R-14 RANGE
FINAL STATUS SURVEY PLAN

REV. 0

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Aberdeen Proving Ground, MD

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ANL	Argonne National Laboratory
APG	Aberdeen Proving Grounds
ARL	Army Research Laboratory
bkg	background
CABRERA	Cabrera Services, Inc.
CFR	Code of Federal Regulations
cm	centimeter(s)
cm^2	square centimeter(s)
cpm	count(s) per minute
DCGL	Derived Concentration Guideline Level
DCGL$_{EMC}$	Derived Concentration Guideline Level used for elevated measurement comparison
DCGL$_w$	Derived Concentration Guideline Level used for non-parametric statistical test
dpm	disintegration(s) per minute
DQO	Data Quality Objective
DU	Depleted Uranium
FRER	Fluence Rate to Exposure Rate
FSS	Final Status Survey
FSSP	Final Status Survey Plan
GPS	Global Positioning System
GWS	Gamma Walkover Survey
H$_a$	alternative hypothesis
H$_0$	null hypothesis
HEPA	High-Efficiency Particulate Air
HP	Health Physicist
in.	inch
JMC	Joint Munitions Command
LBGR	Lower Bound of the Gray Region
m	meter
m^2	square meter
m/s	meters per second
MARSSIM	Multi-Agency Radiological Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
MDCR	Minimum Detectable Count Rate
MDER	Minimum Detectable Exposure Rate
min	minute(s)
mrem/yr	millirem(s) per year
μR/hr	microroentgens per hour
NAD	Normalized Absolute Difference
NaI	sodium iodide
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
OP	Operating Procedure
P	Probability
pCi/g	picocuries per gram
QA	Quality Assurance
QC	Quality Control
RDR	Relative Detector Response
ROC	Radionuclide of Concern
sec	second
SU	Survey Unit
TEDE	Total Effective Dose Equivalent
^{137}Cs	cesium-137
^{99}Tc	technetium-99
^{230}Th	thorium-230
^{234}Th	thorium-234
^{234}U	uranium-234
^{235}U	uranium-235
^{238}U	uranium-238

1.0 INTRODUCTION

Cabrera Services, Inc. (CABRERA) is under contract to the U.S. Army Joint Munitions Command (JMC) to conduct a final status survey (FSS) as part of the decommissioning process for the R-14 Range area at Aberdeen Proving Ground (APG) in Aberdeen, Maryland. The R-14 Range is under the control of the U.S. Army Research Laboratory (ARL), and is subject to the requirements of its U.S. Nuclear Regulatory Commission (NRC) license. Decommissioning activities are being performed to facilitate the release of the site for unrestricted use.

The proposed derived concentration guideline levels (DCGLs) for soil and structures for the R-14 Range are based on the surface activity screening values published by the NRC in NUREG-5512, Volume 3, Tables 5.19 (NRC, 1999), and a site-specific soil DCGL developed by Argonne National Laboratory (ANL) for the APG Transonic Range (ANL, 1999), which was contaminated with similar source material. Implementation of this FSS plan (FSSP) is intended to obtain the data necessary to demonstrate compliance with the DCGL for structure surfaces and outdoor areas. Specifically, when the DCGLs are applied to the FSS and the data obtained indicates that the requirements of this FSSP have been satisfied, the requirements in Title 10 of the Code of Federal Regulations (CFR) Part 20.1402 for unrestricted release are achieved (NRC, 2006).

2.0 SITE INFORMATION

The R-14 Range is a former test firing range located on Spesutie Island at APG. The general location of APG is shown in Figure 2-1. Historical activities involving depleted uranium (DU) have resulted in radiological contamination of the structures and grounds. ARL, a tenant at APG, has responsibility for this area and desires to initiate the decommissioning process so that the range can be released for unrestricted use.

2.1 Site Description

The R-14 Range includes a number of individual structures surrounded by land areas. The general layout of the R-14 Range is shown in Figure 2-2. The structures currently standing at the R-14 Range include:

- R-14 Blast Chamber,
- Hot Line Building,
- Firing Tube (with access shed),
- Air Handling System (including the Muffler, Cartridge, and High-Efficiency Particulate Air [HEPA] filter, and induction fan),
- Water Treatment Shed,
- Wash Rack Shed, and
- Building 1150D (clean room).

A layout of the existing (i.e., pre-remediation) building area, indicating the relative locations and sizes of the range structures, is shown in Figure 2-3.

The R-14 Range also includes approximately five acres of surrounding grounds (i.e., land areas) consisting of the following:

- Firing Fan (includes the firing line and adjacent land areas),
- Laydown Yard (with sediment trap),
- Paved Areas, and
- Grassy Field.

2.2 Site Background

The R-14 Range was operational from 1982 until 1993. Testing operations involved firing DU penetrator rounds through the Firing Tube into the Blast Chamber from a fixed location approximately 300 feet up-range of the tube opening. Stripper/deflector plates (i.e., shredders) were mounted within the Firing Tube to strip or deflect the sabot away from the DU penetrators as they passed through. The stripped projectiles would then impact a hardened armor target mounted inside the Blast Chamber or, if they defeated the target, they would impact a backstop located a short distance behind the target.

There is an air handling system associated with the Blast Chamber, designed to minimize the escape of airborne radioactivity from the structure during firing operations. This system consists of a Muffler, Cartridge, HEPA filter, and induction fan. These items are contained in separate housings connected by ductwork. When operational, the induction fan would draw air out of the Blast Chamber into the Muffler, where an array of baffles would decrease the velocity of airflow and cause large airborne particulates to drop out of suspension and settle to the bottom. The air would then flow through the Cartridge and HEPA filter, with each unit removing successively smaller particles of radioactive dust.

Other portions of the R-14 Range were used for various support activities. The Laydown Yard was used for the staging and replacement of targets and other large appurtenances required for testing. The Sediment Trap was used to collect storm water runoff from the Laydown Yard, and provided a means of removing sediment from the storm water prior to discharge. The Hot Line housed the X-ray equipment and "hot" work areas used in the evaluation of impact testing results. The Water Treatment Shed contained the treatment system (e.g., pumps, tanks, evaporator) used in the treatment of contaminated wash water discharged from the Hot Line sink and washing machine. Building 1105D was used for the storage of non-contaminated supplies and instrumentation necessary for range operations.

2.3 Previous Investigations

In November 2006, CABRERA performed a characterization survey of potentially impacted buildings and grounds at the R-14 Range. Results of the structures surface contamination surveys and soils volumetric sample analyses completed during the characterization survey are presented in the *R-14 Range Characterization Survey Report* (CABRERA, 2007), and summarized below in Tables 2-1, 2-2, and 2-3. Surface contamination results are presented in units of disintegrations per minute per 100 square centimeters (dpm/100 cm^2), and volumetric results are presented in units of picocuries per gram (pCi/g).

Table 2-1: Direct Alpha Measurement Summary for Structures

Structure	Location	Alpha Activity ($dpm/100cm^2$)		
		Average	Standard Deviation	Maximum
Blast Chamber	Floor	366	217	825
	Interior Walls	3710	2129	8175
	Ceiling	4239	1142	5774
	Exterior Wall – North	53	53	106
	Exterior Wall – West and Sliding Door	31	23	58
	Roof	248	233	591
Hotline – Washroom	Floor	102	67	225
	Interior Walls	29	4.2	35
	Ceiling	65	46	100
Hotline – Cassette Room and Hallway	Floor	652	357	1331
	Interior Walls	266	211	679
	Ceiling	19	2.1	21
Hotline – X-Ray Room	Floor	482	196	629
	Interior Walls	816	239	1027
	Ceiling	N/A	N/A	N/A
Firing Tube	Interior (floor)	95	56	209
	Exterior	50	79	367
Firing Tube Shed	Interior and Exterior Surfaces	21	12	35
Muffler	Exterior Walls and Roof	54	62	164
Water Treatment Shed	Exterior Walls and Roof	21	9	35

$dpm/100\ cm^2$ = disintegrations per minute per 100 square centimeters

Table 2-2: Removable Alpha Measurement Summary for Structures

Structure	Location	Alpha Activity (dpm/100cm^2)		
		Average	Standard Deviation	Maximum
Blast Chamber	Floor	126	135	572
	Interior Walls	254	293	1071
	Ceiling	307	246	658
	Exterior Wall – North	1.4	1.0	2.9
	Exterior Wall – West and Sliding Door	3.9	4.0	10.7
	Roof	4.4	3.8	9.6
Hotline – Washroom	Floor	2.0	2.8	7.4
	Interior Walls	7.6	4.4	14
	Ceiling	2.6	1.2	3.9
Hotline – Cassette Room and Hallway	Floor	60	61	136
	Interior Walls	20	51	146
	Ceiling	3.8	3.6	8.5
Hotline – X-Ray Room	Floor	24	29	57
	Interior Walls	5.4	3.3	9.1
	Ceiling	6.5	6.1	10.8
Firing Tube	Interior (floor)	20	18	71
	Exterior	1.5	1.4	6.7
Firing Tube Shed	Interior and Exterior Surfaces	5.5	5.3	14
Muffler	Exterior Walls and Roof	41	84	192
Water Treatment Shed	Exterior Walls and Roof	3	3	8

dpm/100 cm^2 = disintegrations per minute per 100 square centimeters

Table 2-3: Volumetric Sample Results Summary for Land Areas

Location	Maximum Soil Concentration (pCi/g)	
	^{238}U	DU
Firing Fan – Soil	8.6	9.5
Laydown Yard – Soil	511	565
Storm Water Sediment Trap – Soil[1]	52	57.5
Storm Water Sediment Trap – Sediment[2]	620	685.8
Grassy Field - Soil	70	77.4

pCi/g = picocuries per gram
[1]Results are for a surface soil sample collected adjacent to the Sediment Trap.
[2]Results are for a sediment sample collected from inside the Sediment Trap.

3.0 FINAL STATUS SURVEY REQUIREMENTS

A FSS will be planned and conducted for each survey unit (SU) associated with impacted outdoor soil areas, outdoor solid surfaces (i.e., pads, roadways, rails, and structures). The FSSP is prepared in accordance with the guidance presented in the *Multi-Agency Radiological Survey and Site Investigation Manual* (MARSSIM; NRC, 2000) and follows the data quality objective (DQO) process. This ensures that all impacted SUs are surveyed with the necessary rigor that corresponds with their respective contamination potential. The DQO process includes the following seven steps:

Step 1: State the problem

Step 2: Identify the decisions

Step 3: Identify inputs to the decisions

Step 4: Define the study boundaries

Step 5: Develop a decision rule

Step 6: Specify the decisions

Step 7: Optimize the survey design

The following sections provide the requirements for the planning phase of the FSS, including the identification of radionuclides of concern (ROCs) and DCGLs, classification and survey unit designations, survey planning parameters, instrumentation, measurement and sampling procedures, and the data quality assessments that will be implemented.

3.1 Radionuclides of Concern

ROCs known to be present in the R-14 Range area are limited to DU isotopes consisting of uranium-234 (^{234}U), uranium-235 (^{235}U), and uranium-238 (^{238}U) and their short-lived decay progeny. The assumed DU composition is based on the isotopic uranium ratios routinely used for shipments of DU waste from APG (Barg, 1995). The activity fractions are calculated from the weight ratios and specific activities of each uranium isotope. The resulting composition consists of ^{234}U, ^{235}U, and ^{238}U activity fractions of 0.084, 0.012, and 0.904, respectively. This composition is similar to the average activity fractions measured in three DU soil samples described in the ANL report *Derived Uranium Guideline for the Depleted*

Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland (ANL, 1999).

3.2 Derived Concentration Guideline Levels

As described in MARSSIM (NRC, 2000), a DCGL is a derived radionuclide activity concentration that corresponds to a dose-based release criterion; and a $DCGL_W$ is the DCGL used in non-parametric statistical testing to evaluate compliance with the dose-based criterion across a wide area (i.e., SU). For this FSS, the release criterion is based on the 25 millirem per year (mrem/yr) total effective dose equivalent (TEDE) exposure limit specified in 10 CFR 20, Subpart E: *Radiological Criteria for License Termination* (NRC, 2006). The corresponding DCGLs for soil and structures are described below.

3.2.1 Soil $DCGL_W$

A $DCGL_W$ of 230 pCi/g total DU will be used for evaluating soils at the R-14 Range. This value was originally developed for use in decommissioning the APG Transonic Range (ANL, 1999), which was contaminated with source material similar to that at the R-14 Range. The $DCGL_W$ is based on a resident-farmer exposure scenario, and represents the modeled activity concentration corresponding to a potential dose of 25 mrem/yr to a member of the critical group over a 1,000-year period.

3.2.2 Structures $DCGL_W$

The $DCGL_W$ for DU surface activity on structures is based on the screening values published in NUREG/CR-5512, Volume 3, Table 5.19 (P_{crit} = 0.90) (NRC, 1999). The primary method of obtaining surface activity measurements for both total and removable activity will be through use of alpha monitoring instrumentation. Therefore, the surface activity screening values have been calculated based on the total number of alpha particles emitted in each of the applicable radioactive decay chains and the percent contribution from each of the uranium isotopes present in DU, as shown in Table 3-1. The $DCGL_W$ is calculated using the following formula.

$$DCGL_W = \frac{1}{\left(\frac{f_1}{DCGL_1}\right) + \left(\frac{f_2}{DCGL_2}\right) + \left(\frac{f_3}{DCGL_3}\right)}$$

Where:

$DCGL_W$ = Combined gross activity DCGL
$f_{1,2,3}$ = Activity fraction of individual radionuclide
$DCGL_{1,2,3}$ = DCGL for individual radionuclide

Table 3-1: Surface Activity $DCGL_W$

ROC		NUREG/CR-5512 Screening Level (dpm/100 cm^2)	Total Alphas per Decay	Alpha Based Screening Level (dpm/100 cm^2)	DU Alpha $DCGL_W$ (dpm/100 cm^2)
DU	90.4% ^{238}U	101.0	1	101.0	100
	1.2% ^{235}U	97.6	1	97.6	
	8.4% ^{234}U	90.6	1	90.6	

dpm /100 cm^2 = disintegrations per minute per 100 square centimeters

As noted in NUREG/CR-5512 (NRC, 1999), the surface activity screening levels are based on the assumption that the fraction of removable surface contamination is ten percent. Therefore, the removable alpha activity limit applied to the FSS is 10 dpm/100 cm2.

3.3 Area Classification Based on Contamination Potential

Based on historical site information and data obtained during the characterization survey, impacted areas at the R-14 Range have been subdivided into three categories based on contamination potential as either Class 1, 2, or 3, in accordance with MARSSIM (NRC, 2000). A description of each is provided below:

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

Class 2: Buildings or land areas, often contiguous to Class 1 areas, that have a potential for radioactive contamination but at levels less than the $DCGL_W$.

Class 3: Buildings or land areas that are expected to contain little or no residual contamination based on site operating history or previous radiological surveys.

Furthermore, outdoor solid surfaces, land areas, and buildings have been further subdivided into SUs, which provide the fundamental unit for demonstrating compliance with the applicable $DCGL_W$.

3.4 Identification of Survey Units

All impacted outdoor surfaces, land areas, and structures have been subdivided into Class 1, 2, or 3 SUs. Each SU represents a portion of the site with similar contamination potential. The MARSSIM-recommended SU sizes are provided in Table 3-2.

Table 3-2: MARSSIM-Recommended Survey Unit Sizes

Class	Recommended Survey Area	
	Structures	Land Areas
1	Up to 100 m^2	Up to 2,000 m^2
2	100 to 1,000 m^2	2,000 to 10,000 m^2
3	No limit	No limit

m^2 = square meters

Based on the results of characterization surveys and sampling performed, land area SUs at the R-14 Range have been identified as indicated in Table 3-3.

Table 3-3: Land Area Survey Units

Area	Survey Unit	MARSSIM Classification	Matrix
Laydown Yard	1	1	Soil
Firing Line	2	1	Soil
Grassy Field	3	1	Soil
Grassy Field and Laydown Yard Border Area	4	2	Soil
	4A	2	Pavement
Land Area West of Firing Line	5	2	Soil
	5A	2	Pavement
Land Area East of Firing Line	6	2	Soil
	6A	2	Pavement

Many of the existing structures will be removed during decommissioning. These include the Blast Chamber, Firing Tube, Firing Tube Shed, Hot Line, Muffler, Water Treatment Shed, Cartridge House, and HEPA Filter. Only Building 1105D and the Wash Rack Shed will remain following the building demolition and removal.

A general depiction of the R-14 Range land areas and structures that will remain following remediation, as well as the remaining footprint (i.e., concrete slabs, steel floors, asphalt pads) of structures that are removed, is provided in Figure 3-1. Figure 3-2 indicates how the outdoor land area will be divided into SUs for the FSS, as listed in Table 3-3.

The remediation of structures will entail the demolition and removal of the structures specified above. Where possible, the footprint of each structure will be left in place and decontaminated, as necessary, to meet FSS release criteria. In cases where the entire structure (including the footprint materials) must be removed, the underlying soil that remains will be considered part of the adjacent land area SU.

The two structures to remain onsite following the building demolition and removal (i.e., the Wash Rack Shed and Building 1150D) are expected to contain little or no residual contamination. Since the Wash Rack Shed was added to the site after DU firing activities ceased, the probability of surface contamination is low. However, because of the proximity of the shed to the Class 1 Laydown Yard SU, this structure will be surveyed in accordance with MARSSIM Class 3 requirements. Similarly, the contamination potential in Building 1150D (clean room) is also considered low, but due to its proximity to the Hot Line and historical use in support of range operations, this building will also be surveyed as a MARSSIM Class 3 area. For these Class 3 structures, the extent of FSS SUs will be limited to floors and lower walls.

The FSS structure SUs are identified in Table 3-4. Figure 3-3 depicts the location of these structure SUs. A layout of each individual outdoor land area and structure SU shown in Figures 3-2 and 3-3, and listed in Tables 3-3 and 3-4, is provided in Appendix A.

Table 3-4: Structure Survey Units

Area	Survey Unit	MARSSIM Classification
Demolished Structures (Slabs/Floors)	7A	1
	7B	1
	7C	1
	7D	1
	7E	1
	7F	1
	7G	1
	7H	1
Wash Rack Shed	8	3
Building 1150D (Clean Room)	9	3

3.5 Background Reference Area and Materials

Although uranium isotopes present in DU are also present in the environment, the concentrations of uranium isotopes naturally present in soil represents a very small fraction of the soil $DCGL_W$. Therefore, the determination of background uranium concentration in soil is not necessary and will not be considered when comparing soil data with the $DCGL_W$ or when performing statistical tests. Soil sample data will be used for direct comparison with the soil $DCGL_W$ and for performance of the planned non-parametric Sign statistical test without correction for background uranium concentrations.

