ENERGYSOLUTIONS CS-RS-RP-009-04

Phase II Final Status Survey Report
Mallinckrodt Columbium-Tantalum Plant

St. Louis, Missouri

Chapter 4

Project No. 137131 **Revision 0**

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ABBREVIATIONS AND ACRONYMS

Δ	delta
%	percent
σ	sigma; standard deviation
AECOM	AECOM Technical Services
Bi	bismuth
C-T	columbium-tantalum
CFR	Code of Federal Regulations
cm	centimeters
DCGL	derived concentration guideline level
DP	Decommissioning Plan
DQO	data quality objectives
Energy*Solutions*	Energy*Solutions*, LLC
EPA	U.S. Environmental Protection Agency
FSS	final status survey
FSSR	Final Status Survey Report
GPS	Global Positioning System
GWS	gamma walk-over survey
keV	kilo-electron volt
m	meters
m^2	square meters
m/s	meters per second
MDC	minimum detectable concentration
MQO	measurement quality objectives
NAD	North American Datum
NaI	sodium iodide
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picoCuries per gram
QC	quality control
Ra	radium
SOF	sum of fractions
Th	thorium
TPU	total propagated uncertainty
U	uranium

4.0 FINAL STATUS SURVEY DESIGN

The final status survey (FSS) design was based on the assumptions, methods, and performance criteria established through the use of the Data Quality Objectives (DQOs) process to meet the requirements outlined in the Columbium-Tantalum (C-T) Phase II Decommissioning Plan (DP), Section 14.4. This chapter of the Final Status Survey Report (FSSR) provides details regarding the FSS design, with key design elements summarized in Table 4-1. Data evaluation and statistical analyses were performed and a separate decision was made for each survey unit of the C-T Plant as to its suitability for release for unrestricted use based upon the industrial use scenario release criterion as established in C-T Phase II DP Chapter 5.

Table 4-1 Final Status Survey Design

Parameter	Class 1	Class 2	Class 3
Classification	Areas where, prior to remediation, there existed residual radioactivity above the $DCGL_W$.	Areas where, prior to remediation, there may have existed residual radioactivity, but at levels below the $DCGL_W$.	Areas where there is a low likelihood of residual radio-activity. Previous remediation precludes an area from being classified as a Class 3 area.
Survey Unit Maximum Size	2,000 m^2 (1)	10,000 m^2	No limit
Scan Measurements	100%	10% to 100%	0 to 10%
No. of Stationary Measurements	15	15	15
Measurement Locations	Random-start, systematic spacing	Random-start, systematic spacing	Random
Investigation Level	SOF > 0.5	SOF > 0.5	SOF > 0.5 (2)

Notes:
(1) 3,000 m^2 for subsurface material (see C-T Phase II DP, Table 14-4).
(2) Value used in lieu of C-T Phase II DP, Table 14-5 value of 0.1 × DCGL + 95% upper confidence limit of mean concentration of background reference population.

Chapter 2 of this FSSR discussed that two decommissioning contractors performed the remediation and final status surveys for Phase II of the C-T Plant decommissioning. The first decommissioning contractor was AECOM Technical Services (AECOM). The second decommissioning contractor was Energy*Solutions*, LLC (Energy*Solutions*). In general, the methodologies and performance criteria were consistent between the decommissioning contractors. When no distinction is made within this chapter of the FSSR, the discussion applies to both decommissioning contractors. When methodologies or performance criteria were different, they are described separately for each decommissioning contractor.

4.1 DATA QUALITY OBJECTIVES

DQOs were developed to define the purpose of the radiological survey, clarify what data should be collected, and to specify the performance requirements for the quality of information to be obtained from the data.

4.1.1 Step 1: State the Problem

The overall goal of the project was to decommission the former C-T Plant process building floor slabs, affected foundations, sewer lines, pavement, sediment basins, and land within geographic boundaries of the project, in accordance with the U.S. Nuclear Regulatory Commission (NRC) approved Mallinckrodt C-T Phase II DP, in order to secure regulatory termination of NRC License STB-401.

4.1.2 Step 2: Identify the Decision

The principal study question was: "Do the levels of residual radioactivity at the St. Louis Mallinckrodt C-T Plant within the scope of the Phase II decommissioning meet the release criteria?" The following alternative actions would result from resolution of the principle study question:

- If the levels of residual radioactivity meet the release criteria, then the C-T Phase II decommissioning site will be recommended for unrestricted use.
- If the levels of residual radioactivity do not meet the release criteria, then remedial action will be taken to reduce the levels of residual radioactivity such that they meet the release criteria.

Based on the principal study question and the alternative actions listed above, the decision statement was: "Determine whether or not the levels of residual radioactivity meet the release criteria."

The decision was formulated into a statistical hypothesis. The state that was presumed to exist in reality was expressed as the null hypothesis (denoted by H_o):

H_o: The levels of residual radioactivity do not meet the release criteria.

For the given null hypothesis, the alternative hypothesis (denoted as H_a), which is an expression of what is believed to be the state of reality if the null hypothesis was not true:

H_a: The levels of residual radioactivity meet the release criteria.

As the null and alternative hypotheses were applied here, the Phase II site was not be considered suitable for release unless the survey data showed that the levels of residual radioactivity meet the release criteria.

4.1.3 Step 3: Identify Inputs to the Decision

The radionuclides of concern were:

- Uranium-238 (^{238}U), uranium-235 (^{235}U), and uranium-234 (^{234}U), all from naturally occurring uranium [and their progeny thorimum-230 (^{230}Th), radium-226 (^{226}Ra), and other short-lived isotopes]; and
- Thorium-232 (^{232}Th) from naturally occurring thorium, and its progeny [radium-228 (^{228}Ra), thorium-228 (^{228}Th), and other short-lived isotopes].

The impacted media were two types. The first was surface slab material, either concrete or asphalt pavement or building floor, slab, or basin surface. The second type was soil and bulk materials. These materials were almost entirely subsurface, because the surface of the area of interest was nearly entirely covered by either building floor slabs or pavement.

Action levels, shown in Table 4-2, were established to cause further evaluation of locations, identified by scan or stationary measurements, with elevated residual radioactivity. The action levels were based on the classification of the area. Measurements above the investigation level may have indicated the survey unit was improperly classified. It may have also indicated a localized area of elevated residual radioactivity where there was a failure in the remediation process.

Table 4-2 Action Levels

Class 1	Class 2	Class 3
SOF > 1	SOF > 1	SOF > 0.5

As to the principal study question for surface slab material, gross beta-gamma surface scan and stationary measurements were utilized as quantitative inputs. Exposure rate measurements, alpha surface stationary measurements, and samples of removable surface residual radioactivity (swipes) analyzed for alpha/beta radioactivity were used as qualitative inputs.

