REVISION 0

POST-REMEDIAL ACTION REPORT FOR THE ACCESSIBLE SOILS WITHIN THE ST. LOUIS DOWNTOWN SITE PLANT 2 PROPERTY

ST. LOUIS, MISSOURI

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prepared by

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ACROYMNS AND ABBREVIATIONS

Ac	actinium
AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
As	arsenic
Cd	cadmium
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cm	centimeter(s)
COC	contaminants of concern
DCGL	derived concentration guideline level
dpm	disintegration per minute
DQO	data quality objective
EPA	Environmental Protection Agency
EPC	exposure point concentrations
FSSP	Final Status Survey Plan
ft	feet
FUSRAP	Formerly Utilized Sites Remedial Action Program
in	inch (es)
IT	International Technology Corporation
m	meter(s)
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCW	Mallinckrodt Chemical Works
MED	Manhattan Engineer District
mg/kg	milligram per kilogram
mrem/yr	millirem per year
NAD	normalized absolute difference
NPL	National Priority List
OU	Operable Unit
Pa	protactinium
pCi/g	picocuries per gram
PRAR	Post-Remedial Action Report
Ra	radium
RG	remediation goal
ROD	Record of Decision
RPD	relative percent difference
SAIC	Science Applications International Corporation
SLDS	St. Louis Downtown Site
SOR	sum of ratios
SOR_N	sum of ratios (net)
SU	survey unit
Th	thorium
U	uranium
USACE	United States Army Corps of Engineers
WRS	Wilcoxon Rank Sum
yd^3	cubic yards

EXECUTIVE SUMMARY

Background

Mallinckrodt Inc., or The Mallinckrodt Chemical Works (MCW) is one of the older chemical manufacturing companies in the United States. In the early 1940s, MCW became the first commercial producer of purified uranium feed materials as a prime contractor of the United States Army Corps of Engineers (USACE), Manhattan Engineer District/Atomic Energy Commission (MED/AEC). MCW's uranium project operated a uranium processing facility in St. Louis, Missouri, from 1942 until 1957.

Within two months of initiation, MCW had carried out a bench scale test for the purification of uranium "black oxide" (U_3O_8) using the ether extraction process, built and tested a pilot plant, and constructed and placed into operation a production plant capable of producing more than one ton of purified uranium (uranium dioxide, UO_2) per day (Mallinckrodt, 1962). From 1942 to 1945, Plants 1, 2, and 4 (now Plant 10) developed uranium-processing techniques, produced uranium compounds and metal, and recovered uranium metal from residues and scrap. In 1944, driven by the war effort's ever increasing demand for highly purified uranium, the MED began to look for a means of expanding the extraction capabilities of the companies providing the unpurified uranium to MCW. By July 1944, Mallinckrodt began its own development work to extract and purify uranium directly from high-grade pitchblende ore at their St. Louis facility. By 1946, Plant 6, designed to extract uranium from pitchblende ore, was fully operational (Mason, 1977).

The majority of the radioactive contamination at the St. Louis Downtown Site (SLDS) is believed to be the result of fugitive losses of materials (dusts, solid materials, or liquids). Plant 2 was most likely contaminated as a result of such fugitive emissions (DOE, 1995).

Scope

The scope of the Plant 2 remedial action and this report includes all accessible soils. Accessible soils are soils that are not beneath buildings or other permanent structures. Inaccessible soils will be addressed in a future document and are beyond the scope of the SLDS Record of Decision (ROD) for the St. Louis Downtown Site (USACE, 1998) and this report.

In addition to the data and information describing the Plant 2 remediation and residual site condition, this report also documents the data and information necessary to provide the basis for removal of the SLDS from the National Priority List (NPL) when required remedial actions are complete. The data and information provided in this report is in accordance with the requirements outlined in EPA 540-R-98-016, "*Close Out Procedures for National Priority List Sites*". A review of NPL Closeout requirements and their location within this report is provided in Appendix D.

Remediation Goals

The remedial action objectives, including individual remediation goals (RGs), for Plant 2 were established in the *Record of Decision for the St. Louis Downtown Site* (ROD) (USACE, 1998). The RGs set forth in the ROD are:

- 5 pCi/g (picocuries per gram) above background for radium-226 (Ra-226) thorium-230 (Th-230), Ra-228, and Th-232 [surface soils, up to 15 cm (6 in) depth];
- 15 pCi/g above background for Ra-226, Th-230, Ra-228, and Th-232 [subsurface soils, between 15 cm (6 in) and 1.8 m (6 ft) depth];
- 50 pCi/g above background for uranium-238 (U-238) from the surface to 1.8 m (6 ft) depth;
- 50 pCi/g above background for Ra-226, 100 pCi/g above background for Th-230, and 150 pCi/g above background for U-238 [deep soils, greater than 1.8 m (6 ft) depth];
- 5 pCi/g above background for Ra-226 averaged over any 100 m^2 [surface soils, up to 15 cm (6 in) depth];
- 15 pCi/g above background for Ra-226 averaged over any 100 m^2 [subsurface soils, between 15 cm (6 in) and 1.8 m (6 ft) depth];
- 60 mg/kg for arsenic and 17 mg/kg for cadmium within the upper 1.8 m (6 ft) depth; and
- 2500 mg/kg for arsenic and 400 mg/kg for cadmium deeper than 1.8 m (6 ft).

Ra-226 is a decay product of Th-230 and Ra-228 is a decay product of Th-232. These RGs were developed assuming secular equilibrium (equal activity) between the parent-progeny pairs. As a result of processing the uranium ores, the radioactive materials around the St. Louis Sites have been disrupted from secular equilibrium. Consequently, these individual radionuclides were not compared individually with their respective RG. Instead, the higher concentration of the Th-230/Ra-226 pair and the Th-232/Ra-228 pair in each sample was used for comparison with RGs.

The potential presence of multiple contaminants requires that the sum of ratios (SOR) be satisfied to meet the RGs specified in the ROD. To demonstrate compliance with RGs, the above-background concentration of each of the primary contaminants is divided by the respective RG for that radionuclide to determine a ratio to the guideline. Background used the 32 samples collected from the reference areas. The net SOR (SOR_N) is then determined and compared with unity (1.0) as follows:

For the top 15 cm (6 in) of soil or cover material,

$$\frac{\text{Higher of Th-230}_N \text{ or Ra-226}_N}{5\,\text{pCi/g}} + \frac{\text{Higher of Th-232}_N \text{ or Ra-228}_N}{5\,\text{pCi/g}} + \frac{\text{U-238}_N}{50\,\text{pCi/g}} = \text{SOR}_N$$

For any 15 cm thick interval deeper than 15 cm,

$$\frac{\text{Higher of Th-230}_N \text{ or Ra-226}_N}{15\,\text{pCi/g}} + \frac{\text{Higher of Th-232}_N \text{ or Ra-228}_N}{15\,\text{pCi/g}} + \frac{\text{U-238}_N}{50\,\text{pCi/g}} = \text{SOR}_N$$

For soils deeper than 6 feet, the RG [as low as reasonably achievable (ALARA) criteria] may be used to release an area with future land use restrictions (i.e., institutional controls) to ensure protectiveness.

$$\frac{\text{Ra-226}_N}{50\,\text{pCi/g}} + \frac{\text{Th}-230_N}{100\,\text{pCi/g}} + \frac{\text{U-238}_N}{150\,\text{pCi/g}} = \text{SOR}_N$$

For an area represented by a particular sample set to comply with the RGs, the average SOR_N must not exceed 1.0 (within a specified level of confidence).

Remedial Action Summary

The remediation of the impacted area at Plant 2 involved the removal of radioactively contaminated soil from one large excavation area as shown in Figure 4. In addition, several isolated areas exceeding RGs were detected and removed and are also shown in Figure 4. Altogether, approximately 10,800 cubic yards of soil was removed. This material was transported to the Material Handling Building at Mallinckrodt Plant 7 South where it was loaded into railcars and shipped to a licensed radioactive waste disposal facility.

During the course of the remediation, field surveys were performed and post-remedial action samples were collected. Several post-remedial action samples indicated small areas of elevated contamination above RGs that required additional remediation beyond the design boundaries. After additional soils were removed, these areas were resurveyed and resampled.

After all areas had been remediated, they were subjected to final status verification surveys in accordance with the *Radiological Final Status Survey Plan for Accessible Soil Within Plant 1, Plant 2, and the City Property at the St. Louis Downtown Site – St. Louis Missouri* (USACE, 1999). Results of the data assessment indicate that all remediated areas have achieved the remedial action objectives and accessible areas are released without restrictions.

Details of the remedial action and post-remedial action survey and sampling activities are included as Appendix A. A detailed discussion of the final status surveys and sampling, as well as the data quality assessment, are included as Appendix B.

Post Remedial Action Measurements

Plant 2 was divided in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance into Class 1 areas (areas that had radioactive contamination prior to remediation), Class 2 areas (areas that had a potential for radioactive contamination due to its proximity to contaminated areas, but is not expected to exceed the RG), and Class 3 areas (areas not expected to contain residual radioactivity or those expected to contain levels of residual radioactivity at a small fraction of the RG).

The separate areas were assigned as specified by MARSSIM guidance for land areas, which suggests survey unit (SU) sizes for different classes of survey areas. MARSSIM suggests the area of an SU in a Class 1 area may be up to 2,000 m^2. Class 2 SUs are suggested to be set between 2,000 m^2 to 10,000 m^2. Class 3 SU sizes are unlimited. In addition to the land areas, a concrete vault was evaluated as specified by MARSSIM guidance for surface structures.

The final status survey was designed so that Class 1, 2, and 3 survey units in Plant 2 were limited to 1000 m^2, 5000 m^2, and 50,000 m^2, respectively. The survey unit sizes selected by the USACE were limited to one-half of the MARSSIM recommended maximum areal limits. This approach was implemented by the USACE at Plant 2 based on input received from Mallinckrodt and state regulators.

Class 1 Survey Units

The Class 1 SUs consist of a land area (SU-1A, SU-1B, and SU-1C) and a concrete vault (SU-2). The land area consists of the main excavation area and some isolated areas that were remediated after being identified during the final status survey. The main excavation is split into three SUs (1A, 1B, 1C) in order to comply with the stated maximum Class 1 SU size of 1000 m^2 (USACE, 1999). The isolated small excavation areas are included in SU-1A and SU-1C as required by the FSSP (USACE 1999) and as shown on Figures 7a and 7b. The isolated small excavation areas were included in SUs 1A and 1C because they were sampled using the same areal density as other Class 1 SUs and therefore did not have sufficient data to satisfy WRS testing. The data from the isolated areas were combined with data from larger survey units with the same classification and within the same plant area as described in the FSSP. The total area of the survey units were limited to 1000 m^2 ± 10%. The Class 1 land area SUs are illustrated in Figure 5. The land area survey unit sampling results were compared to ROD RGs (15/15/50) as described in Section 3.0 of this report.

All soil samples in Class 1 areas were collected below the top 6 inches of the pre-remediation surface grade, therefore the data in Class 1 SUs were compared to the subsurface RG (15/15/50). The ALARA RG (50/100/150) was not used for Plant 2 SU data comparisons because the USACE chose to remediate rather than release an area with restrictions.

The total combined area of SU-2 is approximately 45 m^2. The concrete vault SU measurement results were compared to a derived concentration guideline level (DCGL) of 12,000 dpm/100 cm^2.

Class 2 Survey Units

The Plant 2 Class 2 SUs consist of all accessible subsurface soils of the plant (to a depth of 6 feet) minus the excavated areas classified as Class 1 survey units. The Class 2 area at the plant was divided into three (3) main areas (Areas 1, 2, and 3) in order to comply with the stated maximum Class 2 survey unit size of 5000 m^2 (USACE, 1999). The three Class 2 areas were further separated into nine (9) SUs by area and depth below cover materials to allow comparison of data with ROD RGs in relevant 6 inch layers. For example, SU-3 samples were collected in Area 1 in the first 6 inches below the cover materials, SU-4 samples were collected in Area 1 at the next sampling interval 18-24 inches below SU-3, etc.

All sampling results were compared to the subsurface RG (15/15/50) in accordance with the guidance contained in NUREG-1727, "NMSS Decommissioning Standard Review Plan" (NRC 2000) so that all Class 2 accessible areas could be released without restrictions. NRC 2000 states that if residual radioactivity is primarily beneath paving, it should be surveyed as subsurface residual radioactivity.

Class 3 Survey Unit

The cover materials (e.g., concrete and asphalt) over the Class 2 soil areas at Plant 2 were classified as a Class 3 area. The Class 3 cover materials being evaluated encompass both Plant 1 and Plant 2. The Plant 2 portion of the survey unit will be evaluated in this report. The Plant 1 PRAR will also report the results for the Plant 1 portion of the survey unit when remedial action is complete in that area.

All sampling results in the Class 3 SU were compared to the surface RG (5/5/50) so that all Class 3 areas could be released without restrictions.

Post Remedial Action Measurements/Samples

Nine types of measurements/samples were collected during the final status survey to determine whether the remedial action had met applicable remedial action objectives. These consisted of:

1. Surface gamma scans of land areas to identify potential locations of elevated activity;
2. Samples collected within the first 6 inches below cover materials in Class 2 areas;
3. Samples collected in the first 6 inches of the excavation surface;
4. Soil samples collected at 18 inch depth intervals (below excavation surface samples or samples collected within the first 6 inches below cover materials) down to a maximum depth below grade of 6 feet;
5. Samples of cover material;
6. Preferential pathway samples collected where excavation depths exceed 6 feet and a means for contamination transport was identified;
7. Surface beta scans on vault concrete surfaces;
8. Fixed point measurements of total beta activity on vault concrete surfaces; and
9. Samples collected for chemical analysis (arsenic and cadmium) throughout the Class 1 and Class 2 areas.

Of these, the subsurface samples collected in the first 6 inches below cover materials (Item 2), subsurface samples collected in the first 6 inches of the excavation surface (Item 3), subsurface samples collected at 24 inch depth intervals (Item 4), samples of cover material (Item 5), soil samples collected for chemical analysis (Item 8), and fixed point measurements of total beta activity on vault concrete surfaces (Item 7) were used to compare against the appropriate RG. The other measurements were taken to identify potential locations of elevated activity (Items 1 and 7) or to identify potential contamination transport (Item 6). Accessible areas that contained residual radioactivity above RGs were investigated and remediated, as appropriate.

Post Remediation Status

The remedial action objectives presented in the ROD are considered to have been attained if the average SOR_N in a survey unit does not exceed unity and the average concentration of cadmium and arsenic does not exceed the RG set for these metals. The Plant 2 remedial action was designed to demonstrate compliance with the remedial action objectives as outlined in the ROD such that materials <0.5 ft below the pre-remediation surface grade met the 5/5/50 surface RG, materials >0.5 ft below the pre-remediation surface grade but less than 6 ft

below the pre-remediation surface grade met the 15/15/50 subsurface RG in remediated areas when averaged over 100 m^2, and materials >6 ft below the pre-remediation surface grade met the 50/100/150 ALARA RG. Although the remedial action was designed to meet the ALARA RG (50/100/150) for soils >6 ft below the pre-remediation surface grade, it was determined that after excavation all remediated areas in Plant 2 had achieved levels below the subsurface soil RG (15/15/50) and could be released without restrictions.

The subsurface RG (15/15/50) was used in the SOR_N calculation in all excavated (Class 1) areas since these areas were backfilled with at least 15 cm of cover following final status sampling.

The SOR_N was based on the subsurface RG (15/15/50) in the Class 2 areas for soil samples since all samples were taken at depths exceeding 15 cm below the pre-remediation surface grade due to at least 15 cm of covermaterial existing over these areas. The USACE made the decision to compare Class 2 survey unit data against the ROD subsurface RG based on the guidance contained in NUREG-1727, "NMSS Decommissioning Standard Review Plan" (NRC 2000). NRC 2000 states that if residual radioactivity is primarily beneath paving, it should be surveyed as subsurface residual radioactivity.

The SOR_N was based on the surface RG (5/5/50) in the Class 3 area for the samples collected in the first 15 cm below pre-remediation grade.

The analytical results for the final status survey samples indicate that the residual radioactivity in Plant 2 soil meets the requirements of the remedial design and are below the concentration-based RGs. Only a few individual samples had SOR_N that exceeded 1.0. The mean SOR_N in each survey unit was well below the RG of 1.0 (SORs ranged between 0.02 – 0.36). Each sample with SOR_N >1.0 satisfies the concentration-based elevated measurements criteria. In addition, all SUs with an individual measurement result SOR_N >1.0 (highest SU measurement minus the lowest reference area measurement) passed Wilcoxon Rank Sum (WRS) testing as required by MARSSIM. Table 4 presents the data summary for the reference (background) sample set. Table 5 summarizes the final status sample results for the primary radionuclides detected at the site. Table 6 presents a summary for each survey unit. All chemical (Cd and As) data was compared to the RGs as defined in the FSSP and the results indicated that all individual chemical sample results in Plant 2 soils are below the RGs established in the ROD. Table 7 summarizes the chemical sample results for Cd and As.

In summary, because chemical and radiological data indicate that all SUs meet the remedial action objectives as listed in the ROD and Section 3.0 of this report, all SLDS Plant 2 SUs are released without restrictions. Figure 13 shows the post-remediation status (i.e., accessible areas released without restrictions and inaccessible areas) of SLDS Plant 2. The complete final status sample data set is presented in Appendix B of this report.

CONCLUSIONS

The USACE and EPA determined that Selective Excavation and Disposal was the most appropriate remedy for groundwater and accessible soil at SLDS based upon consideration of the requirements of CERCLA, a detailed analysis of the alternatives, and extensive public

participation and comment. The remedy addressed soil contaminated with radioactivity, arsenic, and cadmium related to MED/AEC uranium manufacturing and processing at SLDS.

