MALLINCKRODT C-T DECOMMISSIONING PROJECT

Official Project Documents

DRAFT
C-T Phase II Decommissioning Plan
May 15, 2003

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MALLINCKRODT C-T DECOMISSIONING PROJECT
C-T PHASE II DECOMISSIONING PLAN

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C-T PHASE II DECOMISSIONING PLAN

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SECTION 1

EXECUTIVE SUMMARY

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

1. EXECUTIVE SUMMARY

Identity. Mallinckrodt Inc. is a Delaware Corporation with its principal place of business located at 675 McDonnell Boulevard, St. Louis, MO 63042.

License. Mallinckrodt Inc. (Mallinckrodt) has held NRC Radioactive Material License STB-401, docket number 40-6563, since 1961 for the extraction of columbium and tantalum from natural and synthetic ores and slags. On May 3, 2002, the license was amended to authorize C-T process building decommissioning in accordance with a C-T Phase I Decommissioning Plan. Mallinckrodt is requesting that NRC Radioactive Materials License STB-401 be amended to authorize the second phase of C-T decommissioning in accordance with this C-T Phase II Decommissioning Plan.

Location. The licensed facility is the Columbium-Tantalum (C-T) Plant located within the Mallinckrodt St. Louis Plant, at 3600 North Second Street, St. Louis, Missouri 63147. The Plant is a 43-acre (174,016 m^2) site located near the west bank of the Mississippi River in the northeastern section of the City of St. Louis.

Site Description. The St. Louis Plant site is in an urban industrial area, zoned and developed for industrial use. Mallinckrodt has owned the site and has operated chemical manufacturing facilities on the site since 1867. The St. Louis Plant site currently contains more than 50 manufacturing and support buildings in an area of approximately twelve city blocks. The remainder of the St. Louis Plant site is typically paved with asphalt or concrete. Mallinckrodt currently produces a variety of products for the food, drug, cosmetic, pharmaceutical, and specialty chemical industries. It intends to continue industrial use of the site, including Plant 5 where C-T facilities are being decommissioned. Details are described in §3 Facility Description.

Activities. Between 1942 and 1958, Mallinckrodt refined uranium ore and concentrate to produce uranium compounds and metal in support of early Federal Government programs to develop atomic weapons under the Manhattan Engineering District and later the Atomic Energy Commission (MED-AEC).

From 1956 to 1960, Mallinckrodt extracted columbium, tantalum, uranium, thorium, and rare earth elements from euxenite mineral ore for delivery to the AEC and the General Services Administration (GSA) as part of the Defense Materials Procurement Program. The Euxenite operation was performed under AEC source material license R-226. The license expired in 1960. The same processing facilities were subsequently used to extract columbium and tantalum compounds under NRC License STB-401. C-T feed materials included ore and tin slag. Products from this process included tantalum oxide, potassium fluotantalate, and columbium oxide.

In addition to the C-T process, various other operations at the St. Louis Plant site have involved use of radioactive materials. Those licensed activities are described in §2.3 of this decommissioning plan.

Characterization. MED-AEC activities resulted in radioactive contamination on some areas of Mallinckrodt's St. Louis Plant site and adjacent properties. The MED-AEC contamination consists of uranium series, thorium series, and actinium (U^{235}) series radionuclides, including Th^{230} and radium, from refining uranium ore and concentrate. Remediation of radioactive residues remaining from MED-AEC activity in other areas of the St. Louis Plant site has previously been performed by the U.S. Department of Energy (DOE) and is currently being performed by the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Sites Remedial Action Program (FUSRAP).

Residual radioactive sources from C-T processing are the naturally-occurring thorium series, the uranium series, and the actinium (U^{235}) series. The existing distributions of residual source material in soil and on pavement in Plant 5 are described in § 4, Radiological Status of the Facility.

Decommissioning Goals. The goal of the C-T decommissioning is to remediate the radiological constituents associated with C-T production to the extent required to terminate license STB-401. License STB-401 was most recently amended on May 3, 2002 to incorporate the approved C-T Phase I Decommissioning Plan, authorizing decommissioning of the C-T processing buildings. The C-T Phase II Decommissioning Plan will remediate C-T processing building slabs, sewerage, wastewater neutralization basins, and soil affected by C-T processing.

Delineation of responsibility for remediation, particularly in areas known as Plants 6 and 7 within the St. Louis Plant site, remains to be decided between Mallinckrodt and the U.S. Army Corps of Engineers. Mallinckrodt intends that its responsibility for any C-T residue remediation in those areas in question, aside from wastewater basins, will be addressed in a separate license amendment request to remove that source material.

The foreseeable use of Mallinckrodt's St. Louis Plant site where C-T facilities are being decommissioned is for continued industrial or commercial use. Mallinckrodt intends to decommission the land affected by C-T processing in order that it may be used without restriction for continued industrial productivity.

A remediation goal is that radioactivity concentration exceeding the DCGL will be removed. Mallinckrodt expects to ship soil and debris containing residual regulated radionuclides in greater concentration than release criteria by NRC-authorized transfer to a disposal facility.

Thereby, Mallinckrodt plans to remove residual, licensed radioactive material source to assure that the potential radiological dose to people on the site will be less than 25 mrem/yr without necessity for post-remediation activity.

DCGL. Derivation of a radioactivity concentration guideline level (DCGL) applicable to pavement, process building slabs, and soil is described in Section 5 of this Plan. In this derivation, reasonably foreseeable environmental scenarios and exposure pathways have been described by a conceptual model and a mathematical model. A conceptual model of the environmental system, including the radioactive source, its movement in the environment to a receptor, and habits of the receptor of the exposure was formulated for building slabs and streets and separately for soil. These potential exposure pathways are simulated by mathematical models in the RESRAD computer program, which can quantify the relation between radioactive source and radiological dose.

Dose modeling was performed with the RESRAD program for each major nuclide: U^{238}, U^{234}, Th^{230}, Ra^{226}, and Pb^{210} in the uranium series, U^{235} and its progeny in the actinium series, and Th^{232}, Ra^{228}, and Th^{228} in the thorium series. The RESRAD code included dose contributions from short-lived daughters of each of these nuclides.

The RESRAD derivation for each radionuclide is a dose factor (mrem/y per pCi/g soil), which in turn has been interpreted as a maximum acceptable average concentration of the radionuclide in soil, also called the $DCGL_w$, corresponding to a potential radiological dose equivalent of 25 mrem/yr. The RESRAD-computed dose factors and corresponding $DCGL_W$ applicable to soil are in §5 Dose Modeling, Table 5-1. The RESRAD-computed dose factors and corresponding $DCGL_W$ applicable to surfaces of pavement, process building slabs, and wastewater basins are in Table 5-3. DCGL for individual radionuclides or for the U series and or Th series may be combined into a composite $DCGL_W$ representing a mixture of U series and Th series radionuclides.

ALARA. A principle of radiological protection is that reasonable effort should be made to Achieve exposure to ionizing radiation that is As Low As is Reasonable. Action planned to make radiation exposure ALARA may be judged to be sufficient when the expected benefit from additional collective dose averted becomes less than the expected cost of achieving it. Estimates of incremental costs of excavating and disposing of contaminated soil or debris and incremental detriment avoided have been compared to decide what residual radioactive source material concentration in soil subject to Phase II decommissioning is expected to achieve potential radiation exposure that is as low as is reasonably achievable and to estimate whether it is reasonable to reduce the residual concentration in soil to a level below what is necessary to meet the dose criterion.

Analysis found that it would be cost-effective to excavate soil containing more than about 30 times the $DCGL_W$ in order to reduce residual radioactivity concentration, but not if it contains less than that concentration.

Comparison of costs and benefits consequent to removing additional radioactive residue, starting from a baseline of $DCGL_W$, to achieve a lower radioactivity concentration and exposure potential demonstrates that the incremental cost would be greater than the increment of detriment avoided. Therefore, it is not cost-beneficial to try to reduce residual concentration of licensed radioactive residue to any less than the $DCGL_W$. Thus, when remedial action achieves the $DCGL_W$, no further cleanup would be needed to satisfy the ALARA principle. This ALARA analysis is described in § 7, ALARA Analysis.

Schedule. The C-T production and support areas are located within an active manufacturing facility, thereby requiring coordination to avoid without causing disruption to ongoing manufacturing operations. For this reason, Mallinckrodt has proposed and the NRC has approved use of a two-phase decommissioning approach with the assurance that Mallinckrodt will plan, implement, and complete decommissioning as expeditiously as practicable. Phase I of the Decommissioning Plan is underway; C-T process buildings have been dismantled, and building debris has been shipped to an acceptable disposal facility. Completion of C-T decommissioning is anticipated within 19 months after NRC approval of the CT Phase II Decommissioning Plan.

SECTION 2

FACILITY OPERATING HISTORY

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

2.0 FACILITY OPERATING HISTORY

2.1. INTRODUCTION

Mallinckrodt Inc. (Mallinckrodt) has held license STB-401, docket number 40-6563, since 1961 for the extraction of columbium and tantalum from natural and synthetic ores and slags. The Atomic Energy Commission originally issued the license. The license was required because process raw materials and by-products contained sufficient quantities of natural uranium and thorium isotopes. It is currently a possession-only license.

The Columbium-Tantalum (C-T) decommissioning plan activities are designed to decontaminate and decommission the areas of Mallinckrodt's St. Louis Plant involved with the historic processing, storage, and handling of radioactive materials associated with the extraction of columbium and tantalum from ores and slags. The C-T production plant and associated support facilities are located within the boundaries of the Mallinckrodt St. Louis, Missouri Plant.

The ultimate goal of the C-T decommissioning plan is to remediate the radiological constituents associated with C-T production to the extent required to terminate license STB-401. Remediation of radiological constituents in other areas of the St. Louis Plant has previously been performed by the U.S. Department of Energy (DOE) and is currently being performed by the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Sites Remedial Action Program (FUSRAP).

This C-T Decommissioning Plan has been approved for submission in two parts because the C-T decommissioning is being conducted in two phases. The Phase I Plan was submitted previously under separate cover and was approved by NRC on May 3, 2002. Phase I activity is currently decommissioning above-grade buildings, surfaces, and equipment to the extent that whatever remains on-site will be released for *unrestricted use* based on an industrial use scenario. This document is the C-T Phase II Decommissioning Plan ("Phase II Plan") and it describes the activities involving the decontamination and decommissioning of the grade-level and below-grade facilities including pavement and building slabs, soils, underground sewers, and wastewater neutralization basins. Implementation of the Phase II Plan will complete the decommissioning of the building slabs and foundations, paved surfaces, and all subsurface materials to the extent that they can be released for unrestricted use.

The two-phase decommissioning plan provides Mallinckrodt the flexibility necessary to deal with the inherent complexities of an operating manufacturing site and to take immediate steps to reduce the amount of residual radioactive material at the St. Louis Plant. As described in the Phase I Plan, the advantages of a two-phase decommissioning plan are as follows:

The two-phase decommissioning plan follows a logical sequence. The removal of above-grade contaminated equipment and the decommissioning of the buildings where C-T production occurred must be accomplished prior to addressing the subsurface material.

There is limited space available for use as staging areas during decommissioning. The St. Louis Plant is an ongoing operational facility which manufactures a variety of bulk pharmaceuticals and specialty chemicals. Manufacturing will continue during and after the decommissioning of the C-T facility. The decommissioning project has been carefully planned and staged to allow the ongoing operations to continue with minimal impact.

The approval of the Phase I Plan allowed physical remediation work to commence in those areas where on-site workers have the greatest chance of being exposed to residual radioactive material. Building surveys indicated that the majority of residual radioactive material was fixed and, although there are no immediate health and safety issues, the primary process buildings and equipment have not been in use for several years and were starting to physically deteriorate. Subsurface radioactive materials, by comparison, are not easily accessible to on-site workers due to the physical barriers presented by the paved surfaces and building slabs.

Submittal of the Phase I and II Plans has been preceded by several years of planning and site characterization. These efforts significantly enhanced Mallinckrodt's knowledge of the current radiological status of the site. Recent characterization results have been combined with historical knowledge and previous characterization efforts to provide a reasonably complete understanding of the radiological status of the C-T facility and surrounding area. The characterization results for the buildings and equipment were presented in the Phase I Plan. Characterization results for the pavement, slabs, wastewater basins, and subsurface materials are incorporated in this Phase II Plan.

2.2. LICENSE NUMBER/STATUS/AUTHORIZED ACTIVITIES

2.2.1 C-T License Information

The STB-401 licensee is Mallinckrodt Inc., a Delaware Corporation with its principal place of business located at 675 McDonnell Boulevard, St. Louis, MO 63042. The licensed facility is the Columbium-Tantalum (C-T) Plant located at the Mallinckrodt St. Louis Plant, 3600 N. Second Street, St. Louis, MO, 63147.

License STB-401 was most recently amended May 3, 2002 (Amendment 3) to incorporate the approved Phase I Plan. The license was last renewed on March 9, 1989. The renewed license allowed receipt, possession, and manufacturing use of 30,000 kg, each, natural and synthetic uranium and thorium ores. Amendment 1, issued July 20, 1989, deferred application of certain license conditions while the facility was in a stand-by mode. Amendment 2, issued July 12, 1993, amended the license to possession-only use and reduced the maximum possession quantities to 3,000 kg, each, natural uranium and natural thorium in any physical or chemical form.

Following implementation of the Phase I Plan, radionuclides may be present in or on the remaining floor slabs of former C-T operations buildings. Radionuclides may also be present in subsurface sewers that served C-T operations, soils under or adjacent to C-T operations and sewers, and the wastewater neutralization basins. Descriptions and maps of C-T operations were provided in the Phase I plan and are repeated below.

2.2.2 Buildings Supporting C-T Production

C-T production and support buildings are listed in Table 2-1 and displayed in Figure 2-1. Although C-T process operations were performed in an area called Plant 5 at the St. Louis Plant, support activities were conducted in portions of Plants 1, 3, 6, 7, and 8. The Plant and building numbering system is described in Section 3.1 herein. Process Building 238 in Plant 5 was constructed for use by the euxenite operations, while other process buildings in Plant 5 were constructed specifically for the C-T operation. Selected buildings and areas in Plants 6 and 7 were used to receive and store feed materials and drummed URO. Approximately 300 cubic yards of URO was buried in trenches in the western portion of Plant 6 in 1972 and 1973 in conformance with 10 CFR 20.304.

Mallinckrodt began development of Plant 5 in 1947 with the construction of Buildings 200 and 201 along Angelrodt Street. These buildings processed various non-radioactive materials. Building 200 is still in operation today processing organic materials. New underground sewers were installed as Plant 5 was being developed. Wastewater was conveyed in sewers to the northwest corner of Plant 7. From Plant 7, an underground sewer carried the Plant 5 effluent east and connected to the sewer and outfall system previously constructed to support the MED-AEC Destrehan Street Facility. In the early 1970s, two wastewater neutralization basins were constructed in the northwest corner of Plant 7. These basins were used until 1993.

Specific buildings that supported C-T production are described below.

Buildings 213 and 236 were constructed in 1953. Building 213 was originally used as a locker and break facility for Plant 5 operations, including C-T. It now houses plant utility operations, as well as the break room. Building 236 is currently used as a maintenance shop. At one time, C-T product was dried in tray dryers in Building 236.

Building 238 was constructed in 1954 to house the euxenite process, a predecessor to the C-T operation, and was modified in 1961 for use by C-T operations.

Building 235 was constructed in 1959. Building 235 was used as a returned-goods warehouse and at one time was used to store C-T feed materials and URO. All areas of Building 235 have been renovated for manufacturing and associated support activities.

Buildings 246A and 246B were built in 1961 as Building 238 was being converted for C-T processing. C-T operations offices were located in Building 246A. The original C-T organic and aqueous extraction operations were performed in Building 246B.

Building 250 was constructed in 1967 to support C-T and other manufacturing operations. The C-T quality control and research laboratories were located in Building 250, as were manufacturing and laboratory facilities for other Mallinckrodt products. Prior to Building 250 construction, C-T laboratories were located in Building 25 (in Plant 1). Building 25 was also used as a laboratory to support AEC-MED operations and will be remediated under FUSRAP.

Buildings 247A, 247B, and 248 were constructed in 1967 to house expanded C-T extraction and finishing operations.

All Plant 5 streets are paved with asphalt or concrete. Paved streets were installed to serve manufacturing and warehouse buildings as they were constructed.

2.2.3 C-T Process Description

A generalized C-T process flow diagram is shown in Figure 2-2. Feed materials included ore, slag, sodium hydroxide, hydrofluoric acid, sulfuric acid, aqueous ammonia, methyl isobutyl ketone, hydrochloric acid, and potassium chloride. Products from this process included tantalum oxide, potassium fluotantalate, and columbium oxide. Columbium and tantalum oxides and salts were produced in a batch process that included five major steps:

Step 1: Feed materials were received by truck in burlap bags and drums. Usually, the bags were placed in drums or boxes for storage. The drums or boxes were stored in Plant 6 and 7 prior to forklift transport to the ore staging area in Plant 5, where ore batches were selected.

The ore (feed material) was arranged into feed batches in the ore staging area east of Building 245. Ore was also staged on the other paved streets in Plant 5. The feed material was ground into fine-grained slurry in the ball mill room (Building 238 annex) using a wet milling process. The slurry was then pumped into boil-down tanks where excess water was evaporated.

Due to the value of columbium and tantalum, the burlap ore bags were incinerated, and the ash was recycled back to the process to recover columbium-tantalum. The incinerator was originally located west of Building 248. In 1980, the incinerator was installed in its present location west of Building 101 in Plant 6.

Step 2: The ore slurry was pumped into large rubber-lined acid-dissolving tanks in building 238. Hydrochloric, sulfuric, and hydrofluoric acids were used during the tin slag processing. Hydrofluoric and sulfuric acids alone were used in dissolving/leaching columbite and tantalite ores and synthetically upgraded tin slags.

Step 3: The acid C-T mother liquor was decanted from the unreacted ore (URO) by mixing and settling. A flocculating agent was utilized to enhance separation. The decanted liquor was filtered and pumped to Building 247 for Step 4 processing. Initially, the URO acid slurry was filtered on a plate and frame press, washed with water and the cake discharged to the plant sewer system. Between 1975 and 1980, the URO press cake was drummed for future use or disposal. Beginning in 1980, the stored URO was reprocessed by slurrying in Step 4 raffinate in order to form a homogeneous mixture. This mother liquid was then decanted. The URO slurry was diluted with water, neutralized with caustic or ammonia, dewatered in a filter press, dried in a pancake dryer and drummed for disposal. All of the URO processing was performed in Building 238.

Step 4: The acid mother liquor was subjected to a two-series extraction/purification process. In the first series, the C-T mother liquor was extracted using methyl isobutyl ketone (MIBK) and sulfuric acid. This generated a C-T-MIBK stream (organic end) and a raffinate (aqueous end) consisting of hydrofluoric and sulfuric acids, salts, and residual URO material. In the second series, the C-T-MIBK stream was contacted with water in a second extractor to separate the columbium from the MIBK phase. This yielded a tantalum-MIBK stream (organic end) and a fluocolumbic acid stream (aqueous phase). MIBK was removed from the tantalum-MIBK stream by steam stripping, yielding a fluotantalic acid stream. The first series raffinate stream was used to wash columbium and tantalum acid liquors from the URO, reused as feed liquors for the solvent extraction step, or neutralized with ammonia and discharged to the sewer. These process steps were performed in Buildings 246B and 247B. Solvent extraction was not utilized until approximately 1964. Prior to this time, the columbium and tantalum were separated from the mother liquor by precipitation.

Step 5: The primary C-T process products were columbium oxide and potassium fluotantalate salt. Approximately five percent of the tantalum product was produced as tantalum oxide. Columbium and tantalum oxides were precipitated from their respective product streams (fluocolumbic acid, fluotantalic acid) by addition of ammonia. Finishing steps included filtration, drying, and calcining. Columbium oxide precipitation and finishing were performed in Building 248. The potassium fluotantalate salt was precipitated from the fluotantalic acid stream by addition of potassium chloride, separated in a centrifuge, and dried in tray dryers. These steps were conducted in Building 238.

2.3. LICENSE HISTORY

In addition to the C-T process, various operations at the St. Louis Plant have involved use of radioactive materials. These operations are summarized below. Figures 2-1, 2-3 and 2-4 identify the locations of these activities.

2.3.1 MED/AEC Operations

2.3.1.1. Introduction

Between 1942 and 1958, uranium processing and waste management activities were conducted by Mallinckrodt in support of early Federal Government programs to develop atomic weapons under the Manhattan Engineers District and later the Atomic Energy commission (MED/AEC). These activities resulted in radiological contamination on Mallinckrodt property and properties adjacent to the site. The contamination at these locations consists of natural uranium and natural thorium and their associated progeny, including Th-230 and radium. Contamination is present in groundwater, soils, and structures. MED/AEC contamination at the site is being remediated by the Federal Government under the Formerly Utilized Sites Remedial Action Program (FUSRAP). The history of MED/AEC operations is presented below. The status of FUSRAP remediation activities is presented in Section 2.4 below.

2.3.1.2. History

In April 1942, Mallinckrodt, then called Mallinckrodt Chemical Works (MCW), was contracted to extract uranium from ore concentrates for eventual use in the first self-sustaining nuclear chain reaction in the graphite reactor being built at the University of Chicago. The initial contract was signed on July 20, 1942. Within 50 days of accepting the assignment from the War Department, MCW began producing highly refined uranium dioxide (UO_2) for the CP-1 pile reactor at the rate of 1 ton per day. Manufacturing was performed in Plant 2 (Buildings 50, 51, 51A, and 52), with research and other support activities in Plant 1 (Buildings A, K, X, and 25). The UO_2 was also shipped to another MED site for reduction to metallic fuel for the reactor. The intermediary products, uranyl nitrate and uranium trioxide, were produced both as intermediaries to the production of uranium dioxide and as final products. A process to convert UO_2 to uranium tetrafluoride was begun as a batch process in 1942. A process to convert uranium tetrafluoride to uranium metal started in 1943. This activity was performed in process buildings located on the east side of Broadway Street, immediately west of Plant 5. At that time, this area was designated as Plant 4. This area is currently designated Plant 10. The company was the sole supplier of uranium compounds for the Manhattan project well into 1943, and provided high purity uranium products for the duration of the war.

In 1945, the Destrehan Plant (Plants 6 and 7) was built to process pitchblende ore and to increase the capacity of the refinery. Production began in 1946. In 1958, the Destrehan plant was put on standby, and uranium processing was transferred elsewhere.

Figure 2-3 illustrates the areas at the St. Louis Plant site that were used for MED-AEC production.

In 1950 and 1951, the MED-AEC facilities in Plants 1 and 2 were partially decommissioned. In 1960 and 1961, the decommissioning of Plants 1 and 2 was completed, and Plant 4 and the Destrehan Plant were decommissioned. These decommissioning activities were performed to the standards of the day, and additional decontamination and remediation activities have been and are being performed under FUSRAP.

The St. Louis Plant processed approximately 50,000 tons of uranium products from ore concentrates and pitchblende ore during the 1942-1958 MED-AEC operations. It is estimated that the minimum radioactivity throughput was approximately 30,000 Ci of uranium isotopes and 10 Ci of thorium isotopes.

2.3.2 Euxenite Process

From 1956 to 1960, Mallinckrodt extracted columbium, tantalum, uranium, thorium, and rare earth elements from euxenite mineral ore for delivery to the AEC and the General Services Administration (GSA) as part of the Defense Materials Procurement Program. The Euxenite operation was performed under AEC source material license R-226. The license expired in 1960. It is estimated that a total of 95 Ci of natural uranium (U-238, U-234, and U-235) and 10 Ci of natural thorium (Th-232, Th-228) were contained in the ore processed during this time period. Building 238 was constructed to house Euxenite operations and subsequently adapted for use by C-T operations. Euxenite production and support areas are illustrated in Figure 2-4.

2.3.3 Uranyl and Thorium Salt Processes

From 1956 to 1977, Mallinckrodt subdivided and/or resold small quantities of uranyl nitrate, uranyl acetate, and thorium nitrate salts under AEC/NRC licenses SUB-176 and later SUC-872. Maximum licensed quantities were 450 pounds (each) uranyl salts and 400 pounds thorium salts. Licensed activities were performed in buildings 43, 62, and 80. Buildings 43 and 80 were previously demolished. A report of Mallinckrodt's final radioactivity survey under SUC-872 was submitted to NRC on December 13, 1979.

2.3.4 Hematite Pilot Plant

From 1956 to 1961, Mallinckrodt performed research and pilot studies under License SNM-276 to support the design of a reactor fuel rod production facility that was later constructed at Hematite, Missouri. Laboratory support was provided for a time following facility construction.

The pilot plant was located in the original building 5. This building has been demolished. Laboratory analysis was performed in building 25.

2.3.5 Radioisotope Analysis

Mallinckrodt performed laboratory analysis of radiolabeled products produced by Mallinckrodt and others. These operations were performed under license 24-5804-02 and later under 24-5804-04 following expiration of the original license. These operations were licensed to use any byproduct materials listed in 10 CFR 33.100, Schedule A, Column I. Operations were performed in building 25, rooms 102 A, B, and C. These activities ceased in 1995.

2.3.6 Sealed Sources

Mallinckrodt used sealed Cesium 137 sources in gauging devices under license 24-5804-03. Sources ranged from 500 mCi to 2 Ci and were located in buildings 120 (4 sources), 122 (2 sources), and 125 (1 source). The sources were removed in 1995.

2.3.7 General Use Devices

Mallinckrodt uses a variety of general use devices including smoke detectors, exit signs, and analytical instruments. These devices contain small quantities of radioactive material. Mallinckrodt operates and maintains these unlicensed devices in conformance with General License requirements.

2.4. PREVIOUS DECOMMISSIONING ACTIVITIES

2.4.1 C-T Operations

Mallinckrodt is currently implementing the C-T Phase I Plan (Phase I Plan). Phase I is decommissioning buildings and equipment to the extent that whatever remains on-site will be released for *unrestricted use* based on an industrial use scenario.

The Phase I Plan describes the activities during remediation, the characteristics and locations of areas remediated, and the disposition of radioactive material generated during the remediation. Summaries of the results of Phase I activities will available to NRC as described in the Phase I Plan.

2.4.2 MED/AEC Operations

As indicated above, MED-AEC facilities in Plants 1 and 2 were partially decommissioned in 1950 and 1951. Further decommissioning was performed in the early 1960's. MED-AEC facilities in Plants 6, 7, and 4 (now known as Plant 10) were also decommissioned to the standards of the day in the early 1960's. Decommissioning activity included building decontamination or demolition and removal of some soils and subsurface materials.

The Formerly Utilized Sites Remedial Action Program (FUSRAP) was created by the U.S. Congress to identify and control or remediate sites where residual radioactivity remains from activities conducted under contract to MED and AEC during the early years of the nation's atomic energy program. Some facilities that produced radioactive materials for commercial sale are also included under FUSRAP at the direction of Congress.

DOE, under FUSRAP, had the initial responsibility for remediating radioactive and chemical contamination in the areas of the St. Louis Plant that formerly housed MED-AEC operations. However, in October 1997, Congress transferred the FUSRAP from DOE to the U.S. Army Corps of Engineers (USACE). Under FUSRAP, USACE is responsible for the cleanup of both radioactive and hazardous chemical contamination at the St. Louis Plant with oversight by the U.S. Environmental Protection Agency (EPA). These responsibilities are outlined in a Federal Facilities Agreement (FFA) negotiated by EPA Region VII and DOE[1]. The FFA has been amended to transfer these responsibilities to USACE. The FFA further defines the conditions dictated by EPA to manage remediation at St. Louis. The document creates broad obligations for clean up of all residual waste from uranium processing, including such waste that might have mixed or commingled with other radioactive or hazardous material substance at the site.