As to the principal study question for soil and bulk materials, gamma walk-over survey (GWS) measurements and volumetric samples analyzed by gamma spectroscopy were utilized as quantitative inputs.

4.1.4 Step 4: Define the Study Boundaries

The target population was surface and volumetric residual radioactivity concentrations of the radionuclides of concern found in the soil within the excavation of Plant 5 and on the concrete surfaces of the wastewater neutralization basins in Plant 7W. The spatial boundaries were limited to the post-remediation exposed surfaces of:

- The surface soil and subsurface soil exposed by excavation in Plant 5;
- The exposed concrete surfaces of the wastewater neutralization basins in Plant 7W; and
- The internal surfaces of the impacted sewer lines remaining in use downstream of Building 238 extending to the wastewater neutralization basins, and other sewers in the Plant 5 area.

4.1.5 Step 5: Develop a Decision Rule

Decisions will be made on two fundamental levels:

- Localized areas – the decision to collect additional data was made for discrete areas with measurement results that exceed the investigation level.
- Survey unit – a decision was made for each survey unit regarding conformity with the release criteria or, alternatively, the need for remediation and/or additional data collection.

4.1.6 Step 6: Specify Limits on Decision Errors

The two principal decision errors, based on the principal study question, were:

- deciding that the levels of residual radioactivity met the release criteria when, in fact, they did not (referred to as a false negative or Type I decision error); and
- deciding that the levels of residual radioactivity did not meet the release criteria when, in fact, they did (referred to as a false positive or Type II decision error).

Neither type of decision error are desirable. A Type I decision error was defined as the probability of passing a survey unit that should fail. The consequence of a Type I decision error was that material with elevated residual radioactivity was not properly remediated. The potential existed for a resulting dose to exceed the release criteria. A Type II decision error was defined as the probability of failing a survey unit that should have passed. The consequences of a Type II decision error were the collection of additional data and/or unnecessary remediation.

A decision error rate of 0.05 (5%) was applied for both Type I and Type II errors for the statistical test. Decision error rates associated with the calculation of instrument minimum detectable concentrations (MDCs) and the number of static measurements was also set at 0.05 (5%). Decision error rates for scanning sensitivities were set in accordance with Attachment E of the C-T Phase II DP.

4.1.7 Step 7: Optimize the Design

As data were collected and analyzed, the assumptions in this plan were reviewed for accuracy. The DQO process was utilized, as appropriate, throughout remediation and FSS activities to focus efforts and minimize costs.

4.1.8 Measurement Quality Objectives

Measurement quality objectives (MQOs) for radiological data measurements included the routine, standard quality control (QC) measurements specified in the analytical methods, typically made on laboratory-prepared standard materials and samples to monitor MQOs for accuracy and precision. Laboratory QC checks included the following as applicable:

- Calibration checks
- Laboratory control samples
- Duplicate samples
- Method blank samples

Some of the checks listed above are procedure or instrument specific and did not necessarily apply to all analyses. Specific QC checks varied with the analytical methods and instrumentation used.

For laboratory-generated QC measurement data (i.e., the accuracy, or bias), the MQOs were generally accepted industry values. QC results that were not within the acceptance limits may have resulted in qualification of the data, resampling and analysis, or other corrective actions. The measured result, MDC, and the total propagated uncertainty (TPU) were reported.

4.2 CLASSIFICATION

The paved (Figure 4-1 and Figure 4-2) and subsurface (Figure 4-3) areas of the C-T Plant were initially classified as Class 1, Class 2, or Class 3 based on Figures 14-1A, 14-1B, and 14-2 in the C-T Phase II DP. Sewers remaining in use downstream of Building 238 extending to the wastewater neutralization basins and other sewers in the Plant 5 area (Figure 4-4) are classified as Class 3.