The residual radioactivity in accessible areas at SLDS Plant 2 meet all requirements specified in the ROD. This conclusion is the result of comparison of ROD requirements and the residual site condition. The concentration based RGs for Th-230, Ra-226, Th-232, Ra-228, and U-238 are satisfied, noting that no SOR_N value exceeds the RG of 1.0 when averaged over the SU (the average SOR excluding background in Class 1 and Class 2 areas is 0.31 and 0.07, respectively) and no Ra-226 concentration averaged over 100 m^2 exceeds 15 pCi/g. The dose based ARAR from 10 CFR 20 Subpart E, "Radiological Criteria for License Termination" has been satisfied noting that the highest dose of approximately 19.9 mrem/yr was due to a small area of elevated activity using conservative exposure assumptions without regard to existing cover. The residual dose and risk calculated for Plant 2 is less than or equal to 1 mrem/yr and 6 E-05, respectively for all modeled scenarios without regard to existing cover. This dose is <0.01 mrem/yr if existing cover is considered for all Plant 2 areas with the exception of Class 1 SUs. The highest dose calculated in Class 1 SUs when existing cover is considered is 3 mrem/yr. The SUs also satisfy the statistical requirements with all survey units passing the WRS test. Soil concentrations comply with 40 CFR 192 unrestricted release criteria. All Plant 2 SUs are released without restrictions in accordance with the ROD.

In addition to reporting the necessary information to demonstrate compliance with ROD and ARAR remedial action objectives, this report also provides the Plant 2 data and information necessary to provide the input to the decision to remove the SLDS from the National Priority List (NPL) when remedial action at SLDS is complete. The data and information provided in this report is in accordance with the requirements outlined in EPA 540-R-98-016, "*Close Out Procedures for National Priority List Sites*". A review of NPL Closeout requirements and their location within this report is provided in Appendix D.

Comparison to ROD Criteria

The remedial action objectives for SLDS Plant 2 apply to areas affected by the MED/AEC uranium manufacturing and processing activities. This section lists the ROD remedial action objectives and describes how the USACE is demonstrating compliance with the RG. The ROD remedial action objectives consist of the following components(i.e., RGs):

- Excavation of accessible soils according to the ARAR-based composite RG of 5/15 pCi/g above background for Ra-226, Ra-228, Th-232, and Th-230, and 50 pCi/g above background for U-238 in the uppermost 1.8 m (6 ft).

  The 5/5/50 RG was used for comparison against the data collected from covermaterials in the first 0.5 ft below grade (SU-12). The 15/15/50 subsurface RG was used for comparison against the data collected in accessible soils below covermaterials (SU-1A, SU-1B, and SU-1C) in Class 1 SUs and (SU-3 through 11) in Class 2 SUs. In Class 1 SUs, soil samples were collected at the excavation surface and at 18-24 inch intervals until a depth of 6 ft below ground surface was reached. In Class 2 SUs, samples were collected in the first 6 inches below covermaterials and then at 18-24 inch intervals until a depth of 6 ft below ground surface was reached.

All Plant 2 SUs have SOR_N values of less than 1.0 when averaged over the SU. Therefore, the SU data demonstrates compliance with this ROD RG.

In addition, the 40 CFR 192 ARAR for subsurface soils (15 pCi/g Ra-226 averaged over 100 m^2) was used for comparison against the data collected in accessible subsurface soils in excavated areas. The areal density of samples collected in excavated areas (Class 1 SUs) met the 100 m^2 areal density requirement and the average Ra-226 concentration was less than the 15 pCi/g subsurface RG in all Class 1 SUs. The 40 CFR 192 ARAR for surface soils was not used because all remediated areas were excavated deeper than 15 cm below the pre-remediation surface grade.

- Site-specific target removal levels of 50 pCi/g above background for Ra-226, 100 pCi/g above background for Th-230, and 150 pCi/g above background for U-238 (50/100/150 RGs) will be used as the deep-soil RGs below 1.8 m (6 ft) as described in Section 7.3.6. of the ROD.

  The remedial action at Plant 2 was designed to meet the deep soil RG in excavations greater than 6 ft deep. However, when the excavation was complete and final status survey data was collected it was determined that the remediation had successfully attained the 15/15/50 subsurface RG stated above. The 50/100/150 RG was not used for comparison against any data in Plant 2 SUs. The SOR_N is less than 1.0 for all data collected in Class 1 SUs (nearly all samples collected in Class 1 SUs were at depths greater than 6 ft below ground surface).

- For arsenic and cadmium:

  1) within the upper 1.2 or 1.8 m (4 or 6 ft) of grade, soil concentrations of arsenic greater than 60 mg/kg and/or cadmium concentrations greater than 17 mg/kg will be removed, or
  2) below 1.2 or 1.8 m (4 or 6 ft) of grade, soil concentrations of arsenic greater that 2500 mg/kg and/or cadmium are greater than 400 mg/kg will be removed;

  Twenty-nine chemical samples were collected across the Plant 2 site. Ten samples were collected in Class 1 SUs and the remaining were collected in Class 2 SUs. All sample results were less than the most restrictive RG of 60 mg/kg for arsenic and 17 mg/kg for cadmium. Therefore, the chemical data collected at Plant 2 demonstrates compliance with this ROD RG.

- Remediation goals for radiological contaminants are applied to soil concentration above background consistent with the ARAR (40 CFR 192), from which they derive. However, addition of background concentrations to these goals would not alter any judgments regarding protectiveness. Remediation goals for non-radiological RGs are applied to soil concentrations including background consistent with the NCP.

  This statement in the ROD is true for all Plant 2 SUs. The SOR_G for all SUs (the raw data including background) is also less than 1.0 when averaged across the SU. The raw data (including background) provided by the analytical laboratory was used for comparisons against chemical RGs consistent with the NCP.

- Compliance with soil RGs will be verified by methods that are compatible with MARSSIM for soils being cleaned up in the OU effective with MARSSIM publication. (A representative number of samples obtained in the bottom of excavations will also be subjected to chemical analysis and comparison to chemical RGs.);

  The Plant 2 FSSP was designed in accordance with MARSSIM methodology.

  - Class 1 and Class 2 survey unit sizes were selected to be 1000 m^2 and 5000 m^2 (one half of the size recommended in MARSSIM) in order to increase the sample density in each survey unit and the confidence in the final decision to release the survey unit.
  - In survey units that had individual samples with $SOR_N > 1.0$ (SU-1A, and SU-1B), the survey unit was subjected to WRS statistical testing to ensure that the activity in the survey unit is less than the DCGL. All surveys units that required WRS testing passed the WRS test.
  - Final status survey data was used to ensure that enough samples were collected in each survey unit. All Plant 2 SUs have enough samples to satisfy statistical testing requirements.
  - A representative number of samples (10) obtained in the bottom of excavations were subjected to chemical analysis. Chemical sample results were compared to RGs for chemical COCs. All chemical results are less than ROD RGs.
  - Data quality indicators were reviewed for precision, accuracy, representativeness, completeness, and comparability. All data quality indicators are considered acceptable and the data are useable for their intended purpose.

- A post-remedial action risk assessment will be performed to describe the level of risk remaining from MED/AEC contaminants following completion of remedial activities;

  A post-remedial action risk and dose assessment was performed for the modeled scenarios outlined in the ROD. In addition, regulators requested that the USACE develop an on-site residential scenario in case the current land use for Plant 2 areas changed from industrial to residential. The dose and risk from actual residual conditions (without regard to cover materials) at Plant 2 are considered acceptable to release the accessible areas without restrictions. Details of the dose and risk assessment can be found in Appendix B of this report.

- Final determinations as to whether institutional controls and use restrictions are necessary will be based on calculations of post remedial action risk derived from actual residual conditions. Five year reviews will be conducted per the NCP for residual conditions that are unsuitable for release without restrictions.

  The dose and risk from actual residual conditions (without regard to cover materials) are considered acceptable to release Plant 2 accessible areas without restrictions. There are no accessible areas at Plant 2 where it is necessary to apply restrictions or institutional controls.

- Institutional controls may include land use restrictions for those areas having residual concentrations of contaminants unsuitable for release without restrictions. This determination will be made based on risk analysis of the actual post-remedial action conditions. Until a decision is developed to address the ultimate disposition of inaccessible soils, steps will be taken to control uses inconsistent with current uses and to learn of anticipated changes in conditions that might make these soils accessible or increase the potential for exposure. Periodic reviews with affected property owners will be conducted throughout the duration of active site remediation. For residual conditions requiring use restrictions after the period of active remediation, coordination with property owners and local land use planning authorities will be necessary to implement deed restrictions or other mechanisms to maintain industrial/commercial land use.

  The dose and risk from actual residual conditions (without regard to cover materials) are acceptable to release Plant 2 accessible areas without restrictions. Details of the dose and risk assessment can be found in Appendix B of this report. There are no accessible areas at Plant 2 where it is necessary to apply restrictions or institutional controls. Inaccessible soils at Plant 2 are not within the scope of the SLDS ROD or this report. Inaccessible soils will be addressed in a future document.

- A long-term ground-water monitoring strategy will be implemented to confirm expectations that significant impacts to the Mississippi Alluvial Aquifer (B unit) will not occur. Although ground water use in this area is not anticipated, agreements will be proposed to state and local water authorities to prevent well drilling, which may be impacted by the surficially contaminated A unit.

  A long-term ground-water monitoring strategy has been implemented to confirm expectations that significant impacts to the Mississippi Alluvial Aquifer (B unit) will not occur. An Environmental Monitoring Guide for the St. Louis Sites has been written and is currently being implemented by the USACE through Environmental Monitoring Implementation Plans for each fiscal year.

- Perimeter wells in the Mississippi Alluvial Aquifer will be monitored to determine if further action will be required with respect to ground water,

  Perimeter wells in the Mississippi Alluvial Aquifer are being monitored in accordance with the Environmental Monitoring Guide for the St. Louis Sites. The requirements in the guide are currently being implemented by the USACE through Environmental Monitoring Implementation Plans for each fiscal year. These requirements include perimeter well ground-water monitoring.

- Protactinium-231 (Pa-231) and actinium-227 (Ac-227) will be included in the analyses for the post-remedial action residual site risk; and

  Pa-231 and Ac-227 were included in the post-remedial action dose and risk assessments. The average Pa-231 and Ac-227 concentrations were less than 0.5 pCi/g in all SUs and therefore did not significantly affect residual dose or risk. Details of the dose and risk assessment can be found in Appendix B of this report.

- Contaminated sediments in sewers and drains considered to be accessible will be remediated along with the soils.

  Contaminated sediments in sewers and drains considered to be accessible were remediated along with the soils. Inaccessible areas (including sediments in sewers and drains) are beyond the scope of the ROD and this report. Inaccessible areas will be addressed in a future document.

The residual radioactivity in accessible areas at SLDS Plant 2 meet all requirements specified in the ROD. This conclusion is the result of comparison of ROD requirements and the residual site condition in accessible areas. The concentration based RGs for Th-230, Ra-226, Th-232, Ra-228, and U-238 are satisfied, noting that no SOR_N value exceeds the limit of 1.0 when averaged over the SU (the average SOR excluding background in Class 1 and Class 2 areas is 0.31 and 0.07, respectively) and no Ra-226 concentration averaged over 100 m^2 exceeds 15 pCi/g. The dose-based ARAR from 10 CFR 20 Subpart E, "Radiological Criteria for License Termination" has been satisfied noting that the highest dose of approximately 19.9 mrem/yr was due to a small area of elevated activity using conservative exposure assumptions without regard to cover. The residual dose and risk calculated for Plant 2 over the entire site is less than or equal to 1 mrem/yr and 6 E-06, respectively for all modeled scenarios without regard to existing cover. This dose is <0.01 mrem/yr if existing cover is considered for all Plant 2 areas with the exception of Class 1 SUs. The highest dose calculated in Class 1 SUs when existing cover is considered is 3 mrem/yr. The SUs also satisfy the statistical requirements with both required survey units (SU-1A and SU-1B) passing the WRS test. Soil concentrations comply with 40 CFR 192 unrestricted release criteria. All Plant 2 SUs are released without restrictions in accordance with the ROD.

1.0 INTRODUCTION

This report documents and assesses the effectiveness of the remedial action conducted as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP) St. Louis Downtown Site (SLDS) Plant 2. The scope of the Plant 2 remedial action and this report includes all accessible soils. Accessible soils are soils that are not beneath buildings or other permanent structures. Inaccessible soils will be addressed in a future document and are beyond the scope of the SLDS Record of Decision (ROD) for the St. Louis Downtown Site (USACE, 1998) and this report. The location of the SLDS is shown in Figure 1. Plant 2 is located on the Mallinckrodt Chemical Works Site owned by Mallinckrodt Inc. in downtown St. Louis, Missouri, as shown in Figure 2. Major features of Plant 2 are shown in Figure 3.

In addition to the data and information describing the Plant 2 remediation and residual site condition, this report also documents the data and information from Plant 2 necessary for removal of the SLDS from the National Priority List (NPL) when remedial actions are complete. The data and information provided in this report is in accordance with the requirements outlined in EPA 540-R-98-016, *"Close Out Procedures for National Priority List Sites"*. A review of NPL Closeout requirements and their location within this report is provided in Appendix D.

FUSRAP was established to identify and cleanup, or otherwise control, sites where residual radioactive contamination [exceeding current remediation goals (RGs)] remains from the early years of the nation's atomic weapons program or from commercial (non-governmental) operations that caused conditions necessitating their inclusion in the program by Congress. The United States Army Corps of Engineers (USACE) took over the administration and execution of cleanup of FUSRAP Sites as authorized by the Energy and Water Development Appropriations Act in October 1997.

The objectives of FUSRAP, as they apply to the St. Louis Site, are as follows:

- Prevent exposures from surface contamination in soils greater than the criteria prescribed in 40 Code of Federal Regulations (CFR) 192;
- Eliminate or minimize the potential for humans or biota to contact, ingest, or inhale soil containing contaminants of concern (COCs);
- Eliminate or minimize the volume, toxicity, and mobility of impacted soil;
- Eliminate or minimize the potential for migration of radioactive materials off-site;
- Maintain compliance with applicable or relevant and appropriate requirements (ARARs);
- Eliminate or minimize potential exposure to external gamma radiation;
- Remove groundwater sources of COCs in the A Unit; and

- Continue to maintain low groundwater concentrations of Operable Unit (OU) COCs in the B Unit.

The International Technology Corporation (IT) was contracted by USACE as the remediation contractor for the removal of contaminated material from Plant 2. Science Applications International Corporation (SAIC) was contracted by the USACE to prepare and implement the Final Status Survey Plan and to evaluate the final status survey results.