FUSRAP is responsible for the remediation of Buildings K, 25, 50, 51, 51A, 52, 52A, 100, 116, 117, 219, 700, 704, 705, 706, 707,and 708 and other areas of the site, including subsurface areas, containing uranium processing residues. FUSRAP has completed decontamination or demolition of all of these structures except Buildings 25 and 100. FUSRAP is currently remediating soils containing subsurface residues of MED/AEC operations.

Some Plant 6 and 7 buildings and adjacent open areas were used to support C-T manufacturing following their decontamination and release to Mallinckrodt by the AEC in the early 1960s. The Plants 6 and 7 buildings and areas that supported C-T are summarized in Table 2-1. Soils in these areas contain substantial volumes of residues from uranium refining and are therefore subject to remediation by USACE under FUSRAP. The USACE will remediate Plant 6 and 7 soils over the next several years.

The USACE has completed a remedial investigation/feasibility study (RI/FS) process for the St. Louis site and vicinity properties. The RI/FS process was completed in accordance with procedures developed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Four major reports summarized the conduct of the RI/FS process: the Remedial Investigation (RI) report, which describes the nature and extent of contamination; the Baseline Risk Assessment (BRA), which describes the potential risks to the public health and the environment in the absence of cleanup; the Initial Screening of Alternatives (ISA), which identifies the range of alternatives initially considered; and the Feasibility Study (FS), which describes how the cleanup options were developed and evaluated. These documents are the primary evaluation documents prepared to describe the findings of the RI/FS. The RI/FS process concluded with the issuance of a Record of Decision (ROD) that identified the remedy selected for the remediation of the St. Louis Downtown Site (SLDS), the Mallinckrodt site and surrounding properties.

The CERCLA process is USACE's primary method for environmental compliance associated with remedial actions. Under FUSRAP, the CERCLA process is functionally equivalent to the

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[1] Federal Facilities Agreement between US Department of Energy and US Environmental Protection Agency, June of 1990, Docket No. VII-90-F-0005.

requirements of the National Environmental Policy Act (NEPA). Specifically, the RI, BRA, and FS comprise the functional equivalent of an Environmental Impact Statement. The RI/FS ROD is equivalent to an EIS ROD. The USACE states that their decision-making process and conclusion of the RI/FS ROD for the downtown St. Louis FUSRAP properties may satisfactorily be substituted for the EIS ROD of the site. Specifically, the USACE chosen alternative for remediation of the FUSRAP property is acceptable and appropriate for the Mallinckrodt St. Louis Plant and other adjacent property.

USACE will document the locations remediated and post-remediation radionuclide concentrations as part of their project closure activities.

2.5. SPILLS

Documentation does not describe any accidental spills or releases of radioactive material from the time period in which the C-T process site was operational. Therefore, interviews were conducted to obtain historical information from past and present employees involved in C-T operations. The following events were described in these interviews.

Raffinate Tanks - During the operational period of the C-T process site, raffinate tanks located north of Buildings 246 and 247 overflowed on more than one occasion. In the event of an overflow of the main tanks, raffinate was diverted to a backup tank. However, in some instances, the backup tank did not contain all materials.

Steam Jet Emissions - The entrained liquid from a high-pressure vacuum steam jet on the southwest roof of Building 238 occasionally sprayed into the air potentially contaminating roofs of surrounding buildings.

Material Handling Losses – Various C-T raw material and residue handling operations were performed in process and support buildings and outside areas in Plants 5, 6, and 7. Minor spills occurred on occasion during these activities.

Specific information on the types, forms, activities, and concentrations of radionuclides released in spills and similar events is not available. The nature of the materials released would not have differed significantly for those handled under routine operations. Spills and other releases would have occurred in areas where these materials were routinely handled and processed.

Uranium purification activities performed under MED/AEC resulted in widespread release of radioactivity and subsequent contamination of surfaces, structures, and soil. As discussed elsewhere, assessment and remediation is being performed under FUSRAP.

2.6. PRIOR ON-SITE BURIALS

The C-T process generated an unreacted ore (URO) residue that contained materials that were not dissolved in the initial C-T process steps. URO contained natural uranium, natural thorium, and their progeny in addition to nonradioactive constituents. Specific URO composition varied with raw material composition and process conditions.

In 1972 and 1973, approximately 300 cubic yards of drummed URO was buried in conformance with 10 CFR 20.304 in a series of trenches located in Plant 6. Trenches were generally excavated to a depth of six feet. An approximate two-foot thick layer of URO was placed in the trench and compacted. The trench was then backfilled with compacted excavated soil. A finished goods warehouse was subsequently constructed above one of the trenches. URO Burial trench locations are identified in Figure 2-5.

TABLE 2-1
C-T PROCESS AND SUPPORT BUILDINGS

Building No. and Location	C-T Process and Support Areas
Plant 1 Area	
Building 25 (FUSRAP)*	Laboratory
Plant 3 Area	
Building 62	Change Rooms (Lockers)
Plant 5 Area	
Building 213	Change and Break Rooms
Building 214	Transformer/Switchgear Room
Building 235	Feed Material/Storage (East Half)
Building 236	Feed Material Storage
Building 238	C-T Ore Grinding/Dissolving/T Processing
Building 246A	Offices
Building 246B	Solvent Extraction Process
Building 247A	C-T Solvent Extraction/Product Storage
Building 247B	Columbium Filtration and Drying
Building 248	Columbium Filtration/Drying/Calcining
Building 250	Offices and Quality Control Labs
Plant 6 Area	
C-T Incinerator	C-T Incinerator
Building 116 (FUSRAP)	Receipt/Unloading of C-T Ore
Building 117 (FUSRAP)	URO Drum Preparation and Staging
Plant 7 Area	
Building 700 (FUSRAP)	Storage of Tin Slag Feed Material
Building 704 (FUSRAP)	URO Drum Storage
Building 705 (FUSRAP)	C-T Ore Storage
Building 706 (FUSRAP)	C-T Ore Storage
Building 708 (FUSRAP)	Storage of Tin Slag Feed Material
Plant 8 Area	
Building 90/91	Maintenance Areas

* (FUSRAP) These buildings are being addressed under FUSRAP.

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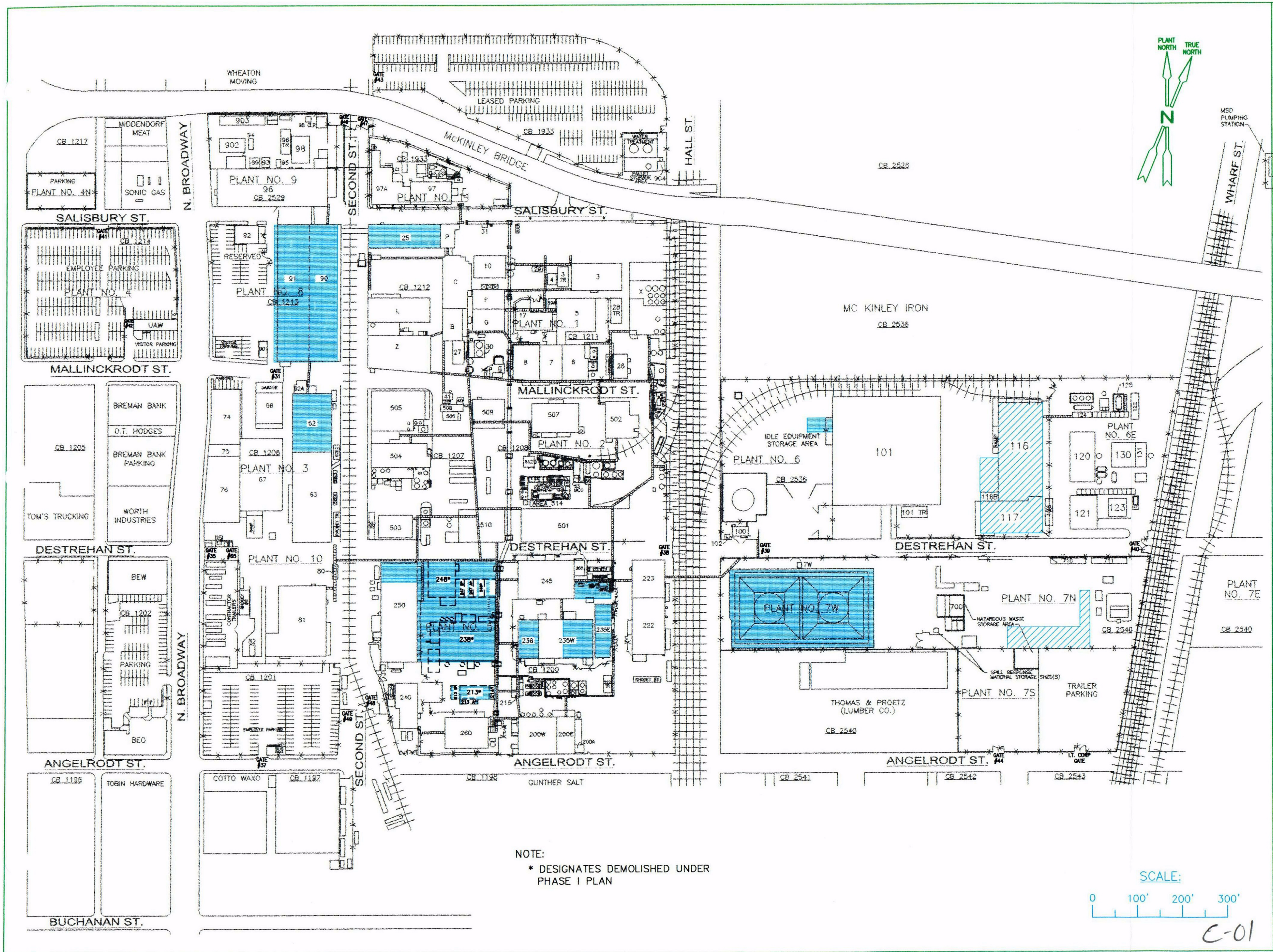

NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

C-01

LEGEND:

🟦	C–T PRODUCTION AND SUPPORT AREAS
▨	C–T SUPPORT AREAS REMOVED UNDER FUSRAP

NO.	DATE	ENGR.	DESCRIPTION
1	03/27/03	R.R.	GENERAL BACKGROUND UPDATING
0	03/18/03		INITIAL ISSUE

DRAWING REVISIONS

JOB NO.
PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

ST. LOUIS PLANT
C–T PRODUCTION PROCESS & SUPPORT AREAS
FIGURE 2–1

SITE STL. PLANT ALL BLDG. ALL FLOOR N/A
SCALE 1"=100'
DATE 11/28/00
DR. BY: J. MCMAHON
ENGR.
CHECKED
DRAWING NO.
FIGURE 2–1
REV. 1

THIS DRAWING IS THE PROPERTY OF MALLINCKRODT AND IS NOT TO BE REPRODUCED, COPIED OR USED FOR ANY PURPOSE EXCEPT AS SPECIFIED BY MALLINCKRODT

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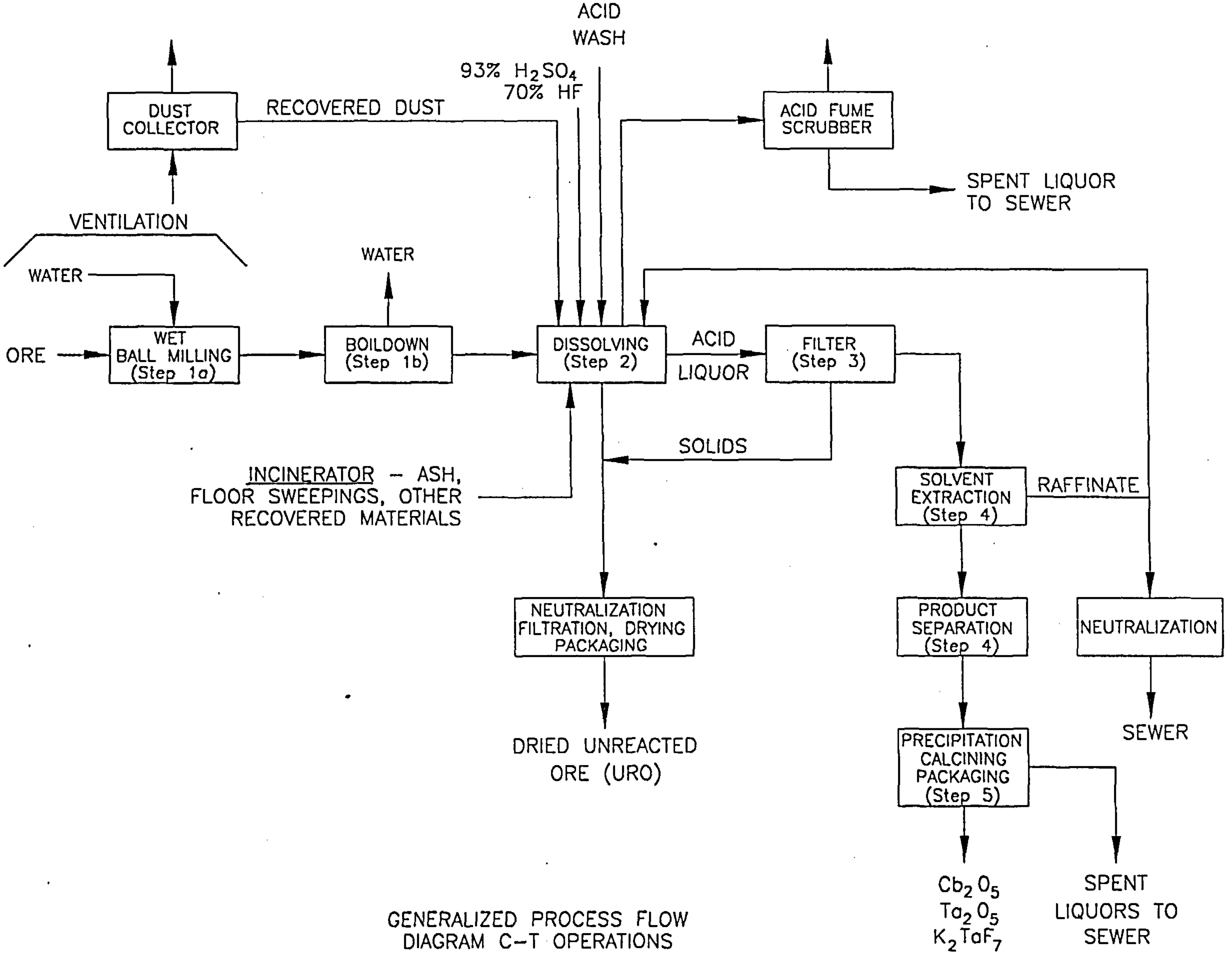
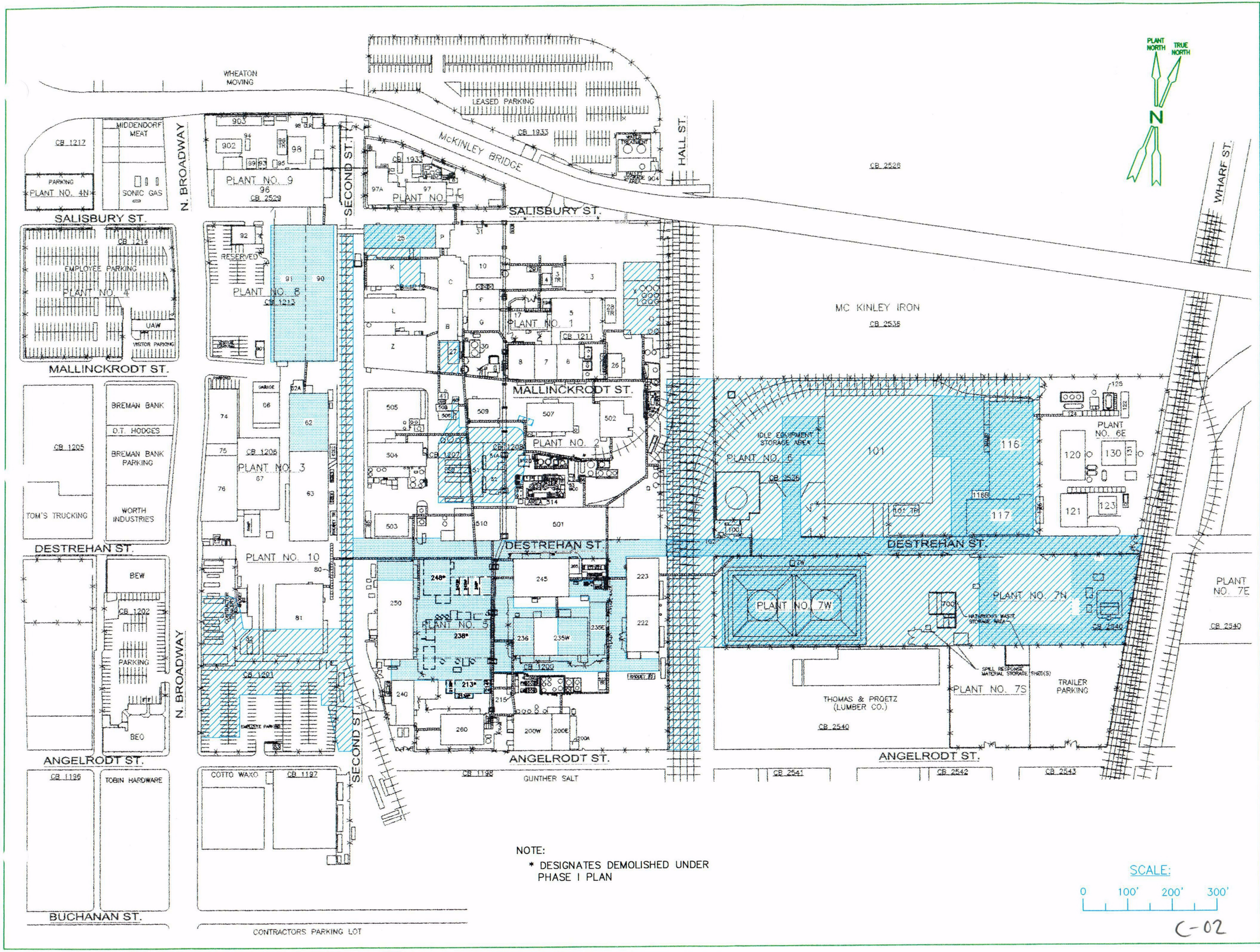


GENERALIZED PROCESS FLOW DIAGRAM C-T OPERATIONS

FIGURE 2-2
GENERALIZED PROCESS FLOW DIAGRAM
C-T OPERATION
REV. 0

fn = Gen_proc 8/6/97



NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

C-02

LEGEND:

THIS IS WHERE OPERATIONS OF EITHER MED-AEC OR C-T HAS OCCURED OVER TIME

▤	C-T PRODUCTION AND SUPPORT AREAS
▨	MED-AEC OPERATIONS PLANTS 1 & 2 (1942-1946) PLANT 4 (1942-1961) PLANT 6 (1946-1958) PLANTS 6E & 7 (1950-1958)

NOTES:

1. THIS DRAWING IS A GENERAL DRAWING SHOWING C-T AND MED-AEC OPERATIONS. ALTHOUGH MANY BUILDINGS AND STRUCTURES HAVE CHANGED OVER TIME, THIS DRAWING IS NOT INTENDED TO DEPICT ACTUAL DELINEATION.

NO.	DATE	ENGR.	DESCRIPTION
1	03/31/03		GENERAL BACKGROUND UPDATING
0	03/18/03		INITIAL ISSUE

DRAWING REVISIONS

JOB NO. PROJECT NO.

MALLINCKRODT

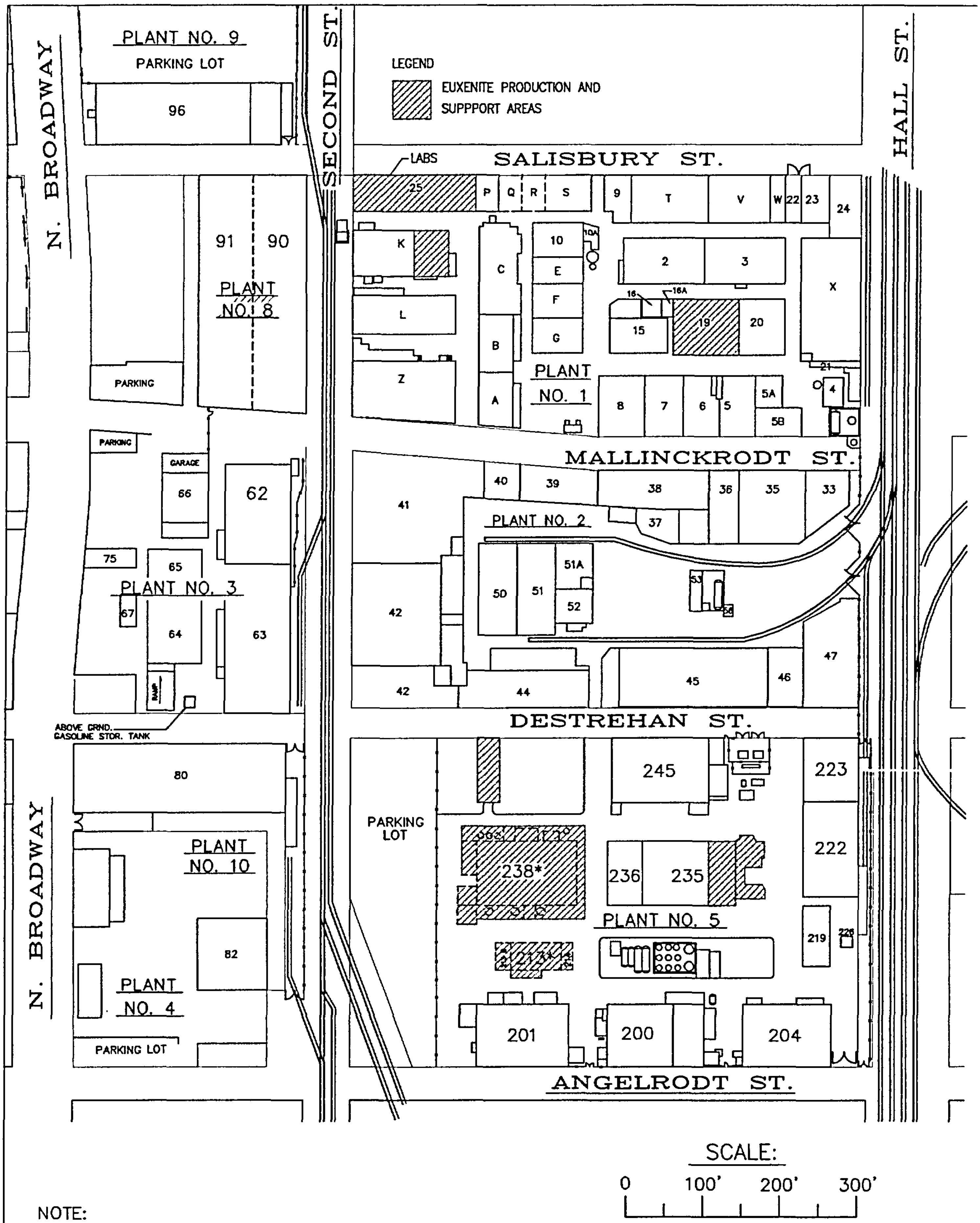
ST. LOUIS, MO.

ST. LOUIS PLANT
MED-AEC PRODUCTION & SUPPORT AREAS
FIGURE 2-3

SITE STL PLANT ALL BLDG. ALL FLOOR N/A
SCALE 1"=100' DATE 11/28/00
DR. BY: J. MCMAHON ENGR.
CHECKED
DRAWING NO. FIGURE 2-3 REV. 1

THIS DRAWING IS THE PROPERTY OF MALLINCKRODT AND IS NOT TO BE REPRODUCED, COPIED OR USED FOR ANY PURPOSE EXCEPT AS SPECIFIED BY MALLINCKRODT

T_BLK25.DWG

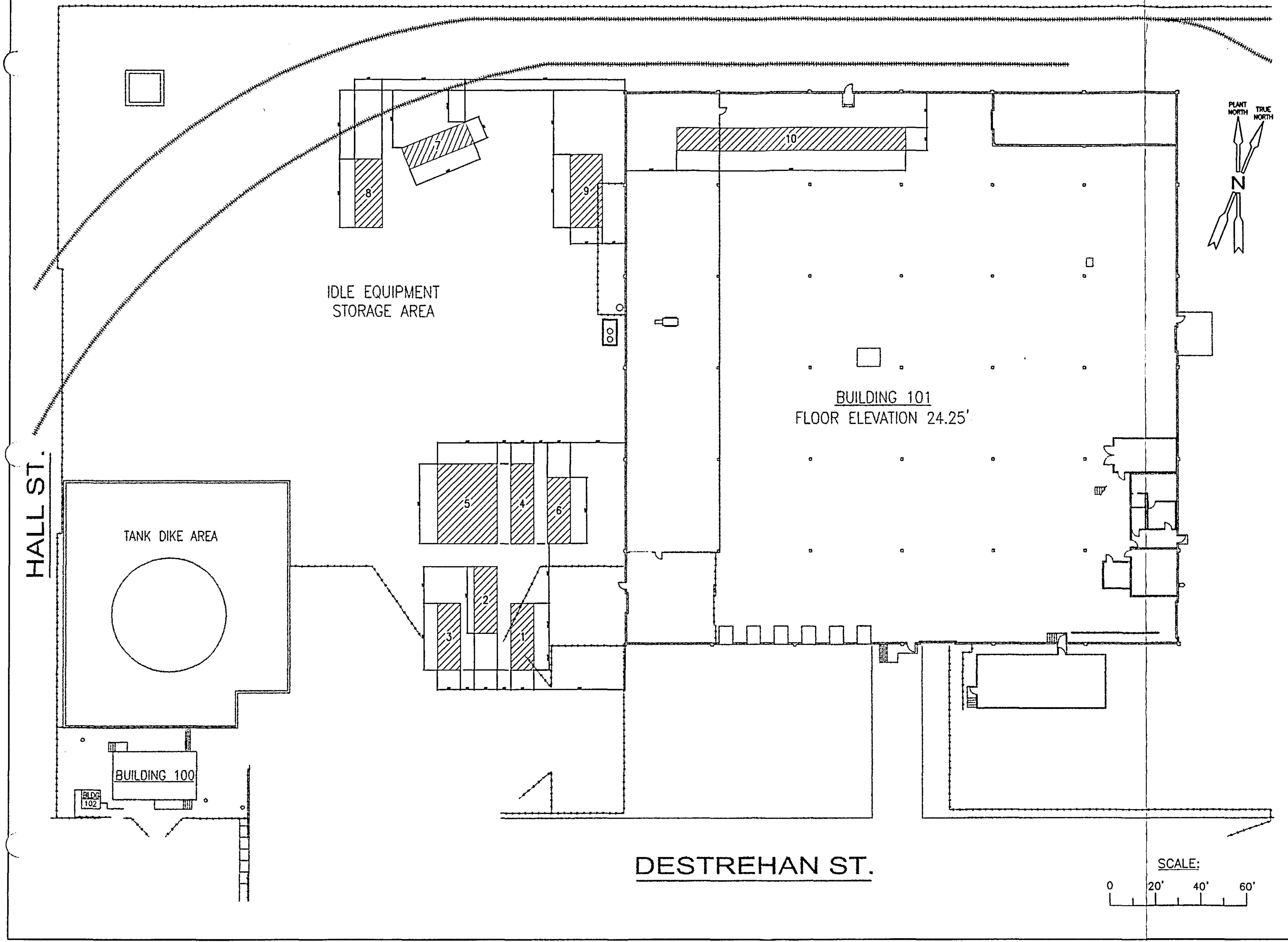


NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

FIGURE 2-4
FORMER EUXENITE SUPPORT AREA
REV. 0

fn=euxenite 10/15/97

S:\CorpEng\DOCS\CT PHASE II\CT PHASE II figure 2-5.dwg 03/19/03 14:59 REVISED BY S. SABO FOR R.ROWE REV NO. 0



LEGEND:

URO BURIAL FROM JULY 2, 1973 THRU JULY 17, 1973

BURIAL SITE NO.	BOTTOM ELEV.(MCW)	TOP ELEV.(MCW)	VOLUME CU. FT.
1	18.00'	20.00'	580
2	17.50'	19.00'	435
3	17.50'	19.00'	580
4	17.50'	19.50'	700
5	17.50'	18.50'	910
6	18.00'	20.00'	580
7	16.25'	18.25'	600
8	16.25'	18.25'	720
9	17.00'	19.00'	896
10	16.80'	18.80'	2000

DWG. NO.	TITLE
SK-11706	URO BURIAL SITE
SK-11819	URO BURIAL DETAILS
4332-201-001	PLANT NO. 7 SOUTH PIT LOCATIONS
4332-202-001	URO BURIAL LAYOUT

REFERENCE DRAWINGS

NO.	DATE	ENGR.	DESCRIPTION
0	03/18/03		INITIAL ISSUE

DRAWING REVISIONS

JOB NO. PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

PLANT 6
URO BURIAL LAYOUT
FIGURE 2-5

SITE STL PLANT 6 BLDG. ALL FLOOR N/A
SCALE 1"=20' DATE 11/28/00
DR. BY: J. MCMAHON ENGR.
CHECKED
DRAWING NO. FIGURE 2-5 REV. 0

T_BLK25.DWG

SECTION 3

FACILITY DESCRIPTION

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

3. FACILITY DESCRIPTION

3.1. SITE LOCATION AND DESCRIPTION

The Mallinckrodt St. Louis Plant is located at 3600 North Second Street, St. Louis, Missouri 63147. The City of St. Louis has the status of a Missouri county. The Plant is a 43-acre (174,016 m^2) site located near the west bank of the Mississippi River in an area zoned and developed for industrial use. The City of Venice, Illinois is the nearest city on the east bank of the Mississippi River. The plant is generally bounded by Angelrodt Street on the south, Salisbury Street on the north, Broadway Street on the west, and Wharf Street on the east. A small Plant 7E area is located east of Wharf Street. Figure 3-1 provides the general location of the St. Louis Plant. Plant topography is generally flat, with a slight decrease in elevation toward the east. Elevations across the site range from approximately 122 m (400 ft) above mean sea level on the east to approximately 130 m (425 ft) at Broadway Street on the west. Although the site is in the historic flood plain of the Mississippi River, it is protected from flooding by a levee constructed by the U. S. Army Corps of Engineers in 1964 and operated by the City of St. Louis. The St. Louis Plant has been in operation since 1867 and has produced a wide range of products including metallic oxides and salts, ammonia, organic chemicals, and various uranium compounds under contract to the Manhattan Engineering District and the Atomic Energy Commission (MED-AEC). The plant currently produces a variety of products for the food, drug, cosmetic, pharmaceutical, and specialty chemical industries.