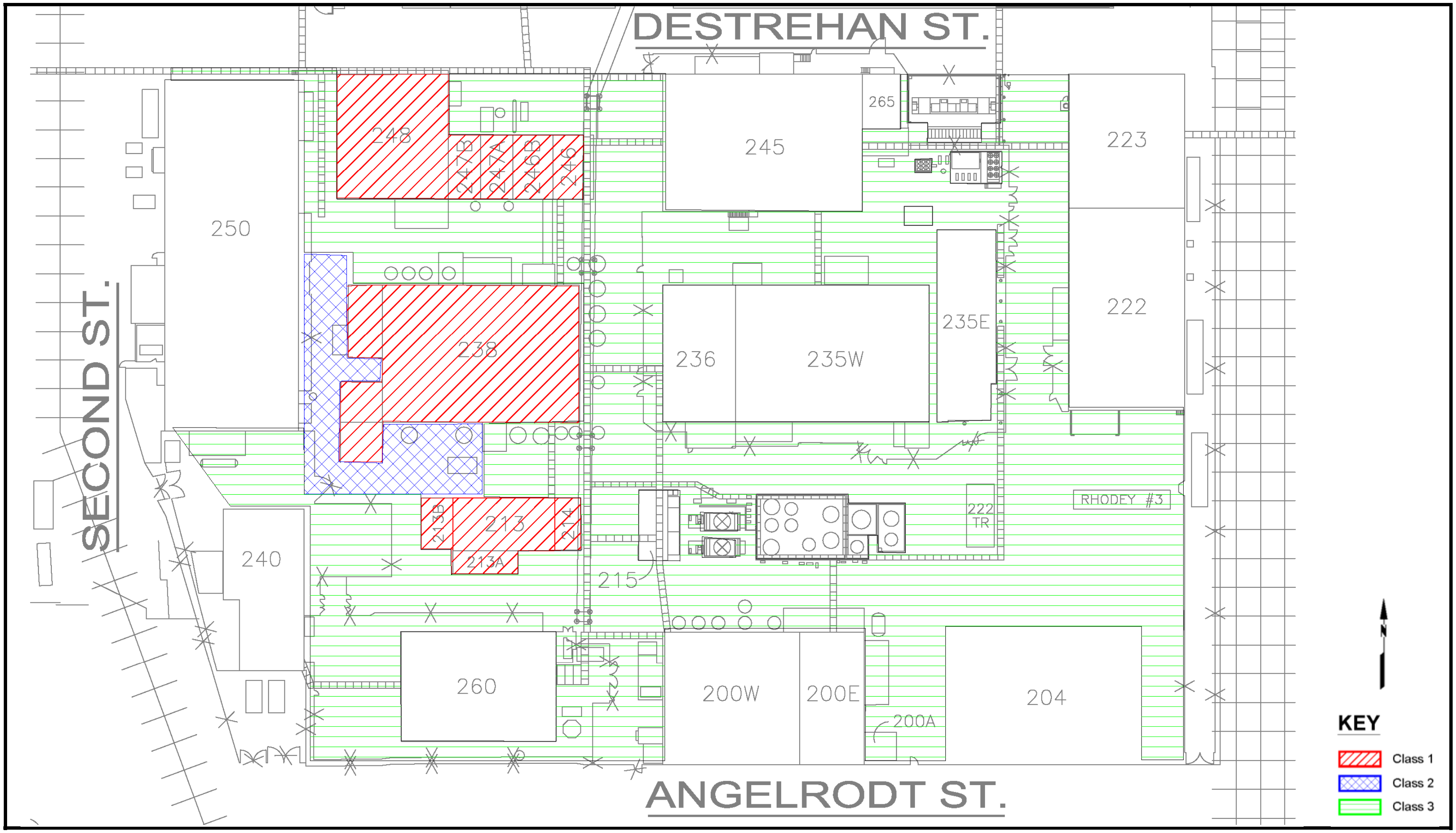

Figure 4-1 Initial Plant 5 Pavement Classification (from C-T Phase II DP Figure 14-1A)

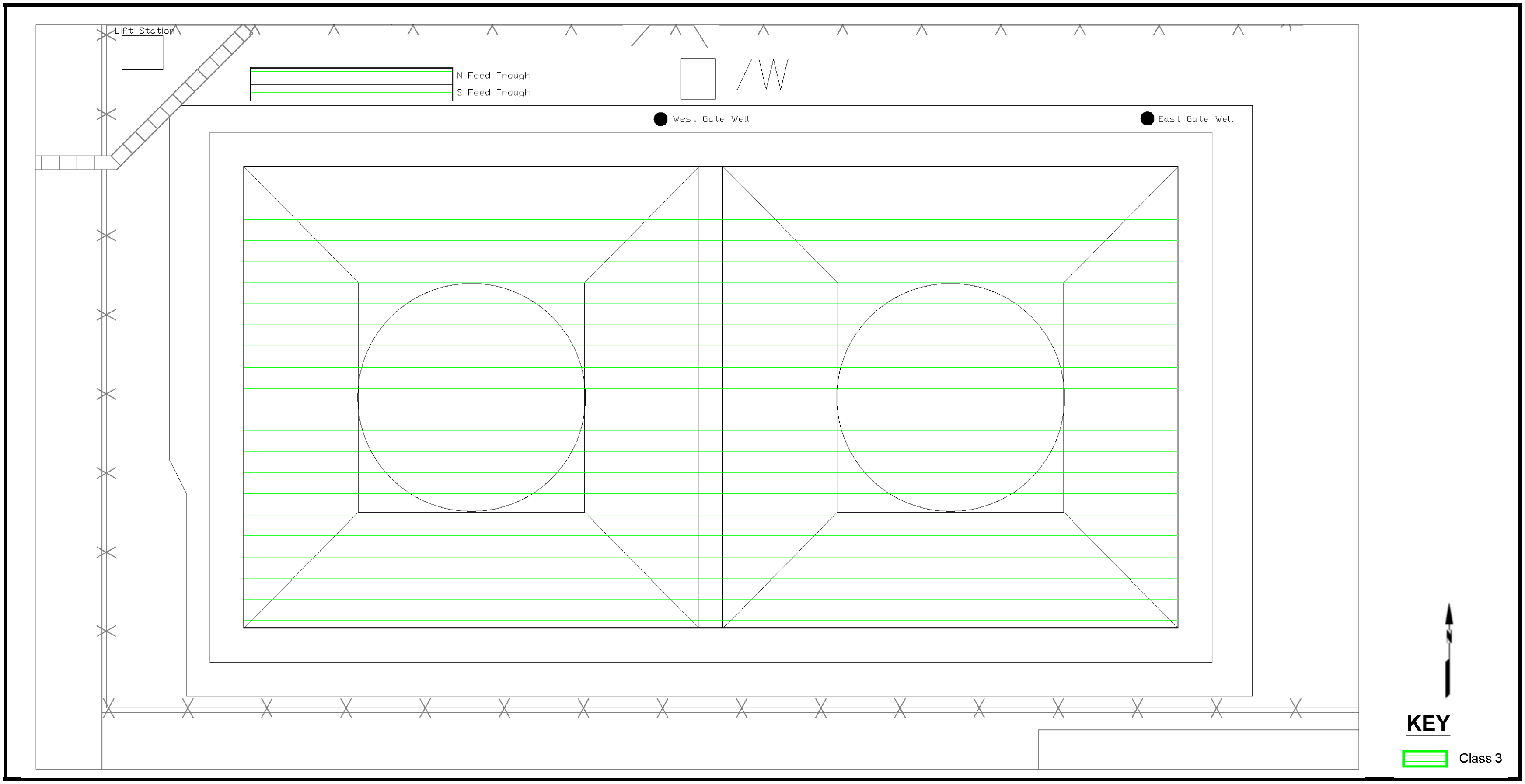

Figure 4-2 Initial Plant 7W Pavement Classification (from C-T Phase II DP Figure 14-1B)