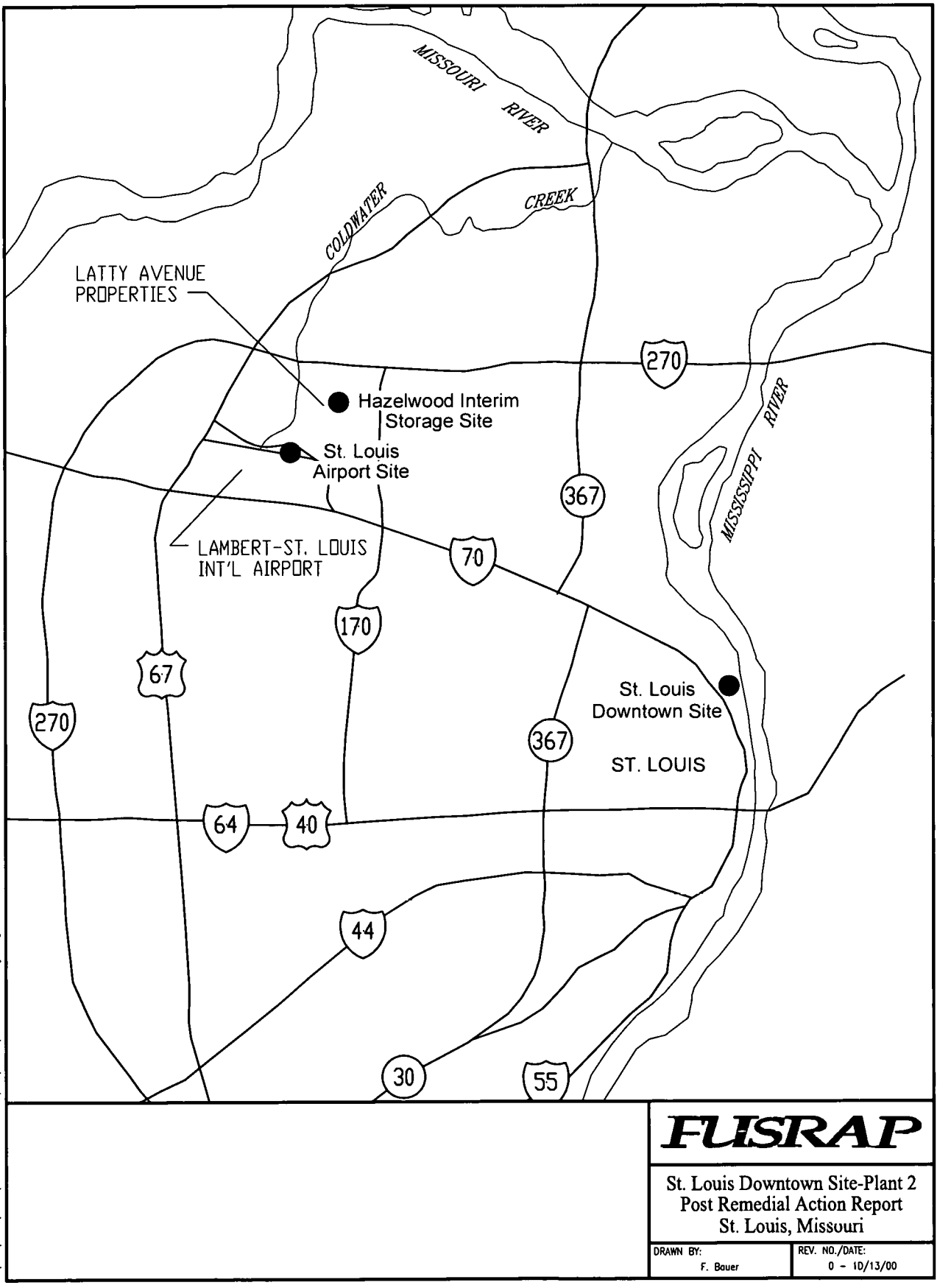

Figure 1. Location of the FUSRAP Sites in St. Louis, Missouri

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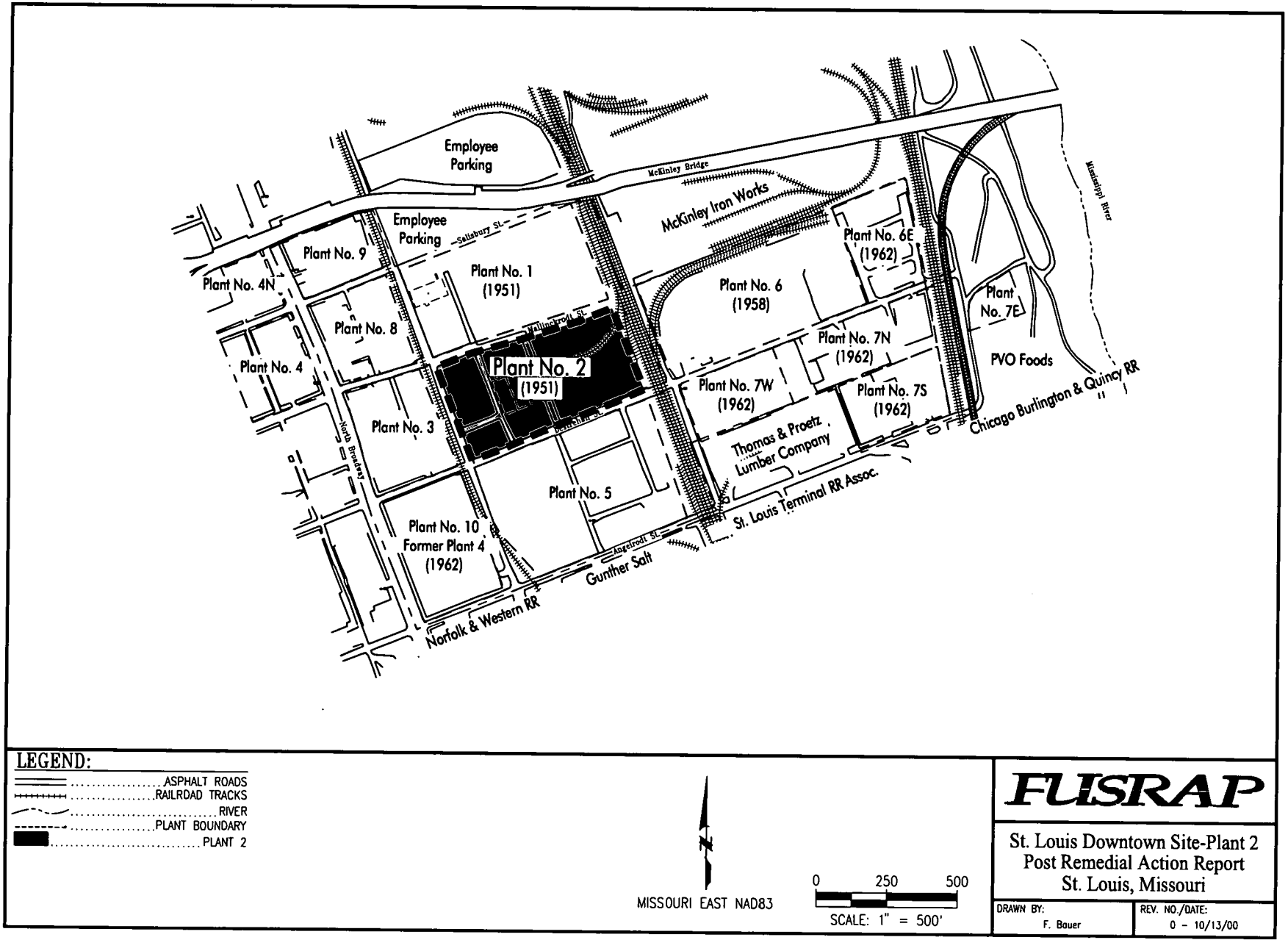

Figure 2. St. Louis Downtown Site

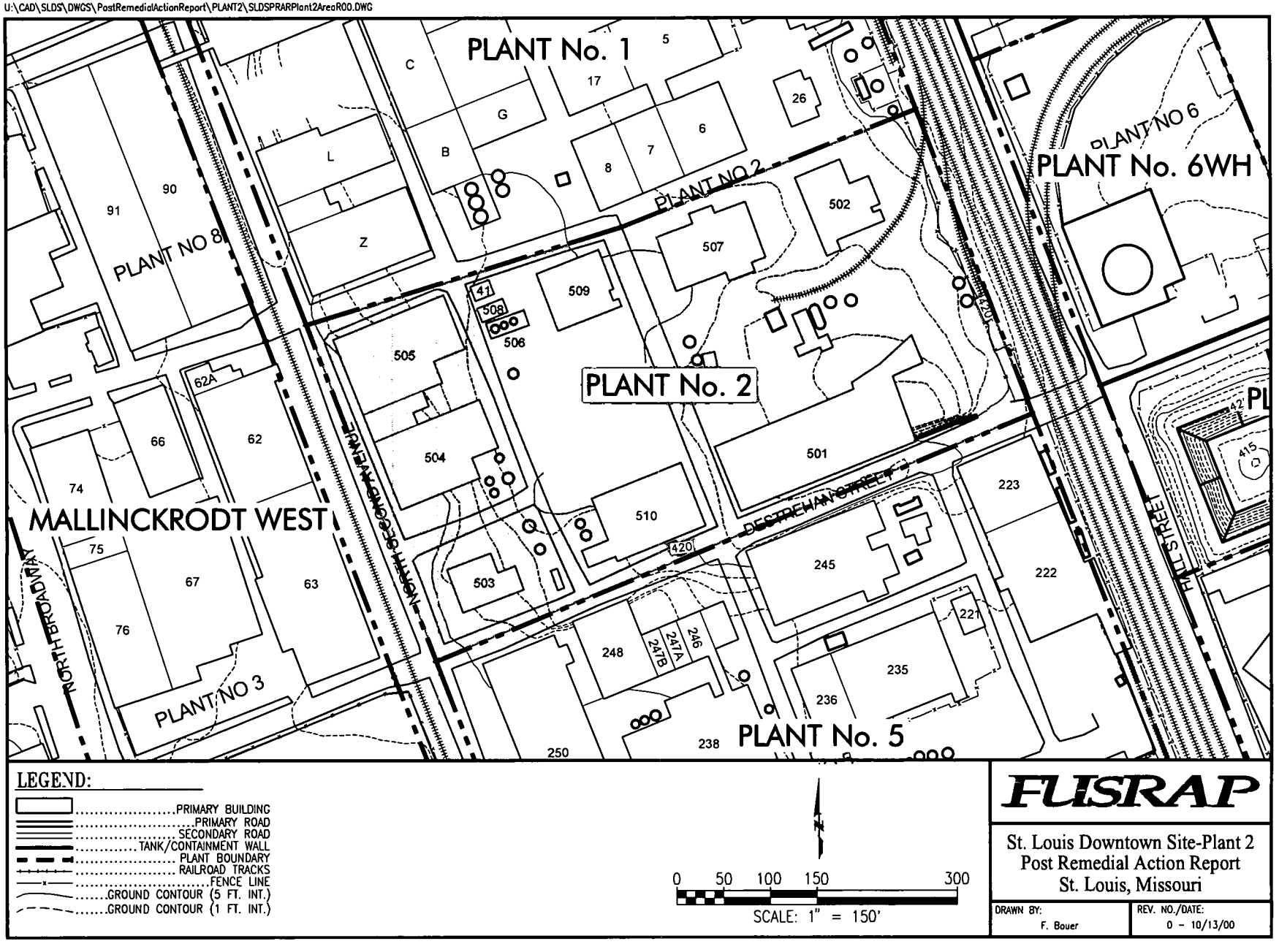

Figure 3. SLDS Plant 2 Area Before Remedial Action

2.0 SITE DESCRIPTION AND HISTORY

Mallinckrodt Inc., or The Mallinckrodt Chemical Works (MCW) (as the St. Louis-based manufacturing operation was previously named), is one of the older chemical manufacturing companies in the United States. In the early 1940s, MCW became the first commercial producer of purified uranium feed materials as a prime contractor of the USACE, Manhattan Engineer District /Atomic Energy Commission (MED/AEC). MCW's uranium project (which later became the Uranium Division) operated a uranium processing facility in St. Louis, Missouri, from 1942 until 1957.

Within two months of initiation, MCW had carried out a bench scale test for the purification of uranium "black oxide" (U_3O_8) using the ether extraction process, built and tested a pilot plant, and constructed and placed into operation a production plant capable of producing more than one ton of purified uranium (uranium dioxide, UO_2) per day (Mallinckrodt, 1962). From 1942 to 1945, Plants 1, 2, and 4 (now Plant 10) developed uranium-processing techniques, produced uranium compounds and metal, and recovered uranium metal from residues and scrap. In 1944, driven by the war effort's ever increasing demand for highly purified uranium, the MED began to look for a means of expanding the extraction capabilities of the companies providing the unpurified uranium to MCW. By July 1944, Mallinckrodt began its own development work to extract and purify uranium directly from high-grade pitchblende ore at their St. Louis facility. By 1946, Plant 6, designed to extract uranium from pitchblende ore, was fully operational (Mason, 1977).

The majority of the radioactive contamination at SLDS is believed to be the result of fugitive losses of materials (dusts, solid materials, or liquids). Plant 2 was most likely contaminated as a result of such fugitive emissions (DOE, 1995).

USACE's remediation of Plant 2 began with remedial design in January 1999 and continued through the completion of site restoration in July of 2000. Details of the remedial action are provided in the Remedial Action Summary Report for the Remediation of the SLDS, Plant 2, included as Appendix A in this document.

After remedial action was completed, SAIC conducted final status walkover surveys and IT conducted soil sampling at specified locations (with USACE oversight) for final status to verify that the residual radioactivity in the remediated area was below the established RGs and that the remedial action objectives established in the ROD were satisfied over the Plant 2 property. Details of the final status survey methodology, and the associated data quality assessment, are included in the *Radiological Final Status Survey Plan for Accessible Soil Within Plant 1, Plant 2, and the City Property at the St. Louis Downtown Site – St. Louis, Missouri* (FSSP) (USACE, 1999) and the Plant 2 Final Status Survey Data Quality Assessment (Appendix B of this document), respectively.

3.0 REMEDIAL ACTION OBJECTIVES

The remedial action objectives, including individual for Plant 2 were established in the *Record of Decision for the St. Louis Downtown Site* (ROD) (USACE, 1998). The RGs set forth in the ROD are:

- 5 pCi/g (picocuries per gram) above background for radium-226 (Ra-226) thorium-230 (Th-230), Ra-228, and Th-232 [surface soils, up to 15 cm (6 in) depth];
- 15 pCi/g above background for Ra-226, Th-230, Ra-228, and Th-232 [subsurface soils, between 15 cm (6 in) and 1.8 m (6 ft) depth];
- 50 pCi/g above background for uranium-238 (U-238) from the surface to 1.8 m (6 ft) depth;
- 50 pCi/g above background for Ra-226, 100 pCi/g above background for Th-230, and 150 pCi/g above background for U-238 [deep soils, greater than 1.8 m (6 ft) depth];
- 5 pCi/g above background for Ra-226 averaged over any 100 m^2 [surface soils, up to 15 cm (6 in) depth];
- 15 pCi/g above background for Ra-226 averaged over any 100 m^2 [subsurface soils, between 15 cm (6 in) and 1.8 m (6 ft) depth];
- 60 mg/kg for arsenic and 17 mg/kg for cadmium within the upper 1.8 m (6 ft) depth; and
- 2500 mg/kg for arsenic and 400 mg/kg for cadmium deeper than 1.8 m (6 ft).

Ra-226 is a decay product of Th-230 and Ra-228 is a decay product of Th-232. The RGs were developed assuming secular equilibrium (equal activity) between the parent-progeny pairs. As a result of processing the uranium ores, the radioactive materials around the St. Louis Sites have been disrupted from secular equilibrium. Consequently, these individual radionuclides were not compared individually with their respective RG. Instead, the higher concentration of the Th-230/Ra-226 pair and the Th-232/Ra-228 pair in each sample was used for comparison with RGs.

The potential presence of multiple contaminants requires that the sum of ratios (SOR) be satisfied to meet the RGs specified in the ROD. To demonstrate compliance with RGs, the above-background concentration of each of the primary contaminants is divided by the respective RG for that radionuclide to determine a ratio to the guideline. Background used the 32 samples collected from the reference areas. The net SOR (SOR_N) is then determined and compared with unity (1.0) as follows:

For the top 15 cm (6 in) of soil or cover material,

$$\frac{\text{Higher of Th-230}_N \text{ or Ra-226}_N}{5\ \text{pCi/g}} + \frac{\text{Higher of Th-232}_N \text{ or Ra-228}_N}{5\ \text{pCi/g}} + \frac{\text{U-238}_N}{50\ \text{pCi/g}} = \text{SOR}_N$$

For any 15 cm thick interval deeper than 15 cm,

$$\frac{\text{Higher of Th-230}_N \text{ or Ra-226}_N}{15\ \text{pCi/g}} + \frac{\text{Higher of Th-232}_N \text{ or Ra-228}_N}{15\ \text{pCi/g}} + \frac{\text{U-238}_N}{50\ \text{pCi/g}} = \text{SOR}_N$$

For soils deeper than 6 ft, the RG [as low as reasonably achievable (ALARA) criteria] may be used to release an area with future land use restrictions (i.e., institutional controls) to ensure protectiveness.

$$\frac{\text{Ra-226}_N}{50\ \text{pCi/g}} + \frac{\text{Th}-230_N}{100\ \text{pCi/g}} + \frac{\text{U-238}_N}{150\ \text{pCi/g}} = \text{SOR}_N$$

For an area represented by a particular sample set to comply with the RGs, the average SOR_N must not exceed 1.0 (within a specified level of confidence).

4.0 REMEDIAL ACTION SUMMARY

The remediation of the impacted area at Plant 2 involved the removal of radioactively contaminated soil from one large excavation area as shown in Figure 4. In addition, several isolated areas exceeding RGs were detected and removed and are also shown in Figure 4. Altogether, approximately 10,800 cubic yards (yd^3) of soil was removed. This material was transported to the Material Handling Building at Mallinckrodt Plant 7 South where it was loaded into railcars and shipped to a licensed radioactive waste disposal facility.

During the course of the remediation, field surveys were performed and post-remedial action samples were collected. Several post-remedial action samples indicated small areas of elevated contamination above RGs that required additional remediation beyond the design boundaries. After additional soils were removed, these areas were resurveyed and resampled.

After all areas had been remediated, they were subjected to final status verification surveys in accordance with the *Radiological Final Status Survey Plan for Accessible Soil Within Plant 1, Plant 2, and the City Property at the St. Louis Downtown Site – St. Louis Missouri* (USACE, 1999). Results of the data assessment indicate that all remediated areas have achieved the remedial action objectives and accessible areas are released without restrictions.

Details of the remedial action and post-remedial action survey and sampling activities are included as Appendix A. A detailed discussion of the final status surveys and sampling, as well as the data quality assessment, are included as Appendix B.

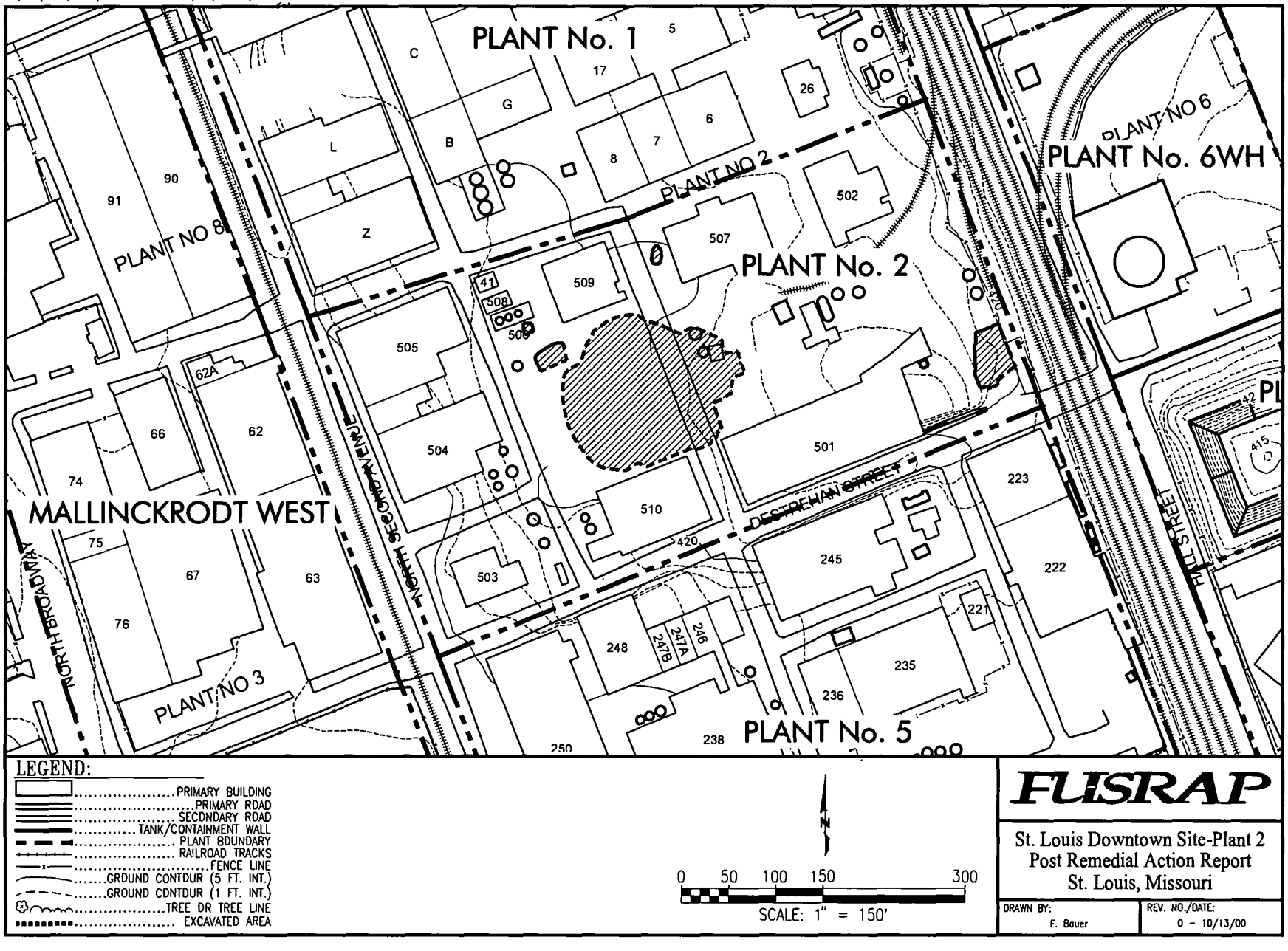

Figure 4. Excavation Areas at SLDS Plant 2

5.0 POST-REMEDIAL ACTION MEASUREMENTS

Plant 2 was divided in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance into Class 1 areas (areas that had radioactive contamination prior to remediation), Class 2 areas (areas that had a potential for radioactive contamination due to its proximity to contaminated areas, but is not expected to exceed the RG), and Class 3 areas (areas not expected to contain residual radioactivity or those expected to contain levels of residual radioactivity at a small fraction of the RG).

