline shows new building area, black outline shows gated area, and red broken line shows property boundaries.*

Figure 2-4. Impacted and Non-impacted Areas on Grounds Slated for New Building Construction.

2.7 Nature and Extent of Soil Contamination

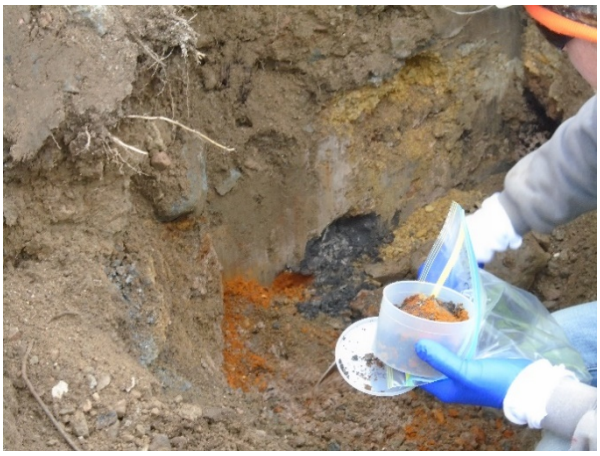
Between 1952 and 1961, the land area north of the WEAC main building may have been partially used to store and handle uranium ore. Processed uranium and uranium byproduct material (i.e., tailings) may also have been produced, handled, and stored in this same area. Potential long-lived COCs include processed natural uranium, Thorium-230 (Th-230), and Ra-226. During remediation, low levels of spotty surface contamination were found in the eastern half of the impacted area. This spottiness increased with proximity to the two locations where buried uranium tailings were eventually discovered. The two burial locations were fairly small – the northern burial (at what was historically referred to as "hotspot 4") was approximately 1.67 meters deep × 14.5 meters wide (containing approximately 275 cubic meters [m^3] of waste). The material appeared visually as grayish-green sandy material exhibiting dose rates ranging from 0.3 to 1.5 mR/h. A picture of this Survey Unit 2 (SU2) material taken during the excavation is provided in Figure 2-5.

Figure 2-5. Buried Contamination found in SU2

The second, southerly burial location was located in the center of SU1 (historically referred to as "hotspot locations 2 and 3"). The material in SU1 was similar in nature to that found in the northern burial location but contained stratified materials of different colors (i.e., yellowish, blackish, grayish) mixed with some debris (i.e., a few broken glass bottles, drum carcass, pipe, and trash) (see Figure 2-6). Several samples were collected from both excavation areas and two samples were selected as being representative of the material to be excavated (WEAC-SS-043 and -046) and were sent off-site analysis used for waste profiling and acceptance purposes. The results of these two samples are provided in Figure 2-7. The buried material in the northern excavation (SU1) appeared to be uranium tailings (byproduct material) based on the sample results that exhibited high concentrations of Th-230 and Ra-226 relative to uranium content. The southern burial area (SU2) looked like a mixture of tailings and uranium process residue.

The area around the two burial locations were surface contaminated down to a few inches to a few feet in certain locations. Most of the surface contamination was found south of the northern excavation, extending down to the southern excavation, and extending south of the southern excavation to the southern border of SU1. This shallow contamination may have been material that was distributed during initial burial operations and through post-burial shallow utility work, which may have brought small quantities of contaminated material to the surface where it was spread around over the last 57 years.

Sampling of material found in the southern burial area located in SU1 (hotspot 2/3).



Material excavated from the southern burial area in SU1. Note the drum carcass lying on the load-out pile.

Figure 2-6. Contaminated Materials found in SU1 at the location formally known as hotspots 2 and 3.

(SET 03)	GEL Data - Samples are from Site Burial Areas located beneath historical hots spots #4 (SS-043) and #2/#3 (SS-46)									
	U-238 Decay Chain									
	Results (pCi/g)			Results (pCi/g) U-238 Chain			Result (pCi/g) Th-232 Chain			Fig 13
Sample ID	U-234	U-235	U-238	Total-U	Ra-226	Th-230	Th-232	Ra-228	Th-228	Loc.
WEAC-SS-043	27.5	1.64	23.4	52.5	149	206	3.28		0.38	#4
WEAC-SS-046	94.4	5.65	94.9	195.0	52.5	75.5	4.93		4.81	#2, #3
n	2	2	2	2	2	2	2		2	
Max	94.4	5.65	94.9	194.95	149	206	4.93		4.81	
average	61.0	3.6	59.2	123.7	100.8	140.8	4.1		2.6	

Figure 2-7. Waste Profile Sample Results for the two WEAC Burial Areas

2.8 Site Features

WEAC is located at 109 Holton Street Winchester, MA 01890 USA. The property boundary is centered at 42°28’16.1” Latitude North, 71°07’56.2” Longitude West. The facility is located between the cities of Woburn to the North and Winchester to the South. The geographic location and current property layout are shown in Figure 2-8.

According to the Ground Water Associates, Inc. (GWA) 1994 Environmental Assessment report, state bedrock maps indicated that the laboratory is situated approximately 500 feet away from a mapped geologic fault trending north to south and mapped along railroad tracks located east to the facility. The site is also located immediately south of a bedrock peak that has been mined and is exposed. Bedrock is also exposed on the northern part of the property and shallow bedrock formations were found during exploratory excavations performed following site remediation.

According to United States Geological Survey (USGS) lithological and lithogeochemical data for the New England Coastal Basin drainage area, WEAC lies upon the Avalon belt geological province localized in eastern Massachusetts in the Milford-Dedham Zone. This area contains predominantly mafic plutonic rocks from the areas of the Proterozoic Z age. The USGS Bedrock Geological Surface Classification is shown in Figure 2-9.

WEAC Geographic Location (Top) and Property Layout (Bottom). WEAC property boundary outlined in red. Buildings identified numerically in table below with approximate construction dates in parentheses. Geographic data downloaded from MassGIS using the Massachusetts OLIVER.

1. WEAC Main Building (1992)	8. Old Radioactive Waste Shed (1959)
2. WEAC Pilot Plant (1955)	9. Pipe Rack Shed (1959)
3. Office Annex (1980)	10. New Radioactive Waste Shed (1998)
4. East Warehouse (1970)	11. Mouse House/Sterility Shed (1998)
5. West Warehouse (1965)	12. Gas Tank Storage (1970)
6. Old Solvent Shed (1952)	13. Walk-in Freezers
7. Hazadous Waste Shed (1994)	14. Whole Body Counting Room (1965)

Figure 2-8. WEAC Geographic Location and Layout.

Note: *USGS 2004 Bedrock Geological Classification where green shaded region indicates Mafic Rocks and red shaded region indicates Avalon Granite. WEAC property boundary outlined in red. Data downloaded from the MassGIS OLIVER.*

Figure 2-9. WEAC Bedrock Geology.

3. CONTAMINANTS OF CONCERN AND CRITERIA

3.1 Contaminants of Concern

During extensive waste characterization activities conducted during site remediation, it was confirmed that that the site was residually contaminated with a mixture of uranium ore, processed natural uranium, and uranium-ore byproduct materials (Ra-226 or Th-230 in uranium tailings). Th-232 and Th-228 were found at natural background levels in all samples or as a small fraction (1 to 4%) of the associated Th-230 activity in the most contaminated samples. However, because the levels of Th-232 are so close to background and because Th-232 is not typically found co-located with uranium ore, Th-232 results were reviewed to confirm this background assumption but it was not considered a COC.

Th-230 and Ra-226 were found to be substantially co-located in all waste samples. This relationship supported real-time scanning to determine when remedial cleanup goals were achieved. Ra-226 was found to be co-located with uranium contamination as well.

3.2 Remedial Goal for Soils

The site is being assessed for industrial use, which is assumed to continue for the next 100 years. All residual contamination has been removed from the site and shipped to an authorized facility for disposal. Any remaining residual contamination on-site will be confirmed to be at or below levels that would result, after soils cleanup, in a dose to the average member of the critical group of greater than 25 millirems per year (mrem/y) over the next 1,000 years. Additionally, as low as reasonable achievable (ALARA) practices were employed to reduce the potential exposure to levels well below 25 mrem/y, when practical, given social and economic constraints. A complete discussion of the dose modeling methods applied and the resultant RGs proposed is provided in the WEAC Decommissioning Plan (North Wind 2017). A summary is provided in the next section.

3.2.1 Summarized Modeling Results

The average member of the critical group was considered under three industrial use scenarios:

1. Indoor industrial worker,
2. Outdoor industrial worker, and
3. Soils construction industrial worker.

Exposure pathways considered include direct radiation, inhalation of radioactive airborne material, and ingestion of contaminated soils. Each of the groups modeled would exhibit exposure at levels greater than that of an off-site average member of a critical group due to the on-site receptor's close proximity to the source term under the pathways considered. A computer code developed by Argonne National Laboratory (residual radioactivity [RESRAD] version 7.2) was used to model dose using probabilistic and deterministic methods. The primary exposure pathway (accounting for > 95% of modeled dose) is direct radiation. For uranium and radium, the first year after remediation represents the peak dose period. For Th-230, the peak dose occurs at time (t) = 1,000 years due to the slow ingrowth of Ra-226 (half-life of 1,600 years).

This presents an opportunity to reduce exposures to levels ALARA using real-time measurements of direct radiation, which were considered and employed at the time of remediation. The results of the RESRAD modeling and the associated RGs (in terms of average concentration in picocuries per gram [pCi/g]) are provided in Table 3-1.

Table 3-1. Recommended $DCGL_W$ values for the WEAC Soils Area–[a]

Nuclide	Indoor Worker			Outdoor Worker			Soils Construction Worker			Most Restrictive	Recom. DCGL
	PMD	90th	Det.	PMD	90th	Det.	PMD	90th	Det.		
Total-U	3,238	1,969	1,506	1,397	1,295	1,163	1,667	1,330	**560**	560	560
Th-230	130	63.5	92.9	55.3	**37.5**	71.6	80.9	55.8	45.9	37.5	37
Ra-226	33.2	19.7	15.6	13.4	12.6	**12.0**	22.9	22.7	21.6	12.0	12

_a, Values in pCi/g, which equate to 25 mrem/y for differing exposure scenarios at the peak of the mean dose (PMD), the PMD at the 90th percentile (90th), and the deterministic model.

3.2.2 ALARA Soils Cleanup Goal (CG_W)

The Cleanup Goal (CG_W) is based upon guidance provided by the EPA in Directive No. 9200.4-35P[1]. This directive allows a site to set the dose benchmark RG based on Ra-226 + Ra-228 at 5 pCi/g (surface) and 15 pCi/g (subsurface) for the cleanup of byproduct material. This approach requires licensees to calculate the potential peak effective dose equivalent (excluding radon) to an individual at the site within 1,000 years from exposure to the residual levels allowed under the radium soil standard. The radionuclides of concern (ROCs) being addressed by the Criterion 6(6) rule are thorium, natural uranium, and radium.

As the CG_W is essentially equivalent to the State's remedial dose goal, it may prove useful to WEAC to demonstrate performance against this objective when practical and thus, it is adopted as an ALARA goal. However, survey design strategy and the ultimate determination of if remedial actions have been successful is assessed against the $DCGL_W$ values.

The site ALARA CG_W has been developed using the criterion modeling conducted prior to remediation and provided to the NRC for approval as part of the Decommissioning Plan (North Wind 2017). The initial modeling assumed an industrial use scenario over the next 1,000 years. Three models were run for the in-door worker, the out-door worker, and the soils construction worker under conservative assumptions using modeling code developed by Argonne National Laboratory (RESRAD Version 7.2). This modeling was used to derive the benchmark dose based on 5 pCi/g of Ra-226 residually found across a 3,000 square meter (m^2) area (approximately the size of the entire residually contaminated site). The dose to source ratio (DSR) for Ra-226 was modeled as 2.08E+00 mrem/yr per pCi/g. At 5 pCi/g, this resulted in a benchmark dose for site remediation of 10.4 mrem/year under a sum of the ratios approach for multiple ROCs. The benchmark criterion for all ROCs are provided in Table 3-2.

Table 3-2. Cleanup Goals based on Benchmark Dose Modeling

Radionuclide of Concern	CG_W (pCi/g)	DSR (mrem/yr per pCi/g)	Benchmark Dose (mrem/yr)
Ra-226	5	2.08E+00	10.4
Total-Uranium	233	4.l66E-02	10.4
Th-230	15.6	6.66E-01	10.4

[1] EPA 2000. Remediation Goals for Radioactively Contaminated CERCLA Site Using the Benchmark Dose Cleanup Criteria in 10 CFR Part 40 Appendix A, I, Criterion 6(6).

3.2.3 ALARA Dose Rate Goal

The FSSP written for the site established an ALARA dose rate goal based on the 25 mrem $DCGL_W$ criterion under conditions of continuous (2,000 hrs/y) exposure; 12.6 µR/h above background with no individual location exhibiting a dose rate > 50 µR/h. However, to be consistent with the benchmarking ALARA CG_W values, the ALARA dose rate goal was lowered during remediation to 10.4 mrem/year; 5.2 µR/h above background with no individual location exhibiting a dose rate > 25 µR/h. Background for the site was found to be ~ 10.8 µR/h based on walkover data collected in the reference area (see Exhibit 5). Thus, the dose rate ALARA objective for the site is ~ 16.0 µR/h as an average dose rate across the site with individual locations to be < 25 µR/h.

Post remedial dose rates were documented by collecting gamma radiation readings at 1 meter above Class I area surfaces using a 2-inch × 2-inch sodium iodide (NaI) detector connected to a Global Positioning System (GPS). Meter readings, normalized to counts per minute (cpm), were developed into dose isopleths using cpm/uR/h conversion factors recommended by the instrument manufacturer, as calibrated using a Cs-137 standard.

The ability to continue to remove soils beyond the soils $DCGL_W$ values was constrained by two primary variables:

1. How quickly the $DCGL_W$ was met, and

2. How much remaining packaging capacity was available for additional soils and debris.

Because significant contamination quantities were not encountered until well into the remediation schedule (i.e., when the buried contamination was found in SU1 and SU2), the packaging constraint was not removed until well into the remediation schedule as well. This resulted in a significantly more aggressive remediation effort in the interior portions of SU1 and SU2. However, overall scheduling constraints remained in effect throughout the project and thus, a few small, elevated spots (slightly above background but still within the CG_W dose goal) remain on site.

3.3 Other Potential Contaminates

Sample data and on-going surveys conducted under WEAC's current broad scope Radioactive Material License indicate there has been no cross contamination from WEAC facility operations to the soil areas subject to this FSSP. However, to confirm this assumption, four of the systematic samples and at least one of the judgmental samples from each survey unit survey was additionally analyzed for gross alpha/beta activity content. A result statistically greater than background, and what would be considered normal contributions from the COCs, would indicate an issue for further investigation.

3.4 Elevated Measurement Criteria

3.4.1 MARSSIM Guidance

Samples taken from areas exhibiting residual activity concentrations greater than criteria are investigated to ensure the overall estimated dose impact does not exceed 25 mrem/y on a survey unit by survey unit basis. Additionally, these results are contrasted with the CG_W ALARA goal of 10.4 mrem/y. The initial investigative process follows the guidance provided in the MARSSIM – if a COC is found to be above the $DCGL_W$ in a small area, in addition to COC concentrations distributed uniformly across the remaining survey unit, the unity rule (MARSSIM Section 4.3.3) may be used to ensure that the total residual activity is within criteria. This is performed using MARSSIM Equations 8-1 and 8-2 (reproduced below). This

requires an assessment of the size of individual elevated areas relative to the survey unit size (referred to as the area factor [AF] or A_m) as a whole and the survey unit's average residual radioactive content (δ). Each elevated area is added as an additional term in Equation 8-2, and the unity rule is applied in evaluation against criteria.

$$DCGL_{EMC} = (A_m)(DCGL_W) \qquad \text{(MARSSIM Equation 8-1)}$$

$$\frac{\delta}{DCGL_W} + \frac{average\ concentration\ in\ elevated\ area - \delta}{(Area\ Factor\ for\ elevated\ area)(DCGL_W)} < 1 \qquad \text{(MARSSIM Equation 8-2)}$$

3.4.2 Elevated Measurement Criteria Data Assembly and Assessment

The following elements are applicable to the overall data assembly and assessment of areas falling above the $DCGL_W$:

- The aerial horizontal extent (i.e., width and length) of the elevated area will be defined using walkover gamma scanning in conjunction with a review of sample data in and around the elevated activity area.

- The vertical thickness (i.e., depth) of elevated activity will be estimated at the time of assessment based on field conditions and any additional analyses that may be available (e.g., boreholes, test pits, and adjacent excavated areas). As a default assumption, the depth is assumed at 1 meter.

- The residual radioactivity concentration level within the elevated area is based on soil sample analysis; the representative concentration value assigned to this area will be determined judgmentally by the RSO. Sample data may be based upon composite samples, averaging of individual samples, or a conservatively biased sample (i.e., the maximum value found).

- Unless agreed upon by WEAC, a clean cover is not be assumed based upon the location of the elevated area relative to final grade specifications for the survey unit area.

- Table 3-3 values will be used to perform a dose assessment for the defined elevated area based upon the physical characteristics of the elevated area.

- Multiple elevated areas may be evaluated in this method.

- The dose from each elevated area may be summed and added to the survey unit average for comparison against the remediation dose goal of 25 mrem/y (this may be completed through a variation of MARSSIM Equation 8-2 [presented above]).

- Since > 95% of the exposure is due to direct radiation (as demonstrated in site-specific $DCGL_W$ modeling), the small area demonstrating the highest as-left residual contamination level may be used to demonstrate a worst case bounding dose condition for the survey unit. This approach may be used when elevated areas are spatially separated such that only the single elevated area under consideration is significantly adding to the unit-wide residual exposure.

Assessments performed in this manner are provided to WEAC, as developed, for review and approval. The assessment includes the overall survey unit data and assessment package that are attached to this FSSR as Exhibits 1 through 4.

Table 3-3. DCGL Elevated Measurement Criteria.

WEAC DCGL, Elevated Measurement Criteria ($DCGL_{EMC}$)								
Dose Criterion (25 mrem/y):	25		25					25
DSRs (most conservative) from initial modeling:	2.08E+00		6.66E-01					4.46E-02
Radionuclides:	**Ra-226**	**Th-228**	**Th-230**	**Th-232**	**U-234**	**U-235**	**U-238**	**U-Total**
DCGLw (25 mrem/y):	12.02	N/A	37.5	N/A	N/A	N/A	N/A	561
DSR at 10 m^2:	1.04E+00		3.28E-01					2.56E-02
DSR at 5m^2:	6.90E-01		2.18E-01	(DSRs are in mrem/yr per pCi/g)				2.05E-02
DSR at 2.5 m^2:	4.44E-01		1.41E-01					1.80E-02
DSR at 1 m^2:	2.25E-01		7.15E-02					1.54E-02
$DCGL_{EMC}$ at 10 m^2:	24.0		76.2					976.6
$DCGL_{EMC}$ at 5 m^2:	36.2		114.7	($DCGL_{EMC}$ in pC/g over the small area)				1219.5
$DCCGL_{EMC}$ at 2.5 m^2:	56.3		177.3					1388.9
$DCGL_{EMC}$ at 1 m^2:	111.1		349.7					1623.4
AF, 10 m^2:	2.0		2.0					1.7
AF, 5 m^2:	3.0		3.1	(Area Factors are unitless)				2.2
AF, 2.5 m^2:	4.7		4.7					2.5
AF, 1.0 m^2:	9.2		9.3					2.9

3.5 Surfaces within Excavation Areas

Any contaminated surfaces encountered within the contaminated material excavations (e.g., abandoned piping) were decontaminated (i.e., wiped off) and assessed for unrestricted release. Briefly, this process includes:

- Preparing the surface for surveying by removing surface residue using methods approved by WEAC. This may include a multiphase approach moving from gross removal of soil/mud to surface wiping and shining. All methods will be approved by WEAC prior to implementation.
- Ensuring surface is dry prior to surveying.
- Once the surface is visually clean and dry, assessing the surface for total and removable alpha radiation emission.

North Wind developed a survey package for surfaces based on the guidance provided in North Wind's procedure for the free release of equipment and materials (North Wind, RP-134, Unrestricted Release of Equipment and Materials [included in Appendix A]) and that found in the MARSAME (NRC 2009).

3.5.1 Criteria and Measurement Approach for Surfaces

From FC 83-23, Table 1, Acceptable Surface Contamination Levels (NRC 1987), the relevant contamination levels for this project are provided in Table 3-4.

Table 3-4. FC 83-23 Surface Release Criteria for the WEAC Partial Decommissioning Project.

Nuclide–[a]	Average–[b,c] (dpm/100 cm^2)	Maximum–[b,d] (dpm/100 cm^2)	Removable–[b,d] (dpm/100 cm^2)
U-Nat and associated decay products	5,000 (α)	15,000 (α)	1,000 (α)
Ra-226, Th-230	100	300	20

The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.1 mrad/hr at 1 centimeter (cm) and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 mg per square centimeter (cm^2) of total absorber.
_a, Where surface contamination by both alpha- and beta-gamma-emitting radionuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.
_b, as used in this table, disintegrations per minute (dpm) means the rate of emission by radioactive material, as determined by correcting the cpm observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.
_c, Measurement of average contaminant should not be averaged over more than 1 m^2. For objects of less surface area, the average should be derived for the each such object.
_d, The maximum contamination level applies to an area of not more than 100 cm^2.
_e, The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

Site instrumentation provides gross beta or alpha readings; thus, a weighted fraction, or derived surface release criteria, will be applied to site surfaces based upon soil radioanalytical data that indicate that site contaminants (U-238, U-234, Th-230, and Ra-226) are qualitatively in activity equilibrium. The derived criteria are developed using the following equation:

$$Release\ Criteria = 1/(\frac{f_1}{C_1} + \frac{f_2}{C_2} + \frac{f_n}{C_n})$$

Where:

f_1, f_2, f_n = group mixture fractions of the ROCs.

C_1, C_2, C_n = associated screening values from Table 3-4.

The mixture fractions are assumed to equal parts U-238, U-234, Th-230, and Ra-226.

Mixture Selection

The uranium group contribution to the mixture is selected to be 50%; the Th-230 and Ra-226 group contribution is selected to be 50%. The resulting derived release criteria are provided in the following calculation:

$$Average\ Release\ Criteria\ (alpha) = \frac{1}{\frac{0.5_{G1}}{5000_{G1}} + \frac{0.5_{G2}}{100_{G2}}} = 196\ dpm/100cm^2$$

Thus, under field conditions, North Wind released equipment and materials using gross counting instrumentation using the limits provided in Table 3-5. Note that the dose rate release values found in FC 83-23 will be assumed to be "not credibly approached" if these release values are attained and thus, dose rates will not normally be collected as part of unrestricted release surveys of equipment and materials. Note also that because beta emissions are associated with the radon decay progeny, which occur at a higher fraction than that provided in Table 3-5, final unrestricted release surveys of equipment and materials will be based on alpha measurements only.

Table 3-5. Derived Surface Release Criteria for the WEAC Partial Decommissioning Project[a].

Nuclide	Average (dpm/100 cm^2)	Maximum (dpm/100 cm^2)	Removable (dpm/100 cm^2)
Gross Alpha	190 (α)	570 (α)	38 (α)
Gross Beta[b]	95 (β)	185 (β)	19 (β)

_a, Prior to application of these limits, reasonable efforts shall be made to eliminate residual contamination.
_b, Assumes two beta emissions (Th-234, Pa-234) per four alpha emissions (U-238, U-234, Th-230, Ra-226).

In field applications, North Wind will apply these release limits unless field data routinely exhibit that mixture assumptions are no longer valid.

3.5.2 Surface Survey Records

For surfaces found and left within impacted survey units, surface assessment records are included in the applicable survey unit report (Exhibits 1 through 4).

4. SURVEY DESIGN

4.1 General Approach

North Wind established several reference markers tied to State Planar grid coordinates to enable referencing of survey locations. These reference points were clearly marked locations on site that allowed North Wind to establish an overall site grid and will serve as a quality check point for GPS equipment used by on-site staff.

North Wind conducted a preliminary walkover gamma survey covering 100% of all areas that were to be mechanically impacted during remediation activities. This survey was used as the working baseline of the site. Additionally, North Wind conducted routine monitoring of impacted areas (e.g., loading areas and areas adjacent to excavations) to ensure no cross contamination was occurring.

Site removal of contaminated soils was conducted at the direction of the excavation lead based on in-situ gross gamma readings. These field screening thresholds were established and confirmed with reference to on-site screening sample results. When it appears that the site RG had been reached, the RSO directed and oversaw the collection of screening samples; once an area was cleared, the FSS process began. Following the FSS, the remediated areas were isolated from any remaining contamination areas to mitigate cross contamination potential.

Survey unit size and classification were finalized as cleanup activities in particular areas were concluded. Areas where contaminated soil excavation occurred were divided into survey units of approximately equal area given the final dimensions of the excavation. Classifications and delineation of survey units, scan coverage, sample numbers and locations, and data assessment and evaluation are based on guidance provided by MARSSIM. Soil samples were analyzed for total uranium, Th-230, and Ra-226. Residual concentrations were compared with the RGs listed in Table 3-1.

4.2 Statistical Tests

The Wilcoxon Rank Sum (WRS) test discussed in this section is used to compare each survey unit with the reference area. This test was chosen because contamination is present in the background at the WEAC Site.

The comparison of measurements from a reference area to the survey unit is made using the WRS test following MARSSIM guidance. The WRS test is effective when residual radioactivity is uniformly present throughout a survey unit (i.e., the sample distribution is symmetrical). The test is designed to detect whether the activity exceeds the $DCGL_W$.

The null hypothesis is assumed to be true unless the statistical test indicates that it should be rejected in favor of the alternative. It is assumed that any difference between the reference area and survey unit concentration distributions is due to a shift in the survey unit concentrations to higher values (i.e., due to the presence of residual radioactivity in addition to background that exceeds cleanup criteria). Survey units may meet the release criteria even though some discrete measurements may exceed discrete reference area measurements. Also, discrete survey unit measurements may exceed some reference area measurements by more than the $DCGL_W$. The result of the hypothesis test determines whether the survey unit as a whole meets the release criterion.

Two underlying assumptions of the WRS test are:

1. Samples from the reference area and survey unit are independent, identically distributed random samples; and

2. Each measurement is independent of every other measurement, regardless of the set of samples from which it came.

If all of the sample results are less than the $DCGL_W$, then no WRS statistical evaluation is required.

4.2.1 Performing the Wilcoxon Rank Sum Test

The WRS test is applied as outlined in the FSSP as developed following MARSSIM guidance. Briefly, the WRS is performed as follows. The $DCGL_W$ value is added to each discrete survey unit result. When a comparison against unity is made (as in the case of multiple COCs), 1.0 is added to the sum-of-ratios (SOR) for each reference area measurement, which is called the "adjusted result." The reference area adjusted SOR results are combined into a single listing with the survey unit results and "ranked" in order of greatest to least SOR. In a "clean" unit, the vast majority of the reference area adjusted results will exceed the survey unit results and thus, will have a majority of the higher ranks. If the sum of the reference ranks (Wr) exceeds the critical value listed in MARSSIM Table 1.4 for the sample size at the confidence level chosen (0.05 for WEAC), then the Null hypothesis is rejected and its alternative is accepted.

4.3 Null Hypothesis and Decision Errors

The null hypothesis (H_0) for soil is: *The median concentration of residual activity in soil for a survey unit is greater than the $DCGL_W$*. The alternative hypothesis (H_a) for soil is: *The median residual concentration of soil in the survey unit exceeds that in the reference area by less than the $DCGL_W$*.

The MARSSIM approach suggests statistical testing against the null hypothesis, meaning that unless the null hypothesis is rejected with a high degree of confidence, it will be concluded that the survey unit median concentration exceeds the $DCGL_W$. Confidence is determined as the combined influence on Type I and Type II errors. A Type I (α) error results when the null hypothesis is rejected (when it is actually true). A Type II (β) error results when the null hypothesis is accepted (when it is actually false). North Wind has determined, in consultation with WEAC, that Type I and Type II soil sample decision errors will be set at 5%.

The decision errors for use in scanning are selected to be 95% for a true positive and 60% for a false positive, resulting in a d' statistic of 1.38 (Table 6.1, NUREG-1507).

4.4 Relative Shift

The lower boundary of the gray region (LBGR) and the target values for α and β are selected during the DQO process. For FSS planning purposes at the WEAC Site, the LBGR is set to one-half the $DCGL_W$. The width of the gray region (DCGL - LBGR) is a parameter that is central to the WRS test, also referred to as the shift, Δ. The absolute size of the shift is actually of less importance than the relative shift (Δ/σ), where σ is an estimate of the standard deviation of the measured values in the survey unit. This estimate of σ includes both the real spatial variability in the quantity being measured and the precision of the chosen measurement system. The relative shift (Δ/σ) is an expression of the resolution of the measurements in terms of measurement uncertainty. The value of the relative shift is used to calculate the number of samples required to demonstrate that a survey unit has met the applicable release criteria.

The number of systematic samples can be estimated following the guidance provided in the MARSSIM, Section 5.5.2.2, for use when the contaminant is present in background. MARSSIM recommends a value for the relative shift of between 1 and 3. Based on the equation for the relative shift (Δ = DCGL – LBRG) and using MARSSIM guidance for the situation where final sample data are not yet available, the relative shift for design purposes is DCGL - $0.5DCGL_W/0.3DCGL_W$, which produces a value of 1.67. This is rounded down to 1.6 to increase sampling and for design conservatism. Based on a relative shift of 1.6 and Type I and Type II decision errors of 0.05, the number of data points required may be obtained from MARSSIM, Table 5.3. This process is provided in next section.

4.5 Sample Numbers

The WRS statistical test will be used to determine whether portions of the site are considered to be suitably free of residual radioactivity. The minimum number of systematic measurement locations required in each survey unit for the WRS statistical test is determined using the following equation from Section 5.5.2.2 of MARSSIM:

$$\frac{N}{2} = \frac{1}{2} x \frac{\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2}{3\left(P_r - 0.5\right)^2}$$

Where:

$N/2$ = minimum number of measurement locations per survey unit or reference area.

$Z_{1-\alpha}$ = percentile represented by the decision error α (Type I).

$Z_{1-\beta}$ = percentile represented by the decision error β (Type II).

P_r = probability that a random measurement from the survey unit exceeds a random measurement from the background reference area by less than the cleanup criterion when the survey unit median is equal to the LBGR, assumed to be one-half the value of the cleanup criterion, above background.

It relies on P_r, the probability that a random measurement from the survey unit exceeds a random measurement from the background reference area by less than the DCGL, when the survey unit median is equal to the LBGR above background (based on the relative shift from Section 4.4.

This plan establishes the acceptable decision errors for Class 1, Class 2, and Class 3 areas as α=0.05 and β=0.05, based on these acceptable decision errors, $Z_{1-\alpha} = Z_{1-\beta}$ = 1.645 (from Table 5.2 in MARSSIM). Using the relative shift of 1.6 from the proceeding section, the specific P_r from Table 5.1 in MARSSIM is 0.871. Given the relative shift, the α and β decision errors, and the Pr factor, the number of systematic samples is derived from MARSSIM Table 5.3 (values of N/2 for use with the WRS test) as 16 per survey and reference unit area. Note that this value has been adjusted up by 20% to account for probability of lost or unusable data and the uncertainty in the calculation of N. This process is completed for each radionuclide in Table 4-1.

Table 4-1. Radionuclide Specific Systematic Sample Number Calculation.

MARSSIM Approach to Sample Number Determination when Final Sample Results are not Available													
	DCGL	LBGR[a]	SU[b]	Rel Shift	Pr[c]	Type I	Type II	Percentile		N	N+20%	Round up	Samples
Analyte	(pCi/g)	(pCi/g)	(σ)	(Δ/σ)		error	error	Type I	Type II			to even #	per Unit
Tot-U	560	280	168	1.67	0.871	0.05	0.05	1.645	1.645	26.2	31.5	32	16
Th-230	37	18.5	11.1	1.67	0.871	0.05	0.05	1.645	1.645	26.2	31.5	32	16
Ra-226	12	6	3.6	1.67	0.871	0.05	0.05	1.645	1.645	26.2	31.5	32	16
_a, LBGR set at 1/2 the DCGL													
_b, survey unit sigma (σ) set at 0.3 of the DCGL													
_c, from table 5.1 MARSSIM. Probability of SU post remediation random sample exceeding RA random sample + the LBGR													
when the SU median is = to the LBGR + background.													

Noting that remediation is driven by the presence of Ra-226 and that Th-230 and uranium are, to a significant degree, collocated with Ra-226, a better estimate of the probably sample number required may be provided by looking at the potential standard error of the final data set against the $DCGL_W$ values. For the ROCs, a reasonable, post remediation estimate of the error term (σ) should be as follows:

- Ra-226, $DCGL_W$ = 12, σ estimated is 25% or 3.0 pCi/g.
- Th-230, $DCGL_W$ = 37, σ estimated at 10% or 3.7 pCi/g.
- Total-U, $DCGL_W$ = 560, σ estimated at 1% or 5.6 pCi/g.

Sigma (σ) is then calculated as the propagated error of the sum of the absolute fractions, as follows:

$$\sqrt{\left[\left(\frac{0.25}{1.0}\right)^2+\left(\frac{0.10}{1.0}\right)^2+\left(\frac{0.01}{1.0}\right)^2\right]}=0.27$$

Following MARSSIM guidance, the LBGR (i.e., the shift) is established at 0.5 of unity, or 0.5 = Δ. The relative shift (Δ/σ) is then calculated as 0.5/0.27 or 1.92. Rounding down to 1.90 and given that σ = β = 0.05, the N/2 value from MARSSIM Table 5.3 is 13. Thus, the likely number of samples required to meet data objectives is likely to fall between 13 and 16 samples; the upper range of this estimate was used to establish sample numbers for each survey unit and reference area. As part of the assessment of each survey unit, the actual number of samples required is calculated retroactively based on the actual sample results. A relative shift result > 1.67 for the systematic sample set demonstrates that the sample number is adequate.

4.6 Physical Data Point Locations

The physical systematic data point (i.e., sample and/or measurement) locations within each survey unit were laid out using a random-start triangular pattern. The distance between survey locations (L) was determined, as detailed in MARSSIM guidance, Section 5.5.2.5, based on the actual area (A) of the survey unit and 16 data points, as shown in the following equation:

$$L = [A/(0.866*16)]^{0.5}$$

The value of L was rounded to the nearest whole value. The distance between rows of survey points was calculated as 0.866 L (MARSSIM Appendix A, Section 3.8.) Additional descriptions of data point locations are presented in each survey unit report (Exhibits 1 through 5). If calculated sampling and

measurement locations are not accessible or have surfaces that do not allow for sampling of the soil (e.g., bedrock, concrete, or metal), the sample was obtained from the nearest location that accommodates sampling. If the required number of sampling locations did not all fall within the boundaries of a sampling unit, then additional, randomly selected locations within the survey unit were identified to ensure adequate data points for that survey unit.

In addition to the samples collected for comparison with cleanup criteria, samples may have also been obtained from locations of elevated direct surface radiation levels, identified by gamma scintillation scans, and/or from surface areas that by appearance or location have a potential for residual contamination. Data from these additional samples (known as judgmental samples) supplement the results from the systematic samples.

4.6.1 Samples at Depth, Trench Samplings, or Laterally into Sidewalls

Judgmental samples were collected from trench spoils that were placed across the survey units. These were collected to ensure that no burial areas remain on site.

4.7 Soil Samples

Soil samples were collected following the methods and QC protocols provided in NW-RP-500 and associated procedures.

4.8 Establishing Survey Units

MARSSIM defines the following three classifications of impacted areas, based on potentials for residual contamination:

- **Class 1**—Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiation surveys) above the $DCGL_W$. Examples include site areas previously subjected to remedial actions, locations where leaks or spills are known to have occurred, former burial or disposal sites, waste storage areas, and areas with contaminants in discrete solid pieces of material with high specific activity.

- **Class 2**—Areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination but are not expected to exceed the $DCGL_W$. Examples include locations where radioactive materials were present in unsealed form, potentially contaminated transport routes, areas downwind from stack release points, areas that handle low concentrations of radioactive materials, and areas on the perimeter of former contamination control areas.

- **Class 3**—Impacted areas that are not expected to contain any contamination, or are expected to contain levels of contamination at a small fraction of the $DCGL_W$, based on site operating history and previous radiation surveys. Examples include buffer zones around Class 1 and Class 2 areas, and areas with a very low potential for residual contamination but having insufficient information to justify a non-impacted classification.

A survey unit is a contiguous physical area of specified size and shape for which a separate decision will be made as to whether the area exceeds the established cleanup criterion. A survey unit possesses similar characteristics, such as the potential contaminants and contamination classification.

MARSSIM provides the following guidance for sizes of land area survey units:

- Class 1: Up to 2,000 m^2;
- Class 2: 2,000 to 10,000 m^2; and
- Class 3: No limit.

Land areas of less than 100 m^2 should not be designated as survey units. Instead, the level of survey effort should be determined by the DQO process and data obtained, based on judgment, and compared directly to the $DCGL_W$. It is not anticipated that any of the WEAC survey units will be smaller than 100 m^2.

At WEAC, the three survey units north of the main plant building (SU1, SU2, and SU3) were considered MARSSIM Class I units. The survey unit surrounding the building (SU4) is considered a MARSSIM Class III and was surveyed for informational purposes only. The Reference Unit (SU5) is found north of the operational area and is considered non-impacted. Table 4-2 provides a list of the survey units, classifications, and surface area. The NRC has asked that SU4 not be included in the FSSR provided for NRC review since it is outside the land area being considered for the future laboratory expansion (i.e., it is outside the future building footprint). Figure 4-1 illustrates the final survey units, their classifications, and surface area.

Table 4-2. WEAC MARSSIM Survey Units and Reference Area.

Survey Unit	**Classification**	**Area (m^2)**
SU1	Class 1	1,440
SU 2	Class 1	970
SU3	Class 2	1,775
SU4	Class 3	2,030
Reference Area–[a]	N/A	3788
_a, Reference area is partially covered in asphalt and contains inaccessible brushy areas. Certain sample locations were relocated to soil-accessible locations when needed.		

4.9 Reference Areas

A background reference area is a geographical area from which representative samples of background conditions are selected for comparison with samples collected in specific survey units at the remediated site. The background reference area has similar physical, chemical, radiological, and biological characteristics to the site being remediated; however, it is not contaminated by site activities. The distribution of background measurements in the reference area should be similar to the distribution of measurements in the survey unit.

The WEAC background reference area is chosen as the area north and east of the fenced-in, impacted soils area. This area is chosen because (1) it is owned and managed by WEAC, (2) the HSA concludes that this area is non-impacted (WEAC 2017), (3) it is geologically similar to the impacted area, and (4) preliminary walkover gamma scanning and soil sampling have been conducted to confirm its non-impacted-status.

To the extent practical, the reference area was scanned and sampled in the same manner as the Class 1 and Class 3 areas.

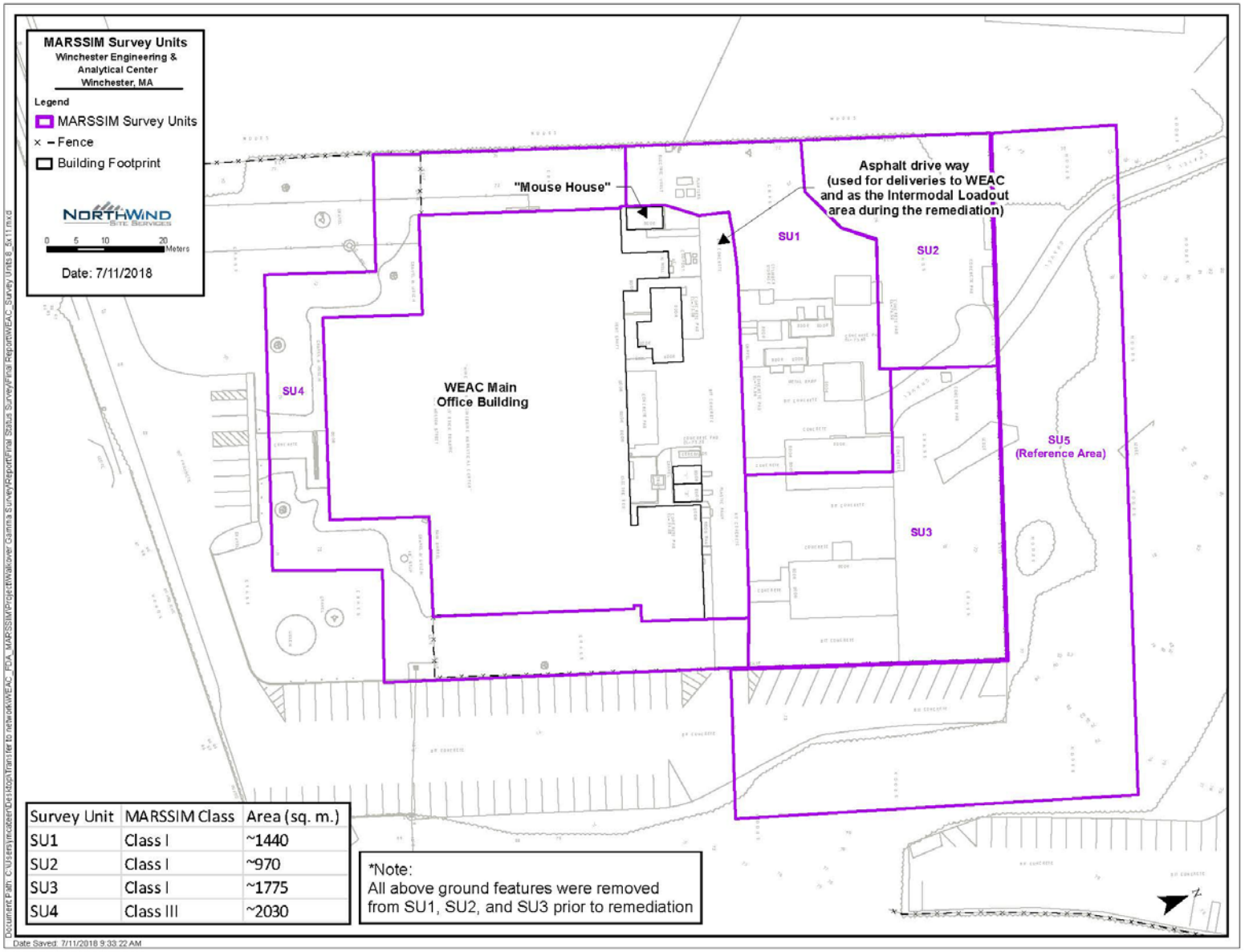


Figure 4-1. WEAC Anticipated Survey Units and Classifications.

5. SURVEY IMPLEMENTATION

Radiological surveying was conducted in accordance with established North Wind procedures; Appendix A contains a list of those procedures, applicable to the FSS of the WEAC site. Table 5-1 provides a list of instruments used for this survey. All instruments are calibrated annually and were performance-tested prior to each daily use. Appendix B and C provides a description of the scanning detection capabilities.

Table 5-1. Radiological Monitoring Instrumentation.

Detector	Readout	Application	Comments
Ludlum 44-10 2-inch × 2-inch NaI	Ludlum 2221	Soil scanning; medium and high energy photons.	GPS equipped
Ludlum 44-9	Ludlum 12 or equivalent	Beta scanning and direct measurements.	
Ludlum 43-5	Ludlum 12 or equivalent	Alpha scanning and direct measurements.	
Ludlum 43-93	Ludlum 2424 or equivalent	Dual a/b scanning and direct measurements	
Ludlum 43-10-1	Ludlum 2929	Low background a/b smear counting.	
High purity germanium (HPGe) Gamma Spectroscopy System –[a]	Print	On-site soil sample screening.	
_a, Efficiencies generated using Canberra's LABSOCS software.			

5.1 Excavation of Impacted Soil Surfaces

5.1.1 Soil Scanning

Following excavation of contaminated material from a particular survey unit, walkover surface scans of the survey unit were conducted using Ludlum 44-10 2-inch × 2-inch NaI gamma scintillation detectors. Scanning was conducted in accordance with North Wind procedures (Appendix A). Scan paths were approximately 0.5 to 1.0 m wide; the scan rate will be approximately 1.0 m/second. The scan height was approximately 5 cm above the surface of interest; however, scan sensitivity analysis has been conservatively performed at 15 cm. All survey units were additional cross-walked to increase scan coverage in each impacted survey unit. Where conditions permitted, walkover scanning instruments were combined with a GPS and a data logging instrument that married the instrument reading with the GPS position data every second.