Outdoor solid surface and structure SUs will also be evaluated using the non-parametric Sign test. Construction material-specific background measurements may be performed in areas of similar construction but without a history of radioactive material use. These material-specific background activity values may then be used to correct direct surface activity measurements for the contribution due to background and natural radioactivity in these materials. However, as a conservative measure, the material-specific background may be assumed to be zero. If used, material-specific background surface material count rates will be subtracted from SU count rates prior to converting the data to units of dpm/100 cm^2 for comparison with the applicable $DCGL_W$.

3.6 Reference System

A reference coordinate system will be utilized for FSS measurements and sampling locations. Direct measurements on structural surfaces will be referenced to prominent building features, or a grid system will be used similar to that implemented for the characterization surveys. Soil sample locations will be referenced to global positioning system (GPS) coordinates obtained using hand-held GPS units.

3.7 Survey Design

Structure surface contamination and DU concentrations in soil will be assessed by collecting the required number of systematic gross alpha surface activity measurements and soil samples within each SU. The Sign test will be used for demonstrating compliance with the applicable $DCGL_W$.

The statistical test (Sign test) is performed to evaluate the SU mean concentration relative to the null hypothesis (H_0). Simply stated, H_0 assumes the residual contamination in the SU exceeds the release criterion. Provided that the statistical test is satisfied at the desired confidence level, then H_0 is rejected and the alternate hypothesis (H_a), residual contamination meets the release criterion, is accepted. The data needs for the statistical test will be determined through the processes in the following sections.

3.7.1 Number of Sample Locations for Survey Units

The following sections describe the bases for and derivation of the minimum required measurements and samples per SU.

<u>Estimation of Relative Shift</u>

The relative shift describes the relationship of site residual radionuclide concentrations to the $DCGL_w$ and is calculated using the following equation:

$$\Delta/\sigma = \frac{DCGL_w - LBGR}{\sigma}$$

Where:

$DCGL_W$	= Applicable value from Section 3.2
LBGR	= Lower bound of the gray region; normally established as the estimated mean activity within the survey unit, but may be adjusted to maximize survey design

σ = Estimate of the standard deviation of the residual radioactivity, or the actual standard deviation obtained from scoping or characterization surveys and/or sampling

The DQOs are evaluated for each SU, and the decision errors are selected. The Type 1 error (or probability of incorrectly rejecting H_0 when it is true) is set at 0.05 (i.e., 5%). The Type 2 error (or probability of incorrectly accepting H_0 when it is false) is also set at 0.05. Once these parameters are established and the relative shift is determined, the number of data points required by the statistical test is calculated using MARSSIM Equation 5-2 (NRC, 2000), obtained directly from MARSSIM Table 5.5 (Sign test), or generated using *COMPASS*, *Visual Sample Plan* or *MARSSIM Power* software.

The $DCGL_W$ for soil radioactivity is 230 pCi/g. The LBGR is estimated to be 115 pCi/g, which represents half of the $DCGL_W$, as suggested in MARSSIM. Using an estimated coefficient of variation of 30% and the LBGR as an estimate of the sample mean, a standard deviation of 34.5 pCi/g is calculated. Using these values and the above equation, the relative shift is initially calculated to be 3.3. Because MARSSIM recommends a relative shift of between 1 and 3, the LBGR was adjusted downward to achieve a value of 3.0. The corresponding number of samples, as specified in MARSSIM, Table 5.5, is 14.

For both buildings and outdoor solid surfaces (i.e., concrete, steel, and asphalt), the $DCGL_W$ for surface alpha radioactivity is 100 dpm/100 cm^2. The LBGR is conservatively estimated as 70 dpm alpha/100 cm^2 based on previous studies with similar instruments on concrete. In the absence of site-specific concrete survey data, the coefficient of variation is assumed to be 30% (MARSSIM, Section 5.5.2.2). Using a coefficient of variation of 30% and the LBGR as an estimate of the sample mean, a standard deviation of 21 dpm/100 cm^2 is estimated. Using these values and the above equation, the relative shift is 1.4. The corresponding number of systematic direct measurement locations, as specified in MARSSIM, Table 5.5, is 20.

<u>Adjustment of the Number of Samples and Direct Measurements Based on Scan Sensitivity</u>

Once the minimum number of samples and direct measurements has been determined for each SU, the scan sensitivity for each Class 1 SU type is evaluated to verify that the sensitivity is sufficient to detect small elevated areas of activity (refer to MARSSIM Section 5.5.2.4). This only applies to Class 1 SUs, as elevated areas of activity are not expected in Class 2 or Class 3 SUs.

As discussed in Section 5.4, outdoor land area gamma scans will be performed using a sodium iodide (NaI) detector with a DU scan sensitivity (minimum detectable concentration [MDC]) of 32.9 pCi/g. Because the actual scan sensitivity is lower than the soil $DCGL_W$, no further evaluation is required, and the previously calculated minimum number of samples (14) is confirmed to be acceptable.

Class 1 structure beta scans will be performed using a Ludlum Model 43-37 or Ludlum Model 43-68 gas proportional detectors. The beta scan minimum detectable count rates (MDCRs) for these two detectors are 185 and 397 counts per minute (cpm), respectively. Because both are higher than the structure alpha $DCGL_W$, an evaluation is required to determine whether the number of direct alpha measurements calculated is sufficient to detect elevated areas of activity. Using the higher scan MDCR, the need for adjustment is determined using MARSSIM, Equation 5-4, and the area factors listed in MARSSIM, Table 8.2. The actual beta scan MDCR is 397 cpm (rounded to 400 cpm for simplicity), and the corresponding area factor is 4. From MARSSIM, Table 8.2, this equates to an area of 9 m^2. Dividing the maximum SU size for a Class 1 structure, 100 m^2, by this area provides the adjusted number of direct measurements, 11 per SU, based on the scan sensitivity. This value is less than the minimum number of direct alpha surface activity measurements previously calculated (20); therefore, no additional direct alpha measurements are necessary.

<u>Determining Measurement/Sampling Locations</u>

Measurement and sampling locations will be established in either a random-start/systematic fashion for Class 1 and Class 2 SUs, or at randomly generated locations for Class 3 SUs. Random-start/systematic locations will follow the recommended guidance using a triangular sampling pattern to increase the probability of identifying small areas of residual activity. The spacing (L) between data points on a triangular grid pattern is determined by:

$$L = \sqrt{\frac{A}{0.866 \times N}}$$

Where:

L = Triangular grid spacing between sample locations
A = Area of SU
N = Number of sample locations

And the spacing between rows is calculated as:

$$0.866 \text{ x } L$$

For land areas, a unique set of GPS coordinates will be generated for each sample location.

3.8 Integrated Survey Strategy

FSS data collected for structure surfaces consists of beta surface activity scans and direct measurements for alpha surface activity. Gamma scans will be performed on outdoor solid surfaces, such as paved areas, in lieu of beta surface activity scans. Smears samples, although not used in the final data quality assessment, will be collected from each direct alpha systematic and biased measurement location to measure removable alpha surface activity. FSS of open land areas will consist of gamma scans to identify locations of residual contamination, and soil samples analyzed for the ROCs. Additional biased measurements and samples will be obtained, as necessary, from locations where scans indicate the potential for elevated activity.

3.8.1 Surface Scans

Surface gamma scans will be performed using NaI scintillation detectors over land areas and outdoor paved areas. Surface scans in building SUs, as well as remaining structure surfaces (e.g., slabs, floors, or pads) will be performed using gas proportional detectors for beta activity. Detectors will be coupled to ratemeters or ratemeter-scalers with audible indicators.

Recommended surface scan coverage, as discussed in MARSSIM, is provided in Table 3-5.

Table 3-5: MARSSIM-Recommended FSS Scan Coverage

Class	Structures	Land Areas
1	100%	100%
2	10 to 100% floors and lower walls 10 to 50% upper walls and ceilings	10 to 100%
3	Judgmental	Judgmental

3.8.2 Soil Sampling and Surface Activity Measurements

FSS surface and subsurface soil samples will be collected from Class 1 land areas at pre-determined random-start/systematic locations. Additionally, biased samples will be collected from locations where elevated direct gamma radiation is detected by surface gamma scans. Soil samples will be maintained under formal chain-of-custody procedures. Surface soil systematic and biased samples will be analyzed for the ROCs, and results will be reported in units of pCi/g. If a systematic or biased surface soil sample result is greater than or equal to the soil $DCGL_W$, the subsurface sample from the same sample location will be submitted for analysis. For FSS of Class 2 land areas, only surface soil samples will be collected, and these will be analyzed in the same manner as the Class 1 soil samples. There are no Class 3 land area SUs identified at the R-14 Range.

FSS direct measurements to quantify total alpha activity on structure surfaces and outdoor solid surfaces will be performed at pre-determined random-start/systematic or random locations, as applicable. Additional biased direct alpha measurements will be performed at locations of elevated activity identified during the scan survey. Direct alpha measurements will be performed using gas proportional or scintillation detectors coupled to ratemeter-scalers.

Smear samples will be collected at each direct systematic or biased surface activity measurement location to quantify the alpha removable contamination within each structure SU. Direct and removable surface activity data will be converted to units of dpm/100 cm^2 for comparison to the removable alpha activity limit.

Specific FSS survey and sampling requirements for the various types of SUs at the R-14 Range are discussed in the following paragraphs.

<u>Class 1 Land Area SUs</u>

Class 1 land area SUs at the R-14 Range include the Laydown Yard, Firing Line, and Grassy Field, which are identified as SU Nos. 1, 2, and 3 (see Table 3-3). A total of 14 surface and 14 subsurface systematic soil samples will be collected in each SU. For systematic soil sampling locations that unexpectedly fall on solid surfaces (e.g., concrete, steel, or asphalt), the sampling location may be moved to the nearest soil location. A gamma scan will be performed over 100 percent of the affected area, and additional biased surface and subsurface soil samples will be collected, if necessary, based on the gamma scan results. The surface soil samples will be submitted immediately for analysis. Upon receipt and review of the analytical data, subsurface soil samples from locations where the associated surface soil sample analytical results exceed the soil $DCGL_W$ will also be submitted for analysis.

<u>Class 2 Land Area SUs</u>

Class 2 land area SUs include the areas surrounding the Grassy Field, to the west of the Firing Line, and to the east of the Firing Line, which are identified as SUs Nos. 4, 5, and 6 (see Table 3-3). A total of 14 surface systematic soil samples will be collected in each of these SUs. For systematic soil sampling locations that unexpectedly fall on solid surfaces (e.g., concrete, steel, or asphalt), the sampling location may be moved to the nearest soil location.

A gamma scan will be performed over 10 to 100 percent of these areas, and additional biased sampling will be conducted, as necessary, based on the gamma scan results.

<u>Class 3 Land Area SUs</u>

There are no Class 3 land area SUs at the R-14 Range.

<u>Class 1 Outdoor Solid Surface SUs</u>

There are no Class 1 outdoor solid surface SUs at the R-14 Range.

<u>Class 2 Outdoor Solid Surface SUs</u>

Class 2 outdoor solid surface SUs include the paved area associated with the Class 2 land area around the Grassy Field, the paved area associated with the Class 2 land area west of the Firing Line, and the paved area associated with the Class 2 land area east of the Firing Line, which are identified as SU Nos. 4A, 5A, and 6A (see Table 3-3). A total of 20 systematic direct alpha measurements will be performed in each of the SUs. A smear will be obtained at each direct measurement location to assess removable contamination. A gamma scan with the NaI detector will be performed over 10 to 100 percent of the accessible surface area, and additional biased direct alpha measurements will be obtained, if necessary, based on the gamma scan results.

<u>Class 3 Outdoor Solid Surface SUs</u>

There are no Class 3 outdoor solid surface SUs at the R-14 Range.

<u>Class 1 Structure SUs</u>

Class 1 structure SUs include the concrete slabs, steel floors, and asphalt pads that remain within the structure footprints following the demolition and removal of structures, as well as any paved areas in the immediate vicinity of the structure footprints. Class 1 structure SUs are identified as SU Nos. 7A through 7H (see Table 3-4). A total of 20 systematic direct alpha measurements will be performed in each of these SUs. Additionally, a smear will be obtained at each direct alpha measurement location to assess removable alpha contamination. Surface activity beta scans will be performed over 100 percent of the accessible concrete and steel areas. For paved areas in these SUs, a gamma scan with the NaI detector may be performed in lieu of the beta scan. Additional biased direct alpha measurements will be obtained, if necessary, based on the results of the surface activity scans.

<u>Class 2 Structure SUs</u>

There are no Class 2 structure SUs at the R-14 Range.

Class 3 Structure SUs

Class 3 structures include the Wash Rack Shed and Building 1150D. In both structures, SUs are limited to floors and lower walls, which comprise a single SU in each. The floor and lower wall SU in the Wash Rack Shed is identified as SU No. 8. The floor and lower wall SU in Building 1150D is identified as SU No. 9. A total of 20 random direct alpha measurements will be collected in each of the SUs. Additionally, a smear will be obtained at each direct alpha measurement location to assess removable alpha contamination. Surface activity beta scans will be performed over 10 percent of accessible floor and lower wall surface area in each SU at locations of greatest contamination potential.

4.0 SURVEY INSTRUMENTATION AND TECHNIQUES

This section describes the instrumentation and methodology that will be used for direct radiation measurement, smear survey collection, gamma scan survey (i.e., gamma walkover survey [GWS]), and volumetric sample analysis during the FSS of the R-14 Range. Specific survey and sampling requirements, including types of surveys and percent coverage, numbers and types of samples, and analytical tests to be performed are discussed in Section 3.8. The MDC and MDCR required for the building surface activity scans, integrated alpha surface activity measurements, and GWS are calculated in accordance with MARSSIM (NRC, 2000) and NUREG-1507 (NRC, 1998).

4.1 Surface Scan Surveys

Building surfaces and outdoor solid surface SUs will be surveyed for radioactivity using direct surface scan and static measurement techniques. Surveys will be performed in accordance with CABRERA Operating Procedure (OP) 020: *Operation of Contamination Survey Meters,* as described in the following sections.

4.1.1 Ludlum Model 43-37

Surface scanning for radioactivity will be performed to identify locations of highest surface activity. Once identified, these locations may be further evaluated by performing integrated alpha activity measurements. Beta scans will be performed on floor surfaces and lower walls using a Ludlum Model 43-37 gas proportional detector (with an active area of 582 cm^2), or equivalent. The scan rate for the Ludlum Model 43-37 will not exceed six inches per second as an upper bounding scan rate, with a measurement interval of one observation per second (1/sec). The Ludlum Model 43-37 beta scan MDCR is indicated in Table 4-1. Details of the MDCR calculation for this instrument are presented in Appendix B.

Scans will be performed by moving the active area of the detector over the surface of interest, with the active area of the detector at a maximum height of 0.5 centimeter (cm) above the surface. During the scan survey in Class 1 SUs, if the surveyor observes a beta count rate higher than approximately twice the scan MDCR above background, the area will be identified as a potential location for additional biased integrated alpha measurements. During scan surveys in Class 2 and Class 3 SUs, if the surveyor observes a beta count rate higher than the scan MDCR, the area will be identified for additional biased integrated alpha measurements. Scan assumptions and the action level to be used in identifying potential biased measurement locations using the Ludlum Model 43-37 are provided in Table 4-1.

4.1.2 Ludlum Model 43-68

Some surfaces may not be readily scanned using the Ludlum Model 43-37 detector due to the large size of the detector. These areas may alternatively be scanned with a Ludlum Model 43-68 handheld gas proportional detector (with an active area of 126 cm^2), or equivalent. The beta scan assumptions, MDCR, and Class 1 action level for the Ludlum Model 43-68 are provided in Table 4-1. Details of the MDCR calculation for this instrument are presented in Appendix B.

Table 4-1: Beta Surface Scan Sensitivity Assumptions

Detector Model No.	Probe Area (cm^2)	Probe Width (cm)	Beta Bkg. (cpm)	Observation Interval (observations/sec)	MDCR (cpm)	Class 1 Scan Action Level (cpm above bkg)
43-37	582	15	1386	1	397	800
43-68	126	9	300	1	185	400

cm = centimeter(s)
bkg = background
sec = second(s)
cm^2 = square centimeter(s)
cpm = count(s) per minute

4.2 Integrated Direct Surface Measurements

Integrated direct measurements (i.e., static measurements) of surface alpha radioactivity will be performed to compare contaminant concentrations at discrete sampling locations to the building release criterion and facilitate statistical testing. If necessary, interior surfaces may be cleaned prior to surveying to remove dirt and grime that could shield alpha emissions from surfaces of interest. The cleaning implements used and the wastes generated during cleaning will be collected and stored onsite, then decontaminated and/or disposed in accordance with project waste management procedures. Integrated alpha activity measurements may be performed using the Ludlum Model 43-37 gas proportional detector, Ludlum Model 43-68 handheld gas proportional detector (operating in alpha mode only), Ludlum Model 43-89 handheld scintillation detector (with an active area of 126 cm^2), or equivalent. The estimated detector sensitivity and relevant assumptions are presented in Table 4-2.

Integrated alpha measurements will be performed in accordance with CABRERA procedures OP-020: *Operation of Contamination Survey Meters;* OP-021: *Alpha-Beta Counting Instrumentation;* and CABRERA standard radiation instrumentation templates contained in the *Alpha Beta Counting and Smear Worksheet.* The net count rate at each location will be calculated as the difference between the measurement count rate and the background count rate.

Table 4-2: Integrated Alpha Measurement Sensitivity Assumptions

Model No.	Count Time (min)	Bkg. Count Time (min)	Probe Area (cm^2)	Total Alpha Efficiency (cpm/dpm)	Alpha Background (cpm)	Alpha Static MDC[1] (dpm/100 cm^2)
43-37	1	1	582	0.165	23	18
43-68	1	1	126	0.165	5	64
43-89	1	1	126	0.111	3	79

min = minute(s)
Bkg = background
cm^2 = square centimeter(s)
cpm = count(s) per minute
dpm = disintegration(s) per minute
[1]Static alpha measurements will be compared to the building surface $DCGL_W$ (100 dpm/100 cm^2).

4.3 Smear Sample Collection and Analysis

Smear samples will be collected at systematic and biased direct surface activity measurement locations to quantify transferable surface alpha radioactivity. Smear samples will be obtained in accordance with CABRERA OP-021: *Alpha-Beta Counting Instrumentation* and analyzed using a Ludlum Model 43-10-1 detector coupled to a Ludlum Model 2929 dual scaler, or equivalent.