The St. Louis Plant currently contains more than 50 operations and support buildings in an area of approximately twelve city blocks. The St. Louis Plant has traditionally been subdivided into geographic areas called Plants. These Plants have been named by a number from 1 to 10 and in some cases a number and letter, *e.g.*, Plant 5 and Plant 7E. Individual buildings within each Plant are designated by numbers, letters, or a combination of both. Additionally, areas of particular operations could be described by a process-related name, *e.g.* C-T Plant and Destrehan Street Plant. Support facilities include maintenance shops, research and quality control laboratories, warehouses, steam boilers, wastewater and air treatment operations for Pharmaceuticals operations, inactive wastewater neutralization basins, and a permitted facility for drum storage of hazardous waste. The current arrangement of Plants and buildings within the St. Louis Plant is provided in Figure 3-2. C-T Process and Support Buildings have been described in section 2 of this Phase 2 Plan.

A number of investigations of subsurface geology and groundwater have been performed at the site. These studies have been performed by Mallinckrodt, the U.S. Department of Energy (DOE), the DOE contractor Bechtel National, Inc. (BNI), the U.S. Army Corps of Engineers (USACE), and the USACE contractor IT Corp. (IT). Several of these studies are described in Appendix A. Maps and figures are provided where appropriate.

3.2. POPULATION DISTRIBUTION

Approximately 1,100 employees work at the St. Louis Plant. Manufacturing and direct support functions operate 24 hours per day, seven days per week and employ approximately one half of the total workforce.

The City of St. Louis population on April 1, 2000 was 348,189. Population in the City of St. Louis decreased by 12% over the period 1990-2000.[1]

The St. Louis Plant is located in census tract 1267 and surrounded on the North, East, South, and West by tracts 1097, 4007, 1266, and 1202, respectively. Tract 4007 is located east of the Mississippi River in Illinois. The 2000 U.S. census reports a total population of 1,997 in tract 1267 and a total of 12,904 in 1267 and surrounding tracts. Total population in these tracts decreased by 29% over the period 1990-2000.[2]

The 2000 population in census tract 1267 and surrounding tracts was 84% black or African American, 14% white, and 1% other races. Black or African American and other races comprised 70% of the population in tract 1267 and 95%, 94%, 71%, and 86% of the population in census tracts to the north, east, south, and west, respectively.[3]

Projections of population change in the St. Louis area are inconsistent. The state of Missouri projects continued decreases of 9-12% per year in the City of St. Louis population for the 2000-2025 period.[4] The East-West Gateway Coordinating Council predicts an increase of approximately 0.4% per year over the same period.[5]

3.3. CURRENT/FUTURE LAND USE

The Mallinckrodt site is in an urban industrial area in the northeastern section of the City of St. Louis. Manufacturing and support buildings cover a large portion of the site, and the remainder of the area is typically paved with asphalt or concrete. Mallinckrodt limits access to its facilities to employees, subcontracting construction workers, and authorized visitors and maintains 24-hour security at the property. Three railroads cross, serve, or are adjacent to the site: Burlington, Northern, and Santa Fe; Norfolk Southern; and the St. Louis Terminal Railroad Association. The site area is zoned "K" (unrestricted district) by the City of St. Louis. This industrial zone allows all uses except new or converted dwellings. Some uses allowed within this zone under conditional use permit are acid manufacture, petroleum refining, and stockyards.[6] The long-term

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[1] U.S. Census 1990 and 2000 Summary Files 1 (SF 1) 100-Percent Data

[2] U.S. Census 1990 and 2000 Summary Files 1 (SF 1) 100-Percent Data

[3] U.S. Census 2000 Summary File 1 (SF 1) 100-Percent Data

[4] State of Missouri, Office of Administration / Division of Budget and Planning, http://www.oa.state.mo.us/bp/projections/FinalComponentsOutput.htm, Accessed 4/5/02

[5] East-West Gateway Coordinating Council, Our Region, Population, http://www.ewgateway.org/ourregion/trendicators/Pop/PopProj-2025/popproj-2025.htm, Accessed 4/5/02

[6] St. Louis City Revised Code, Chapter 26.60, K UNRESTRICTED DISTRICT

plans for this area are to retain the industrial uses, encourage the wholesale produce district, and phase out any junkyards, truck storage lots, and the remaining marginal residential uses. Land use within a 1.6 km (1-mi) radius of the site reflects a mixture of commercial, industrial, and residential uses (Figure 3-3).[7] The closest residential dwelling is located on North Broadway, approximately 60 m (200 ft) south of the site.[8] Table 3-1 identifies adjacent and other significant properties in the immediate area.

Property owned by the City of St. Louis is located between Mallinckrodt and the Mississippi River. The Mississippi River levee is located on this city property. The Riverfront Trail hiking and bicycle trail runs along the top of the levee, but the property is otherwise undeveloped and unfenced.

3.4. METEOROLOGY AND CLIMATOLOGY

St. Louis is located at the confluence of the Mississippi and Missouri Rivers, near the geographical center of the US. Its position in the middle latitudes allows the area to be affected by warm moist air that originates in the Gulf of Mexico, as well as cold air masses that originate in Canada. The alternate invasion of these air masses produces a wide variety of weather conditions and allows the region to enjoy a true four-season climate.

During the summer months, air originating from the Gulf of Mexico tends to dominate the area, producing warm and humid conditions. Since 1870, records indicate that temperatures of 90 degrees or higher occur on about 35-40 days per year. Extremely hot days (100 degrees or more) are expected on no more than five days per year.

Winters are brisk and stimulating. Prolonged periods of extremely cold weather are rare. Records show that temperatures drop to zero or below an average of 2 or 3 days per year, and temperatures as cold as 32° F or lower occur less than 25 days in most years. Snowfall has averaged a little over 45 cm (18 inches) per winter season, and snowfall of an inch or less is received on 5 to 10 days in most years.

Normal annual precipitation for the St. Louis area is approximately 86 cm (34 inches). The three winter months are the driest, with an average total of about 15 cm (6 inches) of precipitation. The spring months of March through May are normally the wettest with normal total rainfall of approximately 27 cm (10.5 inches). It is not unusual to have extended dry periods of one to two weeks during the growing season.

Thunderstorms normally occur on an average of between 40 and 50 days per year. During any year, some of these thunderstorms can become severe and produce large hail and damaging winds. Tornadoes have produced extensive damage and loss of life in the St. Louis area.[9]

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[7] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, Figure 2-2.

[8] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-4.

[9] Climatology of St. Louis, National Oceanographic and Atmospheric Administration, http://www.crh.noaa.gov/lsx/climate/cli-sum1.htm. Accessed 3/23/02.

Normal, mean, and extreme climatologically and meteorological data from the Lambert-St. Louis International Airport are summarized in Table 3-2.[10] The Lambert airport is located 16 km (10 miles) northwest of the site. Lambert meteorological data and observed conditions are therefore representative of those at the site.

Table 3-3 summarizes severe weather events for the City of St. Louis.[11] Thunderstorm wind is the most frequently occurring extreme weather event, with an historic frequency of one event per year.

It can be seen from Table 3-2 that the average wind vector is 4.3 m/s (9.5 mi/hr) from the south. The maximum vector is 27 m/s (60 mi./hr) from the southeast. Precipitation greater than 0.25 cm (0.1 in) occurs an average of 108 days per year. The record 24-hour precipitation of 8.4 cm (3.3 in) occurred in June 1960. A more recent data set indicates a 24-hour precipitation maximum of 14.2 cm (5.59 in) on March 16, 1995.[12]

As indicated elsewhere, the site is in an urban industrial zone and is paved with asphalt or concrete. Climatological events will have no impact on radionuclide migration or deterioration of cover except during the brief periods when soils are exposed during site activities.
Like the rest of the Midwest, atmospheric stability varies significantly throughout the day and between day and night. Daytime conditions are typically unstable while stable conditions typically occur at night. Nocturnal inversions are common when the night sky is clear and the wind speed is low. As the site is adjacent to the Mississippi River, it experiences morning fog more frequently than other areas in the region.

The St. Louis air quality control region is designated attainment for the criteria pollutants particulate matter, sulfur oxides, nitrogen oxides, and carbon monoxide. The area is currently designated nonattainment for ozone, a contaminant attributed to hydrocarbon emissions from mobile and stationary sources. Recent data indicates that the area complies with the 1-hour National Ambient Air Quality Standard for ozone.

The region is designated Class II. The nearest Class I area is the Mingo National Wildlife Refuge, located approximately 177 km (110 miles) south of the site. Decommissioning emissions, if any, will have no impact on this area.

3.5. GEOLOGY AND SEISMOLOGY

3.5.1. Geology

The site is located in an area of fill, alluvial deposits, and limestone bedrock, adjacent to the west bank of the Mississippi River, and approximately ten miles south of the confluence of

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[10] Normals, Means, and Extremes, St. Louis, MO (STL), The Weather Almanac, Tenth Edition, Richard A, Wood, Ph.D., Editor, Gale Group, Detroit, 2001.

[11] Storm Events for Missouri, National Climate Data Center, http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms, Accessed 2/27/02.

[12] Midwest Regional Climate Center, http://mcc.sws.uiuc.edu/Summary/Data/237455.txt. Accessed 4/6/02.

Mississippi and Missouri Rivers. The site is near the western limit of the Mississippi River flood plain.

The City of St. Louis is located in the Central Lowlands, at the southeast corner of the Dissected Till Plains Subprovince of the Interior Plains Province. The Interior Plains region spreads across the stable core of North America. Precambrian metamorphic and igneous rocks form the basement of the region and make up the stable nucleus of North America. A thick series of sedimentary units overlay the Precambrian rock. The region has generally low relief, reflecting more than 500 million years of relative tectonic stability.[13] The Dissected Till Plains Subprovince west of the Mississippi River is characterized by a maturely eroded plain that preserves only limited remnants of an original glacial plain.[14]

The St. Louis Plant site is located in the Oak-Hickory-Bluestem Parkland section of the Prairie Parkland Province[15] and within the Florissant Basin[16]. The area adjacent to the St. Louis Plant is completely developed, with no pre-settlement vegetation existing. Soil types at the site and surrounding area are generally Urban Land (6A, bottom land and 7B, upland), and Urban Land-Harvester complexes (18A). Urban Land soils are typically more than 85 percent covered with asphalt, concrete, buildings or other impervious materials. The Harvester complex typically consists of silty loam and silty clay loam fill material overlying silty clay.[17]

Geologic features of St. Louis County and Missouri are provided in Figures 3-4[18] and 3-5.[19] McCracken identifies the following tectonic structures in the site area.[20]

- The St. Louis fault runs north-south for a distance of 72 km (45 miles) and is located approximately 1.6 km (one mile) west of the site. It consists of two vertical fault planes with a fault zone width of several hundred feet and a throw of 3 m (10 ft). Sphalerite occurs on or near the fault planes.
- The North St. Louis Syncline runs northwest-southeast for a distance of 3.2 km (two miles) and is located approximately 3.2 km (two miles) northwest of the site.

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[13] USGS, Geologic Provinces of the US, Interior Plains Province, http://wrgis.wr.usgs.gov/docs/usgsnps/province/intplain.html. Accessed 3/2/02

[14] Final Environmental Impact Statement / Section 4(F) Evaluation For the Mississippi River Crossing and Relocated I-70 and I-64 Connector, U.S. Department of Transportation Federal highway Administration and Illinois Department of Transportation and Missouri Department of Transportation, March, 2001

[15] Bailey 1980. Bailey, R.G. *Description of the Ecoregions of the United States*, U.S. Department of Agriculture, Forest Service Miscellaneous Publication No. 1391, 77p. 1980.

[16] Lark, J. 1992. Lark and Associates, personal communications with T. Doerr, SAIC. 1992.

[17] Final Environmental Impact Statement / Section 4(F) Evaluation For the Mississippi River Crossing and Relocated I-70 and I-64 Connector, U.S. Department of Transportation Federal highway Administration and Illinois Department of Transportation and Missouri Department of Transportation, March, 2001

[18] Brill, Geologic Map of St. Louis County, Missouri, 1991

[19] Geologic Map of Missouri (1979), Missouri Department of Natural Resources, 1979.

[20] McCracken, Mary H., Major Structural Features of Missouri, Missouri Department of Natural Resources, 1966.

- The Chentenham Syncline runs northwest-southeast for a distance of 4.8 km (three miles) and is located approximately 8 km (five miles) southwest of the site.
- The Dupo Anticline runs northwest-southeast for a distance of 19 km (twelve miles) and is located approximately 6 km (four miles) southwest of the site.
- The Florissant Dome is located approximately 21 km (thirteen miles) northwest of the site. It is Missouri's most productive oil field. The Laclede Gas Company uses it as a gas storage facility. Gas is stored in St. Peter sandstone while oil is found in the Kimmswick formation. Both are of Mid-Ordovician age.
- The Cap Au Gres Fault runs northwest-southeast for a distance of approximately 56 km (35 miles) and is located approximately 40 km (twenty-five miles) northwest of the site. It is a narrow band of steeply dipping rock and discontinuous faults.

None of these structures occurs at the site. None are tectonically active.[21] Seismic activity in the site area is discussed in section 3.5.2 below.

The residual source material addressed by the Phase II Plan is in an area of imported fill. Material with concentrations greater than the approved release criterion will be removed. Faults, folds, fractures, shear zones, mineralogy, particle size and other geologic features are not significant to the remediation outcome and are not further discussed in this Plan.

Glaciation forming the Till Plains and erosion of the Mississippi River flood plain are the most significant geomorphic processes in the site's recent geologic history. The urban nature of the site and the protection provided by the Mississippi River levy system will minimize the influence of additional flood plain erosion on the site for the foreseeable future.

The Mississippi River flood plain in the vicinity of the site extends westward from the river to approximately 9th Street.[22] The flood plain consists of unconsolidated alluvial sediments extending to bedrock. Site stratigraphy consists of fill underlain by an impermeable alluvial unit, a sandy alluvial unit, and limestone bedrock.[23] Site stratigraphy and hydrostraigraphy are discussed in Appendix A.

Pennsylvanian age deposits west of the site in the downtown and midtown St. Louis area were subject to karst action and subsequent subsidence. These deposits have been removed from the site area by erosion. The presence of karst action in the Mississippian limestone bedrock at the site is unknown.[24]

There are no current or former mines or quarries on the site.

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[21] Glenn R. Osburn, Laboratory Administrator/Geologist, Department of Earth and Planetary Sciences, Washington University in St. Louis, 2/26/02.

[22] Preliminary Hydrogeologic Assessment, St. Louis Plant, CH2M Hill, August 1986.

[23] C-T Phase I Decommissioning Plan, Mallinckrodt Inc., Revised 1/10/02. Page 1-5.

[24] Glenn R. Osburn, Laboratory Administrator/Geologist, Department of Earth and Planetary Sciences, Washington University in St. Louis, Private Conversation, 2/26/02

3.5.2. Seismology

The New Madrid seismic zone, which is the primary region of seismic activity for the mid-continent region, is located approximately 161 km (100 mi.) south of the St. Louis area. The fault zone is characterized by high angle normal faults forming a complex horst and graben system. The strongest recorded earthquakes resulting from this fault zone occurred in December 1811 through February 1812, with three principal earthquakes of estimated magnitude 8.0 or greater.[25] A secondary area of seismic activity is the Ste. Genevieve fault zone, which extends northwest/southeast from southwestern Illinois toward Ste. Genevieve County, Missouri. This fault zone's northern terminus is located within 80 km (50 miles) of the St. Louis area. The last movement along the Ste. Genevieve fault zone in southwestern Illinois was between 2 million and 40 million years ago. [26]

332 earthquakes with magnitude of 3.0 or greater occurred within 320 km (200 miles) of St. Louis in the period 1812-1986. Table 3-4 summarizes their magnitudes. Table 3-5 provides information obtained from the USGS National Earthquake Information Center for these earthquakes.[27]

As the site is in an area of alluvial material, the potential for liquefaction and soil amplification exists.[28]

Movement of the St. Louis fault was determined to be the cause of a magnitude 3.5 earthquake that occurred on Sept. 20, 1978.[29] Table 3-6 provides probabilistic ground motion hazard values predicted by the USGS Earthquake Hazards Program, National Seismic Hazard Mapping Project.[30]

As residual source material with concentrations greater than the approved release criteria will be removed by implementation of this Plan, the seismic and tectonic characteristics of the site are not significant to the remediation outcome and are not further discussed in this Plan.

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[25] Final Environmental Impact Statement / Section 4(F) Evaluation For the Mississippi River Crossing and Relocated I-70 and I-64 Connector, U.S. Department of Transportation Federal highway Administration and Illinois Department of Transportation and Missouri Department of Transportation, March, 2001

[26] John Nelson, Quaternary Faulting In Southernmost Illinois, USGS Award No.: 1434-95-G-2525, Annual Technical Report, Illinois State Geological Survey, 615 E Peabody, Champaign IL 61820, http://erp-web.er.usgs.gov/reports/abstract/1995/cu/g2525ann.htm. Accessed 4/5/02.

[27] NEIC Circular Area Search, Eastern, Central and Mountain States of U.S., 1534 – 1986, http://neic.usgs.gov/neis/epic/epic_circ.html, Accessed 3/26/02.

[28] Earthquake Hazard Map of the St. Louis Metro Area, Missouri Department of Natural Resources Division of Geology and Land Survey, 1995

[29] C.D. Stelzer, On Shaky Ground, Riverfront Times, December 15, 1999

[30] USGS Earthquake Hazards Program, National Seismic Hazard Mapping Project http://eqint.cr.usgs.gov/eq/cgi-bin/zipcode.cgi, Accessed 4/7/02.

3.6. SURFACE WATER HYDROLOGY

The site is located on the western bank of the Mississippi River at River Mile 182.5, 20 km (12.7 miles) downstream from the confluence of the Mississippi and Missouri Rivers. The site is approximately 32 km (20 miles) upstream of the confluence of the Mississippi and Meramec Rivers. The Mississippi, Missouri, and Meramec Rivers, supply 97 percent of the 4.5 billion liters (1.2 billion gallons) per year of drinking and industrial water for the St. Louis area.[31]

Local surface water drainage patterns have been radically altered by urbanization in the St. Louis area. Site wastewater, storm water, and all other surface drainage flow via site sewers and drains to a combined municipal sewer system and then to the Metropolitan St. Louis Sewer District (MSD) Bissell Point Treatment Plant. The Bissell Point Plant is located approximately 1 km (0.7 mi.) north (upstream) of the site. Treated water is discharged to the Mississippi River. During storm periods, the combined sewer system serving the site is diverted directly to the Mississippi River. There is no significant storm water run-on to the property from off-site sources.

The Mississippi River at the St. Louis gauging station has a drainage area of approximately 1.8 x 10^6 km^2 (700,000 sq. miles). The average flow for a 114-year period is 5 x 10^6 m^3/s [177,000 cubic feet per second (cfs), 114390 million gallons per day (MGD)]. The minimum flow recorded in this period is 5 x 10^5 m^3/s (18,000 cfs), and the maximum measure flow is 3 x 10^7 m^3/s (1,019,000 cfs). Lowest flows typically occur during December or January.[32]

The Mississippi River in the St. Louis area is classified as a Class "P" (permanent flow) waterway. It is a significant commercial waterway and navigable from Minneapolis to the Gulf of Mexico. It is protected for the following water uses: irrigation, livestock and wildlife watering, aquatic life, boating, drinking water supply, and industrial uses. The water quality of the Mississippi River in this area is fair to good. It meets all of the water quality standards set by the State of Missouri except for chlordane in fish tissue. For this reason, the State of Missouri has issued a fish advisory.[33]

Although flooding has occurred every month of the year, higher flows are frequently associated with snow melt and heavy rains in spring. A levee and floodwall system constructed in 1964 on city property east of the site protects it from Mississippi River floodwaters. The system is operated by the City of St. Louis and maintained by the U.S. Army Corps of Engineers.[34]

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[31] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-11.

[32] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-11.

[33] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-11.

[34] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-11.

The City of St. Louis operates the metropolitan municipal water system. This system provides all the water required for domestic, industrial, and other uses within the City. The system intake and treatment plant are located upstream of the site and the MSD Bissell Point Plant discharge. The Illinois-American Water Plant is located on the east bank of the Mississippi River approximately 12 km (7.5 mi.) downstream of the site. This plant supplies a small percentage of the water required by the City of East St. Louis[35]. Total consumptive use of Mississippi River water by downstream Missouri and Illinois users during 1990 was approximately 0.5% of the long term average river flow measured at St. Louis.[36] Water resource availability is not an issue of concern.

Mississippi River Lock and Dam No. 26 is located approximately 15 miles upstream of the site. Its operation does not influence the site. As indicated elsewhere in this section, the site is protected from Mississippi River flooding by a levee system. No other water control structures or diversions now influence the site or are anticipated to do so in the future.

3.7. GROUNDWATER HYDROLOGY

Mallinckrodt and the U.S. DOE and USACE under FUSRAP have extensively studied the subsurface hydrogeologic conditions at the facility. This section presents a summary of the groundwater hydrology of the St. Louis Downtown Site. A more complete description, including a discussion of groundwater flow directions and a conceptual hydrogeologic model, is presented Appendix A to this decommissioning plan.

Two hydrostratigraphic units are recognized above bedrock beneath the facility. The first zone, or the Upper Hydrostratigraphic Zone (upper zone), consists of the surficial fill and the underlying unit of low permeability silts and clays. The second, or Lower Hydrostratigraphic Zone (lower zone), is composed dominantly of sands, silty sands, and gravels. The fine-grained alluvial silt and clay at the base of the upper zone acts as a relatively impermeable barrier between the surficial fill in the upper zone and the relatively permeable alluvium in the lower zone.

The surficial fill material is 2 to 6 meters (7 to 18 ft) thick beneath Plant 5 and up to 7.6 meters (25 ft) thick elsewhere beneath the St. Louis Downtown Site. The fill extends slightly beyond Broadway Street west of the site, east to the Mississippi River, and north and south of the site for a significant distance. Perched groundwater occurs within the fill at depths ranging from 1 to 3 meters (6-9 ft) below ground surface. The fine-grained alluvial silt and clay below the fill is 6 to 11 meters (18-37 ft) thick and extends to the west to approximately Broadway Street, east to the Mississippi River, and north and south of the site for a significant distance.

The lower zone is 0 to 2 meters (0 to 7 ft) thick beneath Plant 5 and up to 15 meters (50 ft) thick elsewhere at the site. The unit thickens eastward towards the Mississippi River and extends north and south of the site. The groundwater potentiometric surface in the lower zone occurs at

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[35] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-11.

[36] USGS National Water-Use Data Archive, http://water.usgs.gov/watuse/wudl.wrsr.ascii.html, Accessed 3/5/02

depths of approximately 3 to 10 m (10 to 35 ft) below ground surface. Groundwater in the lower zone is in hydraulic communication with the Mississippi River. Groundwater flow in the lower zone is generally towards the river during low river stage and away from the river during high river stage.

The limestone bedrock surface beneath Plant 5 occurs at depths ranging from 10 to 16.5 m (32-54 ft) and slopes towards the Mississippi River where it is found at a depth of approximately 24 m (80 ft). Bedrock is recharged from up-gradient areas and discharges to the Mississippi River.

3.8. NATURAL RESOURCES

The site is located in an urban industrial area. There are no mineral, fuel, or hydrocarbon resources on or near the site that could reasonably be exploited.

As indicated above, the City of St. Louis municipal water system supplies the region's needs for drinking, industrial, and other uses. Municipal supplies are obtained from the region's ample surface water resource. Groundwater is not used for drinking, industrial, or other uses.

The Mississippi River in the site vicinity is used for both commercial and recreational fishing. Commercial fishing includes buffalo, carp, catfish, drum, sturgeon, and paddlefish. Recreational fish include carp, catfish, drum, paddlefish, sauger, walleye, and white bass.[37] No commercially or recreationally important plant or terrestrial animal species are known to occur in the site area. Federal and state designated endangered, or threatened species that may occur within the area are the pallid sturgeon, bald eagle, and peregrine falcon. The pallid sturgeon is found in both the Mississippi and Missouri rivers. Bald eagles are known to winter in the region. It is doubtful that they use the downtown area because of poor habitat quality (i.e. sparse vegetation, significant noise and human activity).[38] A peregrine falcon pair has recently nested on the McKinley Bridge north of the site. The nest was established and maintained throughout an almost continuous period of site construction and demolition activity.