Following MARSSIM guidance, surface scans were conducted to provide a minimum of 100% surface coverage for Class 1 survey units. The Class 3 unit (SU4) was also scanned at 100% coverage since this was reasonably convenient to accomplish. Resultant logged radiological walkover data and GPS location data were downloaded into a computer plotting program (e.g., Virtual Sample Plan, ArcView, or Surfer) to provide a graphic representation of the walkover scan survey efforts and results. During scanning, detectable increases in count rate above the ambient background level were investigated by further scanning and/or sampling.

5.1.2 Soil Sampling

Soil sampling was conducted on-going to provide a reference point (gamma cpm per pCi/g) for persons conducting excavation control. When it appeared that areas were likely to meet the site RG detailed walkover gamma scanning was completed to document the gamma signature in the survey unit. Surface soils samples of 500 to 1,000 grams (g) each will be collected at the specified 16 systematic and additional judgmental locations, as identified by the RSO in each respective survey unit. No sample preparation steps were performed during field processing of soil samples other than removal of non-soil material (i.e., grass, sticks, large rocks, etc.) and decanting of free water (which was never necessary).

Sampling was performed in accordance with North Wind procedures (Appendix A). FSS samples were labeled as directed in the Survey Unit Soil Collection form developed for each survey unit. Generally, sample labeling adhered to the following nomenclature:

Identification No.: WEAC-FS-SU#-00X
Date:
Depth:
Sample Tech:

Where:

WEAC = Winchester Engineering and Analytical Center.

FS = Final Status. Other designators may have included SS (special sample).

SU# = Survey unit number (e.g., SU2 is survey unit 2).
A field duplicate sample would be indicated by adding a "Q" to the survey unit number (e.g., WEAC-FS-SU#Q-00X where the "Q" indicates this is a QC sample).

00X = Systematic sample number for the survey unit or the site. Typically, the systematic samples are given sample numbers 1 through 16.
Judgmental samples were indicated by a "J" designator added behind the sequential number (e.g., WEAC-FS-SU#-00XJ).

5.2 Quality Assurance/Quality Control

Quality assurance (QA)/QC activities include training and qualification of surveyor personnel for the activities being performed, current instrument calibration (within the past year), and performance testing each day of use.

On-site QC routines include the use of standardized SOPs and forms, field logbooks, chain-of-custody maintenance, and duplicate sample collection.

The off-site laboratory vendor shall meet the requirements of ISO/IEC 17025:2005, "General Requirements for the competence of Testing and Calibration Laboratories" and the U.S. Department of Defense Environmental Laboratory Accreditation Program (80 FR 61997), or an approved equivalent. North Wind requested a QA Level IV data package for all sample analyses used to assess the final status of the site. Detection sensitivity was specified to be well below <10% of the $DCGL_W$. The approved laboratory (GEL Laboratories) analyzed method blanks, matrix spike samples, laboratory control samples, and replicates at the minimum frequencies in accordance with laboratory procedures.

Laboratory data packages were verified by the North Wind Corporate Health Physicist as being complete and useable for use in the final status assessment of the site.

5.3 Sample Analyses

5.3.1 On-Site Analysis

On-site radiological laboratory analysis (i.e., screening) was performed using a HPGe system. This commercial grade unit was calibrated and maintained following standard WEAC laboratory quality and operating procedures but lacked commercial laboratory certification with respect to soils testing. The on-site HPGe system was used to assess U-238 content by assessment of its Th-234 progeny, which is in equilibrium with U-238. Gamma spectroscopy identification parameters for U-238 and other radionuclides of potential interest are listed in Table 5-2.

Table 5-2. Gamma Spectroscopy Identification Parameters for Select Radionuclides.

Radionuclide	Method	Progeny (half-life)	Photon (keV)	Photons/decay (%)	Est. MDC (pCi/g)
U-238	Via progeny	Th-234 (24.1d)	63.3–[a] 92.38 92.8	3.7 2.1 2.1	<10
U-234	--[b]				
Th-230	Direct	NA	12.3–[x] 67.6–[x]	7.7 0.38	45 to 12–[x1], 20 to 6–[x2]
Ra-226	Direct	NA	186.0	3.28	<4
	Via progeny	Pb-214 (3.82d–[d])	242.0 295.2 351.9	7.3 18.4 35.6	<0.5
	Via progeny	Bi-214 (3.82d–[d])	609.3 1120.3 1764.5	46.3 14.9 15.8	<0.5
U-235–[c]	Direct	NA	185.7–[d]	54	<2
Th-232	Via progeny	Ac-228 (5.75–[e])	911	25.8	<0.5
	Via progeny	Pb-212 (5.75–[e])	238.6	43.3	
	Via progeny	Tl-208 (5.75–[e,f])	277 510.8 583 860 2610	(branching fraction of 0.36) 6.8 21.6 85.8 12 100	<0.5

a, Primary identification energy (others may not be listed in this table).
b, Not practically identifiable by photon emission.
c, Due to low fraction found in U-nat (2.2%), U-235 becomes identifiable at U-238 levels > 50 pCi/g.
c, May be confounded by Ra-226 content, which produces a photon near this energy.
d. Longest ½-life of decay progeny above Bi-214; Ra-226, Rn-222 (3.82d), Po-218 (3.05m), Pb-214 (26.8m), Bi-214 (19.9m).
e, Longest ½-life of decay progeny above Ac-228, Pb-212, or Tl-208; Th-232, Ra-228 (5.75y), Ac-228 (6.13h), Th-228 (1.913y), Ra-224 (3.66d), Rn-220 (55.6s), Po-215 (0.15s), Pb-212 (10.64h), Bi-212 (60.55m), Po-212 BF 0.64 (305ns), Tl-208 BF 0.36 (3.07m).
f, Tl-208 has a branching fraction (BF) of ~0.36.
x, Identified by Gamma-ray emission; x1 estimated minimum detectable activity (MDA) for a 1 hour count, x2 estimated MDA for a 12 hour count; range is based upon which detector is used.

5.3.2 Off-Site Analysis

Samples were packaged and sent to GEL Laboratories in Charleston, South Carolina for analyses of the potential COCs. Standard methods requested were isotopic-uranium and isotopic-thorium analysis by alpha spectroscopy. Gamma spectral analysis of Ra-226 content via the decay progeny was conducted at 21 days in-growth. Several samples (i.e., 4 to 5) from each survey unit were sent for gross alpha/beta analysis to confirm the absence of unknown COCs. No additional contaminants were identified. Minimum detectable concentrations (MDCs) of the analyses will be ≤10% of the $DCGL_W$ values. Standard turn-around-time was 30 days.

6. EVALUATION OF RESULTS

Data assessments for each survey unit (Exhibits 1 through 4) were performed by the North Wind Corporate Health Physicist. Walkover gamma isopleths, in terms of cpm, were plotted for each area providing a graphical representation of each area. One-meter-height gamma walkover surveys were conducted and plotted in terms of µR/h for each survey unit. Systematic and judgmental soil samples were collected and analyzed per the FSSP. Trenching down to 4 feet below ground surface was performed in each MARSSIM Class 1 unit to provide confirmation that additional burial areas do not exist on site. The survey unit systematic samples were used to develop the following:

- Sample-by-sample comparison against the $DCGL_W$ value (both directly and through a SOF comparison),
- Mean result (direct and SOF),
- 1-sigma value (direct and SOF),
- Results of WRS test (if any SOF result exceeded unity),
- Results in terms of residual mean concentration levels and residual dose, and
- Retrospective calculation of the relative shift to confirm that the number of samples collected was sufficient.

Elevated areas of residual activity above the $DCGL_W$ (as identified by systematic or judgmental samples) were evaluated using an area weighted dose-based ($DCGL_{EMC}$) following the unity rule for the unit.

If all sample results for the survey unit have associated concentrations that are less than the release criteria, the survey unit is deemed radiologically appropriate for release. If any of the sample results for the survey unit exceed unity, the WRS test is performed. If W_r (the sum of the adjusted reference area ranks from the WRS test) is greater than the applicable critical value, then the mean value for residual radioactivity in the survey unit is less than the $DCGL_W$ to the specified confidence level. In this case, the null hypothesis is rejected and the survey unit is deemed to be appropriate for release, assuming all elevated measure criteria (EMC) areas are addressed. If W_r is less than the critical value, the null hypothesis is accepted, the survey unit is not considered to meet the release criteria, and further remediation may be evaluated.

7. FINAL STATUS SURVEY SUMMARY RESULTS

7.1 Survey Unit 1

Data from the FSS of the SU1 area are presented in Exhibit 1. The radiological assessment of SU1 indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the ALARA CG_W criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 2.82 mrem/year to the maximally exposed individual (MEI). Extensive trenching, post remediation, performed across SU1 indicates that it is unlikely that buried contamination remains within the unit.

SU1 Summary Statistics:

- Unit Average Net Sum of Fraction (SOF) is calculated as 0.11 resulting in a residual total effective dose estimate of 2.82 mrem/year.
- Unit EMC used in one location results in an estimated maximum dose of 8.85 mrem/year.
- All Systematic Samples are < the $DCGL_W$.
- All Systematic Samples are < the CG_W.
- All judgmental Samples are < $DCGL_W$ values.
- Eight of nine Judgmental Samples are < the CG_W.
- One Judgmental Sample was found at 7.13 pCi/g for Ra-226 (slightly above the CG_W of 5.0 pCi/g) but on an Elevated Criteria Basis; did not result in a SOF value greater than unity for the $DCGL_W$.
- All Judgmental Trench samples are < the $DCGL_W$ and the CG_W.
- The 1-meter gamma dose rates are < the CG_W values across the entire unit.
- A WRS test is not required for the unit since all results are < the $DCGL_W$.
- A retrospective calculation of the relative shift (Δ/σ) resulted in a value of 4.20 based on the systematic sample results. Since this is greater than the FSSP design relative shift of 1.67, this demonstrates that sample quantity is adequate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the survey unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and the alternative hypothesis (that the survey unit median concentration is less than the $DCGL_W$ criterion) is accepted. SU1 Systematic Sample Summary Data are provided in Table 7-1.

Table 7-1. SU1 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.61	1.21	12	0.134		
Th-230	2.51	2.13	37	0.068		
Total-U	3.98	2.13	560	0.007		
			SOF Sum:	0.21		
			SOF Ref. Area:	0.10		
			Net SOF:	0.11		
SOF in Residual Dose Terms:				**2.82**	mrem/year	

7.2 Survey Unit 2

Data from the FSS of SU2 are presented in Exhibit 2. The radiological assessment of SU2 indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the ALARA CG_W criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 3.23 mrem/year to the MEI. One small elevated area remains in the far northwest corner of the unit that meets the $DCGL_{EMC}$ limits. Extensive trenching (post remediation) performed across SU2 indicates that it is unlikely that buried contamination remains within the unit.

SU2 Summary Statistics:

- Unit Average Net SOF is < Unity for the $DCGL_W$ and is calculated as 0.13, resulting in a residual total effective dose estimate of 3.23 mrem/year.
- The WRS test resulted in a rejection of the Null Hypothesis and its alternative, that the unit average concentration value is < $DCGL_W$, is accepted.
- Unit EMC used in one location resulted in an estimated maximum effective dose of 20.21 mrem/year or, if averaged into the unit wide systematic average, would be 6.15 mrem/year. Thus, $DCGL_{EMC}$ limits are satisfied.
- Fifteen of sixteen Systematic Samples are < Unity for the $DCGL_W$ (SOF for SU2-09 was 1.07).
- All Judgmental Trench samples are < the $DCGL_W$ and the CG_W.
- The 1-meter gamma dose rates are < the CG_W values across the entire unit except at a small elevated area in the northwest corner of the unit. Here the dose rate was < 25 µR/h and thus, the ALARA dose objective is achieved.
- A retrospective calculation of the relative shift (Δ/σ) resulted in value of 2.46 based on the systematic sample results. Since this is > the FSSP design relative shift of 1.67, this demonstrates that sample quantity is adequate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and the Alternative Hypothesis (that the survey unit median concentration is less than the $DCGL_W$ criterion) is accepted. SU2 Systematic Sample Summary Data are provided in Table 7-2.

Table 7-2. SU2 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.88	2.08	12	0.157		
Th-230	2.30	3.14	37	0.062		
Total-U	3.51	2.22	560	0.006		
			SOF Sum:	0.23		
			SOF Ref. Area:	0.10		
			Net SOF:	0.13		
SOF in Residual Dose Terms:				**3.23**	mrem/year	

7.3 Survey Unit 3

Data from the FSS of SU3 are presented in Exhibit 3. The radiological assessment of SU3 indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the ALARA CG_W criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 2.96 mrem/year to the MEI. Some small, spotty, elevated areas remained following cleanup, which are adequately accounted for within the systematic sample set. Extensive trenching (post remediation) performed across SU3 indicates that it is unlikely that buried contamination remains within the unit.

SU3 Summary Statistics:

- Unit Average Net SOF is < Unity for the $DCGL_W$ and is calculated as 0.12, resulting in a residual total effective dose estimate of 2.96 mrem/year.
- The WRS was not required since all samples were < the $DCGL_W$; thus, the Null Hypothesis is rejected and its alternative, that the unit average concentration value is < $DCGL_W$, is accepted.
- All Systematic Samples are < Unity for the $DCGL_W$ (Maximum Net SOF found at systematic sample location WEAC-FS-SU3-09 at 0.46).
- All Systematic Samples are < the CG_W ALARA values.
- All Judgmental samples are < the $DCGL_W$ and the CG_W values.
- The 1-meter gamma dose rates are < the CG_W value across the entire unit except at a few small areas where the dose rate ranged up to 20 µR/h. Thus, the ALARA objective for the unit is achieved.
- A retrospective calculation of the relative shift (Δ/σ) resulted in value of 3.51 based on the systematic sample results. Since this is > the FSSP design relative shift of 1.67, this demonstrates that sample quantity is adequate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and the Alternative Hypothesis (that the survey unit median concentration is less than the $DCGL_W$ criterion) is accepted. SU2 Systematic Sample Summary Data are provided in Table 7-3.

Table 7-3. SU3 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.70	1.15	12	0.142		
Th-230	2.34	4.21	37	0.063		
Total-U	5.60	1.32	560	0.010		
			SOF Sum:	0.21		
			SOF Ref. Area:	0.10		
			Net SOF:	0.12		
SOF in Residual Dose Terms:				**2.96**	mrem/year	

7.4 Survey Unit 4 (Information Only Unit)

The SU4 FSS was performed for informational purposes only. This MARSSIM Class 3 unit was surveyed in the same manner as the Class 1 units, although the surface area was slightly greater than 2,000 m^2, at 2,030 m^2. Data from the FSS of SU4 are presented in Exhibit 4. The radiological assessment of SU4 indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the ALARA CG_W criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 1.34 mrem/year to the MEI. No contamination was encountered in SU4 during remediation and is considered a non-impacted unit.

SU4 Summary Statistics:

- Unit Average Net SOF is < Unity for the $DCGL_W$ and is calculated as 0.05, resulting in a residual total effective dose estimate of 1.34 mrem/year.
- The WRS was not required since all samples were < the $DCGL_W$; thus, the Null Hypothesis is rejected and its alternative, that the unit average concentration value is < $DCGL_W$, is accepted.
- All Systematic Samples are < Unity for the $DCGL_W$ (Maximum Net SOF found at systematic sample location WEAC-FS-SU4-06 at 0.12).
- All Systematic Samples are < the CG_W ALARA values.
- All Judgmental samples are < the $DCGL_W$ and the CG_W values.
- The 1-meter gamma dose rates are < the CG_W value across the entire unit except up against the brick building (higher natural background) where a few locations range up to 22 µR/h. Thus, the ALARA objective for the unit is achieved.
- A retrospective assessment of the relative shift (Δ/σ) based on the systematic sample results demonstrates that sample quantity is adequate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the unit does not meet the $DCGL_W$ criterion) should be rejected and its alternative (that the survey unit does meet criterion) is accepted. SU4 Systematic Sample Summary Data are provided in Table 7-4.

Table 7-4. SU4 Systematic Sample Summary Data

SU3	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.14	0.16	12	0.095		
Th-230	1.82	1.47	37	0.049		
Total-U	2.92	0.60	560	0.005		
			SOF Sum:	0.15		
			SOF Ref. Area:	0.10		
			Net SOF:	0.05		
SOF in Residual Dose Terms:				**1.34**	mrem/year	

7.5 Survey Unit 5 (Reference Area)

Data from the FSS of SU5, the Reference Area, are presented in Exhibit 5. The radiological assessment of SU5 is performed to establish a background reference area used in parametric statistical testing of MARSSIM Classes I, II, and III radiologically impacted survey units. SU5 is designated as a non-impacted Reference Area based upon the HSA (WEAC 2017) documented for the WEAC Facility.

SU5 Summary Statistics:

- Unit Average SOF is < Unity for the $DCGL_W$ and is calculated as 0.10, resulting in a background total effective dose estimate of 2.5 mrem/year; the Net SOF and Residual effective dose is, of course, zero (0).

SU5 Systematic Sample Summary Data are provided in Table 7-5.

Table 7-5. Reference Area (SU5) Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	0.84	0.17	12	0.070		
Th-230	0.82	0.24	37	0.022		
Total-U	2.16	0.43	560	0.004		
			SOF Sum:	0.10		
			SOF Ref. Area:	0.10		
			Net SOF:	0.00		
SOF in Residual Dose Terms:				**0.00**	mrem/year	

7.6 Quality Assurance/Quality Control

Sample analysis was provided by GEL Laboratories of Charleston, SC. The analysis was provided in electronic form, via an electronic spreadsheet, accompanied by a scanned image Standard Level IV analytical package. GEL provided data packages through a user (North Wind) specific interface, which were downloaded and placed onto North Wind servers for project use. Analytical MDCs (referred to as minimum detectable levels in GEL reports) satisfied project specifications, as confirmed within this section. Field duplicates were collected at a rate of two duplicates per survey unit. Laboratory Duplicates (DUP), Laboratory Control Samples (LCS), and Method Blanks (MB) were developed and analyzed at a rate of 5% of samples, or a minimum of one per sample batch.

7.6.1 Minimum Detectable Activity Analysis

Analytical MDCs were easily below 10% of the $DCGL_W$ for the ROCs. In comparison to natural background concentration levels (assuming background for the ROCs is approximately 1.0 pCi/g and approximately 0.05 pCi/g for U-235), the MDCs were, on average, measured as follows:

- MDC for Ra-226 is around 10% of background.
- MDC for Th-228 and Th-230 is around 54% and around 33% for Th-232.
- MDC for the uranium isotopes was 71% for U-234, 1,000% for U-235, and 63% for U-238.

The data set for MDC analysis was developed from all samples collected and analyzed for SU1 (which is considered typical for all GEL analysis). One sample in the data set (WEAC-FS-SU1-7Q-158) exhibited an outlier MDC for all the uranium isotopes. Reported results for U-235 were often less than the associated MDC (Lab code "U"), which is typical for U-235 analysis in background or near background activity samples. Since U-235 contributes ~5% to total uranium activity, the reported result (whether < MDC or not) is assessed as is since error associated with this radionuclide is insignificant in the overall assessment. The MDC data set is presented in Table 7-6.

Table 7-6. Typical MDC Values for WEAC Radionuclides

GEL Laboratory Minimum Detectable Concentration (MDC) Reported Values (pCi/g)									
MDC Assessment	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	ALPHA	BETA
WEAC-FS-SU1-1-151	0.09	0.47	0.40	0.20	0.82	0.74	1.02		
WEAC-FS-SU1-2-152	0.10	0.58	0.40	0.25	0.72	0.44	0.84		
WEAC-FS-SU1-3-153	0.07	0.59	0.87	0.28	0.47	0.30	0.49		
WEAC-FS-SU1-4-154	0.08	0.61	0.65	0.38	0.49	0.26	0.43	4.65	2.96
WEAC-FS-SU1-5-155	0.11	0.76	1.09	0.27	0.63	0.50	0.59		
WEAC-FS-SU1-6-156	0.08	0.60	0.73	0.53	0.46	0.45	0.55		
WEAC-FS-SU1-7-157	0.08	0.58	0.52	0.43	0.76	0.62	0.73		
WEAC-FS-SU1-7Q-158	0.07	0.82	0.55	0.30	2.63	1.43	2.35		
WEAC-FS-SU1-8-159	0.07	0.48	0.22	0.36	0.62	0.54	0.60	4.78	3.25
WEAC-FS-SU1-9-160	0.09	0.45	0.32	0.20	0.61	0.30	0.24		
WEAC-FS-SU1-10-161	0.10	0.49	0.35	0.22	0.45	0.44	0.22		
WEAC-FS-SU1-11-178	0.08	0.44	0.39	0.21	0.59	0.77	0.52		
WEAC-FS-SU1-12-179	0.07	0.56	0.52	0.24	0.70	0.47	0.56	4.83	3.24
WEAC-FS-SU1-13-164	0.08	0.46	0.46	0.23	0.79	0.32	0.48		
WEAC-FS-SU1-14-165	0.06	0.46	0.27	0.34	0.97	0.57	0.70		
WEAC-FS-SU1-14Q-166	0.08	0.45	0.32	0.22	0.66	0.46	0.60		
WEAC-FS-SU1-15-167	0.11	0.56	0.34	0.34	0.68	0.54	0.56		
WEAC-FS-SU1-16-168	0.09	0.59	0.46	0.40	0.77	0.64	0.71	4.80	2.77
WEAC-FS-SU1-180J	0.13	0.55	0.44	0.37	0.78	0.48	0.92	4.89	2.88
WEAC-FS-SU1-171J	0.08	0.72	0.63	0.54	0.48	0.31	0.51		
WEAC-FS-SU2-172J	0.14	0.47	0.64	0.30	0.56	0.43	0.61		
WEAC-FS-SU1-173J	0.11	0.62	0.65	0.33	0.62	0.43	0.75		
WEAC-FS-SU1-174J	0.13	0.53	0.54	0.31	0.52	0.39	0.35		
WEAC-FS-SU1-175J	0.06	0.57	0.70	0.45	0.54	0.53	0.36		
WEAC-FS-SU1-176J	0.07	0.42	0.61	0.37	0.42	0.22	0.48		
WEAC-FS-SU1-177J	0.09	0.48	0.74	0.54	0.64	0.54	0.21		
Survey Unit 1 MDC Statistics									
$DCGL_W$:	12.00	NA	37.00	NA	280.00	14.00	280.00	NA	NA
Count:	26.00	26.00	26.00	26.00	26.00	26.00	26.00	5.00	5.00
Average:	0.09	0.55	0.53	0.33	0.71	0.50	0.63	4.79	3.02
Average as a % of the $DCGL_W$:	0.7%		1.4%		0.3%	3.6%	0.2%		
Standard Deviation (1 sigma):	0.02	0.10	0.20	0.10	0.41	0.23	0.40	0.09	0.22
Max:	0.14	0.82	1.09	0.54	2.63	1.43	2.35	4.89	3.25
Notes									
Uranium $DCGL_W$ split evenly between U-234 and U-238 (560/2), U-235 set at 5% of 560 or 14.0.									

7.6.2 Analysis of Field Duplicates

Field duplicate samples (sometimes referred to as replicate samples) are samples collected at the same, or nearly the same, field location point as the original sample. This sample is used to demonstrate the consistency and accuracy of the overall sampling and analysis approach and, to a certain extent, soil homogeneity over very short distances in the field. Field duplicate QA samples were evaluated using the relative error ratio (RER) method presented in the following equation.

$$RER = \frac{\left|A_{smp} - A_{dup}\right|}{\sqrt{\left(U_{smp}\right)^2 + \left(U_{dup}\right)^2}}$$

Where:

A_{smp} = activity in the original sample.

A_{dup} = activity in the duplicate sample.

U_{smp} = uncertainty (error) in the sample at 1 σ.

U_{dup} = uncertainty (error) in the duplicate at 1 σ.

Results generally indicate good agreement between original and duplicate samples with an overall average RER of 0.92. The maximum RER for a single analyte and sample was 3.98 for Ra-226 in Sample WEAC-FS-SU1-7, and 7Q. An acceptable RER is typically considered to be < 3.0 (indicating the results are within 3 σ of each other). It appeared that the sample results (or perhaps the mixing techniques) at sample points 7 and 7Q were slightly different; results were reported as 1.02 and 1.59 pCi/g for 7 and 7Q, respectively. Additionally, due the relative high sensitivity of the analysis method for Ra-226 (average error at 1σ is about 0.12), small variations in location-specific activity and/or sampling technique are more pronounced than they might otherwise be for the other analytes.

Except as discussed above, the average and maximum RER for all samples were found to be < 3.0 for all analytes and samples; see Table 7-7 for sample specific and summary RER data. The average RER was < 2 for all samples. It should be noted that the majority of U-235 results were reported as < MDA and, as can been seen in the table, average error at 1σ is routinely > the sample result. For U-235, the RER is more of an indication of analysis consistency in measuring and reporting results at or near the detection system's low limit of detection.

Overall, the field duplicates indicate that field sampling and analysis were consistently employed and that soil sample activity levels are consistent across small areas.

Table 7-7. Relative Error Ratio Results and Analysis

		Soil Sample (pCi/g)		Field Duplicate (pCi/g)					Ave.	Ave.	Ave. dup	Ave.	RER Summary Results		
Sample IDs	Analyte	Activity	U_{smp} (1σ)	Activity	U_{dup} (1σ)	RER	Analyte	N	Act.	U_{smp} (1σ)	Act.	U_{dup} (1σ)	RER Ave.	Max RER	Min RER
WEAC-FS-SU1-7-157	Ra-226	2.70	0.09	3.02	0.10	2.42	Ra-226	10	1.35	0.10	1.39	0.12	1.75	3.98	0.22
WEAC-FS-SU1-7Q-158	Th-228	2.06	0.43	1.22	0.40	1.43	Th-228	10	1.27	0.32	1.14	0.29	1.01	1.70	0.18
	Th-230	4.88	0.63	3.92	0.64	1.07	Th-230	10	2.20	0.40	2.01	0.38	0.76	1.89	0.03
	Th-232	1.69	0.38	1.19	0.36	0.96	Th-232	10	1.15	0.29	1.02	0.27	0.82	2.31	0.14
	U-234	3.11	0.54	8.43	1.90	2.70	U-234	10	2.14	0.43	2.46	0.58	1.08	2.70	0.10
	U-235	0.13	0.18	0.48	0.68	0.49	U-235	10	0.31	0.22	0.34	0.26	0.50	1.64	0.01
	U-238	4.29	0.62	4.73	1.45	0.28	U-238	10	1.91	0.41	2.02	0.50	0.56	1.86	0.15
WEAC-FS-SU1-7-157	Ra-226	0.61	0.05	0.78	0.07	2.03									
WEAC-FS-SU1-7Q-158	Th-228	1.43	0.31	0.79	0.22	1.70							N:	70	
	Th-230	1.28	0.28	1.05	0.23	0.64							Max:	3.98	
	Th-232	0.41	0.17	0.59	0.17	0.75							Min:	0.01	
	U-234	1.18	0.39	0.88	0.30	0.60			Overall Average (all samples, all analytes) RER:					0.92	
	U-235	0.46	0.25	0.64	0.27	0.48			REL Results < 3.0 are considered acceptable.						
	U-238	1.56	0.39	1.64	0.38	0.15									
WEAC-FS-SU1-7-157	Ra-226	1.23	0.11	1.20	0.09	0.22									
WEAC-FS-SU1-7Q-158	Th-228	0.87	0.29	0.76	0.24	0.30									
	Th-230	1.50	0.40	1.66	0.35	0.30									
	Th-232	1.20	0.32	1.11	0.28	0.21									
	U-234	1.40	0.35	1.35	0.33	0.10									
	U-235	0.02	0.13	0.02	0.12	0.01									
	U-238	0.90	0.29	1.06	0.31	0.38									
WEAC-FS-SU1-7-157	Ra-226	1.02	0.09	1.59	0.11	3.98									
WEAC-FS-SU1-7Q-158	Th-228	1.53	0.37	0.98	0.32	1.13									
	Th-230	1.20	0.34	2.30	0.47	1.89									
	Th-232	0.69	0.25	0.85	0.29	0.42									
	U-234	1.69	0.34	2.30	0.46	1.08									
	U-235	0.52	0.21	0.10	0.14	1.64									
	U-238	1.16	0.28	1.55	0.36	0.85									
WEAC-FS-SU1-7-157	Ra-226	3.13	0.16	2.55	0.14	2.67									
WEAC-FS-SU1-7Q-158	Th-228	1.21	0.31	1.49	0.29	0.66									
	Th-230	4.11	0.54	4.09	0.48	0.03									
	Th-232	1.24	0.29	1.05	0.24	0.50									
	U-234	6.37	0.65	4.59	0.78	1.75									
	U-235	0.61	0.26	0.53	0.34	0.20									
	U-238	4.78	0.57	4.28	0.74	0.54									
WEAC-FS-SU1-7-157	Ra-226	0.91	0.09	1.10	0.09	1.55									
WEAC-FS-SU1-7Q-158	Th-228	1.60	0.39	0.84	0.25	1.63									
	Th-230	2.83	0.52	2.16	0.38	1.04									
	Th-232	1.51	0.37	1.10	0.27	0.90									
	U-234	3.15	0.57	3.06	0.58	0.11									
	U-235	0.70	0.31	0.58	0.28	0.29									
	U-238	2.27	0.48	2.57	0.51	0.43									
WEAC-FS-SU1-7-157	Ra-226	1.27	0.11	1.01	0.11	1.71									
WEAC-FS-SU1-7Q-158	Th-228	0.91	0.28	1.35	0.31	1.05									
	Th-230	2.61	0.45	1.95	0.36	1.13									
	Th-232	1.94	0.38	1.87	0.34	0.14									
	U-234	1.15	0.47	0.52	0.34	1.08									
	U-235	0.19	0.28	0.22	0.25	0.06									
	U-238	1.38	0.53	1.10	0.41	0.42									
WEAC-FS-SU1-7-157	Ra-226	1.28	0.10	1.03	0.10	1.72									
WEAC-FS-SU1-7Q-158	Th-228	0.83	0.27	1.17	0.34	0.79									
	Th-230	1.91	0.41	1.37	0.36	0.99									
	Th-232	1.72	0.37	0.70	0.25	2.31									
	U-234	1.22	0.34	1.66	0.40	0.84									
	U-235	0.17	0.17	0.60	0.28	1.31									
	U-238	0.50	0.25	1.32	0.36	1.86									
WEAC-FS-SU1-7-157	Ra-226	0.77	0.10	0.91	0.11	0.94									
WEAC-FS-SU1-7Q-158	Th-228	1.30	0.28	1.38	0.34	0.18									
	Th-230	0.93	0.23	0.78	0.25	0.43									
	Th-232	0.82	0.21	1.16	0.29	0.94									
	U-234	1.04	0.31	1.49	0.38	0.92									
	U-235	0.07	0.14	0.09	0.14	0.11									
	U-238	1.30	0.33	1.15	0.32	0.33									
WEAC-FS-SU1-7-157	Ra-226	0.63	0.08	0.69	0.24	0.22									
WEAC-FS-SU1-7Q-158	Th-228	0.99	0.24	1.38	0.21	1.20									
	Th-230	0.75	0.21	0.77	0.23	0.07									
	Th-232	0.31	0.15	0.58	0.19	1.12									
	U-234	1.09	0.36	0.34	0.30	1.61									
	U-235	0.24	0.21	0.16	0.07	0.38									
	U-238	0.94	0.33	0.81	0.12	0.37									

8. ISOLATION AND CONTROL

The remediation effort was designed and scheduled to move contamination from the east and north to the south and west within the impacted area following the natural downgradient flow of the site. The areas were cleared as they were down posted, and the remaining radiological area was resized and controlled to mitigate the likelihood of cross contamination. Due the small footprint of the site, waste loading and shipping operations were limited to two intermodals per day; each capable of holding approximately 18 yd^3 of material. As an operational objective, excavation of contaminated materials was limited to a volume that could be effective staged and covered on a daily basis (typically no more than 80 yd^3 at any one time). Thus, the majority of site contaminated soil remained buried until just before shipping, with the last of the contaminated soil being excavated on the last day of shipping. Together, staging and tightly controlling the aboveground waste volume, which required limiting the size of the excavation at any one time, along with shipping waste off site as it was generated, all assisted with the isolation and control program implemented at the site.

9. SUMMARY

Remedial actions were undertaken in the spring of 2018 to remove uranium ore and uranium ore tailings from open grounds north of the WEAC main office building, which fall within the footprint of a proposed laboratory expansion. Initially, the site was believed to contain very little (less than 40 yd^3) contaminated soil; however, two small burial areas were encountered – this produced a final removed soil volume of approximately 970 yd^3. Following removal of residual contamination to levels believed to be less than the site DCGLs, the site was subjected to extensive trenching, scanning, and sampling designed to ensure that additional burial areas were unlikely. Lastly, a MARSSIM style FSS was conducted at the site following an approved FSSP. The FSSR and its supporting exhibits concluded that the site has met remedial objectives, including the ALARA remedial goal of < 10 mrem/year to the MEI of the public.

10. REFERENCES

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APPENDIX A

Plans and Procedures Applicable to Final Status Survey

- RP-105 Instrumentation and Measurement: General
- RP-105.100 Instrumentation: Calibration
- RP-105.200 Instrumentation: Set Up and Performance Checks
- RP-105.300 Instrumentation Selection and Use
- RP-105.301 Operation of the Ludlum Model 19 Micro R Meter
- RP-105.303 Operation of the Ludlum Model 2929 alpha/beta
- RP-105.304 Operation of the Ludlum Model 2221 Ratemeter/Scaler
- RP-105.307 Operation of the Ludlum Model 12 Count Ratemeter
- RP-105.308 Operation of Ludlum Model 44-10 Gamma Scintillation Detector
- RP-105.309 Operation of the Ludlum Model 44-9 GM Detector
- RP-105.311 Operation of the Ludlum Model 43-5 Alpha Scintillation Detector
- RP-105.312 Operations of Ludlum Model 43-89 and 43-93 Alpha/Beta Scintillation detectors
- RP-105.350 Operation of FIDLER Gamma Scintillation Detector
- RP-105.347 Field Operation of the Trimble GeoExplorer
- RP-105.400 Calculating Detection Sensitivity
- RP-500 Radiological Survey Activities
- RP-117 Contamination Control and Decontamination of Personnel
- RP-126 Survey Methods
- RP-134 Unrestricted Release of Equipment and Materials

APPENDIX B

Gamma Scan Sensitivity for the WEAC Survey

B-1.0 Introduction

The primary instrument used for scanning soils is the Ludlum Model 44-10 2-inch diameter × 2-inch thick detector for all other photon energies. This detector is coupled with a Ludlum Model 2221 scaler/ratemeter. The 2221 is operated in an open window energy mode for all photon energies above the input threshold setting of 10 mV. The detector is passed over the ground surface in a serpentine pattern. The nominal distance from the detector to the surface is estimated at 5 to 15 cm, although the sensitivity analysis performed in the MARSSIM is performed at 15 cm (resulting in a conservative estimate). The serpentine path of the detector will be approximately 0.5 to 0.75 m in width, and the rate of advancement will be approximately 1.0 m/second. Using a two-stage detection approach (sensing an increase in count rate and pausing to confirm), the audible signal from the instrument will be monitored by the surveyor, detectable changes in the count rate will be noted, and the immediate area will be resurveyed at a reduced speed to confirm the change in audible signal and, if applicable, to identify the boundary of the impacted area.

As the nominal *a priori* scan MDC for Th-230, Ra-226, and natural uranium, the values supplied in MARSSIM Table 6.7 are used. These values have been developed following the methodology provided in NUREG-1507 (NRC 1997). The relevant results are reproduced in Table B-1.

Table B-1. Detector Response and Estimated Scan Sensitivities for Potential Radiological Contaminants in Soils.

	2-in. × 2-in. NaI Detector	
Radionuclide	**Weighted cpm/µR/h**	**Scan MDC[a] (pCi/g)**
Th-230	9,580	2,119
Ra-226	760	2.8
U-Nat[b]	3,990	80

a. MDC = minimum detectable concentration.

b. U-Nat on an activity basis is assumed at 48.9% U-238 and U-234, 2.25% U-235.

APPENDIX C

Direct Measurement and Scan Sensitivity for the WEAC Surveys

C-1.0 Introduction

The final status of the WEAC site may include scan, direct, and removable surveys of hard surfaces (e.g., fire hydrant supply piping) left within excavated areas. The WEAC release criteria is based upon unrestricted release criterion provided in FC 83-23, *Policy and Guidance Directive FC 83-23: Termination of Byproduct, Source, and Special Nuclear Licenses* (NRC 1987). This criteria are provided in the Decommissioning Plan (North Wind 2017), with further justification provided in WEAC's response to requests for additional information submitted to the NRC in February 2018. The FC 83-23 limits are weighted by the FC 83-23 radionuclide-category based upon assumed mixture ratios in the Decommissioning Plan. The limits from the Decommissioning Plan are reproduced in Table C-1.

Table C-1. Derived Surface Release Criteria for the WEAC Partial Decommissioning Project_a.

Nuclide	Average– (dpm/100 cm^2)	Maximum (dpm/100 cm^2)	Removable– (dpm/100 cm^2)
Gross Alpha	190 (α)	570 (α)	38 (α)
Gross Beta–[b]	95 (β)	185 (β)	19 (β)

_a, Prior to application of these limits, reasonable efforts shall be made to eliminate residual contamination.
_b, Assumes 2 beta emissions (Th-234, Pa-234) per 4 alpha emissions (U-238, U-234, Th-230, Ra-226).

In field applications, North Wind will apply these release limits unless field data routinely exhibit that mixture assumptions are no longer valid. It is important to note that at the concentration levels associated with WEAC contaminated media (on average <100 pCi/g), it would take several grams of material to equate to a dpm value that would exceed the release limits. As an example, the release limit for removable alpha is 38 dpm, or 17 pCi/g 100 cm^2. If the suspect material had an average concentration of 10 pCi/g, then it would take 1.7 g of material to exceed the limit. Ensuring surfaces are essentially free of soil, mud, and dust is a primary first step in the release process.

Field scanning and direct surveys will be performed with a Ludlum Model 43-5 alpha scintillation detector connected to a Ludlum Model 12 (or equivalent) rate-meters/scaler. The Ludlum 44-9 pancake G-M detector is used to perform scan and direct survey for beta radiation. Alternatively, a dual Ludlum Model 43-93 alpha/beta scintillation detector may also be used.

Scanning will be conducted using a two-stage detection approach by monitoring the audible signal from the instrument, sensing an increase in count rate, and pausing to confirm. The surveyor will pause when an increase in count rate is noticed, and the immediate area will be resurveyed at a reduced speed to confirm the change in audible signal. A direct, timed count may be used to confirm if residual contamination is present. This appendix presents an estimate of the concentrations of the potential contaminants that are detectable using these survey techniques**.**

C-2.0 Surface Measurement Instrumentation

Ludlum 43-5

Scanning will be conducted at a speed of approximately one detector width per second at approximately 1 cm or less above the surface of interest; thus, residence time is approximately 1 second. Per the manufacture specifications:

- Active detector face is 76 cm^2 (50 cm^2 open).
- 4π efficiency is reported at 13% for Pu-239. Note that a 2π efficiency would be approximately 26% for Pu-239, which is a fair calibration source in comparison to processed uranium, Th-230, and Ra-226.
- Background is reported at 0 to 3 cpm for alpha radiation.

Ludlum 44-9

The Ludlum 44-9 may be used in tight spots where the 43-93 would have difficulty reaching. Scanning will be conducted at a speed of approximately one detector width per second at approximately 1 cm or less above the surface of interest; thus, residence time will be 1 second. Per the manufacturer specifications:

- Detector face is 15.5 cm^2.
- Beta 4π efficiency is reported at 22% for SrY-90 and 19% for Tc-99 (approximately 44% and 36% 2π, respectively).
- Alpha 4π efficiency is reported at 15% for Pu-239.
- Background is reported at 60 cpm for beta and 3 cpm for alpha radiation.
- Energy response typically 3,300 cpm per mR/h (~3.3 cpm per µR/h).

Ludlum 43-93

The Ludlum 43-93 is used to conduct surface scanning and direct measurements. Scanning will be conducted at a speed of approximately one detector width per second at approximately 1 cm or less above the surface of interest; thus, residence time will be 2 second. Per the manufacturer specifications:

- Detector face is ~100 cm^2 (16.7 cm x 6.94 cm, w x l respectively).
- Beta 4π efficiency is reported at 20% for SrY-90 and 15% for Tc-99 (approximately 40% and 30% 2π, respectively).
- Alpha 4π efficiency is reported at 20% for Pu-239.
- Background (in 10 µR/h field) is reported at 300 cpm or less for beta and 3 cpm for alpha radiation.
- Energy response typically 15-20 cpm per µR/h (Cs-137).

C-3.0 Contaminants of Concern

Surface Contaminant

Detection and measurement of emitted radiation from the WEAC COCs is a function of the energy and form of the emitted radiation, how it interacts with the material within which it is contained, and the nature of the detection system used. At the WEAC site, the COCs are natural uranium, Th-230, and Ra-226. The applicable release criteria are found in the main body of this document. U-Nat consists of a combination of uranium isotopes that exhibit the following alpha activity ratios:

- U-238 = 0.489,
- U-234 = 0.489 (in equilibrium with U-238), and
- U-235 = 0.022 (found in a consistent ratio in nature).

Th-230 is a pure alpha emitter. Ra-226 and its progeny produce both alpha and beta radiation in roughly equal parts.

Beta Surrogate Measurements and Visual Inspections

The screening criteria for the free release of surfaces at the WEAC site are provided in terms of total alpha and total beta activity. Except in the case where Th-230 might be found alone (which has not been observed at the WEAC site), the WEAC COCs produce approximately 2 alpha to each beta particles. However, because beta particles are much easier to measure under field conditions in comparison to alpha particles, beta measurements may be used as a screening measurement when making comparisons to release criteria (i.e., if the beta measurements are at or near background, it is likely that the alpha limit will be reached as well). Thus, under field conditions, screening surveys may be conducted using a Ludlum 44-9 or the 43-93 to confirm the absence of gross residual contamination. Once the surface is cleared, a full release survey will be conducted by collecting both the alpha and beta scan and direct measurements.

Additionally, due to the low specific activity of the material being remediated at WEAC, if a survey is essentially free of soil, it is free of contamination. Thus, documenting the cleanliness of item is an important step in the overall release process.

Surface Efficiency Values

MARSSIM recommends ISO-7503-1 as an alternative to experimentally determining source efficiencies (E_S). The source efficiencies recommended in this standard are:

- 0.5 for beta emitters with energies >0.4 MeV (E_{max}).
- 0.25 for alpha emitters and beta emitters with energies between 0.15 and 0.4 MeV (E_{max}).

Noting that the average beta max energy is well above 0.4 MeV, a source efficiency of 0.5 is assumed for the site.

C-4.0 Direct Measurement and Sensitivity

Surface activity is determined using the following equation:

$$Surface\ Activity\ \left(\frac{dpm}{100cm^2}\right) = \frac{cpm_g - cpm_b}{(E_T)(ACF)(k)} \qquad \text{(Equation C1)}$$

Where:

cpm_g = gross counts per minute.

cpm_b = background counts per minute.

E_T = total efficiency as the product of surface efficiency (E_S) and the instrument efficiency (E_i).

ACF = area correction factor for the detector, which is defined as the area of the probe in cm^2 divided by 100 cm^2.

k = all other modifying factors (set at 1.0).

From NUREG-1507, the MDC and L_C are developed using the following equations:

$$MDC = \frac{3+3.29\sqrt{R_b t_g (1+{}^{t_g}/_{t_b})}}{(E_T)(t_g)(ACF)(k)} \quad \text{(Equation C2)}$$

Where:

R_b = rate of background in cpm, t_g is the time (i.e., minutes) of the gross sample count.

t_b = time of the background sample count.

$$L_C = 1.645\sqrt{\frac{R_b}{t_b}+\frac{R_b}{t_g}} \quad \text{(Equation C3)}$$

When $t_b = t_g$, the equation is simplified as follows.

$$L_C = 2.33\sqrt{\frac{R_b}{t_b}} \quad \text{(Equation C4)}$$

C-4.1 Direct Measurement Sensitivity Results

The measurement sensitivity results for the Ludlum 43-5 and 44-9 are provided in Table C-2, while the direct static measurement sensitivity results for the Ludlum 43-93 are included in Table C-3.

Table C-2. Direct Static Measurement Sensitivity for the Ludlum 43-5 and 44-9.