The separate areas were assigned as specified by MARSSIM guidance for land areas, which suggests survey unit (SU) sizes for different classes of survey areas. MARSSIM suggests the area of an SU in a Class 1 area may be up to 2,000 m^2. Class 2 SUs are suggested to be set between 2,000 m^2 to 10,000 m^2. Class 3 SU sizes are unlimited. In addition to the land areas, a concrete vault was evaluated as specified by MARSSIM guidance for surface structures.

The final status survey was designed so that Class 1, 2, and 3 SUs in Plant 2 were limited to 1,000 m^2, 5,000 m^2, and 50,000 m^2, respectively. The survey unit sizes selected by the USACE were limited to one-half of the MARSSIM recommended maximum areal limits. This approach was implemented by the USACE at Plant 2 based on input received from Mallinckrodt and state regulators. A description of all survey units is included in Table 1 below.

Table 1. Survey Unit Descriptions

SU No.	Class	Description
1A-1C	1	Class 1 soil samples collected at the excavation surface and at depths up to 6 ft below original grade. Compare data to 15/15/50 pCi/g subsurface RG.
2	1	Class 1 vault concrete surfaces. Compare data to 12,000 dpm/100 cm^2 total beta surface release criteria.
3 through 11	2	Class 2 soil samples collected at depths up to 6 ft below original grade (below cover material). Compare data to 15/15/50 pCi/g subsurface RG.
12	3	Class 3 cover material. Compare to 5/5/50 pCi/g surface RG.

Class 1 Survey Units

The Class 1 SUs consist of a land area (SU-1A, SU-1B, and SU-1C) and a concrete vault (SU-2). The land area consists of the main excavation area and some isolated areas that were remediated after being identified during the final status survey. The main excavation is split into three SUs (1A, 1B, 1C) in order to comply with the stated maximum Class 1 SU size of 1,000 m^2 (USACE, 1999). The isolated small excavation areas are included in SU-1A and SU-1C as required by the FSSP (USACE, 1999) and as shown on Figures 7a and 7b. The isolated small excavation areas were included in SUs 1A and 1C because they were sampled using the same areal density as other Class 1 SUs and therefore did not have sufficient data to satisfy WRS testing. The data from the isolated areas were combined with data from larger survey units with the same classification and within the same plant area as described in the FSSP. The total area of the survey units were limited to 1,000 m^2 ± 10%. The Class 1 land area SUs are illustrated in

Figure 5. The land area survey unit sampling results were compared to ROD RGs as described in Section 3.0 of this report.

All soil samples in Class 1 areas were collected below the top 6 in of the pre-remediation surface grade, therefore the data in Class 1 SUs were compared to the subsurface RG (15/15/50). The ALARA RG (50/100/150) was not used for Plant 2 SU data comparisons because the USACE chose to remediate rather than release an area with restrictions.

The total combined area of SU-2 is approximately 45 m^2. The concrete vault SU measurement results were compared to a derived concentration guideline level (DCGL) of 12,000 dpm/100 cm^2.

Class 2 Survey Units

The Plant 2 Class 2 SUs consist of all accessible subsurface soils of the plant (to a depth of 6 ft) minus the excavated areas classified as Class 1 SUs. The Class 2 area at the plant was divided into three (3) main areas (Areas 1, 2, and 3) in order to comply with the stated maximum Class 2 SU size of 5,000 m^2 (USACE, 1999). The three Class 2 areas were further separated into nine (9) SUs by area and depth below cover materials to allow comparison of data with ROD RGs in relevant 24 in layers. For example, SU-3 samples were collected in Area 1 in the first 6 in below the cover materials, SU-4 samples were collected in Area 1 at the next sampling interval 18 to 24 in below SU-3, etc.

All Class 2 sample results were compared to the subsurface RG (15/15/50) in accordance with the guidance contained in NUREG-1727, *NMSS Decommissioning Standard Review Plan* (NRC, 2000). NRC 2000 states that if residual radioactivity is primarily beneath paving, it should be surveyed as subsurface residual radioactivity. The Class 2 SUs are illustrated in Figure 5. A description of Class 2 survey unit location and depth of samples is located in Table 2 below.

Table 2. Class 2 Survey Unit Descriptions

SU No.	Description
3	Class 2 Area 1, subsurface materials in the first 6 inches below cover materials.
4	Class 2 Area 1, subsurface materials 24-30 inches below cover materials.
5	Class 2 Area 1, subsurface materials 48-54 inches below cover materials.
6	Class 2 Area 2, subsurface materials in the first 6 inches below cover materials.
7	Class 2 Area 2, subsurface materials 24-30 inches below cover materials.
8	Class 2 Area 2, subsurface materials 48-54 inches below cover materials.
9	Class 2 Area 3, subsurface materials in the first 6 inches below cover materials.
10	Class 2 Area 3, subsurface materials 24-30 inches below cover materials.
11	Class 2 Area 3, subsurface materials 48-54 inches below cover materials.

Class 3 Survey Unit

The cover material (e.g., concrete and asphalt) over the Class 2 soil areas at Plant 2 were classified as a Class 3 area. The Class 3 cover material being evaluated encompass both Plant 1 and Plant 2. The Plant 2 portion of the survey unit will be evaluated in this report. The Plant 1 PRAR will report the results for the Plant 1 portion of the survey unit when remedial action is complete in that area.

All sample results in the Class 3 SU were compared to the surface RG (5/5/50). The Class 3 SU is illustrated in Figure 6.

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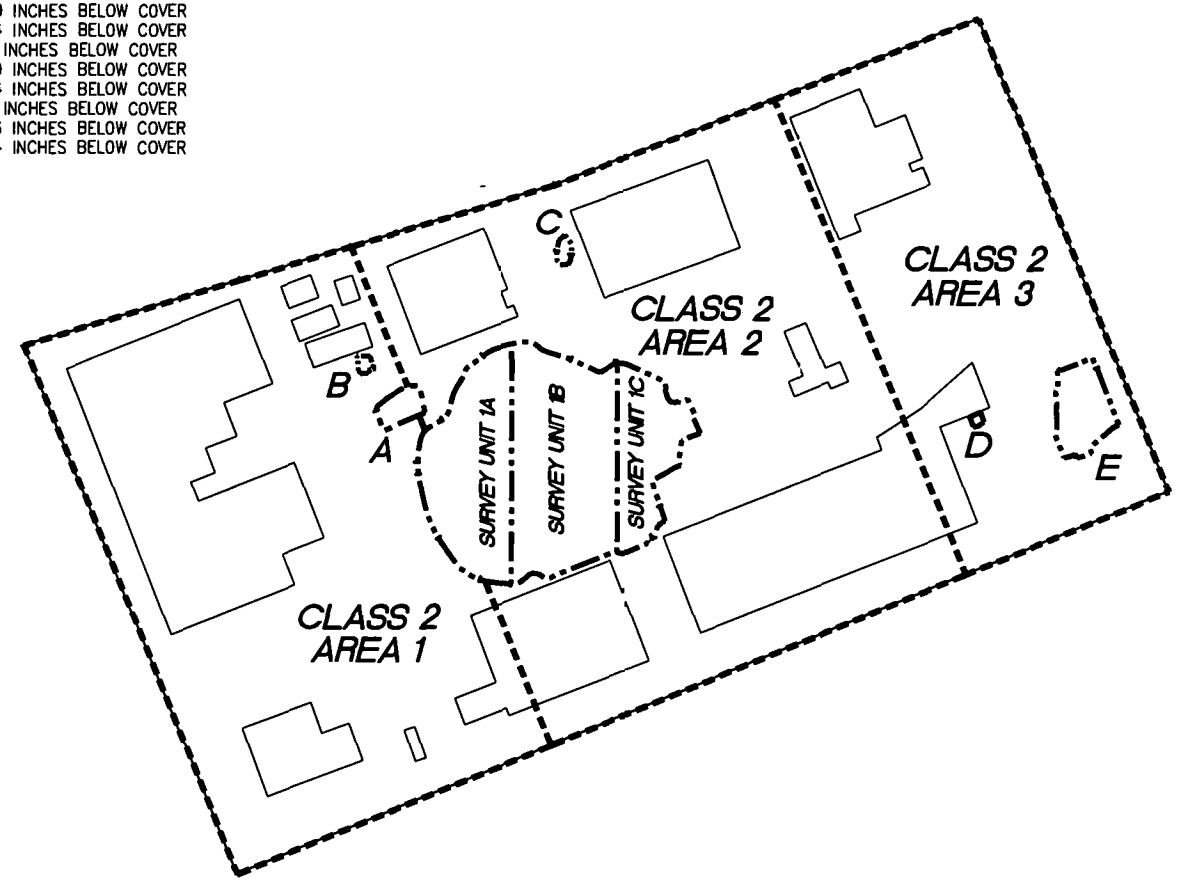
SU-1A, SU-1B, SU-1C: 0 TO 6 INCHES BELOW THE EXCAVATION SURFACE AND AT 18 INCH INTERVALS TO 6 FEET IN DEPTH.
SU-3: AREA 1; 0 TO 6 INCHES BELOW COVER
SU-4: AREA 1; 24 TO 30 INCHES BELOW COVER
SU-5: AREA 1; 48 TO 54 INCHES BELOW COVER
SU-6: AREA 2; 0 TO 6 INCHES BELOW COVER
SU-7: AREA 2; 24 TO 30 INCHES BELOW COVER
SU-8: AREA 2; 48 TO 54 INCHES BELOW COVER
SU-9: AREA 3; 0 TO 6 INCHES BELOW COVER
SU-10: AREA 3; 24 TO 36 INCHES BELOW COVER
SU-11: AREA 3; 48 TO 54 INCHES BELOW COVER



Legend:
- BUILDINGS
- PROPERTY BOUNDARY
- CLASS 1 SURVEY UNIT
- CLASS 2 SURVEY UNIT
- RELEASED AREA

Notes:
THE SMALL EXCAVATION AREAS A, B, AND C ARE INCLUDED IN SU-1A.
EXCAVATION AREAS D AND E ARE INCLUDED IN SU-1C.

SU-3 THROUGH SU-11 ARE CLASS 2 SURVEY UNITS.

N

0 20 40 80

SCALE: 1" = 40 Meters

FUSRAP

St. Louis Downtown Site-Plant 2
Post Remedial Action Report
St. Louis, Missouri

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Figure 5. MARSSIM Class 1 and Class 2 Final Status Survey Units at SLDS Plant 2

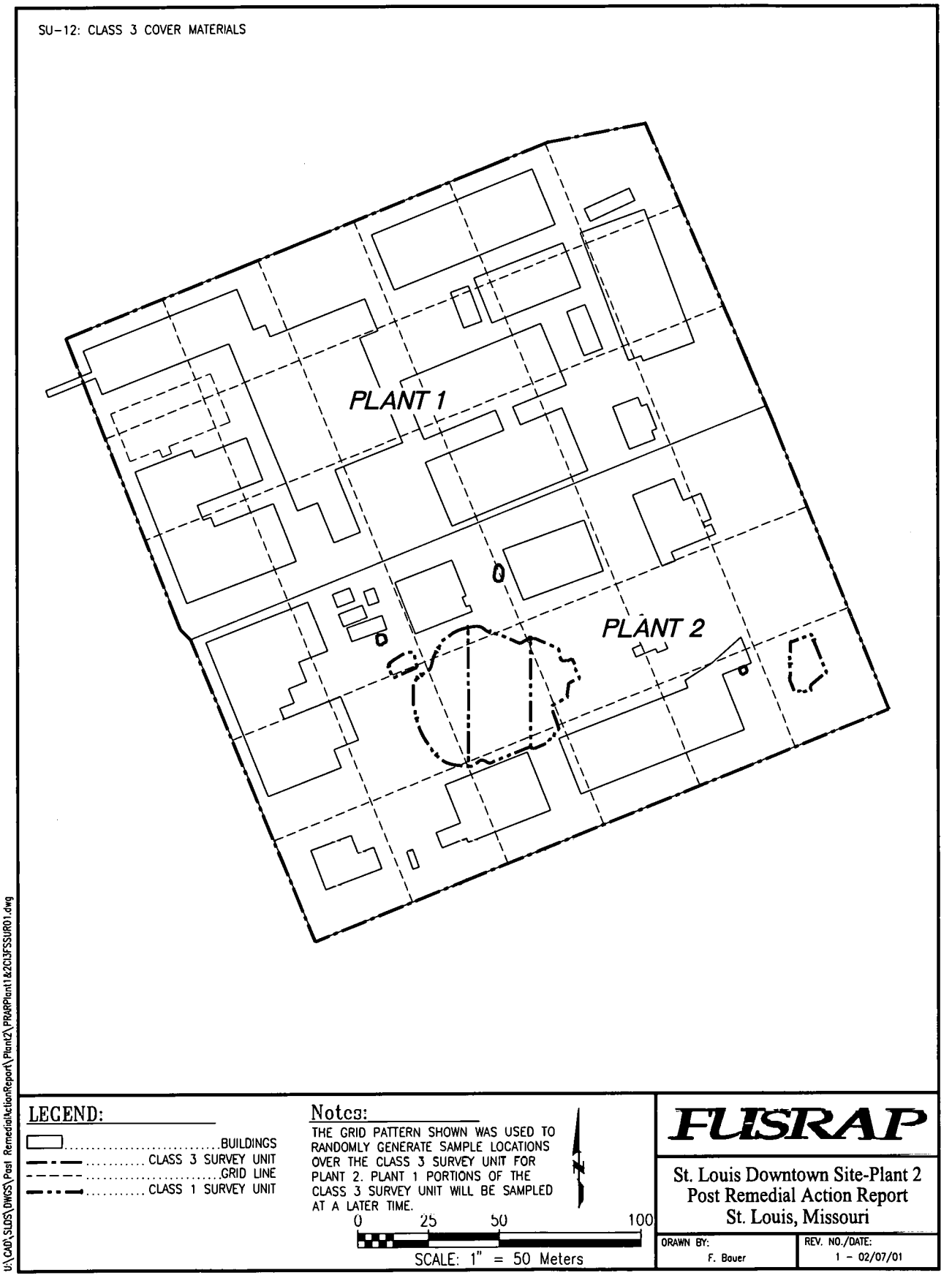

Figure 6. MARSSIM Class 3 Final Status Survey Unit at SLDS Plant 2

Post Remedial Action Measurements/Samples

Nine types of measurements/samples were collected during the final status survey to determine whether the remedial action had met applicable remedial action objectives. These consisted of:

1. Surface gamma scans of land areas to identify potential locations of elevated activity;
2. Soil samples collected within the first 6 inches below cover materials in Class 2 areas;
3. Soil samples collected in the first 6 inches of excavation surfaces;
4. Soil samples collected at 24 inch depth intervals (below excavation surface samples or samples collected within the first 6 inches below cover materials) down to a maximum depth below grade of 6 ft;
5. Samples of cover material;
6. Preferential pathway soil samples collected where a means for contamination transport was identified;
7. Surface beta scans on vault concrete surfaces;
8. Fixed point measurements of total beta activity on vault concrete surfaces; and
9. Soil samples collected for chemical analysis (arsenic and cadmium) throughout the Class 1 and Class 2 arcas.

Of these, the subsurface soil samples collected in the first 6 inches below cover materials (Item 2), subsurface soil samples collected in the first 6 inches of excavation surfaces (Item 3), subsurface soil samples collected at 24 inch depth intervals (Item 4), samples of cover material (Item 5), soil samples collected for chemical analysis (Item 8), and fixed point measurements of total beta activity on vault concrete surfaces (Item 7) were used to compare against the appropriate RG. The other measurements were taken to identify potential locations of elevated activity (Items 1 and 7) or to identify potential contamination transport pathways (Item 6). Accessible areas that contained residual radioactivity above RGs were investigated and remediated, as appropriate. Figures 7 through Figure 9 show sample locations for Class 1, 2, and 3 SUs. Figure 10 shows sample locations for Preferential Pathway samples. Figure 11 shows locations for samples collected for chemical analysis (arsenic and cadmium).

Inaccessible Areas

Figures 12 and 13 show the areas of Plant 2 that are inaccessible. The approach used to delineate the inaccessible soils at Plant 2 was derived directly from the ROD definition of accessible soils. The ROD defines accessible soils as soils that are not beneath buildings or other permanent structures (e.g., active rail lines, roadways, the levee, sewers, etc.). In addition, the ROD states that inaccessible soils containing MED/AEC contamination and associated buildings and structures are excluded from the scope of the ROD because they do not present a significant threat in their current configuration and because activities critical to the continued operation of the Mallinckrodt facility prevent excavation beneath the encumbrances (i.e., roads, railroads, buildings, and other permanent structures). Attachment B-1 in Appendix B of this document shows the limited data that has been obtained in these areas. Inaccessible soils at Plant 2 are not within the scope of the SLDS ROD and will be addressed at a later time.