Count times for smears will initially be set at 4 minutes for surface smear measurements and 20 minutes for background measurements. Count times may be adjusted, if necessary, in accordance with the OP. If necessary, smears will be allowed to decay for at least 24 hours to eliminate radon progeny prior to onsite measurement. Smears that must be counted immediately will be recounted after at least 24 hours of decay time, if necessary. The smear sample alpha MDC and relevant assumptions are provided in Table 4-3.

Table 4-3: Removable Surface Activity (Smear) Sensitivity Assumptions

Instrument Model No.	Count Time (min)	Bkg. Count Time (min)	Probe Area (cm^2)	Alpha Efficiency (cpm /dpm)	Alpha Background (cpm)	Alpha MDC[1] (dpm/100 cm^2)
2929	4	20	Smear	0.33	0.8	7

min = minute(s)
Bkg = background
cm^2 = square centimeter(s)
cpm = count(s) per minute
dpm = disintegration(s) per minute
[1]Smear measurements of alpha activity will be compared to the removable activity $DCGL_W$ (10 dpm/100 cm^2).

4.4 Gamma Scans

Outdoor gamma scans will be performed in accordance with CABRERA OP-001: *Radiological Surveys*. Scan surveys on pavement and land areas will be performed using a Ludlum Model 44-20 three-inch by three-inch (3-in. x 3-in.) NaI detector coupled to a Ludlum Model 2221 ratemeter, or equivalent. This instrument will be enabled with a differential GPS so that activity measurements can be spatially referenced.

The MDC for DU in soil is provided in terms of pCi/g in Table 4-4. A more detailed evaluation of the MDC for the GWS instrumentation is presented in Appendix B.

Table 4-4: Gamma Scan Survey Sensitivity Assumptions

Detector Model No.	Survey Speed (m/sec)	Bkg. (cpm)	Observation Interval (observations/sec)	MDCR[1] (cpm)	MDC (pCi/g)
44-20	0.5	27,000	1	2,484	32.9

m = meter(s)
cpm = count(s) per minute
pCi/g = picocuries per gram
sec = second(s)
MDCR = minimum detectable count rate
MDC = minimum detectable concentration
[1] Assumes a surveyor efficiency of 50%

4.5 Volumetric Sample Collection and Analysis

Volumetric systematic and biased soil/sediment samples from land areas will be collected and submitted to an off-site laboratory for analysis by gamma spectroscopy. Samples will be collected in accordance with CABRERA OP-005: *Volumetric and Material Sampling*, and analyzed in accordance with the analytical laboratory's standard operating procedures. The analytical test methods used to analyze radionuclides in volumetric samples at the off-site laboratory will be verified as being able to achieve an MDC of 10% of the soil $DCGL_W$.

Soil and sediment samples will be collected using a hand auger or stainless steel trowel, and homogenized in a stainless steel bowl prior to containerization. During the homogenization of soil samples, twigs, stones, and other non-soil items will be removed from the sample material. Samples will be handled, labeled, packaged, preserved, and shipped as described in CABRERA OP-005. Sample chain of custody will be maintained in accordance with CABRERA OP-008: *Chain of Custody*. Field quality control (QC) samples (e.g., duplicate) will be collected and analyzed at a frequency of one per ten target samples. Laboratory QC samples will be prepared and analyzed in accordance with the analytical laboratory's Quality Assurance Plan.

5.0 SURVEY QUALITY ASSURANCE/QUALITY CONTROL

Activities associated with this work plan will be performed in accordance with written operating procedures and/or protocols to ensure consistent, repeatable results and to provide auditable documentation of activities. Topics addressed in project procedures and protocols include, but are not limited to, the following:

- Proper use of instrumentation,
- QC source and background checks, and
- Duplicate measurements.

Specific quality assurance (QA) and QC measures to be implemented during the R-14 Range FSS are described in this section.

5.1 Instrumentation Requirements

The Project Health Physicist (HP) will be responsible for selecting the instrumentation required to complete the FSS. Only instrumentation approved by the Project HP will be used to collect radiological data. The Project HP will be responsible for ensuring that individuals are appropriately trained to use the instrumentation and other equipment, and that the selected instrumentation meets the required detection sensitivities. Instrumentation will be operated in accordance with either a written operating procedure or manufacturers' manual, as determined by the Project HP. The procedure and/or manual will provide guidance to field personnel on the proper use and limitations of the instrument.

Instruments used during the FSS will have current calibration and maintenance records that will be maintained onsite for review and inspection. The records will include, at a minimum, the following types of information: description of equipment, equipment identification (model and serial number), manufacturer, date of last calibration, and calibration due date.

Instrumentation will be maintained and calibrated to manufacturers' specifications to ensure that the required traceability, sensitivity, accuracy, and precision of the equipment/instruments are maintained. Instruments will be calibrated at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using National Institute of Standards and Technology (NIST) traceable sources.

5.2 Instrument QC Source and Background Checks

The following subsections describe the techniques that will be used to evaluate accuracy and precision of measurements obtained using project instrumentation. Daily instrument response check data and calibration certificates for each instrument will be included in an appendix to the FSS Report.

5.2.1 Gross Gamma Instruments

NaI detectors coupled to count rate meters and GPS systems will be used to perform gamma walkover surveys and integrated fixed location measurements, as well as to frisk equipment and personnel. Instruments will be calibrated at least annually at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Gross gamma instruments will be response-checked daily for QC purposes by comparing the instrument response to a cesium-137 (^{137}Cs) source. Response checks will consist of a one-minute integrated count of the ^{137}Cs source positioned in a reproducible geometry (i.e., a jig). The acceptance criteria for these instrument response checks are +/- 20% of the mean response generated using ten initial source checks and ten measurements of ambient background. A response check outside these limits will be cause for evaluation of conditions (e.g., instrument operation, source/detector geometry), and the response check will be repeated once prior to field use of that instrument. Instruments that fail the second response check will be removed from service. During daily response checks, instruments will be inspected for physical damage, battery voltage levels, current calibration, and erroneous readings, in accordance with CABRERA procedures.

Background checks will be performed daily for each instrument. These checks will be performed to monitor fluctuations in ambient gamma background that could impact the interpretation of the gross gamma measurements, not to monitor the performance of the instruments. The results of the background measurements will be recorded and presented on a control chart.

5.2.2 Alpha/Beta Detectors and Smear Counter

Alpha/beta detectors (e.g., Ludlum Models 43-68, 43-37, and 43-89) and a smear counter (Ludlum Model 2929) will be used to obtain quantitative measurements for final status survey purposes. These instruments will be calibrated at least annually at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Instruments used for quantitative measurements will be response checked daily by comparing response to designated thorium–230 (^{230}Th) and technetium-99 (^{99}Tc) NIST-traceable sources and to ambient background. Response checks will consist of a one-minute count of the ^{230}Th and ^{99}Tc sources positioned in a reproducible geometry and location within the detector system. Background measurements will be performed in an identical fashion for a twenty-minute count, with the source removed. The acceptance criteria for these instrument response checks will be two and three-sigma of the mean response generated using ten initial source checks and ten measurements of ambient background. A response check outside the two-sigma range, but within the three-sigma range will be cause for a recount prior to further evaluation. A response check outside the two-sigma range on the second count or three-sigma range on the initial count will be cause for further evaluation prior to continued use. A response check outside these limits is cause for an evaluation of conditions (e.g., instrument operation, source/detector geometry) prior to further counts and/or removal of the instrument from service. Instruments must pass a response check prior to field use. During daily response checks, instruments used to obtain radiological data will also be inspected for physical damage, battery voltage levels, current calibration, and erroneous readings, in accordance with CABRERA procedures.

5.3 Duplicate Measurements

Duplicate measurements will be required for 10% of the total soil samples collected from all SUs. Duplicate measurements of radioactivity concentration will be compared to the initial analytical results by determining a z-score and comparing it against the performance criteria as follows.

The z-score for each data set will be calculated using the following equation:

$$\text{Z-score} = \frac{|\text{Sample - Duplicate}|}{\sqrt{\sigma^2_{\text{Sample}} + \sigma^2_{\text{Duplicate}}}}$$

Where:

Sample = First sample value (original),

Duplicate = Second sample value (duplicate),

σ_{Sample} = 2σ counting uncertainty of the sample, and,

$\sigma_{Duplicate}$ = 2σ counting uncertainty of the duplicate.

The calculated z-score results will be compared to a performance criterion of less than or equal to 1.96. Calculated z-scores less than 1.96 will be considered acceptable, and values greater than 1.96 will be investigated for possible discrepancies in analytical precision, or for sources of disagreement with the following assumptions of the test:

- The sample measurement and duplicate or replicate measurement are of the same normally distributed population.
- The standard deviations, σ_{Sample} and $\sigma_{Duplicate}$, represent the true standard deviation of the measured population.

6.0 DATA EVALUATION AND COMPLIANCE DEMONSTRATION

The data generated during the FSS will be reviewed to ensure that the quality and quantity are consistent with the FSSP and design assumptions. Data deemed to be acceptable will be used to evaluate compliance with the DCGLs established for this site, as described below.

6.1 Data Review and Investigation Thresholds

Analytical data received from the off-site laboratory will be reviewed to ensure that the data are of acceptable quality for its intended use. The following types of information will be evaluated:

- Correlation among the FSSP, chain-of-custody, and laboratory reports with respect to sample identification numbers and analytical methods;
- Whether project-specific MDCs were achieved;
- Instrumentation or cross-contamination issues that may have impacted the integrity and/or accuracy of reported results; and
- Comparison of QC sample data to project acceptability criteria.

The FSS measurement data for each SU will be evaluated by comparing the standard deviations of data sets with the assumptions used in establishing the number of data points for each SU. Individual and average data values will be compared with the applicable $DCGL_W$ for the SU, and proper survey area classification will be confirmed. Individual measurements in excess of the $DCGL_W$ for Class 1 and 2 areas will be further investigated by means of additional measurements and evaluation of background.

For Class 3 structure SUs, measurements in excess of 50% of the $DCGL_W$ will be investigated. This is less conservative than the recommendation provided in MARSSIM (NRC, 2000), which suggests that any measurements higher than the MDCR be investigated. However, a higher investigation threshold is necessary at the R-14 Range due to the low $DCGL_W$ values relative to background. Should a SU require further investigation, reclassification, remediation, and/or re-survey, a determination of the cause will be initiated, and the data conversion and assessment process will be repeated for new data sets.

6.2 Determining Compliance With DCGLs

As discussed in Section 3.2, both soil concentration and surface activity DCGLs have been developed for evaluation of the FSS data. These DCGLs address the mean activity concentration over a wide area (i.e., the $DCGL_W$), and also provide for small areas of elevated contamination in excess of the $DCGL_W$ (i.e., the $DCGL_{EMC}$). Demonstrations of compliance with both requirements for each SU are discussed in the following sections.

6.2.1 Land Area and Structure SUs

Land area systematic soil samples and structure SU direct surface activity measurements will be evaluated using the Sign test. Individual sample activity values and the average SU activity will be calculated. If all values from the random or random-start/systematic locations for a SU are less than the guideline ($DCGL_w$ for Class 1 and 2 land and structure SUs; 50% of the $DCGL_w$ for Class 3 structure SUs), the SU satisfies the criterion and no further evaluation is necessary.

If the average activity value is greater than the guideline, the SU does not satisfy the criterion and further investigation, possible reclassification, remediation, and/or re-survey is required. If the average activity value is less than the guideline, but some individual values are greater, data evaluation using the Sign test will be performed, as follows:

1. List each of the sample results or SU measurements.
2. Subtract each measurement or sample result from the guideline value.
3. Discard all differences that are “0”; determine a revised sample size.
4. Count the number of positive differences; this value is the test statistic, S+.
5. Compare the value of S+ to the critical value in MARSSIM Table I.3 (NRC, 2000) for the appropriate sample size and decision level.

If S+ is greater than the critical value, the null hypothesis is rejected and the SU meets the established criteria. If S+ is less than or equal to the critical value, the null hypothesis is not rejected, and the SU does not meet the established criteria; investigation, remediation, reclassification, and/or re-survey should be performed, as appropriate.

6.2.2 Elevated Measurement Comparison Criteria

Soil samples or direct surface activity measurement results from Class 1 SUs that exceed the $DCGL_W$ must also be evaluated for compliance with the $DCGL_{EMC}$[1]. The statistical tests for

[1] Soil sample and direct surface activity results from Class 2 and Class 3 survey units are not expected to exceed the $DCGL_W$. Therefore, the $DCGL_{EMC}$ does not apply to Class 2 and Class 3 survey units. A confirmed result

demonstrating compliance are such that some samples/measurements may exceed the $DCGL_W$, yet the null hypothesis may still be rejected. Therefore, both the statistically based and biased samples exceeding the $DCGL_W$ must be compared with a $DCGL_{EMC}$ that corresponds with the size of a given area of elevated activity, defined as the $DCGL_W$ times the Area Factor.

Default area factors for land SUs and structures, obtained from MARSSIM Table 5.6 and Table 5.7 (NRC, 2000), which will be applied to the R-14 Range FSS are provided in Table 6-1 and Table 6-2.

Table 6-1: Land Survey Unit Area Factors

Area (m^2):	1	3	10	30	100	300	1,000	3,000	10,000
^{238}U Area Factor:	30.6	18.3	11.1	8.4	6.7	4.4	1.3	1.0	1.0

Table 6-2: Structure Survey Unit Area Factors

Area (m^2):	1	4	9	16	25	36
^{238}U Area Factor:	35.7	9.0	4.0	2.2	1.4	1.0

When individual samples or measurements with elevated concentrations are less than the respective $DCGL_{EMC}$, the impact of multiple hot spots on the mean concentration in a SU must also be evaluated. This will be performed using MARSSIM Equation 8-2 (NRC, 2000). Any measurement that exceeds the $DCGL_W$ within a Class 2 or Class 3 SU will be investigated as discussed in Section 6.1, and may require reclassification of the SU.

from one of these survey units in excess of the $DCGL_W$ will typically require reclassification of all or part of the survey unit to Class 1.

7.0 REPORTING

The results of the FSS will be compiled into a detailed FSS Report. The contents of the report will provide all applicable data and documentation necessary to demonstrate the R-14 Range is suitable for unrestricted release in accordance with 10 CFR 20, Subpart E.

8.0 REFERENCES

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NRC, 2006. Title 10, Code of Federal Regulations, Part 20, Subpart E, January 2006.