Ludlum 43-5 alpha sensitivity

bkg cpm	t_b (min)	t_s (min)	Surface Eff	Instrument Eff (2 pi)	Total Eff	ACF	k	Lc (cpm)	Lc (dpm)	Lc (dpm/100cm^2)	MDC (dpm/100 cm^2)
0	5	1	0.25	0.26	0.065	0.76	0.95	0	0	0	64
1	5	1	0.25	0.26	0.065	0.76	0.95	2	29	38	141
2	5	1	0.25	0.26	0.065	0.76	0.95	3	41	54	173
3	5	1	0.25	0.26	0.065	0.76	0.95	3	51	67	197

Ludlum 44-9 beta sensitivity

bkg cpm	t_b (min)	t_s (min)	Surface Eff	Instrument Eff (2 pi)	Total Eff	ACF	k	Lc (cpm)	Lc (dpm)	Lc (dpm/100cm^2)	MDC (dpm/100 cm^2)
40	5	1	0.5	0.4	0.2	0.15	1	11	57	380	860
50	5	1	0.5	0.4	0.2	0.15	1	13	64	425	949
60	5	1	0.5	0.4	0.2	0.15	1	14	70	465	1031
70	5	1	0.5	0.4	0.2	0.15	1	15	75	503	1105

The "point" source Lc and MDA is calculated at right. This is used to define the detection capability for activity found within the probe area of the detector. If the point source is twice this size, the MDC would doubled, at 3x the detector face, it would be tripled, and so forth up to a 100 cm2 area at which point the reading is multiplied by 6.6, which is the inverse of the ACF for the 44-9. This calculation note is added to demonstrate that the 44-9 is a good indicator of contamination and works well in tight spots or for contamination areas less than 100 cm^2.	Lc (dpm/15.5 cm^2)	MDC (dpm/15.5 cm^2)
	57	129
	64	142
	70	155
	75	166

Table C-3. Direct Static Measurement Sensitivity for the Ludlum 43-93.

Ludlum 43-93 beta sensitivity											
bkg	t_b (min)	t_s (min)	Surface	Instrument	Total	ACF	k	Lc	Lc	Lc	MDC
cpm			Eff	Eff (2 pi)	Eff			(cpm)	(dpm)	(dpm/100cm^2)	(dpm/100 cm^2)
250	5	1	0.5	0.30	0.15	1	1	28	190	190	400
300	5	1	0.5	0.30	0.15	1	1	31	208	208	436
350	5	1	0.5	0.30	0.15	1	1	34	225	225	469
400	5	1	0.5	0.30	0.15	1	1	36	240	240	501
Ludlum 43-93 alpha sensitivity											
bkg	t_b (min)	t_s (min)	Surface	Instrument	Total	ACF	k	Lc	Lc	Lc	MDC
cpm			Eff	Eff (2 pi)	Eff			(cpm)	(dpm)	(dpm/100cm^2)	(dpm/100 cm^2)
1	5	1	0.50	0.40	0.20	1	1	2	9	9	33
2	5	1	0.50	0.40	0.20	1	1	3	13	13	40
3	5	1	0.50	0.40	0.20	1	1	3	16	16	46
4	5	1	0.50	0.40	0.20	1	1	4	18	18	51

C-5.0 Scan Measurement Sensitivity

The methodology described in the MARSSIM is used to estimate direct and scan sensitivity. The approach to determining surface scanning sensitivity involves a two-step process whereby the surveyor slowly moves the detector over the surface and listens to the audible response; an increase in "click" rate would cause the surveyor to pause over the area of interest to confirm if the increase is due to a natural fluctuation in background or the presence of residual contamination. This ability is referred to as the "surveyor efficiency (ρ)," which has been experimentally determined to range between 0.5 and 0.7. MARSSIM recommends using the lower end of this range for the purposes of developing *a priori* sensitivity calculations. How this is applied in the overall scan sensitivity determination is discussed at the end of this section.

The desired level of detection performance (true positive versus false positive detections) is selected from Table 6.5 of the MARSSIM. For the WEAC site, the true positive portion is set a 0.95 and the false positive portion is set at 0.6, resulting in a d' statistic of 1.38. This performance term is built into the minimum detectable net count determination (S_i), as defined by the following equation.

$$S_i = d'\sqrt{b_i} \qquad \text{(Equation C5)}$$

Where

b_i = number of background counts in the residence interval (R_i).

For example, if R_b is 150 cpm and the R_i is 2 seconds (i.e., the detector is over the surface of interest for approximately 2 seconds), then b_i is 150 cpm/60 seconds × 2 = 5 counts.

The minimum detectable count rate (MDCR) is provided in the MARSSIM as Equation 6-9, as reproduced below:

$$MDCR = S_i \, x \, \frac{60}{R_i} \qquad \text{(Equation C6)}$$

So, if bi = 5 counts, the MDCR (at a d' of 1.38) would be calculated as follows:

$$MDCR = S_i \, x \, \frac{60}{R_i}$$

$$MDCR = d'\sqrt{b_i}\, x\, \frac{60}{R_i}$$

$$MDCR = 1.38\sqrt{5} x \frac{60}{2} = 93\ cpm$$

Under the two-stage scanning approach, the surveyor's ability to discern contamination (ρ) is provided by the following equation:

$$MDCRsurveyor = \frac{MDCR}{\sqrt{\rho}}; where\ \rho = 0.5 \qquad \text{(Equation C7)}$$

From the proceeding example, if the MDCR = 93 cpm, the MDCR surveyor would be:

$$MDCRsurveyor = \frac{93\ cpm}{0.71} = 131\ cpm$$

When the original assumed background count rate (150 cpm) is added back into this number, a gross count of 180 cpm is derived (150 + 131 = 280 counts).

To convert the scan MDCR into terms of dpm/100 cm^2, the following equation is applied.

$$Scan\ MDC = \frac{MDCR}{\sqrt{\rho}(E_s)(E_i)(ACF)(k)}$$

C-5.1 Scan Measurement Sensitivity Results

The scan measurement sensitivity results for the Ludlum 43-5 and 44-9 are provided in Tables C-4 and C-5, respectively. These tables include an assessment on sensitivity when the area of contamination is spread out over an area larger than the probe, resulting in an extended residence interval and low detection capability.

The alpha and beta scan measurement sensitivity results for the Ludlum 43-93 are included in Tables C-6 and C-7, respectively.

Table C-4. Scan Measurement Sensitivity for the Ludlum 43-5.

	Ludlum 43-5 Scan Detection Sensitivity										
	Eff. Total	d'	bkg cpm	Ri (seconds)	bi (counts/R_i)	Si	MDCR (cpm)	Suv Eff	ACF	k	*Scan MDC (dpm/100 cm^2)
Concrete	**0.065**	1.38	**1**	2	0.0	0.3	8	0.71	0.78	**1**	210
	0.065	1.38	**2**	2	0.1	0.4	11	0.71	0.78	1	297
	0.065	1.38	**3**	2	0.1	0.4	13	0.71	0.78	1	364
Steel	0.065	1.38	1	2	0.0	0.3	8	0.71	0.78	1	210
	0.065	1.38	2	2	0.1	0.4	11	0.71	0.78	1	297
	0.065	1.38	3	2	0.1	0.4	13	0.71	0.78	1	364
Impact on sensitivity when area of contamination is 2 detector widths wide									0.78	1	
Concrete	0.065	1.38	1	4	0.1	0.4	5	0.71	0.78	1	148
	0.065	1.38	2	4	0.1	0.5	8	0.71	0.78	1	210
	0.065	1.38	3	4	0.2	0.6	9	0.71	0.78	1	257
Steel	0.065	1.38	1	4	0.1	0.4	5	0.71	0.78	1	148
	0.065	1.38	2	4	0.1	0.5	8	0.71	0.78	1	210
	0.065	1.38	3	4	0.2	0.6	9	0.71	0.78	1	257
Impact of sensitivity when area of contamination is 4 detector widths wide.									0.78	1	
Concrete	0.065	1.38	1	8	0.1	0.5	4	0.71	0.78	1	105
	0.065	1.38	2	8	0.3	0.7	5	0.71	0.78	1	148
	0.065	1.38	3	8	0.4	0.9	7	0.71	0.78	1	182
Steel	0.065	1.38	1	8	0.1	0.5	4	0.71	0.78	1	105
	0.065	1.38	2	8	0.3	0.7	5	0.71	0.78	1	148
	0.065	1.38	3	8	0.4	0.9	7	0.71	0.78	1	182
* Assumes contamination is uniformly spread under the detector area of 78 cm^2.											

Table C-5. Scan Measurement Sensitivity for the Ludlum 44-9.

	Ludlum 44-9 Scan Detection Sensitivity										
	Eff. Total	d'	bkg cpm	Ri (seconds)	bi (counts/R_i)	Si	MDCR (cpm)	Suv Eff	ACF	k	*Scan MDC (dpm/100 cm^2)
Concrete	**0.2**	1.38	**40**	2	1.3	1.6	48	0.71	0.185	**1**	1820
	0.2	1.38	**50**	2	1.7	1.8	53	0.71	0.185	1	2035
	0.2	1.38	**60**	2	2.0	2.0	59	0.71	0.185	1	2229
Steel	0.2	1.38	40	2	1.3	1.6	48	0.71	0.185	1	1820
	0.2	1.38	50	2	1.7	1.8	53	0.71	0.185	1	2035
	0.2	1.38	60	2	2.0	2.0	59	0.71	0.185	1	2229
Impact on sensitivity when area of contamination is 2 detector widths wide									0.185	1	
Concrete	0.2	1.38	40	4	2.7	2.3	34	0.71	0.185	1	1287
	0.2	1.38	50	4	3.3	2.5	38	0.71	0.185	1	1439
	0.2	1.38	60	4	4.0	2.8	41	0.71	0.185	1	1576
Steel	0.2	1.38	40	4	2.7	2.3	34	0.71	0.185	1	1287
	0.2	1.38	50	4	3.3	2.5	38	0.71	0.185	1	1439
	0.2	1.38	60	4	4.0	2.8	41	0.71	0.185	1	1576
Impact of sensitivity when area of contamination is 4 detector widths wide.									0.185	1	
Concrete	0.2	1.38	40	8	5.3	3.2	24	0.71	0.185	1	910
	0.2	1.38	50	8	6.7	3.6	27	0.71	0.185	1	1017
	0.2	1.38	60	8	8.0	3.9	29	0.71	0.185	1	1114
Steel	0.2	1.38	40	8	5.3	3.2	24	0.71	0.185	1	910
	0.2	1.38	50	8	6.7	3.6	27	0.71	0.185	1	1017
	0.2	1.38	60	8	8.0	3.9	29	0.71	0.185	1	1114
* Assumes contamination is uniformly spread under the detector area of 18.5 cm^2.											

Table C-6. Alpha Scan Measurement Sensitivity for the Ludlum 43-93.

	Ludlum 43-93 Alpha Scan Detection Sensitivity										
	Eff. Total	d'	bkg cpm	Ri (seconds)	bi (counts/R_i)	Si	MDCR (cpm)	Suv Eff	ACF	k	*Scan MDC (dpm/100 cm^2)
Concrete	**0.2**	1.38	**1**	2	0.0	0.3	8	0.71	**1**	**1**	53
	0.2	1.38	**2**	2	0.1	0.4	11	0.71	1	1	75
	0.2	1.38	**3**	2	0.1	0.4	13	0.71	1	1	92
Steel	0.2	1.38	1	2	0.0	0.3	8	0.71	1	1	53
	0.2	1.38	2	2	0.1	0.4	11	0.71	1	1	75
	0.2	1.38	3	2	0.1	0.4	13	0.71	1	1	92
Impact on sensitivity when area of contamination is 2 detector widths wide									1	1	
Concrete	0.2	1.38	1	4	0.1	0.4	5	0.71	1	1	38
	0.2	1.38	2	4	0.1	0.5	8	0.71	1	1	53
	0.2	1.38	3	4	0.2	0.6	9	0.71	1	1	65
Steel	0.2	1.38	1	4	0.1	0.4	5	0.71	1	1	38
	0.2	1.38	2	4	0.1	0.5	8	0.71	1	1	53
	0.2	1.38	3	4	0.2	0.6	9	0.71	1	1	65
Impact of sensitivity when area of contamination is 4 detector widths wide.									1	1	
Concrete	0.2	1.38	1	8	0.1	0.5	4	0.71	1	1	27
	0.2	1.38	2	8	0.3	0.7	5	0.71	1	1	38
	0.2	1.38	3	8	0.4	0.9	7	0.71	1	1	46
Steel	0.2	1.38	1	8	0.1	0.5	4	0.71	1	1	27
	0.2	1.38	2	8	0.3	0.7	5	0.71	1	1	38
	0.2	1.38	3	8	0.4	0.9	7	0.71	1	1	46
* Assumes contamination is uniformly spread under the detector area of 100 cm^2.											

Table C-7. Beta Scan Measurement Sensitivity for the Ludlum 43-93.

	Ludlum 43-93 Beta Scan Detection Sensitivity										
	Eff. Total	d'	bkg cpm	Ri (seconds)	bi (counts/R_i)	Si	MDCR (cpm)	Suv Eff	ACF	k	*Scan MDC (dpm/100 cm^2)
Concrete	**0.15**	1.38	**250**	2	8.3	4.0	120	0.71	**1**	**1**	1122
	0.15	1.38	**300**	2	10.0	4.4	131	0.71	1	1	1229
	0.15	1.38	**350**	2	11.7	4.7	141	0.71	1	1	1328
Steel	0.15	1.38	250	2	8.3	4.0	120	0.71	1	1	1122
	0.15	1.38	300	2	10.0	4.4	131	0.71	1	1	1229
	0.15	1.38	350	2	11.7	4.7	141	0.71	1	1	1328
Impact on sensitivity when area of contamination is 2 detector widths wide									1	1	
Concrete	0.15	1.38	250	4	16.7	5.6	85	0.71	1	1	793
	0.15	1.38	300	4	20.0	6.2	93	0.71	1	1	869
	0.15	1.38	350	4	23.3	6.7	100	0.71	1	1	939
Steel	0.15	1.38	250	4	16.7	5.6	85	0.71	1	1	793
	0.15	1.38	300	4	20.0	6.2	93	0.71	1	1	869
	0.15	1.38	350	4	23.3	6.7	100	0.71	1	1	939
Impact of sensitivity when area of contamination is 4 detector widths wide.									1	1	
Concrete	0.15	1.38	250	8	33.3	8.0	60	0.71	1	1	561
	0.15	1.38	300	8	40.0	8.7	65	0.71	1	1	615
	0.15	1.38	350	8	46.7	9.4	71	0.71	1	1	664
Steel	0.15	1.38	250	8	33.3	8.0	60	0.71	1	1	561
	0.15	1.38	300	8	40.0	8.7	65	0.71	1	1	615
	0.15	1.38	350	8	46.7	9.4	71	0.71	1	1	664
* Assumes contamination is uniformly spread under the detector area of 100 cm^2.											

Exhibit 1

Cleanup Status Report and Data Package for Survey Unit 1 Winchester Engineering and Analytical Center

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Cleanup Status Report and Data Package for Survey Unit 1 Winchester Engineering and Analytical Center 109 Holton Street Winchester, MA 01890

Revision 0

Prepared for:
Winchester Engineering and Analytical Center
Food and Drug Administration

Contract Number:
HHSF223201710022C

July 2018

North Wind Site Services
2800 Solway Road
Knoxville, TN 37931

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
AF	Area Factor
ALARA	As Low as Reasonable Achievable
bgs	below ground surface
CG	Cleanup Goal [ALARA]
CG_{EMC}	Cleanup Goal, Elevated Measurement Criteria
CG_W	Cleanup Goal, unit wide or average concentration
cpm	counts per minute
DCGL	Derived Concentration Guideline Value
$DCGL_{EMC}$	DCGL, Elevated Measurement Criteria
$DCGL_W$	DCGL, unit wide or average value criteria
EMC	Elevated Measurement Criteria
EPA	Environmental Protection Agency
FSSP	Final Status Survey Plan
GPS	Global Positioning System
HOG	High Outdoor Gamma
HSA	Historical Site Assessment
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MEI	Maximally Exposed Individual
NaI	Sodium Iodide
NRC	Nuclear Regulatory Commission
Ra-226	Radium 226
ROC	Radionuclide of Concern
SOF	Sum of Fraction
SU1	Survey Unit 1
SW	Southwest
Th-228	Thorium 228
Th-230	Thorium 230
Th-232	Thorium 232
UCL	Upper Confidence Level
WEAC	Winchester Engineering and Analytical Center
WRS	Wilcoxon Rank Sum

List of Symbols

δ	Unit Wide, Average Residual Activity
σ	Sigma, standard error
α	Critical Value for Wilcox Rank Sum Test
β	False negative error parameter
µ	micro (1/1,000)

List of Units

cm	centimeter
cm^2	centimeters square
cpm	counts per minute
dpm	disintegrations per minute
k	kilo, 1,000
m/second	meter per second
m^2	Meter square
mrem/hr	millirem per hour
pCi/g	pico curie per gram
uR/h	micro roentgen per hour
urem/hr	micro rem per hour

1. SURVEY UNIT 1 ASSESSMENT SUMMARY

The radiological assessment of Survey Unit 1 (SU1) indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the as low as reasonably achievable (ALARA) cleanup goal (CG_W) criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 2.82 mrem/year to the maximally exposed individual (MEI). Extensive trenching (post remediation) performed across SU1 indicates that it is unlikely that buried contamination remains within the unit.

SU1 Summary Statistics:

- Unit Average Net Sum of Fraction (SOF) is calculated as 0.11, resulting in a residual total effective dose estimate of 2.82 mrem/year.
- Unit Elevated Measurement Criteria used in one location results in an estimated maximum dose of 8.85 mrem/year.
- All Systematic Samples are < the $DCGL_W$.
- All Systematic Samples are < the CG_W.
- All Judgmental Samples are < $DCGL_W$ values.
- Eight of nine Judgmental Samples are < the CG_W.
- One Judgmental Sample was found at 7.13 pCi/g for Ra-226 (slightly above the CG_W of 5.0 pCi/g) but still < unity against the $DCGL_W$.
- All Judgmental Trench samples are < the $DCGL_W$ and the CG_W.
- The 1-meter gamma dose rates are < the CG_W values across the entire unit.
- A Wilcoxon Rank Sum (WRS) test is not required for the unit since all results are < the $DCGL_W$.
- A retrospective calculation of the relative shift (Δ/σ) resulted in a value of 4.26 based on the systematic sample set. Since this is > the FSSP design relative shift of 1.67 this demonstrates that sample quantity is appropriate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the survey unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and its alternative (the survey unit median is less than the $DCGL_W$ criterion) is accepted. SU1 Systematic Sample Summary Data are provided in **Table 1**.

Table 1. SU1 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.61	1.21	12	0.134		
Th-230	2.51	2.13	37	0.068		
Total-U	3.98	2.13	560	0.007		
			SOF Sum:	0.21		
			SOF Ref. Area:	0.10		
			Net SOF:	0.11		
SOF in Residual Dose Terms:				**2.82**	mrem/year	

2. SURVEY UNIT 1 REMEDIATION

SU1 (**Figure 1)** is one of three Class I survey units found at the site. The survey unit contained three concrete pads and some asphalt just prior to remediation. These were broken up and removed as residually contaminated rad-waste. Soil contamination was found and removed from one deep (1 to 1.5 meters below ground surface [bgs]) 64-m^2 area in the center of the unit. The surrounding area near this small excavation was generally cleaned down to 6 to 15 cm bgs out to several meters. A few small shallow excavations were completed in the southwest (SW) corner of the unit; in one of these small excavations, an abandoned 2-inch diameter steel pipe was uncovered, surveyed, and released in place.

The majority of the southern boundary of this unit borders an asphalt driveway, which was used to stage and load intermodals during remediation. The southern edge of the survey unit, up against the asphalt load out area, became residually surface contaminated due to the migration of staged soils from the near-by contaminated load-out pile. This surface material was remediated and in a few locations and the excavation continued down to approximately 0.5 meters bgs. It appears that a lens of material may be running to the south under the asphalt.

The survey unit is assessed against derived concentration guideline levels ($DCGL_W$) and, as an ALARA objective, to an additional Cleanup Goal (CG_W). The $DCGL_W$ is comparable to the Nuclear Regulatory Commission (NRC) 25 mrem/yr effective annual dose limit; the CG_W is comparable to an effective annual dose limit of 10.4 mrem/yr.

The CG_W is based upon guidance provided by the Environmental Protection Agency (EPA) in Directive No. 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Site Using the benchmark Dose Cleanup Criteria in 10 CFR 40, Appendix A, I, Criterion 6(6)*. This directive allows a site to set the dose benchmark remediation goal based on Ra-226 + Ra-228 at 5 pCi/g (surface) and 15 pCi/g (subsurface) for the cleanup of byproduct material. This approach requires licensees to calculate the potential peak effective dose equivalent (excluding radon) to an individual at the site within 1,000 years from exposure to the residual levels allowed under the radium soil standard. The radionuclides of concern (ROCs) being addressed by the Criterion 6(6) rule are thorium, natural uranium, and radium.

As the CG_W is essentially equivalent to the State's remedial dose goal, it may prove useful to the Winchester Engineering and Analytical Center (WEAC) to demonstrate performance against this objective (when practical) and thus, it is adopted as an ALARA goal. However, survey design strategy and the ultimate determination if remedial actions have been successful are assessed against the $DCGL_W$ values. The radionuclide specific $DCGL_W$ and CG_W values are provided in **Table 2**.

Table 2. WEAC $DCGL_W$ Criteria and ALARA CG_W Values (pCi/g)

Radionuclide	**$DCGL_W$**	**ALARA CG_W**
Ra-226	12	5
Th-230	37	15.6
Total-Uranium	560	233
ALARA Dose Goal: Unit average dose rate < 16.0 µR/h with no small area > 25 µR/h.		

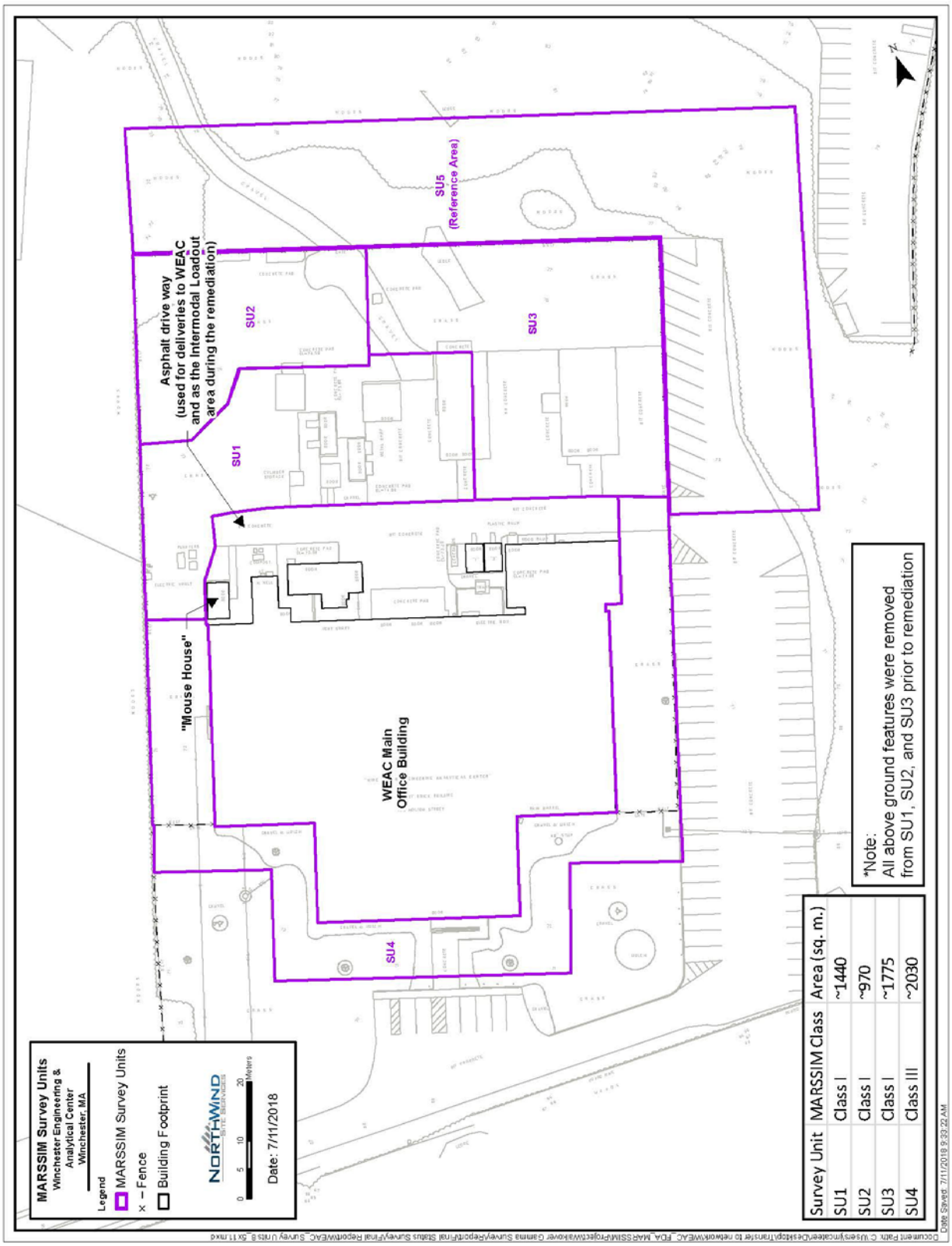


Figure 1. WEAC Survey Units

3. SURVEY UNIT 1 EVALUATION

SU1 is a 1,440-m^2, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Class I land area found north of the WEAC main office building. During remediation, two separate locations of contamination were found; one, in the SW corner of the unit, consisted of a few yards of elevated soil material near the as-found soil surface. A relatively large area of contamination was found in the center of the unit, which, based upon sample results, contain buried uranium tailings. The buried material extended down approximately 1 to 1.5 meters over a 64 m^2 area. An area directly south of the 64-m^2 excavation and running to the edge of the survey unit was remediated down to a depth of 0.25 to 0.5 meters. Residual surface contamination (1 to 5 pCi/g) extending out several meters was found and removed from around the 64-m^2 burial site.

3.1 Trenching

All areas were remediated using real-time gamma scanning (2 x 2-inch sodium iodide [NaI] detectors) to lead soil removal efforts. Soil samples were collected and analyzed on-site to determine if the survey unit was nearing the site DCGLs. Once it appeared that SU1 was free of residual contamination, trenches were dug down to approximately 1.2 meters (4 feet) bgs to ensure no additional buried material was located on site (see **Figure 2**). The trench spoils were placed next to each trench and gamma scanned for gamma anomalies. Soil samples were collected from each trench spoils pile based upon the highest outdoor gamma (HOG) anomaly found – if no anomaly was found, a composite sample was collected along the length of the trench spoils. The trench spoils samples were sent off site as judgmental samples for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Trench sample results are provided in **Table 3**.

Table 3. Trench Soil Sample Results

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U
WEAC-SS-051J	0.6	NA	ND	0.81	NA	0.043	ND	0.86
WEAC-FS-SU1-171J	0.726	1.28	0.394	0.834	1.26	0.102	0.355	1.7
WEAC-FS-SU1-173J	1.36	1.44	1.67	1.19	1.82	0.51	1.21	3.5
WEAC-FS-SU1-174J	0.87	0.786	0.956	0.834	0.867	0.393	0.707	2.0
WEAC-FS-SU1-175J	0.747	1.04	0.993	0.689	2.37	-0.0765	1.39	3.7
WEAC-FS-SU1-176J	0.996	0.774	1.19	0.479	2.41	0.0735	1.97	4.5
WEAC-FS-SU1-177J	1.16	1.13	1.7	1.92	1.65	0.288	2.2	4.1
WEAC-FS-SU1-078J	0.75	1.22	0.0866	0.936	1.03	0.455	1.22	2.7
WEAC-FS-SU1-102J	0.797	0.823	0.653	1.07	1.41	0.423	1.04	2.9
WEAC-FS-SU1-143J	1.29	0.72	1.84	0.725	2.72	0.811	2.54	6.1
WEAC-FS-SU1-144J	0.978	1.1	1.07	0.819	1.73	0.217	1.32	3.3
Sample Descriptions								
051J, 6 pt composite, SU1, sample of soil under gravel (WEAC Screening Lab, Tot-U estimated at 20x(U-235 value)								
171J, 5 pt composite, SU1, Trench Hog, N-S trench through center of SU1								
173J, 5 pt composite, SU1, Trench Hog, N-S along west fence								
174J, 5 pt composite, SU1, Bottom of far west N-S trench, 16 to 18k cpm								
175J, 5 pt composite, SU1, Trench Hog, short trench running east of the deep excavation in SU1								
176J, 5 pt composite, SU1, Trench hog, short trech running north from SU1 deep excavation; trench spoils.								
177J, 5 pt composite, SU1, 2nd N-S trench from west fence line in SU1, taken from spoils.								
078J, SU1, 5 pt composite of trench spoils (north to south), HOG								
102J, Su1, 5 pt composite of trench spoils, HOG								
143J, SU1, Grab sample from the northern trench, grab at hotspot (HOG)								
144J, SU1, 5 point composite from the northern trench, of and around hotspot.								

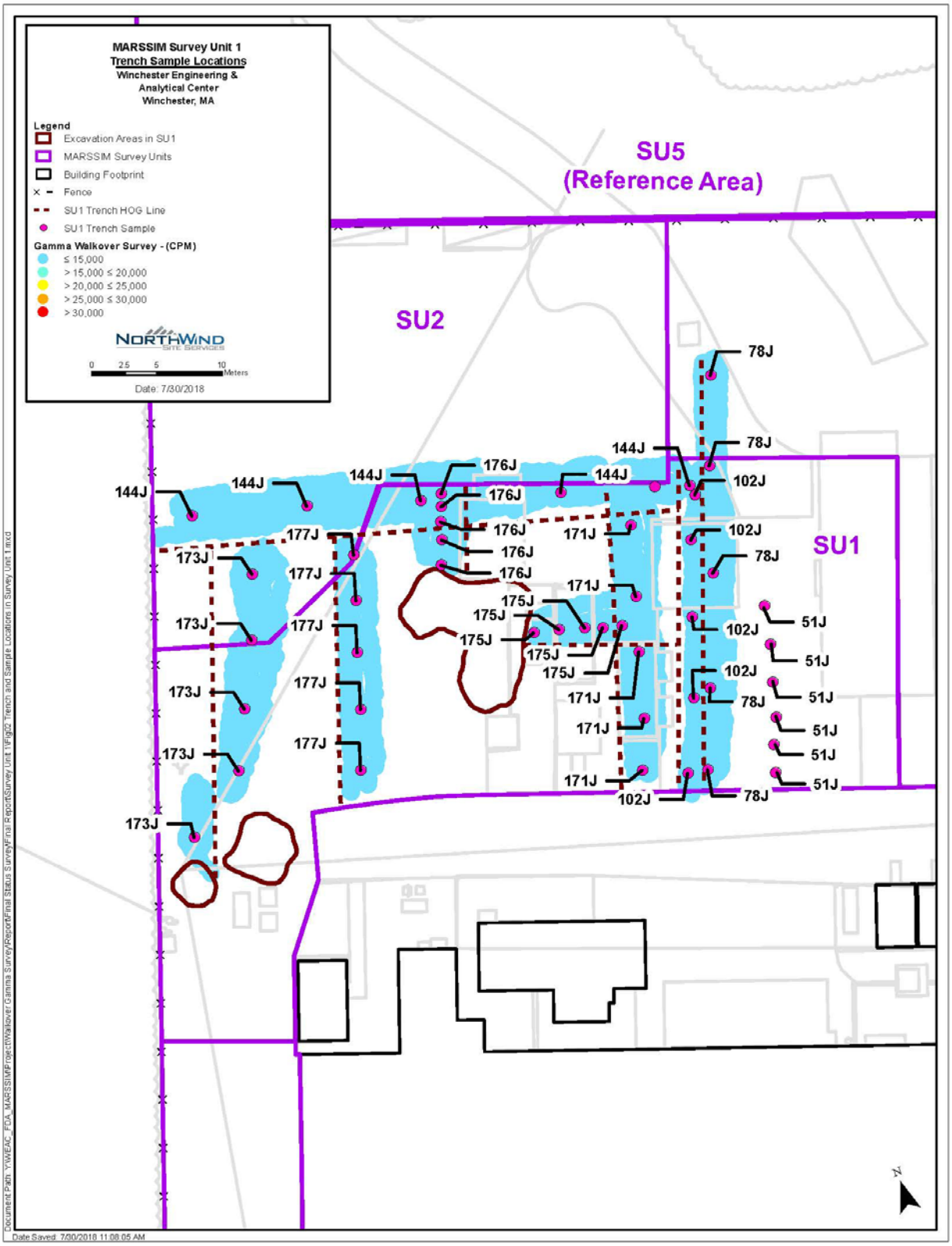


Figure 2. SU1 Trench lines, Trench Soil Sample Locations, and Excavation Areas

3.2 Gamma Walkover Scanning

Global positioning system (GPS)-enabled gamma walkover scans were conducted across the survey unit as areas were cleaned and readied for final assessment. These were performed following the Final Status Survey Plan (FSSP) prepared for the site and consisted of slowly moving the NaI detector across the surface at approximately 0.5 m/second at a height of 15 cm. Scan paths were approximately 0.5 to 1.0 meters apart. All Class I units were additionally cross walked to ensure full coverage. Gamma walkover survey results are provided in **Figure 3**.

3.3 ALARA Dose Rate Assessment

Criteria dose modeling demonstrates that the primary exposure pathway is direct radiation, which contributes over 95% to dose under the most restrictive exposure scenario (used to set the $DCGL_W$ and CG_W values for each radionuclide). This includes Th-230, which reaches its maximum residual exposure at t=1,000 years. At this point, Ra-226 has significantly ingrown, which results in additional direct radiation exposure in 1,000 years but is taken into account today.

At the WEAC site, an ALARA residual dose rate goal is established at 5.2 uR/h as a unit average. This would equate to 10.4 mrem of residual exposure to an occupational outdoor worker spending 2,000 hours in the survey unit. The Reference Area (SU5) average dose rate was measured at 10.8 ± 1.3 (1σ) µR/h. Thus, the dose goal is 5.2 + 10.8, or 16 µR/h, over the whole of the survey unit with no small area exceeding 25 µR/h.

Dose rates were collected across the whole of SU1 at a height of 1 meter above the surface or from side walls in excavations. These were collected using a NaI 2 x 2-inch detector, which records penetrating radiation in counts per minute (cpm). The count rate data were converted into µR/h using the manufacture's reported nominal exposure rate response in µR/h per cpm; reported as 900 cpm/(µR/h) (Reference Ludlum Instrumentation User's Manual for the Ludlum 44-10 detector). The result of this assessment is provided in **Figure 4**. For SU1, all dose rates were < 16 µR/h and thus, the direct radiation dose CG_W is achieved.

3.4 Reference Area

A Reference Area (i.e., the MARSSIM background area) was selected as the area north and east of the impacted area. The Historical Site Assessment (HSA) determined that this area was unlikely to have been impacted by site radiological operations. The Reference Area was assessed as SU5 and found to be consistent with anticipated background conditions for the Boston, MA region; average dose rates were measured at 10.8 ± 1.3 (1 σ) µR/h. Soil sample results were within anticipated background concentration levels (~ 1 ± 0.5 pCi/g) for the naturally occurring ROCs. The Reference Area average SOF against the ROCs is 0.10 ± 0.02 (1 σ). The reference area differed somewhat from the impacted survey units in that much more of the impacted survey unit soil consisted of backfill material, which contained a significant fraction of large rocks (presumably relocated from an off-site backfill site).

The Reference Area is used to perform statistical tests and other comparisons to the survey unit under study when ROCs are found in natural background at significant levels in comparison to the site $DCGL_W$ values. Reference Area (SU5) sample data are provided in **Table 4**.

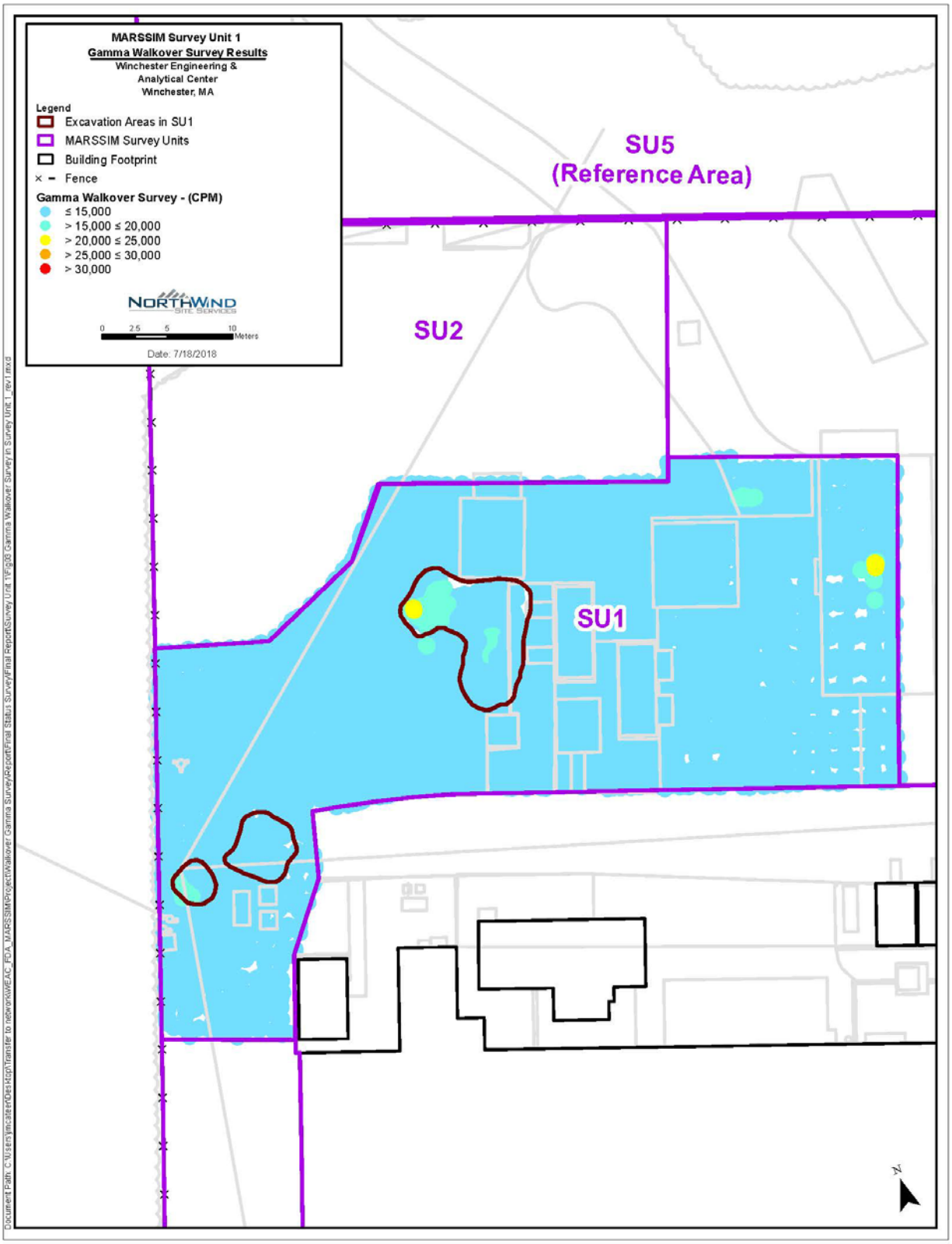


Figure 3. SU1, Gamma Detector (2 x 2 Inch, NaI) Walkover Survey Results

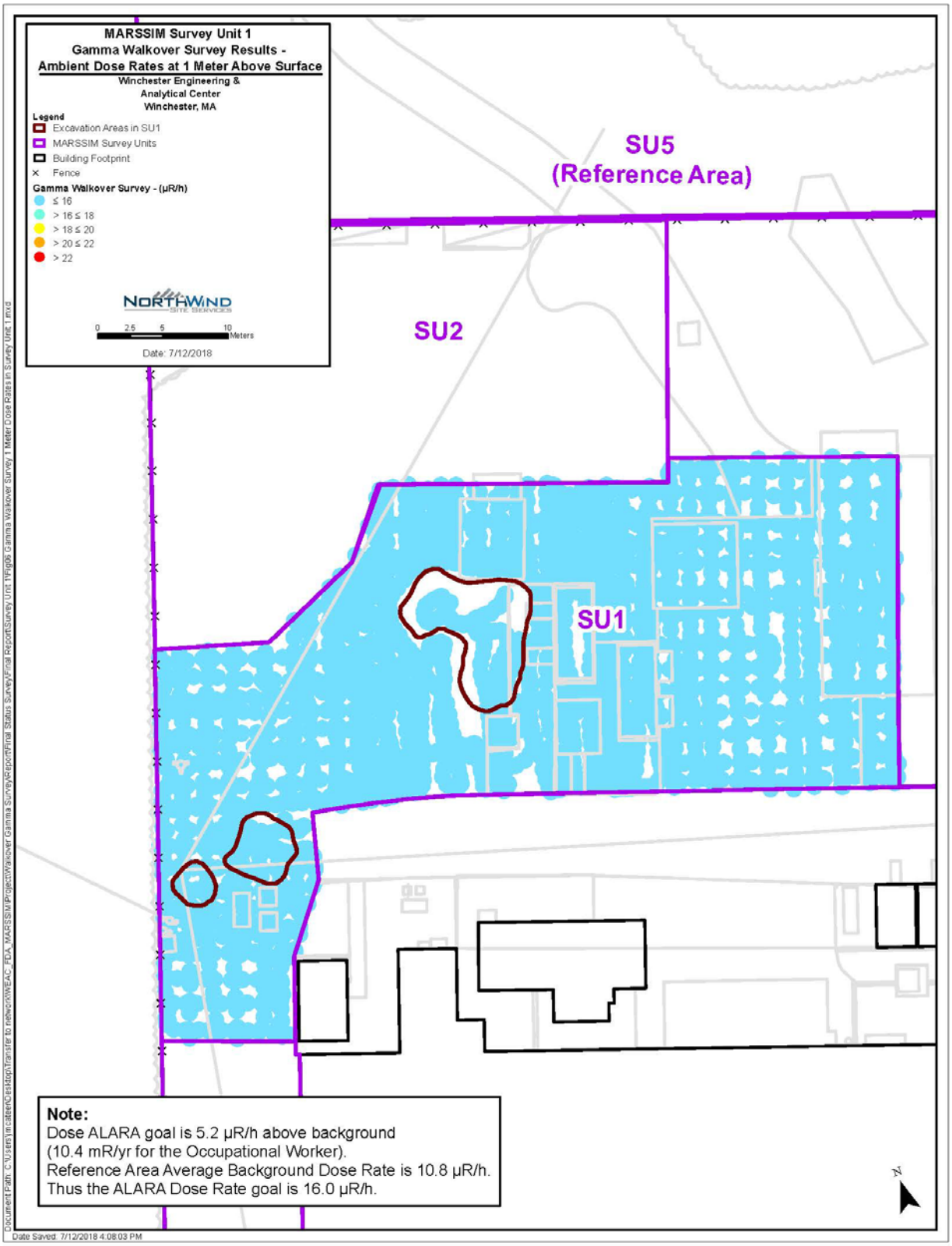


Figure 4. Dose Rate Survey Results for SU1

Table 4. Reference Area (SU5) Systematic Sample Results

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	SOF	ALPHA	BETA
WEAC-FS-SU5-1-105	1.04	1.61	0.82	0.705	0.898	0.204	1.05	2.15	0.11		
WEAC-FS-SU5-2-106	0.931	1.25	0.96	1.15	0.83	0.0584	0.965	1.85	0.11		
WEAC-FS-SU5-3-107	0.799	1.62	1.33	1.41	1.26	0.167	0.831	2.26	0.11	19.7	22.9
WEAC-FS-SU5-4-108	0.772	1.97	0.434	1.34	0.90	0.2	1.8	2.90	0.08	18.7	23.1
WEAC-FS-SU5-5-109	0.85	0.937	0.647	0.923	1.16	0.346	0.961	2.47	0.09		
WEAC-FS-SU5-6-110	0.678	1.5	0.738	0.447	0.807	0.0203	0.734	1.56	0.08		
WEAC-FS-SU5-7-111	0.768	1.3	0.928	0.821	1.04	0.0726	1.3	2.41	0.09		
WEAC-FS-SU5-8-113	0.796	1.42	0.964	0.946	1.02	0.0606	1.27	2.35	0.10	23.1	28.7
WEAC-FS-SU5-9-114	0.724	0.773	1.02	1.03	1.04	0.182	0.811	2.03	0.09		
WEAC-FS-SU5-10-115	0.721	1.49	0.613	0.598	0.507	0.335	0.736	1.58	0.08		
WEAC-FS-SU5-11-116	0.926	1.71	1.02	0.992	1.41	0.0555	1.17	2.64	0.11		
WEAC-FS-SU5-12-117	0.618	0.797	0.318	0.653	0.416	0.0782	0.879	1.37	0.06	19.8	25.6
WEAC-FS-SU5-13-118	1.22	1.14	0.895	0.998	0.935	0.24	0.664	1.84	0.13		
WEAC-FS-SU5-14-119	0.631	0.99	0.746	0.309	1.09	0.243	0.936	2.27	0.08	25.7	35.6
WEAC-FS-SU5-15-121	0.993	1.16	0.87	1.03	0.659	0.222	1.82	2.70	0.11		
WEAC-FS-SU5-16-122	1.02	1.33	0.788	0.546	0.856	0.0959	1.28	2.23	0.11	23.4	26.2
Reference Area Summary	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U		ALPHA	BETA
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	6.00	6.00
Average	0.84	1.31	0.82	0.87	0.93	0.16	1.08	2.16	0.10	21.73	27.02
SD,n-1	0.17	0.34	0.24	0.31	0.26	0.10	0.35	0.43	0.02	2.74	4.72
1.96SD,n-1	0.33	0.66	0.48	0.61	0.51	0.20	0.69	0.85	0.03	5.36	9.25
Ave + 1.96SD, n-1	1.17	1.97	1.30	1.47	1.43	0.36	1.76	3.01	0.13	27.10	36.27
Initial Assessment:	Reference Area									SOF	Net SOF
Net Residual Average Activity (pCi/g):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560		1	1
Fraction (A/CG):	0.00		0.00					0.00		0.00	0.00
SOF (CGw):	0.00										
SOF ($DCGL_W$) in terms of Dose:	0.00	mrem/y, max dose over next 1000 years									

3.5 Systematic and Judgmental Soil Sampling

Systematic soil samples were collected, based upon a random start triangular grid, to provide a non-biased statistical sample set for the survey unit wide ($DCGL_W$) evaluation. Portions of the 64-m^2 excavation area were remediated to bedrock and a 5-point composite sample was collected from the remaining soils. An additional test pit sample was collected from a test pit dug at the bottom of the 64-m^2 area. The test pit was placed at a location were undulations in the bedrock allowed for an additional 2 feet of soil removal (where bedrock was again encountered). The soil sample was collected from soils just above bedrock. No water was encountered at this location. All systematic and judgmental samples were sent off site for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Additionally, five of these samples were selected for gross alpha/beta analysis. Systematic soil sample locations are provided in **Figure 5**. Judgmental soil sample locations are provided in **Figure 6**.