No wetlands in the site area have been designated by USACE or the U.S. Fish and Wildlife Service.[39]

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[37] Mr. Danny Brown, Fisheries Management Biologist, Missouri Department of Conservation, St. Louis, MO, 4/8/02.

[38] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-14.

[39] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-15.

Table 3-1. Properties Adjacent to the St. Louis Plant

Name and Location	Contact	Phone
West		
Sonic Gas Service 3707 St. Louis, MO 63147 North Broadway		314-621-9814
U.A.W. Union Hall 3607 North Broadway St. Louis. MO 63147	Norma Aimley, Secretary	314-241-8377
Bremen Bank and Trust Co. 3529 North Broadway St. Louis, MO 63147	Neil Brokelman, VP	314-231-5212
Big Ed's Chili Mac's 3523 North Broadway St. Louis, MO 63147	Peggy Massey, Manager	314-342-9562
Worth Industries, Inc. 3501 North Broadway St. Louis, MO 63147	Christine Oswald General Manager	314-231-6600
West of I-70		
Montgomery's Amoco Service 1110 Salisbury St. Louis, MO 63107		314-621-2090
Holy Trinity Church 3519 North 14th Street St. Louis, MO 63107	Fr. Rich Creason	314-241-9165
Clay School 3820 North 14th Street St. Louis, MO 63107	Joyce Hill, Principal	314-231-9608
South		
Tobin Electric and Sign Co. 3321 North Broadway St. Louis, MO 63147	Pearl Pringle, Owner	314-231-1163
Cotto-Waxo Co. 3330 North Broadway St. Louis, MO 63147	David Bussen, Owner	314-436-0300
Gunther Salt, Co. 101 Buchanan St. Louis, MO 63147	Barry Gunther, Owner	314-241-7075
Morton Salt Co. 44 Dock Street St. Louis, MO 63147	Phil Baker, Manager	314-241-1851
Thomas and Proetz Lumber Co. 3400 North Hall St.	Skip Holmes	314-231-9343

St. Louis, MO 63147		
Heintz Steel Co. 3300 North Hall St St. Louis, MO 63147	Bill Holtgrieve, Pres.	314-231-9073
Lange Stegmann Co. #1 Angelica St. Louis, MO 63147	Rich Stegmann, Owner	314-241-9531
Midwest Waste Inc. (vacant)		
PVO Foods, Inc		
North		
McKinley St. Bridge 802 Main Ave. Venice, IL	Tom Fields, Chief Engineer City of Venice, IL	618-452-1386
Phillip Services, Inc. 3620 North Hail Street St. Louis, MO 63147	Erick Schnackel	314-231-6077
Norfolk Southern Railroad 7021 Hall Street St. Louis, MO 63147	Dennis Williams	314-679-1807
East		
City of St. Louis		
Burlington Northern Railroad 3500 Wellington St. Louis, MO 63139		314-768-7034
PVO Foods, Inc. (vacant)		

Table 3-2 St. Louis Climatological Data, Normals, Means, and Extremes[1]

Parameter	**Value**	**Period**	**Parameter**	**Value**	**Period**
Temperature, Normal, °F			**Wind**		
Daily Max	65.6	1941-1970	Prevailing		
Daily Min	46.2	1941-1970	mean speed, mph	9.5	1948-1976
Monthly	55.9	1941-1970	direction	S	1962-1976
			Fastest Mile		
Temperature, Extreme, °F			speed, mph	60	1958-1976
Record Highest	106	1957-1976	direction	SE	1958-1976
Year	Jul-66		year	Jun-64	
Record Lowest	-11	1957-1976			
Year	Jan-63		**Sky Cover**	59	1959-1976
			% of possible days sunshine	6	1948-1976
Precipitation, in.			mean sky cover, tenths (sunrise to sunset)		
Water Equivalent					
Normal	35.89	1941-1970	**Mean number of days**		
Maximum Monthly	9.09	1957-1976	Clear (sunrise to sunset)	105	1948-1976
Year	Apr-70		Partly Cloudy (sunrise to sunset)	101	1948-1976
Minimum Monthly	0.08	1957-1976	Cloudy (sunrise to sunset)	159	1948-1976
Year	Aug-71		Precip. 0.1 in or more	108	1957-1976
Maximum 24 Hour	3.29	1957-1976	Snow, ice pellets 1 in or more	6	1957-1976
Year	Jun-60		Thunderstorms	45	1957-1976
Snow			Heavy Fog, Visibility 1/4 mi.or less	11	1957-1976
Maximum Monthly	26.3	1936-1976	Temperature	37	1960-1976
Year	Dec-73		Max 90 and above	26	1960-1976
Maximum in 24 hours	12	1936-1976	Max 32 and below	107	1960-1976
Year	Dec-73		Min 32 and below	3	1960-1976
			Min 0 and below		
Relative Humidity, %					
00 hour	77	1960-1976	**Average Station pressure, mb**	996.8	1972-1976
06 hour	84	1960-1976			
12 hour	59	1960-1976			
18 hour	61	1960-1976			

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[1] Source: James A. Ruffner, National Oceanic and Atmospheric Administration, Narrative Summaries, tables, and Maps for Each State with Overviews of State Climatologist Programs, Second Edition, Volume 1, Gales Research Co., Detroit, 1980

Table 3-3 Summary of Extreme Weather Events Reported in St. Louis, Missouri Between 01/01/1950 and 11/30/2001[1]

Event	Occurrences	Frequency (per year)
Thunderstorm Wind	52	1.0
Hail	33	0.6
Excessive Heat	29	0.6
Winter Storm	16	0.3
Flash Flood	6	0.1
High Wind	5	0.1
Flood	4	0.1
Heat	3	0.1
Tornado	3	0.1
Ice Storm	2	< 0.1
Ice/Glaze ice	2	< 0.1
Cold	1	< 0.1
Extreme wind chill	1	< 0.1
Heavy Snow	1	< 0.1
Snow	1	< 0.1

Note: The Mississippi River levee protects the Mallinckrodt site from flooding. No streams are nearby to create a flash flood hazard at the site.

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[1] Storm Events for Missouri, National Climate Data Center, http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms, 2/27/02

Table 3-4. Summary Of Earthquakes With Magnitude Of 3.0 and Greater Within 100 Miles of St. Louis, 1812-1989[1]

Magnitude (Richter)		Number
3.0-3.99	Minor	203
4.0-4.99	Light	114
5.0-5.99	Moderate	12
6.0-6.99	Strong	1
7.0-7.99	Major	2
<8.0	Great	0

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[1] NEIC Circular Area Search, Eastern, Central and Mountain States of U.S., 1534 – 1986, http://neic.usgs.gov/neis/epic/epic_circ.html