FIGURES

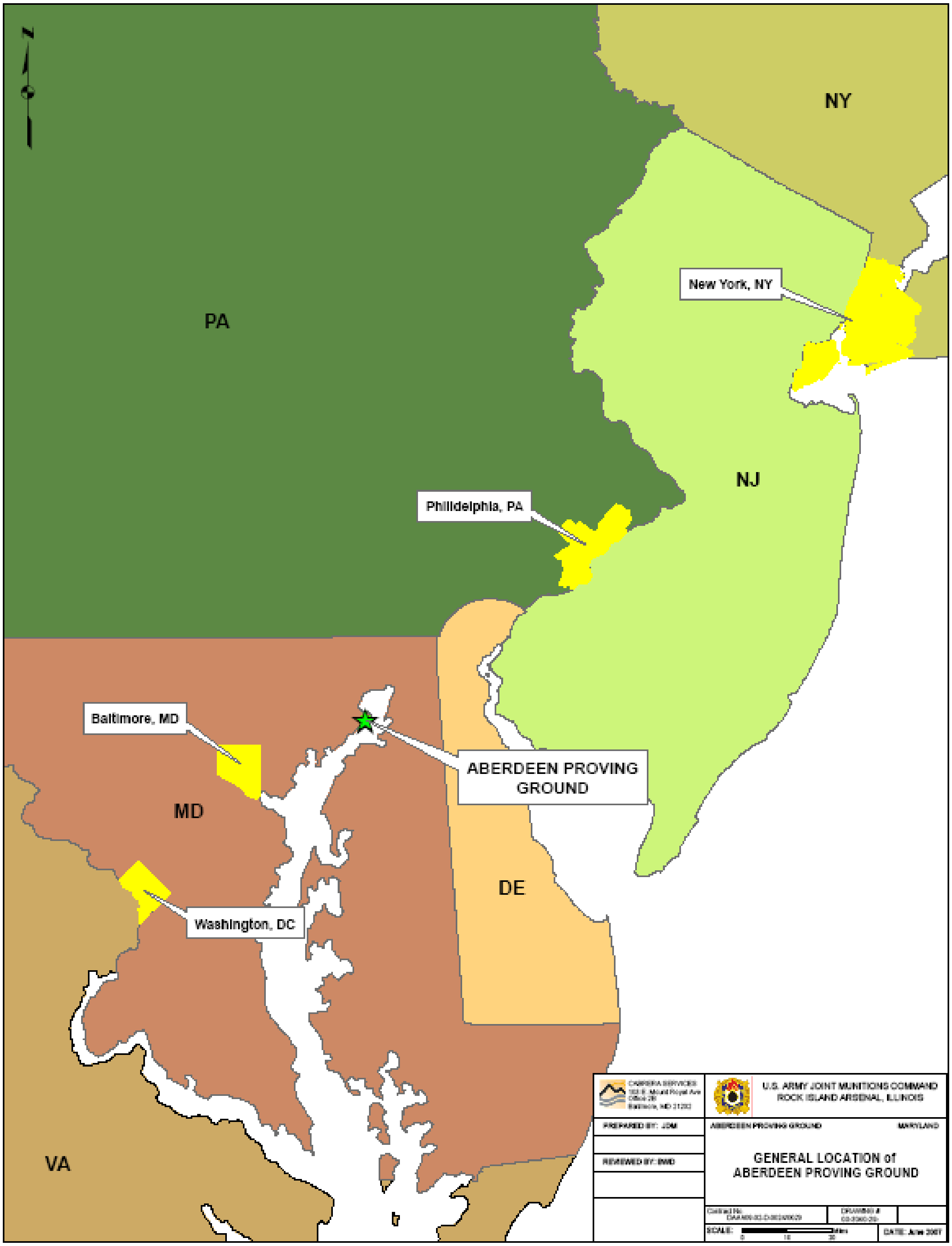


FIGURE 2-1: GENERAL LOCATION OF ABERDEEN PROVING GROUND

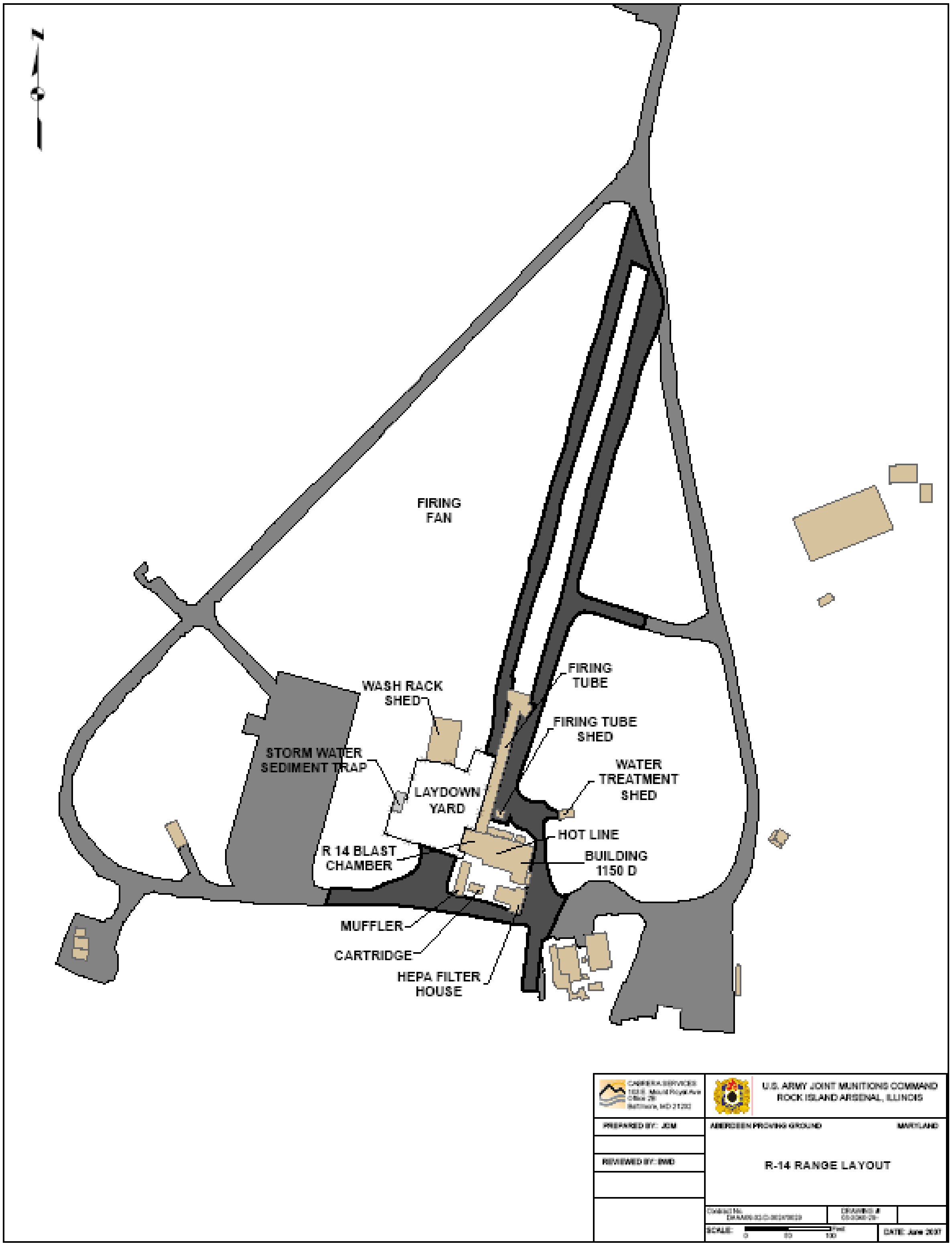


FIGURE 2-2: R-14 RANGE LAYOUT (CURRENT)

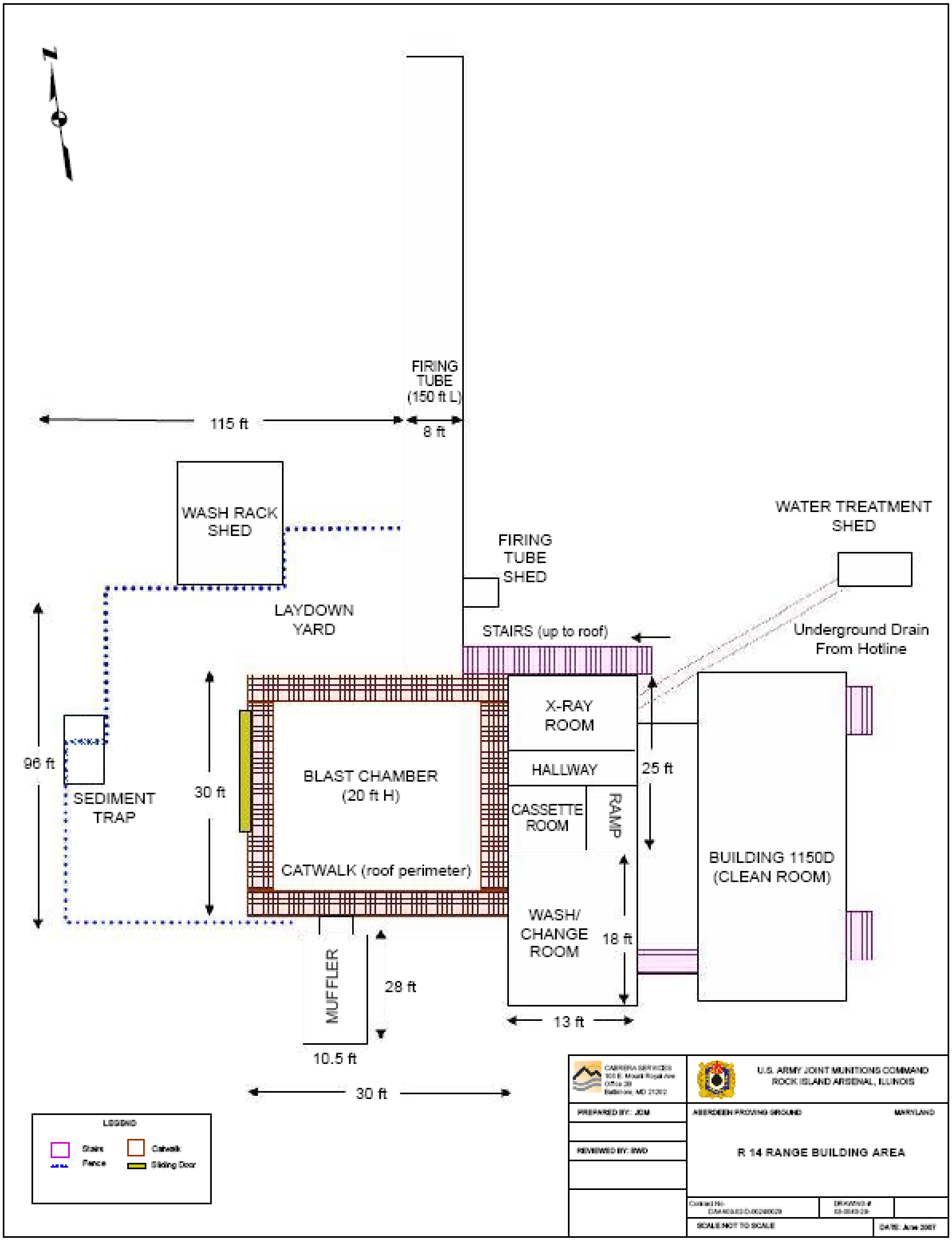


FIGURE 2-3: R-14 RANGE BUILDING AREA (CURRENT)

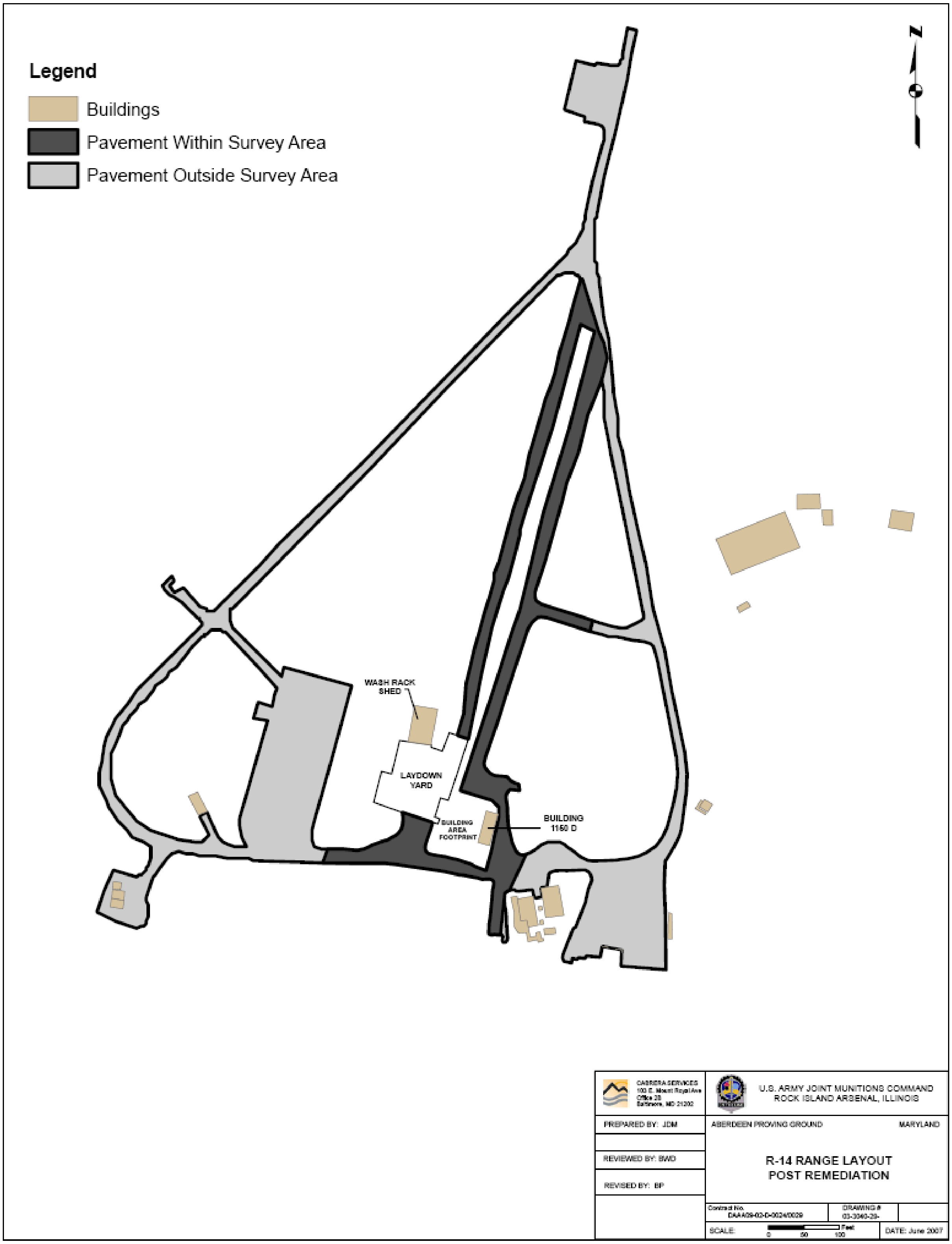


FIGURE 3-1: R-14 RANGE LAYOUT (POST-REMEDIATION)