3.6 Systematic Soil Sample Results

Systematic samples were collected at 16 locations based upon a random start, triangular grid.
A retrospective calculation of the relative shift (Δ/σ) results in a value of 4.20; since this is > the FSSP design parameter of 1.67, this confirms that the number of samples collected is adequate to demonstrate achievement of this data quality objective. Systematic soil sample results are provided in **Table 5**.

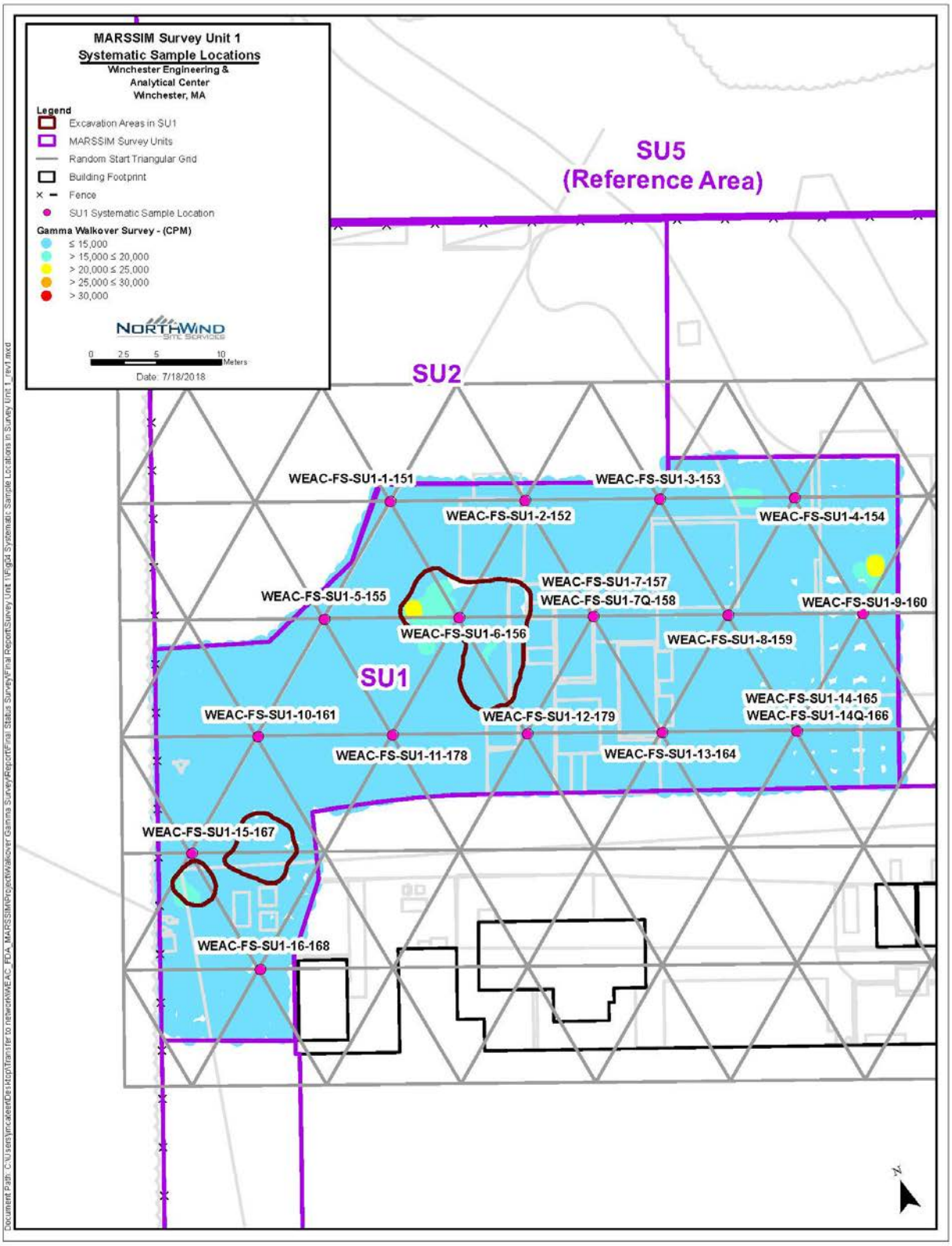


Figure 5. SU1 Systematic Soil Sample Locations

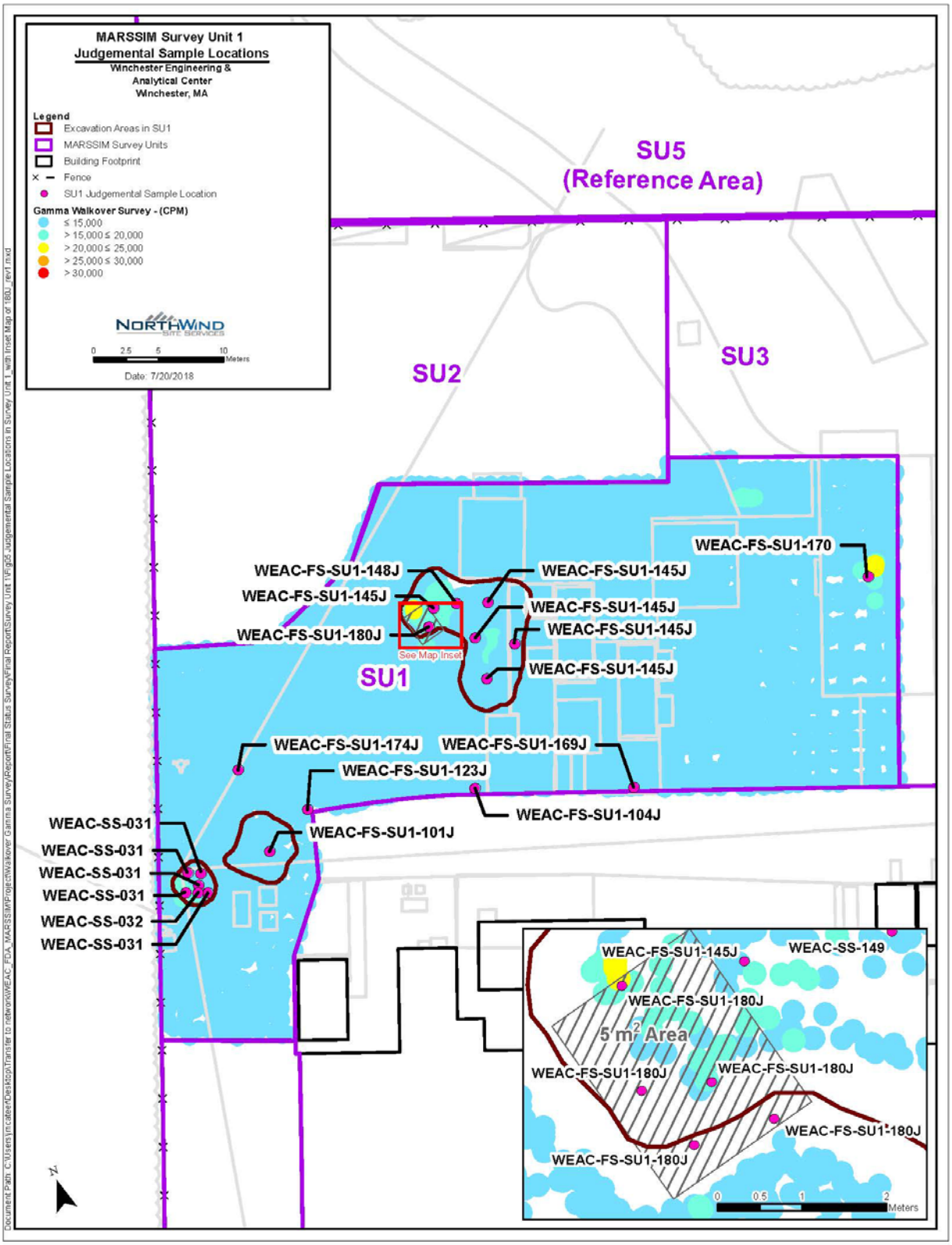


Figure 6. SU1 Judgmental Sample Locations

Table 5. SU1 Systematic Survey Sample Data

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-FS-SU1-1-151	1.16	0.713	1.32	1.3	1.73	0.0338	1.75	3.51		
WEAC-FS-SU1-2-152	0.971	1.35	1.56	1.57	1.52	0.622	2.23	4.37		
WEAC-FS-SU1-3-153	0.881	1.24	0.541	0.918	1.53	0.887	2.26	4.68		
WEAC-FS-SU1-4-154	0.968	1.23	1.64	1.41	1.92	0.344	1.55	3.81	24.7	27.8
WEAC-FS-SU1-5-155	3.86	2.52	7.47	0.999	2.9	0.0472	3.46	6.41		
WEAC-FS-SU1-6-156	3.39	1.65	4.87	1.96	3.81	0.55	4.34	8.70		
WEAC-FS-SU1-7-157	2.7	2.06	4.88	1.69	3.11	0.13	4.29	7.53		
WEAC-FS-SU1-8-159	0.527	0.536	0.297	0.278	0.803	0.423	0.55	1.78	11	13.2
WEAC-FS-SU1-9-160	1.63	1.27	2.75	0.984	2.43	0.298	2.25	4.98		
WEAC-FS-SU1-10-161	1.57	1.11	2.3	1.15	2.03	0.255	1.8	4.09		
WEAC-FS-SU1-11-178	0.981	1.54	1.81	0.851	1.05	0.00467	1.84	2.89		
WEAC-FS-SU1-12-179	0.692	0.953	0.558	0.869	0.502	0.173	0.62	1.30	17.6	22.4
WEAC-FS-SU1-13-164	0.693	1.57	1.08	0.979	1.49	0.107	0.914	2.51		
WEAC-FS-SU1-14-165	0.609	1.43	1.28	0.407	1.18	0.463	1.56	3.20		
WEAC-FS-SU1-15-167	4.13	1.1	5.94	0.407	0.849	-0.027	0.389	1.21		
WEAC-FS-SU1-16-168	0.999	1.97	1.82	0.866	0.862	0.135	1.77	2.77	30.6	29.7
	All results are in pCi/g									
Count	16	16	16	16	16	16	16	16	4	4
Average	1.61	1.39	2.51	1.04	1.73	0.28	1.97	3.98	20.98	23.28
Max	4.13	2.52	7.47	1.96	3.81	0.887	4.34	8.7	30.6	29.7
Min	0.527	0.536	0.297	0.278	0.502	-0.027	0.389	1.211	11	13.2

3.7 Judgmental Design Modifications

SU1 served as the waste load out area for the site. Due to space limitations and the desire to limit the amount of contaminated material above ground at any one time, final clearance assessment was not possible until immediately following loading of the last intermodal. Thus, gamma scanning and site assessment were somewhat confounded by the presence of a large pile of contaminated material until the final few days of remediation.

The final assessment indicated one spot (approximately 2 to 3 m^2) of elevated material near and partially running down the side of the 64-m^2 excavation in the upper western portion of the excavation and around and south of a large rock (Figure 3). This was sampled as 5-point composite sample WEAC-FS-SU1-180J. The 180J sample is below the $DCGL_W$; it is also assessed against the ALARA CG_W objective later in this document. The elevated material found in the bottom of the 64-m^2 excavation was sampled as 5-point composite sample WEAC-FS-SU1-145J. A test pit sample (WEAC-FS-SU1-148J) was collected at the bottom of the excavation; the test pit extended another 2 feet down. Results for these three samples are provided in **Table 6**.

Table 6. Judgmental Samples from Elevated Areas in and around the 64-m^2 Excavation, SU1

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
	Additional Samples in and directly around the 64-m^2 excavation.									
WEAC-FS-SU1-180J	7.13	1.68	11.9	1.22	4.21	0.883	5.46	10.6	48.6	32
WEAC-FS-SU1-145J	2.28	1.19	3.43	0.535	13.1	0.712	14.8	28.6		
WEAC-FS-SU1-148J	0.87	1.13	0.566	0.917	6.75	0.351	6.58	13.7		
Sample Descriptions										
180J, Judgmental HOG (High outdoor gamma) elevated gamma sample, Composite sample collected from small 2m^2 hot spot.										
145J, SU1, 5 point composite from the elevated material remaining at the bottom of the 64-m^2 excavation.										
148J, SU1, Grab sample from test pit at the base of the 64-m2 excavation; test pit went 2 feet deeper to bedrock.										

The final assessment also indicated that a potential lens of contaminated material continues under the asphalt found along the southern border of the survey unit. A shallow trench was dug along this area until it appeared that the gamma results were associated from the asphalt side wall shine rather than the bottom of the trench. The trench was sampled as several 5-point composite samples provided in **Table 7**.

Table 7. Judgmental Sample from Shallow Trench just north of the Asphalt Load-out Area

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
	Additional Samples just north of the asphalt load-out area.									
WEAC-FS-SU1-104J	1.83	1.16	0.982	0.694	5.94	0.681	5.27	11.9		
WEAC-FS-SU1-123J	0.881	1.03	1.42	0.918	1.93	0.127	2.53	4.6		
WEAC-FS-SU1-169J	1.43	1.72	0.747	0.744	1.69	0.453	1.2	3.3		
Sample Desriptions										
104J, SU1, 5 point composite from the shallow dig (about 2 feet) just north of the asphalt load-out area; shine issue from sidewall.										
123J, SU1, grab sample from west end of asphalt drive (just north of the load-out area), suspect shine from soil face under asphalt.										
169J, SU1, 5 point composite collected from the 2' deep trench just north of the ashpalt along the load-out area; suspect shine.										

Two small areas (a few m^2 each) were excavated down 15 to 30 cm in the SW corner of SU1. The more western of these two locations was sampled by both a composite and grab sample (WEAC-SS-031 and -32, respectively) and analyzed on site using the WEAC screening laboratory. A single grab sample was collected from the more eastern of these two areas as WEAC-FS-101J. Results for these samples are presented in **Table 8**.

Table 8. Judgmental Samples from shallow excavations in the SW Corner of SU1

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
	Additional Samples collected from the two shallow excavations in the SW Corner of the Survey Unit									
WEAC-FS-SU1-101J	0.92	1.64	1.19	0.46	1.58	0.63	1.48	3.69		
WEAC-SS-SU1-31	1.87		ND	1.1		0.322	5.46	11.6	WEAC Screening Lab	
WEAC-SS-SU1-32	1.82		ND	0.94		0.221	3.05	6.5	WEAC Screening Lab	
Sample Description										
101J, SU1, grab sample from shallow excavation at 3 feet depth.										
WEAC-SS-SU1-31, 5-point composite from excavation, counted on site only. Total-U (est) at 2x (U-238 + U-235).										
WEAC-SS-SU1-32, grab sample from excavation, counted on site onle. Total-U (est) at 2x (U-238 + U-235).										

4. ASSESSMENT RESULTS

The Reference Area average SOF (for the ROCs) in regards to the $DCGL_W$ is 0.10; this value is used to assess "net SOF" results for SU1. SU1 Th-232 and Th-228 results are compared to the Reference Area average 95% upper confidence level (UCL) to assess if these radionuclides are consistent with background; to be inconsistent with background, both Th-232 and Th-228 would need to exceed these values.

In SU1, all systematic sample results were below the $DCGL_W$ and the CG_W for the ROCs (**Table 9**). The maximum net SOF result was for Systematic Sample WEAC-FS-SU1-155 at 0.44. The average net SOF for SU1 was 0.11 (e.g., SU1 average SOF [0.21], less the Reference Area SOF [0.10], is 0.11). This results in a derived residual dose of 2.82 mrem/yr for a person working within the survey unit. Since no sample exceeded unity for the SOF, the WRS test is not required.

Table 9. SU1 Systematic Sample Results (Activity in pCi/g) and CG_W Assessment

SU1_DGCLw Assessment	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total	SOF	Net SOF
WEAC-FS-SU1-1-151	1.16	0.713	1.32	1.3	1.73	0.0338	1.75	3.51	0.14	0.04
WEAC-FS-SU1-2-152	0.971	1.35	1.56	*1.57*	1.52	0.622	2.23	4.37	0.13	0.03
WEAC-FS-SU1-3-153	0.881	1.24	0.541	0.918	1.53	0.887	2.26	4.68	0.10	0.00
WEAC-FS-SU1-4-154	0.968	1.23	1.64	1.41	1.92	0.344	1.55	3.81	0.13	0.04
WEAC-FS-SU1-5-155	3.86	*2.52*	7.47	0.999	2.9	0.0472	3.46	6.41	0.53	0.44
WEAC-FS-SU1-6-156	3.39	1.65	4.87	*1.96*	3.81	0.55	4.34	8.70	0.43	0.33
WEAC-FS-SU1-7-157	2.7	*2.06*	4.88	*1.69*	3.11	0.13	4.29	7.53	0.37	0.27
WEAC-FS-SU1-8-159	0.527	0.536	0.297	0.278	0.803	0.423	0.55	1.78	0.06	-0.04
WEAC-FS-SU1-9-160	1.63	1.27	2.75	0.984	2.43	0.298	2.25	4.98	0.22	0.12
WEAC-FS-SU1-10-161	1.57	1.11	2.3	1.15	2.03	0.255	1.8	4.09	0.20	0.10
WEAC-FS-SU1-11-178	0.981	1.54	1.81	0.851	1.05	0.00467	1.84	2.89	0.14	0.04
WEAC-FS-SU1-12-179	0.692	0.953	0.558	0.869	0.502	0.173	0.62	1.30	0.08	-0.02
WEAC-FS-SU1-13-164	0.693	1.57	1.08	0.979	1.49	0.107	0.914	2.51	0.09	0.00
WEAC-FS-SU1-14-165	0.609	1.43	1.28	0.407	1.18	0.463	1.56	3.20	0.09	-0.01
WEAC-FS-SU1-15-167	4.13	1.1	5.94	0.407	0.849	-0.027	0.389	1.21	0.51	0.41
WEAC-FS-SU1-16-168	0.999	1.97	1.82	0.866	0.862	0.135	1.77	2.77	0.14	0.04
Radionuclide results are in pCi/g, SOF is unit less.									SOF	Net SOF
Average:	1.61	1.39	2.51	1.04	1.73	0.28	1.97	3.98	0.21	0.11
Standard Deviation:	1.21	0.50	2.13	0.47	0.93	0.26	1.19	2.13	0.16	0.16
Maximum:	4.13	2.52	7.47	1.96	3.81	0.887	4.34	8.7	0.53	0.44
Any Samples > $DCGL_W$?:	No		No					No		
Any Samples > CG_W?:	No		No					No		
Max SOF > Unity?:									No	No
Initial Assessment:	Since no samples exceeded the clean up goal, the WRS test is not required.									
	Since only one sample (at 1.05) is > Unity, the WRS is not required.								SOF_{ave}-SOF_{bkg}	Net SOF
SU1 Average Net Activity (δ) (pCi/g):	0.77	0.08	1.69	0.17	0.81	0.12	0.90	1.82	0.11	0.11
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560	1	1
Fraction (δ/CG_W):	0.06		0.05					0.00	0.11	0.11
SOF (CG_W):	0.11									
SOF (CGw) in terms of Dose:	**2.82**	**mrem/y, max dose over next 1000 years**								

One sample exceeded the Th-232/Th-228 combined background screening values for both Th-232 and Th-228 (results in red *italics*) at just over the 95% UCLs. Since this is the only exceedance within all survey units, additional consideration, beyond noting it here, does not appear warranted.

4.1 Elevated Measurement Assessment

No systematic or judgmental sample exceeded the $DCGL_W$. One judgmental sample/area approached the $DCLW_W$ with a net SOF of 0.84 over what is approximately a 2 to 3 m^2 area. This area is associated with soil sample WEAC-FS-SU1-180J and will be referred to as the "180J" area in this section.

The area factors associated with the $DCGL_{EMC}$ are provided in **Table 10**. These area factors are developed following the same modeling assumptions used to derive the selected $DCGL_W$ values, with only the horizontal extent of the contaminated area allowed as a variable. Notably, the depth of contamination is assumed to be 1 meter thick, which is likely to be overly conservative.

Table 10. WEAC DCGL Elevated Measurement Criteria ($DCGL_{EMC}$)

WEAC DCGL, Elevated Measurement Criteria ($DCGL_{EMC}$)								
Dose Criterion (25 mrem/y):	25		25					25
DSRs (most conservative) from initial modeling:	2.08E+00		6.66E-01					4.46E-02
Radionuclides:	**Ra-226**	**Th-228**	**Th-230**	**Th-232**	**U-234**	**U-235**	**U-238**	**U-Total**
DCGLw (25 mrem/y):	12.02	N/A	37.5	N/A	N/A	N/A	N/A	561
DSR at 10 m^2:	1.04E+00		3.28E-01					2.56E-02
DSR at 5m^2:	6.90E-01		2.18E-01	(DSRs are in mrem/yr per pCi/g)				2.05E-02
DSR at 2.5 m^2:	4.44E-01		1.41E-01					1.80E-02
DSR at 1 m^2:	2.25E-01		7.15E-02					1.54E-02
$DCGL_{EMC}$ at 10 m^2:	24.0		76.2					976.6
$DCGL_{EMC}$ at 5 m^2:	36.2		114.7	($DCGL_{EMC}$ in pC/g over the small area)				1219.5
$DCCGL_{EMC}$ at 2.5 m^2:	56.3		177.3					1388.9
$DCGL_{EMC}$ at 1 m^2:	111.1		349.7					1623.4
AF, 10 m^2:	2.0		2.0					1.7
AF, 5 m^2:	3.0		3.1	(Area Factors are unitless)				2.2
AF, 2.5 m^2:	4.7		4.7					2.5
AF, 1.0 m^2:	9.2		9.3					2.9

The elevated criteria assessment is performed following guidance from MARSSIM for when a ROC is found to be above the $DCGL_W$ for a small area in addition to the residual contamination spread uniformly across the remaining unit. In this approach, the unity rule (MARSSIM Section 4.3.3) is used to ensure that the total residual activity is within criteria. This is performed using MARSSIM Equations 8-1 and 8-2 (reproduced below). This process requires an assessment of the size of the individual elevated area relative to the survey unit size (referred to as the area factor [AF] or A_m) as a whole and the survey unit's average residual radioactive content (δ). Each elevated area is added as an additional term in Equation 8-2, and the unity rule is applied in evaluation against criteria.

$$DCGL_{EMC} = (A_m)(DCGL_W) \qquad \text{(MARSSIM Equation 8-1)}$$

$$\frac{\delta}{DCGL_W} + \frac{average\ concentration\ in\ elevated\ area - \delta}{(Area\ Factor\ for\ Elevated\ Area)(DCGL_W)} \qquad \text{(MARSSIM Equation 8-2)}$$

180J elevated area parameters are provided in **Table 11**.

The result of the elevated measurement criteria (EMC) evaluation is provided in **Table 12**. The AF-weighted SOF for the 180J area is 0.24. When added to the overall $DCGL_W$ SOF (0.11), the combined SOF is 0.35; this equates to approximately 8.85 mrem per year of residual exposure to the MEI under conservative modeling conditions. Thus, both the $DCGL_W$ and CG_W effective dose criterion for SU1 are satisfied.

Table 11. 180J Elevated Area Parameters

Parameter Description	Parameter
Horizontal extent	Assumed at 5 m^2, the actually area is ~ 3 m^2.
Depth of contamination	1 meter, likely to be very conservative.
Residual activity	Based on composite sample 180J, which was collected from the side wall and top lip of the excavation.
Cover	No cover assumed.
Note: The MARSSIM EMC approach may fundamentally fail in the case where the primary exposure pathway is direct exposure – e.g., given multiple small areas of elevated material and assuming that these areas are not directly adjoined, then the receptor is only exposed to one elevated area at any given time. Thus, in this example, adding multiple EMC dose terms (MARSSIM Equation 8-2) does not represent a realistic exposure scenario.	

Table 12. $DCGL_{EMC}$ Evaluation of the 180J Small Area of Elevated Residual Contamination

Assessment of Elevated Areas	SU1										Approximate
Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total	SOF	Net SOF	Surface Area (m^2)
WEAC-FS-SU1-180J	7.13	1.68	11.9	1.22	4.21	0.883	5.46	10.6	0.93	0.84	3.2
$C_{elevated\ area}$ (Net of Ref. Area) Activity:	6.29	0.37	11.08	0.35	3.28	0.72	4.38	8.39	0.84		
SU1 Average Net Activity (δ) (pCi/g):	0.77	0.08	1.69	0.17	0.81	0.12	0.90	1.82			
CG_W (10.4 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560			
Fraction (δ/$DCGL_W$):	0.06		0.05					0.00			
(1) $C_{elevated}$ - δ:	5.52		9.39					6.57			
AF, 5.0 m^2:	3.01		3.06					2.18			
(2) AF x DCGLw	36.2		113.0					1218			
Fraction [(1)/(2)]:	0.15		0.08					0.01			
SOF_{EMC}:	0.24										
Total SOF (DCGLw + $DCGL_{EMC}$):	0.35	A SOF < 1 is acceptable; note the SOF for the unit wide average ($DCGL_W$							0.11		
SOF in terms of Dose:	8.85	mrem/y, max dose over next 1000 years assuming MEI spends all time over the 5m^2 elevated area.									
	Notes:										
	Judgmental HOG (High outdoor gamma) elevated gamma sample, Composite sample collected from small 2 to 3m^2 hot spot.										
$\frac{\delta}{DCGL_W} + \frac{C_{elevated\ area} - \delta}{AF_{elevated\ area} x\ DCGL_W} \leq 1$	δ is residual average concentration value in the survey unit whole.										
	$C_{elevated}$ is the concentration in the elevated area										

5. SURFACES WITHIN SU1

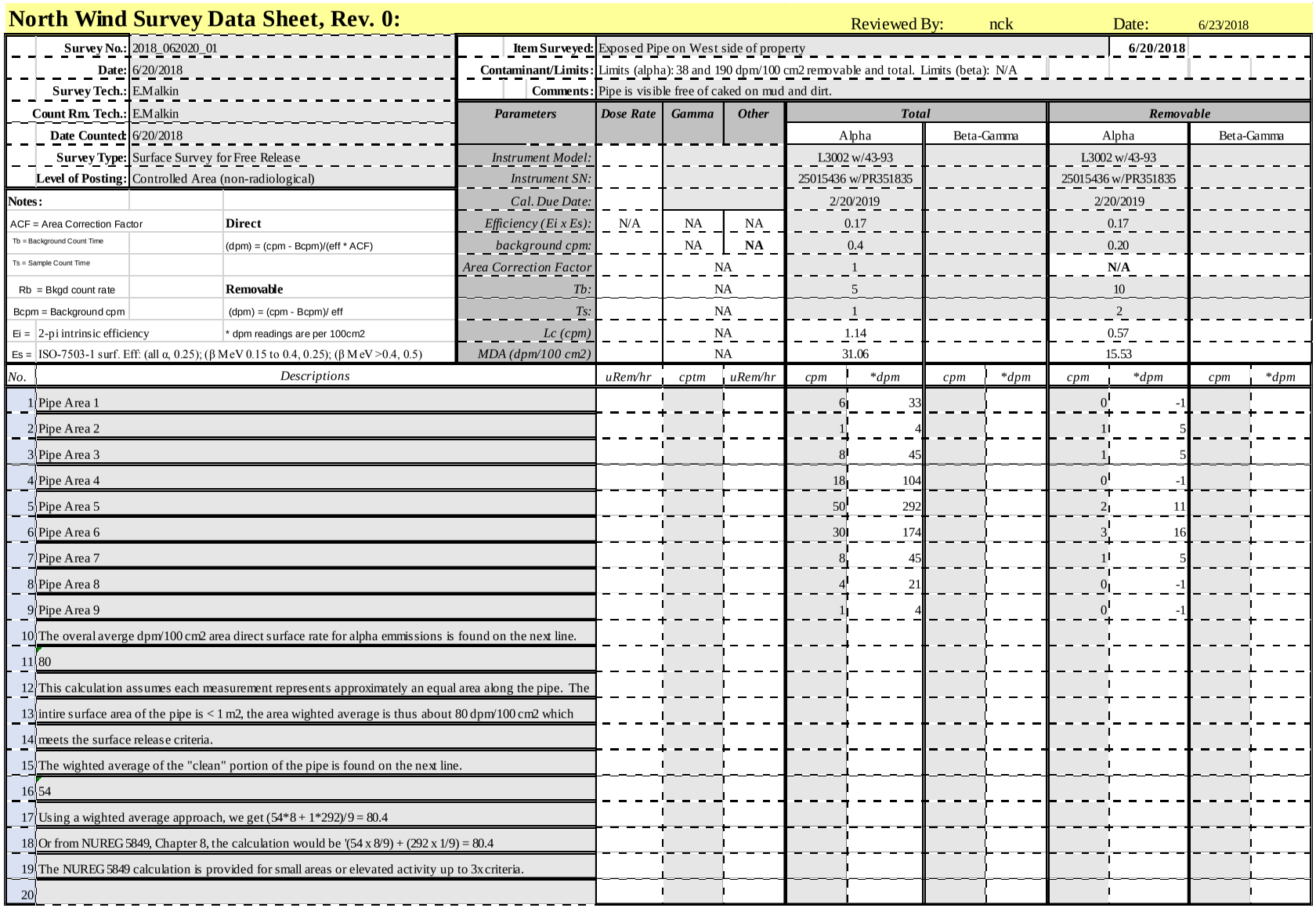
Surface criteria for the site were established recognizing that any remaining surfaces would likely be removed and discarded during future construction activities. Thus, the criteria selected is based on "unrestricted release" guidance provided in FC 83-23, Table 1, Acceptable Surface Contamination Levels (essentially equivalent to Reg. Guide 1.86 guidance). A weighted derived surface limit (in terms of alpha emissions) is developed for the site in the FSSP. The derived surface criteria is listed below:

- Average: 190 dpm/100 cm^2, alpha,
- Maximum: 570 dpm/100 cm^2, alpha, and
- Removable: 38 dpm/100 cm^2, alpha.

An abandoned 2-inch steel pipe was found just below ground surface in one of the small shallow excavations in the SW corner of SU1. The center portion of this pipe exhibited elevated surface alpha emissions; however, the average emission of the whole of the impacted area of pipe (< 1 m^2) is less than the derived surface release criteria. A photograph of the pipe and dimensional parameters are presented in **Figure 7**. The survey data sheet associated with the pipe surface survey is presented in **Figure 8**. The maximum direct surface reading was 292 dpm/100 cm^2, and the area weighted average (following NUREG 5849 methodology) was 80.4 dpm/100 cm^2. All removable results are less than the removable release criteria. The pipe surface satisfies the surface release criteria, as summarized below:

- Average activity is of 80.4 dpm/100 cm^2 is < 190 dpm/100 cm^2,
- Maximum activity of 292 dpm/100 cm^2 is < 570 dpm/100 cm^2, and
- Removable activity at all points is < 38 dpm/100 cm^2.

Figure 7. Exposed Pipe Left in SU1



North Wind Survey Data Sheet, Rev. 0:

Reviewed By: nck Date: 6/23/2018

Survey No.:	2018_062020_01	**Item Surveyed:**	Exposed Pipe on West side of property **6/20/2018**
Date:	6/20/2018	**Contaminant/Limits:**	Limits (alpha): 38 and 190 dpm/100 cm2 removable and total. Limits (beta): N/A
Survey Tech.:	E.Malkin	**Comments:**	Pipe is visible free of caked on mud and dirt.
Count Rm. Tech.:	E.Malkin		
Date Counted:	6/20/2018		
Survey Type:	Surface Survey for Free Release		
Level of Posting:	Controlled Area (non-radiological)		

Notes:

ACF = Area Correction Factor
Tb = Background Count Time
Ts = Sample Count Time
Rb = Bkgd count rate
Bcpm = Background cpm
Ei = 2-pi intrinsic efficiency
Es = ISO-7503-1 surf. Eff: (all α, 0.25); (β MeV 0.15 to 0.4, 0.25); (β MeV >0.4, 0.5)

Direct
(dpm) = (cpm - Bcpm)/(eff * ACF)

Removable
(dpm) = (cpm - Bcpm)/ eff
* dpm readings are per 100cm2

Parameters	*Dose Rate*	*Gamma*	*Other*	*Total* Alpha	*Total* Beta-Gamma	*Removable* Alpha	*Removable* Beta-Gamma
Instrument Model:				L3002 w/43-93		L3002 w/43-93	
Instrument SN:				25015436 w/PR351835		25015436 w/PR351835	
Cal. Due Date:				2/20/2019		2/20/2019	
Efficiency (Ei x Es):	N/A	NA	NA	0.17		0.17	
background cpm:		NA	**NA**	0.4		0.20	
Area Correction Factor		NA		1		**N/A**	
Tb:		NA		5		10	
Ts:		NA		1		2	
Lc (cpm)		NA		1.14		0.57	
MDA (dpm/100 cm2)		NA		31.06		15.53	

No.	Descriptions	uRem/hr	cptm	uRem/hr	cpm	*dpm	cpm	*dpm	cpm	*dpm	cpm	*dpm
1	Pipe Area 1				6	33			0	-1		
2	Pipe Area 2				1	4			1	5		
3	Pipe Area 3				8	45			1	5		
4	Pipe Area 4				18	104			0	-1		
5	Pipe Area 5				50	292			2	11		
6	Pipe Area 6				30	174			3	16		
7	Pipe Area 7				8	45			1	5		
8	Pipe Area 8				4	21			0	-1		
9	Pipe Area 9				1	4			0	-1		
10	The overal averge dpm/100 cm2 area direct surface rate for alpha emmissions is found on the next line.											
11	80											
12	This calculation assumes each measurement represents approximately an equal area along the pipe. The											
13	intire surface area of the pipe is < 1 m2, the area wighted average is thus about 80 dpm/100 cm2 which											
14	meets the surface release criteria.											
15	The wighted average of the "clean" portion of the pipe is found on the next line.											
16	54											
17	Using a wighted average approach, we get (54*8 + 1*292)/9 = 80.4											
18	Or from NUREG 5849, Chapter 8, the calculation would be '(54 x 8/9) + (292 x 1/9) = 80.4											
19	The NUREG 5849 calculation is provided for small areas or elevated activity up to 3x criteria.											
20												

Figure 8. Surface Survey Results of Exposed Pipe, SU1

Exhibit 2

Cleanup Status Report and Data Package for Survey Unit 2 Winchester Engineering and Analytical Center

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Cleanup Status Report and Data Package for Survey Unit 2 Winchester Engineering and Analytical Center 109 Holton Street Winchester, MA 01890

Revision 0

Prepared for:
Winchester Engineering and Analytical Center
Food and Drug Administration

Contract Number:
HHSF223201710022C

August 2018

North Wind Site Services
2800 Solway Road
Knoxville, TN 37931

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
AF	Area Factor
ALARA	As Low as Reasonable Achievable
bgs	below ground surface
CG	Cleanup Goal [ALARA]
CG_{EMC}	Cleanup Goal, Elevated Measurement Criteria
CG_W	Cleanup Goal, unit wide or average concentration
cpm	counts per minute
DCGL	Derived Concentration Guideline Value
$DCGL_{EMC}$	DCGL, Elevated Measurement Criteria
$DCGL_W$	DCGL, unit wide or average value criteria
EMC	Elevated Measurement Criteria
EPA	Environmental Protection Agency
FSSP	Final Status Survey Plan
GPS	Global Positioning System
HOG	High Outdoor Gamma
HSA	Historical Site Assessment
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MEI	Maximally Exposed Individual
NaI	Sodium Iodide
NRC	Nuclear Regulatory Commission
NW	Northwest
Ra-226	Radium 226
ROC	Radionuclide of Concern
SE	Southeast
SOF	Sum of Fraction
SSE	South Southeast
SU2	Survey Unit 2
Th-228	Thorium 228
Th-230	Thorium 230
Th-232	Thorium 232
UCL	Upper Confidence Level
WEAC	Winchester Engineering and Analytical Center
WRS	Wilcoxon Rank Sum

List of Symbols

δ	Unit Wide, Average Residual Activity
σ	Sigma, standard error
α	Critical Value for Wilcox Rank Sum Test
β	False negative error parameter
µ	micro (1/1,000)

List of Units

cm	centimeter
cm^2	centimeters square
cpm	counts per minute
dpm	disintegrations per minute
k	kilo, 1,000
m/second	meter per second
m^2	Meter square
mrem/hr	millirem per hour
pCi/g	pico curie per gram
uR/h	micro roentgen per hour
urem/hr	micro rem per hour

1. SURVEY UNIT 2 ASSESSMENT SUMMARY

The radiological assessment of Survey Unit 2 (SU2) indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the as low as reasonably achievable (ALARA) cleanup goal (CG_W) criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 3.23 mrem/year to the maximally exposed individual (MEI). One small elevated area remains in the far northwest (NW) corner of the unit, which meets the $DCGL_{EMC}$ limits. Extensive trenching (post remediation) performed across SU2 indicates that it is unlikely that buried contamination remains within the unit.

SU2 Summary Statistics:

- Unit Average Net Sum of Fraction (SOF) is < Unity for the $DCGL_W$ and is calculated as 0.13, resulting in a residual total effective dose estimate of 3.23 mrem/year.
- The Wilcoxon Rank Sum (WRS) test resulted in a rejection of the Null Hypothesis and its alternative, that the unit average concentration value is < $DCGL_W$, is accepted.
- Unit Elevated Measurement Criteria used in one location resulted in an estimated maximum effective dose of 20.21 mrem/year or, if averaged into the unit wide systematic average, would be 6.15 mrem/year. Thus, $DCGL_{EMC}$ limits are satisfied.
- Fifteen of 16 Systematic Samples are < Unity for the $DCGL_W$ (SOF for SU2-09 was 1.07)
- All Judgmental Trench samples are < the $DCGL_W$ and the CG_W.
- The 1-meter gamma dose rates are < the CG_W values across the entire unit except at a small elevated area in the NW corner of the unit. Here the dose rate was < 25 µR/h and thus, the ALARA dose objective is achieved.
- A retrospective calculation of the relative shift (Δ/σ) resulted in a value of 4.20 based on the systematic sample set. Since this is > the FSSP design relative shift of 1.67 this demonstrates that sample quantity is appropriate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the survey unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and its alternative (the survey unit median is less than the $DCGL_W$ criterion) is accepted. SU1 Systematic Sample Summary Data are provided in **Table 1**.

Table 1. SU2 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.88	2.08	12	0.157		
Th-230	2.30	3.14	37	0.062		
Total-U	3.51	2.22	560	0.006		
			SOF Sum:	0.23		
			SOF Ref. Area:	0.10		
			Net SOF:	0.13		
SOF in Residual Dose Terms:				**3.23**	mrem/year	

2. SURVEY UNIT 2 REMEDIATION

SU2 (**Figure 1)** is one of three Class I survey units found at the site. The survey unit contained two small concrete pads along the northern fence line and four or five mature trees in the far NW corner of the unit. The concrete was broken up and removed as residually contaminated rad-waste. The tree trunks were taken down and separated from the stumps and roots. The trunks and branches were moved out of the impacted area and left on site. The stumps and root balls were disposed of as rad-waste. Buried soil contamination was found and removed from one deep (1 to 2.0 meters below ground surface [bgs]) area in the center of the unit. The surrounding area south of this excavation was generally cleaned down to 6 to 15 cm bgs south through the southern border of the unit. A small area in the NW corner of the unit (where the trees resided) contained what appeared to be surface contamination that was built up over the years as residual soils were deposited there along with grass clippings and leaf removal efforts.

The survey unit is assessed against derived concentration guideline levels ($DCGL_W$) and, as an ALARA objective, to an additional Cleanup Goal (CG_W). The $DCGL_W$ is comparable to the Nuclear Regulatory Commission (NRC) 25 mrem/yr effective annual dose limit; the CG_W is comparable to an effective annual dose limit of 10.4 mrem/yr.

The CG_W is based upon guidance provided by the Environmental Protection Agency (EPA) in Directive No. 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Site Using the benchmark Dose Cleanup Criteria in 10 CFR 40, Appendix A, I, Criterion 6(6)*. This directive allows a site to set the dose benchmark remediation goal based on Ra-226 + Ra-228 at 5 pCi/g (surface) and 15 pCi/g (subsurface) for the cleanup of byproduct material. This approach requires licensees to calculate the potential peak effective dose equivalent (excluding radon) to an individual at the site within 1,000 years from exposure to the residual levels allowed under the radium soil standard. The radionuclides of concern (ROCs) being addressed by the Criterion 6(6) rule are thorium, natural uranium, and radium.

As the CG_W is essentially equivalent to the State's remedial dose goal, it may prove useful to the Winchester Engineering and Analytical Center (WEAC) to demonstrate performance against this objective (when practical) and thus, it is adopted as an ALARA goal. However, survey design strategy and the ultimate determination of if remedial actions have been successful are assessed against the $DCGL_W$ values. The radionuclide specific $DCGL_W$ and CG_W values are provided in **Table 2**.

Table 2. WEAC $DCGL_W$ Criteria and ALARA CG_W Values (pCi/g)

Radionuclide	**$DCGL_W$**	**ALARA CG_W**
Ra-226	12	5
Th-230	37	15.6
Total-Uranium	560	233
ALARA Dose Goal: Unit average dose rate < 16.0 µR/h with no small area > 25 µR/h.		