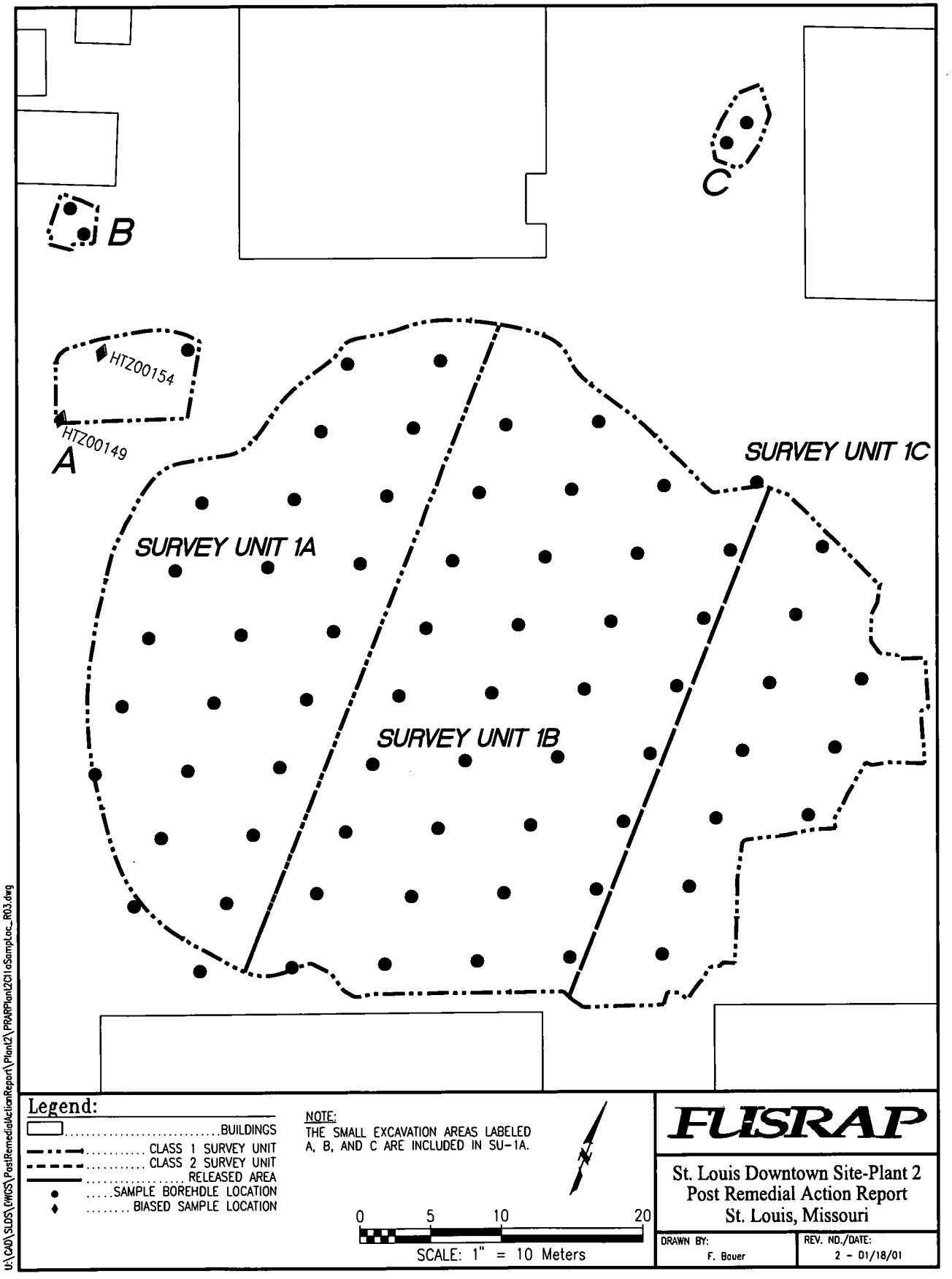

Figure 7a. MARSSIM Class 1 Final Status Survey Sample Locations at SLDS Plant 2

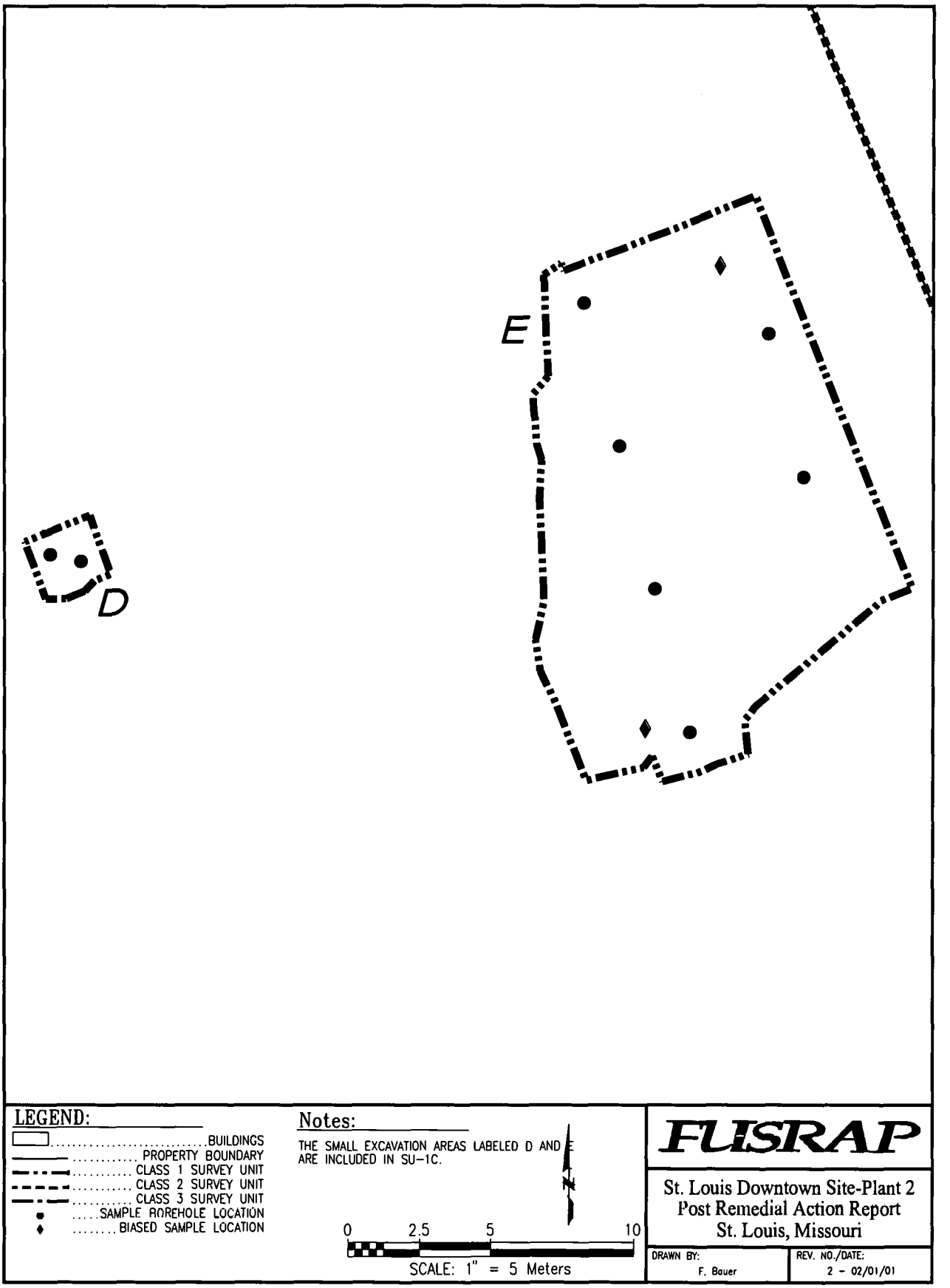

Figure 7b. MARSSIM Class 1 Final Status Survey Sampling Locations at SLDS Plant 2

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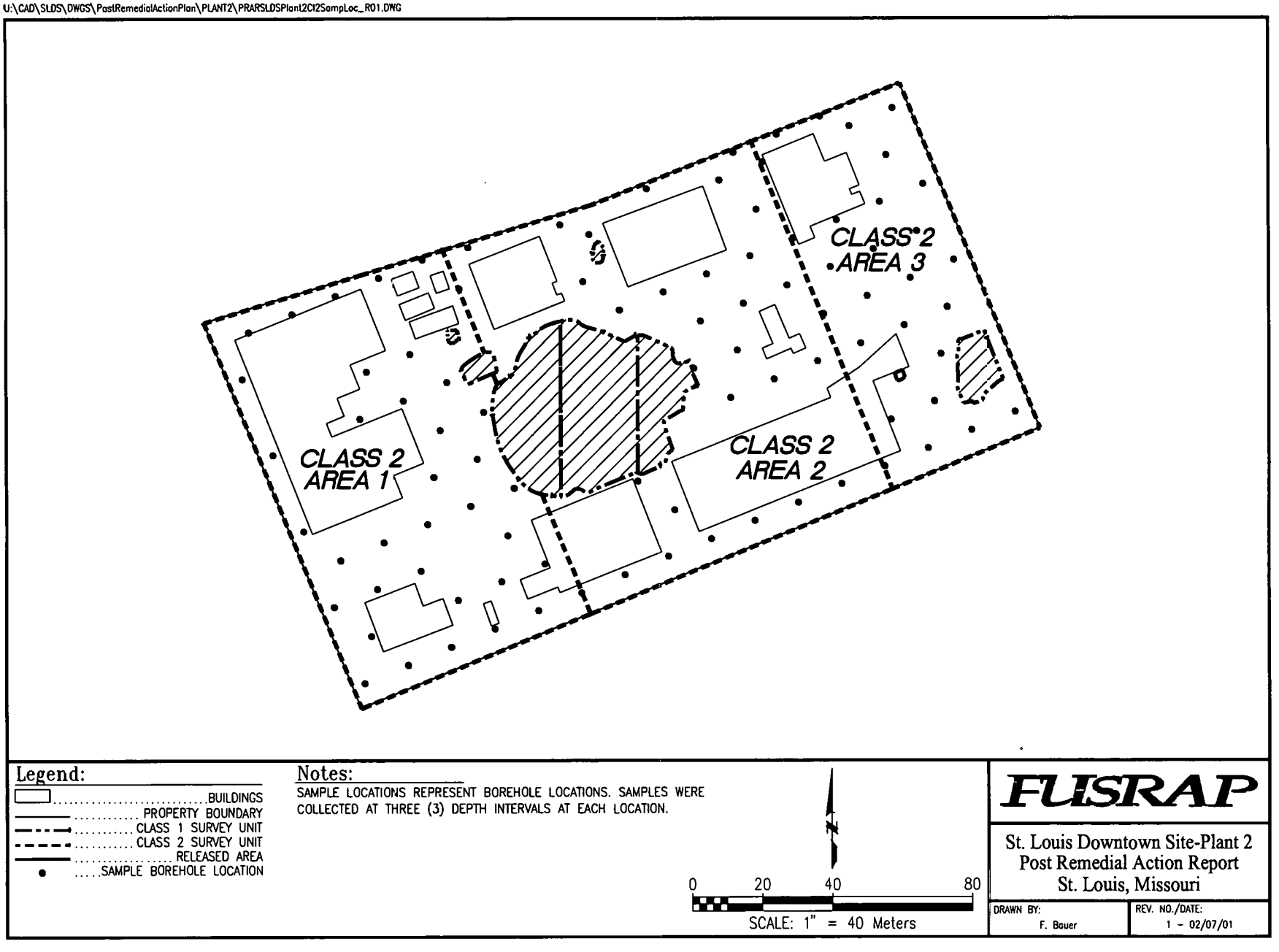

Figure 8. MARSSIM Class 2 Final Status Survey Sample Locations at SLDS Plant 2

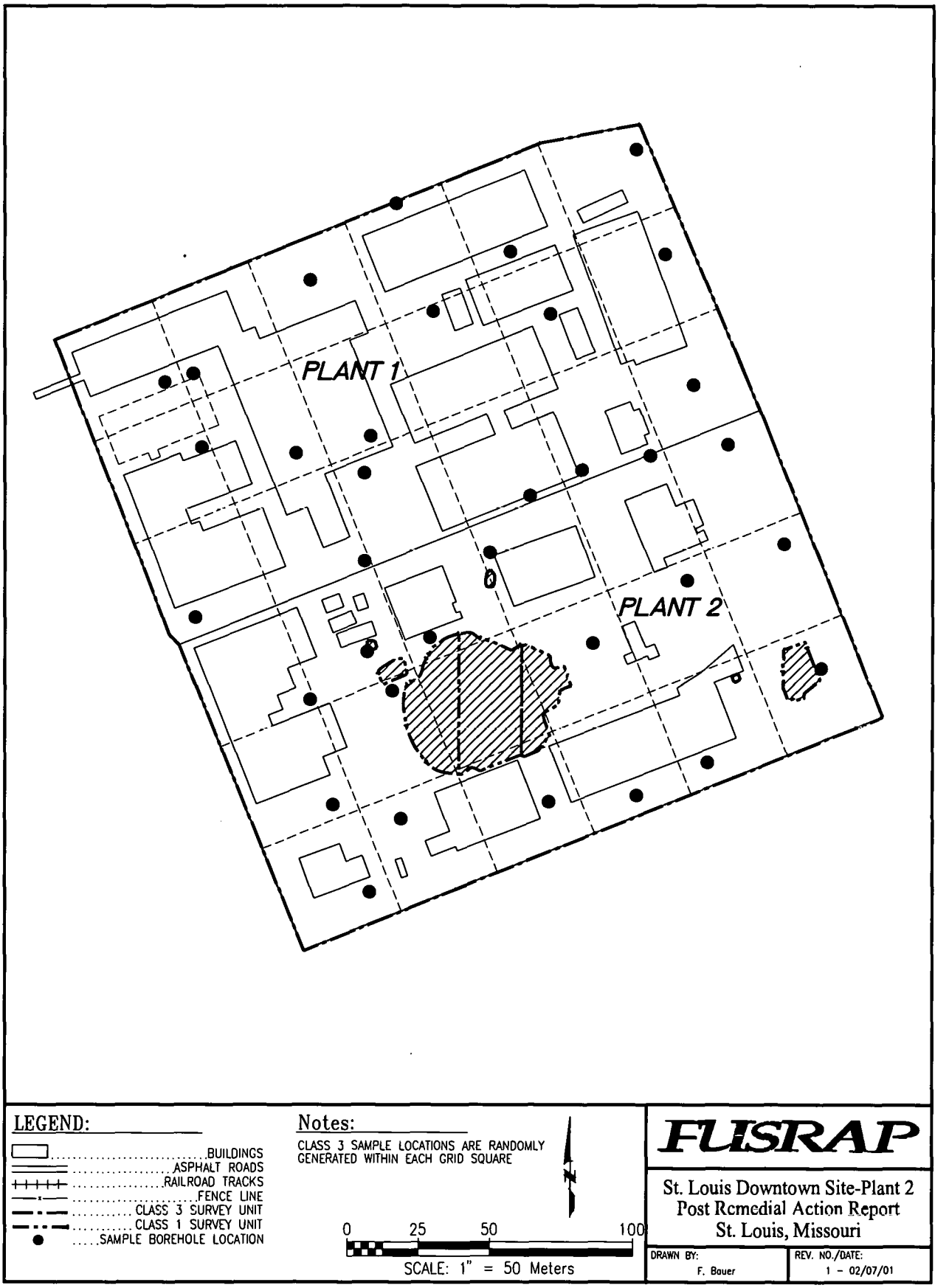

Figure 9. MARSSIM Class 3 Final Status Survey Sample Locations for SLDS Plant 2 Cover Materials