Table 3-5. U.S. Geological Survey Earthquake Database, Circle Area Search of Earthquakes With Magnitude Of 3.0 and Greater Within 200 Miles of St. Louis, 1812-1989

```
FILE CREATED:  Mon Mar 25 23:15:09 2002
Circle Search   Earthquakes=       331
Circle Center Point Latitude:   38.675N  Longitude:    90.183W
Radius:     320.000 km
Catalog Used: SRA
Magnitude Range:   3.0  -   9.9
Data Selection: Eastern, Central and Mountain States of U.S. (SRA)


CAT   YEAR   MO DA ORIG TIME   LAT    LONG   DEP  MAGNITUDE      IEFM DTSVNWG DIST
                                                                 NFPO          km
                                                                 TFS

SRA   1812   01 23 15         36.30  -89.60       7.10 FASRA     E... .......  268
SRA   1812   02 07 0945       36.50  -89.60       7.30 FASRA     E... .......  246
SRA   1819   09 02 0830       37.70  -89.70       4.20 FASRA     5... .......  116
SRA   1827   07 05 1130       38.00  -87.50       5.00 FASRA     6... .......  246
SRA   1827   08 07 0430       38.00  -88.00       4.80 FASRA     5... .......  204
SRA   1841   12 28 0550       36.60  -89.20       4.60 FASRA     5... .......  245
SRA   1850   04 05 0205       37.00  -88.00       4.90 FASRA     5... .......  267
SRA   1856   11 09            36.60  -89.50       4.40 FASRA     4... .......  237
SRA   1857   10 08 10         38.70  -89.20       5.30 FASRA     7... .......   85
SRA   1860   08 07 1530       37.80  -87.50       4.40 FASRA     5... .......  254
SRA   1865   08 17 15         36.00  -89.50       5.30 FASRA     7... .......  302
SRA   1871   07 25 1840       38.50  -90.00       3.20 FASRA     3... .......   25
SRA   1873   05 03 21         36.00  -89.60       4.20 FASRA     4... .......  301
SRA   1875   10 07            36.00  -89.60       4.30 FASRA     3... .......  301
SRA   1876   09 25 06         38.50  -87.80       4.70 FASRA     6... .......  208
SRA   1876   09 25 0615       38.50  -87.70       4.70 FASRA     7... .......  217
SRA   1877   07 15 0040       37.70  -89.20       4.30 FASRA     4... .......  138
SRA   1878   03 12 10         36.80  -89.10       4.20 FASRA     5... .......  228
SRA   1882   07 28            37.60  -90.60       4.10 FASRA     3... .......  124
SRA   1882   09 27 1020       39.00  -89.50       4.50 FASRA     6... .......   69
SRA   1882   10 15 0550       39.00  -89.50       4.20 FASRA     5... .......   69
SRA   1882   10 15 1035       39.00  -89.50       4.20 FASRA     5... .......   69
SRA   1883   01 11 0712       37.00  -89.20       4.70 FASRA     6... .......  204
SRA   1883   07 14 0730       37.00  -89.10       4.10 FASRA     5... .......  208
SRA   1883   12 05 1520       36.30  -91.20       4.60 FASRA     5... .......  278
SRA   1887   02 06 2215       38.70  -87.50       4.70 FASRA     6... .......  233
SRA   1887   08 02 1836       37.20  -88.50       5.20 FASRA     6... .......  220
SRA   1891   07 27 0228       37.90  -87.50       4.00 FASRA     6... .......  249
SRA   1891   09 27 0455       38.25  -88.50       5.50 FASRA     7... .......  154
SRA   1895   10 31 1108       37.00  -89.40       6.20 FASRA     9... .......  198
SRA   1898   06 14 1526       36.50  -88.50       4.50 FASRA     5... .......  283
SRA   1899   04 30 0205       38.50  -87.40       4.50 FASRA     7... .......  243
SRA   1901   02 15 0015       36.00  -90.00       4.40 FASRA     4... .......  297
SRA   1902   01 24 1048       38.60  -90.30       4.70 FASRA     6... .......   13
SRA   1903   02 09 0021       37.80  -89.30       4.80 FASRA     7... .......  124
SRA   1903   10 05 0256       38.30  -90.20       3.90 FASRA     5... .......   41
SRA   1903   11 04 1818       36.50  -89.50       4.40 FASRA     6... .......  248
SRA   1903   11 04 1914       36.50  -89.80       4.80 FASRA     7... .......  243
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SRA	1903	11	27	07	36.50	-89.50	4.20	FASRA	5...	....	248
SRA	1903	11	27	07	37.00	-89.50	4.00	FASRA	5...	....	195
SRA	1903	11	27	0920	36.50	-89.50	4.20	FASRA	5...	....	248
SRA	1905	04	13	1630	40.40	-91.40	4.00	FASRA	5...	....	218
SRA	1905	08	22	0508	37.20	-89.30	4.80	FASRA	6...	....	181
SRA	1906	05	11	0615	38.50	-87.20	3.80	FASRA	4...	....	260
SRA	1907	01	31	0530	38.90	-89.50	3.60	FASRA	5...	....N..	64
SRA	1907	07	04	0920	37.80	-90.40	3.40	FASRA	4...	....	98
SRA	1908	09	28	1934	36.60	-89.60	4.00	FASRA	4...	....	235
SRA	1908	10	28	0027	37.00	-89.20	4.00	FASRA	5...	....	204
SRA	1908	11	12	12	38.70	-93.20	3.80	FASRA	4...	....N..	262
SRA	1908	12	27	2115	37.50	-88.00	4.10	FASRA	4...	....	231
SRA	1909	07	19	0434	40.20	-90.00	4.50	FASRA	7...	....	169
SRA	1909	08	16	2245	38.30	-90.10	4.30	FASRA	4...	....	42
SRA	1909	09	27	0945	39.80	-87.20	5.40	FASRA	7...	....	286
SRA	1909	10	23	0710	37.00	-89.50	4.60	FASRA	5...	....	195
SRA	1909	10	23	0947	39.00	-87.70	4.20	FASRA	5...	....	218
SRA	1915	02	05	0655	37.70	-88.60	3.40	FASRA	4...	....	175
SRA	1915	02	19	0435	37.10	-89.20	3.40	FASRA	4...	....	194
SRA	1915	04	15	1320	38.70	-88.10	3.80	FASRA	3...	....	181
SRA	1915	04	28	2340	36.50	-89.50	3.20	FASRA	4...	....	248
SRA	1915	12	07	1840	36.00	-90.00	4.60	FASRA	5...	....	297
SRA	1916	01	07	1945	39.10	-87.00	3.80	FASRA	3...	....	280
SRA	1916	05	21	1824	36.60	-89.50	4.10	FASRA	4...	....	237
SRA	1916	08	24	09	37.00	-89.20	3.90	FASRA	4...	....	204
SRA	1917	04	09	2052	38.10	-90.20	5.00	FASRA	7...	....	63
SRA	1917	05	09	09	36.80	-90.40	3.90	FASRA	3...	....	208
SRA	1917	06	09	1314	36.80	-89.40	4.30	FASRA	4...	....	219
SRA	1918	02	17	0810	37.00	-89.20	3.80	FASRA	3...	....	204
SRA	1918	10	13	0930	36.10	-91.00	3.80	FASRA	5...	....	294
SRA	1918	10	16	0215	36.00	-89.20	4.50	FASRA	5...	....	309
SRA	1919	02	11	0337	37.80	-87.50	3.80	FASRA	4...	....	254
SRA	1919	05	23	1230	36.60	-89.20	3.90	FASRA	3...	....	245
SRA	1919	05	24	1330	36.60	-89.20	3.90	FASRA	3...	....	245
SRA	1919	05	25	0945	38.30	-87.50	4.40	FASRA	5...	....	237
SRA	1919	05	26	1325	36.80	-89.20	3.80	FASRA	3...	....	225
SRA	1919	05	28	1130	36.60	-89.20	3.80	FASRA	3...	....	245
SRA	1919	05	28	1345	36.40	-89.50	3.80	FASRA	3...	....	259
SRA	1920	02	29	0302	37.20	-93.30	4.30	FASRA	4...	....	318
SRA	1920	04	07	2045	36.30	-88.20	3.80	FASRA	2...	....N..	316
SRA	1920	04	30	1512	38.60	-89.10	3.90	FASRA	4...	....	94
SRA	1920	05	01	1515	38.50	-89.50	4.30	FASRA	5...	....	62
SRA	1921	01	09	2154	36.40	-89.50	3.80	FASRA	4...	....	259
SRA	1921	02	27	2216	37.00	-89.20	3.80	FASRA	3...	....	204
SRA	1921	03	14	1215	39.50	-87.50	4.50	FASRA	6...	....	249
SRA	1921	09	09	03	38.30	-90.10	3.90	FASRA	4...	....	42
SRA	1921	10	01	09	37.70	-88.60	3.90	FASRA	4...	....	175
SRA	1921	10	09	0750	38.30	-90.10	3.80	FASRA	3...	....	42
SRA	1922	01	11	0342	37.90	-87.80	4.20	FASRA	5...	....	225
SRA	1922	03	22	222930	37.40	-89.40	4.20	FASRA	7...	....	157
SRA	1922	03	23	0220	37.40	-89.40	4.50	FASRA	6...	....	157
SRA	1922	03	23	2145	37.00	-88.90	4.30	FASRA	5...	....	217
SRA	1922	03	28	1642	36.70	-90.40	4.10	FASRA	3...	....	219
SRA	1922	03	30	1653	36.10	-89.60	4.20	FASRA	5...	....	290
SRA	1922	11	27	0331	37.80	-88.50	4.50	FASRA	7...	....	176
SRA	1923	03	09	0245	38.90	-89.40	3.90	FASRA	3...	....	72
SRA	1923	05	06	0750	37.00	-89.20	3.90	FASRA	3...	....	204

SRA	1923	05	15	2342	37.00	-89.20		3.80	FASRA	3...	....	204
SRA	1924	01	01	0305	36.00	-90.00		4.50	FASRA	6...	....	297
SRA	1924	04	02	1115	37.00	-88.80		4.00	FASRA	5...	....	222
SRA	1924	06	07	0542	36.50	-89.80		3.90	FASRA	4...	....	243
SRA	1925	01	27	2242	36.20	-91.70		3.80	FASRA	3...	....	305
SRA	1925	04	27	0405	38.20	-87.80		4.80	FASRA	6...	....	214
SRA	1925	05	13	11	36.70	-88.60		3.80	FASRA	5...	....	259
SRA	1925	09	02	1156	37.90	-87.20		4.70	FASRA	6...	....	274
SRA	1925	09	20	09	37.80	-87.60		4.10	FASRA	4...	....	246
SRA	1926	03	22	1430	37.80	-88.60		3.90	FASRA	4...	....	169
SRA	1926	04	28	0216	36.20	-89.00		3.90	FASRA	4...	....	293
SRA	1926	10	27	1622	36.70	-90.40		3.90	FASRA	4...	....	219
SRA	1926	10	27	1627	36.70	-90.40		3.90	FASRA	4...	....	219
SRA	1926	12	13	2303	36.70	-89.80		3.80	FASRA	4...	....	221
SRA	1926	12	17		36.40	-89.50		3.90	FASRA	4...	....	259
SRA	1927	02	02	0130	37.40	-89.70		3.90	FASRA	4...	....	147
SRA	1927	02	03	08	36.70	-90.40		3.80	FASRA	4...	....	219
SRA	1927	04	18	1030	36.30	-89.50		3.90	FASRA	4...	....	270
SRA	1927	04	18	1230	36.30	-89.50		3.90	FASRA	3...	....	270
SRA	1927	08	13	1610	36.40	-89.50		4.40	FASRA	5...	....	259
SRA	1928	03	17	2115	38.60	-90.20		3.30	FASRA	2...	....	8
SRA	1929	02	14	2012	38.30	-87.60		3.60	FASRA	4...	....	229
SRA	1929	05	13	0350	36.40	-89.50		3.70	FASRA	3...	....	259
SRA	1930	08	29	062611	37.00	-89.10		3.90	FASRA	4...	....	208
SRA	1930	09	01	202637	36.60	-89.40		3.90	FASRA	5...	....	240
SRA	1930	12	23	1444	38.50	-90.70		3.60	FASRA	4...	....	49
SRA	1931	01	06	0251	39.00	-87.00		3.50	FASRA	5...	....	278
SRA	1931	04	01	232009	36.90	-88.30		3.80	FASRA	3...	....	257
SRA	1931	04	06	153703	36.90	-89.00		3.50	FASRA	4...	....	222
SRA	1931	07	18	1452	36.60	-89.50		3.80	FASRA	4...	....	237
SRA	1931	12	10	081136	35.90	-89.80		3.80	FASRA	4...	....	309
SRA	1932	11	22	075642	36.00	-90.20		3.60	FASRA	3...	....	296
SRA	1933	08	04	043415	37.90	-89.90		3.50	FASRA	4...	....	89
SRA	1933	11	16	092901	38.60	-90.60		3.70	FASRA	4...	....	37
SRA	1934	08	20	004727	37.00	-89.20		4.30	FASRA	7...	....	204
SRA	1934	10	30	022547	37.50	-88.50		3.70	FASRA	4...	....	196
SRA	1934	11	12	1445	41.50	-90.50		4.00	FASRA	6...	....	314
SRA	1935	01	05	1840	41.50	-90.60		3.40	FASRA	4...	....	315
SRA	1936	08	02	2215	36.70	-89.00		4.10	FASRA	3...	....	242
SRA	1937	01	30	085709	36.20	-89.70		3.70	FASRA	4...	....	277
SRA	1937	05	17	004946	36.10	-90.60		4.30	FASRA	4...	....	287
SRA	1937	11	17	170447.70	38.60	-89.10		4.20	FASRA	5...	....	94
SRA	1939	04	15	1730	36.80	-89.40		3.40	FASRA	3...	....	219
SRA	1939	11	23	151452	38.18	-90.14	0	4.90	FASRA	5...	....	55
SRA	1940	05	31	190304	37.10	-88.60		3.60	FASRA	5...	....	223
SRA	1940	12	29	0230	37.90	-87.30		3.60	FASRA	3...	....	266
SRA	1941	10	08	0751	36.20	-89.70		3.70	FASRA	5...	....	277
SRA	1941	10	21	1653	37.00	-89.10		3.70	FASRA	4...	....	208
SRA	1942	01	14	180506.40	38.60	-90.20		3.60	FASRA	3...	....	8
SRA	1942	03	01	144306	41.20	-89.70		4.00	FASRA	4...	....	283
SRA	1942	03	29	124306	37.70	-88.60		3.20	FASRA	4...	....	175
SRA	1942	11	17	1818	38.60	-90.20		3.20	FASRA	4...	....	8
SRA	1944	01	07	051815	37.50	-89.70		3.60	FASRA	4...	....	137
SRA	1944	09	25	113723	37.90	-90.10		4.40	FASRA	4...	....	86
SRA	1945	01	16	02	37.80	-90.20		3.60	FASRA	4...	....	97
SRA	1945	03	28	014558	38.60	-90.20		3.90	FASRA	3...	....	8
SRA	1945	05	02	102212.60	36.40	-89.70		3.70	FASRA	4...	....	255

SRA	1945	11	13	0821	37.00	-89.20		4.10	FASRA	4...	....	204
SRA	1946	02	25	0052	38.60	-89.10		3.60	FASRA	4...	....	94
SRA	1946	05	15	061001	36.60	-90.80		4.20	FASRA	4...	....	236
SRA	1946	10	08	011202.50	37.50	-90.60		4.40	FASRA	5...	....	135
SRA	1947	06	30	042353	38.40	-90.20		4.20	FASRA	6...	....	30
SRA	1947	12	01	084733	36.70	-90.60		4.20	FASRA	4...	....	222
SRA	1948	01	06	0134	38.60	-89.10		3.30	FASRA	4...	....	94
SRA	1949	01	14	034519.60	36.40	-89.70		3.60	FASRA	5...	....	255
SRA	1949	06	08	195136	38.10	-90.30		3.30	FASRA	3...	....	64
SRA	1950	02	08	103706.70	37.70	-92.70		4.20	FASRA	5...	....	245
SRA	1951	09	20	023843	38.70	-89.90		3.60	FASRA	4...	....	24
SRA	1952	02	20	223439	36.40	-89.50		4.20	FASRA	5...	....	259
SRA	1952	05	28	095414	36.60	-89.70		3.60	FASRA	4...	....	234
SRA	1952	10	17	041618	36.00	-89.40		3.40	FASRA	4...	....	304
SRA	1952	12	25	042324	35.90	-89.80		4.10	FASRA	4...	....	309
SRA	1953	02	11	105054	36.50	-89.50		3.60	FASRA	4...	....	248
SRA	1953	09	11	182628	38.80	-90.10		4.10	FASRA	6...	....	15
SRA	1953	12	30	22	38.60	-89.10		3.60	FASRA	4...	....	94
SRA	1954	01	17	0715	36.00	-89.40		3.50	FASRA	4...	....	304
SRA	1954	02	02	1653	36.70	-90.30		4.40	FASRA	5...	....	219
SRA	1955	01	25	072439.10	36.07	-89.83	8	4.50	FASRA	6...	....	290
SRA	1955	03	29	090240	36.00	-89.50		4.00	FASRA	6...	....	302
SRA	1955	04	09	130123.30	38.23	-89.79	11	4.30	FASRA	6...	....	60
SRA	1956	03	13	1505	40.50	-90.40		3.70	FASRA	4...	....	203
SRA	1956	11	26	041243.30	36.91	-90.39	1	4.40	FASRA	6...	....	196
SRA	1957	03	26	082706	37.10	-88.60		3.30	FASRA	5...	....	223
SRA	1958	01	26	165537	36.10	-89.70		4.10	FASRA	5...	....	288
SRA	1958	01	28	055640	37.10	-89.20		4.20	FASRA	5...	....	194
SRA	1958	04	08	222533	36.30	-89.20		3.60	FASRA	5...	....	277
SRA	1958	04	26	0730	36.40	-89.50		3.60	FASRA	5...	....	259
SRA	1958	11	08	024112.60	38.44	-88.01	5	4.40	FASRA	6...	....	191
SRA	1959	02	13	0837	36.20	-89.50		3.30	FASRA	5...	....	281
SRA	1959	12	21	162339.60	36.03	-89.34	5	3.40	FASRA	5...	....	302
SRA	1962	02	02	064330	36.37	-89.51	4	4.30	MnSLM	6..G	....	262
SRA	1962	03	25		36.50	-89.50		3.20	MnSRA	....	....	248
SRA	1962	05	24		36.50	-89.50		3.00	MnSRA	....	....	248
SRA	1962	06	27	012859.30	37.90	-88.64	7	3.90	MnSRA	5...	....	160
SRA	1962	07	14	022344	36.56	-89.82	1	3.20	MnSRA	3...	....	236
SRA	1962	07	14	042349	36.50	-89.90		3.20	MnSLM	...G	....	242
SRA	1962	07	23	060515.70	36.04	-89.40	8	3.60	MnBAR	6..G	....	299
SRA	1963	03	03	173010.60	36.64	-90.05	9	4.80	MnDG	6..G	....	225
SRA	1963	03	31	133104	36.90	-89.00		3.00	MnSLM	...G	....	222
SRA	1963	04	06	081222.70	36.46	-89.58	6	3.10	MnSLM	...G	....	251
SRA	1963	04	19	143155	36.70	-90.10	0	3.50	MnSRA	....	....	219
SRA	1963	05	02	010921.40	36.67	-89.54	10	3.10	MnSRA	....	....	229
SRA	1963	07	08	235142.10	36.97	-90.47	0	4.10	mb GS	....	....	190
SRA	1963	08	03	003749.10	36.98	-88.77	7	3.80	MnDG	5..G	....	225
SRA	1964	01	16	050957.60	36.84	-89.46	6	4.50	mb GS	...G	....	212
SRA	1964	01	25	195410	36.50	-89.50		3.00	MnSRA	....	....	248
SRA	1964	03	17	021606	36.20	-89.60		3.50	MnSLM	4..G	....	279
SRA	1964	05	23	112534.50	36.58	-90.02	3	4.50	mb GS	5..G	....	232
SRA	1964	05	23	150034.90	36.60	-90.01	8	4.30	mb GS	3..G	....	230
SRA	1964	09	24	080934	37.10	-91.10	0	3.10	MnSRA	....	....	192
SRA	1965	02	11	034024.80	36.52	-89.59	3	3.30	MnDG	3..G	....	244
SRA	1965	03	06	210850.30	37.40	-91.03	7	4.00	MnDG	3..G	....	160
SRA	1965	03	25	125927.70	36.46	-89.52	3	3.90	MnDG	3..G	....	252
SRA	1965	03	26		36.50	-89.50		3.10	MnSRA	....	....	248

SRA	1965	05	25	071543	36.50	-89.50		3.30	MnSRA	....	....	248
SRA	1965	06	01	072457	36.50	-89.50		3.30	MnSRA	....	....	248
SRA	1965	07	08	070350	36.50	-89.50		3.30	MnSRA	....	....	248
SRA	1965	08	14	054618.40	37.21	-89.29	1	3.00	MnDG	4..G	....	180
SRA	1965	08	14	131356.90	37.23	-89.31	1	5.00	mb GS	7..G	....	178
SRA	1965	08	15	041901	37.20	-89.30		3.50	MnSLM	5..G	....	181
SRA	1965	08	15	060729	37.22	-89.30	2	3.10	MnDG	5..G	....	179
SRA	1965	10	21	020439.10	37.48	-90.94	7	5.10	mb GS	6..G	....	148
SRA	1965	10	21	040649.20	37.45	-90.94	1	3.90	mb GS	....	....	151
SRA	1965	11	03	123322	37.10	-91.10	0	3.00	MnSRA	....	....	192
SRA	1965	11	04	074337.90	37.03	-90.93	4	4.50	mb GS	...G	....	193
SRA	1965	12	09	220451	37.40	-91.10		3.50	MnSRA	....	....	162
SRA	1965	12	19	221912	36.03	-89.76	1	5.30	mb GS	....	....	295
SRA	1966	02	12	043212.80	35.96	-89.87	1	4.30	mb GS	4..G	....	302
SRA	1966	02	13	231937.80	37.04	-90.90	6	4.70	mb GS	...G	....	191
SRA	1966	02	26	081017.70	37.05	-90.88	1	4.20	mb GS	...G	....	190
SRA	1966	03	13	142442	36.50	-89.50		3.10	MnSRA	....	....	248
SRA	1966	06	22	112753	38.60	-88.20	0	3.22	MnSRA	....	....	172
SRA	1967	02	12		36.00	-90.00		3.10	MnSRA	....	....	297
SRA	1967	07	06	164351	35.80	-90.40		3.40	MnSRA	....	....	319
SRA	1967	07	21	091448.80	37.44	-90.44	12	4.30	MnSTT	6..G	....	138
SRA	1967	08	25	191518	37.10	-91.10	0	3.30	MnSRA	....	....	192
SRA	1967	10	18	050836	36.50	-89.50		3.10	MnSRA	....	....	248
SRA	1968	01	23	1616	36.50	-89.50		3.30	MnSRA	....	....	248
SRA	1968	02	10	013430.60	36.52	-89.86	7	3.80	mb GS	3..G	....	241
SRA	1968	03	31	175809.60	38.02	-89.85	1	4.50	mb GS	....	....	78
SRA	1968	05	29	015933	36.50	-89.50		3.20	MnSRA	....	....	248
SRA	1968	07	14	042125	36.50	-89.50		3.10	MnSRA	....	....	248
SRA	1968	11	09		38.00	-88.50		3.80	MnSRA	....	....	165
SRA	1968	11	09	170140.50	37.91	-88.37	21	5.50	MnSLM	7..G	....	179
SRA	1968	11	09	170817	38.00	-88.50	0	3.80	MnSRA	4...	....	165
SRA	1968	11	09	1845	38.00	-88.50		3.00	MnSRA	....	....	165
SRA	1968	11	11	110420	38.00	-88.50		3.00	mbSRA	....	....	165
SRA	1969	01	20	1925	37.70	-90.50	0	3.20	MnSRA	3...	....	111
SRA	1969	02	28	131013.10	37.90	-88.90		3.20	MnSLM	...G	....	141
SRA	1969	07	27		36.50	-89.50		3.10	MnSRA	....	....	248
SRA	1970	02	06	0422	37.90	-90.60	0	3.00	MnSRA	2...	....	93
SRA	1970	02	06	0428	37.90	-90.60	0	3.20	MnSRA	2...	....	93
SRA	1970	02	06	045302	37.90	-90.60	0	3.40	MnSRA	2...	....	93
SRA	1970	03	27	034429.20	36.60	-89.54	5	3.00	MnDG	3..G	....	237
SRA	1970	11	05	102535	36.00	-90.00		3.00	MnSRA	....	....	297
SRA	1970	11	17	021354.10	35.86	-89.95	14	4.30	MnDG	6..G	....	313
SRA	1970	12	08	2316	38.00	-89.00		3.00	MnSRA	.F..	....	127
SRA	1970	12	24	101756.80	36.71	-89.54	15	4.80	mb GS	4...	....	225
SRA	1971	02	12	124427.50	38.50	-87.85	15	3.10	MnDG	4..G	....	204
SRA	1971	10	18	063931	36.70	-89.60		3.00	MnSLM	...G	....	225
SRA	1972	02	01	054209.50	36.37	-90.85	3	4.10	mb GS	5..G	....	262
SRA	1972	03	29	203831.70	36.12	-89.74	7	3.70	MnBAR	5..G	....	286
SRA	1972	05	07	021208.70	35.93	-89.97	1	3.40	MnSLM	4..G	....	305
SRA	1972	06	09	191518.90	37.62	-90.37	12	3.10	MnSRA	3...	....	118
SRA	1972	06	19	054615.10	36.93	-89.10	6	4.50	mb GS	4..G	....	216
SRA	1972	06	19	161518.80	37.00	-89.08	13	4.50	mb GS	4...	....	209
SRA	1973	01	07	225606.20	37.40	-87.22	14	3.20	MnSLM	...G	....	295
SRA	1973	01	12	115656.20	37.89	-90.48	17	3.20	MnSLM	4..G	....	90
SRA	1973	10	03	035019.80	35.87	-90.04	6	3.40	MnSLM	4..G	....	311
SRA	1973	10	09	201526.50	36.49	-89.62	3	3.80	MnDG	4..G	....	247
SRA	1973	12	20	104500.90	36.14	-89.69	10	3.10	MnSRA	3...	....	284

SRA	1974	01	08	011238.10	36.18	-89.47	7	4.10	mb GS	5..G	....	284
SRA	1974	04	03	230502.80	38.55	-88.07	14	4.70	MnDG	6..G	....	184
SRA	1974	05	13	065218.70	36.74	-89.36	4	4.30	mb GS	6...	....	226
SRA	1974	06	05	080610.70	38.65	-89.91	12	4.00	mb GS	5...	....	24
SRA	1974	06	05	080711	36.80	-89.90		3.60	MnSTT	...G	....	209
SRA	1974	08	11	142945.40	36.93	-91.16	6	3.20	MnSRA	5...	....	212
SRA	1975	01	10	153101.50	38.11	-91.03	0	3.20	MnSRA	....	....N..	96
SRA	1975	02	13	194358	36.55	-89.59	3	3.40	MnSRA	5...	....	241
SRA	1975	06	13	224027.50	36.54	-89.68	9	4.30	mb GS	6..G	....	240
SRA	1976	04	08	073853	39.35	-86.68	20	3.00	MnSRA	5...	....	312
SRA	1976	04	15	070334.40	37.38	-87.31	4	3.30	MnSRA	5...	....	290
SRA	1976	05	22	074046.10	36.03	-89.83	9	3.20	MnSRA	5...	....	294
SRA	1976	12	11	070501.10	38.10	-91.04	0	4.20	mb GS	....	....N..	98