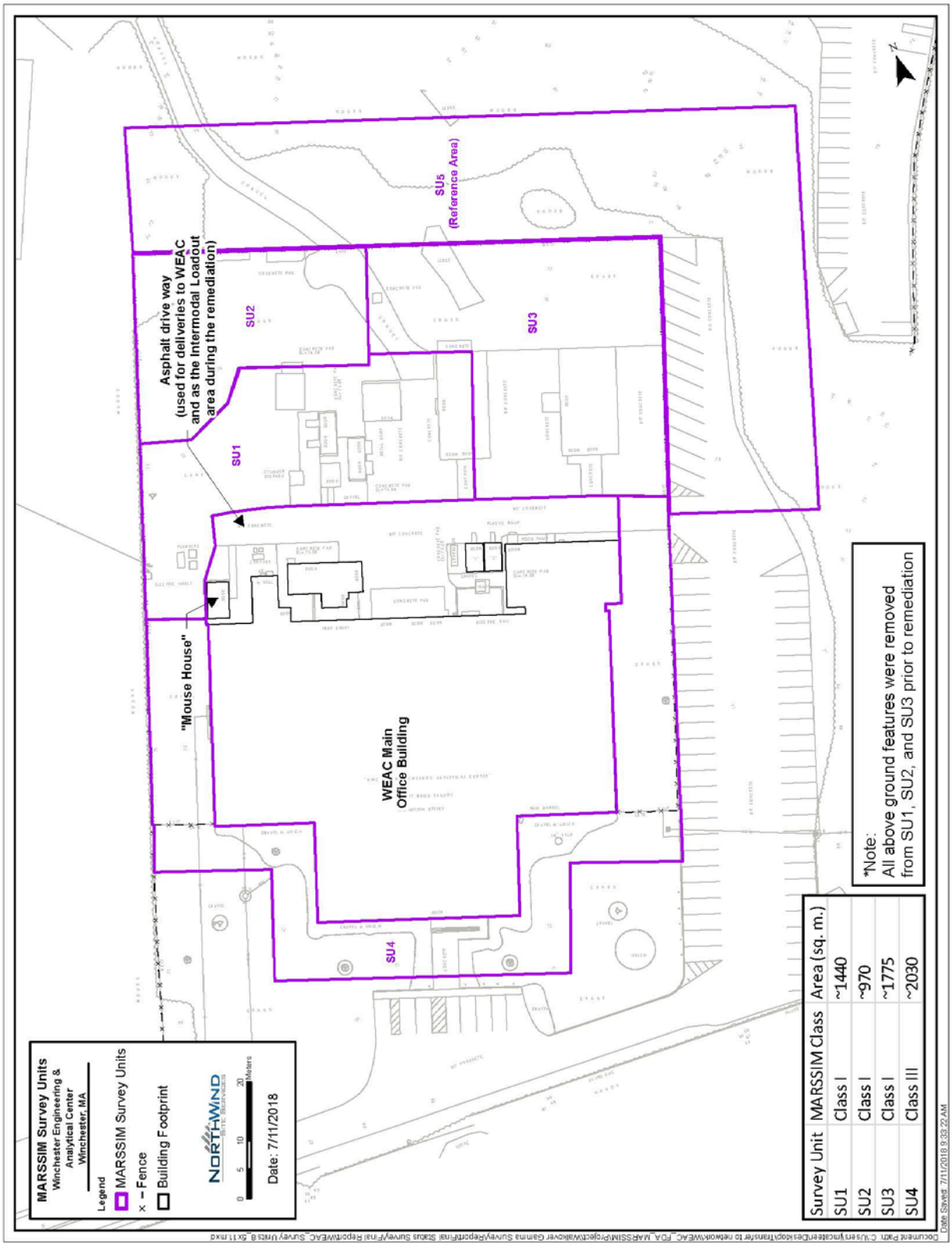

Figure 1. WEAC Survey Units

3. SURVEY UNIT 2 EVALUATION

SU2 is a 970-m^2, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Class I land area found north of the WEAC main office building. During remediation, two separate locations of contamination were found; one in the far NW corner of the unit consisted of a few yards of elevated soil material near where grass/leaf piles were staged. A relatively large area of buried contamination was found in the center of the unit, which, based upon sample results, contain buried uranium tailings. The buried material extended down approximately 1.5 to 2.5 meters in an area referred to as the "swimming pool" due to its round shape and uniform depth. The area directly south of the swimming pool excavation and running to the edge of the survey unit was remediated down to a depth of ~ 0.25 meters. Except for the grass clippings area in the NW corner of the unit, the areas east, west, and north of the swimming pool area were free of contamination.

3.1 Trenching

All areas were remediated using real-time gamma scanning (2 x 2-inch sodium iodide [NaI] detectors) to lead soil removal efforts. Soil samples were collected and analyzed on-site to determine if the survey unit was nearing the site DCGLs. Once it appeared that SU2 was free of residual contamination, trenches were dug down to approximately 1.2 meters (4 feet) bgs to ensure no additional buried material was located on site (see **Figure 2**). The trench spoils were placed next to each trench and gamma scanned for gamma anomalies. Soil samples were collected from each trench spoils pile based upon the highest outdoor gamma anomaly found – if no anomaly was found, a composite sample was collected along the length of the trench spoils. The trench spoils samples were sent off site as judgmental samples for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Trench sample results are provided in **Table 3**.

Table 3. Trench Soil Sample Results

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Tota-U
WEAC-FS-SU2-172J	1.74	1.68	2.23	1.83	2.84	0.336	4.19	7.37
WEAC-FS-SU2-074J	1.06	1.64	1.27	1.93	0.665	0.226	0.768	1.66
WEAC-FS-SU2-075J	1.39	1.31	0.736	1.25	1.73	0.392	1.12	3.24
WEAC-FS-SU2-076J	0.852	1.24	0.839	1.06	0.814	0.139	1.02	1.97
WEAC-FS-SU2-077J	0.901	2.26	0.674	1.47	1.8	0.456	1.12	3.38
WEAC-FS-SU2-081J	1.17	2.05	1.82	1.7	1.97	0.151	1.42	3.54
Sample Descriptions								
5 pt composite, SU2, Elevated spot at NW corner of fence trench								
SU2, 5 point composite (South), collected from west trench spoils hog.								
SU2, 5 point composite (North), collected from west trenh spoils HOG..								
SU2, 5 point composite (South), collected from East trench spoils HOG.								
SU2, 5 point composite (North), collected from the East Trench spoils HOG.								
SU2, 5 point composite, Southwest SU2 Trenc HOG.								

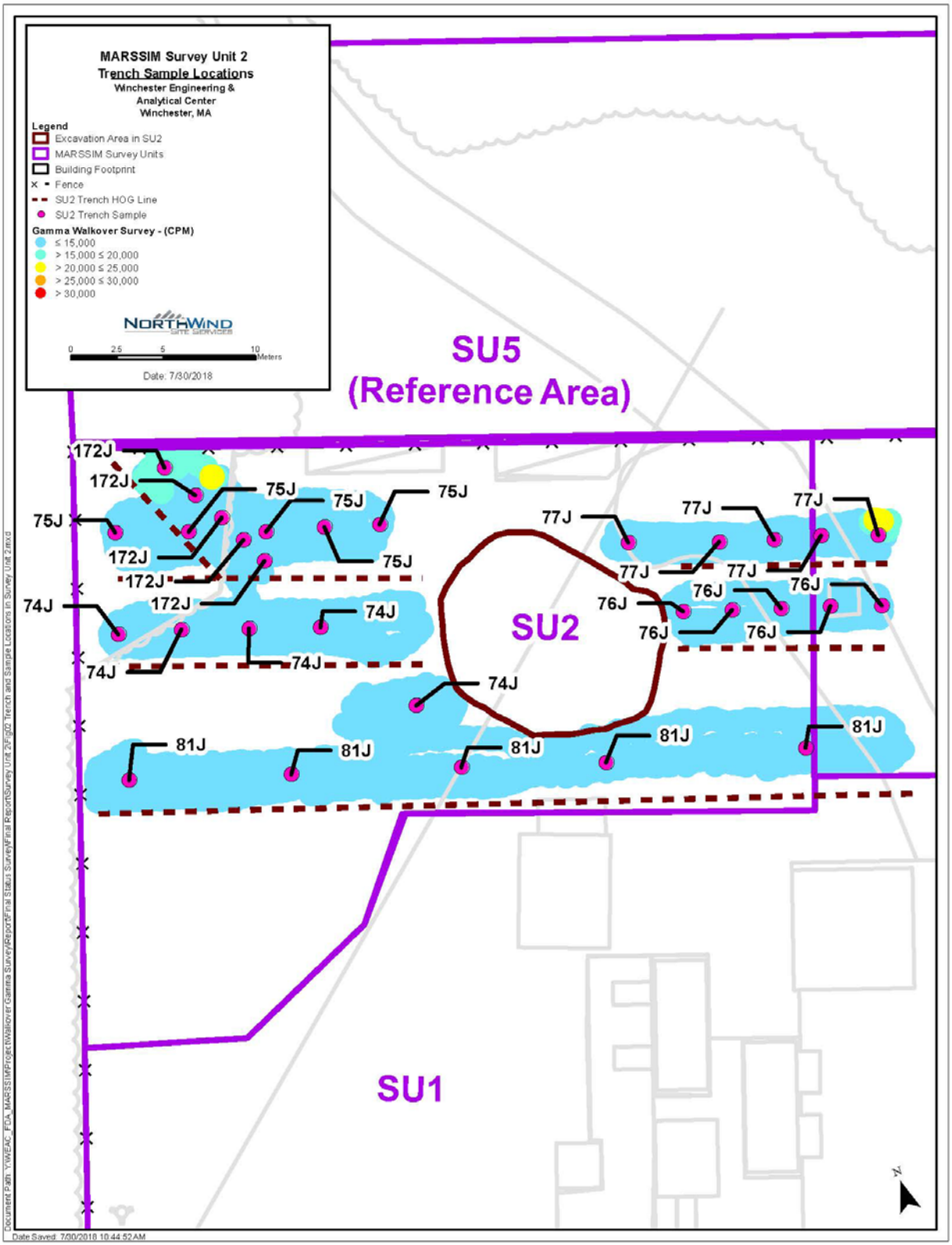

Figure 2. SU2 Trench lines, Trench Soil Sample Locations, and Excavation Area

3.2 Gamma Walkover Scanning

Global positioning system (GPS)-enabled gamma walkover scans were conducted across the survey unit as areas were cleaned and readied for final assessment. These were performed following the Final Status Survey Plan (FSSP) prepared for the site and consisted of slowly moving the NaI detector across the surface at approximately 0.5 m/second at a height of 15 cm. Scan paths were approximately 0.5 to 1.0 meters apart. All Class I units were additionally cross walked to ensure full coverage. Gamma walkover survey results are provided in **Figure 3**.

3.3 ALARA Dose Rate Assessment

Criteria dose modeling demonstrates that the primary exposure pathway is direct radiation, which contributes over 95% to dose under the most restrictive exposure scenario (used to set the $DCGL_W$ and CG_W values for each radionuclide). This includes Th-230, which reaches its maximum residual exposure at t=1,000 years. At this point, Ra-226 has significantly ingrown, which results in additional direct radiation exposure in 1,000 years but is taken into account today.

At the WEAC site, an ALARA residual dose rate goal is established at 5.2 uR/h as a unit average. This would equate to 10.4 mrem of residual exposure to an occupational outdoor worker spending 2,000 hours in the survey unit. The Reference Area (SU5) average dose rate was measured at 10.8 ± 1.3 (1σ) µR/h. Thus, the dose goal is 5.2 + 10.8, or 16 µR/h, over the whole of the survey unit with no small area exceeding 25 µR/h.

Dose rates were collected across the whole of SU2 at a height of 1 meter above the surface or from side walls in excavations. These were collected using a NaI 2 x 2-inch detector, which records penetrating radiation in counts per minute (cpm). The count rate data were converted into µR/h using the manufacture's reported nominal exposure rate response in µR/h per cpm; reported as 900 cpm/(µR/h) (Reference Ludlum Instrumentation User's Manual for the Ludlum 44-10 detector). The result of this assessment is provided in **Figure 4**. For SU2, the majority of dose rates were < 16 µR/h, the deep excavation is < 18 µR/h, and one small area (in the NW Corner of the unit) was < 22 µR/h. Thus, the direct radiation ALARA dose CG_W is achieved.

3.4 Reference Area

A Reference Area (the MARSSIM background area) was selected as the area north and east of the impacted area. The Historical Site Assessment (HSA) determined that this area was unlikely to have been impacted by site radiological operations. The Reference Area was assessed as SU5 and found to be consistent with anticipated background conditions for the Boston, MA region; average dose rates were measured at 10.8 ± 1.3 (1 σ) µR/h. Soil sample results were within anticipated background concentration levels (~ 1 ± 0.5 pCi/g) for the naturally occurring ROCs. The Reference Area average SOF against the ROCs is 0.10 ± 0.02 (1 σ). The reference area differed somewhat from the impacted survey units in that the survey unit soil consisted of more backfill material, which contained a significant fraction of large rocks (presumably relocated from an off-site backfill site).

The Reference Area is used to perform statistical tests and other comparisons to the survey unit under study when ROCs are found in natural background at significant levels in comparison to the site $DCGL_W$ values. Reference Area (SU5) sample data are provided in **Table 4**.

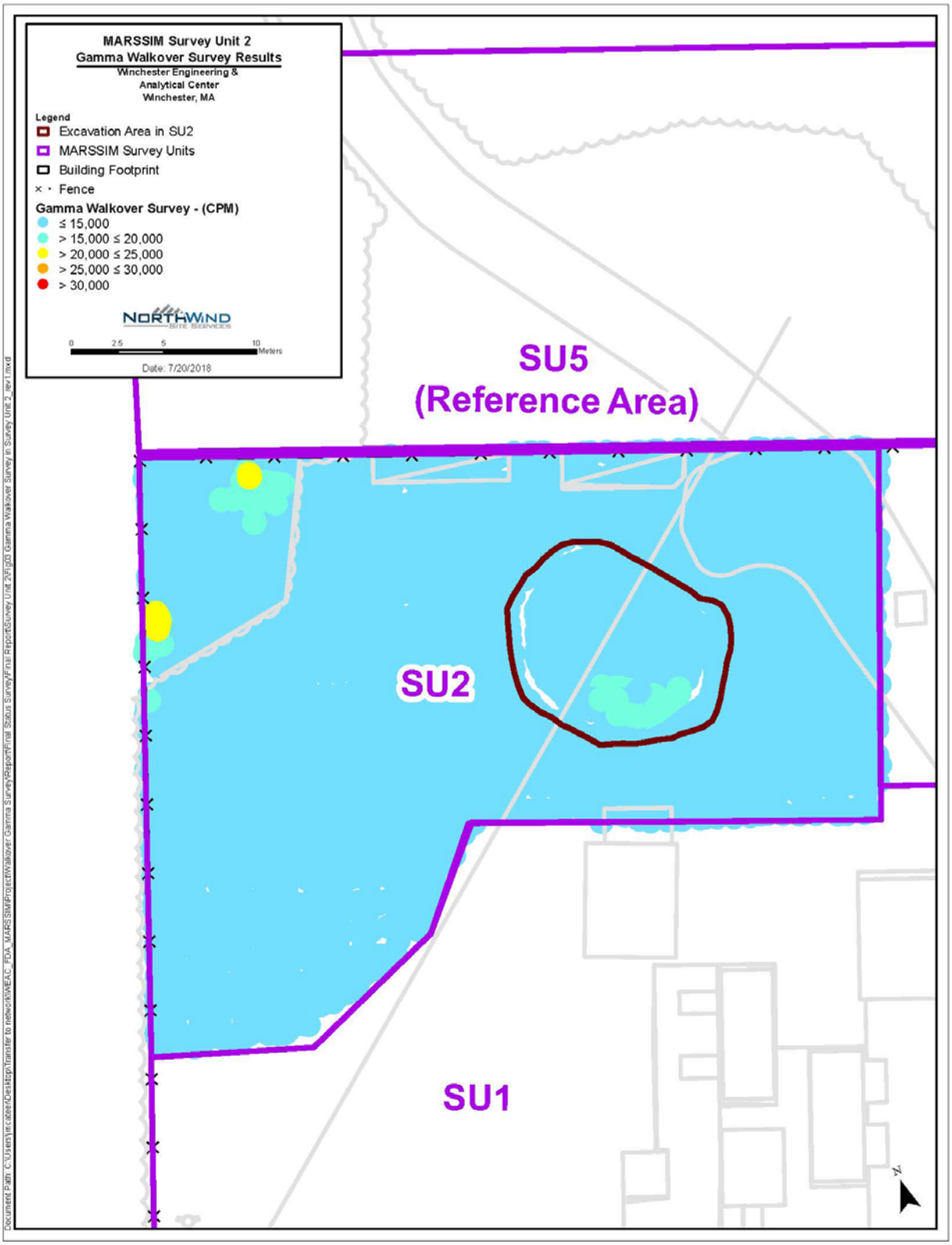

Figure 3. SU2, Gamma Detector (2 x 2 Inch, NaI) Walkover Survey Results

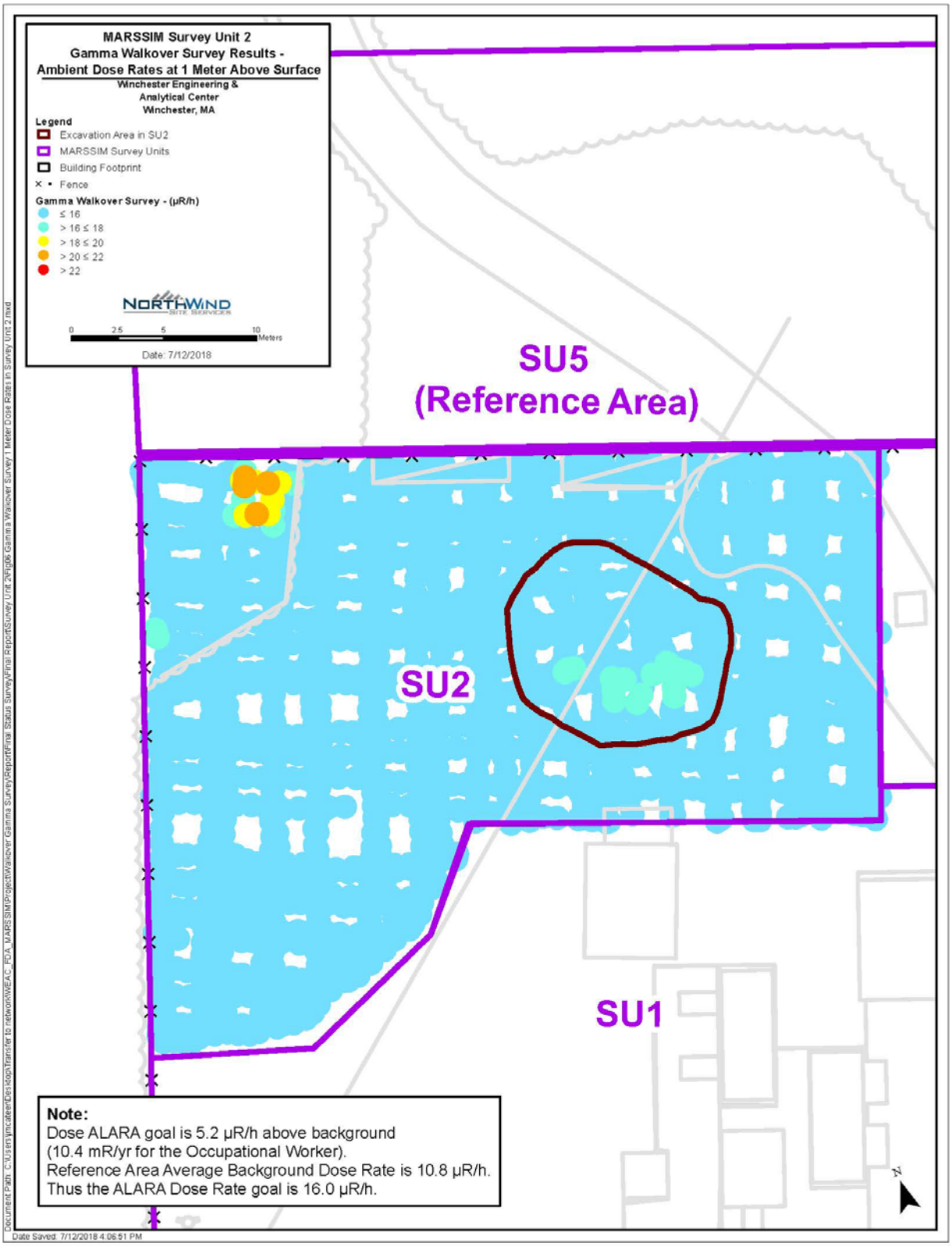

Figure 4. Dose Rate Survey Results for SU2

Table 4. Reference Area (SU5) Systematic Sample Results

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	SOF	ALPHA	BETA
WEAC-FS-SU5-1-105	1.04	1.61	0.82	0.705	0.898	0.204	1.05	2.15	0.11		
WEAC-FS-SU5-2-106	0.931	1.25	0.96	1.15	0.83	0.0584	0.965	1.85	0.11		
WEAC-FS-SU5-3-107	0.799	1.62	1.33	1.41	1.26	0.167	0.831	2.26	0.11	19.7	22.9
WEAC-FS-SU5-4-108	0.772	1.97	0.434	1.34	0.90	0.2	1.8	2.90	0.08	18.7	23.1
WEAC-FS-SU5-5-109	0.85	0.937	0.647	0.923	1.16	0.346	0.961	2.47	0.09		
WEAC-FS-SU5-6-110	0.678	1.5	0.738	0.447	0.807	0.0203	0.734	1.56	0.08		
WEAC-FS-SU5-7-111	0.768	1.3	0.928	0.821	1.04	0.0726	1.3	2.41	0.09		
WEAC-FS-SU5-8-113	0.796	1.42	0.964	0.946	1.02	0.0606	1.27	2.35	0.10	23.1	28.7
WEAC-FS-SU5-9-114	0.724	0.773	1.02	1.03	1.04	0.182	0.811	2.03	0.09		
WEAC-FS-SU5-10-115	0.721	1.49	0.613	0.598	0.507	0.335	0.736	1.58	0.08		
WEAC-FS-SU5-11-116	0.926	1.71	1.02	0.992	1.41	0.0555	1.17	2.64	0.11		
WEAC-FS-SU5-12-117	0.618	0.797	0.318	0.653	0.416	0.0782	0.879	1.37	0.06	19.8	25.6
WEAC-FS-SU5-13-118	1.22	1.14	0.895	0.998	0.935	0.24	0.664	1.84	0.13		
WEAC-FS-SU5-14-119	0.631	0.99	0.746	0.309	1.09	0.243	0.936	2.27	0.08	25.7	35.6
WEAC-FS-SU5-15-121	0.993	1.16	0.87	1.03	0.659	0.222	1.82	2.70	0.11		
WEAC-FS-SU5-16-122	1.02	1.33	0.788	0.546	0.856	0.0959	1.28	2.23	0.11	23.4	26.2
Reference Area Summary	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U		ALPHA	BETA
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	6.00	6.00
Average	0.84	1.31	0.82	0.87	0.93	0.16	1.08	2.16	0.10	21.73	27.02
SD,n-1	0.17	0.34	0.24	0.31	0.26	0.10	0.35	0.43	0.02	2.74	4.72
1.96SD,n-1	0.33	0.66	0.48	0.61	0.51	0.20	0.69	0.85	0.03	5.36	9.25
Ave + 1.96SD, n-1	1.17	1.97	1.30	1.47	1.43	0.36	1.76	3.01	0.13	27.10	36.27
Initial Assessment:	Reference Area									SOF	Net SOF
Net Residual Average Activity (pCi/g):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560		1	1
Fraction (A/CG):	0.00		0.00					0.00		0.00	0.00
SOF (CGw):	0.00										
SOF ($DCGL_W$) in terms of Dose:	0.00	mrem/y, max dose over next 1000 years									

3.5 Systematic and Judgmental Soil Sampling

Systematic soil samples were collected, based upon a random start triangular grid, to provide a non-biased statistical sample set for the survey unit wide ($DCGL_W$) evaluation. A 5-point composite sample (WEAC-FS-SU2-072J) was collected from the bottom of the swimming pool excavation following remediation. A test pit was dug to bedrock (approximately 2-feet below the remediated surface) in the center of the swimming pool excavation and a sample was collected (WEAC-FS-SU2-073J). The test pit soil sample was collected from soils just above bedrock. No water was encountered at this location. All systematic and judgmental samples were sent off site for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Additionally, four of these samples were selected for gross alpha/beta analysis. Systematic soil sample locations are provided in **Figure 5**. Judgmental soil sample locations are provided in **Figure 6**.

3.6 Systematic Soil Sample Results

Systematic samples were collected at 16 locations based upon a random start, triangular grid.
A retrospective calculation of the relative shift (Δ/σ) results in a value of 2.46; since this is > the FSSP design parameter of 1.67, this confirms that the number of samples collected is adequate to demonstrate achievement of this data quality objective. This results of this assessment are provided in **Figure 7**.

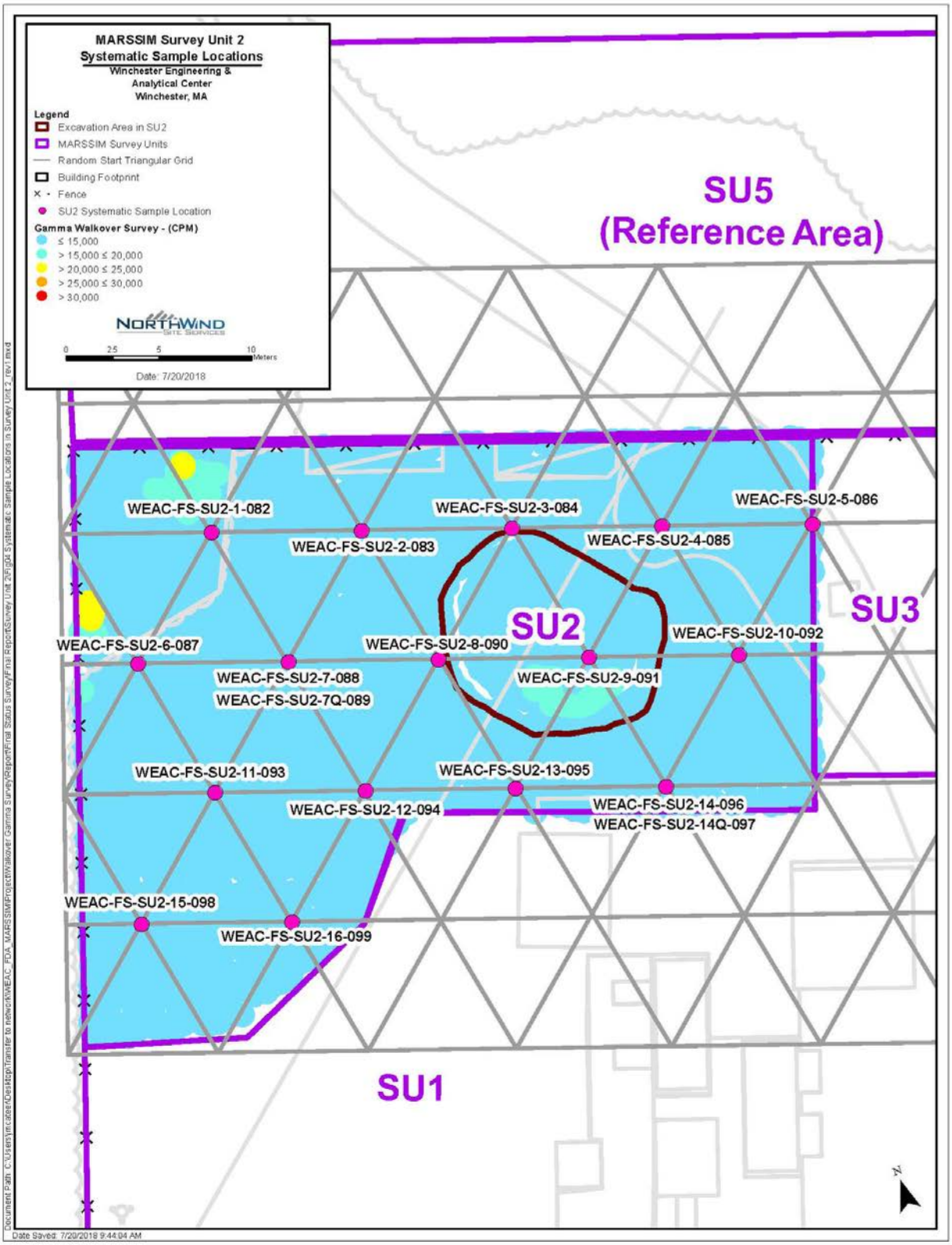

Figure 5. SU2 Systematic Soil Sample Locations

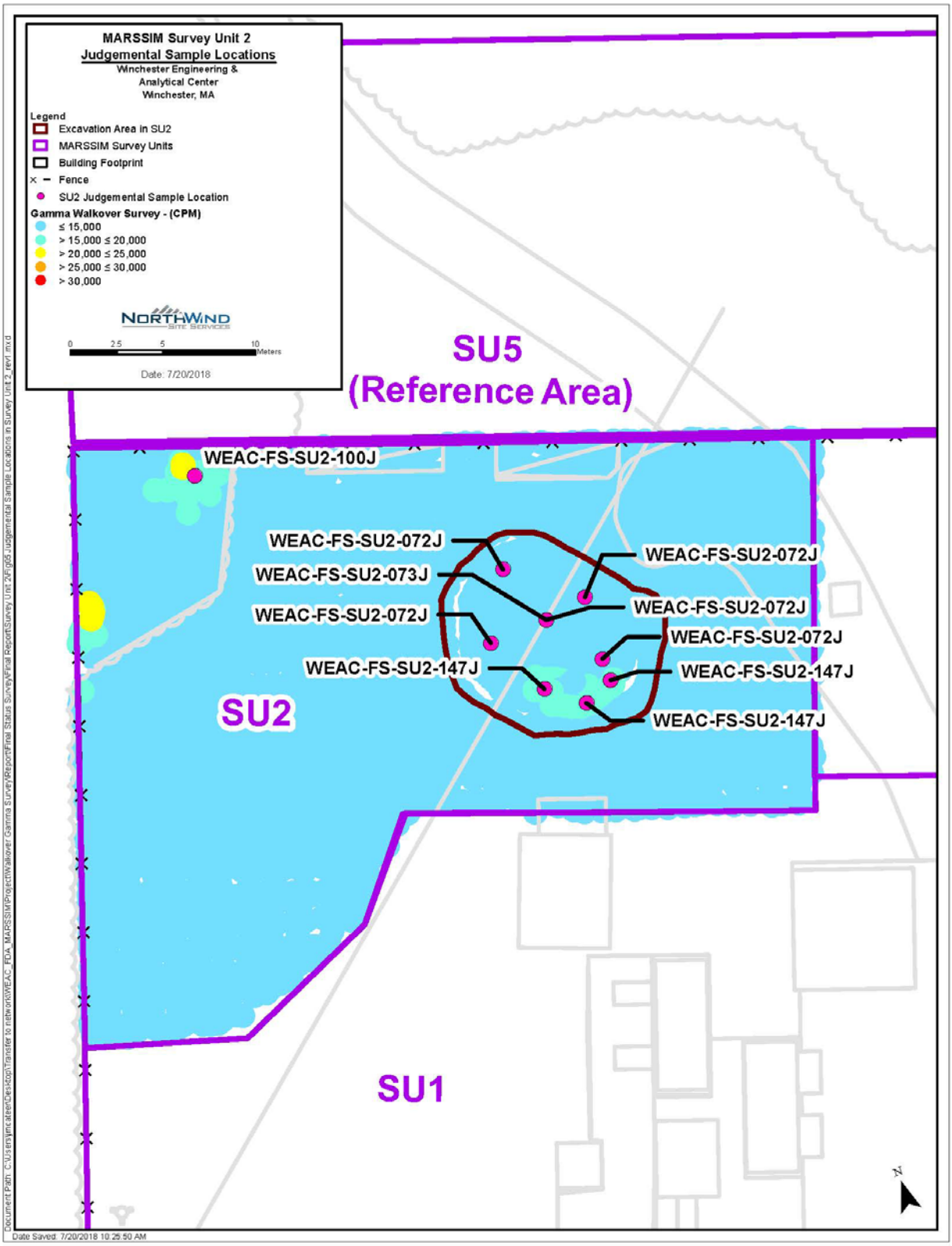

Figure 6. SU2 Judgmental Sample Locations

Post Sampling, Assessment of Sample Numbers $DCGL_W$								
	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total
(1) $(SD/DCGL_W)^2$:	*0.03*		*0.01*					*0.00*
(2) SOF $(SD/DCGL_W)^2$:	*0.04*							
Sqrt of (2):	*0.20*	*Sigma for the Weighted Sum*						
$DCGL_W$ (25 mrem/y):	12		37					560
Post Sampling, Assessment of Sample Numbers against the $DCGL_W$								
Delta = DCGLw - LBGR	0.5	Set at 1/2 the DCGLw per MARSSIM Guidance						
Sigma	0.20	Sigma for the data set, propagated error against unity						
Delta/Sigma	2.46	Relative Shift						
Decision Error	0.05	for alpha and beta errors						
Number of Sample	11	From MARSSIM Table 5.3, Values of N/2 for Use with the WRS Test						
Samples per Unit	16	Number of Samples Actually Collected per WEAC Survey Unit.						
Initial Assessment:	The number of samples collected exceeds that required based on							
	the retrospective calculation, Delta/Sigma = 2.46 which is > 1.67.							

Figure 7. Retrospective Calculation of the Required Number of MARSSIM Samples

Systematic soil sample results are provided in **Table 5**.

Table 5. SU2 Systematic Survey Sample Data

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-FS-SU2-1-082	3.62	1.54	3.84	1	1.7	0.232	1.74	3.67		
WEAC-FS-SU2-2-083	1.35	0.604	1.03	0.966	1.69	0.263	1.14	3.09		
WEAC-FS-SU2-3-084	1.13	1.74	1.61	1.29	0.829	0.0859	0.87	1.78		
WEAC-FS-SU2-4-085	1.12	1.41	0.628	0.883	1.64	0.533	2.06	4.23	30.9	28.7
WEAC-FS-SU2-5-086	1.03	0.953	0.902	1.05	1.63	0.0748	1.94	3.64		
WEAC-FS-SU2-6-087	1.5	1.62	1.26	4.99	0.902	0.175	1.29	2.37		
WEAC-FS-SU2-7-088	1.23	0.873	1.5	1.2	1.4	0.0243	0.901	2.33		
WEAC-FS-SU2-8-090	0.926	1.03	1.4	0.761	0.648	0.165	0.986	1.80	21.3	25.8
WEAC-FS-SU2-9-091	9.3	1.02	13.7	0.984	5.65	0.605	4.84	11.10		
WEAC-FS-SU2-10-092	1.28	0.765	2.09	1.11	1.48	0.00318	1.03	2.51		
WEAC-FS-SU2-11-093	1.05	1.05	1.1	1.4	0.893	0.0498	0.935	1.88		
WEAC-FS-SU2-12-094	0.897	1.64	1.23	1.61	1.3	0.204	0.678	2.18		
WEAC-FS-SU2-13-095	1.42	0.521	0.786	1.04	1.7	0.302	1.67	3.67		
WEAC-FS-SU2-14-096	1.02	1.53	1.2	0.693	1.69	0.52	1.16	3.37		
WEAC-FS-SU2-15-098	1.21	1.03	1.82	1.31	1.68	0.085	2.02	3.79		
WEAC-FS-SU2-16-099	2.07	1.28	2.73	1.08	1.97	0.26	2.56	4.79	33.8	32.9
	All results are in pCi/g									
Count	16	16	16	16	16	16	16	16	3	3
Average	1.88	1.16	2.30	1.34	1.68	0.22	1.61	3.51	28.67	29.13
Max	9.3	1.7	13.7	5.0	5.7	0.6	4.8	11.1	33.8	32.9
Min	0.9	0.5	0.6	0.7	0.6	0.0	0.7	1.8	21.3	25.8

3.7 Judgmental Design Modifications

The gamma walkover survey indicated that two small elevated areas remained in SU2 post remediation. One small area (3- or 4-m^2) was located in the NW corner of the unit, and the other was found around a large rock in the south southeast (SSE) portion of the deep excavation area (also around 3- to 4-m^2).

The NW corner elevated area was sampled as WEAC-FS-SU2-100J. Additionally, a trench was dug to confirm that buried contamination would not be found at this location (see Figure 2). This area is later assessed in Section 4.2 under the $DCGL_{EMC}$ protocol and found to meet both $DCGL_W$ and CG_W criteria. The sample results for this elevated area are provided in **Table 6**.

Table 6. Judgmental Sample from NW Corner Elevated Area, SU2

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U
	Samples collected from the NW Corner Elevated Area							
WEAC-FS-SU2-100J	18.9	1.04	24.4	1.3	9.44	0.69	9.2	19.33
Sample Description								
100J, Judgemental Sample collected from elevated spot in NW Corner of SU2								

A small, elevated area remained in the center of the excavation following remediation. This was associated with a large bolder or an up-cropping of bedrock in the southeast (SE) corner of the excavation. A 3-point composite sample (WEAC-FS-SU2-147J) was collected from the whole of the elevated area (approximately 2 to 3 m^2). A systematic sample (WEAC-FS-SU2-9-091) happened to be located in this area as well. The floor of the center excavation was sampled with a 5-point composite sample (WEAC-FS-SU2-072J). A test pit was dug down approximately 2 feet below the floor of the excavation where bedrock was encountered, and a sample was collected just above bedrock at this location (WEAC-FS-SU2-073J). The results of all samples collected from the center excavation is provided in **Table 7**. Note that the Systematic Sample (SU2-9) has a very similar activity in comparison to the composite Judgmental Sample (SU2-147J) and is thus added into and accounted for in terms of unit wide average residual exposure.

Table 7. SU2, Judgmental & Systematic Samples Collected from the Center Excavation Area

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
	Samples collected from center deep excavation									
WEAC-FS-SU2-072J	1.82	1.27	7.54	1.19	4.4	0.00372	3.35	7.75		
WEAC-FS-SU2-073J	0.757	1.55	1.03	1.74	3.77	0.428	3.76	7.96	34.7	44.7
WEAC-FS-SU2-147J	8.92	2.05	11	2.24	4.2	0.515	4.01	8.73		
WEAC-FS-SU2-9-091	9.3	1.02	13.7	0.984	5.65	0.605	4.84	11.10		
Sample Descriptions										
072J, SU2, 5 point composite collected from the bottom of the deep excavation in SU2 (from hotspot 4).										
073J, SU2, Test Pit Sample from center of center-deep-excavation. Test pit went down 2 more feet to bed rock.										
147J, SU2, 3 point composite, along SU2 Excavation, sidewall, (South Side).about 2 m2 area.										
Systematic, SU2, Location 9.										

4. ASSESSMENT RESULTS

The Reference Area average SOF (for the ROCs) in regards to the $DCGL_W$ is 0.10; this value is used to assess "net SOF" results for SU2. SU2 Th-232 and Th-228 results are compared to the Reference Area average 95% upper confidence level (UCL) to assess if these radionuclides are consistent with background; to be inconsistent with background, both Th-232 and Th-228 would need to exceed these values.

In SU2, all systematic sample results were below the $DCGL_W$. Systematic Sample SU2-09 exceeded the CG_W for Ra-226 at 9.3 pCi/g, the net SOF at this location was 1.07. All sample results are provided in **Table 8**. The average net SOF for SU2 was 0.13 (e.g., SU2 average SOF [0.23], less the Reference Area SOF [0.10], is 0.13). This results in a derived residual dose of 3.23 mrem/yr for a person working within the survey unit. Since one sample exceeded unity for the SOF, the WRS test is performed to test the rejection of the null hypothesis (**Table 9**).

No sample exceeded the Th-232/Th-228 combined background screening values for both Th-232 and Th-228 (results in red *italics*).

Table 8. SU2 Systematic Sample Results (Activity in pCi/g) and $DCGL_W$ Assessment

SU2_$DCGL_W$ Assessment	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total	SOF	Net SOF
WEAC-FS-SU2-1-082	3.62	1.54	3.84	1.00	1.7	0.232	1.74	3.67	0.41	0.32
WEAC-FS-SU2-2-083	1.35	0.604	1.03	0.966	1.69	0.263	1.14	3.09	0.15	0.05
WEAC-FS-SU2-3-084	1.13	1.74	1.61	1.29	0.829	0.0859	0.87	1.78	0.14	0.04
WEAC-FS-SU2-4-085	1.12	1.41	0.628	0.883	1.64	0.533	2.06	4.23	0.12	0.02
WEAC-FS-SU2-5-086	1.03	0.953	0.902	1.05	1.63	0.0748	1.94	3.64	0.12	0.02
WEAC-FS-SU2-6-087	1.5	1.62	1.26	*4.99*	0.902	0.175	1.29	2.37	0.16	0.07
WEAC-FS-SU2-7-088	1.23	0.873	1.5	1.2	1.4	0.0243	0.901	2.33	0.15	0.05
WEAC-FS-SU2-8-090	0.926	1.03	1.4	0.761	0.648	0.165	0.986	1.80	0.12	0.02
WEAC-FS-SU2-9-091	9.3	1.02	13.7	0.984	5.65	0.605	4.84	11.10	1.17	1.07
WEAC-FS-SU2-10-092	1.28	0.765	2.09	1.11	1.48	0.00318	1.03	2.51	0.17	0.07
WEAC-FS-SU2-11-093	1.05	1.05	1.1	1.4	0.893	0.0498	0.935	1.88	0.12	0.02
WEAC-FS-SU2-12-094	0.897	1.64	1.23	*1.61*	1.3	0.204	0.678	2.18	0.11	0.02
WEAC-FS-SU2-13-095	1.42	0.521	0.786	1.04	1.7	0.302	1.67	3.67	0.15	0.05
WEAC-FS-SU2-14-096	1.02	1.53	1.2	0.693	1.69	0.52	1.16	3.37	0.12	0.03
WEAC-FS-SU2-15-098	1.21	1.03	1.82	1.31	1.68	0.085	2.02	3.79	0.16	0.06
WEAC-FS-SU2-16-099	2.07	1.28	2.73	1.08	1.97	0.26	2.56	4.79	0.25	0.16
Radionuclide results are in pCi/g, SOF is unitless.									SOF	Net SOF
Average:	1.88	1.16	2.30	1.34	1.68	0.22	1.61	3.51	0.23	0.13
Standard Deviation:	2.08	0.38	3.14	1.00	1.13	0.19	1.02	2.22	0.26	0.26
Maximum:	9.3	1.74	13.7	4.99	5.65	0.605	4.84	11.10	1.17	1.07
Any Samples > $DCGL_W$?:	No		No					No		
Any Samples > CG_W?:	Yes		No					No		
Any Samples > Unit?:									Yes	Yes
Initial Assessment:	One sample is > Unity, conduct the WRS Test.									
	Check if a Judgmental Sample better represents location WEAC-SU2-FS-9-091.								SOF_{av}-SOF	Net SOF
SU2 Average Net Activity (δ) in pCi/g:	1.04	-0.15	1.48	0.47	0.75	0.06	0.54	1.35	0.13	0.13
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560	1	1
Fraction (δ/$DCGL_W$):	0.09		0.04					0.00	0.13	0.13
SOF ($DCGL_W$):	0.13									
SOF ($DCGL_W$) in terms of Dose:	3.23	mrem/y, max dose over next 1000 years								

Table 9. SU2 Wilcox Rank Sum Test

WRS Test, Survey Unit 2						$DCGL_W$			SOF					
			Results		12.00	37	560	SOF	Ref	SOF		RANKS	
Sample ID		Ra-226	Th-230	U-Tot	Ra-226	Th-230	U-Total	RAW	Adj	Combined	Combined	Suv	Ref
WEAC-FS-SU5-1-105	R	1.04	0.82	2.15	0.09	0.02	0.00	0.11	1.00	1.11	30		30
WEAC-FS-SU5-2-106	R	0.931	0.96	1.85	0.08	0.03	0.00	0.11	1.00	1.11	26		26
WEAC-FS-SU5-3-107	R	0.799	1.33	2.26	0.07	0.04	0.00	0.11	1.00	1.11	25		25
WEAC-FS-SU5-4-108	R	0.772	0.434	2.90	0.06	0.01	0.01	0.08	1.00	1.08	20		20
WEAC-FS-SU5-5-109	R	0.85	0.647	2.47	0.07	0.02	0.00	0.09	1.00	1.09	22		22
WEAC-FS-SU5-6-110	R	0.678	0.738	1.56	0.06	0.02	0.00	0.08	1.00	1.08	18		18
WEAC-FS-SU5-7-111	R	0.768	0.928	2.41	0.06	0.03	0.00	0.09	1.00	1.09	23		23
WEAC-FS-SU5-8-113	R	0.796	0.964	2.35	0.07	0.03	0.00	0.10	1.00	1.10	24		24
WEAC-FS-SU5-9-114	R	0.724	1.02	2.03	0.06	0.03	0.00	0.09	1.00	1.09	21		21
WEAC-FS-SU5-10-115	R	0.721	0.613	1.58	0.06	0.02	0.00	0.08	1.00	1.08	19		19
WEAC-FS-SU5-11-116	R	0.926	1.02	2.64	0.08	0.03	0.00	0.11	1.00	1.11	27		27
WEAC-FS-SU5-12-117	R	0.618	0.318	1.37	0.05	0.01	0.00	0.06	1.00	1.06	16		16
WEAC-FS-SU5-13-118	R	1.22	0.895	1.84	0.10	0.02	0.00	0.13	1.00	1.13	31		31
WEAC-FS-SU5-14-119	R	0.631	0.746	2.27	0.05	0.02	0.00	0.08	1.00	1.08	17		17
WEAC-FS-SU5-15-121	R	0.993	0.87	2.70	0.08	0.02	0.00	0.11	1.00	1.11	29		29
WEAC-FS-SU5-16-122	R	1.02	0.788	2.23	0.09	0.02	0.00	0.11	1.00	1.11	28		28
WEAC-FS-SU2-1-082	S	3.62	3.84	3.67	0.30	0.10	0.01	0.41		0.41	15	15	
WEAC-FS-SU2-2-083	S	1.35	1.03	3.09	0.11	0.03	0.01	0.15		0.15	8	8	
WEAC-FS-SU2-3-084	S	1.13	1.61	1.78	0.09	0.04	0.00	0.14		0.14	7	7	
WEAC-FS-SU2-4-085	S	1.12	0.628	4.23	0.09	0.02	0.01	0.12		0.12	3	3	
WEAC-FS-SU2-5-086	S	1.03	0.902	3.64	0.09	0.02	0.01	0.12		0.12	2	2	
WEAC-FS-SU2-6-087	S	1.5	1.26	2.37	0.13	0.03	0.00	0.16		0.16	12	12	
WEAC-FS-SU2-7-088	S	1.23	1.5	2.33	0.10	0.04	0.00	0.15		0.15	10	10	
WEAC-FS-SU2-8-090	S	0.926	1.4	1.80	0.08	0.04	0.00	0.12		0.12	4	4	
WEAC-FS-SU2-9-091	S	9.3	13.7	11.10	0.78	0.37	0.02	1.17		1.17	32	32	
WEAC-FS-SU2-10-092	S	1.28	2.09	2.51	0.11	0.06	0.00	0.17		0.17	13	13	
WEAC-FS-SU2-11-093	S	1.05	1.1	1.88	0.09	0.03	0.00	0.12		0.12	5	5	
WEAC-FS-SU2-12-094	S	0.897	1.23	2.18	0.07	0.03	0.00	0.11		0.11	1	1	
WEAC-FS-SU2-13-095	S	1.42	0.786	3.67	0.12	0.02	0.01	0.15		0.15	9	9	
WEAC-FS-SU2-14-096	S	1.02	1.2	3.37	0.09	0.03	0.01	0.12		0.12	6	6	
WEAC-FS-SU2-15-098	S	1.21	1.82	3.79	0.10	0.05	0.01	0.16		0.16	11	11	
WEAC-FS-SU2-16-099	S	2.07	2.73	4.79	0.17	0.07	0.01	0.25		0.25	14	14	
										Sum:	528	152	376
							Wr =	376					
		MARSSIM Table I.4, Critical Value, for n = 16, m = 16:							Wr > α?	Reject Null Hypothesis?			
						α	0.001	343	Yes	Yes			
						α	0.005	331	Yes	Yes			
						α	0.01	325	Yes	Yes			
						α	0.025	316	Yes	Yes			
						α	0.05	308	Yes	Yes			
						α	0.1	298	Yes	Yes			

4.1 Wilcox Rank Sum Test

In SU2, the unit net average SOF is 0.13, which indicates that the unit very likely meets criterion. However, since one systematic sample exceeded unity under the SOF rule, the WRS test is run to confirm this assumption. In this test, the combined (Reference Area + Survey Unit) results of all individual SOFs are ranked and summed. The numerical sum of the Reference Area ranks (Wr) is compared to Critical Value from MARSSIM Table I.4 at an alpha (α) error value of 0.05 (as pre-determined in the FSSP). This is shown in Table 9. Since Wr is > the Critical Value, the Null Hypothesis (that the survey unit median concentration is > the $DCGL_W$) is rejected and its alternative, that the $DCGL_W$ criterion is met, is accepted.