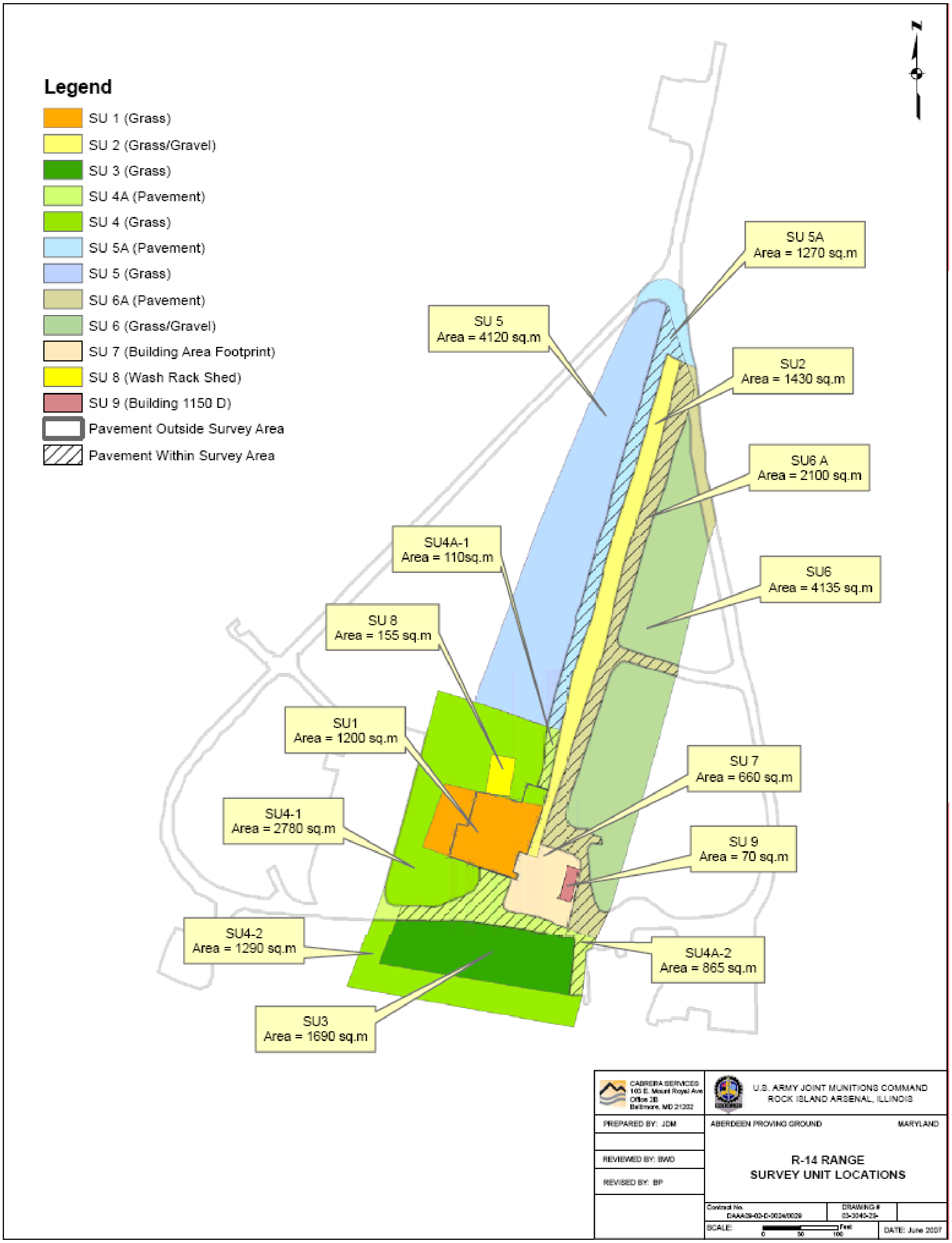


FIGURE 3-2: R-14 RANGE SURVEY UNIT LOCATIONS

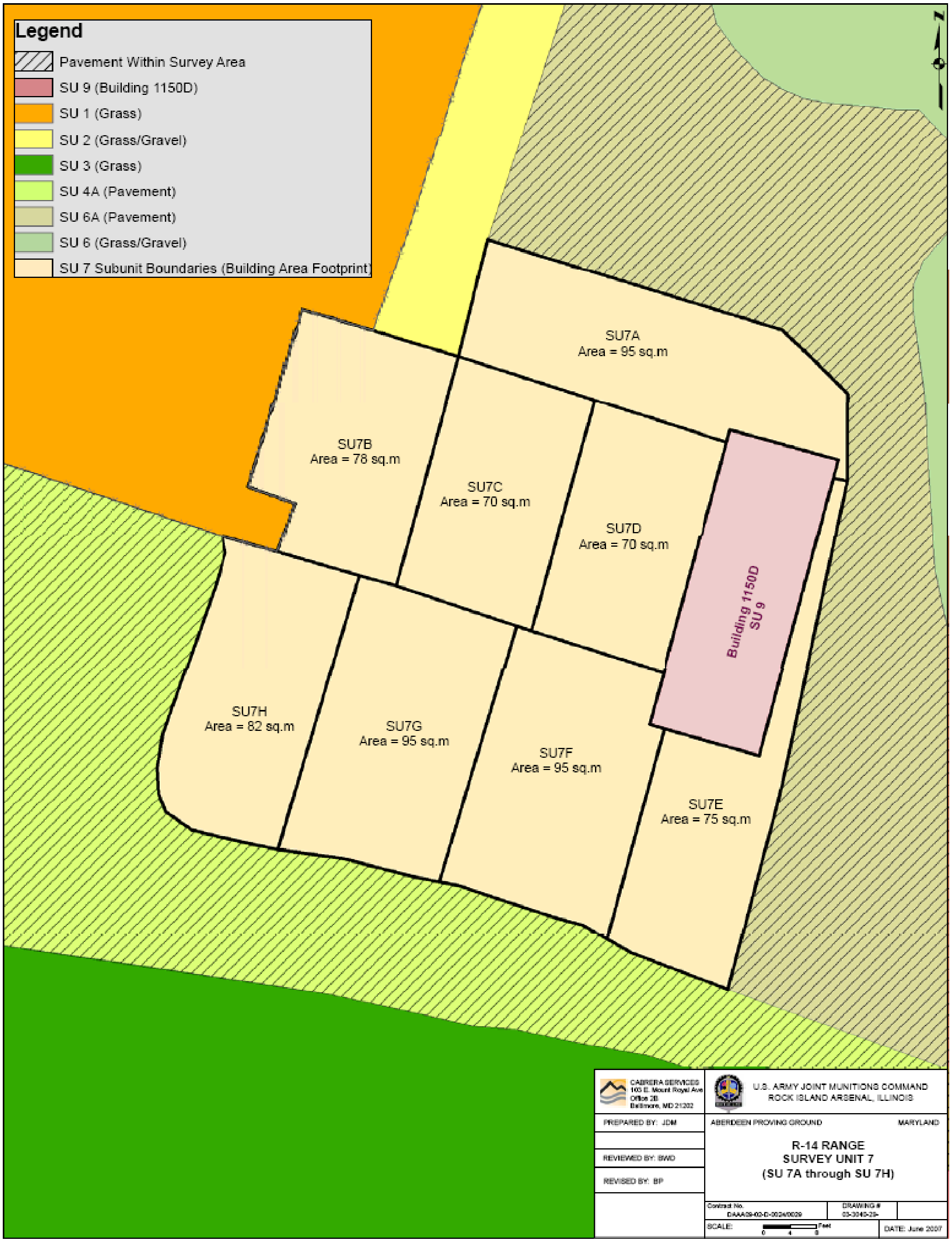
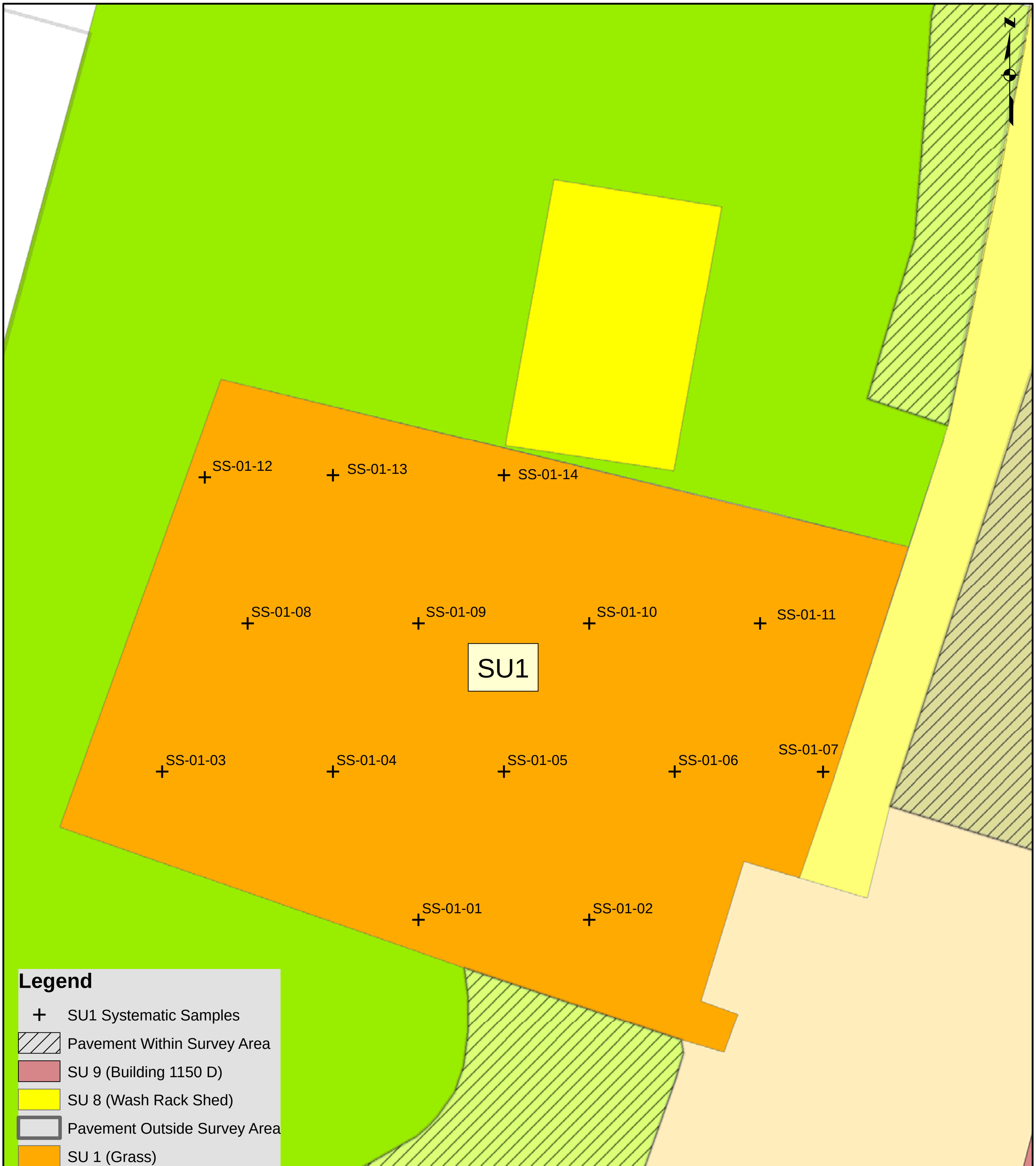


FIGURE 3-3: R-14 RANGE SURVEY UNIT 7 (SU 7A THROUGH SU 7H)

APPENDIX A

SURVEY UNIT MAPS



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REVISED BY: BP

ABERDEEN PROVING GROUND MARYLAND

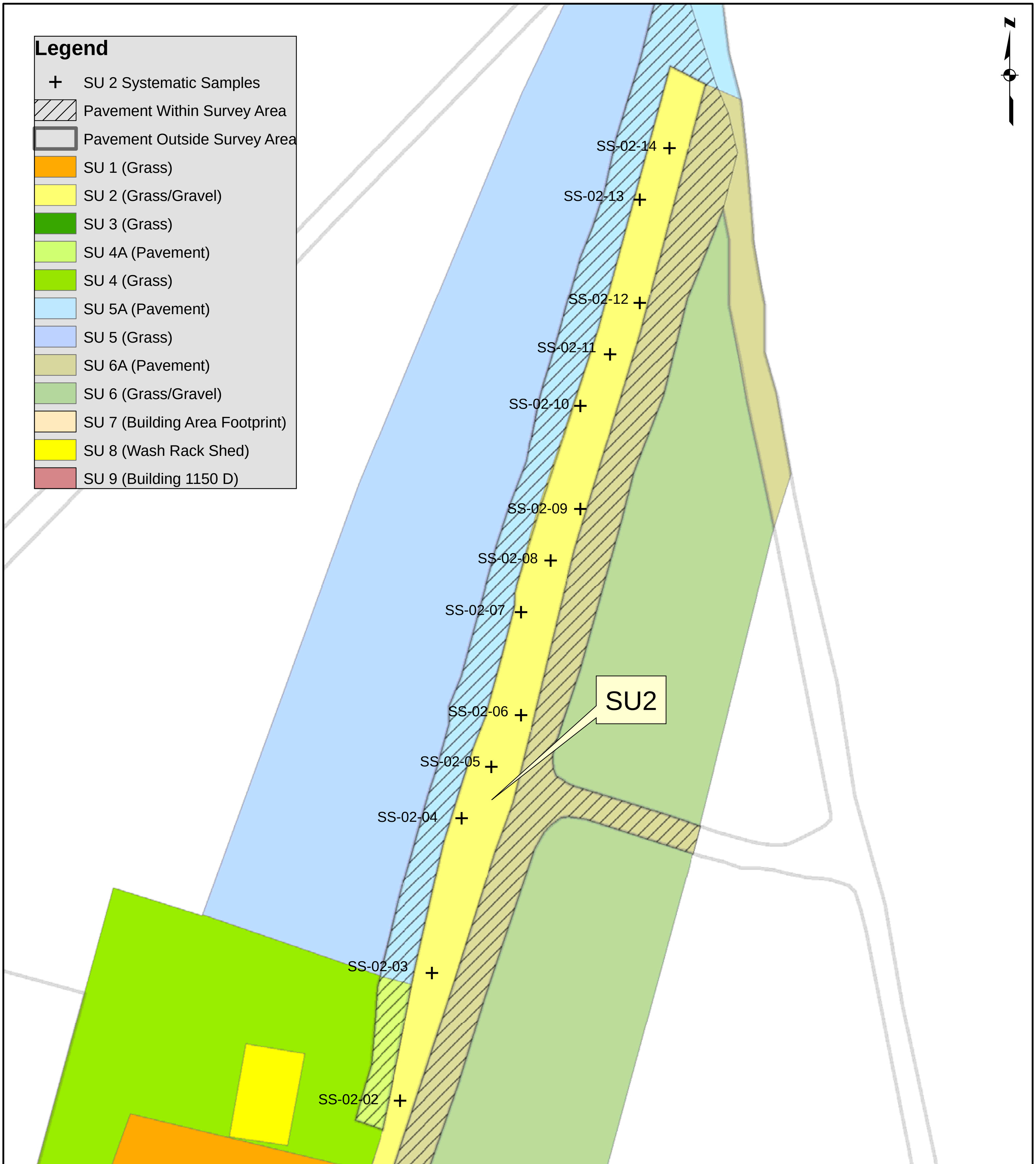
R-14 RANGE
SU 1 SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 10 20 Feet

DATE: June 2007



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ABERDEEN PROVING GROUND MARYLAND

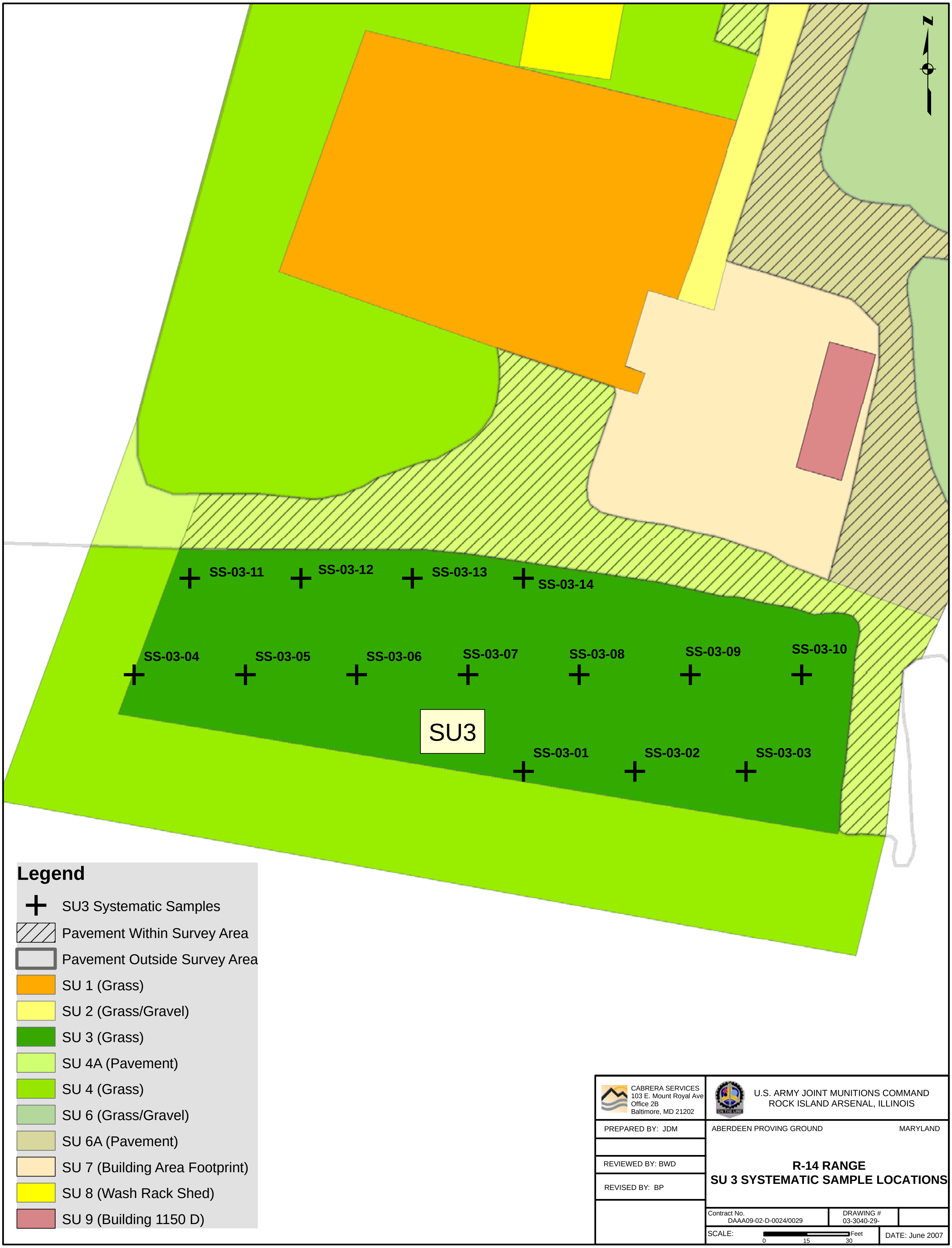
R-14 RANGE
SU 2 SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 30 60 Feet

DATE: June 2007



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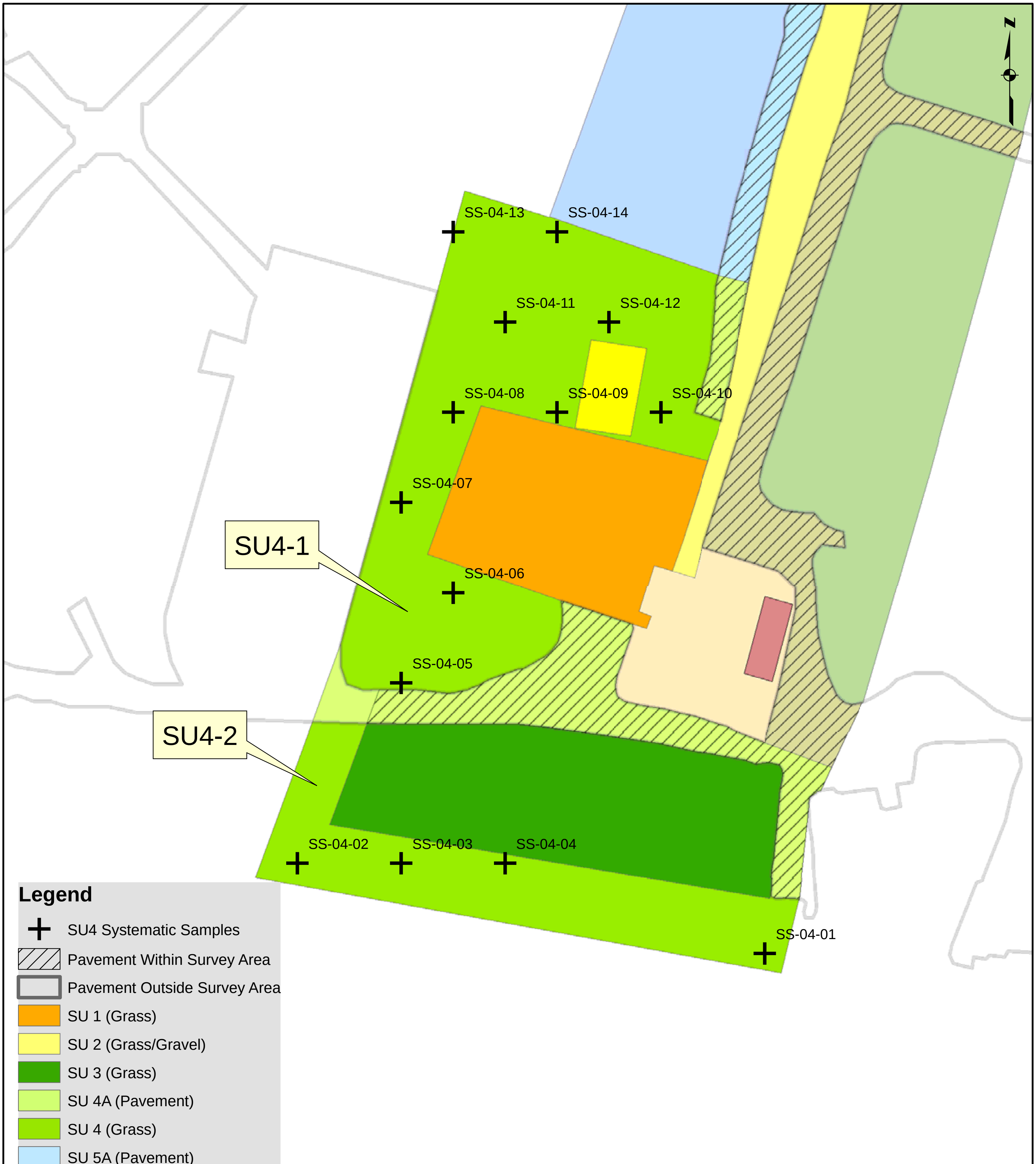
R-14 RANGE
SU 3 SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 15 30 Feet

DATE: June 2007



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REVIEWED BY: BWD

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ABERDEEN PROVING GROUND MARYLAND

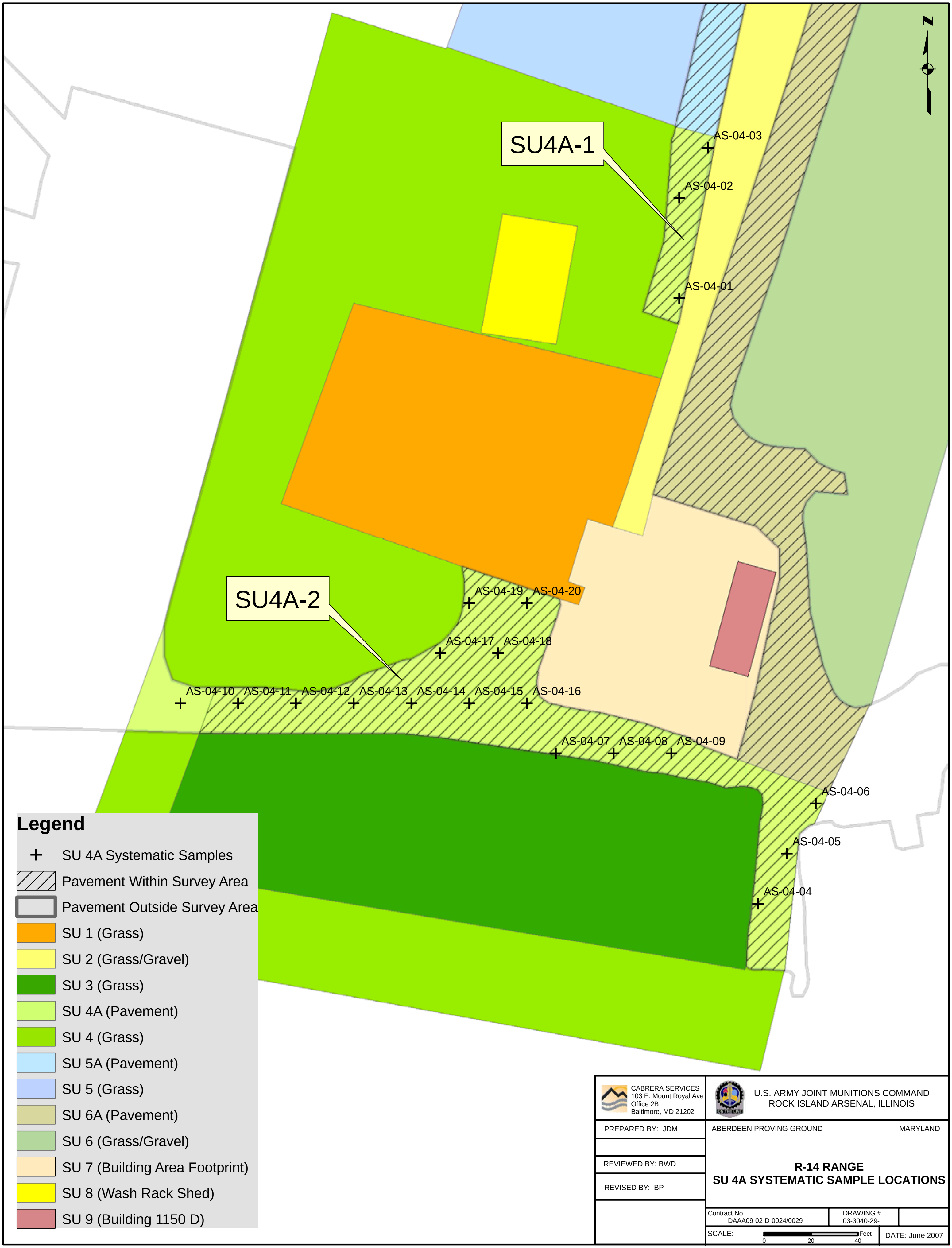
R-14 RANGE
SU 4 SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 30 60 Feet