SRA	1976	12	13	083555.10	37.81	-90.26	9	3.50	MnSRA	5...	....	96
SRA	1977	01	03	225648.50	37.58	-89.71	5	5.00	mb GS	6...	....	127
SRA	1978	04	03	122421.50	36.63	-90.00	9	3.10	MnSRA	....	....	227
SRA	1978	06	02	020728.90	38.41	-88.46	20	3.20	MnSRA	4...	....	152
SRA	1978	08	31	003100.60	36.09	-89.44	1	3.50	MnSRA	5...	....	293
SRA	1978	09	20	122408.90	38.58	-90.28	1	3.10	MnSRA	5...	....	13
SRA	1978	12	05	014801.60	38.56	-88.37	23	3.50	MnSRA	5...	....	158
SRA	1979	02	05	053109.40	35.84	-90.10	10	3.20	MnSRA	4...	....	314
SRA	1979	02	27	225454.80	35.96	-91.20	10	3.40	MnSRA	5...	....	314
SRA	1979	06	11	041217.10	36.15	-89.64	15	3.80	MnSRA	4...	....	283
SRA	1979	07	08	123515.50	36.91	-89.31	2	3.10	MnSRA	4...	....	210
SRA	1979	11	05	163525.90	36.46	-91.04	6	3.20	MnSRA	4...	....	257
SRA	1980	03	13	022313.40	37.90	-88.44	20	3.30	MnSRA	4...	....	175
SRA	1980	07	05	085440.10	36.56	-89.60	4	3.50	MnSRA	4...	....	240
SRA	1980	07	12	235956.30	37.29	-86.99	0	3.10	MnSRA	3...	....N..	319
SRA	1980	12	02	085929.70	36.17	-89.43	5	3.80	MnSRA	6...	....	285
SRA	1981	04	08	015313	38.87	-89.38	1	3.50	MnSRA	.F..	....	73
SRA	1981	05	25	225018.20	36.76	-91.63	1	3.00	MnSRA	3...	....	247
SRA	1981	06	09	141547.70	37.82	-89.02	20	3.40	MnSRA	5...	....	139
SRA	1981	06	26	083327	35.85	-90.07	9	3.60	MnSRA	5...	....	313
SRA	1981	08	07	115341.80	35.95	-89.12	10	4.00	MnSRA	6...	....	316
SRA	1981	11	08	171119	36.10	-89.39	12	3.00	MnSRA	4...	....	294
SRA	1982	02	02	092646.20	35.91	-90.05	12	3.50	MnSRA	4...	....	306
SRA	1982	08	11	103238.80	37.25	-88.73	5	3.00	MnSRA	3...	....	203
SRA	1983	02	23	085127	36.19	-89.60	1	3.70	MnSRA	4...	....	280
SRA	1983	05	15	051621.60	38.77	-89.57	9	4.30	MnSRA	5...	....	54
SRA	1983	05	16	140303.80	38.48	-92.36	5	3.00	MnSRA	....	....	190
SRA	1983	07	08	094140.20	37.10	-90.94	10	3.00	MnSRA	....	....	186
SRA	1983	07	10	025425.40	37.11	-90.93	6	3.00	MnSRA	....	....	185
SRA	1984	01	12	024815.70	37.59	-89.75	2	3.00	MnSRA	3...	....	126
SRA	1984	01	28	212922.10	36.61	-89.92	1	3.20	MnSRA	4...	....	230
SRA	1984	02	13	224245.30	37.21	-89.02	5	3.20	MnSRA	4...	....	191
SRA	1984	02	14	225610.40	37.21	-89.00	2	3.60	MnSRA	4...	....	192
SRA	1984	02	25	210157.20	37.22	-89.01	5	3.00	MnSRA	....	....	191
SRA	1984	04	17	044444.90	38.41	-88.48	14	3.20	MnSRA	4...	....	151
SRA	1984	06	12	182648.20	38.92	-87.46	3	3.40	MnSRA	4...	....	237
SRA	1984	06	26	151519.90	36.10	-89.39	12	3.20	MnSRA	3...	....	293
SRA	1984	06	29	075829.30	37.70	-88.47	2	4.10	MnSRA	6...	....	184
SRA	1984	07	16	035053.50	36.50	-89.53	7	3.00	MnSRA	....	....	248
SRA	1984	07	28	233927.40	39.22	-87.07	10	4.00	MnSRA	5...	....	276
SRA	1984	07	30	073346.50	37.83	-90.92	7	3.00	MnSRA	.F..	....	113
SRA	1984	08	29	065059.50	39.11	-87.45	10	3.10	MnSRA	5...	....	241
SRA	1984	12	03	115544.50	36.15	-89.70	12	3.00	MnSRA	4...	....	283
SRA	1985	01	30	093512.40	35.93	-89.91	9	3.00	MnSRA	....	....	305

SRA	1985	02	13	102224	38.42	-87.50	3	3.00	MnSRA	....	....	235
SRA	1985	02	15	155610	37.23	-89.33	5	3.30	MnSRA	4...	....	176
SRA	1985	05	04	070712.50	36.27	-90.77	9	3.10	MnSRA	3...	....	271
SRA	1985	12	05	225941:20	35.88	-89.99	5	3.90	MnSRA	5...	....	310
SRA	1985	12	29	085656.30	38.55	-88.96	5	3.50	MnSRA	5...	....	106
SRA	1986	05	24	124813.50	36.58	-89.88	10	3.40	MnSRA	4...	....	233
SRA	1986	08	26	164124.80	38.32	-89.79	5	3.70	MnSRA	5...	....	52
SRA	1986	12	30	071519.10	36.42	-89.58	14	3.50	MnSRA	4...	....	255

Table 3-6. Probabilistic Ground Motion Hazard Values

The input zip-code is 63147.

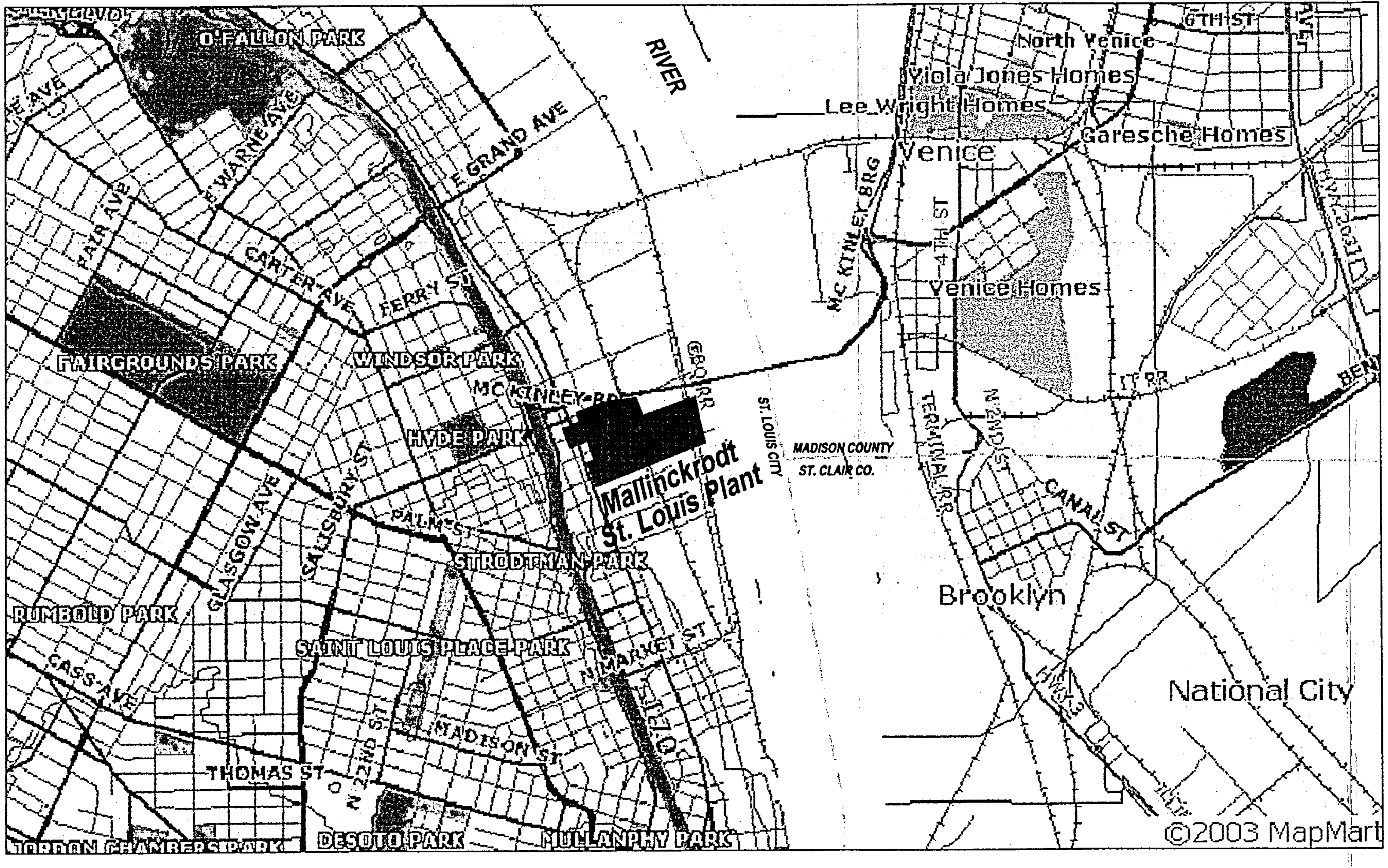
ZIP CODE	63147
LOCATION	38.6965 Lat. -90.2208 Long.
DISTANCE TO NEAREST GRID POINT	1.9 km

NEAREST GRID POINT 38.7 Lat. -90.2 Long.

Probabilistic ground motion values, in %g, at the Nearest Grid Point

	10%PE in 50 yr	5%PE in 50 yr	2%PE in 50 yr
PGA	9.4	15.7	27.9
0.2 sec SA	19.4	32.5	56.8
0.3 sec SA	15.6	25.4	42.7
1.0 sec SA	5.4	9.3	18.0

USGS Earthquake Hazards Program, National Seismic Hazard Mapping Project http://eqint.cr.usgs.gov/eq/cgi-bin/zipcode.cgi



0	03/20/03	R.R.	INITIAL ISSUE
NO.	DATE	ENGR.	DESCRIPTION

DRAWING REVISIONS

JOB NO.
PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

ST. LOUIS PLANT
SITE LOCATION MAP
FIGURE 3-1

SITE STL PLANT ALL BLDG. ALL FLOOR N/A
SCALE NONE
DATE 03/20/03
DR. BY: J. MCMAHON
ENGR. R.ROWE
CHECKED
DRAWING NO. FIGURE 3-1
REV. 0

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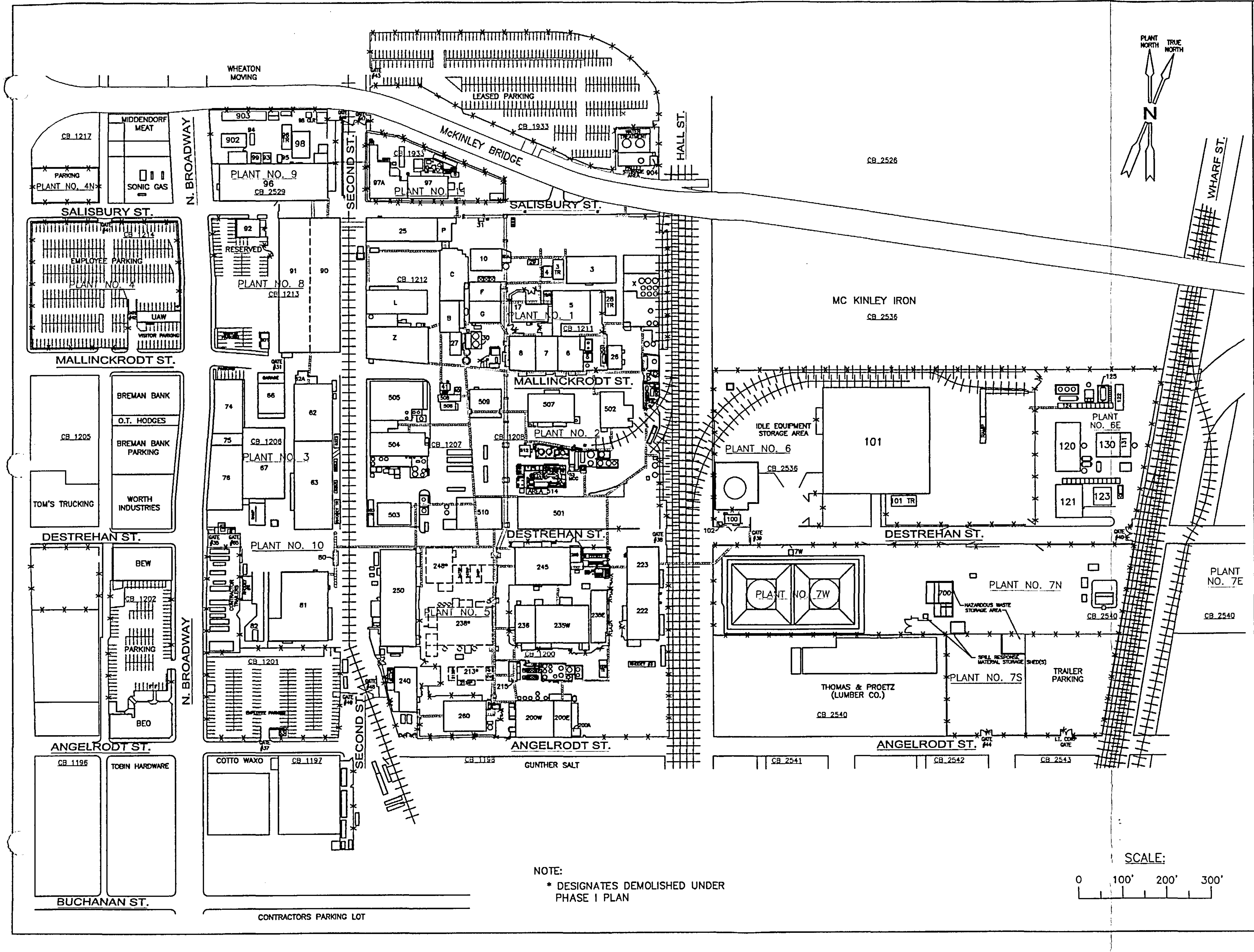
T_BLK25.DWG

S:\CorpEng\DOCS\CT PHASE II\CT PHASE II figure 3-2 REV 1.dwg 03/31/03 12:51 REVISED BY S. SABO FOR R.ROWE REV NO. 1



NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

1	03/31/03		GENERAL BACKGROUND UPDATING
0	03/18/03		INITIAL ISSUE
NO.	DATE	ENGR.	DESCRIPTION

DRAWING REVISIONS

JOB NO. PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

ST. LOUIS PLANT
SITE MAP
FIGURE 3-2

SITE STL PLANT ALL BLDG. ALL FLOOR N/A
SCALE 1"=100' DATE 11/28/00
DR. BY: J. MCMAHON ENGR.
CHECKED
DRAWING NO. FIGURE 3-2 REV. 1

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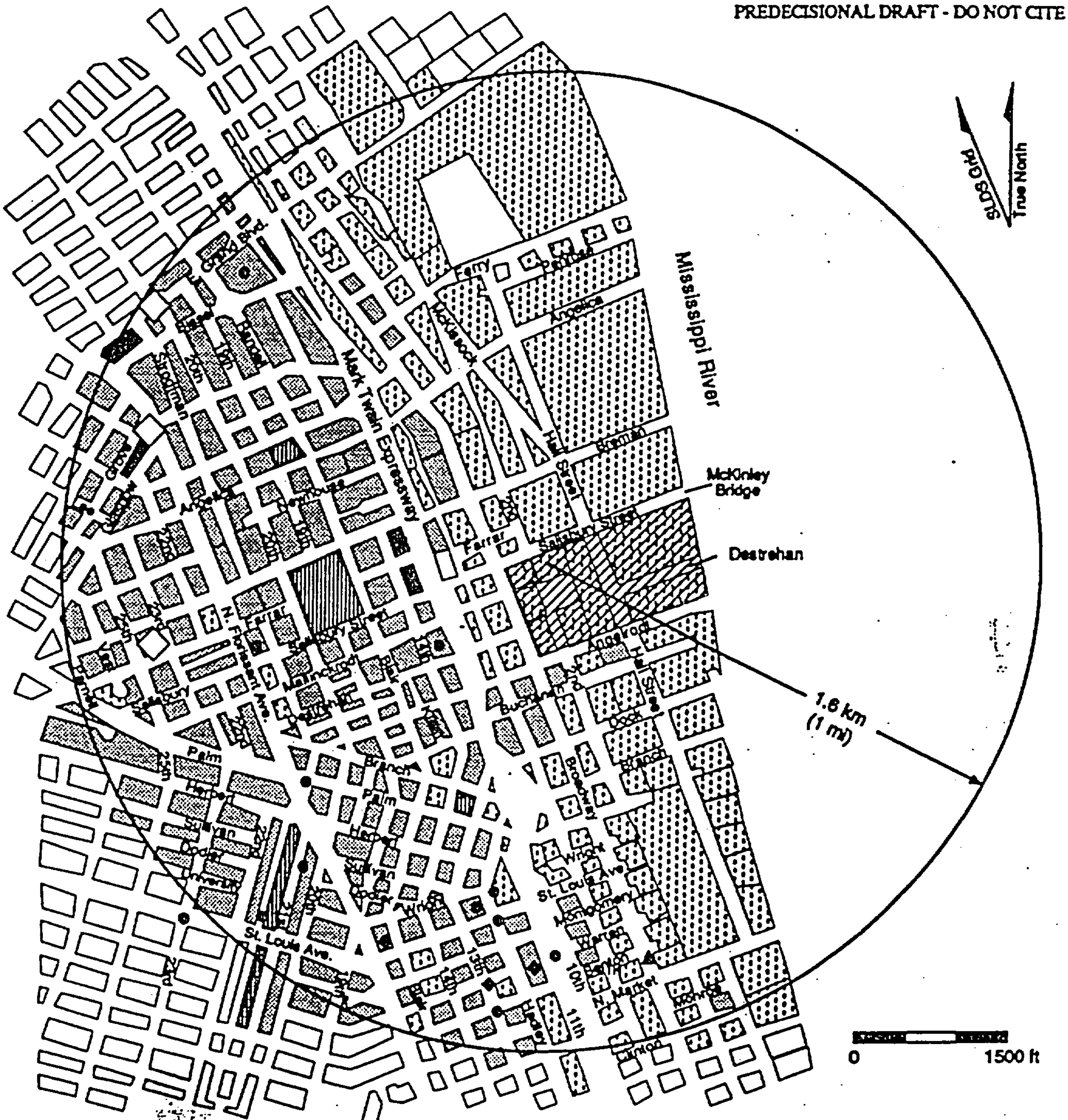
T_BLK25.DWG



KEY

▒	Residential Blocks	▨	SLDS and Vicinity Properties
⁙	Commercial and Industrial	●	Association (Church, Mission, community center)
▥	Parks and Recreation	◆	Education
▩	Educational Facilities	▲	Medical

Figure 3-3. Land Use Within a 1.6-km (1-mi) Radius of SLDS
(St. Louis Community Development Agency 1992)

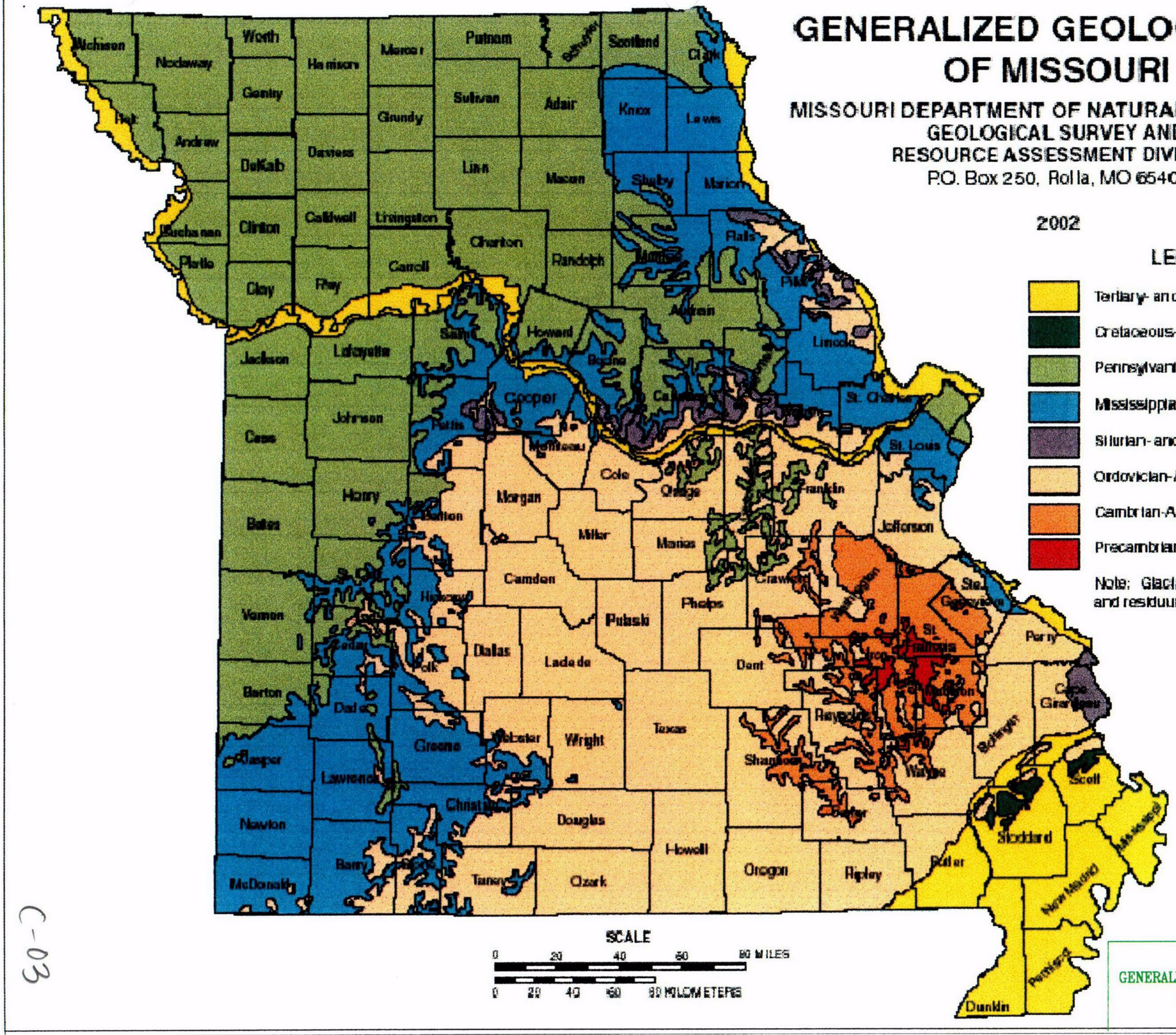
THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:

FIGURE 3-4
"GEOLOGIC MAP OF ST. LOUIS CITY AND COUNTY, MISSOURI"

WITHIN THIS PACKAGE

NOTE: Because of this page's large file size, it may be more convenient to copy thefile to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.



GENERALIZED GEOLOGIC MAP OF MISSOURI

MISSOURI DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY AND RESOURCE ASSESSMENT DIVISION

P.O. Box 250, Rolla, MO 65402

2002

LEGEND

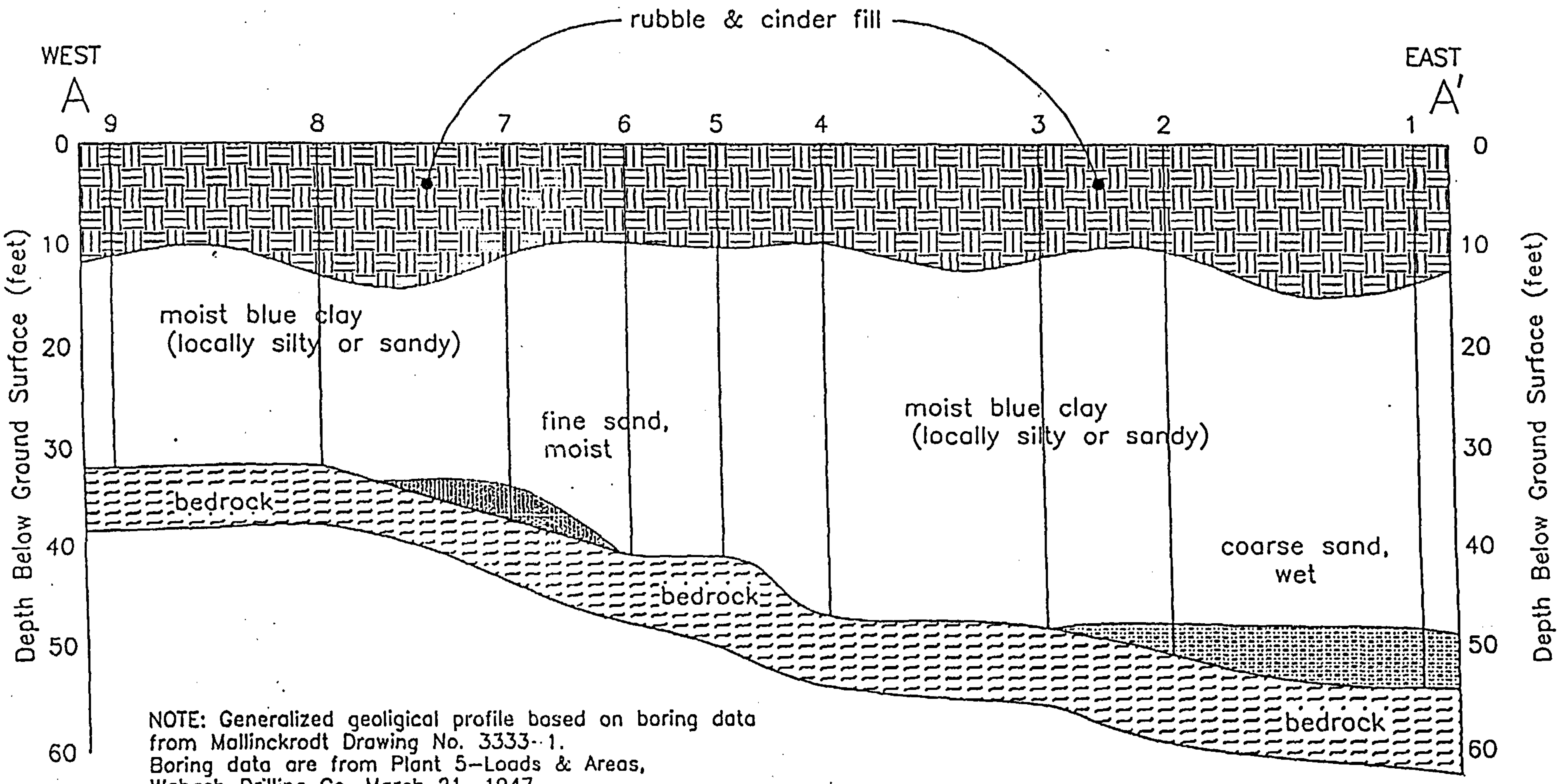
- 🟨 Tertiary- and Quaternary-Age Materials
- ⬛ Cretaceous-Age Bedrock
- 🟩 Pennsylvanian-Age Bedrock
- 🟦 Mississippian-Age Bedrock
- 🟪 Silurian- and Devonian-Age Bedrock
- ▨ Ordovician-Age Bedrock
- 🟧 Cambrian-Age Bedrock
- 🟥 Precambrian-Age Bedrock

Note: Glacial drift, loess and residuum not shown.

N

C-03

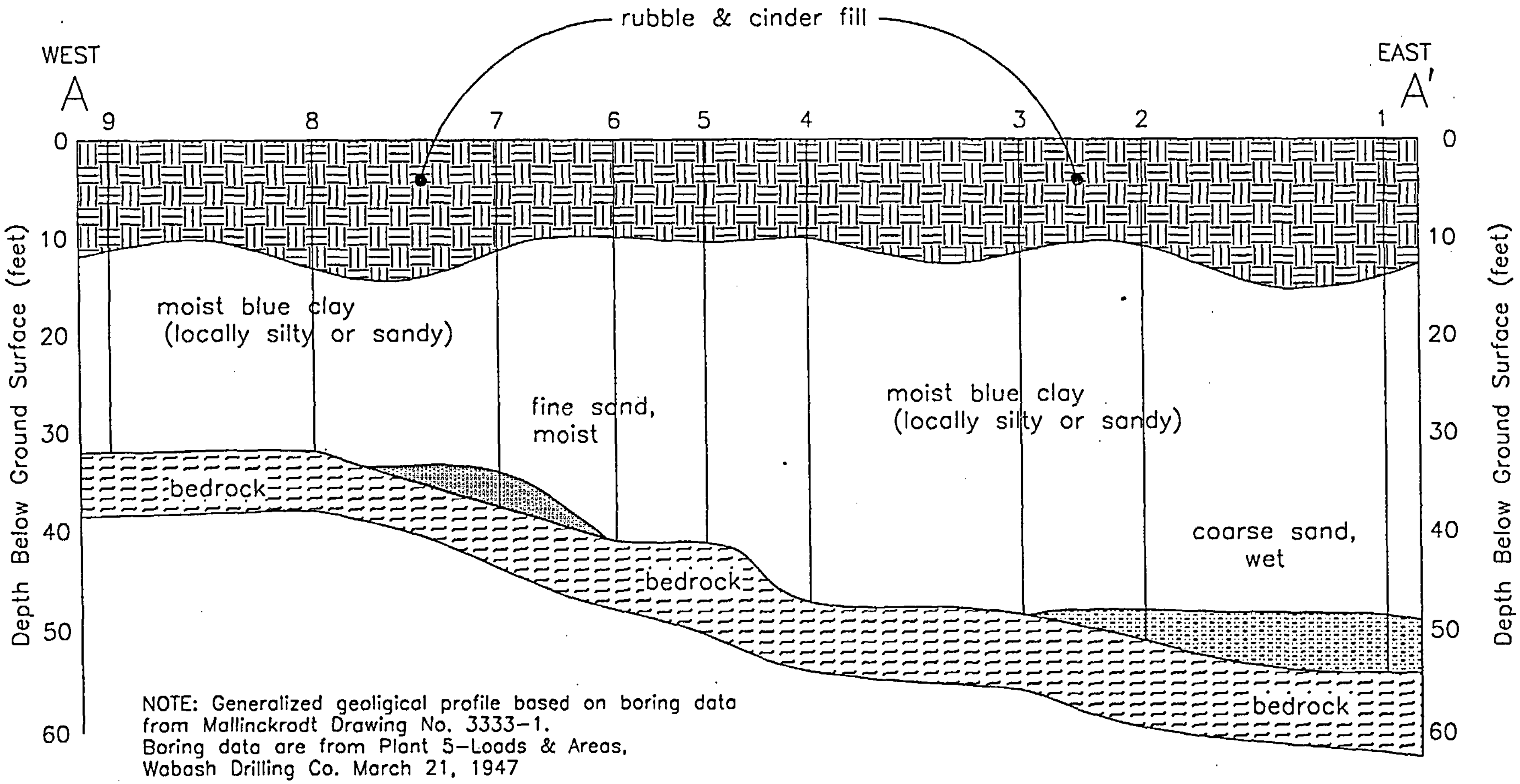
FIGURE 3-5
GENERALIZED GEOLOGICAL MAP
OF MISSOURI



NOTE: Generalized geoligical profile based on boring data from Mallinckrodt Drawing No. 3333-1.
Boring data are from Plant 5–Loads & Areas, Wabash Drilling Co. March 21, 1947

GENERALIZED GEOLOGICAL PROFILE
PLANT 5

FIGURE 3-6
GENERALIZED GEOLOGIC
PROFILE

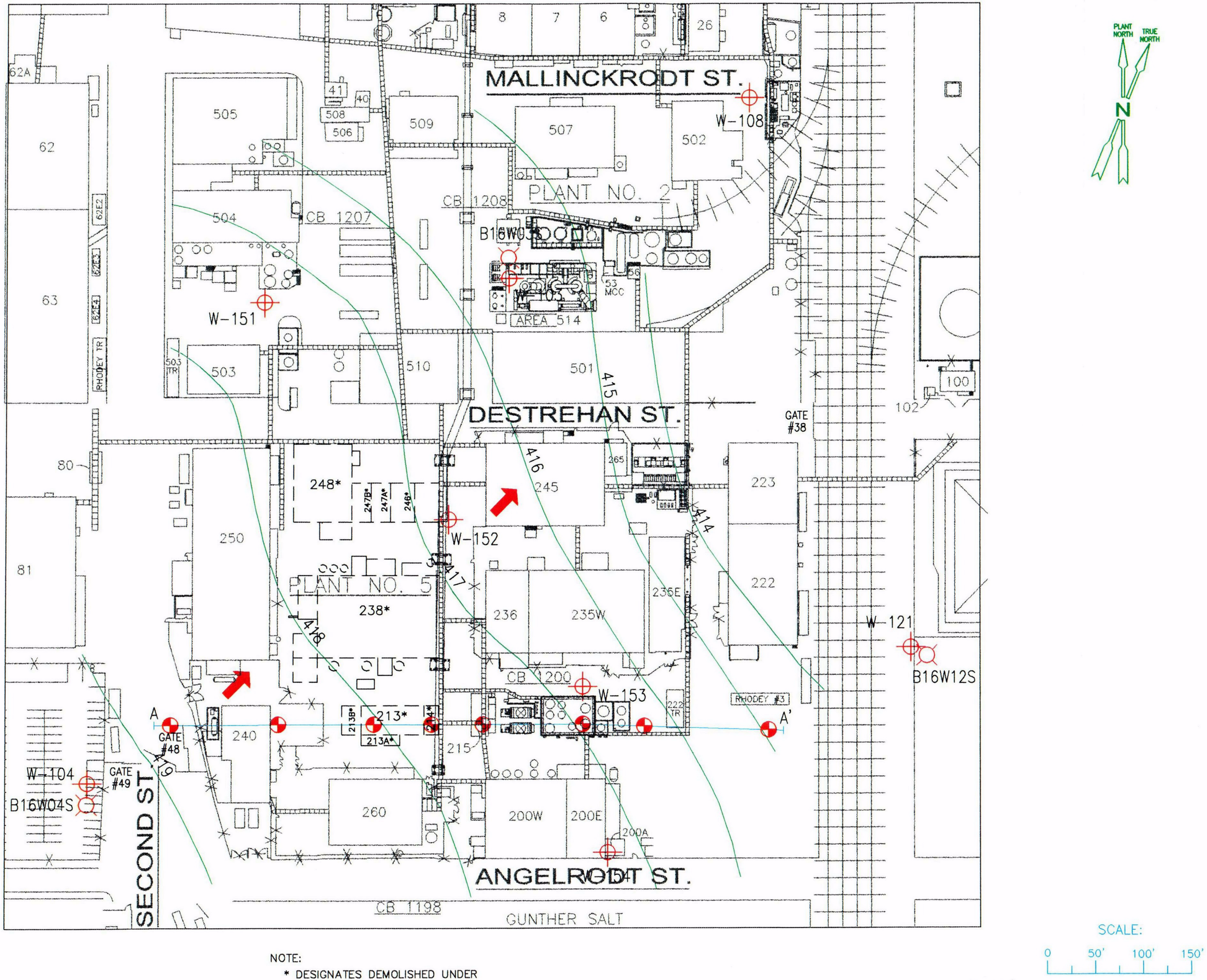


NOTE: Generalized geoligical profile based on boring data from Mallinckrodt Drawing No. 3333-1.
Boring data are from Plant 5-Loads & Areas, Wabash Drilling Co. March 21, 1947

GENERALIZED GEOLOGICAL PROFILE
PLANT 5

FIGURE 3-7
GENERALIZED GEOLOGIC PROFILE
PLANT 5
REV. 0

fn = Geo_prof 8/6/97



NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

C-04

NOTES:

1. FIELD INFORMATION COMPILED ON JUNE 12, 1989
2. THE SOURCE FOR THIS DRAWING IS: BECHTEL NATIONAL, INC. SEPTEMBER, 1990. RADIOLOGICAL, CHEMICAL, AND HYDROGEOLOGICAL CHARACTERIZATION REPORT FOR THE ST. LOUIS DOWNTOWN SITE IN ST. LOUIS, MO. FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM (FUSRAP) VOLUMES 1-3; REVISION 1. DOE/OR/20722-258.

LEGEND:

¤	FUSRAP/DOE MONITORING WELL (1988)
⌖	MALCOM PIRNIE MONITORING WELL (1989)
414	WATER LEVEL CONTOUR, PERCHED GROUNDWATER JUNE 12, 1989 (FEET, MSL)
➚	GENERAL DIRECTION OF GROUNDWATER FLOW
●	WABASH DRILLING CO. (1947)
A A'	LOCATION OF GEOLOGIC PROFILE

NO.	DATE	ENGR.	DESCRIPTION
1	03/31/03		GENERAL BACKGROUND UPDATING
0	03/18/03		INITIAL ISSUE

DRAWING REVISIONS

JOB NO. PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

ST. LOUIS PLANT
MONITORING WELL LOCATIONS
FIGURE 3-8

SITE STL	PLANT ALL	BLDG. ALL	FLOOR N/A
SCALE 1"=50'		DATE 12/06/00	
DR. BY: J. MCMAHON		ENGR.	
CHECKED			

DRAWING NO. FIGURE 3-8 REV. 1

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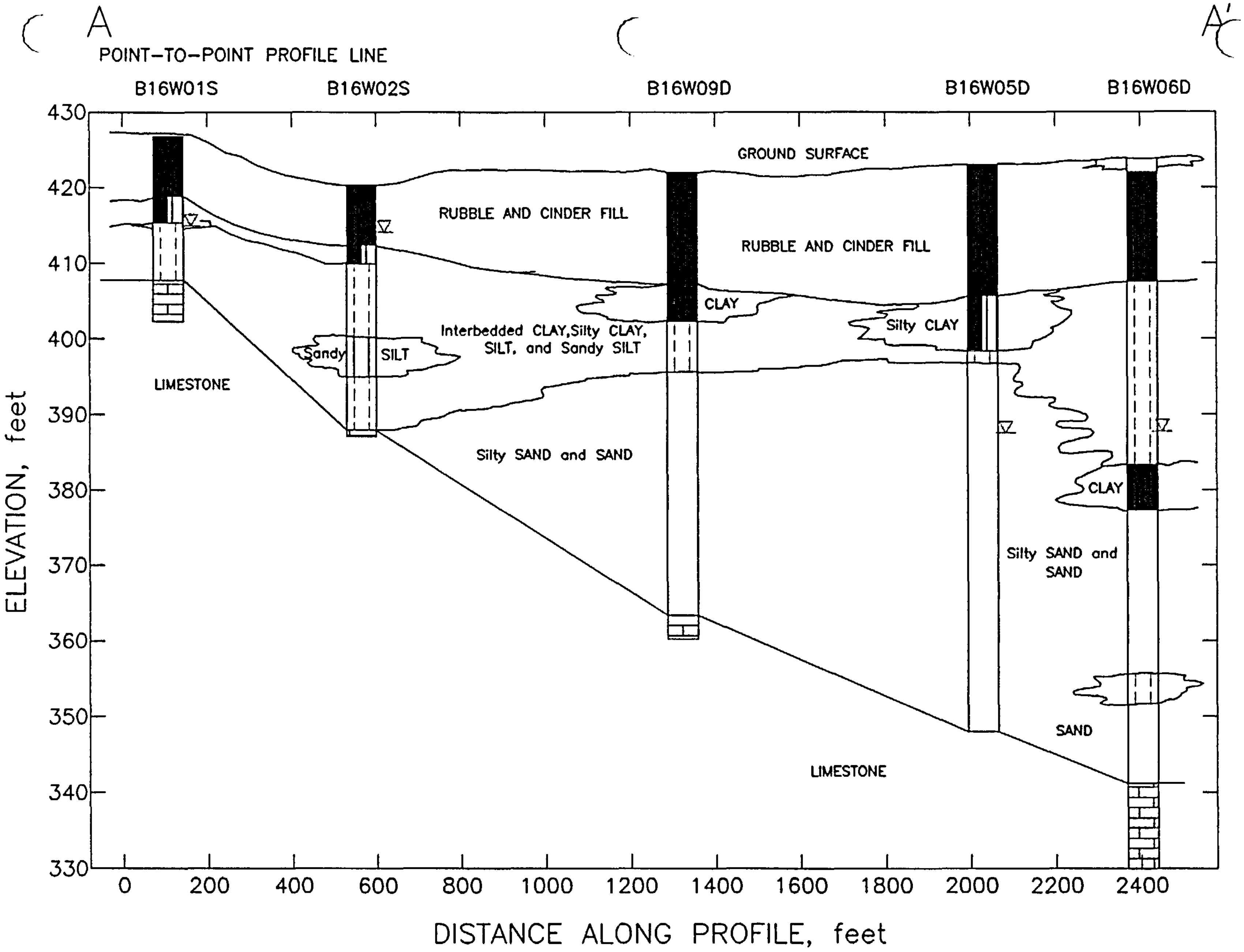
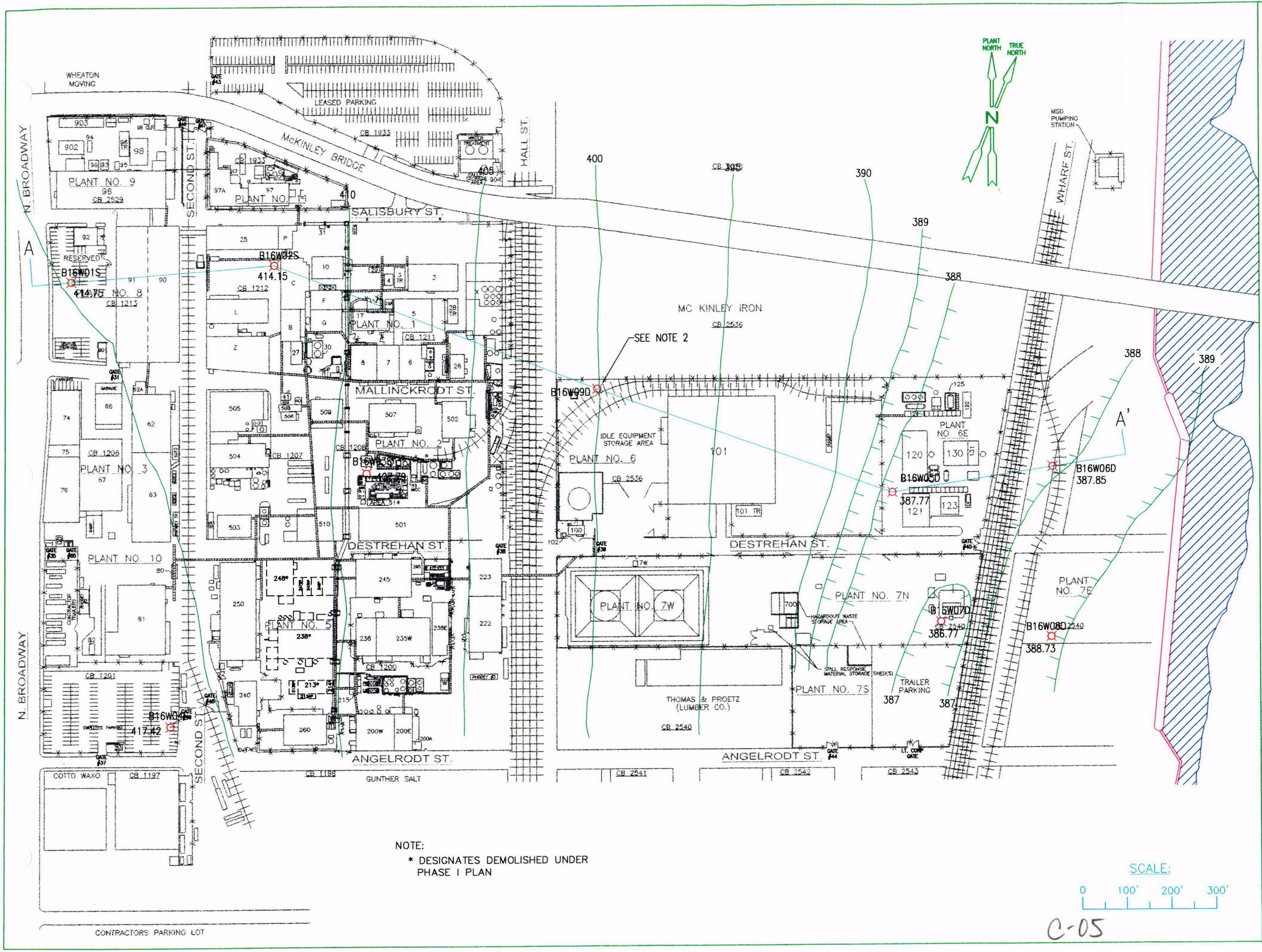


SOURCE:
Bechtel National, Inc. September 1990. Radiological, Chemical, and Hydrogeological Characterization Report for the St. Louis Downtown Site in St. Louis, MO. Formerly Utilized Sites Remediation Action Program (FUSRAP). Volumes I–III: Revision 1. DOE/OR/20722-258

FIGURE 3-9
HYDROGEOLOGICAL CROSS SECTION
REV. 0

S:\CorpEng\DOCS\CT PHASE II\CT PHASE II FIGURE 3-10 REV 1.dwg 03/31/03 08:41 REVISED BY [illegible]



NOTE:
* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

NOTES:

1. FIELD INFORMATION COMPILED ON JUNE 9, 1989
2. WELL B16W09D WAS NOT COMPLETED UNTIL AFTER THE READINGS WERE TAKEN.
3. THE SOURCE FOR THIS DRAWING IS: BECHTEL NATIONAL, INC. SEPTEMBER, 1990. RADIOLOGICAL, CHEMICAL, AND HYDROGEOLOGICAL CHARACTERIZATION REPORT FOR THE ST. LOUIS DOWNTOWN SITE IN ST. LOUIS, MO. FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM (FUSRAP) VOLUMES 1-3; REVISION 1. DOE/OR/20722-258.

LEGEND:

¤	MONITORING WELL
390	ELEVATION OF GROUNDWATER IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM (NGVD). GRADE ELEVATION OF THE SITE RANGES FROM 419 TO 425 FEET ABOVE NGVD.
—	CONTOUR OF GROUNDWATER ELEVATION

NO.	DATE	ENGR.	DESCRIPTION
1	03/31/03		GENERAL BACKGROUND UPDATING
0	03/18/03		INITIAL ISSUE

DRAWING REVISIONS

JOB NO.
PROJECT NO.

MALLINCKRODT
ST. LOUIS, MO.

ST. LOUIS PLANT
WATER LEVEL CONTOUR MAP-ALLUVIAL SAND UNIT
FIGURE 3-10

SITE STL PLANT ALL BLDG. ALL FLOOR N/A
SCALE 1"=100'
DATE 12/06/00
DR. BY: J. MCMAHON
ENGR.
CHECKED
DRAWING NO. FIGURE 3-10
REV. 1

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T_BLK25.DWG

C-05

SECTION 4

RADIOLOGICAL STATUS OF FACILITY

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

4. RADIOLOGICAL STATUS OF FACILITY

4.1 INTRODUCTION

The radiological status of the C-T Decommissioning Project is interpreted on historical characterization programs. The following discussions provide information about each of the characterization efforts performed to date, as well as the resulting evaluation and current radiological status.

The site assessments were designed to quantify the physical and chemical characteristics of the C-T process and process support areas, and perform an initial assessment of the areal and vertical extent of radioactive contamination. Affected and potentially affected surface and subsurface materials were characterized. The key radionuclides in these characterization studies were U-238 Th-230, Ra-226, Th-232, Ra-228, and Th-228.

The following subsections briefly describe the results of the site assessments. Tables are provided summarizing the analytical results of characterization samples. The "Sum of Fractions" column is the sum of the ratio of each key radionuclide net concentration to its $DCGL_W$. The net concentration was calculated by subtracting the mean background concentration from the value shown in the table. The $DCGL_W$ values are presented in Section 5. In those cases where a concentration value was not available for a key radionuclide, the concentration value was estimated from one of the other key radionuclides in the sample. The method for estimation of key radionuclide concentration(s) in a sample is described in Appendix C. Figures are provided showing the location from which samples were collected.

The Columbium-Tantalum Characterization Plan was submitted to the NRC in January 1994.[1] Comments on the plan were received from the NRC in June 1994 and considered prior to implementation of the plan. Characterization activities were completed in 1996 through 2001. Characterization activities focused on the identified key radionuclides and the former C-T process and support areas in Plant 5.

4.2. CONTAMINATED STRUCTURES

Contaminated structures are not in the scope of the C-T Phase II Decommissioning Plan (Phase II Plan). A precursor document to this one, the C-T Phase I Decommissioning Plan (Phase I Plan)[2], describes the activities involving above-grade decommissioning of the buildings. The objective of the Phase I Plan is to remediate the C-T buildings to obtain unrestricted release or to dismantle them and dispose of the rubble. The NRC approved the Phase I Plan in May 2002.[3]

---

[1] Mallinckrodt Chemical Inc. C-T Plant Characterization Plan. January 1994. Supplement May 1994.

[2] Mallinckrodt, Inc. Phase I Plan for C-T Decommissioning. Submittals January 10, 2002, February 13, 2002, and March 8, 2002.

[3] NRC: Larry Camper. Letter to Mallinckrodt Chemical, Inc.: Mark Puett. May 3, 2002.

4.3. CONTAMINATED SYSTEMS AND EQUIPMENT

Systems and equipment that are above-grade are not in the scope of the Phase II Plan. A precursor document to this one, the Phase I Plan, describes the activities involving decommissioning of the above-grade systems and equipment. The objective of the Phase I Plan is to remediate the C-T buildings to obtain unrestricted release or to dismantle them and dispose of the rubble. The NRC approved the Phase I Plan in May 2002.

Systems that are below-grade are within the scope of the Phase II Plan. These systems include the utility systems used to support operations at the site. These utilities are water, electric, gas, sewer, and communications. The utilities, with the exception of sewer, will be relocated or worked around as necessary to facilitate remediation of surrounding contaminated soil.

Activities carried out under this plan included collection of 18 samples of sediment from sewer pipes at manholes.[4] The analytical results of these samples are provided in Table 4-1. The locations of the manhole samples and associated sewer lines are displayed in Figure 4-1.

4.4. SURFACE CONTAMINATION

There is practically no exposed surface soil at the Plant 5 site. Surfaces are paved with concrete or asphalt, or covered by structures.

Measurement techniques for pavement included gamma scanning while walking over the areas, and beta-gamma activity measurements on a gridded surface using hand-held, direct reading instruments. Discrete samples were also gathered and sent for gamma spectroscopy and alpha spectroscopy.

Summaries of the radiological investigation programs that involved pavement and building slabs, the focus of each program, and the techniques used are discussed below.

4.4.1. Preliminary Radiological Investigation (PRI)

In June 1992 a preliminary radiological investigation was completed of Plant 5. This was basically an alpha and beta/gamma radioactivity investigation on surfaces throughout the C-T process area. As part of this work, gamma scan walkovers were conducted of Plant 5 streets. The streets were divided into 74 survey blocks. Each time a scan reading went above approximately twice background it was recorded as elevated activity. Fifty-four survey blocks exhibited elevated gamma activities.

---

[4] Mallinckrodt Chemical, Inc. Radiological Characterization Data Set for the Mallinckrodt Chemical C-T Plant. Thermo Nutech, Oak Ridge, TN. Volumes 4 and 5, "Results of Radiological Analysis of Samples". October 1998.

4.4.2. Columbium-Tantalum Characterization Plan

The Columbium-Tantalum Characterization Plan, described in Section 4.0, also included paved surfaces in the former C-T process and support areas of Plant 5.

Twenty-four scabble samples were collected of pavement in the Plant 5 area and analyzed for use in determination of release limits.[5] They enabled the relative distribution of key radionuclide concentrations, or spectrum, to be interpreted. The data collected from the scabble results are provided in Table 4-2. The location of the scabble samples are shown in Figure 4-2.

A comprehensive beta survey was conducted on all accessible Plant 5 street surfaces during this characterization.[4] The streets in Plant 5 were first surveyed for beta/gamma activity using a large area gas proportional beta/gamma floor monitor, which provided identification of localized areas of elevated activity where direct measurements for beta/gamma activity could be taken. Direct measurements were then taken on a six-foot grid in the affected areas and on a twelve-foot grid in the unaffected areas. Table 4-3 describes the 3 measurements that exceeded the derived concentration guideline level ($DCGL_w$): the $DCGL_w$ is described in Section 5. Figure 4-3 displays the locations of the measurements.

Thirty-three exposure rate measurements were made in Plant 5.[4] Ten exposure rate measurements, as background measurements, were made off Mallinckrodt property.[4] The results of the on site and off site exposure rate measurements are provided in Table 4-4. The locations of the on site and off site exposure rate measurements are shown in Figure 4-4A and Figure 4-4B, respectively.

The Wastewater Neutralization Basin was also characterized.[4] A surface gamma walkover scan was conducted across each of the two basins. One square foot sections of the liner were removed and direct measurements for beta activity were taken at 26 locations in areas with the highest gamma activity. Table 4-5 reflects that no measurements exceeded the $DCGL_w$: the $DCGL_w$ is described in Section 5. Figure 4-5 displays the measurement locations.

4.5. SOIL CONTAMINATION

Characterization of subsurface materials was achieved by soil core sampling. Samples of soil were collected from cores and analyzed by alpha or gamma spectrometry. Summaries of the radiological investigation programs that involved subsurface soils, the focus of each program, and the techniques used are discussed below.

---

[5] Mallinckrodt Chemical, Inc. Radiological Characterization Data Set for the Mallinckrodt Chemical C-T Plant. Thermo Nutech, Oak Ridge, TN. Volume 1, "Results of Radiological Surveys for Background Radiation"; Volume 3, "Radiological Survey Data and Field Drawings"; and volumes 4 and 5, "Results of Radiological Analysis of Samples". October 1998.

4.5.1. Pre-Phase I Soil Background Characterization

In 1994 preliminary site characterization sampling activities were completed. As part of this characterization, native clay background samples were collected from the National City, IL area. These clay samples were determined to exhibit similar characteristics to those at the Mallinckrodt site. The two native clay samples were analyzed isotopically. The background sample results are provided in Table 4-6. Figure 4-6 indicates the general location from which the samples were collected.

4.5.2. Columbium-Tantalum Characterization Plan