4.2 Elevated Measurement Assessment

No systematic and one judgmental sample exceeded the $DCGL_W$. The one judgmental sample/area exceeding the $DCLW_W$ for Ra-226 and had a Net SOF of 2.17 over what is approximately a 2 to 3-m^2 area located up in the far NW corner of the survey unit. This area is associated with soil sample WEAC-FS-SU2-100J and will be referred to as the "100J" area in this section.

The area factors associated with the $DCGL_{EMC}$ are provided in **Table 10**. These area factors are developed following the same modeling assumptions used to derive the selected $DCGL_W$ values, with only the horizontal extent of the contaminated area allowed as a variable. Notably, the depth of contamination is assumed to be 1 meter thick, which is likely to be overly conservative.

Table 10. WEAC DCGL Elevated Measurement Criteria ($DCGL_{EMC}$)

WEAC DCGL, Elevated Measurement Criteria ($DCGL_{EMC}$)								
Dose Criterion (25 mrem/y):	25		25					25
DSRs (most conservative) from initial modeling:	2.08E+00		6.66E-01					4.46E-02
Radionuclides:	**Ra-226**	**Th-228**	**Th-230**	**Th-232**	**U-234**	**U-235**	**U-238**	**U-Total**
DCGLw (25 mrem/y):	12.02	N/A	37.5	N/A	N/A	N/A	N/A	561
DSR at 10 m^2:	1.04E+00		3.28E-01					2.56E-02
DSR at 5m^2:	6.90E-01		2.18E-01	(DSRs are in mrem/yr per pCi/g)				2.05E-02
DSR at 2.5 m^2:	4.44E-01		1.41E-01					1.80E-02
DSR at 1 m^2:	2.25E-01		7.15E-02					1.54E-02
$DCGL_{EMC}$ at 10 m^2:	24.0		76.2					976.6
$DCGL_{EMC}$ at 5 m^2:	36.2		114.7	($DCGL_{EMC}$, in pC/g over the small area)				1219.5
$DCCGL_{EMC}$ at 2.5 m^2:	56.3		177.3					1388.9
$DCGL_{EMC}$ at 1 m^2:	111.1		349.7					1623.4
AF, 10 m^2:	2.0		2.0					1.7
AF, 5 m^2:	3.0		3.1	(Area Factors are unitless)				2.2
AF, 2.5 m^2:	4.7		4.7					2.5
AF, 1.0 m^2:	9.2		9.3					2.9

The elevated criteria assessment is performed following guidance from MARSSIM for when a ROC is found to be above the $DCGL_W$ for a small area in addition to the residual contamination spread uniformly across the remaining unit. In this approach, the unity rule (MARSSIM Section 4.3.3) is used to ensure that the total residual activity is within criteria. This is performed using MARSSIM Equations 8-1 and 8-2 (reproduced below). This process requires an assessment of the size of the individual elevated area relative to the survey unit size (referred to as the area factor [AF] or A_m) as a whole and the survey unit's average residual radioactive content (δ). Each elevated area is added as an additional term in Equation 8-2, and the unity rule is applied in evaluation against criteria.

$$DCGL_{EMC} = (A_m)(DCGL_W) \qquad \text{(MARSSIM Equation 8-1)}$$

$$\frac{\delta}{DCGL_W} + \frac{average\ concentration\ in\ elevated\ area - \delta}{(Area\ Factor\ for\ Elevated\ Area)(DCGL_W)} \qquad \text{(MARSSIM Equation 8-2)}$$

100J elevated area parameters are provided in **Table 11**.

The result of the elevated measurement criteria (EMC) evaluation is provided in **Table 12**. The AF-weighted SOF for the 100J area is 0.68. When added to the overall $DCGL_W$ SOF (0.13), the combined SOF is 0.81; this equates to approximately 20.21 mrem per year of residual exposure to the MEI under conservative modeling conditions.

Table 11. 100J Elevated Area Parameters

Parameter Description	Parameter
Horizontal extent	Assumed at 5 m^2, the actually area is ~ 3 m^2.
Depth of contamination	1 meter, likely to be very conservative.
Residual activity	Based on grab sample WEAC-FS-SU2-100J, which was collected from the highest outdoor gamma (HOG) that could be found at this location; thus, it is likely biased high.
Cover	No cover assumed.
Note: The MARSSIM EMC approach may fundamentally fail in the case where the primary exposure pathway is direct exposure – e.g., given multiple small areas of elevated material and assuming that these areas are not directly adjoined, then the receptor is only exposed to one elevated area at any given time. Thus, in this example, adding multiple EMC dose terms (MARSSIM Equation 8-2) does not represent a realistic exposure scenario.	

Table 12. $DCGL_{EMC}$ Evaluation of the 100J Small Area of Elevated Residual Contamination

Assessment of Elevated Areas	SU2										
Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total	SOF	Net SOF	$C_{elevated}$ Area (m^2)
WEAC-FS-SU2-100J	18.9	1.04	24.4	1.3	9.44	0.69	9.2	19.3	2.27	2.17	2 to 4
$C_{elevated}$ area (net of Ref. Area) Activity:	18.06	-0.27	23.58	0.43	8.51	0.53	8.12	17.17	2.17		
SU2 Average Net Activity (δ) in pCi/g:	1.04	-0.15	1.48	0.47	0.75	0.06	0.54	1.35			
DCGLW (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560			
Fraction (δ/$DCGL_W$):	0.09		0.04					0.00			
(1) C-elevated - δ :	17.02		22.10					15.82			
AF, 5.0 m^2:	3.01		3.06					2.18			
(2) AF x $DCGL_W$:	36.1		113.2					1221			
Fraction [(1)/(2)]:	0.47		0.20					0.01			
SOF_{EMC}:	0.68										
Total SOF ($DCGL_W$ + $DCGL_{EMC}$):	0.81	A SOF < 1 is acceptable; note the SOF for the unit wide average ($DCGL_W$) is -->							0.13		
SOF in terms of Dose:	**20.21**	mrem/y, max dose over next 1000 years assuming MEI spends all time over the 5-m^2 elevated area.									
	Notes:										
	100J, SU2, Judgmental HOG (High outdoor gamma) elevated gamma sample, Grab sample collected from small hot spot.										
	$\frac{\delta}{DCGL_W} + \frac{C_{elevated\ area} - \delta}{AF_{elevated\ area}\ x\ DCGL_W} \leq 1$								δ is residual average concentration value in the survey unit whole. $C_{elevated}$ is the concentration in the elevated area		

The results from Table 12 demonstrate that the $DCGL_W$ criterion is satisfied. The CG_W effective dose criterion for SU2 fails at this location but is achieved as a unit average (i.e., if this hot spot is conservatively assumed to occupy the same area as the other 16 systematic samples, the SOF for the unit is less than unity), as calculated below:

$$\frac{(16\ samples\ x\ 0.13) + (1\ sample\ x\ 2.17)}{17\ total\ samples} = 0.24\ or\ 6.25\ mrem/year$$

5. SURFACES WITHIN SU2

There are no surfaces within SU2.

Exhibit 3

Cleanup Status Report and Data Package for Survey Unit 3 Winchester Engineering and Analytical Center

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Cleanup Status Report and Data Package for Survey Unit 3 Winchester Engineering and Analytical Center 109 Holton Street Winchester, MA 01890

Revision 0

Prepared for:
Winchester Engineering and Analytical Center
Food and Drug Administration

Contract Number:
HHSF223201710022C

July 2018

North Wind Site Services
2800 Solway Road
Knoxville, TN 37931

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
AF	Area Factor
ALARA	As Low as Reasonable Achievable
bgs	below ground surface
CG	Cleanup Goal [ALARA]
CG_{EMC}	Cleanup Goal, Elevated Measurement Criteria
CG_W	Cleanup Goal, unit wide or average concentration
DCGL	Derived Concentration Guideline Value
$DCGL_{EMC}$	DCGL, Elevated Measurement Criteria
$DCGL_W$	DCGL, unit wide or average value criteria
EPA	Environmental Protection Agency
FS	Final Status
FSSP	Final Status Survey Plan
HOG	High Outdoor Gamma
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MEI	Maximally Exposed Individual
NaI	Sodium Iodide
NRC	Nuclear Regulatory Commission
Ra-226	Radium 226
ROC	Radionuclide of Concern
SOF	Sum of Fraction
SU3	Survey Unit 3
Th-230	Thorium 230
Tot-U	Total Uranium
UCL	Upper Confidence Level
U-Nat	Nature Uranium
U-Tot	Total Uranium
U-Total	Total Uranium
WEAC	Winchester Engineering and Analytical Center

List of Symbols

Δ	Unit Wide, Average Residual Activity
Σ	Sigma, standard error
A	Critical Value for Wilcox Rank Sum Test
B	False negative error parameter
µ	micro (1/1,000)

List of Units

cm	centimeter
cm^2	centimeters square
cpm	counts per minute
dpm	disintegrations per minute
k	kilo, 1,000
m/second	meter per second
m^2	Meter square
mrem/hr	millirem per hour
pCi/g	pico curie per gram
uR/h	micro roentgen per hour
urem/hr	micro rem per hour

1. SURVEY UNIT 3 ASSESSMENT SUMMARY

The radiological assessment of Survey Unit 3 (SU3) indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the as low as reasonably achievable (ALARA) cleanup goal (CG_W) criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 2.96 mrem/year to the maximally exposed individual (MEI). Some small, spotty, elevated areas remained following cleanup, which are adequately accounted for within the systematic sample set. Extensive trenching (post remediation) performed across SU3 indicates that it unlikely that buried contamination remains within the unit.

SU3 Summary Statistics:

- Unit Average Net Sum of Fraction (SOF) is < Unity for the $DCGL_W$ and is calculated as 0.12, resulting in a residual total effective dose estimate of 2.96 mrem/year.
- The Wilcoxon Rank Sum (WRS) was not required since all samples were < the $DCGL_W$; thus, the Null Hypothesis is rejected and its alternative, that the unit average concentration value is < $DCGL_W$, is accepted.
- All Systematic Samples are < Unity for the $DCGL_W$ (Maximum Net SOF found at systematic sample location WEAC-FS-SU3-09 at 0.46).
- All Systematic Samples are < the CG_W ALARA values.
- All Judgmental Samples are < the $DCGL_W$ and the CG_W values.
- The 1-meter gamma dose rates are < the CG_W value across the entire unit except at a few small areas where the dose rate ranged up to 20 µR/h. Thus, the ALARA objective for the unit is achieved.
- A retrospective calculation of the relative shift (Δ/σ) resulted in a value of 3.51 based on the systematic sample set. Since this is > the FSSP design relative shift of 1.67 this demonstrates that sample quantity is appropriate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the survey unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and its alternative (the survey unit median is less than the $DCGL_W$ criterion) is accepted. SU1 Systematic Sample Summary Data are provided in **Table 1**.

Table 1. SU3 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.70	1.15	12	0.142		
Th-230	2.34	4.21	37	0.063		
Total-U	5.60	1.32	560	0.010		
			SOF Sum:	0.21		
			SOF Ref. Area:	0.10		
			Net SOF:	0.12		
SOF in Residual Dose Terms:				**2.96**	mrem/year	

2. SURVEY UNIT 3 REMEDIATION

SU3 (**Figure 1)** is one of three Class I survey units found at the site. Prior to remediation, the survey unit contained a few small hot spots north of the asphalt area that appeared to be surface spills that contaminated the ground down 1 to 2 feet. Just prior to remediation, the southern half of the unit was covered in asphalt, by two 60 x 30 foot concrete pads (former East and West Warehouse), and a few smaller concrete pads just outside the warehouses. All coverings were removed prior to remediation.

A few small (a few m^2 each) elevated areas were excavated just north of the former asphalt edge. No significant additional residual contamination was found in this unit.

The survey unit is assessed against derived concentration guideline levels ($DCGL_W$) and, as an ALARA objective, to an additional Cleanup Goal (CG_W). The $DCGL_W$ is comparable to the Nuclear Regulatory Commission (NRC) 25 mrem/yr effective annual dose limit; the CG_W is comparable to an effective annual dose limit of 10.4 mrem/yr.

The CG_W is based upon guidance provided by the Environmental Protection Agency (EPA) in Directive No. 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Site Using the benchmark Dose Cleanup Criteria in 10 CFR 40, Appendix A, I, Criterion 6(6)*. This directive allows a site to set the dose benchmark remediation goal based on Ra-226 + Ra-228 at 5 pCi/g (surface) and 15 pCi/g (subsurface) for the cleanup of byproduct material. This approach requires licensees to calculate the potential peak effective dose equivalent (excluding radon) to an individual at the site within 1,000 years from exposure to the residual levels allowed under the radium soil standard. The radionuclides of concern (ROCs) being addressed by the Criterion 6(6) rule are thorium, natural uranium, and radium.

As the CG_W is essentially equivalent to the State's remedial dose goal, it may prove useful to the Winchester Engineering and Analytical Center (WEAC) to demonstrate performance against this objective (when practical) and thus, it is adopted as an ALARA goal. However, survey design strategy and the ultimate determination of if remedial actions have been successful is assessed against the $DCGL_W$ values. The radionuclide specific $DCGL_W$ and CG_W values are provided in **Table 2**.

Table 2. WEAC $DCGL_W$ Criteria and ALARA CG_W Values (pCi/g)

Radionuclide	**$DCGL_W$**	**ALARA CG_W**
Ra-226	12	5
Th-230	37	15.6
Total-Uranium	560	233
ALARA Dose Goal: Unit average dose rate < 16.0 µR/h with no small area > 25 µR/h.		

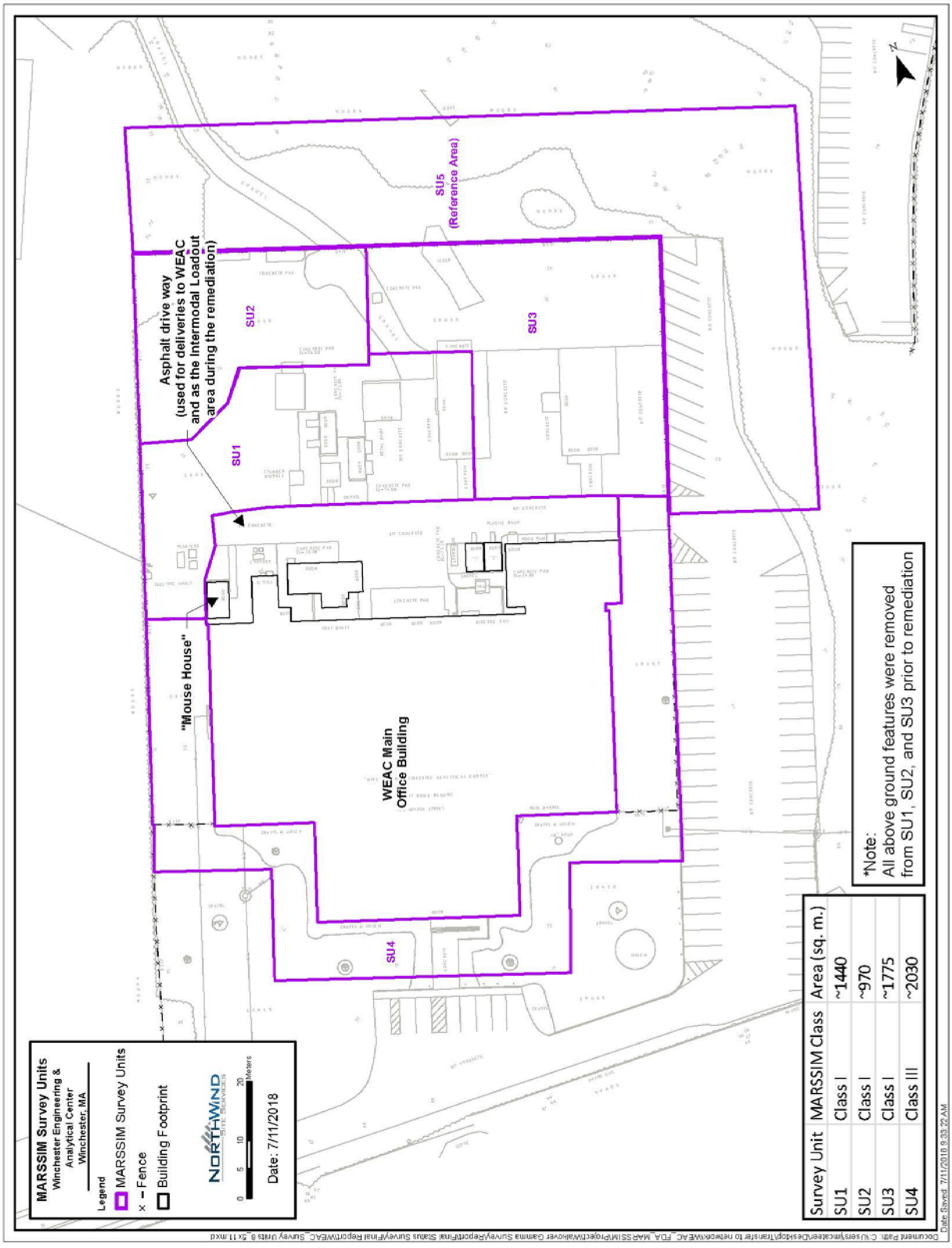

Figure 1. WEAC Survey Units

3. SURVEY UNIT 3 EVALUATION

SU3 is a 1,775-m^2, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Class I land area found north of the WEAC main office building. During remediation, two small separate locations of contamination were found – both along the northern edge of the former asphalt area.

3.1 Trenching

All areas were remediated using real-time gamma scanning (2 x 2-inch sodium iodide [NaI] detectors) to lead soil removal efforts. Soil samples were collected and analyzed on-site to determine if the survey unit was nearing the site DCGLs. Once it appeared that SU3 was free of residual contamination, trenches were dug down to approximately 1.2 meters (4 feet) below ground surface (bgs) to ensure no additional buried material was located on site (see **Figure 2**). The trench spoils were placed next to each trench and gamma scanned for gamma anomalies. Soil samples were collected from each trench spoils pile based upon the highest outdoor gamma anomaly found – if no anomaly was found, a composite sample was collected along the length of the trench spoils. The trench spoils samples were sent off site as judgmental samples for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Trench sample results are provided in **Table 3**. It should be noted the SU3-FS-SU3-049J was actually collected in what would become SU1. This spot was later remediated and a post remediation sample was collected as WEAC-FS-SU1-170.

Table 3. Trench Soil Sample Results

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-FS-SU3-049J	2.12	0.842	2.37	0.753	3.61	0.501	3.13	7.24	23.7	36.4
WEAC-FS-SU3-053J	1.03	0.392	1.44	0.493	1.85	0.415	1.6	3.87		
Sample Descriptions										
049J, SU3, 5 point composite, North Trench Spoils HOG [Note this sample location ended up more in SU1]										
SU3, 5 point composite, South Trench Spoils HOG										

3.2 Gamma Walkover Scanning

Global positioning system (GPS)-enabled gamma walkover scans were conducted across the survey unit as areas were cleaned and readied for final assessment. These were performed following the Final Status Survey Plan (FSSP) prepared for the site and consisted of slowly moving the NaI detector across the surface at approximately 0.5 m/second at a height of 15 cm. Scan paths were approximately 0.5 to 1.0 meters apart. All Class I units were additionally cross walked to ensure full coverage. Gamma walkover survey results are provided in **Figure 3**.

3.3 ALARA Dose Rate Assessment

Criteria dose modeling demonstrates that the primary exposure pathway is direct radiation, which contributes over 95% to dose under the most restrictive exposure scenario (used to set the $DCGL_W$ and CG_W values for each radionuclide). This includes Th-230, which reaches its maximum residual exposure at t=1,000 years. At this point, Ra-226 has significantly ingrown, which results in additional direct radiation exposure in 1,000 years but is taken into account today.

At the WEAC site, an ALARA residual dose rate goal is established at 5.2 uR/h as a unit average. This would equate to 10.4 mrem of residual exposure to an occupational outdoor worker spending 2,000 hours in the survey unit. The Reference Area (SU5) average dose rate was measured at 10.8 ± 1.3 (1σ) µR/h. Thus, the dose goal is 5.2 + 10.8, or 16 µR/h, over the whole of the survey unit with no small area exceeding 25 µR/h.

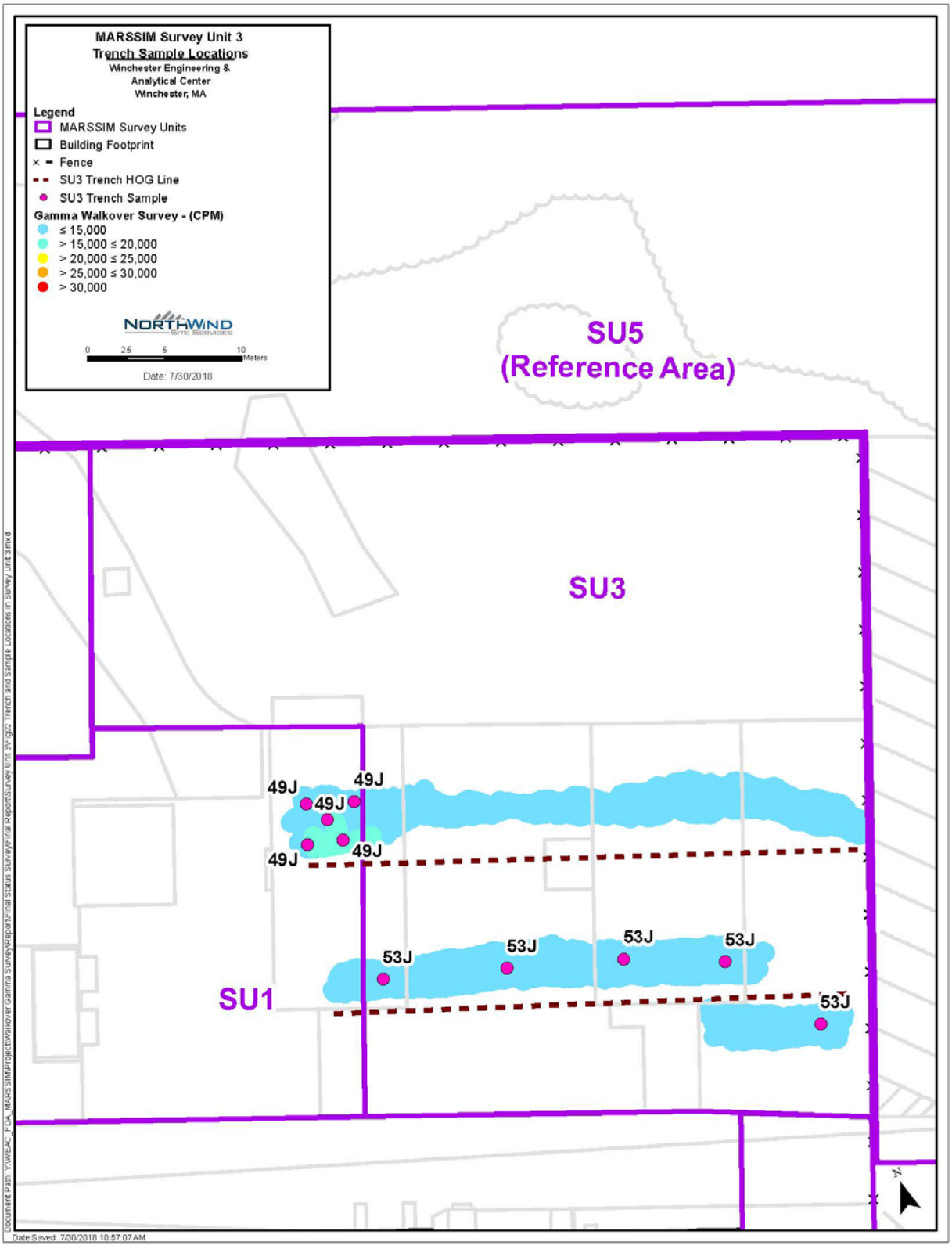

Figure 2. SU3 Trench lines and Trench Soil Sample Locations

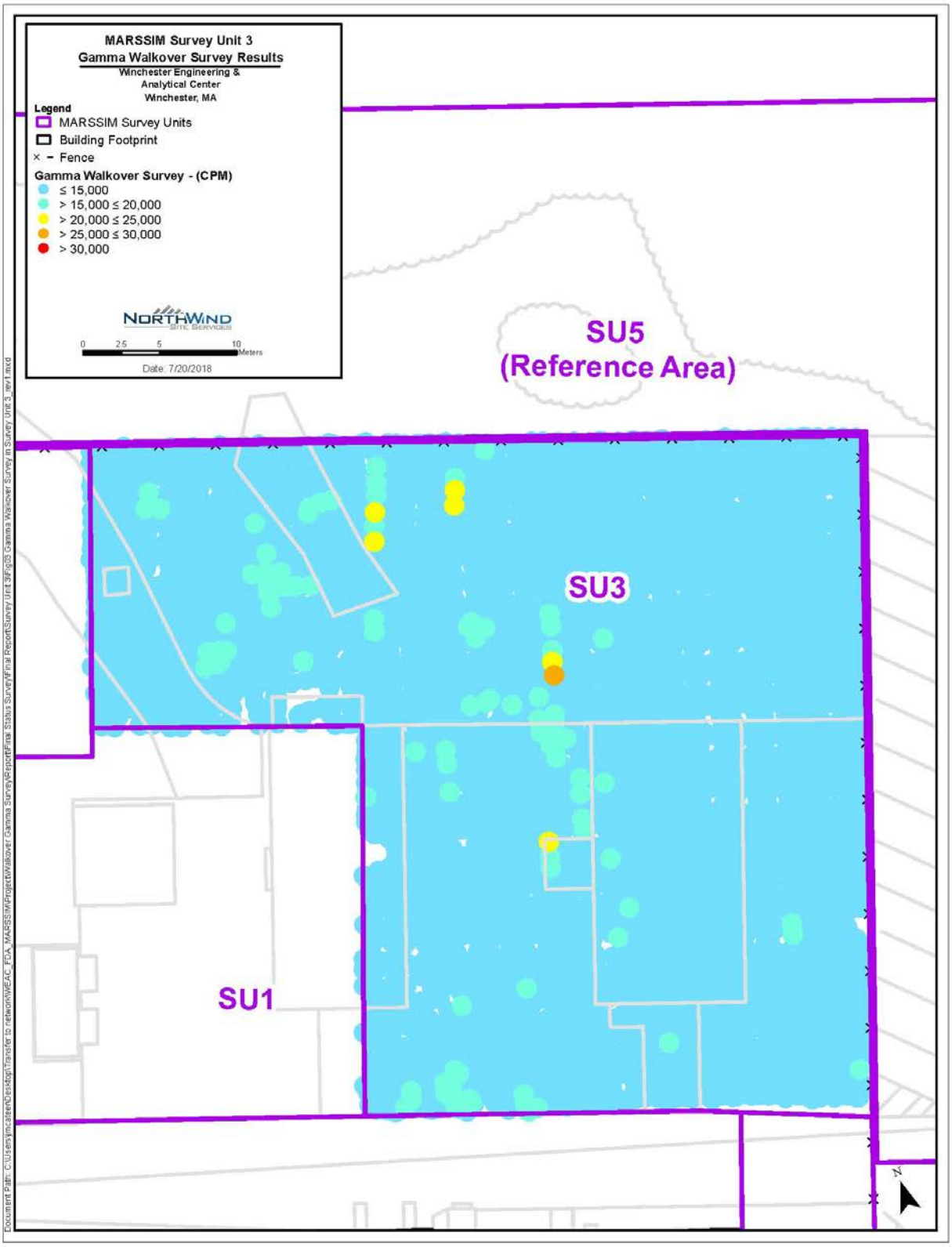

Figure 3. SU3, Gamma Detector (2 x 2 Inch, NaI) Walkover Survey Results

Dose rates were collected across the whole of SU3 at a height of 1 meter above the surface or from side walls in excavations. These were collected using a NaI 2 x 2-inch detector, which records penetrating radiation in counts per minute (cpm). The count rate data were converted into µR/h using the manufacture's reported nominal exposure rate response in µR/h per cpm; reported as 900 cpm/(µR/h) (Reference Ludlum Instrumentation User's Manual for the Ludlum 44-10 detector). The result of this assessment is provided in **Figure 4**. For SU3, the majority of dose rates were < 16 µR/h and a few small areas ranged up to < 20 µR/h; thus, the direct radiation dose CG_W is achieved.

3.4 Reference Area

A Reference Area (the MARSSIM background area) was selected as the area north and east of the impacted area. The Historical Site Assessment (HSA) determined that this area was unlikely to have been impacted by site radiological operations. The Reference Area was assessed as SU5 and found to be consistent with anticipated background conditions for the Boston, MA region; average dose rates were measured at 10.8 ± 1.3 (1 σ) µR/h. Soil sample results were within anticipated background concentration levels (~ 1 ± 0.5 pCi/g) for the naturally occurring ROCs. The Reference Area average SOF against the ROCs is 0.10 ± 0.02 (1 σ). The reference area differed somewhat from the impacted survey units in that the survey unit soil consisted of more backfill material, which contained a significant fraction of large rocks (presumably relocated from an off-site backfill site).

The Reference Area is used to perform statistical tests and other comparisons to the survey unit under study when ROCs are found in natural background at significant levels in comparison to the site $DCGL_W$ values. Reference Area (SU5) sample data are provided in **Table 4**.

Table 4. Reference Area (SU5) Systematic Sample Results

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	SOF	ALPHA	BETA
WEAC-FS-SU5-1-105	1.04	1.61	0.82	0.705	0.898	0.204	1.05	2.15	0.11		
WEAC-FS-SU5-2-106	0.931	1.25	0.96	1.15	0.83	0.0584	0.965	1.85	0.11		
WEAC-FS-SU5-3-107	0.799	1.62	1.33	1.41	1.26	0.167	0.831	2.26	0.11	19.7	22.9
WEAC-FS-SU5-4-108	0.772	1.97	0.434	1.34	0.90	0.2	1.8	2.90	0.08	18.7	23.1
WEAC-FS-SU5-5-109	0.85	0.937	0.647	0.923	1.16	0.346	0.961	2.47	0.09		
WEAC-FS-SU5-6-110	0.678	1.5	0.738	0.447	0.807	0.0203	0.734	1.56	0.08		
WEAC-FS-SU5-7-111	0.768	1.3	0.928	0.821	1.04	0.0726	1.3	2.41	0.09		
WEAC-FS-SU5-8-113	0.796	1.42	0.964	0.946	1.02	0.0606	1.27	2.35	0.10	23.1	28.7
WEAC-FS-SU5-9-114	0.724	0.773	1.02	1.03	1.04	0.182	0.811	2.03	0.09		
WEAC-FS-SU5-10-115	0.721	1.49	0.613	0.598	0.507	0.335	0.736	1.58	0.08		
WEAC-FS-SU5-11-116	0.926	1.71	1.02	0.992	1.41	0.0555	1.17	2.64	0.11		
WEAC-FS-SU5-12-117	0.618	0.797	0.318	0.653	0.416	0.0782	0.879	1.37	0.06	19.8	25.6
WEAC-FS-SU5-13-118	1.22	1.14	0.895	0.998	0.935	0.24	0.664	1.84	0.13		
WEAC-FS-SU5-14-119	0.631	0.99	0.746	0.309	1.09	0.243	0.936	2.27	0.08	25.7	35.6
WEAC-FS-SU5-15-121	0.993	1.16	0.87	1.03	0.659	0.222	1.82	2.70	0.11		
WEAC-FS-SU5-16-122	1.02	1.33	0.788	0.546	0.856	0.0959	1.28	2.23	0.11	23.4	26.2
Reference Area Summary	**Ra-226**	**Th-228**	**Th-230**	**Th-232**	**U-234**	**U-235**	**U-238**	**Total-U**		**ALPHA**	**BETA**
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	6.00	6.00
Average	0.84	1.31	0.82	0.87	0.93	0.16	1.08	2.16	0.10	21.73	27.02
SD,n-1	0.17	0.34	0.24	0.31	0.26	0.10	0.35	0.43	0.02	2.74	4.72
1.96SD,n-1	0.33	0.66	0.48	0.61	0.51	0.20	0.69	0.85	0.03	5.36	9.25
Ave + 1.96SD, n-1	1.17	1.97	1.30	1.47	1.43	0.36	1.76	3.01	0.13	27.10	36.27
Initial Assessment:	Reference Area									SOF	Net SOF
Net Residual Average Activity (pCi/g):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560		1	1
Fraction (A/CG):	0.00		0.00					0.00		0.00	0.00
SOF (CGw):	0.00										
SOF ($DCGL_W$) in terms of Dose:	0.00	mrem/y, max dose over next 1000 years									

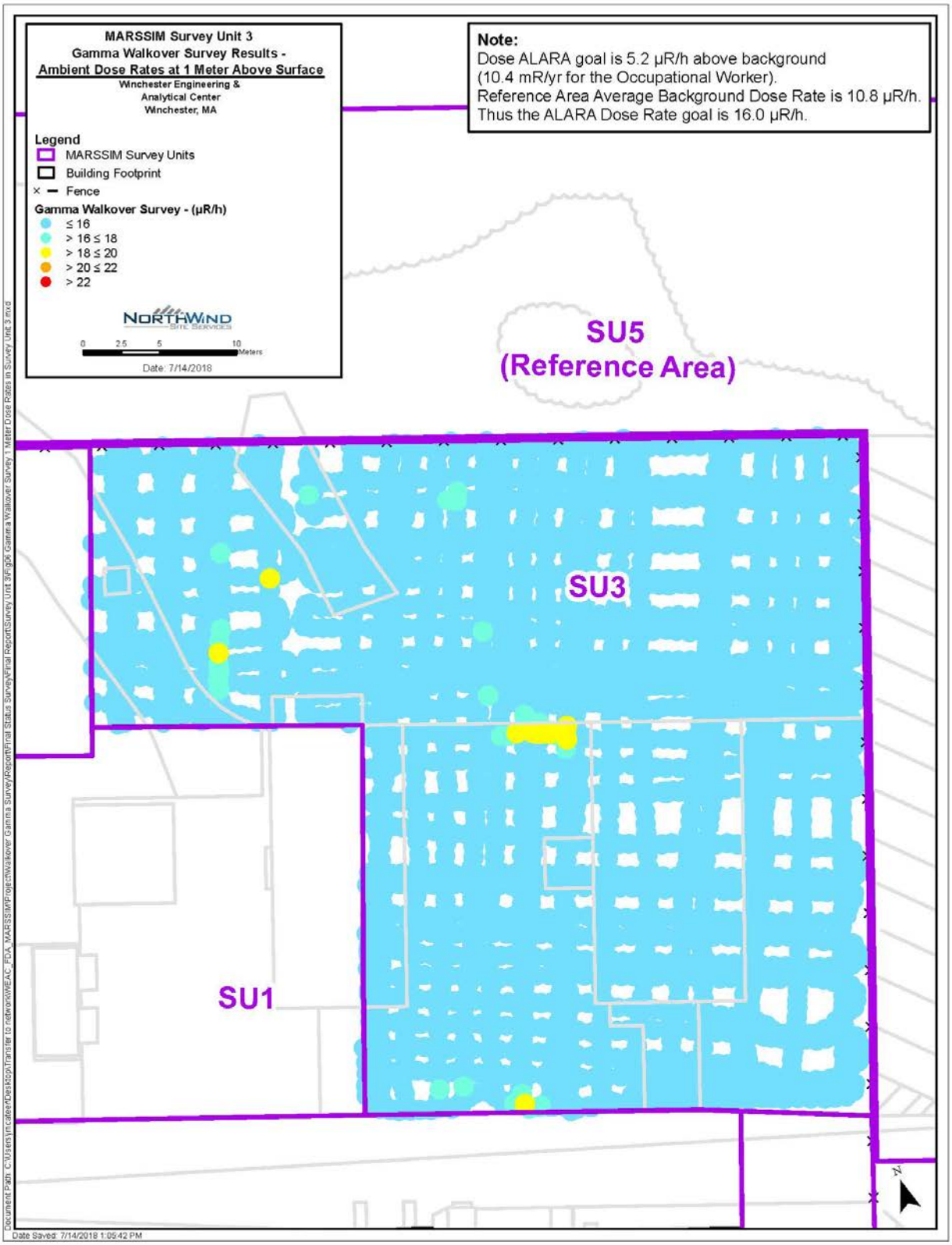

Figure 4. Dose Rate Survey Results for SU3

3.5 Systematic and Judgmental Soil Sampling

Systematic soil samples were collected, based upon a random start triangular grid, to provide a non-biased statistical sample set for the survey unit wide ($DCGL_W$) evaluation. One judgmental sample was collected from a small elevated area located in the southwest corner of the unit. A test pit was dug to bedrock (approximately 6 to 7-feet bgs) and a sample was collected in the southeast (down water-gradient) portion of the unit. The test pit soil sample was collected from soils just above bedrock; the test pit soil was saturated with "perched" water found lying on the bedrock at this location. All systematic and judgmental samples were sent off site for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Additionally, four of these samples were selected for gross alpha/beta analysis. Systematic soil sample locations are provided in **Figure 5**. Judgmental soil sample locations are provided in **Figure 6**.

3.6 Systematic Soil Sample Results

Systematic samples were collected at 16 locations based upon a random start, triangular grid.
A retrospective calculation of the relative shift (Δ/σ) results in a value of 3.51; since this is > the FSSP design parameter of 1.67, this confirms that the number of samples collected is adequate to demonstrate achievement of this data quality objective. This results of this assessment are included in **Figure 7**.

Systematic soil sample results are provided in **Table 5**.