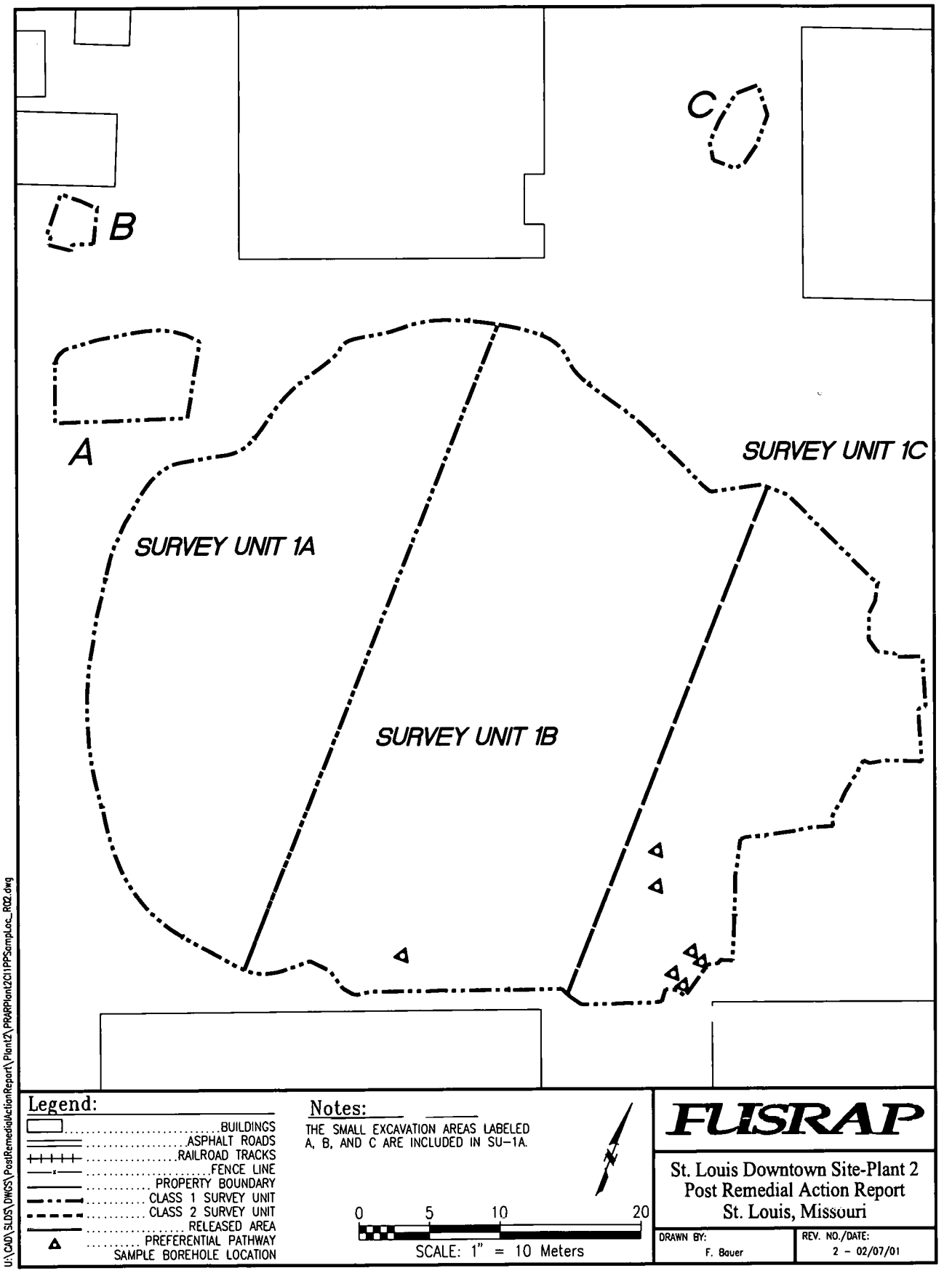

Figure 10. Preferential Pathway Sample Locations at SLDS Plant 2

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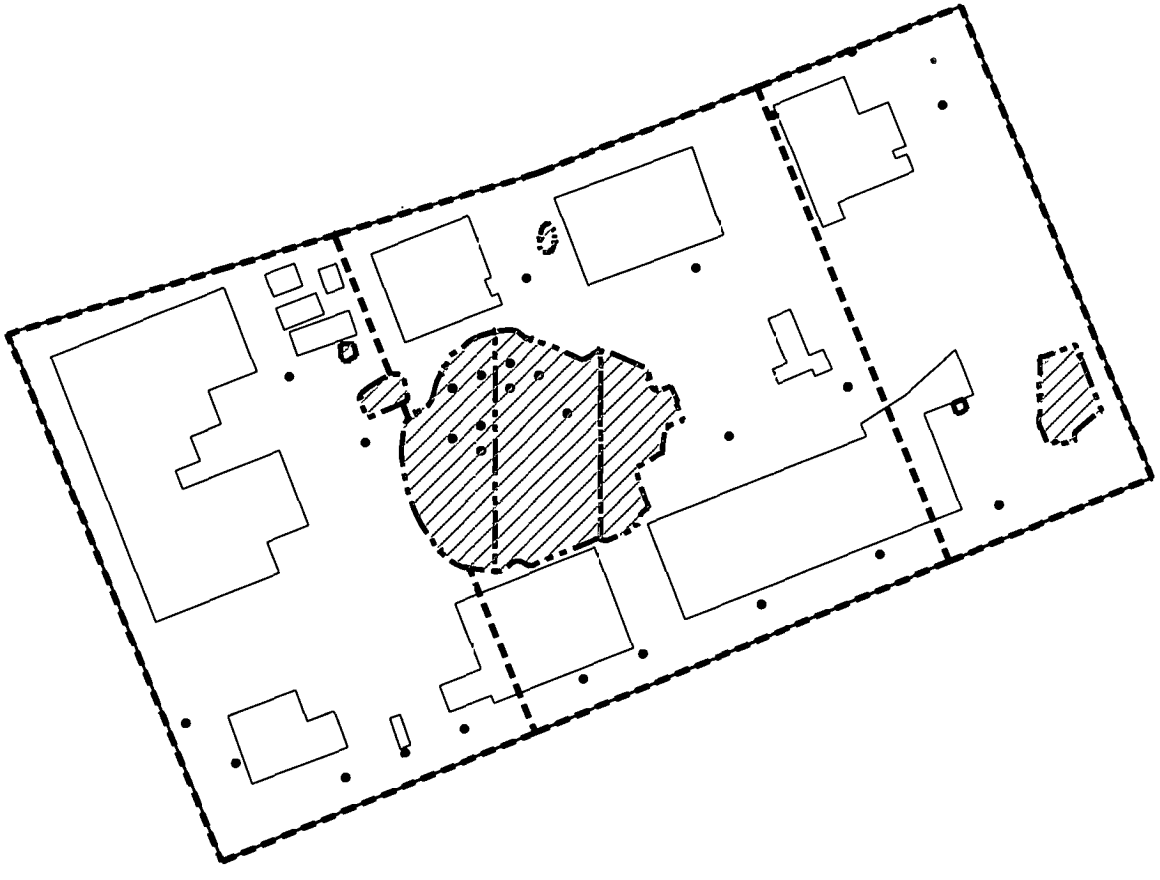

Legend:

- BUILDINGS
- PROPERTY BOUNDARY
- CLASS 1 SURVEY UNIT
- CLASS 2 SURVEY UNIT
- RELEASED AREA
- SAMPLE LOCATION

Notes:

N

0 20 40 80

SCALE: 1" = 40 Meters

FUSRAP

St. Louis Downtown Site-Plant 2
Post Remedial Action Report
St. Louis, Missouri

DRAWN BY:	REV. NO./DATE:
F. Bauer	2 - 02/07/01

Figure 11. Chemical Final Status Survey Sample Locations at SLDS Plant 2

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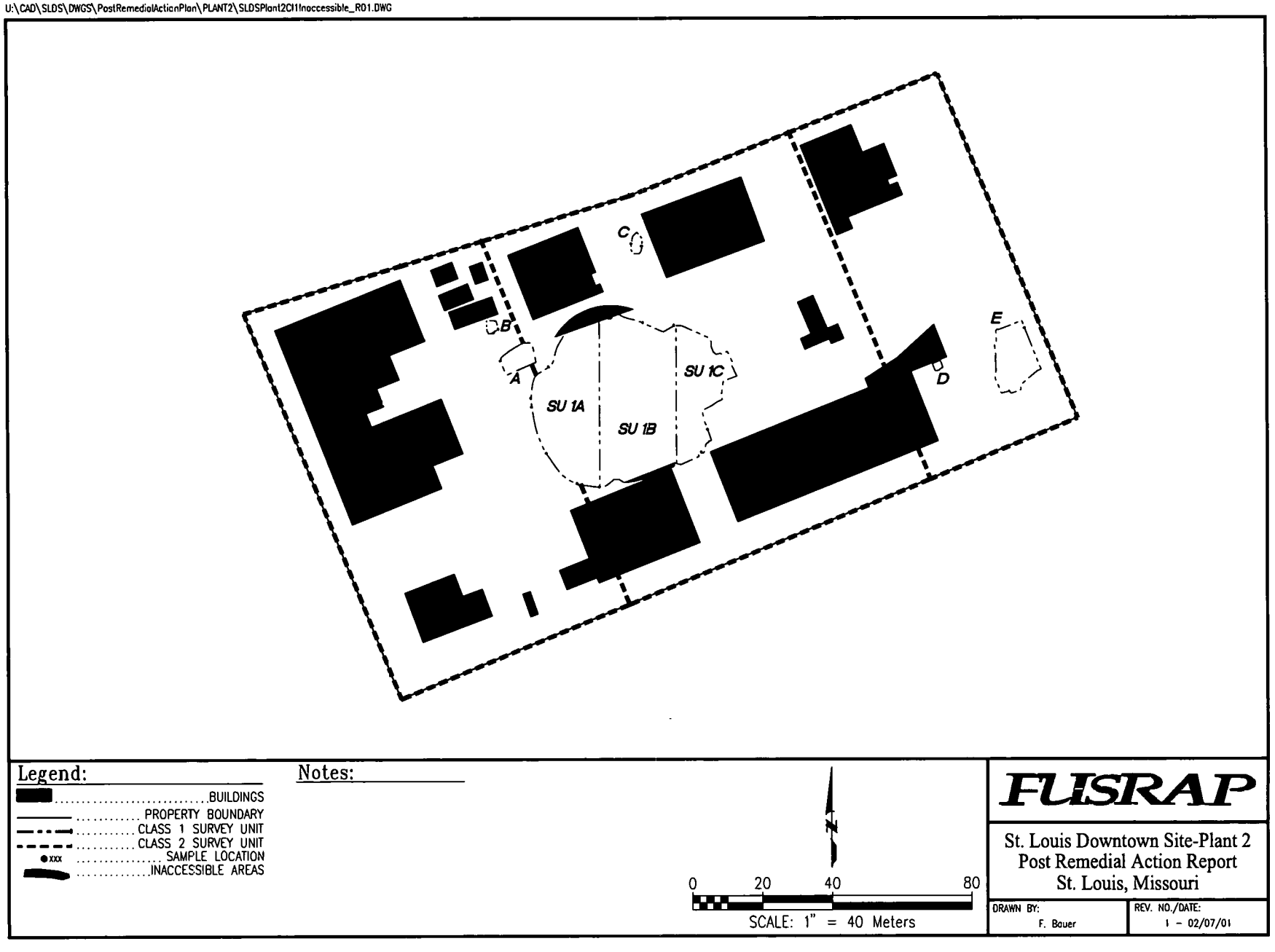

Figure 12. Inaccessible Areas at SLDS Plant 2

Areas shown as inaccessible on Figures 12 and 13 include areas that do not meet the definition of an accessible area as defined in the ROD. Buildings are defined to include the footprint of the structure, supporting soil beneath the footprint, and soil adjacent to the building necessary for structural stability of the building. Roadways and rail lines are defined to include the applicable right-of-way and supporting soil.

5.1 SURFACE SOIL GAMMA SCANS

Screening gamma scans were performed over 100% of accessible Class 1, Class 2, and Class 3 SUs. Sodium iodide radiation detection instruments were used to detect areas of elevated activity during the excavation of contaminated soils. When a Class 1 area was completely excavated, a 100% walkover survey was also performed with the sodium iodide radiation detection instrument and documented prior to the collection of confirmation samples. Locations exceeding the action level established in the Final Status Survey Plan were investigated and either sampled or remediated, as appropriate. When additional soils were removed, the area was re-scanned and sampled, as appropriate, to demonstrate the effectiveness of remedial action. Documentation of walkover surveys is located in Attachment B-5 of Appendix B of this report.

The field radiation detection survey instruments (and their functional and performance specifications) used during the surveys are listed in Table 3 below. Detection sensitivities were determined following the guidance of NUREG-1507 (NRC, 1998).

Table 3. Radiological Field Survey Instruments

Description	Application	Detection Sensitivity[1]
Ludlum Model 44-10; 2-inch × 2-inch NaI gamma scintillation detector	Gamma scans of all surfaces	Th-230 = 1120 pCi/g; Ra-226 = 1.2 pCi/g; and U-natural = 40 pCi/g.
Ludlum Model 2221; Scaler/ratemeter (with earphones)	Readout instrument for gamma scintillation detector	N/A
Ludlum Model 2360 coupled with a Ludlum 43-89 (ZnS plastic scintillator). Effective area 126 cm^2	Beta surface scan on concrete.	4300 dpm/100 cm^2 at 1 inch per second

[1] MDCs shown in table were calculated for areas without surface cover (i.e., rock asphalt, concrete, etc.) based on increased knowledge of site specific parameters. Values shown differ from those listed in the FSSP.

5.2 SOIL SAMPLES

Soil samples were collected in a systematic grid for all Class 1 and 2 SUs. Excavation surface samples were collected in Class 1 SUs to demonstrate whether or not the remedial action (i.e., excavation) was successful. In Class 2 SUs samples were collected to verify that the area satisfied the RG without remediation. The number and location of samples collected in each SU was derived using MARSSIM guidance as described in the FSSP.

Due to the common use of porous fill at SLDS, contamination may have had the potential to distribute non-uniformly in subsurface materials. Therefore, the final status survey incorporated systematic sampling of soils in Plant 2 areas at depth intervals representative of

24 inch layers extending to 6 ft below pre-remediation grade. Sample borings collected at systematic sample locations were scanned to determine if subsurface pockets of contamination existed in the SU. Soil samples were collected at 24 inch depth intervals (6 inch samples collected 18-24 inches below the previous sample) unless scanning indicated elevated contamination levels in other locations of the boring. If soil contamination in excess of the subsurface RG was identified, further investigation, re-classification, and/or remediation was conducted, as appropriate, to demonstrate compliance with ROD remedial action objectives. The survey included the following:

- In Class 1 SUs, a sample was collected at the first 6 inches below the excavation surface at all systematic sampling locations. Systematic sampling locations were extended to collect samples at 24 inch intervals until a total depth below original grade of 6 ft was reached. In addition to collecting samples, the soil boring was scanned prior to separating the samples from the boring to identify pockets of subsurface contamination. If the excavation was greater than 6 feet deep, then only an excavation surface sample was collected at that location. One hundred percent (100%) of the Class 1 samples were subjected to laboratory analysis.

- An additional sample was collected in Class 1 SUs (preferential pathway) if a means of contamination transport was identified. One hundred percent (100%) of the preferential pathway samples were subjected to laboratory analysis.

- In Class 2 SUs, a sample was collected at the first 6 inches below cover materials and at 24 inch intervals at all systematic sampling locations until a depth below original grade of 6 ft was attained. One hundred percent (100%) of the Class 2 samples were subjected to laboratory analysis.

5.3 BETA SCAN MEASUREMENTS ON VAULT SURFACES

Screening beta scans were performed over 100% of accessible Class 1 vault concrete surfaces. Ludlum 43-89 scintillation detection instruments were used to detect areas of elevated activity during the survey of vault concrete surfaces. When the vault was completely excavated, a 100% beta scan survey was performed with the scintillation detection instrument and documented prior to the collection of confirmation measurements. There were no locations on vault concrete that exceeded the action level established in the field.

5.4 TOTAL BETA SURFACE ACTIVITY ON VAULT SURFACES

Total beta surface activity (fixed point) measurements were collected in a systematic sampling pattern. Ludlum 43-89 scintillation detection instruments were used to measure total beta activity on the concrete surfaces. The measurements were used to demonstrate that the SU satisfied the DCGL of 12,000 dpm/100 cm^2. A minimum of ten (10) samples were required to be taken in the survey unit based on the MARSSIM procedure for calculating the number of samples required for the 95% confidence limit. The standard deviation used for the calculation was obtained from data obtained from 26 measurements taken on the vault concrete surfaces prior to final status survey.

5.5 PREFERENTIAL PATHWAY SOIL SAMPLES

Class 1 excavations were inspected by a Professional Geologist for potential migration pathways. An additional subsurface sample was collected below the excavation if a means for contamination transport was identified (i.e., ash fill, utility lines, etc.).

In addition to the preferential pathway samples, utility trenches, sewer lines, and other subsurface structures and areas accessible to workers were scanned and sampled (where material was available to sample). Soil and sludge in excess of RGs was removed.

5.6 CHEMICAL ANALYTE MEASUREMENTS

Two chemical COCs were identified at SLDS in the ROD. These two were cadmium (Cd) and arsenic (As). The number of required samples was calculated using Environmental Protection Agency (EPA) Guidance as outlined in the FSSP. Based on information from the referenced guidance, ten (10) samples were collected from the combined area of the Class 1 SUs and nineteen (19) samples were collected from the combined area of the Class 2 SUs. For Class 1 areas, excavation surface samples were analyzed and compared to the arsenic and cadmium RGs. In Class 2 areas, the nineteen (19) samples collected were alternated between the first two subsurface intervals (i.e., 0-6 inches and 24-36 inches below cover materials).

5.7 QUALITY ASSURANCE AND QUALITY CONTROL

Precision and accuracy are determined by the analysis of field duplicate samples and split samples. Precision is measured by comparing the analytical results of the field duplicates, which are samples taken at the same location as the sample they duplicate and analyzed in the same laboratory. Accuracy is measured by comparing the results of split samples, which are aliquots of samples analyzed by a separate laboratory. Plant 2 split samples were analyzed by Severn-Trent Laboratories (formerly known as Quanterra Environmental Services).

The data quality objectives (DQOs) established in the FSSP require that 5% of the total number of samples be duplicated and split with another laboratory. A total of 20 splits and 21 duplicates were obtained from 427 samples collected during the final status survey. Some duplicate/split samples were eventually removed from final status survey data set because of removal of the parent sample result. The duplicate/split sample results were still utilized for the quality control data assessment even though the parent sample had been removed from the final status survey data set. This is considered an appropriate practice to determine if data quality (i.e., precision and accuracy) are acceptable for their intended purpose. The objective of obtaining 5% field duplicates was achieved for this sampling effort and, for the 21 field duplicate samples taken, the normalized absolute difference (NAD) and relative percent difference (RPD) values indicated good precision for greater than 90% of the samples. The results of duplicate samples are shown in Appendix C. The objectives set by the FSSP were to achieve a RPD between duplicate samples and split samples of 30% or less within the statistical counting error for values determined at levels greater than 2 pCi/g. Measurements determined at levels below 2 pCi/g were considered acceptable if the values were within 1 pCi/g. Of the 21 sets of quality assurance samples, 91% of the field duplicate comparisons indicated acceptable precision and

95% of the QA split sample comparisons indicated acceptable accuracy. Given the inherent heterogeneity of soil and the low level of activity measured, the precision and accuracy are acceptable and the data are useable for their intended purpose. The detailed results of the quality control analysis for SLDS Plant 2 data are provided in Appendix C, SLDS Plant 2 Final Status Survey Quality Control Summary Report.

5.8 SAMPLE ANALYSIS

Samples were transferred to a USACE-certified radio-analytical laboratory located on Latty Avenue for analyses in accordance with documented laboratory-specific standard methods (SAIC, 1999). Samples were dried, homogenized, and analyzed for U-238, Th-230, Ra-226, U-235, protactinium-231 (Pa-231), actinium-227 (Ac-227), Th-232, Ra-228, and Th-228. Each of the potentially FUSRAP-related radionuclides are included in the residual dose and risk assessments.

5.9 DATA EVALUATION

The evaluation of final status sample data included the calculation of the SOR_N to determine if the SOR_N exceeded 1.0 in order to determine compliance with the ROD. Where additional remediation was performed, based on survey or sampling results, scans and sampling of the newly excavated area were repeated.

Duplicate samples were collected for field quality control purposes. Other quality control activities were incorporated into specific field and analytical procedures.

6.0 POST-REMEDIATION STATUS

6.1 FINAL STATUS SURVEY DATA

The remedial action objectives presented in the ROD are considered to have been attained if the average SOR_N in a survey unit does not exceed unity and the average concentration of cadmium and arsenic does not exceed the RGs set for these metals. The Plant 2 remedial action was designed to demonstrate compliance with the remedial action objectives as outlined in the ROD such that materials <0.5 ft below the pre-remediation surface grade met the 5/5/50 surface RG, materials >0.5 ft below the pre-remediation surface grade but less than 6 ft below the pre-remediation surface grade met the 15/15/50 subsurface RG, and materials >6 ft below the pre-remediation surface grade met the 50/100/150 ALARA RG. Although the remedial action was designed to meet the ALARA RG (50/100/150) for soils >6 ft below the pre-remediation surface grade, it was determined that after excavation all remediated areas in Plant 2 had achieved levels below the subsurface soil RG (15/15/50) and could be released without restrictions.