DATE: June 2007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AS-04-13
AS-04-14
AS-04-15
AS-04-16
AS-04-17
AS-04-18
AS-04-19
AS-04-20
N
Legend
SU 4A Systematic Samples
Pavement Within Survey Area
Pavement Outside Survey Area
SU 1 (Grass)
SU 2 (Grass/Gravel)
SU 3 (Grass)
SU 4A (Pavement)
SU 4 (Grass)
SU 5A (Pavement)
SU 5 (Grass)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
SU 7 (Building Area Footprint)
SU 8 (Wash Rack Shed)
SU 9 (Building 1150 D)
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R-14 RANGE
SU 4A SYSTEMATIC SAMPLE LOCATIONS
Contract No.
DAAA09-02-D-0024/0029
DRAWING #
03-3040-29-
SCALE:
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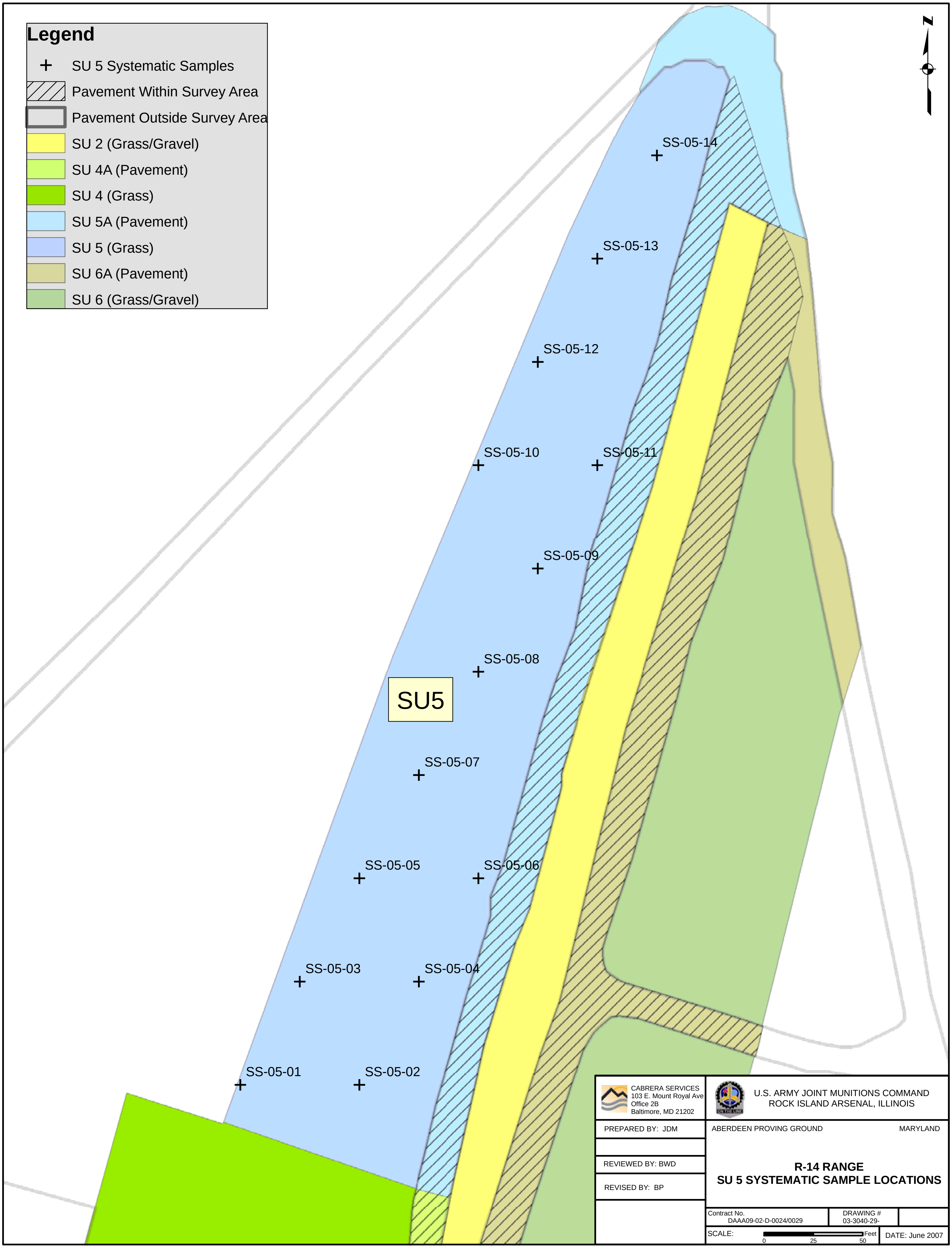
DATE: June 2007



Legend
SU 5 Systematic Samples
Pavement Within Survey Area
Pavement Outside Survey Area
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SU 4A (Pavement)
SU 4 (Grass)
SU 5A (Pavement)
SU 5 (Grass)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
N
SS-05-14
SS-05-13
SS-05-12
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SS-05-11
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SS-05-08
SU5
SS-05-07
SS-05-05
SS-05-06
SS-05-03
SS-05-04
SS-05-01
SS-05-02
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SU 5 SYSTEMATIC SAMPLE LOCATIONS
REVISED BY: BP
Contract No.
DAAA09-02-D-0024/0029
DRAWING #
03-3040-29-
SCALE:
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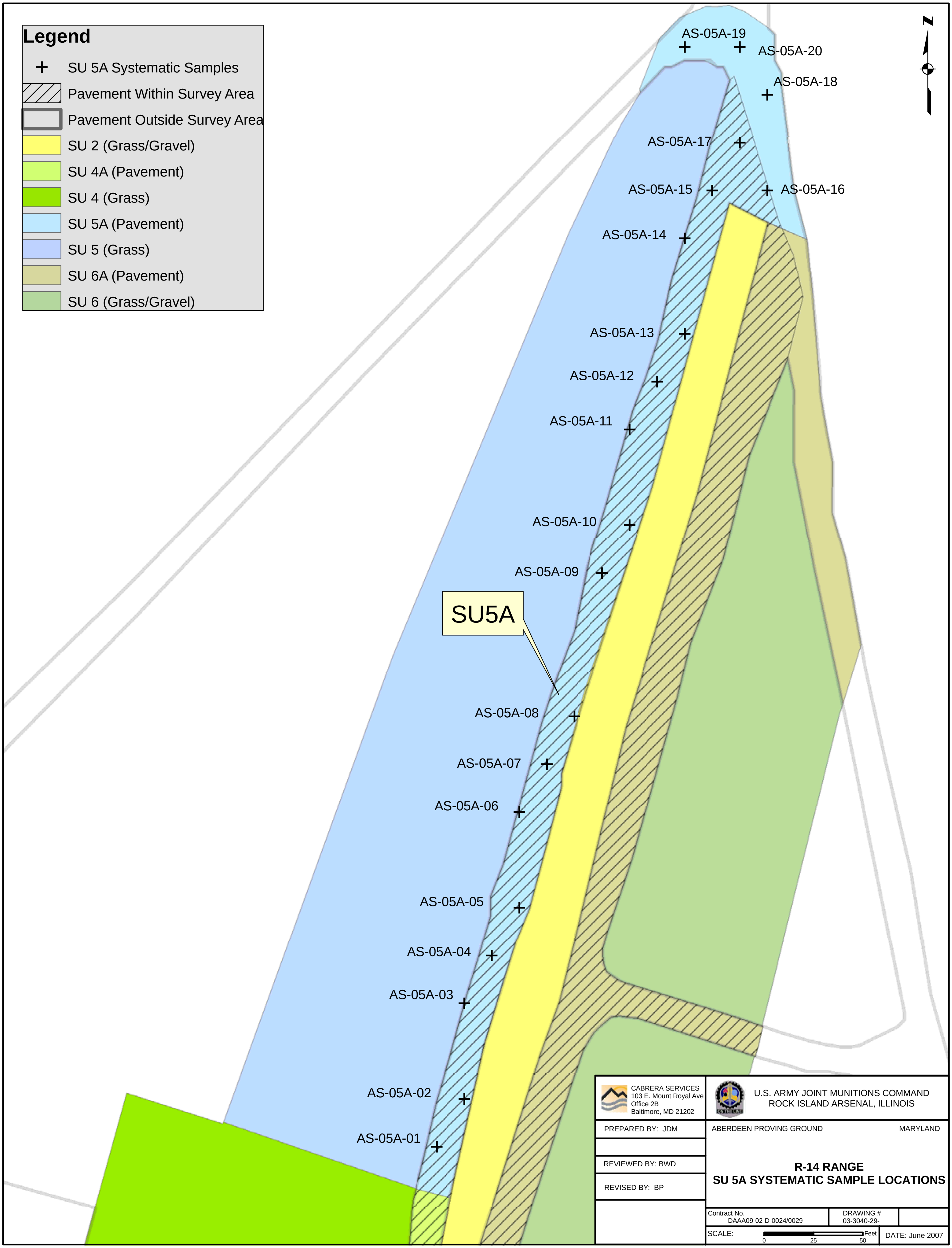
Feet
DATE: June 2007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Pavement Within Survey Area
Pavement Outside Survey Area
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SU 4A (Pavement)
SU 4 (Grass)
SU 5A (Pavement)
SU 5 (Grass)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
N
AS-05A-19
AS-05A-20
AS-05A-18
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AS-05A-15
AS-05A-16
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AS-05A-07
AS-05A-06
AS-05A-05
AS-05A-04
AS-05A-03
AS-05A-02
AS-05A-01
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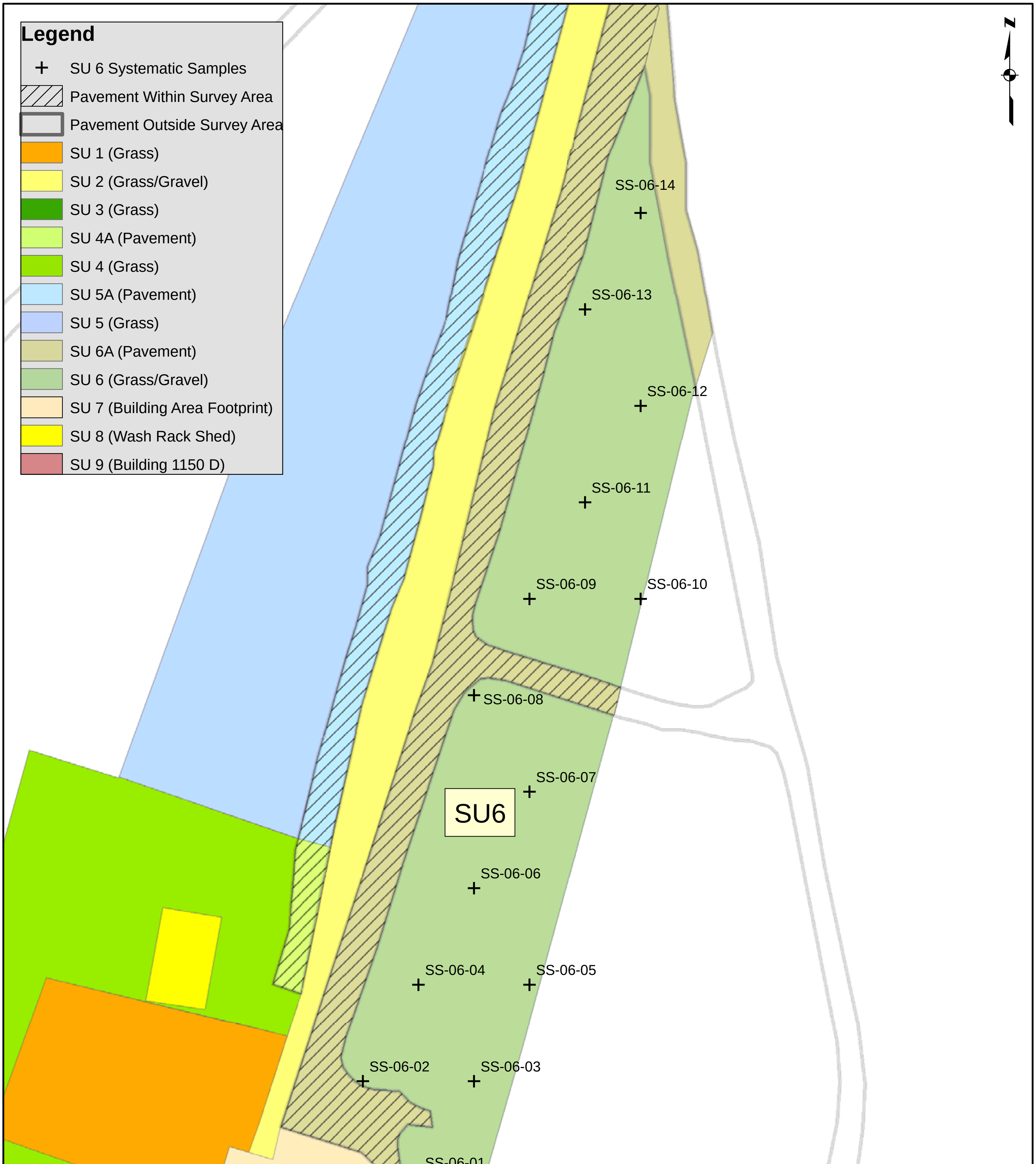
R-14 RANGE
SU 5A SYSTEMATIC SAMPLE LOCATIONS
Contract No.
DAAA09-02-D-0024/0029
DRAWING #
03-3040-29-
SCALE:
0
25
50
Feet
DATE: June 2007



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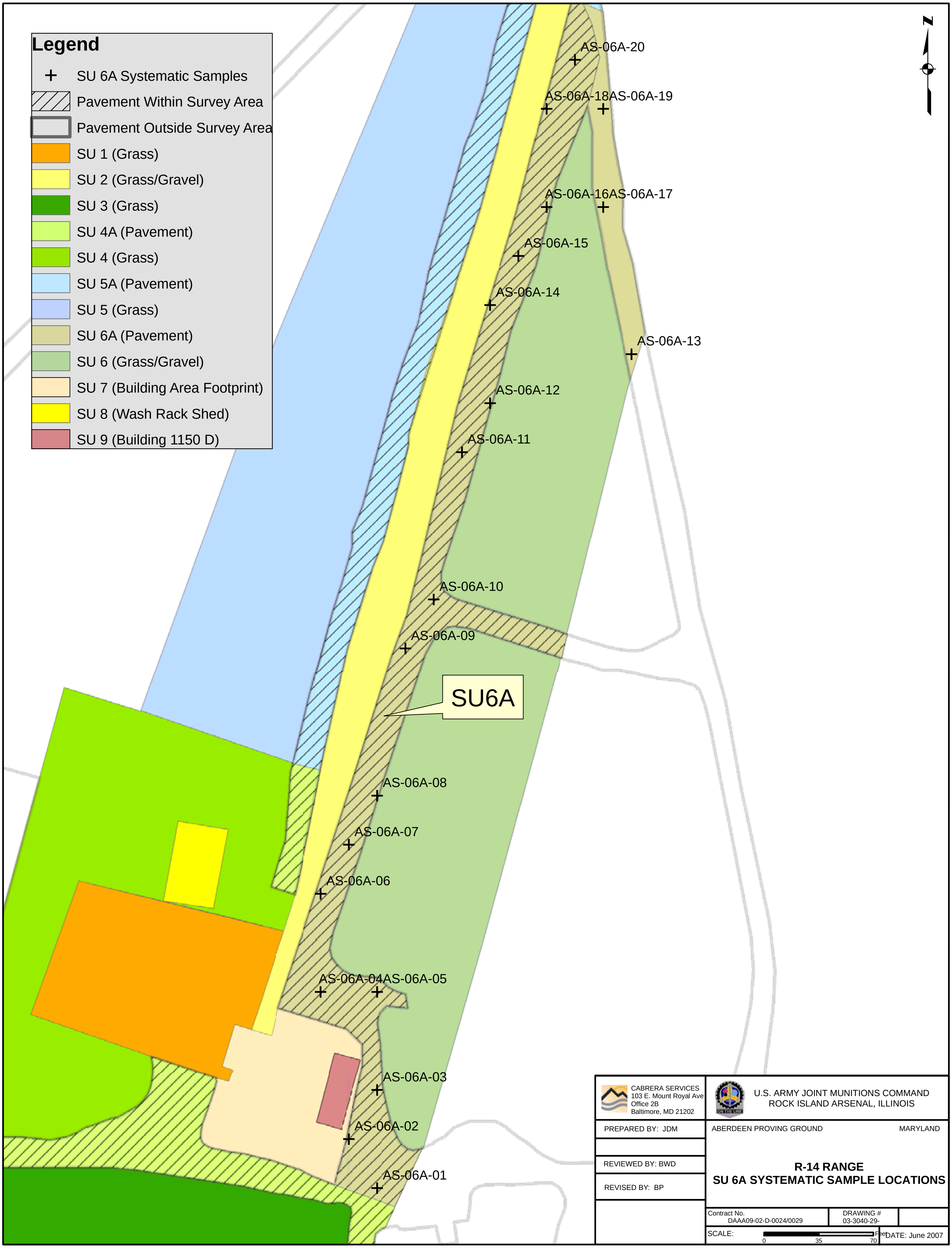
R-14 RANGE
SU 6 SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 30 60 Feet