The Columbium-Tantalum Characterization Plan, described in Section 4.0, also included subsurface soils in the former C-T process and support areas in Plant 5.

Although historical characterization data showed that radioactive contamination was present in the cinder fill regime of the subsurface in Plant 5, the data sets did not completely define the extent. In that regard, an additional 57 boreholes were advanced in Plant 5 during subsurface investigation described by the Columbium-Tantalum Characterization Plan.[6] Table 4-7, contains the radiological results (designated BH-01 through BH-56) from the subsurface sampling. Figure 4-7 displays the locations of the boreholes.

4.5.3. Building 245 Renovation Project – Decontamination and Final Survey

In January 1996, in support of construction activities to install a support column for a chiller east of Building 245, a sample was collected from an excavation (later designated BH-120). In February through April of 1996, decontamination and final survey activities were performed in and around Building 245.[7] This work consisted of characterization, decontamination, and final status survey to support renovation and facility upgrade projects. During this project, 20 analytical samples were collected from eight borehole locations (later designated BH-62 through BH-69) beneath Building 245 for radioactivity analyses. The radioactivity analysis results are provided in Table 4-8. The sample locations are displayed in Figure 4-8.

4.5.4. Soil Sampling and Testing – Building 200 West

In November 1996, sampling of subsurface soils was completed in Building 200 West.[8] The project consisted of drilling and sampling four borings (later designated BH-95 through BH-98) to depths ranging between five and six feet. The radioactivity analysis results are provided in Table 4-9. The sample locations are displayed in Figure 4-9.

---

[6] Mallinckrodt Chemical, Inc. Radiological Characterization Data Set for the Mallinckrodt Chemical C-T Plant. Thermo Nutech, Oak Ridge, TN. Volumes 4 and 5, "Results of Radiological Analysis of Samples". October 1998.

[7] Mallinckrodt Chemical, Inc. Building 245 Renovation Project. Thermo Nutech, Oak Ridge, TN. "Decontamination and Final Survey Report". October 1996.

[8] Mallinckrodt Chemical, Inc. Soil Sampling and Testing, Building 200 West. Geotechnology, Inc, St. Louis, MO. January 17, 1997.

4.5.5. Soil Sampling and Testing – Plant 5 Tank Farm

In June 1997, sampling of subsurface soils was completed in the Plant 5 Tank Farm.[9] The project consisted of drilling and sampling four borings (later designated BH-99 through BH-102) to depth of nine feet. The radioactivity analysis results are provided in Table 4-10. The sample locations are displayed in Figure 4-10.

4.5.6. Environmental Sampling and Testing – Buildings 201/215

In June and July 1999, sampling of subsurface soils was completed in and around Building 201 and east of Building 215.[10] The project consisted of drilling and sampling several borings (later designated BH-103 through BH-111) to various depths. In December 1999, in support of construction activities, a sample was collected from an excavation on the north side of Building 201 (later designated BH-121). The radioactivity analysis results are provided in Table 4-11. The sample locations are displayed in Figure 4-11.

4.5.7. Environmental Sampling and Testing – Building 250

In April 1996, in conjunction with sampling in support of construction activities west of Building 250, a sample was collected from an excavation (later designated BH-94).[11] In July and September 1999, sampling of subsurface soils was completed in southwest of Building 250.[12] The project consisted of drilling and sampling eleven borings to various depths. Eight of these borings (later designated BH-112 through BH-119) included collection of samples for radioactivity analyses. The radioactivity analysis results are provided in Table 4-12. The sample locations are displayed in Figure 4-12.

4.5.8. Environmental Sampling and Testing – Building 235

In August and September 1999, remediation and investigation activities were completed for construction of Building 235E.[13] This work consisted of characterization, remediation, and subsurface investigation to support renovation and facility upgrade projects. During this project samples were collected from 23 borehole locations (designated BH-Z-1 through BH-Z-23) in and around the area that is currently occupied by Building 235E. The radioactivity analysis results are provided in Table 4-13. The borehole locations are displayed in Figure 4-13.

---

[9] Mallinckrodt Chemical, Inc. Soil Sampling and Testing, Plant 5 Tank Farm. Geotechnology, Inc, St. Louis, MO. August 7, 1997.

[10] Mallinckrodt Chemical, Inc. Environmental Sampling and Testing, Buildings 201/215. Geotechnology, Inc, St. Louis, MO. August 26, 1999.

[11] Mallinckrodt Chemical, Inc. Soil Sampling and Testing, Building Boring B-12 – Building 250. Geotechnology, Inc, St. Louis, MO. May 24, 1996.

[12] Mallinckrodt Chemical, Inc. Environmental Sampling and Testing, Building 250. Geotechnology, Inc, St. Louis, MO. December 14, 1999.

[13] Mallinckrodt Chemical, Inc. Environmental Sampling and Testing, Building 235. Geotechnology, Inc, St. Louis, MO. January 12, 2000.

4.5.9. Environmental Sampling and Testing – Building 204

In November 2001, 12 boreholes were advanced in and around Building 204.[14] During this project samples were collected from the borehole locations, later designated BH-70 through BH-81, for radioactivity analyses. The radioactivity analysis results are provided in Table 4-14. The borehole locations are displayed in Figure 4-14.

Building 204 itself was never used to process or handle regulated radioactive material. With appropriate safety demonstration and with NRC concurrence,[15] it was dismantled and disposed appropriately.

4.5.10. Environmental Soil Sampling and Testing – Plant 5

During June of 2002, Mallinckrodt performed biased subsurface characterization throughout Plant 5.[16] Twelve subsurface borings, designated BH-82 through BH-93, were advanced in areas chosen to help find boundaries on the horizontal and vertical extent of contamination. Samples from the boreholes were analyzed for the key radionuclides. The results of the sample analyses are shown in Table 4-15. The borehole locations are displayed in Figure 4-15.

4.5.11. Mallinckrodt Biased Sampling

Over the past several years, Mallinckrodt has performed biased subsurface sampling throughout the Plant 5.[17] These samples were collected in various areas in support of construction and maintenance activities. A total of 26 samples were collected in the Plant 5 area with depth ranging from zero to 10 feet below ground surface. The results are shown in Table 4-16. The sample locations are displayed in Figure 4-16.

4.6. SURFACE WATER

The only surface water in the area is the Mississippi River, adjacent the east side of the plant site. The river flow and site drainage characteristics are described in Section 3 of this report.

There are no other rivers and no lakes or ponds on or adjacent the facility.

Due to the large flow volume of the Mississippi River and the environmental controls established for the site, there would be no detectable impact to surface water from decommissioning activities.

---

[14] Mallinckrodt Chemical, Inc. Environmental Sampling and Testing, Building 204. Geotechnology, Inc, St. Louis, MO. January 9, 2002.

[15] Camper, Larry. NRC. Letter to Mark Puett. Mallinckrodt. November 21, 2001

[16] Mallinckrodt Chemical, Inc. Environmental Sampling and Testing, Plant 5. Geotechnology, Inc, St. Louis, MO. August 29, 2002.

[17] Mallinckrodt Chemical, Inc. Jim Adams, Radiation Safety Officer. Mallinckrodt, Inc, St. Louis, MO. "QA Phase IIJA (1) 030602.xls". March 6, 2002.

4.7. GROUNDWATER

Total uranium, radium-226, and thorium-230 were analyzed in samples collected from eight monitoring wells during four quarterly sampling events between July 1988 and April 1989 (USACE, 1998). The groundwater was sampled again by BNI in during a single event in late 1997/early 1998 that included 17 monitoring wells. Samples were analyzed for actinium-227, lead-210, protactinium-231, radium-226, radium-228, thorium-228, thorium-230, thorium-232, and total uranium[18]. Summary data are presented in Appendix A.

Total uranium was the only radionuclide detected in filtered samples at elevated concentrations. The elevated concentrations have been detected in only a single well, B16W02S, which is screened in perched groundwater in the upper zone in Plant 1. The total uranium concentrations in this well have ranged from a 1988/1989 average of 228 µg/l to a 1997/1998 value of 1,187 µg/l. These detections do not present a groundwater ingestion hazard since the perched groundwater in the upper zone is not a drinking water source.

Although Protactinium-231 was detected at concentrations up to 45 pCi/l in unfiltered groundwater samples from three wells (none in Plant 5), it was not detected in filtered samples from these three wells. USACE has concluded that the protactinium is bound to sediment particles and that the unfiltered results are not representative of groundwater quality at the site[19].

No radionuclides were detected above US EPA MCL in filtered groundwater samples from the lower zone. This finding suggests that the low-permeability silt and clay layers between the upper and lower zones retard contaminant migration between the two zones.

4.8. CURRENT RADIOLOGICAL STATUS

This section provides an evaluation of the results of previously described data collection efforts for sewers, pavement, and subsurface material conducted at the C-T project site (Plant 5). These data evaluations are utilized in later sections of this DP to develop release criteria, compare decommissioning alternatives, identify the location of contamination and support safe removal, decontamination, and deconstruction.

4.8.1. Background

Values were developed to represent naturally occurring levels of radiation, concentrations of radioactivity, or concentrations of radioactive material for each of the primary media characterized in Plant 5. The values were developed either by estimation, direct measurement, or calculated from a group of measurements. The background values are applied to respective gross measurements in order to determine a net value of a parameter. The net value of the parameter, or a result from manipulation of the net value, is used in comparison to the respective

---

[18] USACE. Groundwater Characterization Report of 1997/1998 Baseline Data for the St. Louis Downtown Site. St. Louis, MO. July 1998.

[19] *op. cit.*

release limit (*e.g.* the derived concentration guideline level described in Section 5). The following subsections present the background value(s) for the primary media in Plant 5.

4.8.1.1. Sewers

Background concentrations of radioactive material were not specifically measured for the sediments in the sewers. Background concentrations of radioactive material in sewer sediments are estimated to be equivalent to those values developed for subsurface soil. The development of these values is described in Section 4.7.1.3.

4.8.1.2. Pavement

Background concentration of beta radioactivity on pavement surfaces was developed specifically for asphalt and concrete from measurement of non-contaminated surfaces. The development of these values is described in the Mallinkcrodt site characterization report[20]. The background values of beta radioactivity in pavement surfaces at Plant 5 for asphalt and concrete are 254 $\beta/(\text{min}\cdot 100\text{cm}^2)$ and 180 $\beta/(\text{min}\cdot 100\text{cm}^2)$, respectively[21].

The background gamma exposure rate is calculated from the 10 off site measurements provided in Table 4-4: locations PIC-34 through PIC-43. An upper bound of the background gamma exposure rate is calculated as average plus one standard deviation of the 10 off site measurements to be 10 μR/h (at one significant figure). Figure 4-4A provides a comparison of onsite gamma exposure rate measurements to this upper bound of background exposure rate.

4.8.1.3. Soil

The soils in Plant 5 between the pavement and a lower naturally occurring clay layer are comprised predominantly of coal cinders and other non-soil fill (cinder/fill). Coal, coal ash, and coal cinders are known to have concentrations of radioactive material, in particular the key radionuclides being characterized in Plant 5, greater than found in true or native soils[22]. Then it is desirable to determine values for background concentrations of the key radionuclides in cinder/fill in order to accurately define an extent and concentration of contamination. However, the absence of an isolated, non-contaminated bed of cinder/fill precludes development of such background values by direct measurement.

The NRC has recognized that a background reference area might not be readily available by stating: "A derived reference area may be used when it is necessary to extract background information from the survey unit because a suitable reference area is not readily available. For example it may be possible to derive a background distribution based on areas of the survey unit

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[20] Mallinckrodt Chemical, Inc. Radiological Characterization Data Set for the Mallinckrodt Chemical C-T Plant. Thermo Nutech, Oak Ridge, TN. Volume 1, "Results of Radiological Surveys for Background Radiation". October 1998.

[21] C-T Phase I DP, Table 4-3, January 9, 2002.

[22] Morton, H., "Methods of Interpreting Background Radioactivity Concentration in Soil", presentation to NRC staff, Rockville, MD, January 23, 2002.

where residual radioactivity is not present."[23] In this case, a representative background value for each of the key radionuclides was interpreted from the set of characterization samples for which the sample matrix was cinder/fill. A description of the method of interpretation is provided in Appendix B. The results of the interpretation are provided in Table 4-17.

Background concentrations of radioactive material were not specifically interpreted from radioactivity analyses of the clay layer beneath the cinder/fill. Background concentrations of radioactive material in clay layer are estimated to be equivalent to those values provided in Table 4-6 for the sample at depth of 12 to 28 feet.

4.8.1.4. Groundwater

Groundwater is discussed in Appendix A. Background for groundwater may be derived from measurements in and near the Mallinckrodt property, other than Plant 5.

4.8.2. Sewers (Manholes)

Analytical information and knowledge of process obtained from the characterization studies indicate that portions of the Plant 5 sewer system have radiological constituents in concentrations greater than the proposed release limits; i.e. greater than the derived concentration guideline levels described in Section 5. Specifically, Table 4-1 reveals that several samples have a sum-of-fractions value greater than unity meaning the radionuclide concentrations in combination exceed the proposed release limits. The locations of samples exceeding the proposed release limits are shown in Figure 4-1.

Interpretation of the manhole samples reveals the contaminated sewer line to be confined to segments immediately southwest, west, and north of Building 238. This sewer line subject to remedial action, about 400 linear feet, poses a minimal increment to the total volume of contaminated subsurface soil.

4.8.3. Pavement

The direct survey results and the scabble samples from the characterization studies indicate that almost all of the pavement of Plant 5 may be released for unrestricted use. Specifically, Table 4-3 reveals that only 3 of the 1670 measurement results exceeded the proposed release limit; i.e. exceeded the derived concentration guideline level described in Section 5. Additionally, Table 4-2 reveals that only one pavement sample exceeded the exempt concentration limit for release of source material of 0.05% weight, described in 10 CFR 40.13(a).

An area of pavement 30 feet by 105 feet on the west side of Building 238 and about 109 feet by 46 feet strip on the south side, totaling about 8200 ft^2 has been designated MARSSIM Class 2

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[23] USNRC. "Demonstrating Compliance with the Radiological Criteria for License Termination". Draft Regulatory Guide DG-4006. Section 2.3.1. August 1998.

(ref. Figure 14-1A). If this area of pavement were subject to removal or decontamination, the volume to be removed would be about 8200 ft^2 x 0.5 ft thick.

Slabs of Buildings 213, 213A, 213B, 214, 238, 246, 246B, 247, 247A, 247B, and 248 are prospectively contaminated. The combined area of process and support building floor slabs = 25000 ft^2. The total volume of the slabs is estimated to be 13000 ft^3.

4.8.4. Subsurface Material

Based on the analytical information obtained from the characterization studies performed to date, it has been determined that some soils in the Plant 5 area contain radionuclide concentrations exceeding the proposed release limits; *i.e.*, greater than the derived concentration guideline level described in Section 5. Specifically, tables 4-7 through 4-16 reveal that several samples have a sum-of-fractions value greater than unity, meaning the radionuclide concentrations in combination exceed the proposed release limits. The locations of samples exceeding the proposed release limits are shown in figures 4-7 through 4-16.

An interpretation of the extent and concentration of contaminated subsurface material is provided in figures 4-17 through 4-19. The volume of contaminated soil is estimated relative to a sum-of-fractions value greater than one. The estimated volume of the contaminated subsurface soil expected to exceed DCGL is approximately 42,000 cubic feet. An estimated 29,000 cubic feet of soil is estimated to be more than unrestricted release criteria and less than the *unimportant quantity* of source material as defined in 10 CFR 40.13. The total estimated volume of material expected to be removed from the site is approximately 71,000 cubic feet.

4.8.5. Conclusion