The subsurface RG (15/15/50) was used in the SOR_N calculation in all excavated (Class 1) areas since these areas were backfilled with at least 15 cm of cover following final status sampling.

The SOR_N was based on the subsurface RG (15/15/50) in the Class 2 areas for soil samples since all samples were taken at depths exceeding 15 cm below the pre-remediation surface grade due to at least 15 cm of cover material existing over these areas. The USACE made the decision to compare Class 2 survey unit data against the ROD subsurface RG based on the guidance contained in NUREG-1727, *NMSS Decommissioning Standard Review Plan* (NRC, 2000). NRC 2000 states that if residual radioactivity is primarily beneath paving, it should be surveyed as subsurface residual radioactivity.

The SOR_N was based on the surface RG (5/5/50) in the Class 3 area for the samples collected in the first 15 cm below pre-remediation grade.

The analytical results for the final status survey samples indicate that the residual radioactivity in Plant 2 soil meets the requirements of the remedial design and are below the concentration-based RGs. Only a few individual samples had SOR_N that exceeded 1.0. The mean SOR_N in each survey unit was well below the RG of 1.0 (SORs ranged between 0.02 – 0.36). Each sample with SOR_N >1.0 satisfies the concentration-based elevated measurements criteria. In addition, all SUs with an individual measurement result SOR_N >1.0 (highest SU measurement minus the lowest reference area measurement) passed Wilcoxon Rank Sum (WRS) testing as required by MARSSIM. Table 4 presents the data summary for the reference (background) sample set. Table 5 summarizes the final status sample results for the primary radionuclides detected at the site. Table 6 presents a summary for each survey unit. All chemical (Cd and As) data was compared to the RGs as defined in the FSSP and the results indicated that all individual chemical sample results in Plant 2 soils are below the RGs established in the ROD. Table 7 summarizes the chemical sample results for Cd and As.

In summary, because chemical and radiological data indicate that all SUs meet the remedial action objectives as listed in the ROD and Section 3.0 of this report, all SLDS Plant 2 SUs are released without restrictions. Figure 13 shows the post-remediation status (i.e., accessible areas released without restrictions and inaccessible areas) of SLDS Plant 2. The complete final status sample data set is presented in Appendix B of this report.

Table 4. St. Louis Downtown Site Reference Area Data

Statistic	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	U-235 (pCi/g)	Pa-231 (pCi/g)	Ac-227 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	SOR (5/5/50)	SOR (15/15/50)
Reference Area Data Summary											
Mean	1.4	1.9	2.8	0.1	0.9	0.1	1.1	0.9	1.2	0.8	0.3
Median	1.2	1.2	2.5	0.1	1.0	0.1	1.1	1.0	1.1	0.8	0.3
UCL-95	1.7	2.2	3.0	0.1	1.1	0.2	1.2	1.0	1.3	---	---
St. Dev	0.8	0.8	0.9	0.1	0.8	0.1	0.3	0.2	0.4	0.2	0.1
Range	3.2	3.2	3.9	0.3	2.6	0.8	1.3	0.8	1.6	1.0	0.4
Detects	32	32	32	0	13	7	32	32	32	---	---
No. Samples (m)	32	32	32	32	32	32	32	32	32	32	32

Table 5. Summary of Final Status Survey Results from Plant 2[1]

Statistic	U-238 pCi/g	Th-230 pCi/g	Ra-226 pCi/g	U-235 pCi/g	Pa-231 pCi/g	Ac-227 pCi/g	Th-232 pCi/g	Ra-228 pCi/g	Th-228 pCi/g	SOR_N
Class 1 Areas										
Mean	14	2.5	1.1	0.7	0.2	0.2	1.0	0.9	1.3	0.3
Median	6.9	1.9	0.9	0.4	0.2	0.2	1.0	0.9	1.2	0.2
St. Dev	19	2.0	0.6	0.9	0.5	0.2	0.4	0.3	0.5	0.4
Maximum	123	17	4.5	5.7	2.5	1.0	2.6	1.8	3.4	2.6[2]
Class 2 Areas										
Mean	2.5	2.2	1.1	0.2	0.1	0.1	1.0	0.7	1.2	0.1
Median	1.7	1.8	1.0	0.1	0.1	0.1	0.9	0.7	1.0	0.1
St. Dev	4.3	1.5	0.5	0.2	0.3	0.1	0.5	0.3	0.7	0.1
Maximum	50	15	4.1	2.4	1.3	0.5	6.4	2.3	6.0	1.0

[1] All data reported are gross results (includes background) except for SOR_N.

[2] All individual samples with $SOR_N > 1.0$ were evaluated with other samples in a 100 m^2 grid to ensure that the SOR_N averaged less than 1.0 over the 100 m^2 area. In addition, all SUs that had samples with $SOR_N > 1.0$ were subjected to WRS statistical testing in accordance with MARSSIM guidance.

Table 6. Summary of Final Status Survey Results from Plant 2 by Survey Unit[1]

Statistic	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	U-235 (pCi/g)	Pa-231 (pCi/g)	Ac-227 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	SOR^2_G	SOR^2_N
Survey Unit Data Summary SU 1A (Class 1) 706 m^2											
Mean[4]	15.6	2.7	1.0	0.8	0.2	0.2	1.1	0.9	1.3	0.6	0.4
Median	6.7	2.0	0.9	0.4	0.2	0.1	1.1	0.9	1.3	0.4	0.2
UCL-95[4]	52.9	3.6	1.1	2.7	0.2	0.2	1.2	0.9	1.4		
St. Dev[4]	19.9	2.8	0.4	0.9	0.3	0.1	0.4	0.3	0.4		
Range	63.9	15.5	1.7	3.2	1.3	0.7	2.1	1.2	1.8		
Maximum	64.7	16.5	2.2	3.2	0.8	0.7	2.3	1.5	2.3	2.2	2.0[3]
No. Samples (n)	29	29	29	29	29	29	29	29	29		
Survey Unit Data Summary SU 1B (Class 1) 966 m^2											
Mean[4]	16.6	2.4	1.0	0.8	0.1	0.2	1.0	0.9	1.3	0.6	0.4
Median	10.3	1.8	0.9	0.5	0.1	0.2	1.0	0.9	1.3	0.4	0.2
UCL-95[4]	29.3	2.8	1.1	1.6	0.2	0.2	1.0	0.9	1.4		
St. Dev[4]	22.2	1.3	0.4	1.0	0.3	0.1	0.3	0.2	0.4		
Range	122.5	5.4	2.6	5.7	1.2	0.3	1.1	0.9	2.0		
Maximum	123.4	6.3	3.3	5.7	0.6	0.4	1.5	1.2	2.5	2.8	2.6[3]
No. Samples (n)	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0		
Survey Unit Data Summary SU 1C (Class 1) 408 m^2											
Mean[4]	8.4	2.5	1.5	0.5	0.4	0.2	1.0	0.9	1.2	0.4	0.2
Median	5.5	2.0	1.1	0.3	0.2	0.2	0.9	0.8	1.1	0.3	0.1
UCL-95[4]	9.4	3.5	1.6	0.5	0.5	0.3	1.1	1.2	1.3		
St. Dev[4]	8.9	1.9	0.9	0.5	0.6	0.2	0.4	0.4	0.5		
Range	41.8	9.3	3.8	2.1	2.8	0.9	2.1	1.4	2.7		
Maximum	42.4	10.3	4.5	2.3	2.5	1.0	2.6	1.8	3.4	1.0	0.8
No. Samples (n)	28	28	28	28	28	28	28	28	28		
Survey Unit Data Summary SU 3 (Class 2) 5,350 m^2											
Mean[4]	1.8	2.5	1.0	0.1	0.1	0.1	0.8	0.5	1.4	0.3	0.1
Median	1.3	1.8	0.9	0.1	0.1	0.1	0.8	0.6	1.0	0.2	0.0
UCL-95[4]	2.4	3.3	1.1	0.2	0.2	0.1	1.0	0.6	1.7		
St. Dev[4]	2.0	2.2	0.4	0.1	0.2	0.1	0.4	0.2	1.3		
Range	11.7	11.6	2.5	0.6	1.1	0.4	1.5	0.9	5.2		
Maximum	11.7	8.0	2.9	0.6	0.7	0.3	1.8	1.1	5.5	0.7	0.5
No. Samples (n)	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0		
Survey Unit Data Summary SU 4 (Class 2) 5,350 m^2											
Mean[4]	1.5	2.0	0.9	0.1	0.2	0.1	0.9	0.6	1.2	0.2	0.0
Median	1.5	1.8	0.9	0.1	0.1	0.0	0.8	0.6	0.9	0.2	0.0
UCL-95[4]	1.6	2.2	1.0	0.1	0.2	0.1	1.0	0.7	1.4		
St. Dev[4]	0.6	0.9	0.2	0.1	0.2	0.1	0.4	0.2	0.7		
Range	3.8	3.9	0.8	0.3	1.0	0.3	1.9	0.9	2.9		
Maximum	2.9	4.8	1.3	0.3	0.7	0.3	2.2	1.0	3.3	0.4	0.2
No. Samples (n)	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0		

Table 6. Summary of Final Status Survey Results from Plant 2 by Survey Unit[1] (Con't)

Statistic	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	U-235 (pCi/g)	Pa-231 (pCi/g)	Ac-227 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	SOR^2_G	SOR^2_N
Survey Unit Data Summary SU 5 (Class 2) 5,350 m^2											
Mean[4]	1.6	1.7	0.9	0.1	0.1	0.1	1.0	0.7	1.1	0.2	0.0
Median	1.4	1.6	0.9	0.1	0.1	0.1	0.9	0.7	1.0	0.2	0.0
UCL-95[4]	1.8	2.0	1.1	0.1	0.2	0.1	1.1	0.7	1.3		
St. Dev[4]	0.9	0.9	0.4	0.1	0.2	0.1	0.6	0.2	0.7		
Range	4.1	3.8	2.6	0.3	1.0	0.3	2.9	0.9	3.8		
Maximum	4.5	4.6	3.0	0.3	0.6	0.2	3.1	1.1	3.9	0.6	0.3
No. Samples (n)	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0		
Survey Unit Data Summary SU 6 (Class 2) 5,215 m^2											
Mean[4]	3.3	1.9	1.1	0.2	0.2	0.1	0.9	0.7	1.0	0.3	0.1
Median	1.9	1.8	1.0	0.1	0.1	0.1	0.9	0.7	0.9	0.2	0.0
UCL-95[4]	5.1	2.1	1.2	0.3	0.3	0.1	1.0	0.8	1.1		
St. Dev[4]	6.0	0.9	0.3	0.3	0.3	0.1	0.3	0.2	0.4		
Range	33.9	3.6	1.2	1.9	1.3	0.6	1.2	0.8	1.8		
Maximum	34.7	4.1	1.8	1.8	1.0	0.5	1.6	1.1	2.1	1.0	0.8
No. Samples (n)	30	30	30	30	30	30	30	30	30		
Survey Unit Data Summary SU 7 (Class 2) 5,215 m^2											
Mean[4]	4.2	2.2	1.3	0.2	0.1	0.1	1.0	0.8	1.1	0.3	0.1
Median	1.7	1.8	1.0	0.2	0.1	0.1	0.9	0.7	0.9	0.2	0.0
UCL-95[4]	6.8	2.6	1.5	0.4	0.2	0.1	1.1	0.8	1.2		
St. Dev[4]	9.0	1.5	0.7	0.4	0.3	0.1	0.5	0.3	0.5		
Range	49.7	8.0	3.2	2.4	1.7	0.4	2.8	1.2	2.8		
Maximum	50.3	9.0	3.6	2.4	0.5	0.2	3.2	1.5	3.5	1.2	1.0
No. Samples (n)	30	30	30	30	30	30	30	30	30		
Survey Unit Data Summary SU 8 (Class 2) 5,215 m^2											
Mean[4]	3.7	1.9	1.1	0.2	0.2	0.1	0.9	0.7	1.0	0.3	0.1
Median	2.1	1.6	0.9	0.2	0.1	0.0	0.9	0.7	1.0	0.2	0.0
UCL-95[4]	5.9	2.2	1.4	0.3	0.3	0.1	1.0	0.8	1.1		
St. Dev[4]	6.1	1.1	0.7	0.3	0.3	0.1	0.4	0.2	0.3		
Range	35.4	6.1	3.6	1.9	1.3	0.5	1.5	0.9	1.4		
Maximum	35.9	6.8	4.1	1.8	1.0	0.3	1.7	1.3	1.7	1.0	0.7
No. Samples (n)	30	30	30	30	30	30	30	30	30		
Survey Unit Data Summary SU 9 (Class 2) 3,886 m^2											
Mean[4]	2.9	2.5	1.3	0.2	0.1	0.1	1.1	0.7	1.1	0.3	0.1
Median	2.4	2.4	1.2	0.2	0.1	0.1	1.1	0.8	1.1	0.3	0.1
UCL-95[4]	3.5	2.9	1.5	0.2	0.3	0.1	1.2	0.9	1.3		
St. Dev[4]	1.8	0.9	0.6	0.1	0.3	0.1	0.3	0.4	0.4		
Range	6.7	3.2	2.4	0.4	1.7	0.3	1.4	2.1	2.0		
Maximum	7.3	4.4	3.0	0.4	1.3	0.3	1.8	2.3	2.3	0.4	0.2
No. Samples (n)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0		

Table 6. Summary of Final Status Survey Results from Plant 2 by Survey Unit[1] (Con't)

Statistic	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	U-235 (pCi/g)	Pa-231 (pCi/g)	Ac-227 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	SOR^2_G	SOR^2_N
Survey Unit Data Summary SU 10 (Class 2) 3,886 m^2											
Mean[4]	2.1	2.5	1.1	0.1	0.1	0.1	1.3	0.7	1.4	0.3	0.1
Median	1.9	2.1	1.1	0.1	0.1	0.1	0.9	0.7	1.3	0.2	0.0
UCL-95[4]	2.5	3.0	1.3	0.2	0.2	0.1	1.6	0.8	1.8		
St. Dev[4]	1.5	1.5	0.5	0.1	0.3	0.1	1.2	0.2	1.0		
Range	6.6	6.8	2.6	0.5	1.4	0.4	6.1	1.0	5.7		
Maximum	7.0	8.2	3.1	0.4	0.7	0.2	6.4	1.2	6.0	0.7	0.5
No. Samples (n)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0		
Survey Unit Data Summary SU 11 (Class 2) 3,886 m^2											
Mean[4]	1.6	1.9	1.0	0.1	0.1	0.1	1.0	0.7	1.1	0.2	0.0
Median	1.5	1.8	0.9	0.1	0.1	0.1	1.0	0.7	1.0	0.2	0.0
UCL-95[4]	1.9	2.1	1.1	0.1	0.2	0.1	1.1	0.7	1.2		
St. Dev[4]	0.8	0.7	0.3	0.1	0.4	0.1	0.3	0.2	0.3		
Range	2.6	2.6	1.1	0.4	1.8	0.3	1.3	0.7	1.4		
Maximum	3.1	3.3	1.6	0.4	0.6	0.2	1.6	0.9	1.7	0.4	0.1
No. Samples (n)	26	26	26	26	26	26	26	26	26		
Survey Unit Data Summary SU 12 (Class 3) 12,100 m^2											
Mean[4]	0.6	1.1	0.4	0.1	0.0	0.0	0.3	0.1	0.4	0.3	0.0
Median	0.5	1.0	0.4	0.0	0.0	0.0	0.3	0.1	0.4	0.3	0.0
UCL-95[4]	1.2	1.8	0.7	0.1	0.0	0.0	0.4	0.2	0.5		
St. Dev[4]	0.2	0.4	0.1	0.0	0.2	0.0	0.2	0.1	0.2		
Range	0.6	1.3	0.4	0.1	0.9	0.1	0.6	0.3	0.6		
Maximum	1.0	1.9	0.7	0.1	0.5	0.1	0.7	0.3	0.7	0.5	0.0
No. Samples (n)	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0		

[1] All data reported are gross results (including background) except for SOR_N.

[2] The sum of ratios is based on subsurface RGs (15/15/50) for all survey units except Survey Unit 12. Survey Unit 12 (Class 3 cover material) sum of ratios is based on surface RGs (5/5/50). SOR_G = sum of ratios including background; SOR_N = sum of ratios above background.

[3] All individual samples with SOR_N >1.0 were evaluated with other samples in a 100 m^2 grid to ensure that the SOR_N averaged less than 1.0 over the 100 m^2 area. In addition, all SUs that had samples with SOR_N >1.0 were subjected to WRS statistical testing.

[4] Mean, standard deviation and UCL-95 were calculated based on the type of statistical distribution (i.e., normal, lognormal, etc.) that the data represented.