Table 5. SU3 Systematic Survey Sample Data

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-FS-SU3-1-054	0.95	1.21	0.79	1.24	1.06	0.24	1.14	2.44		
WEAC-FS-SU3-2-055	1.63	0.99	1.12	0.47	0.93	0.32	1.38	2.63		
WEAC-FS-SU3-3-056	1.22	1.17	1.92	1.12	2.90	0.34	2.68	5.92		
WEAC-FS-SU3-4-057	4.07	0.94	5.58	1.31	5.34	0.73	4.94	11.01	50	39.7
WEAC-FS-SU3-5-058	0.88	1.33	0.94	1.11	1.73	0.59	1.15	3.47		
WEAC-FS-SU3-6-059	4.21	0.74	6.10	1.45	9.99	1.32	8.78	20.09		
WEAC-FS-SU3-7-060	3.13	1.21	4.11	1.24	6.37	0.61	4.78	11.76		
WEAC-FS-SU3-8-062	0.97	1.54	1.76	1.32	1.44	0.49	1.75	3.68	19.9	32.8
WEAC-FS-SU3-9-063	1.21	0.56	1.14	0.71	1.28	0.49	1.72	3.49		
WEAC-FS-SU3-10-064	1.54	0.71	1.56	0.95	2.32	0.57	2.22	5.11		
WEAC-FS-SU3-11-065	1.02	0.71	1.26	0.82	1.56	0.35	1.51	3.42		
WEAC-FS-SU3-12-066	1.08	0.49	1.28	1.02	1.76	0.08	1.54	3.38	18.2	31.1
WEAC-FS-SU3-13-067	0.74	0.32	0.52	0.74	0.88	0.00	1.01	1.89		
WEAC-FS-SU3-14-068	0.91	1.60	2.83	1.51	3.15	0.70	2.27	6.12		
WEAC-FS-SU3-15-070	1.04	1.17	1.31	1.52	1.19	0.90	0.71	2.79		
WEAC-FS-SU3-16-071	2.57	0.84	5.17	1.11	1.34	0.08	0.93	2.35	23.1	24.2
	All results are in pCi/g									
Count	16	16	16	16	16	16	16	16	4	4
Average	1.70	0.97	2.34	1.10	2.70	0.49	2.41	5.60	27.80	31.95
Max	4.21	1.60	6.10	1.52	9.99	1.32	8.78	20.09	50	39.7
Min	0.74	0.32	0.52	0.47	0.88	0.00	0.71	1.89	18.2	24.2

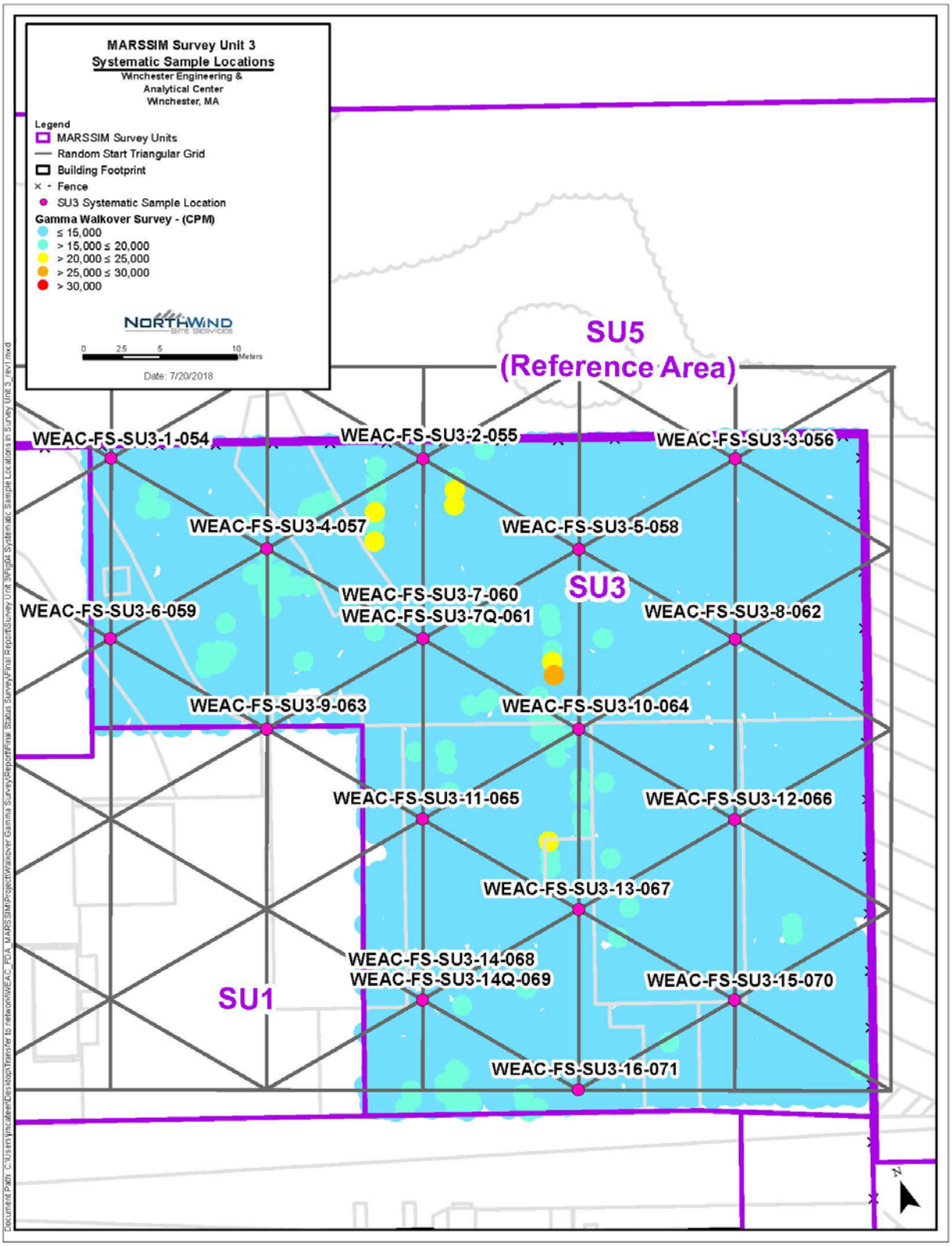

Figure 5. SU3 Systematic Soil Sample Locations

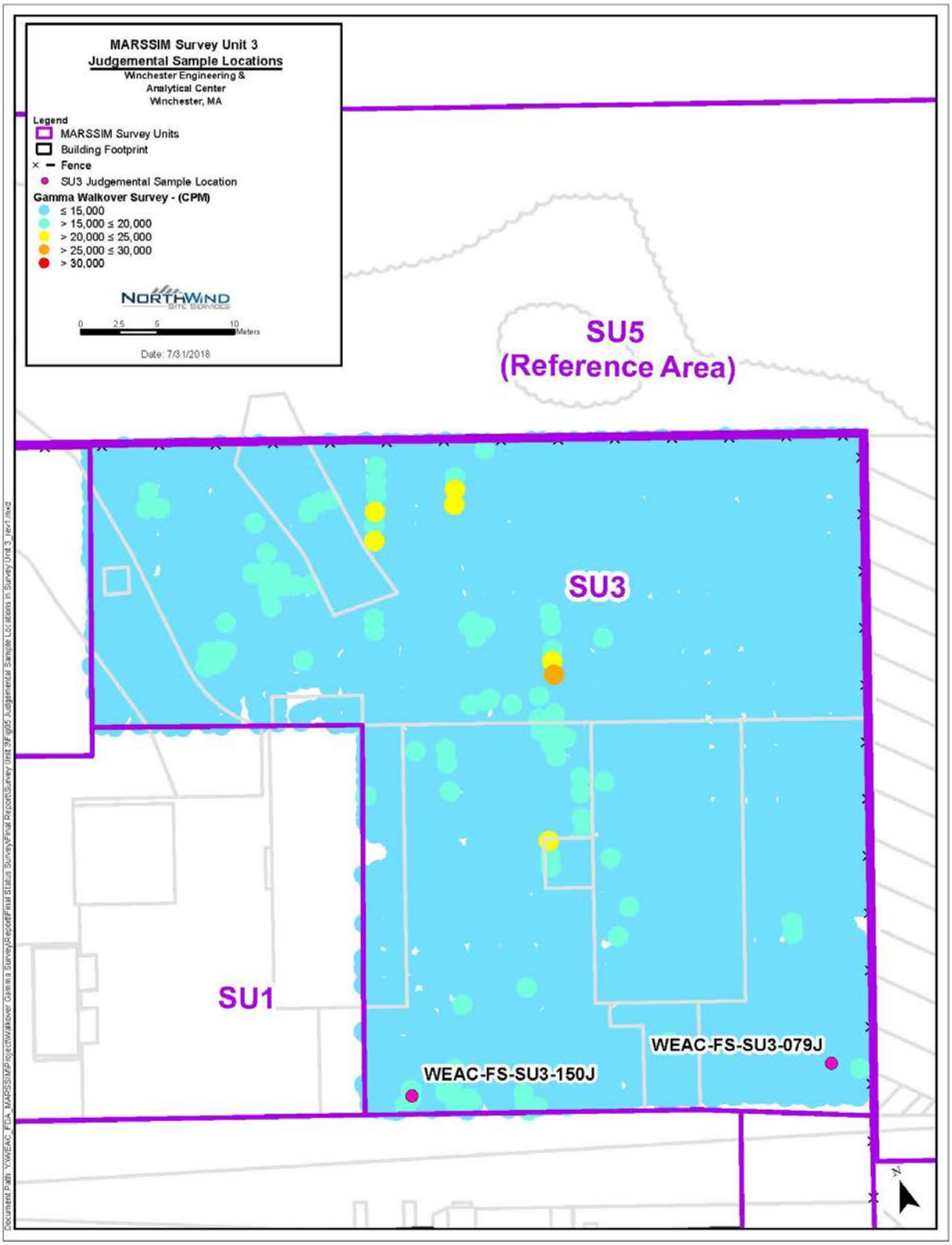

Figure 6. SU3 Judgmental Sample Locations

Post Sampling, Assessment of Sample Numbers $DCGL_W$								
	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total
(1) $(SD/DCGL_W)^2$:	*0.01*		*0.00*					*0.01*
(2) SOF $(SD/DCGL_W)^2$:	*0.02*							
Sqrt of (2):	*0.14*	*Sigma for the Weighted Sum*						
$DCGL_W$ (25 mrem/y):	12		37					560
Post Sampling, Assessment of Sample Numbers against the $DCGL_W$								
Delta = DCGLw - LBGR	0.5	Set at 1/2 the DCGLw per MARSSIM Guidance						
Sigma	0.14	Sigma for the data set, propagated error against unity						
Delta/Sigma	3.51	Relative Shift						
Decision Error	0.05	for alpha and beta errors						
Number of Sample	9	From MARSSIM Table 5.3, Values of N/2 for Use with the WRS Test						
Samples per Unit	16	Number of Samples Actually Collected per WEAC Survey Unit.						
Initial Assessment:	The number of samples collected exceeds that required based on							
	the retrospective calculation, Delta/Sigma = 3.51 which is > 1.67.							

Figure 7. Retrospective Calculation of the Required Number of MARSSIM Samples

3.7 Judgmental Design Modifications

The gamma walkover survey indicated that spotty residual contamination, at just over background, was found sporadically through the western half of the unit. Several of these small locations of contamination were excavated. One location considered to be representative of this spotty, post remediation, residual contamination was sampled as WEAC-FS-SU1-150J (see **Table 6,** note that the results are not net of background). Additionally, two parallel trenches were dug the length of the unit from East to West to confirm that buried contamination would not be found at this location (see Figure 2). A test pit was dug at a select location based at what is believed to be downgradient of ground water flow through the unit. Saturated soil was found at approximately 7 feet bgs in a location containing what is believed to be "perched" water (water trapped in a shallow indentation in the bed rock that was encountered at this location). This soil was sampled as WEAC-FS-SU3-079J (see Table 6). The judgmental sample location areas is provided in Figure 6.

Table 6. Judgmental Samples from SU3

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total
WEAC-FS-SU3-079J	0.934	1.5	0.718	0.987	0.932	0.185	0.843	1.96
WEAC-FS-SU3-150J	5.48	1.44	8.95	0.665	7.33	1.05	6.94	15.32
Sample Description								
079J, SU3, Test Pit at 7 foot below ground surface (saturated soil just above bedrock).								
150J, Grab Sample at small elevated area, post remediation								

4. ASSESSMENT RESULTS

The Reference Area average SOF (for the ROCs) in regards to the $DCGL_W$ is 0.10; this value is used to assess "net SOF" results for SU3. SU3 Th-232 and Th-228 results are compared to the Reference Area average 95% upper confidence level (UCL) to assess if these radionuclides are consistent with background; to be inconsistent with background, both Th-232 and Th-228 would need to exceed these values.

In SU3, all systematic sample results were below the $DCGL_W$ and the ALARA CG_W. Systematic Sample SU3-06 exhibited the greatest net SOF at 0.46. All sample results are provided in **Table 7**. The average net SOF for SU3 was 0.12 (e.g., SU3 average SOF [0.21], less the Reference Area SOF [0.10], is 0.12 [apparent error is due to rounding performed in excel, which is not accounted for at two decimal places, as presented in Table 7]). This resulted in a derived residual dose of 3.23 mrem/yr for a person working within the survey unit. Since no sample exceeded unity for the SOF, the WRS test unnecessary to demonstrate rejection of the null hypothesis.

No sample exceeded the Th-232/Th-228 combined background screening values for both Th-232 and Th-228 (results in red *italics*).

Table 7. SU3 Systematic Sample Results (Activity in pCi/g) and CGW Assessment

Sample_No	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total	SOF	Net SOF
WEAC-FS-SU3-1-054	0.95	1.21	0.79	1.24	1.06	0.24	1.14	2.44	0.11	0.01
WEAC-FS-SU3-2-055	1.63	0.99	1.12	0.47	0.93	0.32	1.38	2.63	0.17	0.07
WEAC-FS-SU3-3-056	1.22	1.17	1.92	1.12	2.90	0.34	2.68	5.92	0.16	0.07
WEAC-FS-SU3-4-057	4.07	0.94	5.58	1.31	5.34	0.73	4.94	11.01	0.51	0.41
WEAC-FS-SU3-5-058	0.88	1.33	0.94	1.11	1.73	0.59	1.15	3.47	0.11	0.01
WEAC-FS-SU3-6-059	4.21	0.74	6.10	1.45	9.99	1.32	8.78	20.09	0.55	0.46
WEAC-FS-SU3-7-060	3.13	1.21	4.11	1.24	6.37	0.61	4.78	11.76	0.39	0.30
WEAC-FS-SU3-8-062	0.97	1.54	1.76	1.32	1.44	0.49	1.75	3.68	0.14	0.04
WEAC-FS-SU3-9-063	1.21	0.56	1.14	0.71	1.28	0.49	1.72	3.49	0.14	0.04
WEAC-FS-SU3-10-064	1.54	0.71	1.56	0.95	2.32	0.57	2.22	5.11	0.18	0.08
WEAC-FS-SU3-11-065	1.02	0.71	1.26	0.82	1.56	0.35	1.51	3.42	0.13	0.03
WEAC-FS-SU3-12-066	1.08	0.49	1.28	1.02	1.76	0.08	1.54	3.38	0.13	0.03
WEAC-FS-SU3-13-067	0.74	0.32	0.52	0.74	0.88	0.00	1.01	1.89	0.08	-0.02
WEAC-FS-SU3-14-068	0.91	1.60	2.83	*1.51*	3.15	0.70	2.27	6.12	0.16	0.07
WEAC-FS-SU3-15-070	1.04	1.17	1.31	*1.52*	1.19	0.90	0.71	2.79	0.13	0.03
WEAC-FS-SU3-16-071	2.57	0.84	5.17	1.11	1.34	0.08	0.93	2.35	0.36	0.26
Radionuclide Results are in pCi/g, SOF is unitless									SOF	Net SOF
Average:	1.70	0.97	2.34	1.10	2.70	0.49	2.41	5.60	0.21	0.12
Standard Deviation:	1.15	0.37	1.85	0.30	2.50	0.34	2.11	4.84	0.15	0.15
Maximum:	4.21	1.6	6.1	1.52	9.99	1.32	8.78	20.09	0.55	0.46
Any Samples > $DCGL_W$:	No		No					No		
Samples > CG_W?:	No		No					No		
Any Sample > Unity?:									No	No
Initial Assessment:	Since no samples exceeded the $DCGL_W$ the WRS test is not required.								SOF_{av}-SOF_b	Net SOF
SU3 Average Net Activity (δ) in pCi/g:	0.86	-0.34	1.52	0.23	1.78	0.33	1.33	3.43	0.12	0.12
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560	1	1
Fraction (δ/$DCGL_W$):	0.07		0.04					0.01	0.12	0.12
SOF ($DCGL_W$):	0.12									
SOF ($DCGL_W$) in terms of Dose:	2.96	mrem/y, max dose over next 1000 years								

4.1 Wilcox Rank Sum Test

In SU3, the unit net average SOF is 0.12 and no sample is > the $DCGL_W$; thus, the WRS test (if performed) would obviously result in a rejection of the Null hypothesis. Therefor the Null alternative hypothesis (that the $DCGL_W$ criterion is met) is accepted.

4.2 Elevated Measurement Assessment

No systematic or judgmental sample exceeded the $DCGL_W$. Four of the systematic samples exceeded 20% of the $DCGL_W$ as a net SOF. These four samples reasonably account for the remaining low level of spotty, above background contamination, which may remain within the unit; thus, no individual elevated measurement criteria (EMC) assessments are performed.

5. SURFACES WITHIN SU3

There are no surfaces within SU3.

Exhibit 4

Cleanup Status Report and Data Package for Survey Unit 4 Winchester Engineering and Analytical Center

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Cleanup Status Report and Data Package for Survey Unit 4 Winchester Engineering and Analytical Center 109 Holton Street Winchester, MA 01890

Revision 0

Prepared for:
Winchester Engineering and Analytical Center
Food and Drug Administration

Contract Number:
HHSF223201710022C

July 2018

North Wind Site Services
2800 Solway Road
Knoxville, TN 37931

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ALARA	As Low as Reasonable Achievable
bgs	below ground surface
CG	Cleanup Goal [ALARA]
CG_{EMC}	Cleanup Goal, Elevated Measurement Criteria
CG_W	Cleanup Goal, unit wide or average concentration
cpm	counts per minute
DCGL	Derived Concentration Guideline Value
$DCGL_{EMC}$	DCGL, Elevated Measurement Criteria
$DCGL_W$	DCGL, unit wide or average value criteria
EPA	Environmental Protection Agency
FSSP	Final Status Survey Plan
GPS	Global Positioning System
HSA	Historical Site Assessment
MARSSIM	Multi-Agency Radiation survey and site Investigation Manual
MEI	Maximally Exposed Individual
NaI	Sodium Iodide
NRC	Nuclear Regulatory Commission
Ra-226	Radium 226
ROC	Radionuclide of Concern
SOF	Sum of Fraction
SU4	Survey Unit 4
Th-228	Thorium 228
Th-230	Thorium 230
Th-232	Thorium 232
UCL	Upper Confidence Level
WEAC	Winchester Engineering and Analytical Center
WRS	Wilcoxon Rank Sum

List of Symbols

δ	Unit Wide, Average Residual Activity
σ	Sigma, standard error
α	Critical Value for Wilcox Rank Sum Test
β	False negative error parameter
μ	micro (1/1,000)

List of Units

cm	centimeter
cm^2	centimeters square
cpm	counts per minute
dpm	disintegrations per minute
k	kilo, 1,000
m/second	meter per second
m^2	Meter square
mrem/hr	millirem per hour
pCi/g	pico curie per gram
uR/h	micro roentgen per hour
urem/hr	micro rem per hour

1. SURVEY UNIT 4 ASSESSMENT SUMMARY

The radiological assessment of Survey Unit 4 (SU4) indicates that the unit meets the 25 mrem/year $DCGL_W$ remediation criterion. Additionally, the as low as reasonably achievable (ALARA) cleanup goal (CG_W) criterion of 10.4 mrem/yr has also been achieved. The average residual total effective dose for the unit is calculated at 1.34 mrem/year to the maximally exposed individual (MEI). No contamination was encountered in SU4 during remediation and is considered a non-impacted unit; the unit is surveyed for informational purposes only.

SU4 Summary Statistics:

- Unit Average Net Sum of Fraction (SOF) is < Unity for the $DCGL_W$ and is calculated as 0.05, resulting in a residual total effective dose estimate of 1.34 mrem/year.
- The Wilcoxon Rank Sum (WRS) was not required since all samples were < the DCGLW; thus, the Null Hypothesis is rejected and its alternative, that the survey unit median concentration value is < $DCGL_W$, is accepted.
- All Systematic Samples are < Unity for the $DCGL_W$ (Maximum Net SOF found at systematic sample location WEAC-FS-SU4-06 at 0.12).
- All Systematic Samples are < the CG_W ALARA values.
- All Judgmental Samples are < the $DCGL_W$ and the CG_W values.
- The 1-meter gamma dose rates are < the CG_W value across the entire unit except up against the brick building (higher natural background) where a few locations range up to 22 µR/h. Thus, the ALARA objective for the unit is achieved.
- A retrospective calculation of the relative shift (Δ/σ) resulted in a value of 9.8 based on the systematic sample set. Since this is > the FSSP design relative shift of 1.67 this demonstrates that sample quantity is appropriate to assess results with adequate statistical power.

All collected and assessed evidence indicates that the Null Hypothesis (that the survey unit median concentration exceeds the $DCGL_W$ criterion) should be rejected and its alternative (the survey unit median is less than the $DCGL_W$ criterion) is accepted. SU1 Systematic Sample Summary Data are provided in **Table 1**.

Table 1. SU4 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	1.14	0.16	12	0.095		
Th-230	1.82	1.47	37	0.049		
Total-U	2.92	0.60	560	0.005		
			SOF Sum:	0.15		
			SOF Ref. Area:	0.10		
			Net SOF:	0.05		
SOF in Residual Dose Terms:				**1.34**	mrem/year	

2. SURVEY UNIT 4 REMEDIATION

SU4 (**Figure 1)** is designated as a Class III Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) unit (non-impacted) surveyed for informational purposes. The Unit was surveyed using Class I protocols (100% gamma scan) since this was convenient to perform with little additional effort. No remediation was performed in the unit. Two test pits, one on the East and West sides of the main office building, were dug and sampled for informational purposes. The unit radionuclide activity averages vary slightly from the background reference unit averages; however, this may be more indicative of differing background soils than evidence of residual contamination. The unit appears to exhibit a relatively elevated Th-232 background in the absence of elevated Th-228 levels (which should be in equilibrium with Th-232). It is also noted that Th-228 levels closely correspond to the reference unit levels. Natural residual thorium, resulting from historical operations, would exhibit activity levels of these two radioisotopes in equilibrium (T-1/2 of Th-228 is 1.91 years); thus, the difference may be indicative of a slight analysis bias for one isotope over the other.

The survey unit is assessed against derived concentration guideline levels ($DCGL_W$) and, as an ALARA objective, to an additional Cleanup Goal (CG_W). The $DCGL_W$ is comparable to the Nuclear Regulatory Commission (NRC) 25 mrem/yr effective annual dose limit; the CG_W is comparable to an effective annual dose limit of 10.4 mrem/yr.

The CG_W is based upon guidance provided by the Environmental Protection Agency (EPA) in Directive No. 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Site Using the benchmark Dose Cleanup Criteria in 10 CFR 40, Appendix A, I, Criterion 6(6)*. This directive allows a site to set the dose benchmark remediation goal based on Ra-226 + Ra-228 at 5 pCi/g (surface) and 15 pCi/g (subsurface) for the cleanup of byproduct material. This approach requires licensees to calculate the potential peak effective dose equivalent (excluding radon) to an individual at the site within 1,000 years from exposure to the residual levels allowed under the radium soil standard. The radionuclides of concern (ROCs) being addressed by the Criterion 6(6) rule are thorium, natural uranium, and radium.

As the CG_W is essentially equivalent to the State's remedial dose goal, it may prove useful to the Winchester Engineering and Analytical Center (WEAC) to demonstrate performance against this objective (when practical) and thus, it is adopted as an ALARA goal. However, survey design strategy and the ultimate determination of if remedial actions have been successful are assessed against the $DCGL_W$ values. The radionuclide specific $DCGL_W$ and CG_W values are provided in **Table 2**.

Table 2. WEAC $DCGL_W$ Criteria and ALARA CG_W Values (pCi/g)

Radionuclide	**$DCGL_W$**	**ALARA CG_W**
Ra-226	12	5
Th-230	37	15.6
Total-Uranium	560	233
ALARA Dose Goal: Unit average dose rate < 16.0 µR/h with no small area > 25 µR/h.		

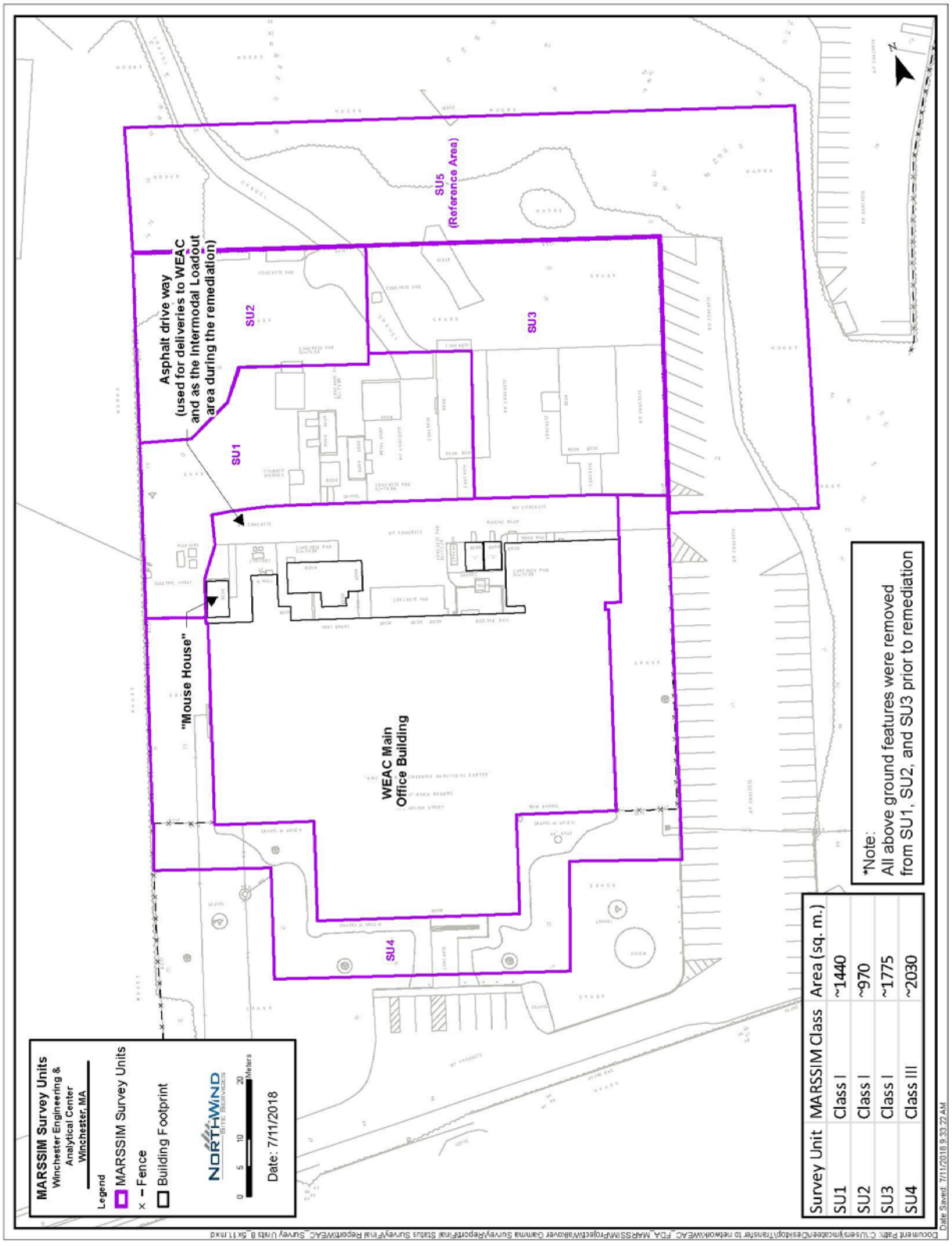

Figure 1. WEAC Survey Units

3. SURVEY UNIT 4 EVALUATION

SU4 is a 2,030-m^2, MARSSIM Class III land area that surrounds three sides of the WEAC main office building. No residual contamination was encountered within the unit. Dose rates collected at 1-meter above ground surfaces exhibit normal anticipated variations in background due to the presence of the brick office building (brick will often exhibit higher background dose levels compared to natural soils), and due to geometric variations between the source (walls and wall-corners vs open ground) and the detector.

3.1 Trenching and Test Pits

No trenching was performed in SU4. Two test pits were dug to 4 feet below ground surface (bgs); one on the east and one on the west side of the building. A 4-point composite sample was collected from the bottom of each of these test pits. The results of these samples are discussed later in this document.

3.2 Gamma Walkover Scanning

Global positioning system (GPS)-enabled gamma walkover scans were conducted across the survey unit as areas were readied for final assessment. These were performed following the Final Status Survey Plan (FSSP) prepared for the site and consisted of slowly moving the sodium iodide (NaI) detector across the surface at approximately 0.5 m/second at a height of 15 cm. Scan paths were approximately 0.5 to 1.0 meters apart. The unit was additionally cross walked to ensure full coverage. Gamma walkover survey results are provided in **Figure 2**.

3.3 ALARA Dose Rate Assessment

Criteria dose modeling demonstrates that the primary exposure pathway is direct radiation, which contributes over 95% to dose under the most restrictive exposure scenario (used to set the $DCGL_W$ and CG_W values for each radionuclide). This includes Th-230, which reaches its maximum residual exposure at t=1,000 years. At this point, Ra-226 has significantly ingrown, which results in additional direct radiation exposure in 1,000 years but is taken into account today.

At the WEAC site, an ALARA residual dose rate goal is established at 5.2 uR/h as a unit average. This would equate to 10.4 mrem of residual exposure to an occupational outdoor worker spending 2,000 hours in the survey unit. The Reference Area (SU5) average dose rate was measured at 10.8 ± 1.3 (1σ) µR/h. Thus, the dose goal is 5.2 + 10.8, or 16 µR/h, over the whole of the survey unit with no small area exceeding 25 µR/h.

Dose rates were collected across the whole of SU4 at a height of 1 meter above the surface or from side walls of the main office building. These were collected using a NaI 2 x 2-inch detector, which records penetrating radiation in counts per minute (cpm). The count rate data were converted into µR/h using the manufacture's reported nominal exposure rate response in µR/h per cpm; reported as 900 cpm/(µR/h) (Reference Ludlum Instrumentation User's Manual for the Ludlum 44-10 detector). The result of this assessment is provided in **Figure 3**. For SU4, the majority of dose rates were < 16 µR/h, and a few small areas ranged up to < 22 µR/h up near the brick walls of the main office building; thus, the direct radiation dose CG_W is achieved.

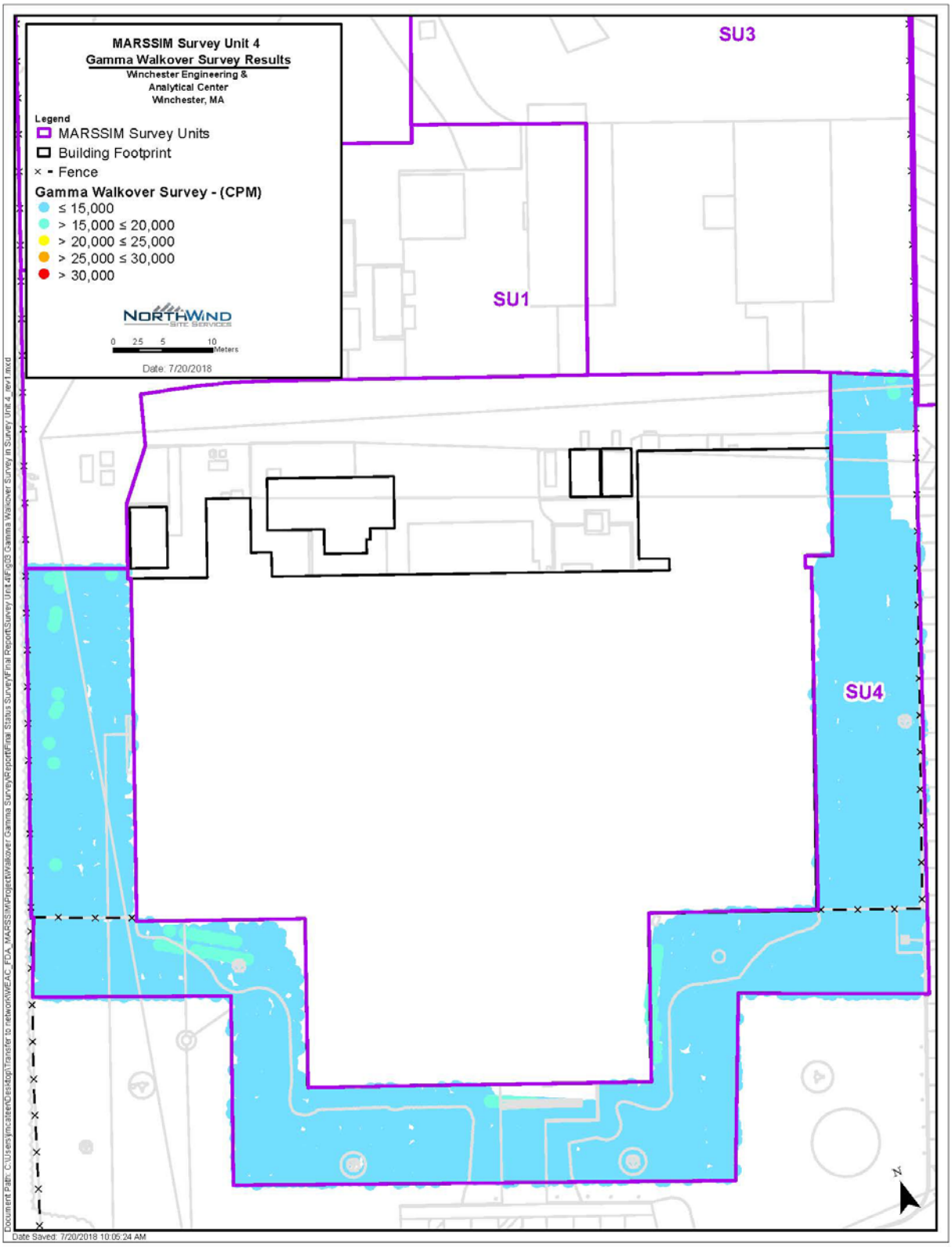

Figure 2. SU4, Gamma Detector (2 x 2 Inch, NaI) Walkover Survey Results

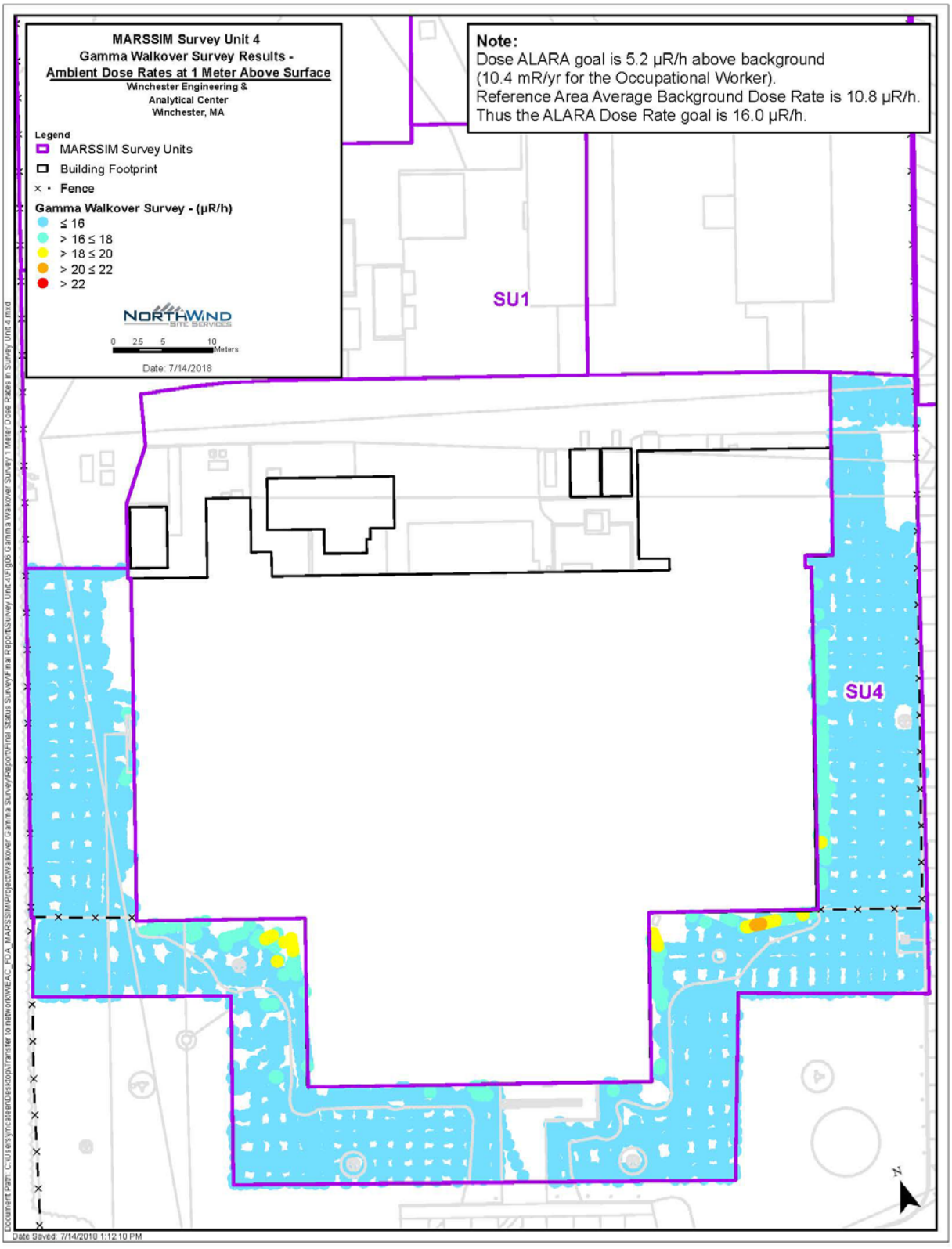

Figure 3. Dose Rate Survey Results for SU4

3.4 Reference Area

A Reference Area (the MARSSIM background area) was selected as the area north and east of the impacted area. The Historical Site Assessment (HSA) determined that this area was unlikely to have been impacted by site radiological operations. The Reference Area was assessed as SU5 and found to be consistent with anticipated background conditions for the Boston, MA region; average dose rates were measured at 10.8 ± 1.3 (1 σ) µR/h. Soil sample results were within anticipated background concentration levels (~ 1 ± 0.5 pCi/g) for the naturally occurring ROCs. The Reference Area average SOF against the ROCs is 0.10 ± 0.02 (1 σ).

The Reference Area is used to perform statistical tests and other comparisons to the survey unit under study when ROCs are found in natural background at significant levels in comparison to the site $DCGL_W$ values. Reference Area (SU5) sample data are provided in **Table 3**.

Table 3. Reference Area (SU5) Systematic Sample Results

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	SOF	ALPHA	BETA
WEAC-FS-SU5-1-105	1.04	1.61	0.82	0.705	0.898	0.204	1.05	2.15	0.11		
WEAC-FS-SU5-2-106	0.931	1.25	0.96	1.15	0.83	0.0584	0.965	1.85	0.11		
WEAC-FS-SU5-3-107	0.799	1.62	1.33	1.41	1.26	0.167	0.831	2.26	0.11	19.7	22.9
WEAC-FS-SU5-4-108	0.772	1.97	0.434	1.34	0.90	0.2	1.8	2.90	0.08	18.7	23.1
WEAC-FS-SU5-5-109	0.85	0.937	0.647	0.923	1.16	0.346	0.961	2.47	0.09		
WEAC-FS-SU5-6-110	0.678	1.5	0.738	0.447	0.807	0.0203	0.734	1.56	0.08		
WEAC-FS-SU5-7-111	0.768	1.3	0.928	0.821	1.04	0.0726	1.3	2.41	0.09		
WEAC-FS-SU5-8-113	0.796	1.42	0.964	0.946	1.02	0.0606	1.27	2.35	0.10	23.1	28.7
WEAC-FS-SU5-9-114	0.724	0.773	1.02	1.03	1.04	0.182	0.811	2.03	0.09		
WEAC-FS-SU5-10-115	0.721	1.49	0.613	0.598	0.507	0.335	0.736	1.58	0.08		
WEAC-FS-SU5-11-116	0.926	1.71	1.02	0.992	1.41	0.0555	1.17	2.64	0.11		
WEAC-FS-SU5-12-117	0.618	0.797	0.318	0.653	0.416	0.0782	0.879	1.37	0.06	19.8	25.6
WEAC-FS-SU5-13-118	1.22	1.14	0.895	0.998	0.935	0.24	0.664	1.84	0.13		
WEAC-FS-SU5-14-119	0.631	0.99	0.746	0.309	1.09	0.243	0.936	2.27	0.08	25.7	35.6
WEAC-FS-SU5-15-121	0.993	1.16	0.87	1.03	0.659	0.222	1.82	2.70	0.11		
WEAC-FS-SU5-16-122	1.02	1.33	0.788	0.546	0.856	0.0959	1.28	2.23	0.11	23.4	26.2
Reference Area Summary	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U		ALPHA	BETA
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	6.00	6.00
Average	0.84	1.31	0.82	0.87	0.93	0.16	1.08	2.16	0.10	21.73	27.02
SD,n-1	0.17	0.34	0.24	0.31	0.26	0.10	0.35	0.43	0.02	2.74	4.72
1.96SD,n-1	0.33	0.66	0.48	0.61	0.51	0.20	0.69	0.85	0.03	5.36	9.25
Ave + 1.96SD, n-1	1.17	1.97	1.30	1.47	1.43	0.36	1.76	3.01	0.13	27.10	36.27
Initial Assessment:	Reference Area									SOF	Net SOF
Net Residual Average Activity (pCi/g):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560		1	1
Fraction (A/CG):	0.00		0.00					0.00		0.00	0.00
SOF (CGw):	0.00										
SOF ($DCGL_W$) in terms of Dose:	0.00	mrem/y, max dose over next 1000 years									

3.5 Systematic and Judgmental Soil Sampling

Systematic soil samples were collected, based upon a random start triangular grid, to provide a non-biased statistical sample set for the survey unit wide ($DCGL_W$) evaluation. One judgmental sample was collected within the unit. Two test pits were dug in the east and west sides of the building. The test pits were dug to 4 feet bgs and the bottom was sampled as a 4-point composite sample.

All systematic and judgmental samples were sent off site for isotopic-uranium, isotopic-thorium, and Ra-226 analysis. Additionally, three of the systematic and the two test pit samples were selected for gross

alpha/beta analysis. Systematic soil sample locations are provided in **Figure 4**. Judgmental soil sample locations are provided in **Figure 5**.

3.6 Systematic Soil Sample Results

Systematic samples were collected at 16 locations based upon a random start, triangular grid.
A retrospective calculation of the relative shift (Δ/σ) results in a value of 9.80; since this is > the FSSP design parameter of 1.67, this confirms that the number of samples collected is adequate to demonstrate achievement of this data quality objective. This results of this assessment are provided in **Figure 6**.

Systematic soil sample results are provided in **Table 4**.

Table 4. SU4 Systematic Survey Sample Data

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-FS-SU4-1-124	0.941	1.2	1.51	1.63	0.896	0.0762	1.63	2.60		
WEAC-FS-SU4-2-125	1.39	1.65	1.52	2.19	1.35	0.598	1.3	3.25		
WEAC-FS-SU4-3-126	1	1.08	1.5	1.39	1.38	0.379	1.72	3.48		
WEAC-FS-SU4-4-127	1.21	1.06	1.69	1.79	1.08	0.122	1.64	2.84	16.6	32.5
WEAC-FS-SU4-5-128	1.06	0.855	2.39	2.2	1.51	-0.0364	0.894	2.37		
WEAC-FS-SU4-6-129	1.47	0.759	2.95	1.69	3.3	0.383	3.57	7.25		
WEAC-FS-SU4-7-130	1.27	0.913	2.61	1.94	1.15	0.193	1.38	2.72		
WEAC-FS-SU4-8-132	1.07	0.885	2.13	2.82	0.84	0.2	1.31	2.35	12.3	29
WEAC-FS-SU4-9-133	1.08	1.35	1.58	1.82	0.705	0.0353	1.2	1.94		
WEAC-FS-SU4-10-134	1.22	1.22	2.44	1.47	1.36	0.196	1.62	3.18		
WEAC-FS-SU4-11-135	1.14	1.84	1.06	1.38	1.48	0.109	1.41	3.00		
WEAC-FS-SU4-12-136	0.945	0.997	1.82	1.82	1.3	0.315	1.03	2.65	20.8	25.9
WEAC-FS-SU4-13-137	0.96	0.793	1.33	0.951	1.53	0.243	0.758	2.53		
WEAC-FS-SU4-14-138	1.28	0.827	1.91	1.72	1.22	0.173	0.504	1.90		
WEAC-FS-SU4-15-140	1.07	0.747	1.6	1.72	1.65	0.0257	0.639	2.31		
WEAC-FS-SU4-16-141	1.18	1.25	1.08	1.29	0.501	0.0813	1.73	2.31		
	All results are in pCi/g									
Count	16	16	16	16	16	16	16	16	3	3
Average	1.14	1.09	1.82	1.74	1.33	0.19	1.40	2.92	16.57	29.13
Max	1.47	1.84	2.95	2.82	3.3	0.598	3.57	7.25	20.8	32.5
Min	0.941	0.747	1.06	0.95	0.50	-0.036	0.50	1.90	12.3	25.9

3.7 Judgmental Design Modifications

The gamma walkover survey did not produce evidence of residual contamination. A typical area exhibiting a slightly elevated gamma signature was selected as the judgmental sample location (WEAC-FS-SU4-142J-1) (see **Table 5)**.

The two test pit samples are identified as WEAC-SS-041 (East of building) and WEAC-SS-042 (West of building) (see Table 5). The relatively high Th-230 results at the two test pit locations is curious. In the absence of similar uranium results, one could conclude this is not natural background material. However, if this material was associated with historical site activities (e.g., if tailings were used as fill material), one would expect much higher Th-230 results along with high Ra-226 results. Finding high background Th-230 by itself may also indicate a slight laboratory bias or indicate some unidentified error in the thorium analysis.

All judgmental sample locations are provided in Figure 5.