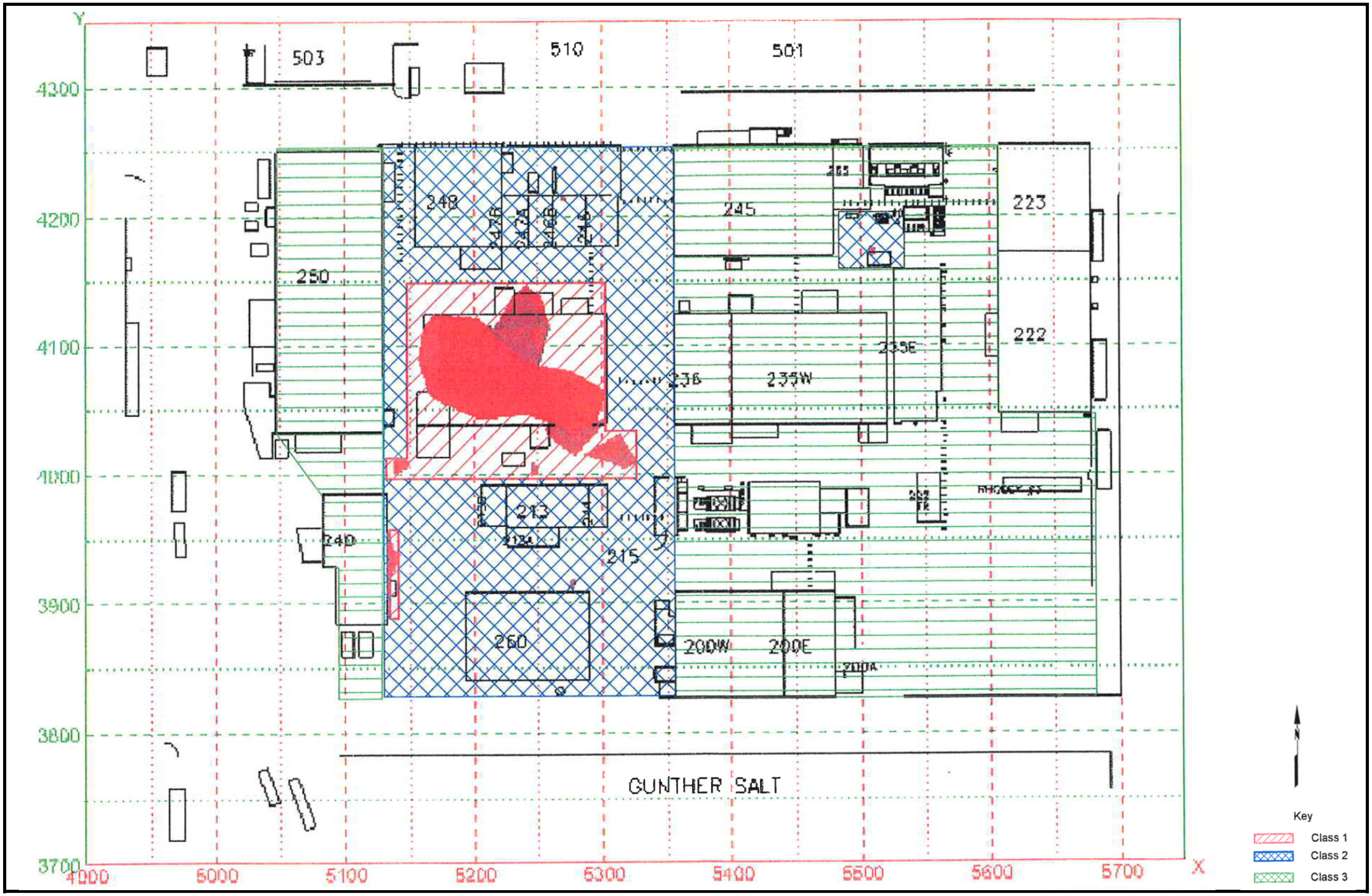

Figure 4-3 Initial Subsurface Classification (from C-T Phase II DP Figure 14-2)

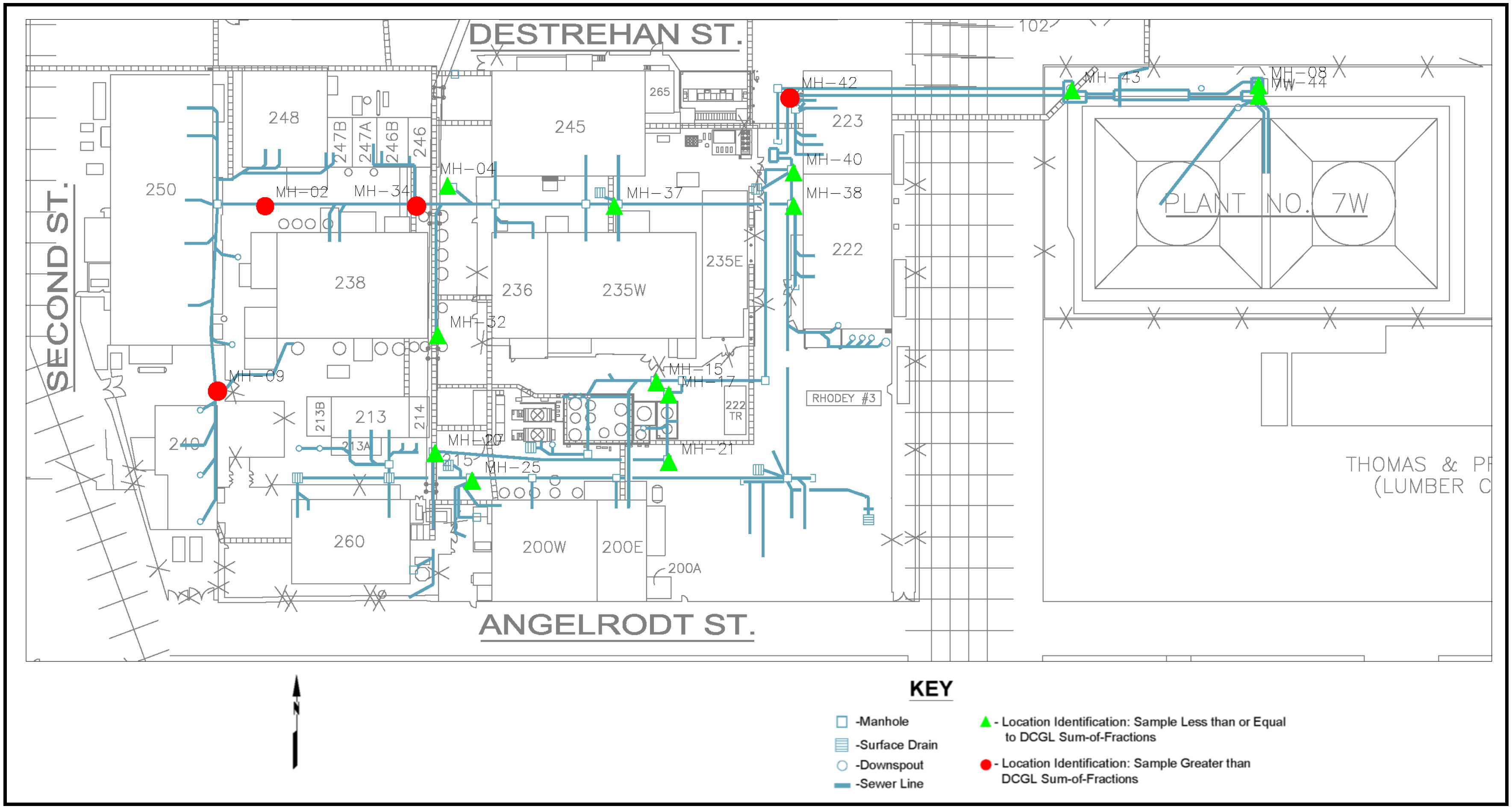

Figure 4-4 Sewer Lines (from C-T Phase II DP Figure 4-1)

4.3 SURVEY UNITS

As areas of the C-T Plant were remediated, they were divided into survey units based on their classification and accessibility at certain times during the remediation. Each survey unit was composed of a physical area with similar characteristics and potential for residual radioactivity for which data evaluation and statistical analysis were performed. Controls were instituted to ensure survey units were not contaminated by ongoing remediation activities in adjacent areas.