DATE: June 2007



Legend
SU 6A Systematic Samples
Pavement Within Survey Area
Pavement Outside Survey Area
SU 1 (Grass)
SU 2 (Grass/Gravel)
SU 3 (Grass)
SU 4A (Pavement)
SU 4 (Grass)
SU 5A (Pavement)
SU 5 (Grass)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
SU 7 (Building Area Footprint)
SU 8 (Wash Rack Shed)
SU 9 (Building 1150 D)
N
AS-06A-20
AS-06A-18
AS-06A-19
AS-06A-16
AS-06A-17
AS-06A-15
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AS-06A-13
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AS-06A-05
AS-06A-03
AS-06A-02
AS-06A-01
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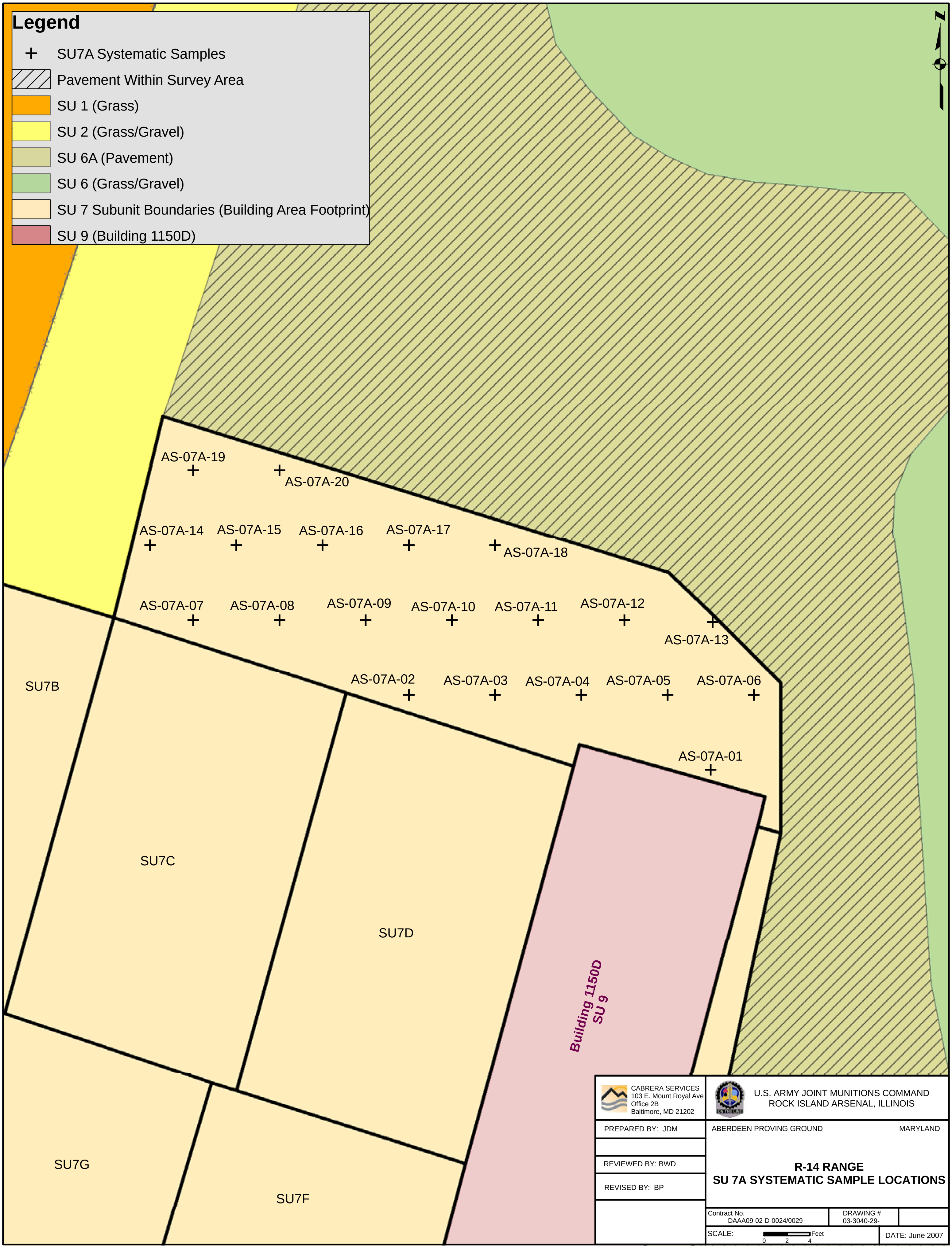
MARYLAND
R-14 RANGE
SU 6A SYSTEMATIC SAMPLE LOCATIONS
Contract No.
DAAA09-02-D-0024/0029
DRAWING #
03-3040-29-
SCALE:
0
35
70
Feet
DATE: June 2007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SU7A Systematic Samples
Pavement Within Survey Area
SU 1 (Grass)
SU 2 (Grass/Gravel)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
SU 7 Subunit Boundaries (Building Area Footprint)
SU 9 (Building 1150D)
N
AS-07A-19
AS-07A-20
AS-07A-14
AS-07A-15
AS-07A-16
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AS-07A-18
AS-07A-07
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AS-07A-13
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AS-07A-03
AS-07A-04
AS-07A-05
AS-07A-06
AS-07A-01
SU7B
SU7C
SU7D
Building 1150D
SU 9
SU7G
SU7F
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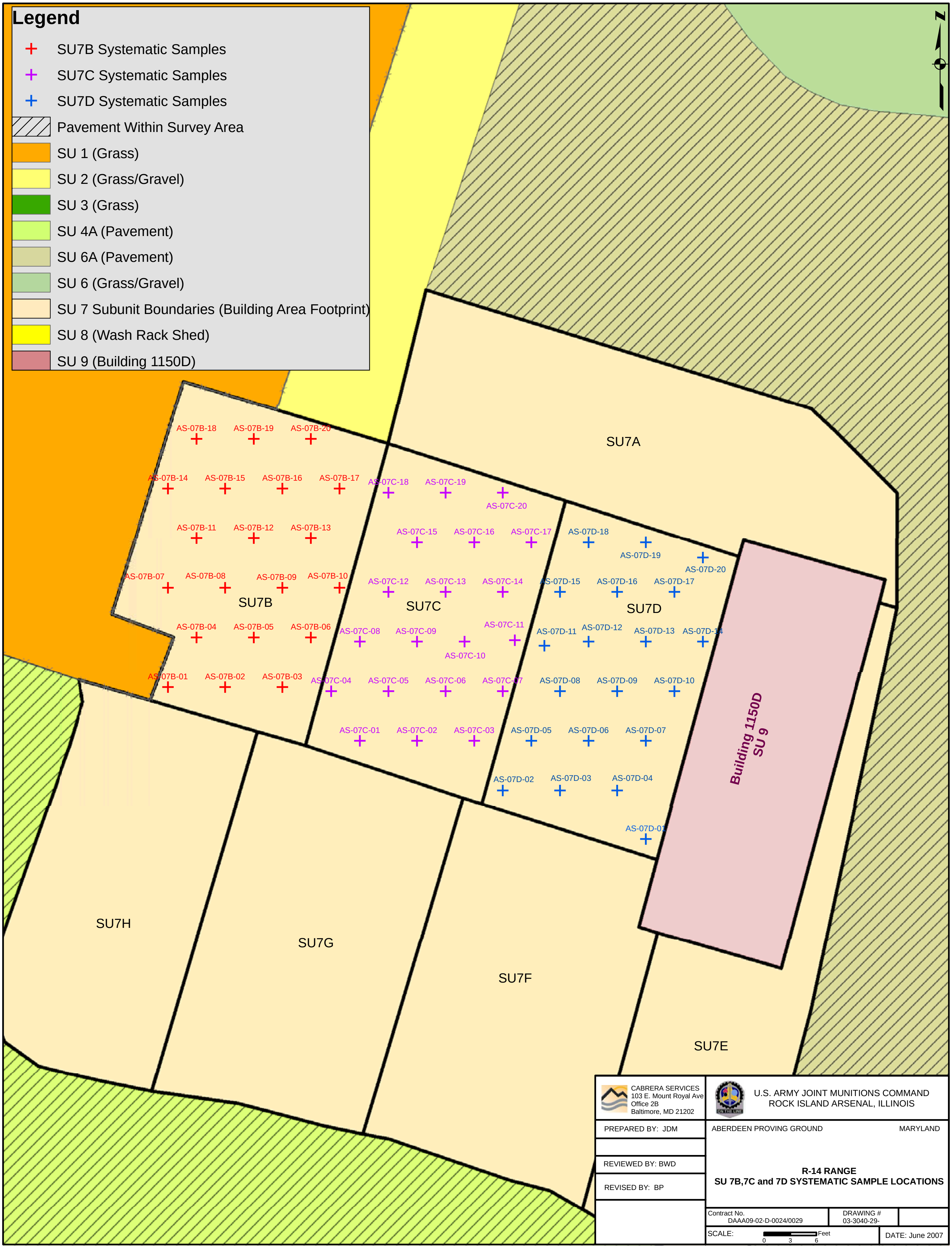
SU 7A SYSTEMATIC SAMPLE LOCATIONS
Contract No.
DAAA09-02-D-0024/0029
DRAWING #
03-3040-29-
SCALE:
0 2 4
Feet
DATE: June 2007



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ABERDEEN PROVING GROUND MARYLAND

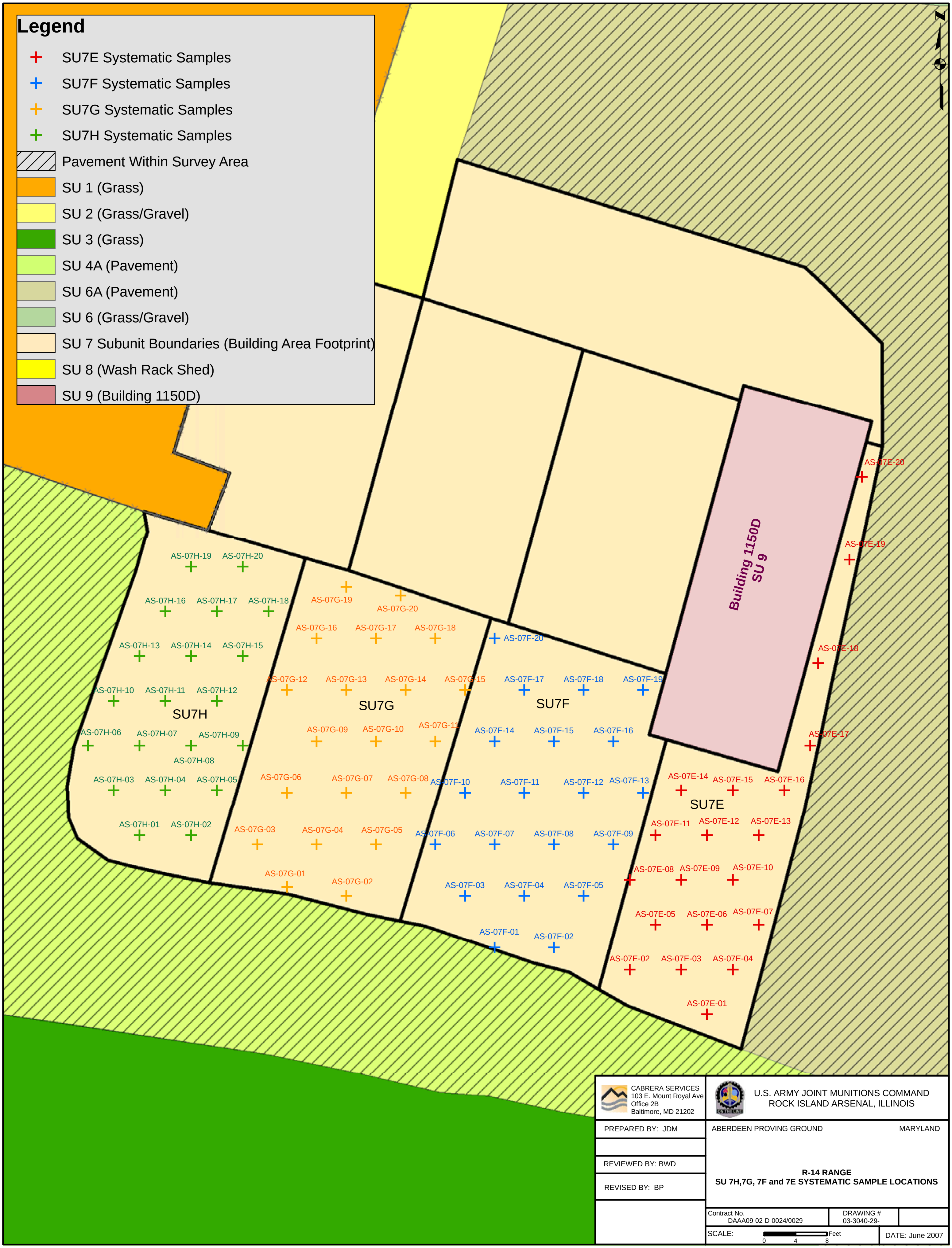
R-14 RANGE
SU 7B,7C and 7D SYSTEMATIC SAMPLE LOCATIONS

Contract No. DAAA09-02-D-0024/0029

DRAWING # 03-3040-29-

SCALE: 0 3 6 Feet

DATE: June 2007



Legend
SU7E Systematic Samples
SU7F Systematic Samples
SU7G Systematic Samples
SU7H Systematic Samples
Pavement Within Survey Area
SU 1 (Grass)
SU 2 (Grass/Gravel)
SU 3 (Grass)
SU 4A (Pavement)
SU 6A (Pavement)
SU 6 (Grass/Gravel)
SU 7 Subunit Boundaries (Building Area Footprint)
SU 8 (Wash Rack Shed)
SU 9 (Building 1150D)
N
Building 1150D
SU 9
SU7H
SU7G
SU7F
SU7E
AS-07H-01
AS-07H-02
AS-07H-03
AS-07H-04
AS-07H-05
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R-14 RANGE
SU 7H,7G, 7F and 7E SYSTEMATIC SAMPLE LOCATIONS
Contract No.
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DRAWING #
03-3040-29-
SCALE:
0
4
8
Feet
DATE: June 2007

APPENDIX B

FIELD INSTRUMENT DETECTION SENSITIVITY

FIELD INSTRUMENTATION DETECTION SENSITIVITY

Introduction

This appendix describes the detection sensitivities for field instrumentation used during the final status survey (FSS) of the R-14 Range and surrounding area of the U.S. Army Research Laboratory (ARL) located at Aberdeen Proving Ground (APG) in Aberdeen, Maryland. This includes instruments used for gamma walkover surveys (GWS) of land areas, and instruments used for detection of contamination on building and/or structure surfaces through surface activity scans and direct measurements of total and removable surface contamination.

Radionuclides of concern (ROC) known to be present in the R-14 Range area are limited to depleted uranium (DU) isotopes (i.e., uranium-234 [^{234}U], uranium-235 [^{235}U], and uranium-238 [^{238}U]) and their short-lived decay progeny. DU composition is based on the isotopic uranium weight ratios routinely used for shipments of DU waste from APG (Barg, 1995). The activity fractions are calculated from the weight ratios and specific activities of each uranium isotope. The resulting composition consists of ^{234}U, ^{235}U, and ^{238}U activity fractions of 0.084, 0.012, and 0.904, respectively. This composition is similar to the 0.190, 0.021, 0.790 average activity fractions measured in three DU soil samples described in the Argonne National Laboratory (ANL) report *Derived Uranium Guideline for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland* (ANL, 1999).

The parent radionuclides in the two radioactive decay chains associated with DU, ^{238}U and ^{235}U, emit alpha particles. The daughter products in both chains decay by emission of alpha or beta particles, some with accompanying emission of gamma rays. The decay schemes for both are very well documented, and this knowledge is used in the design of the FSS and selection of appropriate survey instruments and analysis methods.

As presented in the following sections, the GWS minimum detectable concentration (MDC) for DU plus progeny in soil, using a 3”x3” sodium iodide (NaI) scintillation detector, is 32.9 picocuries per gram (pCi/g). The instrument scan minimum detectable count rate (MDCR), integrated or static measurement MDC, and the MDC for smear analysis are also presented in the following sections.

Gamma Walkover Survey Detection Sensitivity

The GWS will be performed using a Ludlum 44-20 3”x 3” NaI scintillation detector or equivalent detector. The GWS is accomplished by walking at a speed of approximately 1.5 feet per second (0.5 meters per second) with the detector at a height of approximately 2 to 4 inches above the ground surface. Results are recorded in units of counts per minute (cpm). The determination of NaI detection sensitivity (i.e., MDC in soil) for DU is provided below. This evaluation assumes the contaminant is present in the upper 15 cm layer of soil with an area of 56 cm for modeling and calculation purposes.

The methodology used to determine the NaI scintillation detector scan MDC is based on the Nuclear Regulatory Commission (NRC) document, *NUREG-1507: Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*, dated December 1997. Factors included in this analysis are the surveyor scan efficiency, index of sensitivity, natural background of the surveyed area, scan rate, detector-to-source geometry, areal extent of the hot spot, and energy and yield of gamma emissions.

The computer code *Microshield* was used to model the presence of a normalized 1 pCi/g of total DU with its 50-year decay progeny in soil with the further assumption that the activity is uniformly distributed to a depth of 15 cm and spread over a disk shaped area having a diameter of 56 cm. The non-contaminated soil cover has zero thickness (i.e., contamination is at the surface), and there is a 0.051-cm aluminum shield simulating the cover of the NaI detector to complete the model source term. The dose point is centered over the contaminated disk of soil. This model is consistent with the *NUREG-1507* methodology and provides for the calculation of a count rate-to-exposure rate ratio in terms of counts per minute (cpm) to microroentgens per hour (μR/hr). Additional details and discussion describing the *NUREG-1507* analysis methodology are described in that publication.

Fluence Rate to Exposure Rate (unitless)

The fluence rate to exposure rate (FRER) may be approximated by:

$$\text{FRER} \sim (1\ \mu\text{R/hr})/\ (E_\gamma)\ (\mu_{en}/\rho)_{air}$$

Where:

E_γ = energy of the gamma photon of concern, keV
$(\mu_{en}/\rho)_{air}$ = the mass energy absorption coefficient for air, cm^2/g

The FRER over a gamma energy range of 40 keV to 2 MeV is provided in Table 1.