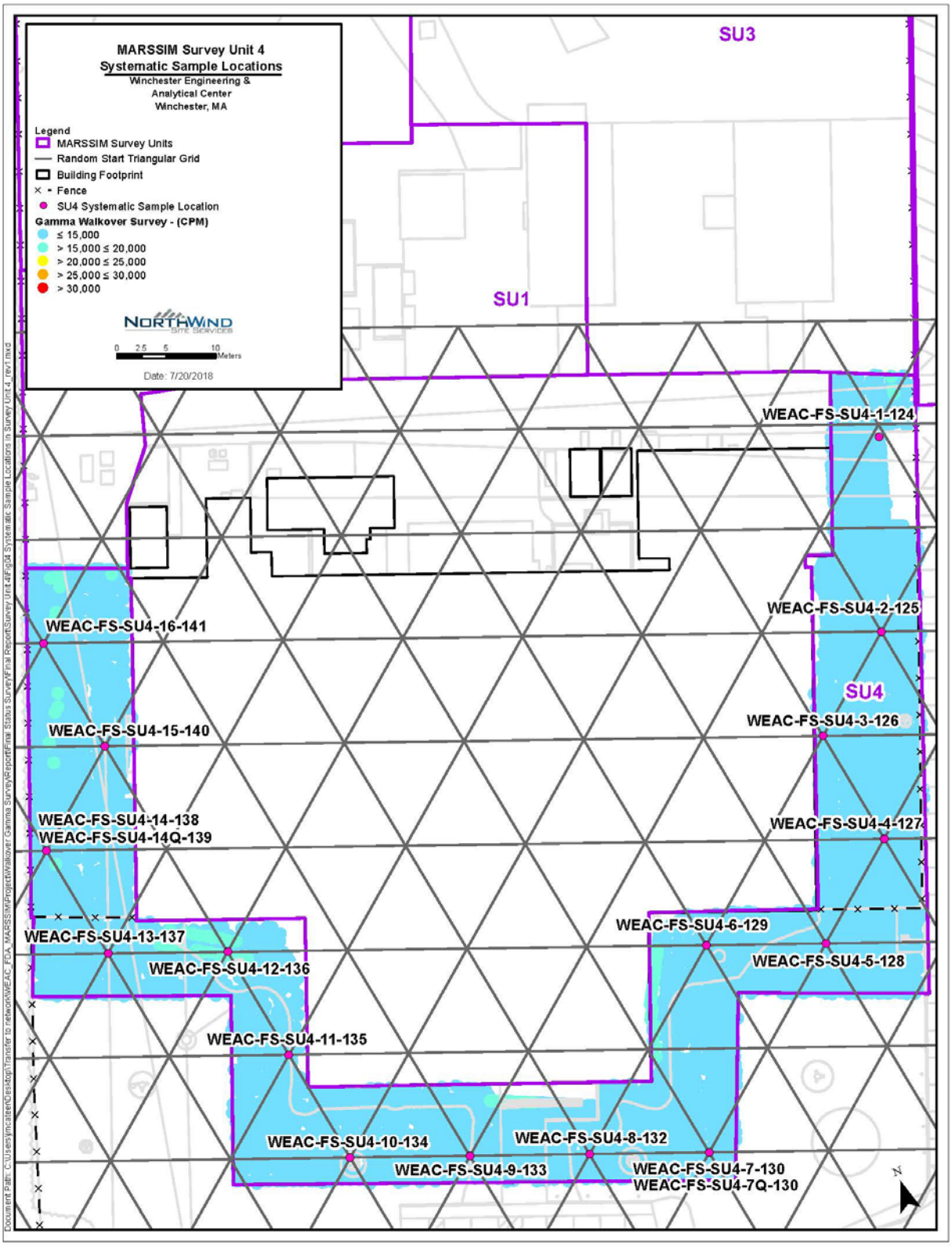

Figure 4. SU4 Systematic Soil Sample Locations

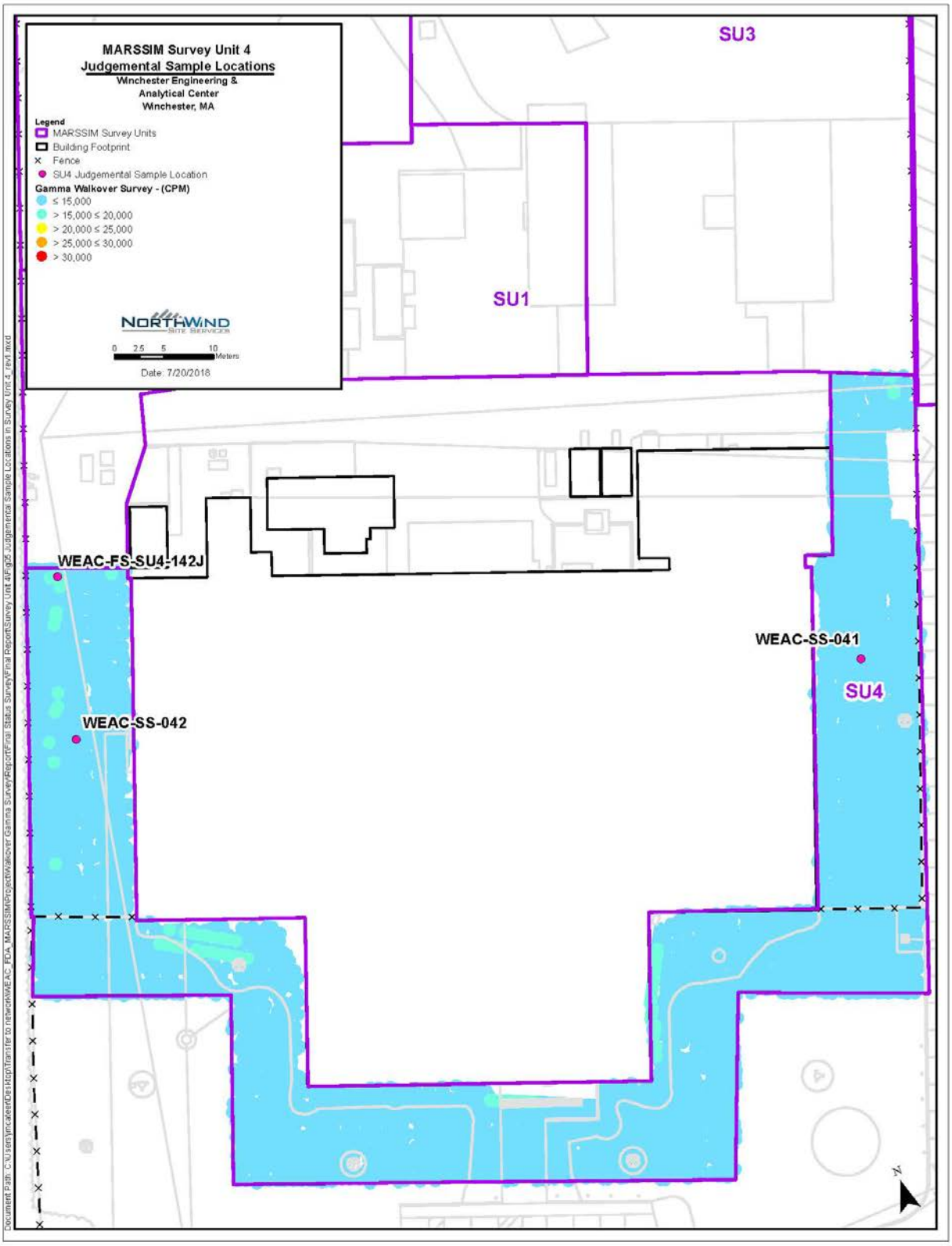

Figure 5. SU4 Judgmental Sample Locations

Post Sampling, Assessment of Sample Numbers $DCGL_W$								
	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	U-Total
(1) $(SD/DCGL_W)^2$:	*0.00017*		*0.00022*					*0.00221*
(2) SOF $(SD/DCGL_W)^2$:	*0.0026*							
Sqrt of (2):	*0.05*	*Sigma for the Weighted Sum*						
$DCGL_W$ (25 mrem/y):	12		37					560
Post Sampling, Assessment of Sample Numbers against the $DCGL_W$								
Delta = DCGLw - LBGR	0.5	Set at 1/2 the DCGLw per MARSSIM Guidance						
Sigma	0.05	Sigma for the data set, propagated error against unity						
Delta/Sigma	9.80	Relative Shift						
Decision Error	0.05	for alpha and beta errors						
Number of Sample	9	From MARSSIM Table 5.3, Values of N/2 for Use with the WRS Test						
Samples per Unit	16	Number of Samples Actually Collected per WEAC Survey Unit.						
Initial Assessment:	The number of samples collected exceeds that required based on							
	the retrospective calculation, Delta/Sigma = 9.80 which is > 1.67.							

Figure 6. Retrospective Calculation of the Required Number of MARSSIM Samples

Table 5. Judgmental Samples from SU4

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	ALPHA	BETA
WEAC-SS-041	0.724	0.911	3.00	0.896	0.981	0.202	0.551	1.73	23.1	27
WEAC-SS-042	0.774	1.22	4.00	1.77	1.04	0.162	1.56	2.76	27.7	29.4
WEAC-FS-SU4-142J-1	1.06	0.728	2.52	0.612	1.77	0.368	1.9	4.04		
Sample Description										
SS-041, 4-pt composite sample from the east side test pit.										
SS-042, 4-pt compoiste sample from the west test pit.										
142J-1, resample of 142J, judgmental FS sample from SU4.										

4. ASSESSMENT RESULTS

The Reference Area average SOF (for the ROCs) in regards to the $DCGL_W$ is 0.10; this value is used to assess "net SOF" results for SU4. SU4 Th-232 and Th-228 results are compared to the Reference Area average 95% upper confidence level (UCL) to assess if these radionuclides are consistent with background; to be inconsistent with background, both Th-232 and Th-228 would need to exceed these values.

In SU4, all systematic sample results were below the $DCGL_W$ and the ALARA CG_W. Systematic Sample SU4-06 exhibited the greatest net SOF at 0.12. All sample results are provided in **Table 6**. The average net SOF for SU4 was 0.05 (e.g., SU4 average SOF [0.15], less the Reference Area SOF [0.10], is 0.0.05). This results in a derived residual dose of 1.34 mrem/yr for a person working within the survey unit. Since no sample exceeded unity for the SOF, the WRS test is not performed.

Table 6. SU4 Systematic Sample Results (Activity in pCi/g) and CG_W Assessment

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	**SOF**	**Net SOF**
WEAC-FS-SU4-1-124	0.941	1.2	1.51	*1.63*	0.896	0.0762	1.63	2.60	0.12	0.03
WEAC-FS-SU4-2-125	1.39	1.65	1.52	*2.19*	1.35	0.598	1.3	3.25	0.16	0.07
WEAC-FS-SU4-3-126	1	1.08	1.5	1.39	1.38	0.379	1.72	3.48	0.13	0.03
WEAC-FS-SU4-4-127	1.21	1.06	1.69	*1.79*	1.08	0.122	1.64	2.84	0.15	0.06
WEAC-FS-SU4-5-128	1.06	0.855	2.39	*2.2*	1.51	-0.0364	0.894	2.37	0.16	0.06
WEAC-FS-SU4-6-129	1.47	0.759	2.95	*1.69*	3.3	0.383	3.57	7.25	0.22	0.12
WEAC-FS-SU4-7-130	1.27	0.913	2.61	*1.94*	1.15	0.193	1.38	2.72	0.18	0.09
WEAC-FS-SU4-8-132	1.07	0.885	2.13	*2.82*	0.84	0.2	1.31	2.35	0.15	0.05
WEAC-FS-SU4-9-133	1.08	1.35	1.58	*1.82*	0.705	0.0353	1.2	1.94	0.14	0.04
WEAC-FS-SU4-10-134	1.22	1.22	2.44	1.47	1.36	0.196	1.62	3.18	0.17	0.08
WEAC-FS-SU4-11-135	1.14	1.84	1.06	1.38	1.48	0.109	1.41	3.00	0.13	0.03
WEAC-FS-SU4-12-136	0.945	0.997	1.82	*1.82*	1.3	0.315	1.03	2.65	0.13	0.04
WEAC-FS-SU4-13-137	0.96	0.793	1.33	0.951	1.53	0.243	0.758	2.53	0.12	0.02
WEAC-FS-SU4-14-138	1.28	0.827	1.91	*1.72*	1.22	0.173	0.504	1.90	0.16	0.07
WEAC-FS-SU4-15-140	1.07	0.747	1.6	*1.72*	1.65	0.0257	0.639	2.31	0.14	0.04
WEAC-FS-SU4-16-141	1.18	1.25	1.08	1.29	0.501	0.0813	1.73	2.31	0.13	0.04
Radionuclide Results are in pCi/g, SOF is unitless									SOF	Net SOF
Average	1.14	1.09	1.82	1.74	1.33	0.19	1.40	2.92	0.15	0.05
Standard Deviation	0.16	0.32	0.55	0.43	0.62	0.16	0.70	1.24	0.03	0.03
Max	1.47	1.84	2.95	2.82	3.3	0.598	3.57	7.25	0.22	0.12
Any Samples > $DCGL_W$:	No		No					No		
Samples > CG_W?:	No		No					No		
Any Sample > Unity?:									No	No
Initial Assessment:	Since no samples exceeded the $DCGL_W$ the WRS test is not required.								SOF_{av}-SOF_b	Net SOF
SU3 Average Net Activity (δ) in pCi/g:	0.30	-0.22	1.00	0.87	0.40	0.03	0.32	0.75	0.05	0.05
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560	1	1
Fraction (δ/$DCGL_W$):	0.02		0.03					0.00	0.05	0.05
SOF ($DCGL_W$):	0.05									
SOF ($DCGL_W$) in terms of Dose:	1.34	mrem/y, max dose over next 1000 years								

No sample exceeded the Th-232/Th-228 combined background screening values for both Th-232 and Th-228 (results in red *italics*).

4.1 Elevated Measurement Assessment

No systematic or judgmental sample exceeded the $DCGL_W$.

5. SURFACES WITHIN SU4

There are no surfaces within SU4.

Exhibit 5

Status Report and Data Package for Survey Unit 5 Winchester Engineering and Analytical Center

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Status Report and Data Package
for Survey Unit 5
Winchester Engineering and Analytical Center
109 Holton Street
Winchester, MA 01890

Revision 0

Prepared for:
Winchester Engineering and Analytical Center
Food and Drug Administration

Contract Number:
HHSF223201710022C

July 2018

North Wind Site Services
2800 Solway Road
Knoxville, TN 37931

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ALARA	As Low as Reasonable Achievable
CG	Cleanup Goal [ALARA]
CG_{EMC}	Cleanup Goal, Elevated Measurement Criteria
CG_W	Cleanup Goal, unit wide or average concentration
cpm	counts per minute
DCGL	Derived Concentration Guideline Value
$DCGL_{EMC}$	DCGL, Elevated Measurement Criteria
$DCGL_W$	DCGL, unit wide or average value criteria
FSSP	Final Status Survey Plan
GPS	Global Positioning System
HSA	Historical Site Assessment
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
NaI	Sodium Iodide
Ra-226	Radium 226
ROC	Radionuclide of Concern
SOF	Sum of Fraction
SU5	Survey Unit 5
Th-230	Thorium 230
WEAC	Winchester Engineering and Analytical Center

List of Symbols

δ	Unit Wide, Average Residual Activity
σ	Sigma, standard error
α	Critical Value for Wilcox Rank Sum Test
β	False negative error parameter
μ	micro (1/1,000)

List of Units

cm	centimeter
cm^2	centimeters square
cpm	counts per minute
dpm	disintegrations per minute
k	kilo, 1,000
m/second	meter per second
m^2	Meter square
mrem/hr	millirem per hour
pCi/g	pico curie per gram
uR/h	micro roentgen per hour
urem/hr	micro rem per hour

1. SURVEY UNIT 5 ASSESSMENT SUMMARY

The radiological assessment of Survey Unit 5 (SU5) is performed to establish a background reference area used in parametric statistical testing of Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Class I, II, and III radiologically impacted survey units. SU5 is designated as a non-impacted Reference Area based upon the Historical Site Assessment (HSA) documented for the Winchester Engineering and Analytical Center (WEAC) Facility.

SU5 Summary Statistics:

- Unit Average Sum of Fraction (SOF) is < Unity for the $DCGL_W$ and is calculated as 0.10, resulting in a background total effective dose estimate of 2.5 mrem/year; the Net SOF and residual effective dose is, of course, zero (0).

SU5 Systematic Sample Summary Data are provided in **Table 1**.

Table 1. SU5 Systematic Sample Summary Data

	Average	1 σ	$DCGL_W$	Fraction		
Ra-226	0.84	0.17	12	0.070		
Th-230	0.82	0.24	37	0.022		
Total-U	2.16	0.43	560	0.004		
			SOF Sum:	0.10		
			SOF Ref. Area:	0.10		
			Net SOF:	0.00		
SOF in Residual Dose Terms:				**0.00**	mrem/year	

2. SURVEY UNIT 5 DESCRIPTION

SU5 (**Figure 1**) is designated as a MARSSIM Reference Unit (non-impacted) surveyed to support parametric statistical testing of impacted survey units. SU5 is located north of the impacted area residing outside of the fenced-in area that served as the historical boundary used to conduct historical uranium operations at the site. SU5 contains trees and brush to the north and portions of the unit are occupied by a parking lot. The gamma scan was conducted over all accessible areas within the unit; however, the global positioning system (GPS) was hampered by the amount overhead foliage in certain areas. Soil samples were collected at locations were the soil was accessible.

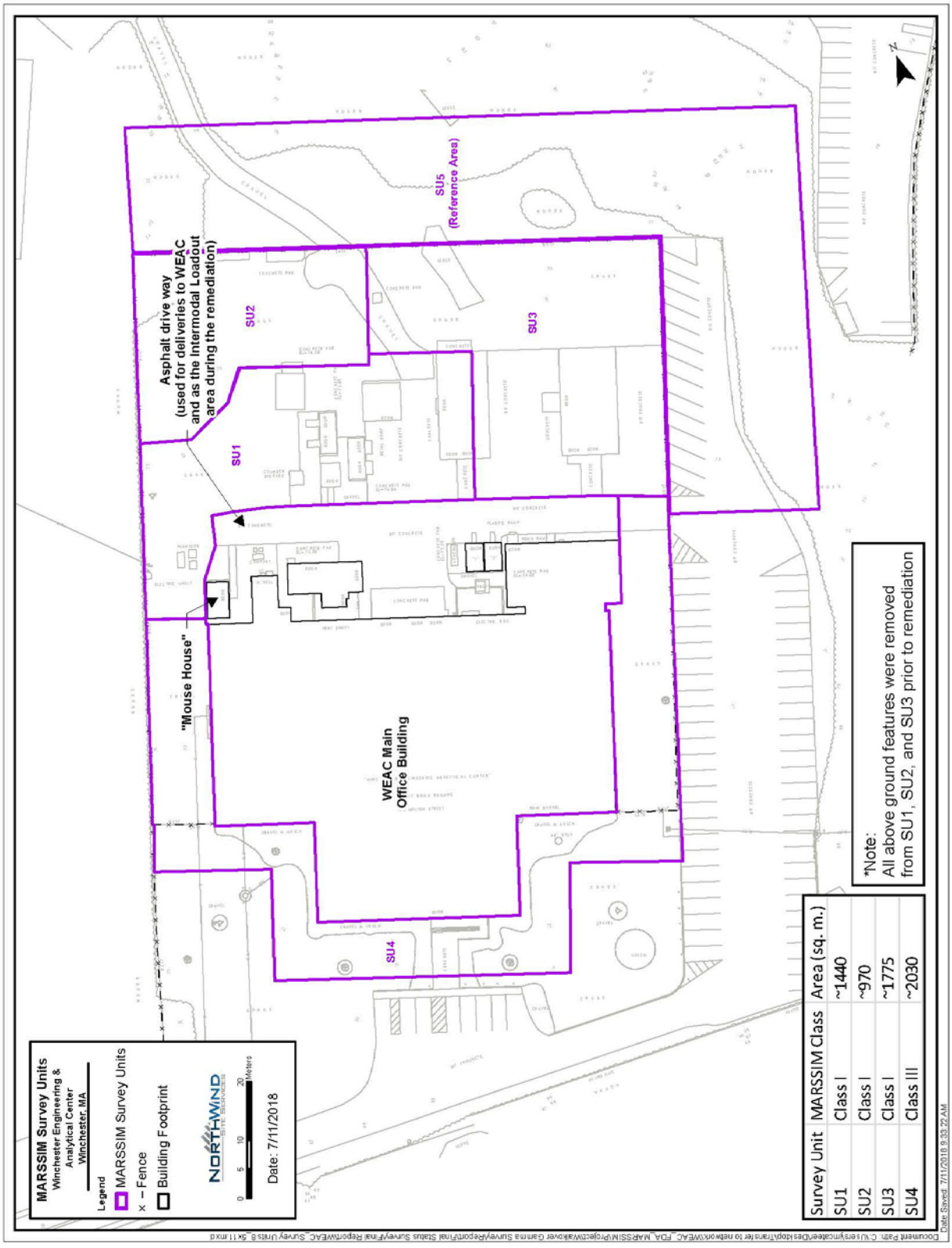

Figure 1. WEAC Survey Units

3. SURVEY UNIT 5 EVALUATION

SU5 is a 3,788-m^2, MARSSIM Reference Area found north of the radiologically impacted area. Walkover gamma exposure levels and dose rates collected at 1-meter above ground surfaces exhibit normal anticipated variations in background.

3.1 Trenching and Test Pits

No trenching was performed in SU5. One test pit was dug in SU5 in an attempt to find "upgradient" ground water; the pit was dug to bedrock and no water was encountered. This test pit did indicate that the reference area soil was different that the soil found in the impacted areas; SU5 soil appeared more natural with no large rocks (which was found throughout impacted areas) (see **Figure 2**).

Test Pit – SU5

The background soil is reletively free of large rocks and it is laid in layers, which appears natural.

Trench – SU1 (running North from Center Excavation)

Typical of the impacted area, soil is a mix of sand, soil, rocks, and bolders. This appreared to be backfill material.

Figure 2. Reference Area Soil in Contrast to Impacted Area Soil

3.2 Gamma Walkover Scanning

GPS-enabled gamma walkover scans were conducted across the Reference Area. These were performed following the Final Status Survey Plan (FSSP) prepared for the site and consisted of slowly moving the sodium iodide (NaI) detector across the surface at approximately 0.5 m/second at a height of 15 cm. Scan paths were approximately 0.5 to 1.0 meters apart in accessible areas. Gamma walkover survey results are provided as a histogram in **Figure 3** and as isopleths in **Figure 4**.

Criteria dose modeling demonstrates that the primary exposure pathway is direct radiation, which contributes over 95% to dose under the most restrictive exposure scenario (used to set the $DCGL_W$ and CG_W values for each radionuclide). This includes Th-230, which reaches its maximum residual exposure at t=1,000 years. At this point, Ra-226 has significantly ingrown, which results in additional direct radiation exposure in 1,000 years but is taken into account today.

At the WEAC site, a low as reasonably achievable (ALARA) residual dose rate goal is established at 5.2 uR/h as a unit average. This would equate to 10.4 mrem of residual exposure to an occupational outdoor worker spending 2,000 hours in the survey unit. The Reference Area (SU5) average dose rate, as measured using the walkover gamma scan data, was measured at 10.8 ± 1.3 (1σ) µR/h. Thus, the dose goal is set for the site at 5.2 + 10.8, or 16 µR/h, over the whole of the impacted survey units with no small area exceeding 25 µR/h.

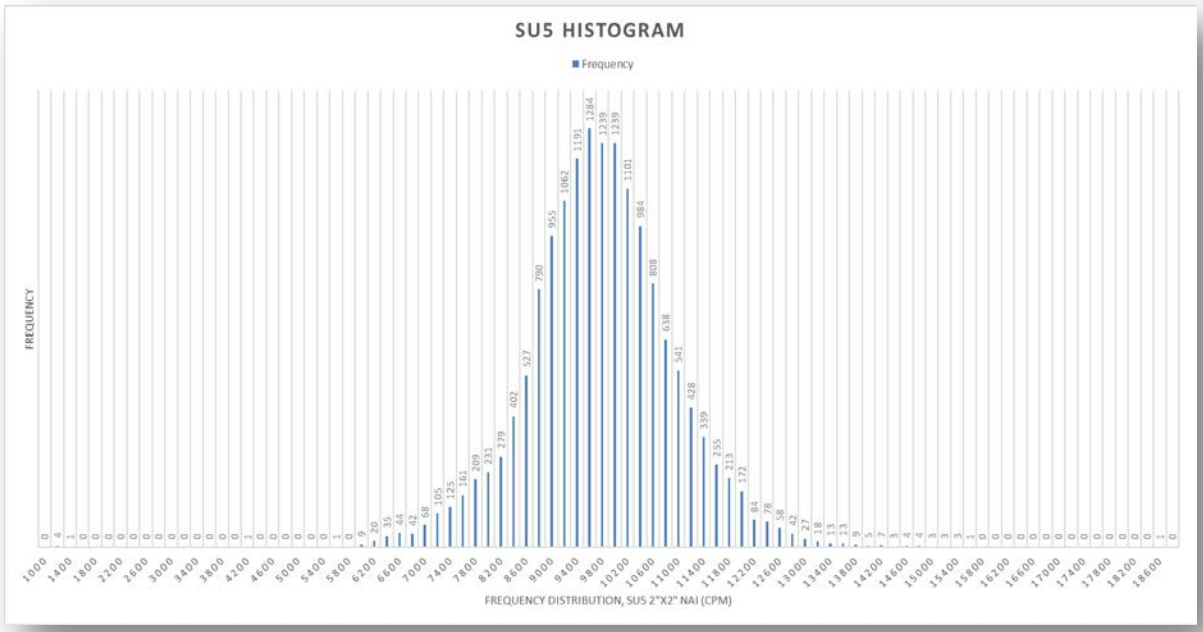

Figure 3. Walkover Gamma Scan (2 x 2 inch NaI) Results (cpm) as a Histogram for SU5

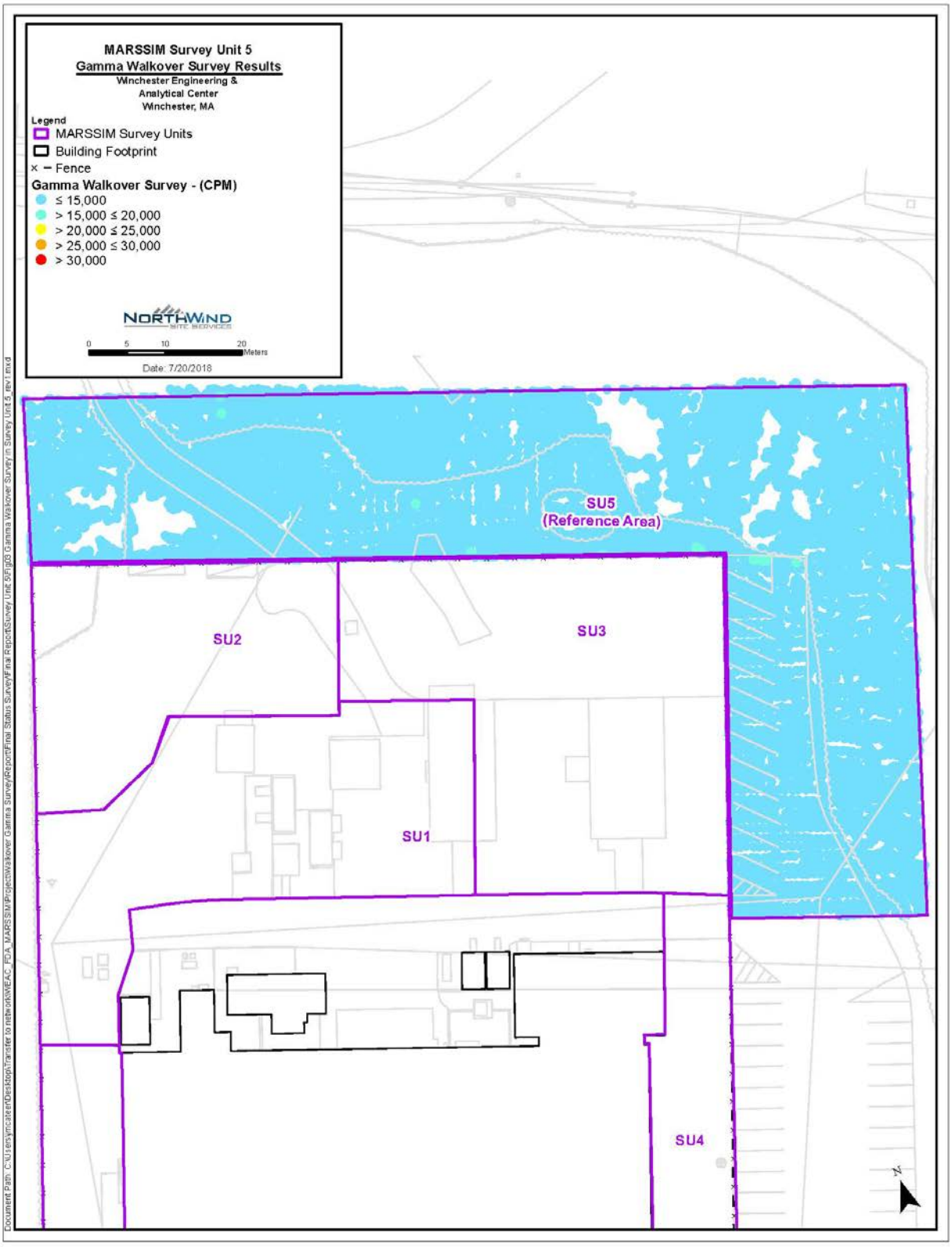

Figure 4. SU5, Gamma Detector (2 x 2 Inch, NaI) Walkover Survey Results

3.3 Background Dose Rate Assessment

Dose rates were collected from an accessible area within SU5 at a height of 1 meter above the surface. These were collected using a NaI 2 x 2-inch detector that records penetrating radiation in counts per minute (cpm). The count rate data were converted into µR/h using the manufacture's reported nominal exposure rate response in µR/h per cpm; reported as 900 cpm/(µR/h) (Reference Ludlum Instrumentation User's Manual for the Ludlum 44-10 detector). The results of this assessment are provided as a histogram in **Figure 5** and gamma isopleths in **Figure 6**.

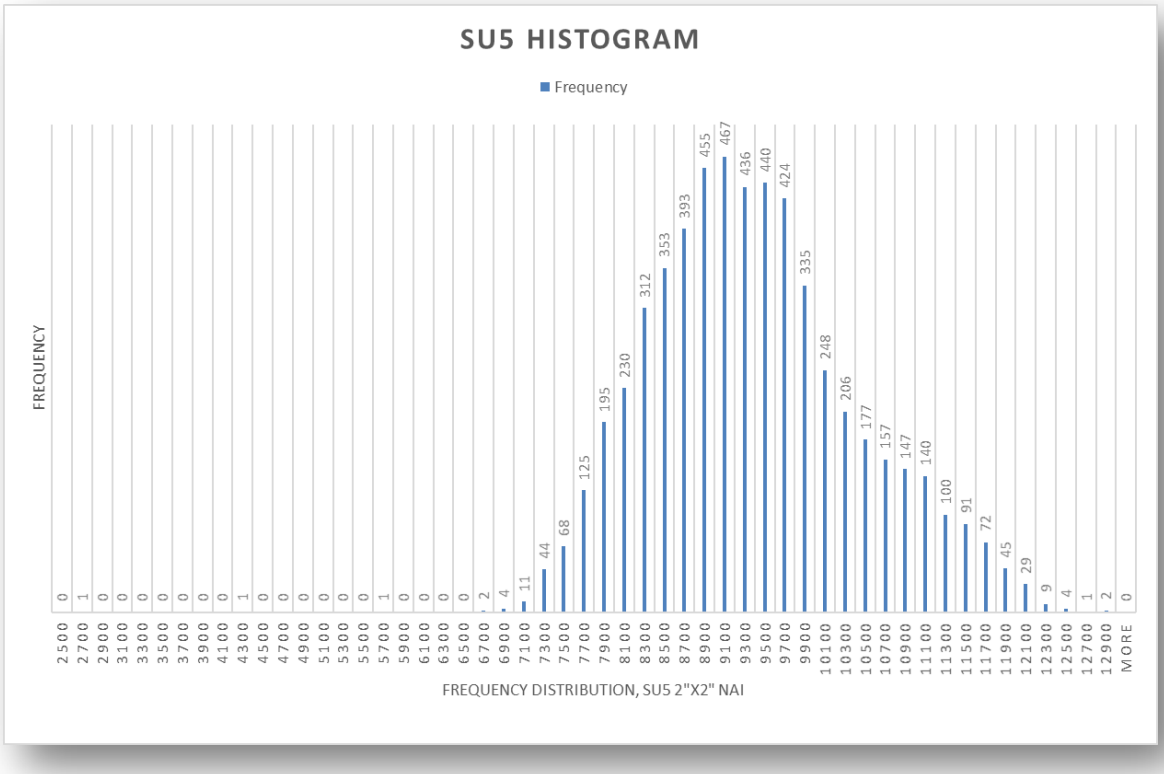

Figure 5. 1-Meter Walkover Gamma Scan Results (cpm) as a Histogram for SU5

3.4 Reference Area Soil Sample Results

A Reference Area (the MARSSIM background area) was selected as the area north and east of the impacted area. The HSA determined that this area was unlikely to have been impacted by site radiological operations. The Reference Area was assessed as SU5 and found to be consistent with anticipated background conditions for the Boston, MA region; average dose rates were measured at 10.8 ± 1.3 (1 σ) µR/h. Soil sample results were within anticipated background concentration levels (~ 1 ± 0.5 pCi/g) for the naturally occurring radionuclides of concern (ROCs). The Reference Area average SOF against the ROCs is 0.10 ± 0.02 (1 σ). The reference area differed somewhat from the SU5 in that the survey unit soil consisted of more backfill material, which contained a significant fraction of large rocks (presumably relocated from an off-site backfill site).

The Reference Area is used to perform statistical tests and other comparisons to the survey unit under study when ROCs are found in natural background at significant levels in comparison to the site $DCGL_W$ values. Reference Area (SU5) sample data are provided in **Table 2**. The Systematic Soil sample locations are provided in **Figure 7**. Note that a few of the systematic locations were relocated to allow access to soil surfaces.

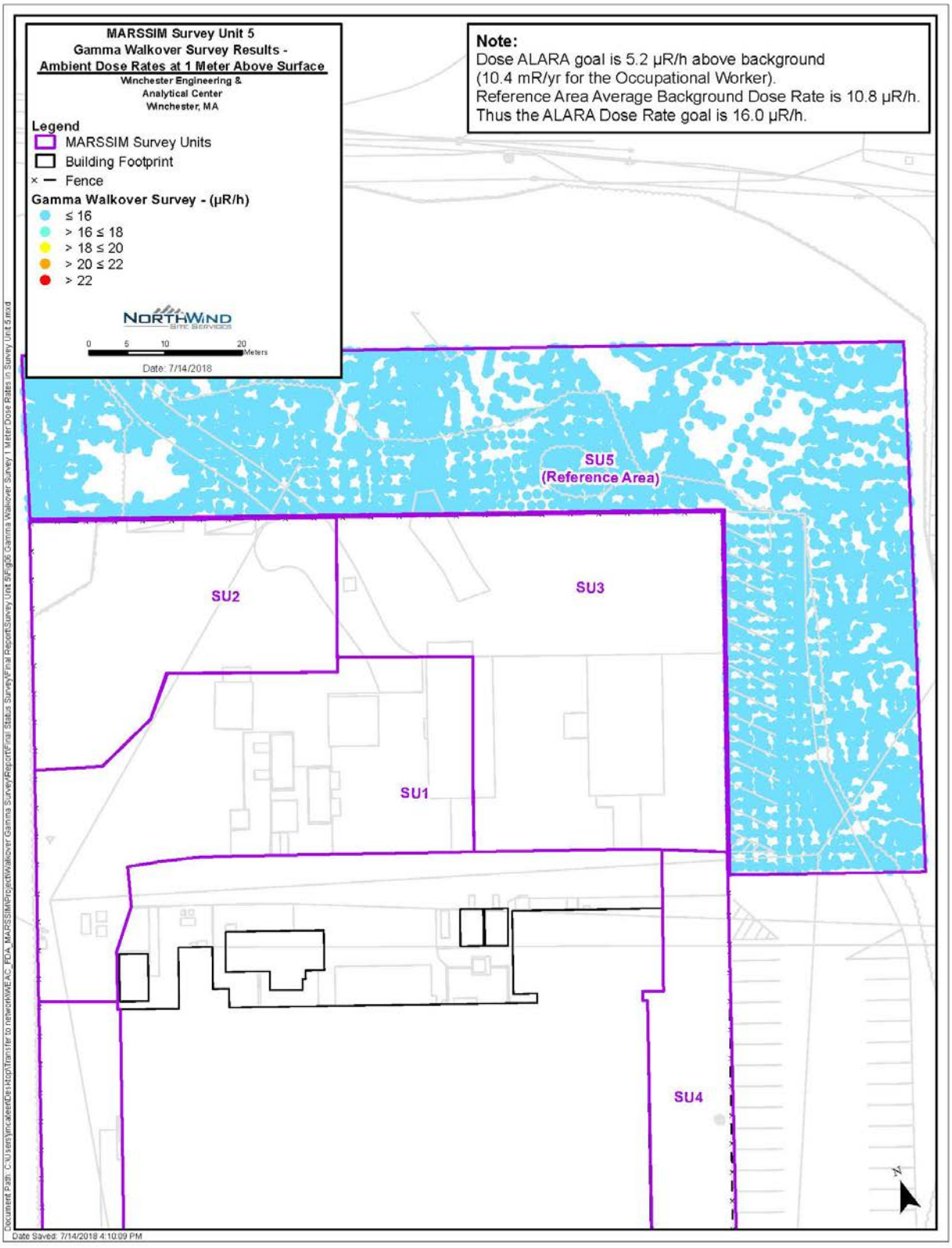

Figure 6. Dose Rate Survey Results for SU5

Table 2. Reference Area (SU5) Systematic Sample Results

Sample ID	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U	SOF	ALPHA	BETA
WEAC-FS-SU5-1-105	1.04	1.61	0.82	0.705	0.898	0.204	1.05	2.15	0.11		
WEAC-FS-SU5-2-106	0.931	1.25	0.96	1.15	0.83	0.0584	0.965	1.85	0.11		
WEAC-FS-SU5-3-107	0.799	1.62	1.33	1.41	1.26	0.167	0.831	2.26	0.11	19.7	22.9
WEAC-FS-SU5-4-108	0.772	1.97	0.434	1.34	0.90	0.2	1.8	2.90	0.08	18.7	23.1
WEAC-FS-SU5-5-109	0.85	0.937	0.647	0.923	1.16	0.346	0.961	2.47	0.09		
WEAC-FS-SU5-6-110	0.678	1.5	0.738	0.447	0.807	0.0203	0.734	1.56	0.08		
WEAC-FS-SU5-7-111	0.768	1.3	0.928	0.821	1.04	0.0726	1.3	2.41	0.09		
WEAC-FS-SU5-8-113	0.796	1.42	0.964	0.946	1.02	0.0606	1.27	2.35	0.10	23.1	28.7
WEAC-FS-SU5-9-114	0.724	0.773	1.02	1.03	1.04	0.182	0.811	2.03	0.09		
WEAC-FS-SU5-10-115	0.721	1.49	0.613	0.598	0.507	0.335	0.736	1.58	0.08		
WEAC-FS-SU5-11-116	0.926	1.71	1.02	0.992	1.41	0.0555	1.17	2.64	0.11		
WEAC-FS-SU5-12-117	0.618	0.797	0.318	0.653	0.416	0.0782	0.879	1.37	0.06	19.8	25.6
WEAC-FS-SU5-13-118	1.22	1.14	0.895	0.998	0.935	0.24	0.664	1.84	0.13		
WEAC-FS-SU5-14-119	0.631	0.99	0.746	0.309	1.09	0.243	0.936	2.27	0.08	25.7	35.6
WEAC-FS-SU5-15-121	0.993	1.16	0.87	1.03	0.659	0.222	1.82	2.70	0.11		
WEAC-FS-SU5-16-122	1.02	1.33	0.788	0.546	0.856	0.0959	1.28	2.23	0.11	23.4	26.2

Reference Area Summary	Ra-226	Th-228	Th-230	Th-232	U-234	U-235	U-238	Total-U		ALPHA	BETA
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	6.00	6.00
Average	0.84	1.31	0.82	0.87	0.93	0.16	1.08	2.16	0.10	21.73	27.02
SD,n-1	0.17	0.34	0.24	0.31	0.26	0.10	0.35	0.43	0.02	2.74	4.72
1.96SD,n-1	0.33	0.66	0.48	0.61	0.51	0.20	0.69	0.85	0.03	5.36	9.25
Ave + 1.96SD, n-1	1.17	1.97	1.30	1.47	1.43	0.36	1.76	3.01	0.13	27.10	36.27

Initial Assessment:	Reference Area									SOF	Net SOF
Net Residual Average Activity (pCi/g):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
$DCGL_W$ (25 mrem/y):	12	N/A	37	N/A	N/A	N/A	N/A	560		1	1
Fraction (A/CG):	0.00		0.00					0.00		0.00	0.00
SOF (CGw):	0.00										
SOF ($DCGL_W$) in terms of Dose:	0.00	mrem/y, max dose over next 1000 years									

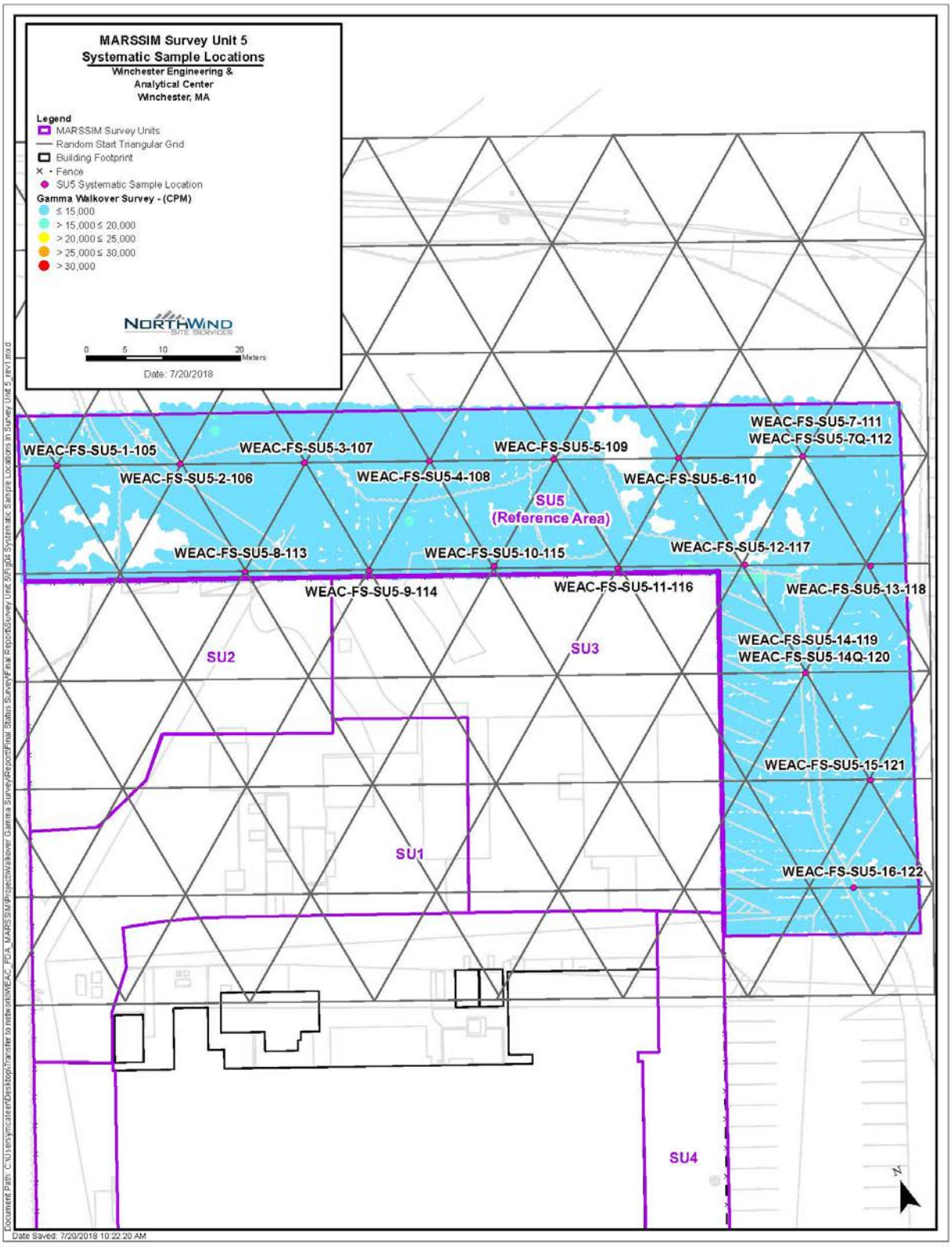

Figure 7. SU5 Systematic Soil Sample Locations