The sizes of Class 1 and Class 2 survey units were limited in order to preserve a reasonable sampling density. The following areas were divided into survey units in accordance with the unit sizes provided in Table 4-1:

- Plant 5 Area – survey units within the Plant 5 excavation area were either Class 1 or Class 2. The balance of the Plant 5 area outside the excavation area was composed of two Class 3 survey units.
- Wastewater Neutralization Basins – This area was divided into two survey units.
- Sewer Lines / Lift Stations – The drains and subsurface sewers that served the C-T support buildings, C-T yard areas, the Plant 7 lift stations, the sewer lines remaining in use downstream of Building 238 extending to the wastewater neutralization basins, and other sewers in the Plant 5 area were considered a separate survey unit.

Figure 4-5 and Figure 4-6 show the survey units for pavement and subsurface, respectively. The classifications of some areas increased from those presented in the C-T Phase II DP, which is an acceptable and conservative change. Sewers remaining in use downstream of Building 238 extending to the wastewater neutralization basins and other sewers in the Plant 5 area (Figure 4-4) were one survey unit.

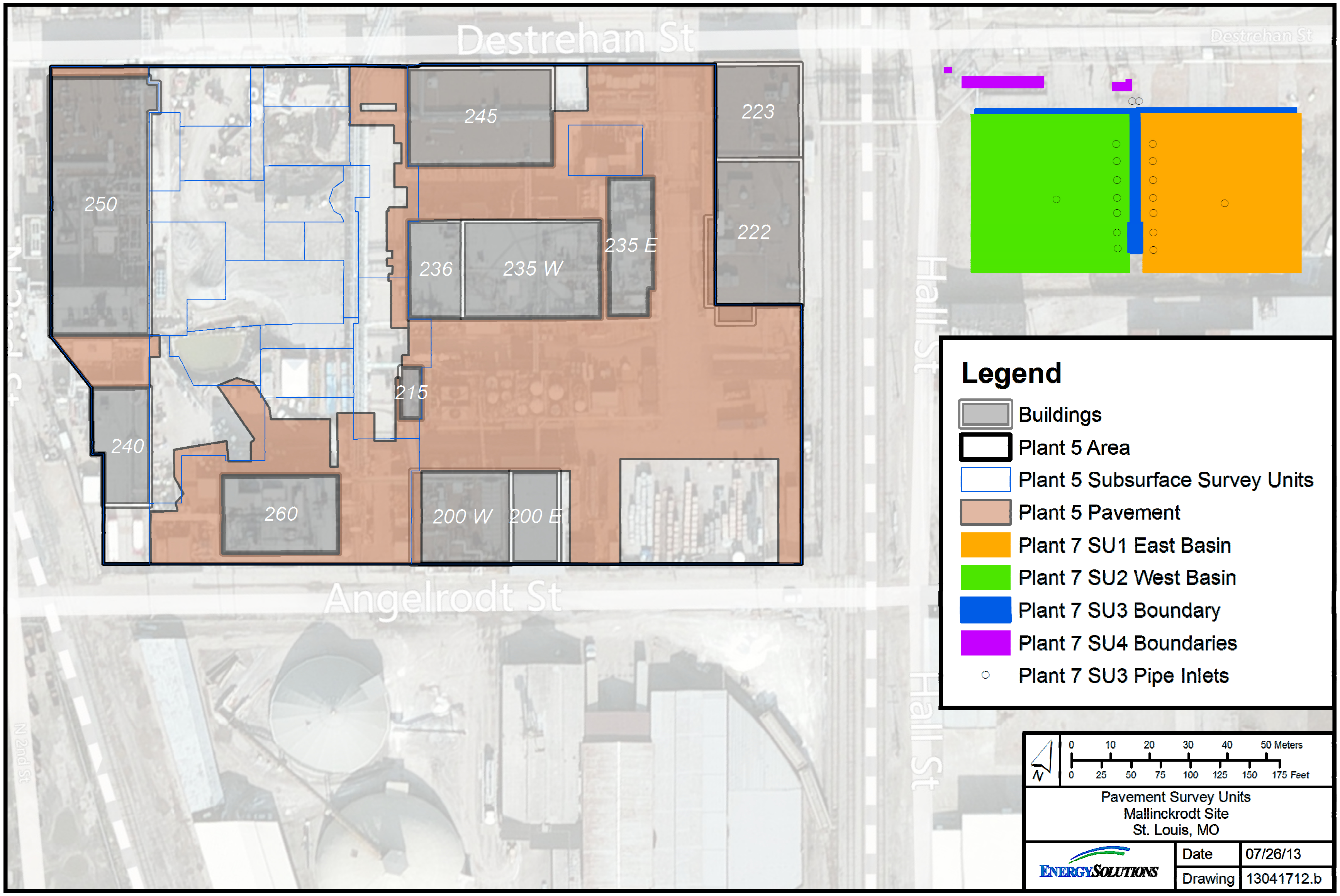

Figure 4-5 Pavement Survey Units

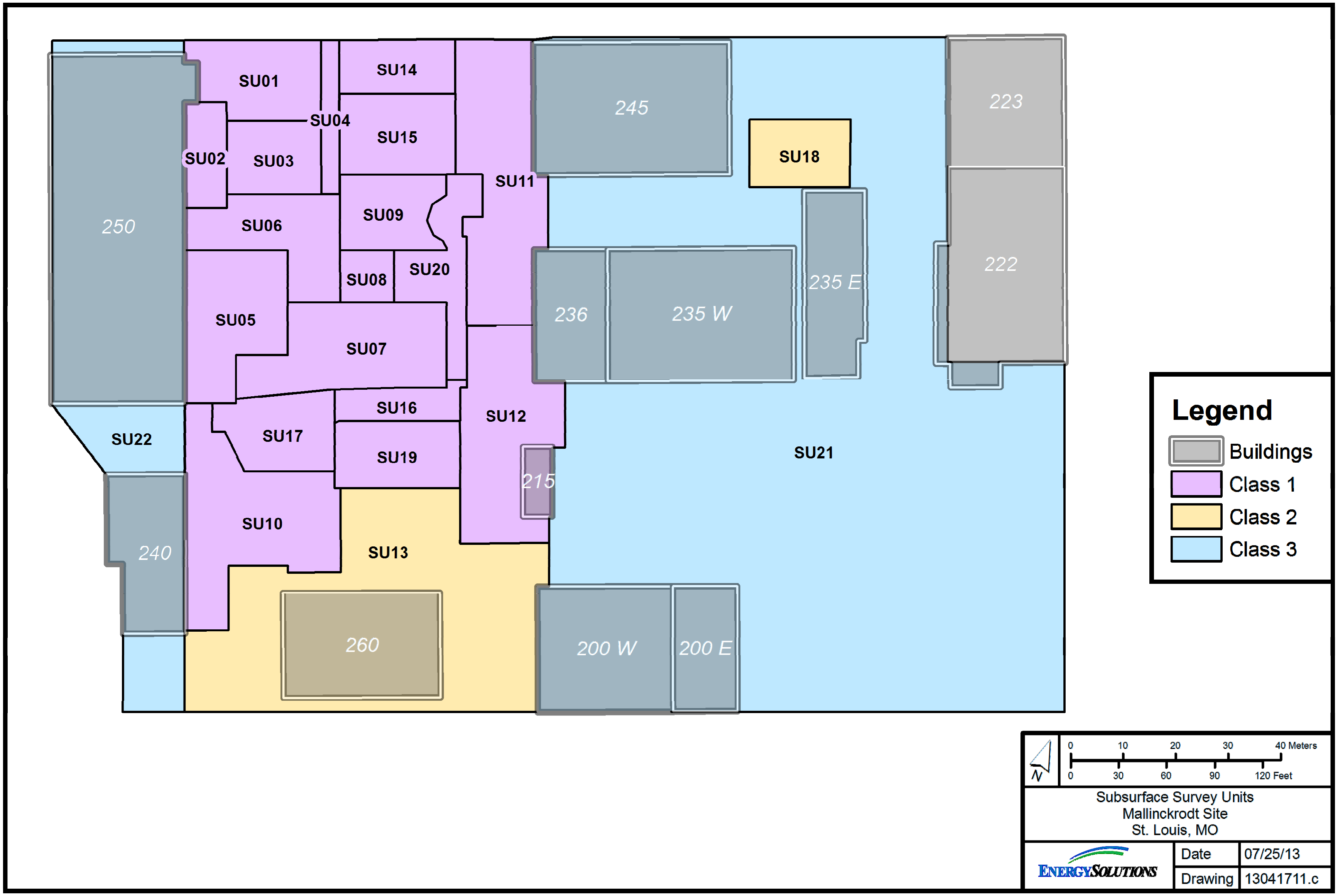

Figure 4-6 Plant 5 Subsurface Survey Units

Chapter 2 of this FSSR discussed that two decommissioning contractors, AECOM and Energy*Solutions*, performed remediation and FSS of the C-T Plant. Both decommissioning contractors completed FSS activities for the Plant 5 pavement survey unit. The Plant 5 subsurface survey units completed by each decommissioning contractor are listed in Table 4-3 and graphically depicted in Figure 4-7. AECOM completed FSS activities for the Plant 7W pavement survey units and the sewerage survey unit.

Table 4-3 Plant 5 Subsurface Survey Units Completed by Decommissioning Contractor

AECOM	Energy*Solutions*
SU01	SU10
SU02	SU11
SU03	SU12
SU04	SU13
SU05	SU18 [a]
SU06	SU19
SU07	SU21 [a]
SU08	SU22
SU09	
SU14	
SU15	
SU16	
SU17	
SU20	

[a] Incorporated AECOM collected data for this survey unit.

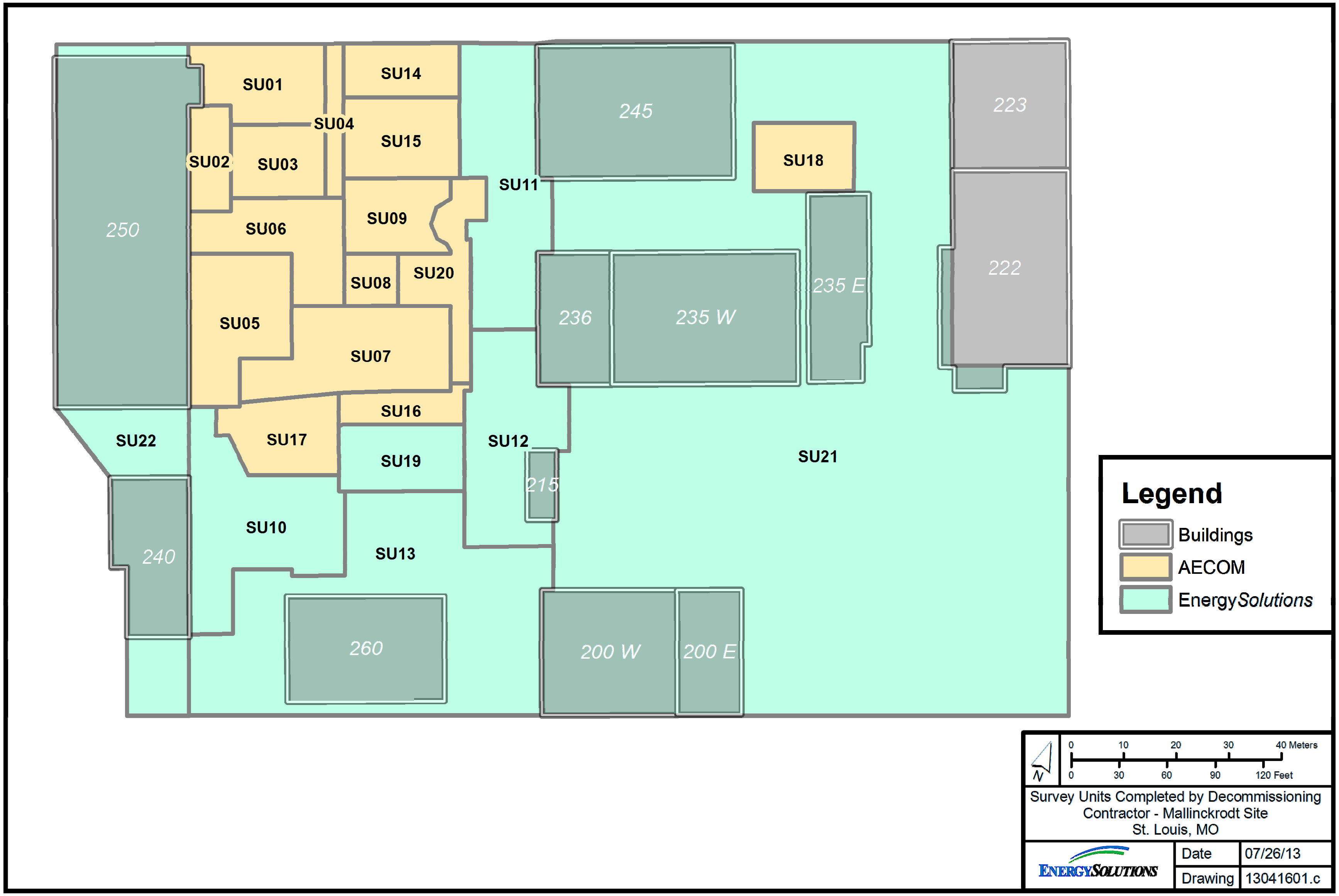

Figure 4-7 Plant 5 Subsurface Survey Units Completed by Decommissioning Contractor