TABLE 1: FLUENCE TO EXPOSURE RATE (FRER)

Energy$_\gamma$, keV	$(\mu_{en}/\rho)_{air}$, cm^2/g	FRER
15	1.29	0.0517
20	0.516	0.0969
30	0.147	0.2268
40	0.064	0.3906
50	0.0384	0.5208
60	0.0292	0.5708
80	0.0236	0.5297
100	0.0231	0.4329
150	0.0251	0.2656
200	0.0268	0.1866
300	0.0288	0.1157
400	0.0296	0.0845
500	0.0297	0.0673
600	0.0296	0.0563
800	0.0289	0.0433
1,000	0.0280	0.0357
1,500	0.0255	0.0261
2,000	0.0234	0.0214

Probability of Interaction Through Detector End for a Given Energy

The probability, P, of a gamma ray interaction in the NaI scintillation crystal entering through the end of the crystal is given by:

$$\text{Probability (P)} = 1\text{-}e^{-(\mu/\rho)\text{NaI}(X)(\rho\text{NaI})}$$

Where:

$(\mu/\rho)_{NaI}$ = the mass attenuation coefficient for NaI
X = the thickness through the bottom edge (end facing the soil) of the 3”x3” NaI crystal, 7.6cm
ρ = the density of the NaI crystal, 3.67 g/cm^3

The probability of interaction in the NaI detector over the same energy range is provided in Table 2.

TABLE 2: PROBABILITY OF INTERACTION (P)

Energy$_\gamma$, keV	$(\mu/\rho)_{NaI}$, cm^2/g	P
15	47.4	1.00
20	22.3	1.00
30	7.45	1.00
40	19.3	1.00
50	10.7	1.00
60	6.62	1.00
80	3.12	1.00
100	1.72	1.00
150	0.625	1.00
200	0.334	1.00
300	0.167	0.99
400	0.117	0.96
500	0.0955	0.93
600	0.0826	0.90
800	0.0676	0.85
1,000	0.0586	0.80
1,500	0.0469	0.73
2,000	0.0413	0.68

Relative Detector Response

The relative detector response (RDR) by energy is determined by multiplying the FRER by the probability (P) of an interaction and is given by:

$$RDR = FRER \times P$$

The RDR for a NaI detector over the same energy range is provided in Table 3.

TABLE 3: RELATIVE DETECTOR RESPONSE (RDR)

Energy$_\gamma$, keV	FRER	P	RDR
15	0.0517	1.00	0.0517
20	0.0969	1.00	0.0969
30	0.2268	1.00	0.2268
40	0.3906	1.00	0.3906
50	0.5208	1.00	0.5208
60	0.5708	1.00	0.5708
80	0.5297	1.00	0.5297
100	0.4329	1.00	0.4329
150	0.2656	1.00	0.2656
200	0.1866	1.00	0.1866
300	0.1157	0.99	0.1146
400	0.0845	0.96	0.0812
500	0.0673	0.93	0.0626
600	0.0563	0.90	0.0507
800	0.0433	0.85	0.0367
1,000	0.0357	0.80	0.0287
1,500	0.0261	0.73	0.0191
2,000	0.0214	0.68	0.0146

Determination of CPM per μR/HR as a Function of Energy

The equivalent FRER, P, and RDR may be calculated for a NaI scintillation detector at the Cs-137 energy of 662 keV. Manufacturers of this equipment typically provide an instrument response in terms of cpm and μR/hr at the Cs-137 energy level. This point allows determination of the cpm per μR/hr and, ultimately, the activity concentration and minimum detection sensitivity in terms of pCi/g.

Based on measured counts in a known field it is estimated that a typical Ludlum Model 44-20 NaI response is 2,700 cpm/μR/hr. Using the same methodology as shown in the tables above, the FRER, P, and RDR can be calculated. The mass energy absorption coefficient for air and the mass attenuation coefficient for NaI are interpolated from tables in the *Radiological Health Handbook, Revised Edition*, dated January 1970, pages 139 and 140. These values are provided for Cs-137 in Table 4.

TABLE 4: FRER, P, AND RDR FOR CS-137 GAMMA ENERGY (BA-137M)

$Energy_{\gamma}$, keV	FRER	$(\mu_{en}/\rho)_{air}$, cm^2/g	$(\mu/\rho)_{NaI}$, cm^2/g	P	RDR
662	0.0514	0.0294	0.0780	0.89	0.0455

The detector response (in terms of cpm) to a different energy is based on the ratio of the RDR at that energy to the known Cs-137 energy RDR, as shown in the following equation:

$$cpm/\mu R/hr,\ E_i = (cpm_{Cs\text{-}137}) \times (RDR_{Ei}) / (RDR_{Cs\text{-}137})$$
$$= (2{,}700) \times (RDR_{Ei}) / (RDR_{Cs\text{-}137})$$

The NaI count rate over the same gamma energy range presented previously is provided in Table 5.

Table 5: Count Rate (E_i) in cpm/µR/hr

$Energy_{\gamma}$, keV	RDR_{Ei}	NaI Detector, E_i, cpm per µR/hr
15	0.0517	3064
20	0.0969	5745
30	0.2268	13445
40	0.3906	23161
50	0.5208	30881
60	0.5708	33842
80	0.5297	31404
100	0.4329	25667
150	0.2656	15748
200	0.1866	11061
300	0.1146	6797
400	0.0812	4816
500	0.0626	3714
600	0.0507	3005
662	0.0455	2700
800	0.0367	2175
1,000	0.0287	17404
1,500	0.0191	1131
2,000	0.0146	867

Finally, the count rate to exposure rate ratio for the DU isotopes and progeny gamma emissions and the contribution to the total exposure rate are determined using the output of the *Microshield* runs and the count rate to exposure rate ratios from Table 5. The weighted cpm/µR/hr over the same energy range in previous tables is presented in Table 6.

TABLE 6: WEIGHTED COUNT RATE TO EXPOSURE RATE IN CPM/µR/HR

keV	MicroShield Exposure Rate With Buildup (µR/hr)	Count Rate to Exposure Rate (cpm/µR/hr)	Weighted Count Rate to Exposure Rate (cpm/µR/hr)
15	7.662E-09	3064	0
20	6.224E-11	5745	0
30	4.751E*06	13445	8
40	8.301E-09	23161	0
50	7.223E-07	30881	3
60	3.724E-04	33842	1545
80	5.073E-05	31404	195
100	1.656E-03	25667	5212
150	1.272E-04	15748	246
200	6.157E-04	11061	835
300	1.432E-05	6797	12
400	1.608E-05	4816	9
500	2.927E-05	3714	13
600	1.416E-04	3005	52
800	1.023E-03	2175	273
1,000	3.968E-03	1704	829
1,500	1.162E-04	1131	16
2,000	1.873E-05	867	2
Total	**8.155E-03**		**9252**

Scan MDC Value

The scan MDC is calculated using the *NUREG-1507* methodology, where the average number of background counts in a one second interval, b_i , is cpm/60.

For the Ludlum 3" x 3" NaI scintillation detector and a background count rate of 27,000 cpm, the calculated background counts in a one second interval is:

$$b_i = (27{,}000 \text{ cpm}) / (60 \text{ sec/min}) = 450 \text{ counts}$$

The minimum detectable count rate (MDCR) is:

$$\text{MDCR} = (d') \times (b_i)^{0.5} \times (60 \text{ sec/min})$$

Where:

d' = 1.38 from *NUREG-1507* Table 6.1, which represents the rate of detection at a 95% true positive proportion with a false positive proportion of 60%.

The resulting MDCR is:

$$\text{MDCR} = (1.38) \times (450 \text{ counts/sec})^{0.5} \times (60 \text{ sec/min}) = 1{,}756 \text{ cpm}$$

The MDCR for the surveyor is represented as follows:

$$\text{MDCR}_{\text{surveyor}} = \text{MDCR} / (p)^{0.5}$$

Where:

P = surveyor efficiency, equal to 0.75 to 0.5 as given by *NUREG-1507* (0.5 is selected as a conservative choice).

The resulting surveyor MDCR is:

$$\text{MDCR}_{\text{surveyor}} = 1{,}756 / 0.707 = 2{,}484 \text{ cpm}$$

The minimum detectable exposure rate (MDER) for the surveyor, obtained from the $\text{MDCR}_{\text{surveyor}}$ divided by the Table 6 weighted count rate to exposure rate value of 9,252 cpm/μR/hr for DU and progeny, is:

$$\text{MDER} = (2{,}484 \text{ cpm}) / (9{,}252 \text{ cpm} / \mu\text{R/hr}) = 0.2685\ \mu\text{R/hr}$$

The scan MDC is then equal to the ratio of the MDER in the field to the exposure rate determined for the normalized 1 pCi/g concentration of total DU, and is represented as follows:

$$\text{Scan MDC} = (\text{Normalized DU}_{\text{Total Conc}}) \times (\text{Exposure Rate MDCR}_{\text{Surveyor}}) / (\text{Exposure Rate}_{\text{normalized DU conc}})$$

The resulting scan MDC for the outdoor GWS is:

$$\text{Scan MDC} = (1 \text{ pCi/g}) \times (0.2685\ \mu\text{R/hr}) / (8.155\text{E-}03\ \mu\text{R/hr}) = \mathbf{32.9\ pCi/g}$$

Building and/or Structure Surface Activity Measurements

As indicated in the work plan, building and/or structure surfaces will be surveyed using direct surface scan and static measurement techniques. Smears will also be obtained and analyzed to determine the amount of removable contamination present on a surface. Surveys will be performed in accordance with CABRERA standard operating procedures.

Surface scans will be performed using instruments capable of measuring the beta emissions from the DU radionuclides. Since many of the interior building surfaces within the scope of this FSS are known to be contaminated, the scan survey will attempt to determine the distribution of contaminants, as well as identify areas of contamination significantly higher than other areas (hot spots). The results of the beta scan surveys will then be used to identify locations for collection of biased integrated or static alpha total surface activity measurements and collection of smears to determine the removable contamination fraction in these areas. Because many of the interior surfaces are known to be contaminated with DU, the postulated hot spot area for performance of scan surveys is 1 square meter (m^2).

For the purpose of building surface and/or structure FSS, a hot spot is defined as any area exhibiting greater than two times the instrument minimum detectable count rate (MDCR). Following completion of the beta scan surveys, integrated or static alpha measurements may be performed at systematic and/or biased locations, including hot spot areas identified through surface beta scans. Smears may also be obtained at these locations to determine the removable fraction of contamination present on the surface. Only the results of the integrated or static alpha measurements will be compared to the screening limits presented in the work plan.

Beta surface scans may be performed using a Ludlum Model 43-37 floor monitor (582 cm^2) gas proportional detector, Ludlum Model 43-68 hand-held gas proportional detector (126 cm^2), or equivalent instrumentation. Integrated or static surface activity measurements may be performed using the Ludlum Model 43-37 floor monitor, Ludlum Model 43-68 gas proportional detector, Ludlum Model 43-89 ZnS scintillation detector (126 cm^2), or equivalent instrumentation. Smears may be analyzed using a Ludlum Model 2929 scaler coupled to a Ludlum Model 43-10-1 scintillation detector. The following sections discuss the detection sensitivity for each of these instruments used for FSS surveys at the R-14 Range area.

<u>Beta Scan Minimum Detectable Count Rate</u>

The detection sensitivity derived for instruments used to perform beta scans focuses on the information provided directly from the measurement and available to the surveyor for decisions regarding survey performance. Therefore, the beta scan sensitivity is derived in terms of the measurement MDCR. The MDCR is determined for the Ludlum Model 43-37 floor monitor and the Ludlum Model 43-68 gas proportional detector, using *MARSSIM* Equations 6-8 and 6-9.

The observed background count (*b'*) is defined as the number of background counts observed within the observation interval (*i*). The equation used for calculating *b'* is as follows:

$$b' = (\text{BCPM}) * (i) * (1 \text{ min}/60 \text{ sec}) = \text{counts/interval}$$

Where:

BCPM = instrument or reference area background count rate (cpm)
i = observation interval (seconds)

The minimum detectable number of net source counts in the interval is given by s_i. Therefore, for an ideal observer, the number of source counts required for a specified level of performance can be arrived at by multiplying the square root of the number of background counts by the detectability value associated with the desired performance (d'), as shown below:

$$s_i = d\sqrt{b'} \qquad \textit{MARSSIM Equation 6-8}$$

The MDCR is defined as the increase above background recognizable during a survey in a given period of time. The variable, *d*, is defined as the index of sensitivity and is dependent on the selected decision errors for Type I (alpha) and Type II (beta) errors. A true positive error (1–β) of 95% and a false positive error (alpha) of 60% may be selected to be consistent with NUREG 1507. The value of 1.38 was obtained from *NUREG 1507*, Table 6.1 (*MARSSIM* Table 6.5).

$$\text{MDCR (cpm)} = s_i \times (60/\text{i}) \qquad \textit{MARSSIM Equation 6-9}$$

The measurement interval (*i*) for both the Ludlum Model 43-37 and Ludlum Model 43-68 is one per second.

Ludlum Model 43-68

The background count rate for the Ludlum Model 43-68 reported by the manufacturer is 300 cpm (consistent with a typical concrete background count rate for this instrument).

$$b' = (300 \text{ cpm}) * (1) * (1 \text{ min}/60 \text{ sec}) = 5 \text{ counts in the 1 second observation interval}$$

Using *d* = 1.38:

$$s_i = 1.38\sqrt{5}$$

$$s_i = 3.1$$

Thus, the Ludlum Model 43-68 beta scan MDCR is:

$$\text{MDCR (cpm)} = 3.1 \times (60/1) = 185 \text{ cpm (above background)}$$

The beta scan action level for identifying a hot spot would therefore be:

Scan Action Level (MDCR) = MDCR x 2

= 370 cpm above background

For simplicity and to aid in surveyor decisions, this value is rounded to **400 cpm above background**.

Ludlum Model 43-37

The beta scan MDCR for the Ludlum Model 43-37 floor monitor is same manner as the Ludlum Model 43-68 except the background is adjusted to account for the significant increase in detector area. This is accomplished simply by multiplying the Ludlum Model 43-68 background by the ratio of the Ludlum Model 43-37 detector area (582 cm^2) to the Ludlum Model 43-68 detector area (126 cm^2) or 4.6.

Ludlum Model 43-37 BCPM = 300 x 4.6 = 1386 cpm

Using this background count rate, the values and formulas from the previous section, the Ludlum Model 43-37 floor monitor beta scan MDCR is 397 cpm above background. Rounding for simplicity and ease, the MDCR is approximately 400 cpm above background, resulting in a beta scan action level for the Ludlum Model 43-37 of **800 cpm above background**.

Integrated (Static) Alpha Surface Activity Measurements

Integrated direct measurements (i.e., static measurements) of surface alpha contamination will be performed to compare contaminant concentrations at discrete sampling locations to the screening limit presented in the work plan.

Integrated alpha activity measurements will be performed using a Ludlum Model 43-37 gas proportional detector, Ludlum Model 43-68 gas proportional detector, Ludlum Model 43-89 handheld scintillation detector, or equivalent. Although the background count rates are slightly different, the parameters and static measurement requirements are very similar for the Ludlum Model 43-68 and Ludlum Model 43-89 detectors.

Since the background and gross (or sample) count times are the same for all three detectors, the following equation is used to determine instrument MDC:

$$\text{MDC (dpm/100cm}^2) = \frac{3 + 4.65\sqrt{(R_b)}}{\frac{[DA]}{100}[\varepsilon_i][\varepsilon_s]}$$ *MARSSIM Equation 6-7*

Where:

ε_i = instrument efficiency (cpm/dpm)
ε_s = surface efficiency (unitless)
R_b = background count rate (cpm)
DA = detector area (cm^2)

For the purpose of this evaluation, instrument efficiency values (ε_i) were obtained from *NUREG 1507*, Table 4.4. Surface efficiency values (ε_s) were obtained from *NUREG 1507*, Table 5.5, for a sealed concrete surface with distributed alpha emitting radioactive source.

When using large area detectors, such as the detector associated with the Ludlum Model 43-37, it is typically not appropriate to account for detector area corrections. This is because the area of contamination is assumed to be much smaller than the detector area, on the order of 100 cm^2. However, since it is known that many interior surfaces are contaminated, and the postulated hot spot is much greater than the Ludlum Model 43-37 detector area, this correction is necessary and appropriate.

The integrated or static measurement MDC and assumptions used for each of the detectors are presented in Table 7. The MDC was determined using the above equation.

TABLE 7: INTEGRATED/STATIC MEASUREMENT MDC AND ASSUMPTIONS

Ludlum Model No.	Count Time (min)	Bkg Count Time (min)	Detector Area (cm^2)	ε_i (cpm/dpm)	ε_s	α Bkg (cpm)	α Static MDC (dpm/100 cm^2)
43-37	1	1	582	0.349	0.473	10	18
43-68	1	1	126	0.349	0.473	5	64
43-89	1	1	126	0.259	0.428	3	79

min = minutes
cpm = counts per minute
bkg = background
cm^2 = square centimeters
dpm = disintegrations per minute

<u>Removable Contamination (Smear) Analysis MDC</u>

Smear samples will be collected at biased building surface locations, as appropriate, to quantify transferable/removable surface alpha contamination. Samples of removable surface contamination are typically obtained by wiping a surface area of 100 cm^2 using a cloth or paper disc or other suitable media. These samples (smears) will be analyzed using a Ludlum 2929 scaler coupled to a Ludlum Model 43-10-1 scintillation detector. Since the background and gross (sample) count times for this instrument are typically different when analyzing smears for alpha emitting contamination, the following equation is used to determine the measurement MDC:

$$\text{Smear MDC (dpm/100 cm}^2) = \frac{3 + 3.29\sqrt{(R_b)(T_s)(1+\frac{T_s}{T_b})}}{(T_s)\,(\varepsilon_i)}$$ *NUREG 1507, Equation 3-11*

Where:

ε_i = instrument efficiency (cpm/dpm)
R_b = background count rate (cpm)
T_b = background count time (minutes)
T_s = sample count time (minutes)

The smear analysis MDC and assumptions are presented in Table 8.

TABLE 8: SMEAR ANALYSIS MDC AND ASSUMPTIONS

Ludlum Model No.	Count Time (min)	Bkg Count Time (min)	Probe Area (cm^2)	α Efficiency (cpm/dpm)	α Bkg (cpm)	α Static MDC (dpm/100 cm^2)
2929	4*	20	Smear	0.33	0.8	7

min = minutes
cm^2 = square centimeters
cpm = counts per minute
dpm = disintegrations per minute
* Actual sample count time may be determined based on actual measured alpha background count rate and detector specific alpha efficiency. Background and sample count times may be adjusted to maintain a target MDC not greater than 10 dpm/100 cm^2 or 10% of the screening limit presented in the work plan.

Summary

GWS sensitivity parameters, beta surface scan MDCRs, and static measurement and smear analysis MDCs have been calculated for each instrument to be used during the R-14 Range and surrounding area FSS. Calculation of MDCs for each instrument ensures that direct measurements are performed using radiation survey instrumentation sufficient to evaluate radiological conditions in accordance with the requirements of the work plan. Due to the potential variations of conditions in the field, parameters such as static measurement and smear count times may be adjusted onsite with the permission of the CABRERA project Health Physicist.