Table 7. Plant 2 Final Status Survey Chemical Data Summary

Statistic	Arsenic	Cadmium
Mean	12.9	0.6
Median	10.1	0.3
Standard Deviation	8.9	1.3
Number of samples	29.0	29.0
Student $t_{(n-1)}$ test	1.8	1.8
Maximum	32.6	6.0
Range	31.8	6.0
Detects	15.0	5.0
UCL (normal)	15.8	1.0

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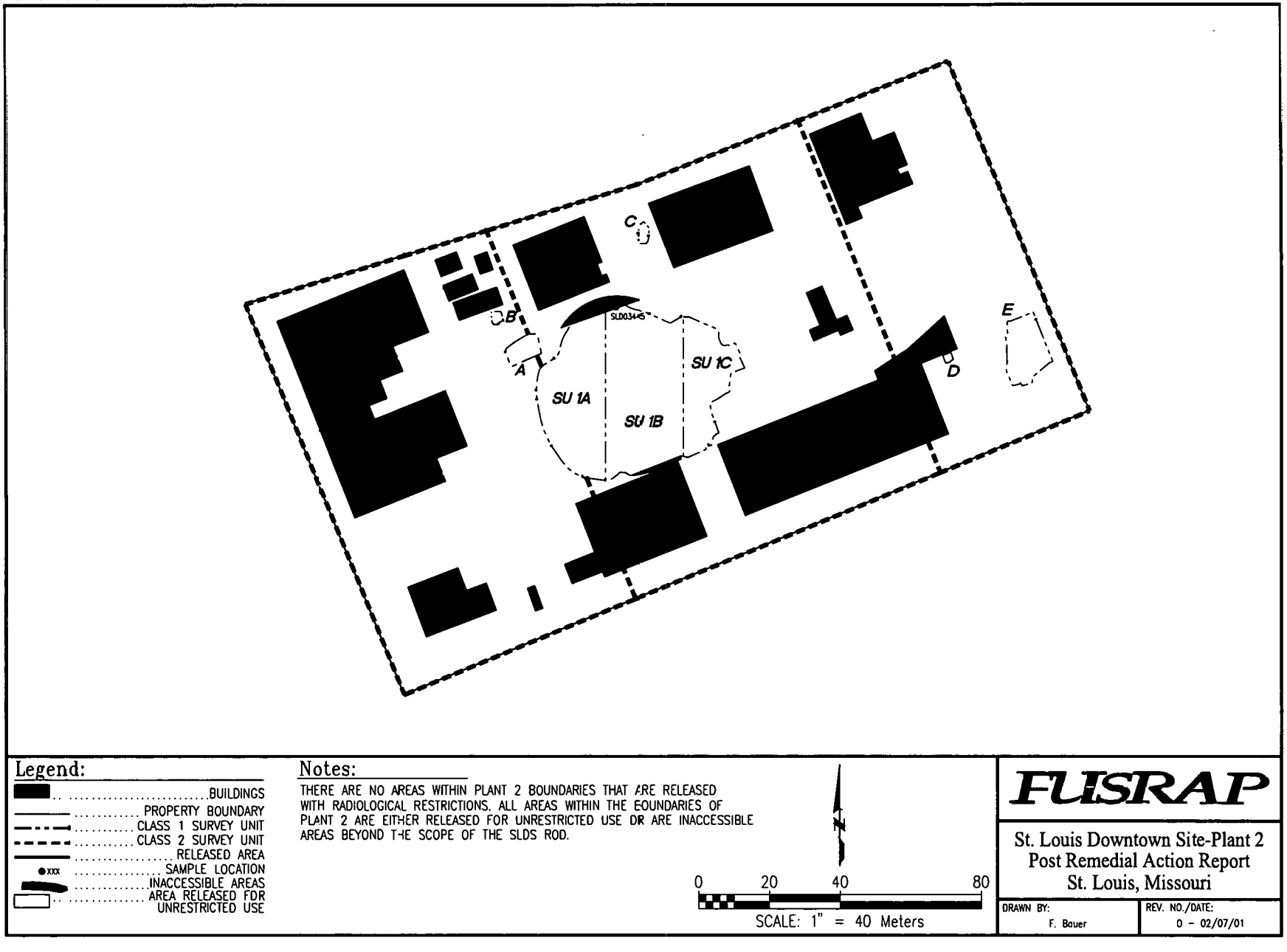

Figure 13. Post Remediation Status of SLDS Plant 2

6.2 RESIDUAL DOSE AND RISK ASSESSMENT SUMMARY

In addition to evaluating the data against the RGs established by the ROD, conservative dose and risk calculations were performed to determine the dose and risk to a range of hypothetical receptors. These receptors include a industrial/utility worker, a industrial/construction worker, and an potential future on-site resident. The industrial/utility worker may participate in utility work or other intrusive outdoor activities around the site. The industrial/construction worker is modeled as a typical site worker who spends most of the time indoors. The on-site resident is modeled as a potential future receptor in case the current land use for Plant 2 changes from industrial to residential. A more detailed description of receptors is provided in Appendix B.

Source terms were developed by subtracting average background concentrations from the appropriate UCL-95 concentrations providing estimates of reasonable maximum exposure point concentrations (EPCs). The EPC value used in the dose assessment was the smaller value of the calculated UCL-95 and the maximum concentration in the area. Background used the 32 samples collected from the reference areas (see Attachment B-2). If the UCL-95 concentration is less than the average background, the EPC was set to zero to avoid negative dose estimates. Dose and risk were explicitly calculated for small areas containing elevated activity as well as for each survey unit and the overall site (see Tables B-4 and B-5). The exposure pathways considered applicable to the dose and risk assessment for all scenarios were external gamma, soil ingestion, and inhalation of particulates. Also, the residual dose and risk were calculated assuming direct contact with contaminated soils without regard to the existence of clean backfill and/or existing cover materials. Backfill in Class 1 areas consists of crushate from the excavation surface to 6 ft below ground surface and approved clean borrow from 6 ft to ground surface.

Results indicate that dose and risk based on UCL-95 concentrations are below the limits described in the ROD. The highest industrial/construction worker dose and risk estimates for a single survey unit (SU-1A) is 3 mrem/yr and 2 E-05, respectively. The highest industrial/utility worker dose and risk is less than 1 mrem/yr and 5 E-08, respectively. The highest residential dose and risk is 8 mrem/yr and 8 E-05, respectively. When averaging across the Plant 2 property, dose and risk to the industrial worker, construction worker, and on-site resident is less than or equal to 1 mrem/yr and 6 E-06, respectively. Residual dose is <0.01 mrem/yr if existing cover is considered for all Plant 2 areas with the exception of Class 1 SUs. The highest dose calculated in Class 1 SUs when existing cover is considered is 3 mrem/yr. The four samples with the elevated concentrations were evaluated to determine if, under a worst case scenario, the receptors could receive an unacceptable dose while exposed to small areas of elevated activity. Dose and risk results for each sample are presented in Table B-5.

In summary, dose and risk estimates averaged over the site, individual survey units, and elevated measurements are less than the applicable RG [i.e., 10 CFR 20 Subpart E for dose and EPA Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) for risk] at SLDS Plant 2. Details of the residual dose and risk-assessment are in Appendix B of this report. RESRAD output files for all modeled scenarios are in Appendix E of this report.

7.0 CONCLUSIONS

The USACE and EPA determined that Selective Excavation and Disposal was the most appropriate remedy for groundwater and accessible soil at SLDS based upon consideration of the requirements of CERCLA, a detailed analysis of the alternatives, and extensive public participation and comment. The remedy addressed soil contaminated with radioactivity, arsenic, and cadmium related to MED/AEC uranium manufacturing and processing at SLDS.

7.1 COMPARISON TO ROD RGs

The RGs for SLDS Plant 2 apply to areas affected by the MED/AEC uranium manufacturing and processing activities. This section lists the ROD RGs and describes how the USACE is demonstrating compliance with the RG. The ROD RGs consist of the following components:

- Excavation of accessible soils according to the ARAR-based composite RG of 5/15 pCi/g above background for Ra-226, Ra-228, Th-232, and Th-230, and 50 pCi/g above background for U-238 in the uppermost 1.8 m (6 ft).

  The 5/5/50 RG was used for comparison against the data collected from cover materials in the first 0.5 ft below pre-remediation grade (SU-12). The 15/15/50 subsurface RG was used for comparison against the data collected in accessible soils below cover materials (SU-1A, SU-1B, and SU-1C) in Class 1 SUs and (SU-3 through 11) in Class 2 SUs. In Class 1 SUs, soil samples were collected at the excavation surface and at 24 inch intervals until a depth of 6 ft below original ground surface was reached. In Class 2 SUs, samples were collected in the first 6 inches below cover materials and then at 24 inch intervals until a depth of 6 ft below original ground surface was reached. All Plant 2 SUs have SOR_N values of less than 1.0 when averaged over the SU. Therefore, the SU data demonstrates compliance with this ROD RG.

  In addition, the 40 CFR 192 ARAR for subsurface soils (15 pCi/g Ra-226 averaged over 100 m^2) was used for comparison against the data collected in accessible subsurface soils in remediated (excavated) areas. The areal density of samples collected in excavated areas (Class 1 SUs) met the 100 m^2 areal density requirement and the average Ra-226 concentration was less than the 15 pCi/g subsurface RG in all Class 1 SUs. The 40 CFR 192 ARAR for surface soils was not used because all remediated areas were excavated deeper than 15 cm below the pre-remediation surface grade.

- Site-specific target removal levels of 50 pCi/g above background for Ra-226, 100 pCi/g above background for Th-230, and 150 pCi/g above background for U-238 (50/100/150 RGs) will be used as the deep-soil RGs below 1.8 m (6 ft) as described in Section 7.3.6. of the ROD.

The remedial action at Plant 2 was designed to meet the deep soil RG in excavations greater than 6 ft deep. However, when the excavation was complete and final status survey data was collected it was determined that the remediation had successfully attained the 15/15/50 subsurface RG stated above. The 50/100/150 RG was not used for comparison against any data in Plant 2 SUs. The SOR_N is less than 1.0 for all data collected in Class 1 SUs (nearly all samples collected in Class 1 SUs were at depths greater than 6 ft below ground surface).

- For arsenic and cadmium:

  1) within the upper 1.2 or 1.8 m (4 or 6 ft) of grade, soil concentrations of arsenic greater than 60 mg/kg and/or cadmium concentrations greater than 17 mg/kg will be removed, or
  3) below 1.2 or 1.8 m (4 or 6 ft) of grade, soil concentrations of arsenic greater that 2,500 mg/kg and/or cadmium are greater than 400 mg/kg will be removed.

  Twenty-nine chemical samples were collected across the Plant 2 site. Ten samples were collected in Class 1 SUs and the remaining nineteen were collected in Class 2 SUs. All sample results were less than the most restrictive RG of 60 mg/kg for arsenic and 17 mg/kg for cadmium. Therefore, the chemical data collected at Plant 2 demonstrates compliance with this ROD RG.

- RGs for radiological contaminants are applied to soil concentration above background consistent with the ARAR (40 CFR 192), from which they derive. However, addition of background concentrations to these goals would not alter any judgments regarding protcctiveness. Remediation goals for non-radiological RGs are applied to soil concentrations including background consistent with the NCP.

  This statement in the ROD is true for all Plant 2 SUs. The SOR_G for all SUs (the gross data including background) is also less than 1.0 when averaged across the SU. The gross data (including background) provided by the analytical laboratory was used for comparisons against chemical RGs consistent with the NCP.

- Compliance with soil RGs will be verified by methods that are compatible with MARSSIM for soils being cleaned up in the OU effective with MARSSIM publication. (A representative number of samples obtained in the bottom of excavations will also be subjected to chemical analysis and comparison to chemical RGs.);

  The Plant 2 FSSP was designed in accordance with MARSSIM methodology.

  - Class 1 and Class 2 survey unit sizes were selected to be 1,000 m^2 and 5,000 m^2 (one half of the maximum size recommended in MARSSIM) in order to increase the sample density in each survey unit and the confidence in the final decision to release the survey unit.

- In survey units that had individual samples with $SOR_N > 1.0$ (SU-1A, and SU-1B), the survey unit was subjected to WRS statistical testing to ensure that the activity in the survey unit is less than the DCGL. All surveys units that required WRS testing passed the WRS test.
- Final status survey data was used to ensure that enough samples were collected in each survey unit. All Plant 2 SUs have enough samples to satisfy statistical testing requirements.
- A representative number of samples (10) obtained in the bottom of excavations were subjected to chemical analysis. Chemical sample results were compared to RGs for chemical COCs. All chemical results are less than ROD RGs.
- Data quality indicators were reviewed for precision, accuracy, representativeness, completeness, and comparability. All data quality indicators are considered acceptable and the data are useable for their intended purpose.
- A post-remedial action risk assessment will be performed to describe the level of risk remaining from MED/AEC contaminants following completion of remedial activities;
- A post-remedial action risk and dose assessment was performed for the modeled scenarios outlined in the ROD. In addition, regulators requested that the USACE develop an on-site residential scenario in case the current land use for Plant 2 areas changed from industrial to residential. The dose and risk from actual residual conditions (without regard to cover materials) at Plant 2 are considered acceptable to release the accessible areas without restrictions. Details of the dose and risk assessment are in Appendix B of this report. RESRAD output files are in Appendix E of this report.
- Final determinations as to whether institutional controls and use restrictions are necessary will be based on calculations of post remedial action risk derived from actual residual conditions. Five year reviews will be conducted per the NCP for residual conditions that are unsuitable for release without restrictions.
- The dose and risk from actual residual conditions (without regard to cover materials) are considered acceptable to release Plant 2 accessible areas without restrictions. There are no accessible areas at Plant 2 where it is necessary to apply restrictions or institutional controls.
- Institutional controls may include land use restrictions for those areas having residual concentrations of contaminants unsuitable for release without restrictions. This determination will be made based on risk analysis of the actual post-remedial action conditions. Until a decision is developed to address the ultimate disposition of inaccessible soils, steps will be taken to control uses inconsistent with current uses and to learn of anticipated changes in conditions that might make these soils accessible or increase the potential for exposure. Periodic reviews with affected property owners will be conducted throughout the duration of active site remediation. For residual conditions requiring use restrictions after the period of active remediation, coordination with property owners and local land use planning authorities will be necessary to implement deed restrictions or other mechanisms to maintain industrial/commercial land use.

The dose and risk from actual residual conditions (without regard to cover materials) are acceptable to release Plant 2 accessible areas without restrictions. Details of the dose and risk assessment are in Appendix B of this report. RESRAD output files are in Appendix E of this report. There are no accessible areas at Plant 2 where it is necessary to apply restrictions or institutional controls. Inaccessible soils at Plant 2 are not within the scope of the SLDS ROD or this report. Inaccessible soils will be addressed in a future document.

- A long-term ground-water monitoring strategy will be implemented to confirm expectations that significant impacts to the Mississippi Alluvial Aquifer (B unit) will not occur. Although ground water use in this area is not anticipated, agreements will be proposed to state and local water authorities to prevent well drilling, which may be impacted by the surficially contaminated A unit.

  A long-term ground-water monitoring strategy has been implemented to confirm expectations that significant impacts to the Mississippi Alluvial Aquifer (B unit) will not occur. An Environmental Monitoring Guide for the St. Louis Sites has been written and is currently being implemented by the USACE through Environmental Monitoring Implementation Plans for each fiscal year.

- Perimeter wells in the Mississippi Alluvial Aquifer will be monitored to determine if further action will be required with respect to ground water,

  Perimeter wells in the Mississippi Alluvial Aquifer are being monitored in accordance with the Environmental Monitoring Guide for the St. Louis Sites. The requirements in the guide are currently being implemented by the USACE through Environmental Monitoring Implementation Plans for each fiscal year. These requirements include perimeter well ground-water monitoring.

- Protactinium-231 (Pa-231) and actinium-227 (Ac-227) will be included in the analyses for the post-remedial action residual site risk; and

  Pa-231 and Ac-227 were included in the post-remedial action dose and risk assessments. The average Pa-231 and Ac-227 concentrations were less than 0.5 pCi/g in all SUs and therefore did not significantly affect residual dose or risk. Details of the dose and risk assessment are in Appendix B of this report. RESRAD output files are in Appendix E of this report.

- Contaminated sediments in sewers and drains considered to be accessible will be remediated along with the soils.

- Accessible contaminated sediments in sewers and drains were remediated along with the soils. Inaccessible areas (including sediments in sewers and drains) are beyond the scope of the ROD and this report. Inaccessible areas will be addressed in a future document.

The residual radioactivity in accessible areas at SLDS Plant 2 meet all requirements specified in the ROD. This conclusion is the result of comparison of ROD RGs and the residual site condition in accessible areas. The concentration based RGs for Th-230, Ra-226, Th-232, Ra-228, and U-238 are satisfied, noting that no SOR_N value exceeds the limit of 1.0 when averaged over the SU (the average SOR excluding background in Class 1 and Class 2 areas is

0.31 and 0.07, respectively) and no Ra-226 concentration averaged over 100 m^2 exceeds 15 pCi/g. The dose-based ARAR from 10 CFR 20 Subpart E, "Radiological Criteria for License Termination" has been satisfied noting that the highest dose of approximately 19.9 mrem/yr was due to a small area of elevated activity using conservative exposure assumptions and without regard to cover. The residual dose calculated for Plant 2 over the entire site is less than or equal to 1 mrem/yr for all modeled scenarios without regard to cover. This dose is <0.01 mrem/yr if existing cover is considered for all Plant 2 areas with the exception of Class 1 SUs. The highest dose calculated in Class 1 SUs when existing cover is considered is 3 mrem/yr. The SUs also satisfy the statistical requirements with all survey units requiring WRS testing passing the WRS test. Soil concentrations comply with 40 CFR 192 unrestricted release criteria. All Plant 2 SUs are released without restrictions in accordance with the ROD.

8.0 REFERENCES

Code of Federal Regulations, Title 40, Part 192 (40 CFR 192), Environmental Protection Agency.

DOE 1995. *Remedial Investigation Addendum for the St. Louis Site*, DOE/OR/21950-132, Science Applications International Corporation, September.

Mallinckrodt 1962. Mallinckrodt Uranium Division News, Vol. 7, Nos. 3 & 4, June.

Mason, Mont G. 1977. *History & Background Relative to the Radiological Re-Monitoring of Mallinckrodt by the Energy Research & Development Administration*, BNI-CCN-062819, August

NRC 1998. *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*, NUREG-1507, Nuclear Regulatory Commission, June.

NRC 2000. *NMSS Decommissioning Standard Review Plan,* NUREG-1727, Nuclear Regulatory Commission, September.

SAIC 1999. *FUSRAP St. Louis Laboratory Quality Assurance Plan and Laboratory Procedures Manual,* March.

USACE 1998. *Record of Decision for the St. Louis Downtown Site – St. Louis, Missouri,* October.

USACE 1999. *Radiological Final Status Survey Plan for Accessible Soil Within Plant 1, Plant 2, and the City Property at the St. Louis Downtown Site – St. Louis, Missouri,* May.

APPENDIX A

REMEDIAL ACTION SUMMARY REPORT FOR THE REMEDIATION ACTIVITIES AT THE ST. LOUIS DOWNTOWN SITE, PLANT 2

Remedial Action Summary for Plant 2
FUSRAP St. Louis Downtown Site,
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