4.4 SCAN MEASUREMENTS

Scan measurements were performed to locate radiation anomalies that might indicate elevated areas of residual radioactivity requiring further investigation. A beta-gamma surface scan was performed on building materials (i.e., asphalt and concrete foundations) in Plant 5 and sewer survey units. A GWS was performed in Plant 5 excavated areas. The level of scanning effort was proportional to the classification of the survey unit, i.e., potential for finding elevated areas of residual radioactivity.

Scan coverage is provided in Table 4-1. Where scan coverage was less than 100%, those areas with the highest potential for elevated residual radioactivity, based on professional judgment, were selected for scanning. This provided a qualitative level of confidence that no areas of elevated residual radioactivity were missed by the random measurements and that there were no errors made in the classification of the survey unit.

Scan measurements of sewer lines were performed, where possible, at the sewer access locations within the excavation.

4.4.1 AECOM

4.4.1.1 GWS

GWS data were collected using a Ludlum Model 44-20 3-inch by 3-inch sodium iodide (NaI) gamma scintillation detector with a Ludlum Model 2221 ratemeter/scaler. The detector was suspended at a height of 10 centimeters (cm) above the ground and moved over the surface at a speed of approximately 0.5 meters per second (m/s). Parallel passes about 0.5 meters (m) apart were made moving in a north-south manner, followed by a second set of passes moving over the survey unit in an east-west manner (or vice-versa).

4.4.1.2 Beta-Gamma Scans

Beta-gamma scan measurements were performed using a Ludlum Model 43-37-1 (821 cm^2) large area gas proportional detector by moving the detector approximately 2 cm above the surface of interest at a scan rate of approximately one detector width per second.

4.4.1.3 Location Correlation

Scan data were position-correlated using a Trimble Global Positioning System (GPS) Pathfinder® ProXH receiver with a GeoExplorer handset unit. GPS data (i.e., northing and easting point) of scan measurements were automatically logged at 1-second intervals. The GPS link tied survey data to spatial locations using state plane coordinates for Missouri, North American Datum (NAD) 1983.

Where GPS was ineffective or unavailable, measurement locations were recorded manually. Typically, a grid system was used such that each square meter of the survey unit was measured for its highest gross gamma activity and the data were then captured on a hand-written survey using hand-drawn maps and digital images to document measurement locations.

4.4.1.4 Data Analysis

The mean and standard deviation of the scan data were calculated, z-scores (the number of standard deviations the result lies from the mean) were computed, and a color-coded contour map of the scan data was created to identify potential biased sample locations. The contouring process involved creating a regularly spaced grid and assigning values to every spot on the grid. The grid spacing and the values assigned at the grid nodes determined what the contour plot looks like. Grid node values were assigned using a weighted average based on the inverse square law, which is generally used to describe how radiation levels drop off with distance from a source. Once the grid was complete, color-coded contours were created from grid node values within the specified ranges of values. The three color divisions represent various ranges of z-score values with red being the highest, followed by yellow and green being the lowest. Generally, a z-score contour greater than 3.0 (i.e., red) was used as an indicator for investigating areas with potentially elevated residual radioactivity. Statistically, a very small number of points with z-scores above 3.0 were expected. Approximately 0.135% of normally distributed data exceed a z-score of 3.0.

4.4.2 Energy*Solutions*

4.4.2.1 GWS

GWS data were collected using a Ludlum Model 44-10 2-inch by 2-inch NaI gamma scintillation detector with a Ludlum Model 2350-1 ratemeter/scaler. The detector was suspended at a height of 10 cm above the ground and moved over the surface at a speed of approximately 0.5 m/s. Parallel passes about 1 m apart were made, followed by a second set of perpendicular passes.

4.4.2.2 Beta-Gamma Scans

Energy*Solutions* used the same technique as AECOM (Section 4.4.1.2), except the detector used was a Ludlum Model 43-37 (584 cm^2).

4.4.2.3 Location Correlation

Energy*Solutions* used the same technique as AECOM (Section 4.4.1.3), except the scan data were position-correlated using a Trimble GPS GeoExplorer GeoXH.

4.4.2.4 Data Analysis

Energy*Solutions* used the same technique as AECOM (Section 4.4.1.4), except instead of contouring the scan data, every data point was plotted as a 1-m diameter circle that represented the 1-m scan pass coverage.

4.5 STATIONARY MEASUREMENTS

Stationary measurements (i.e., static measurements and media samples) were collected at a frequency and at representative locations throughout the survey unit such that a statistically sound conclusion regarding the radiological condition of the survey unit could be developed. Stationary measurements were also collected at locations of elevated residual radioactivity identified by scan measurements. Beta-gamma surface measurements were performed on building materials (i.e., asphalt and concrete foundations) in Plant 5, wastewater neutralization basin, and sewer survey units in accordance with the methodology described in the C-T Phase II DP, Section 14.4.3.7. Bulk material samples were collected in Plant 5 subsurface survey units.

4.5.1 Number of Measurements

A minimum of 15 measurements were planned to be collected per survey unit. This number of measurements is more than sufficient to apply the statistical tests and to protect against the possibility of some of the data being unusable. The *a priori* assumptions used to derive the number of measurements are listed in Table 4-4. When the number of measurements deviated from 15 for a survey unit, the basis thereof is documented in the chapter of this FSSR applicable to that survey unit.

Table 4-4 *A Priori* Number of Measurements

Parameter	*A Priori* Value	Comments
Remediation Action Level	0.5 x SOF	Allowed for high level of confidence in remediation effectiveness and a low number of FSS measurements
Data Set Variability (σ)	1/6 x $DCGL_W$ (1)	Relative high value allowed less precision in excavation without loss of confidence of data representativeness
Relative Shift (Δ/σ)	3	Little gained by making Δ/σ > 3 (i.e., no reduction in number of FSS measurement required)
Number of Measurements	15	Exceeds number of measurements required for the statistical tests (C-T Phase II DP Equations 14-1 and 14-2)

Note:
(1) The variability estimated from background survey data (C-T Phase II DP, Table 4-17) is equivalent to 0.11 x $DCGL_W$, using the SOF. The proposed value of 1/6 x $DCGL_W$ conservatively bounds that variability.

4.5.2 Measurement Locations

4.5.2.1 Class 3

Measurements in Class 3 survey units were collected at random locations. Random means that each measurement location in the survey unit had an equal probability of being selected.

4.5.2.2 Class 1 and Class 2

For Class 1 and Class 2 survey units, a random-start systematic pattern was used in place of a random pattern. This was done in order to locate small areas of elevated contamination that may have existed within the survey unit. The starting point was randomly selected.

For a square grid, the physical spacing of the measurement locations, L, was determined as follows:

$$L = \sqrt{\frac{A}{n}}$$

where: n = number of measurements

A = total surface area of the survey unit

The calculated value of L was rounded down to the nearest tenth of a meter.

The measurement locations were identified around the starting point in a perpendicular manner at intervals of L. This process was repeated to identify the pattern of measurement locations throughout the survey unit.

Measurement locations selected using a random selection process or a systematic pattern that did not fall within the survey unit area or that could not be surveyed due to site conditions, including health and safety considerations, were replaced with other measurement locations determined using the random selection process. Supplemental measurement locations were also determined using the random selection process.

Measurement locations selected based on professional judgment violate the assumption of unbiased measurements used to develop the statistical tests and were not be used in the statistical evaluation.

4.5.3 Surface Activity Measurements

4.5.3.1 AECOM

Direct alpha and beta-gamma surface measurements were performed on structural materials (asphalt and concrete) using a Ludlum Model 43-68 (126 cm^2) or Ludlum Model 43-37-1 (821 cm^2) gas proportional detector with a Ludlum Model 2360 alpha/beta data logger. Measurement locations were recorded using GPS technology as applicable. Stationary measurements were performed by placing the detector on or near the surface to be measured, taking up to a five minute integrated count, and recording the reading. The count time interval was determined based upon actual site background data and MDC (detection sensitivity) requirements.

4.5.3.2 Energy*Solutions*

Energy*Solutions* used the same technique as AECOM (Section 4.5.3.1), except only the 43-68 detector used and it was coupled to a Ludlum Model 2350-1.

4.5.4 Biased Soil Sampling Locations

4.5.4.1 AECOM

Biased soil sample locations were selected in areas identified from the GWS with a z-score above 3.0. Where there were no areas identified with a z-score above 3.0, areas with the highest z-score values were selected as biased soil sample locations. While the GWS was performed for qualitative purposes (i.e., detection and investigation levels are not applicable), it is noted that z-score contour mapping of the GWS data readily identified discrete relatively elevated areas with soil concentrations with SOF values less than 0.5.

4.5.4.2 Energy*Solutions*

Biased soil sample locations were selected in areas identified during the GWS based on audible response and/or from the GWS with a z-score above 3.0. Where there were no areas identified based on audible response or with a z-score above 3.0, areas with the highest z-score values were selected as biased soil sample locations.

4.5.5 Core Bore Sampling

Subsurface soil samples were collected in 1 meter composites, where the soil from a 1-meter depth interval was composited into a single sample. Horizontal core sampling was done in excavation walls when elevated activity was present in areas that could not be excavated.

4.5.6 Removable Surface Activity Measurements

Removable surface radioactivity measurements were collected by swiping a surface area of approximately 100 cm^2 and analyzed by the on-site laboratory for gross alpha and beta radioactivity.

4.5.7 Exposure Rate Measurements

Exposure rate measurements were performed using a Ludlum Model 19 microR meter. The measurements were taken using the “slow” response time constant setting. The detector was positioned approximately 30 cm from the surface of interest and allowed to stabilize prior to recording the measurement (approximately 30 seconds). General area measurements were performed by holding the detector at waist height (approximately 1 meter above grade level).

4.6 LABORATORY ANALYSIS

4.6.1 On-Site

Soil and bulk material samples were analyzed by an on-site laboratory to assist in guiding remediation, waste characterization, and FSS activities. Samples were prepared by drying, grinding, mixing, sifting (no. 4 plus sieve), and weighing prior to analysis. Sample analyses were performed using gamma spectroscopy based on U.S. Environmental Protection Agency (EPA) Method 901.1, including directly measuring ^{226}Ra based on its 186 kilo-electron volt (keV) gamma-ray and indirectly measuring ^{232}Th and ^{238}U by their gamma-emitting progeny ^{228}Ac and

^{234}Th, respectively, in accordance with the laboratory's approved procedures. Radiological data were reported as picoCuries per gram (pCi/g) dry weight.

Sieved (no. 4 plus) material was analyzed separately to verify residual radioactivity was consistent with sample results. Historical records indicate the site was backfilled in the late 1800s with a cinder fill, which included a slag-type material. The material is not part of the C-T process and was separated out by sieve from samples collected from the excavation during the sample preparation process. It was radiologically screened to ensure significant levels of radioactivity, if present, were investigated. None were present. Even though it is Mallinckrodt's position that the slag material is not related to the C-T process, it was checked to ensure that it does not contain residual radioactivity that otherwise is not accounted for in the FSS process.

Swipes collected to measure removable surface radioactivity were analyzed for gross alpha and beta radioactivity using a Protean IPC-9025 or Ludlum 2929 using a one minute count time.

4.6.2 Off-Site

TestAmerica Laboratories Inc. of St. Louis, MO was the off-site laboratory used to perform gamma spectroscopy analysis of soil and bulk material samples for FSS. Most systematic samples (regardless of on-site gross SOF result) and biased samples (on-site gross SOF result of 0.5 and greater) were sent to the off-site laboratory, with exceptions noted in the survey unit summary chapters as applicable. The justification for not sending every sample to the off-site laboratory was the conservative comparison results between the on-site and off-site laboratories.

Sample analyses were performed using gamma spectroscopy based on EPA Method 901.1 in accordance with the laboratory's approved procedures. The activity concentration of ^{226}Ra was inferred from bismuth-214 (^{214}Bi) after a sufficient in-growth period to achieve secular equilibrium. The activity concentrations of ^{232}Th and ^{238}U were inferred by measuring their gamma-emitting progeny ^{228}Ac and ^{234}Th, respectively. Samples were packaged in hermetically sealed containers prior to initiating the in-growth period to avoid radon-222 losses. Radiological data were reported as pCi/g dry weight.

4.7 REFERENCES

Mallinckrodt, *Mallinckrodt Columbium-Tantalum Phase II Decommissioning Plan*, Revision 2, August 2008.

U.S. Nuclear Regulatory Commission, 10CFR20, Title 10 Code of Federal Regulation Part 20, *Standards for the Protection Against Radiation*.