The C-T project pavement and subsurface material have been subjected to comprehensive radioactivity characterization investigations. These programs have delineated the extent and concentration of radioactivity contamination in Plant 5. The characterization has confirmed the suspected radiological conditions based on process history and site knowledge, using surface beta measurements and borehole sampling. Concentrations of key radionuclides that exceed release criteria have been identified and these locations accurately recorded for subsequent remediation.

Table 4-1, Analytical Results of Manhole (Sewer) Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
MH-02		4.17	2.4	0.17	3.1	7.1	2.5	2.6	2.9	1.6	1.4	1.1	3.0
MH-04		7.5	6.6	0.23	7.3	12	5.1	73.2	15.5	3.3	18.6	12	0.0
MH-08		5.33			4.5895	13.7	1.5	2	3.8	1	1.5	1.1	0.0
MH-09		2.33	2	0.15	2.4	5.3	2.7	147.1	-8.2	1.9	31.8	10.6	5.6
MH-10	4	4.33	0.84	-0.01	0.75	2.4	1.1	0.78	2.1	0.4	0.33	0.3	0.0
MH-15		2.67	1	0.02	1.1	2.9	1.3	1.4	0.12	1.1	0.82	0.76	0.0
MH-17		5.42	1.8	0.01	1.2	3.7	1.5	1.9	2.3	0.76	0.73	0.92	0.0
MH-21	4	4.33	0.82	0.02	0.85	3	1.2	0.61	1.1	1.1	0.48	0.73	0.0
MH-25	6	6.25	1	0.07	0.94	1.9	1.9	0.82	0.92	0.68	0.52	0.64	0.0
MH-27	4	4.17	3.2	0.17	2.5	3.2	1.7	2.4	2.7	1.3	2.2	1.6	0.0
MH-32		0.5	3.6	0.17	4.2	3.9	3	7.3	8.3	3.2	3.2	1.4	0.2
MH-34		7.25	26	1.3	29.9	46.4	45.9	101.6	70.1	8.8	22.8	9.4	4.0
MH-37	4	4.17	2.6	0.05	2.7	4.2	4.3	3.8	6.2	2.3	3.5	2.4	0.1
MH-38	4	4.17	1.1	0.07	1.1	5	2.7	1.5	0.76	0.78	0.53	0.78	0.0
MH-40	9	9.25	3.5	0.15	2.8	5.1	1.9	4.4	5	0.79	1.9	1.5	0.1
MH-42	7	7.58	8.7	0.44	8.8	22.7	15.1	33.2	26	26.7	68.3	32.7	3.3
MH-43		15	4	0.3	9.2	14.1	4.3	24.2	2.6	3.3	2.7	2.6	0.8
MH-44		12			4.0535	12.1	2.9	5.7	3.1	2.2	5.5	2.7	0.2

Table 4-2, Analytical Results of Scabble Samples from Plant 5 Street Surfaces

	Sample Depth (ft)		Radionuclide Concentration										Percent weight source material
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	
SC-01			10.5	0.34	12.2	42.5	21	23.7	8.5	20.7	12.3	22	0.02
SC-02			25.2	1.6	27.2	74.5	5	34.7	22.5	1.9	1.5	2.8	0.01
SC-03			11.3	0.4	11.9	27.1	7.8	7.6	3.6	2.5	3	2.7	0.00
SC-04			6.4	0.31	6.7	4.5	3.8	2.8	1.6	3.7	3.4	4.5	0.00
SC-05			31.2	1.3	30.9	106.9	129.4	339.8	61	32.8	32.8	34.9	0.03
SC-06			91.4	3.6	91.3	256.7	66.6	106.7	30.7	28	19.7	29.9	0.04
SC-07			56.6	3.1	58.5	177.5	32.7	157.3	40.7	32.5	26.6	34.2	0.04
SC-08			21	1.2	21.8	70.7	17	89.9	12.8	10.2	5.7	11.7	0.01
SC-09			45	1.7	47.7	118.3	25.7	153.7	36.7	31.7	66.4	35.2	0.04
SC-10			122.2	7.5	125.2	339.9	58.2	978.7	73.1	57.4	42.1	68.9	0.07
SC-11			15.3	1.2	16.1	49.3	22.8	8.3	13.9	12.8	7.2	13.2	0.01
SC-12			19.6	1	17.8	72.7	51.3	32.9	49.2	7.5	6.3	9.8	0.01
SC-13			28.2	0.73	28.4	76.7	12.4	73.6	30.6	2.2	2.4	3	0.01
SC-14			18.8	0.73	18.1	41.7	14.6	40.7	25.9	8.1	9.9	8.1	0.01
SC-15			32.6	1.4	33.5	129.3	17.5	46.8	26.6	4.8	4.3	5.2	0.01
SC-16			17.4	1.1	16.9	48.5	36.6	104.4	30.7	5.6	5.6	5.9	0.01
SC-17			29.1	1.3	26.5	84.3	21.7	65.5	47.4	9.7	10.5	12.1	0.01
SC-18			8.6	0.31	8.5	31.5	5.4	3.6	5.5	1.4	1.3	1.8	0.00
SC-19			8.8	0.46	9.3	27.9	6.2	3.5	5.1	1.9	1.4	1.9	0.00
SC-20			29.9	1.4	32.9	82.3	20.2	10.8	26.5	6.1	4.8	6.3	0.01
SC-21			25.2	1.7	27.2	86.7	19.6	13.8	28.1	5.4	5.9	4.9	0.01
SC-22			215.8	9.9	204	530.96	94.1	263	161	15.4	16.5	17.8	0.04
SC-23			35.7	1.9	38.7	90.7	5.7	3.2	16.5	1.4	1.5	1.2	0.01
SC-24			4.5	0.23	5	9.8	13.5	6.6	5.2	3.4	2	3	0.00

Table 4-3. Direct Measurements of Plant 5 Street Surfaces That Exceed $DCGL_W$

Location ID	Net Activity[a] (dpm/100 cm^2)
ST0449	33197
ST0678	43806
ST0690	355552

[a] dpm = atomic transformations per minute

Table 4-4, Gamma Exposure Rate Measurements in Plant 5 and Off-site

Location	Gross Gamma Exposure Rate (µR/h)	
PIC-01	73	
PIC-02	37	
PIC-03	480	
PIC-04	100	
PIC-05	28	
PIC-06	34	
PIC-07	171	
PIC-08	225	
PIC-09	150	
PIC-10	118	
PIC-11	141	
PIC-12	18	
PIC-13	29	
PIC-14	36	
PIC-15	9	
PIC-16	7	
PIC 17	9	
PIC-18	8	
PIC-19	9	
PIC-20	10	
PIC-21	17	
PIC-22	21	
PIC-23	12	
PIC-24	11	
PIC-25	13	
PIC-26	13	
PIC-27	10	
PIC-28	9	
PIC-29	8	
PIC-30	8	
PIC-31	9	
PIC-32	8	
PIC-33	8	
PIC-34	10	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-35	8	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-36	10	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-37	9	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-38	8	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-39	9	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-40	9	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-41	9	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-42	8	This is a background measurement. This location is not on the Mallinckrodt facility.
PIC-43	10	This is a background measurement. This location is not on the Mallinckrodt facility.

Table 4-5. Direct Measurements of Waste Water Neutralization Basins That Exceed $DCGL_W$

Location ID	Net Activity[a] (dpm/100 cm^2)
none	

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[a] dpm = atomic transformations per minute

Table 4-6, Analytical Results of Pre-Phase 1 Soil Background Characterization

		Radionuclide Concentration					
Borehole Number	Average Depth (ft)	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
MR94043	12 to 28	1.2	1.6	1.3	1.0	1.3	1.5
MR94043	32 to 43	1.1	2.1	1.4	1.2	1.8	1.6

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-001	0.5	2.5					3.3	3.3	4.5	1.1	2	1.7	0.1
BH-001	2.5	4.5					1.8	2.3	6.6	0.67	1.7	0.85	0.0
BH-001	4.5	6.5					2.2	2	3.7	0.7	0.96	0.88	0.0
BH-002	0.5	2.5	2.5		2.5		3.1	2.3	< 5	1.8	1.5	1.5	0.0
BH-002	2.5	4.5					1.9	2.3	3.3	1.1	1.6	1	0.0
BH-002	4.5	6.5					1.5	1.3	3.2	0.91	1.2	1.1	0.0
BH-002	16.5	18.5					1.2	1.2	< 0.71	0.94	1.3	1.1	0.0
BH-003	0.5	2.5	6.2		7.1		6.1	3.5	9.1	1.4	1.5	1.3	0.0
BH-003	4.5	6.5					4.5	4.6	5.4	1.1	1.5	1.2	0.1
BH-003	16	17					4.3	2.5	10	1.6	< 0.55	1.3	0.0
BH-003	18	19					1.5	1.3	1.8	1.3	1.5	1.2	0.0
BH-004	1.5	2.5					0.8	1.4	1.9	0.39	0.56	0.48	0.0
BH-004	2.5	4.5					2.8	3.6	4.1	0.72	1.3	0.76	0.0
BH-004	17.5	18.5					3.6	4.3	9	1.1	1.4	1.3	0.1
BH-004	18.5	19.5					1.6	1.5	1.7	1.4	1.6	1.3	0.0
BH-005	0.5	1.5					4.6	4.3	8.5	1.1	1.8	1.3	0.1
BH-005	4.5	5.5					4.2	4	4.8	1.3	1.5	1.1	0.1
BH-005	6.5	7.5					3	2.6	3.5	1.2	1.1	1.4	0.0
BH-006	0.5	1.5					3.2	3.1	4.6	1	1.4	0.98	0.0
BH-006	4.5	5.5					3.3	2.7	3	1.1	1	1.3	0.0
BH-006	6.5	7.5					3.9	3.4	5.9	1.4	1.1	1.1	0.0
BH-007	0.5	1.5					2.2	2.9	3.9	1.2	1.6	0.84	0.0
BH-007	3.5	4.5					3.3	4.1	8	1.5	2.2	1.5	0.1
BH-007	5.5	6.5					2.2	2.6	3.8	0.73	1.1	0.62	0.0
BH-007	11.5	12.5					4.5	5.1	5.6	1.3	1.9	1.3	0.1
BH-008	0.5	2.5	4.5		5.2		3.9	4.2	8.5	1.6	1.5	1.4	0.1
BH-008	5.5	6.5			7.7		3.2	4.4	7.7	0.8	1.4	1.4	0.1
BH-008	15.5	16.5					2.6	1.2	8.7	1	0.65	0.97	0.0
BH-008	17.5	18.5					3.1	2.2	5.2	1.5	1.3	1.7	0.0

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)			Radionuclide Concentration																				
Location ID	Top	Bottom		U-234 (pCi/g)		U-235 (pCi/g)		U-238 (pCi/g)		U-Tot (µg/g)		Th-230 (pCi/g)		Ra-226 (pCi/g)		Th-234 (pCi/g)		Th-232 (pCi/g)		Ra-228 (pCi/g)		Th-228 (pCi/g)		Sum of Fractions
BH-009	0	2.5		3.5		0.24		3.8		9		27.6		16.3	<	3.7		5.5		6.3		6.4		0.7
BH-010	0	2.5		19.6		1.2		21.5		50.9		262		239.3	<	10.7		51.1		81.5		64.6	<	11.3
BH-010	0	4.5		19		1.1		20				18		31.8		11.1		2.9		17.1		3.3		1.4
BH-010	0	5.5		15		0.68		15				3.1		2.84		14.6		0.45		4.48		0.35		0.1
BH-010A	0	6.5		6.8		0.29		7.1		25.4		11.2		22.5		33.4		10.8		28.2		14.2		1.6
BH-010A	0	9.5				0.19	<	3.98						2.81		0.97		3.1		3.42				0.1
BH-010A	0	13.5		1.3		0.04		1.3		5.3		2.4		1.3		1.1		1		1		1.1		0.0
BH-011	0	2.5		1.1	<	0.1		0.65				0.16		2.12		3.23		0.24		1.53		0.23		0.0
BH-011	0	3.5		2.4		0.15		2.3		748.3		238		115.2		225.6		25.9		47.4		28.1		5.5
BH-011	0	9.5		32.2		1.2		30.4		108		24.8		40.4		47.8		15.3		33.3		19.3		2.5
BH-011	0	13.5		2.5		0.05		2.8		6.5		3.6		2.2		3.7		2.7		1.6		2.4		0.1
BH-011	0	22.5		1.1		0.05		1.2		3.1		1.8		1.4		2.5		1.5		1.1		1.4		0.0
BH-012	0	5.5		9.9		0.49		10.4		30.4		24.3		250.2		28		33.8		40.3		38.3		10.0
BH-012	0	9.5		9.4		0.54		10		24.9		16.3		208.7	<	15.8		8.3		23		12.5		7.5
BH-012	0	11.5				0.55		8.03						17.6		8.56		5.95		5.99				0.8
BH-012	0	12.5				0.96	<	4.88						1.51	<	0.7		1.1		1.14				0.0
BH-012	0	13.5				0.62		7.68						8.07		9.93		1.62		1.73				0.3
BH-012	0	14.5		3.1		0.17		3.4		12.3		4.7		4.8		3.8		2.5		0.85		2.9		0.2
BH-012	0	15.5		2.9		0.23		2.8		5		2.8		3.3		3.8		0.92		1.1		1.4		0.1
BH-013	0	3.5				0.39		7.05						2.85		7.23		1.28		1.45			<	0.0
BH-013	0	5.5		4.2		0.16		4.5		12.7		2.4		1.1		5.6		1.6		1.2		1.3		0.0
BH-013	0	9.5		4		0.16		4.4		10.2		1.7		3.4		4.6		1.1		1.6		1		0.0
BH-013	0	16.5		1.4		0.02		1.7		4.9		1.5		1.8		2.8		0.95		1		1.1		0.0
BH-014	0	1.5		6.6		0.25		7.2		20.6		4.5		0.49		20		1.4		5.5		2.7		0.1
BH-014	0	2.5				0.67		11.1						2.97		23.6		2.48		2.38				0.1
BH-014	0	3.5				1.47		30.9						3.37		25.7		1.99		2.09				0.1
BH-014	0	4.5		27.9		1.2		28.7		70.3		20.2		16.4		27.9		11.9		8.5		16.9		1.1
BH-015	0	5.5		14.9		0.56		16.3		27.5		98.8		327.4	<	10.9		11.1		78		32		13.1
BH-015A	0	9.5		69.3		3.1		71.7		180.6		261.9		744.6	<	44.7		48.2		193.3		60.9		30.2

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-015A	0	11.5	210	6.9	210		6.1	667	< 10.6	0.93	117	2.1	24.5
BH-015A	0	14.5	72	3.8	75		14	462	3.08	2.2	92.4	5.1	17.3
BH-015A	0	15.5	8.5	0.28	9.7	16.7	5.9	< 0.43	< 2.3	2.2	0.67	2.3	0.0
BH-016	0	4.5		< 0.08	< 4.26			1.33	< 0.6	2.74	2.57		0.1
BH-016	0	7.5	5.4	0.29	5.9	16.6	6.3	7.8	8.7	3.5	4.5	3.5	0.3
BH-016	0	7.5			8.92								< 0.7
BH-017	0	3.5	4.8	0.27	5	13.2	11.5	122.5	11.7	4.9	2.1	11.8	< 4.2
BH-017B	0	4.5		0.07	< 4.47			1.91	0.88	1.35	1.33		0.0
BH-019	0	2.5		0.079	< 4.25			1.39	0.87	1.12	1.07		0.0
BH-019	0	9.5	3.4	0.14	4.8	5.6	1.5	2.8	6.9	1.1	2.9	1.4	0.0
BH-020	0	2.5		0.18	< 4.89			1.68	2.56	1.01	0.98		0.0
BH-020	0	4.5	2.9	0.13	3.1	6.8	5	2.8	2.7	1.8	1.1	2.2	0.0
BH-020	0	9.5	4.8	0.18	4.9	12.2	5	2.9	11.5	9.4	11.3	8.3	0.4
BH-021	0	2.5	13.1	0.58	16.6	30.4	10.4	9	17.5	0.78	1	1.1	0.2
BH-021	0	5.5	11	0.45	14.4	37.1	3.1	2.9	20.2	0.63	1.1	0.92	0.0
BH-022	0	2	9.6	0.27	10.3	20.3	5.7	< 0.43	0.67	1.6	< 0.47	1.6	0.0
BH-022	0	5.5	36.1	1.2	34.8	107.1	54.3	9.3	37.5	1.4	1.9	1.6	0.3
BH-022	0	6.5	29	1.4	31		0.58	4.86	17	< 0.07	1.35	< 0.1	0.1
BH-022	0	7.5	17	0.76	17		4.6	4.22	23.4	0.29	1.15	0.28	0.1
BH-022	0	9.5	12.8	0.48	13	39.4	17.3	4.7	15.4	1.6	1.7	1.8	0.1
BH-023	0	9.5	6.6	0.6	6.6	14.1	1.8	0.13	9.1	0.61	1.1	0.64	0.0
BH-023	0	14.5	2.3	0.15	2.5	5.6	2.1	< 0.24	3.1	1.1	1.2	1.4	0.0
BH-025	0	3	81.7	4.7	81.8	225.2	8.9	4.1	74.5	0.66	1.2	0.9	0.2
BH-025	0	4.5		2.68	65.1			2.33	20.4	0.71	0.56		0.1
BH-025	0	8.5	71.3	2.9	76	226.2	1.9	1.6	100.9	0.76	1.6	0.51	0.1
BH-026	0	3.5		0.55	8.15			13.7	8.33		1.14		0.4
BH-026	0	4.5	18.3	0.63	17.8	65.6	24.9	21.9	12.2	0.48	0.51	0.88	0.7
BH-026	0	5.5		0.56	13.3			1.29	3.43		2.6		0.0
BH-026	0	7.5		0.56	11.3			< 0.642	1.64		2.49		0.0

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration																						
Location ID	Top	Bottom	U-234 (pCi/g)		U-235 (pCi/g)		U-238 (pCi/g)		U-Tot (µg/g)		Th-230 (pCi/g)		Ra-226 (pCi/g)		Th-234 (pCi/g)		Th-232 (pCi/g)		Ra-228 (pCi/g)		Th-228 (pCi/g)		Sum of Fractions
BH-026	0	9.5			0.1	<	2.23						1.21		0.82				2.9				0.0
BH-026	0	12.5	7.8		0.35		8.2		23.9		6.8		8.5		7.1		0.96		1.1		1.1		0.2
BH-026	0	15.5	1.1		0.03		1		3.5		1.5		1.2	<	4.2		1.1		1.5		1.2		0.0
BH-027	0	3			0.22	<	4.76						2.16		3.31		0.97		0.98				0.0
BH-027	0	4.5			0.09	<	4.77						1.44		1.67		0.99		0.86				0.0
BH-027	0	5.5	3.7		0.08		3.6		11.7		3.2		1.5		3.5		2.1		1.8		2.1		0.0
BH-027	0	8.5	6.8		0.19		7.1		21.7		7.3		4.6		8.1		2.9		2.4		2.9		0.1
BH-027	0	11.5	2.4		0.05		2.5		6.5		2.6		1.4		1.8		1.9		2		1.9		0.0
BH-027	0	23	1.1		0.08		1.1		2.9		1.5		1.1	<	3.1		1.3	<	0.62		1.3		0.0
BH-028	0	1			1.16		27.9						4.34		4.16		1.42		1.26				0.1
BH-028	0	2.5	23.5		1		23.5		49.8		3.5		5.1		25.2		1.1		1.9		2.7		0.2
BH-028	0	3.5			0.59		13.8						3.63		7.45		1.35		1.23				0.1
BH-028	0	10.5	3.5		0.08		3		7.7		2.8		1.7		3.2		1		0.81		1.4		0.0
BH-028	0	13.5	4.2		0.2		4.1		14.8		5.6		3.3		5.4		1.7		1.2		1.2	<	0.1
BH-029	0	2.5	54.8		1.4		53.4		91		16.9		4.5		75.3		1.6		1.2		1.6		0.1
BH-029	0	4			0.34		5.59						1.84		4.08		0.93		0.92				0.0
BH-029	0	11	5.1		0.33		5.5		14.6		7.8		4		12.8		1.9		1.5		1.5		0.1
BH-029	0	15.5	1.9		0.13		1.6		4.2		1.5		1.4		1.9		0.9		1.2		1.5		0.0
BH-030	0	2.5	24		3.9		28.2		43.6		18.6		3.5		20.3		1.6		1.8		1.1		0.1
BH-030	0	3.5			0.18	<	4.03						2.52		1.82		0.77		0.76				0.0
BH-030	0	4.5			0.33		5.79						2.2		5.98		0.84		0.94				0.0
BH-030	0	10.5			0.48		9.76						1.29		1.67		0.69		0.54				0.0
BH-030	0	12.5	14.3		0.71		14.6		42		8.3		1.3		3.3		2.6		0.83		3.2		0.1
BH-030	0	14.5	6.1		0.17		6.3		23.9		3.2		0.84		7.3		1.4		1.2		1.2		0.0
BH-031	0	1			0.31		5.06						2.72		5.64		1.11		1.19				0.0
BH-031	0	4.5			0.15	<	4.69						1.68		3.05		1.74		1.74				0.0
BH-031	0	6.5			0.16	<	4.08						3.04		2.46		1.63		1.53				0.0
BH-031	0	9			0.64		6.29						22.7		5.23		6.86		6.97				1.0
BH-031	0	10.5	3.8		0.1		4.2		12		9.7		26.5		11.4		2.7		4.7		4		0.9

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-031	0	13.5	1.5	0.07	1.4	6.3	1.5	1.7	3.1	0.67	1.4	0.72	0.0
BH-031	0	17.5	1.1	0.06	1.5	3.9	2.4	1.5	< 3.5	1.1	< 0.35	1.6	0.0
BH-032	0	2	11.7	0.52	12.6	30.2	6.6	6.3	16.7	0.82	2.1	1	0.2
BH-032	0	4		0.45	9.96			2.18	8.21	0.88	0.73		0.0
BH-032	0	5.5		0.18	< 4.93			1.03	2.74	0.66	0.79		0.0
BH-032	0	14.5	16	0.96	16.8	42.5	3	1.6	20.1	1.5	1.9	1.4	0.0
BH-032	0	17.5	7.1	0.26	7	18.2	3.7	1.4	7.9	2.4	1.4	2.2	0.0
BH-032	0	28	0.88	0.04	1.3	3.2	1.3	0.98	< 3.2	1.1	0.89	1.3	0.0
BH-033	0	1	21.1	0.87	20.7	77.5	15.4	2.6	22.6	1.9	0.86	1.9	0.0
BH-033	0	3		1.52	31.6			< 0.891	9.17		2.79		0.1
BH-033	0	6.5		0.24	3.61			1.74	0.69	0.764	0.78		0.0
BH-033	0	11		0.58	13.1			2.67	0.61	2.49	2.35		0.1
BH-033	0	12.5	46.6	2	49.7	126.1	4.2	2.9	46.7	1.4	1.2	1.4	0.1
BH-033	0	16.5	33.4	1.7	33.1	87.3	6.9	1.4	19.8	3.2	2.1	3.4	0.1
BH-034	0	3.5	5.9	0.24	5.2	13.9	6.3	6.9	7.4	1.2	1.5	1.3	0.2
BH-034	0	9.5	4.4	0.11	4.2	12.1	5.8	4.6	5.1	2.6	1.8	2.9	0.1
BH-034	0	15.5	2.4	0.13	2.5	8.8	2.1	1.3	5.1	1.5	1.2	1.5	0.0
BH-035	0	0.5	14.9	0.75	15.2	47.3	13	3.9	9.4	1.8	1.5	2.8	0.1
BH-035	0	1.5		0.26	5.5			3.7	3.35	1.15	1.25		0.0
BH-035	0	3.5		0.15	< 2.21			2.46	2.05	0.895	0.99		0.0
BH-035	0	5.5		0.25	< 3.42			3.17	3.24	1.05	1.1		0.0
BH-035	0	6.5	3.1	0.18	3.5	14.1	4.7	36.3	36.4	1.2	8.4	1.1	1.3
BH-035	0	16.5	1.6	0.04	1.4	5.6	1.8	1.5	2.8	1.2	1.5	1.6	0.0
BH-035	0	29	1	0.06	0.92	3	1.3	0.86	1.4	1.1	1.2	1.3	0.0
BH-036	0	0.5	2.8	0.14	3	8.3	3.6	3.2	< 5.6	0.99	1.6	1.3	0.0
BH-036	0	5.5	2.7	0.14	3.4	7.8	3.9	4.5	5	1	1.6	1.1	0.1
BH-036	0	16.5	5.6	0.26	6	12.1	3.5	2.4	7.3	1.2	1.2	1.2	0.0
BH-037	0	1	10.4	0.41	9.9	19	6.5	< 0.44	< 2.4	1.4	< 0.47	1.4	0.0
BH-037	0	7	5.2	0.1	5.3	8.9	6.1	4.3	4.7	1.7	< 0.55	1.9	0.1

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-037	0	11.5	4.2	0.2	4.4	8.4	2.9	6	1.1	1.7	1.7	1.4	0.1
BH-038	0	1	55.9	3	56.9	168.5	138.6	16.7	72	3.8	8	4.2	0.8
BH-038	0	3.5	62	3.1	61		3.2	4.73	56.6	< 0.1	2.06	< 0.2	0.2
BH-038	0	5.5	13	0.66	13		0.085	3.03	24.4	< 0.02	1.65	0.039	0.0
BH-038	0	6.5	9.9	0.41	10.3	34.2	22.4	3.8	8.9	1.3	1.3	1.3	0.1
BH-038	0	15.5	1.7	0.04	1.9	4.8	1.8	3.2	1.8	1.4	1.7	1.6	0.1
BH-039	0	1.5	22.6	1.2	29.7	50.9	23.3	21.1	20.4	1.2	1.8	1.5	0.7
BH-039	0	2.5		0.21	< 4.12			3.93	1.83	0.86	0.85		0.0
BH-039	0	4.5		< 0.14	5.39			5.56	2.98	0.8	0.86		0.1
BH-039	0	6.5		0.25	3.46			3.7	1.28	0.91	0.9		0.0
BH-039	0	8.5	2.7	0.17	3	8.9	7.7	5	0.95	1	1.3	1.2	0.1
BH-039	0	17.5	1.2	0.09	1.6	4.7	1.8	1	< 3.6	1.3	1.5	1.2	0.0
BH-039	0	30.5	1.5	0.06	1.3	3	2.2	0.96	1.8	1.4	< 1.2	1.5	0.0
BH-040	0	1		0.11	< 3.97			0.87	1.42	0.28	0.31		0.0
BH-040	0	2.5		0.28	< 5.91			2.28	4.31	1.36	1.37		0.0
BH-040	0	3.5	3.1	.0.08	3.3	9.3	2.8	2.8	4.4	1.3	1.6	1.4	0.0
BH-040	0	11.5	6.1	0.4	8	20.2	4.3	1.7	11.3	2.3	2.9	2	0.1
BH-040	0	17.5	0.97	0.08	1.1	3.6	1.3	1.1	0.67	1.3	1.1	1.1	0.0
BH-041	0	3.5	15.8	1	17.5	94.4	61.5	5.9	20.6	1.5	1.6	1.3	0.2
BH-041	0	4.5	6.2	0.29	6.1		0.3	3.04	11.2	< 0.05	1.24	0.17	0.0
BH-041	0	6.5	0.72	< 0.03	0.85		0.07	1.37	1.45	< 0.03	1.03	< 0.05	0.0
BH-041	0	8.5	4	0.19	3.9		0.095	1.35	6.03	< 0.02	1.01	< 0.02	0.0
BH-041	0	12	4.1	0.09	3.9	15.5	2.6	5.6	7.4	1	2.8	2.6	0.2
BH-041	0	16.5	3.9	0.24	4.2	11	2.3	3.9	3.8	1	1.5	1.2	0.1
BH-042	0	1	10.1	0.47	11.1	47.5	32	5	14.6	1.5	2.1	1.6	0.1
BH-042	0	2.5		0.16	< 4.98			1.12	2.43	1.12	1.25		0.0
BH-042	0	5		0.24	< 4.57			2.38	4.85	1.31	1.47		0.0
BH-042	0	7.5		0.25	6.11			2.23	5.61	0.992	0.94		0.0
BH-042	0	9.5		0.76	20.9			2.09	7.37	0.77	0.8		0.0

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-042	0	11	18.1	0.85	19	41	9.7	5.3	11.2	3	4	3.8	0.2
BH-042	0	16.5	2.1	0.04	2.2	5.9	2.9	1.9	3.9	1.3	1.9	1.4	0.0
BH-043	0	0.5	4	0.13	3.7	12.6	3	50.5	4.6	1.2	3.1	1.4	1.6
BH-043	0	2.5		0.4	10.2			24.8	< 0.676	1.67	1.83		0.8
BH-043	0	3.5		0.19	< 4.1			2.21	3.35	1.62	1.9		0.0
BH-043	0	4.5	4.2	0.19	4.4	9.4	2.9	11.8	7.2	1.1	1.7	1.1	0.3
BH-043	0	10.5	5.1	0.26	5.2	12.5	7.7	0.91	5.2	1	1.2	1.7	0.0
BH-044	0	0.5	5	0.39	5.4	16.5	4.1	16.7	13.3	1.4	1.8	1.4	0.5
BH-044	0	1.5		0.17	< 6.01			1.1	0.91	0.48	0.48		0.0
BH-044	0	2.5		0.33	6.71			7.92	5.4		1.02		0.2
BH-044	0	8.5		0.28	7			1.74	3.82	0.9	0.8		0.0
BH-044	0	11	4.1	0.22	4.8	11.5	6	3	4.7	3.1	2.8	3.1	0.1
BH-044	0	17.5	1.6	0.04	2.4	3.6	1.7	1.3	3.9	1.2	1.5	1.3	0.0
BH-045	0	2	2.9	0.17	3.1	9.5	5.6	1.8	3.3	0.89	0.96	1.1	0.0
BH-045	0	9.5	1.3	0.04	1.5	3.5	1.6	1.1	1.8	0.81	1	0.71	0.0
BH-045	0	13.5	1.6	0.11	2.1	5.1	8.3	1.2	1	0.71	0.72	0.65	0.0
BH-046	0	2.5	1.8	0.06	2	5.3	2.2	1.4	3.3	1.4	0.67	0.85	0.0
BH-046	0	9.5	5.3	0.31	6.5	13.5	5.4	3.5	5.5	< 0.61	1.1	2.3	0.1
BH-046	0	13.5	5.2	0.12	5.5	14.3	3	7.4	14.6	2.6	1.6	3.8	0.2
BH-047	0	3.5	6	0.45	6.2	14.3	4.6	2.9	11.9	1.1	1.7	1.3	0.0
BH-047	0	7.5	3.4	0.19	5.8	13.6	2.5	2.3	2.5	1.3	1.6	1.4	0.0
BH-047	0	19.5	1	0.04	1.5	3	1.5	1.3	< 3.9	1	1.2	1.1	0.0
BH-048	0	3.5	1.3	0.11	1.3	3.3	1.5	1.6	< 4.1	1	1.3	1.5	0.0
BH-048	0	9.5	2.1	0.03	2.6	6	1.6	2.4	3.6	1.1	1	0.94	0.0
BH-048	0	16.5	1	-0.01	0.79	2.6	0.94	1.4	1.5	0.59	1	0.82	0.0
BH-049	0	2.5	4.7	0.33	4.9	9.2	3.5	4.8	5.9	1.1	1.9	1.1	0.1
BH-049	0	10.5	6.5	0.32	6.8	10.9	3.4	4.8	10	1.2	1.5	0.85	0.1
BH-049	0	13.5	1.3	0.09	1.1	4.2	1.6	1.2	< 4.2	1.2	1.3	1.3	0.0
BH-050	0	3	13.3	0.79	60.9	196.8	2.1	2.4	79.2	1.1	1.3	1.2	0.0

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-050	0	5.5	1.7	0.21	1.5		1.5			0.81		0.85	0.1
BH-050	0	14.5	16.9	0.8	22.9	31.1	3.4	4.1	25.4	0.87	1.6	0.77	0.1
BH-050	0	18.5	6.4	0.38	10.6	23.2	1.4	1.4	14.3	1.2	1.1	1.1	0.0
BH-051	0	2.5	7.3	0.41	8.6	25.7	4.3	3.6	12.4	0.99	1.4	1	0.0
BH-051	0	6.5	2.1	0.06	1.9	6.3	0.18	2.5	2.4	0.66	1	0.85	0.0
BH-051	0	13.5	5.6	0.19	5.8	17.3	8.3	7.9	12.8	2.2	2.6	1.8	0.2
BH-051	0	18.5	5.2	0.33	5.6	15.4	2.3	1.4	15.8	1	5	1.1	0.1
BH-052	0	4	27.3	0.98	28.5	94	29.4	1511	< 65.8	7	13.3	19	50.3
BH-052	0	7.5		0.49	6.66			19.3	5.25	2.43	2.5		0.6
BH-052	0	9.5		0.2	< 3.74			3.73	1.8	0.58	0.59		0.0
BH-052	0	10.5		0.11	< 2.63			1.62	1.64	0.306	0.32		0.0
BH-052	0	13.5	8.8	0.33	9.5	29.7	2.3	18.4	5.2	0.62	1.3	1.2	0.5
BH-052	0	19.5	1.2	0.04	1.4	5.6	2.2	2.1	3.7	1.5	1.6	1.8	0.0
BH-053	0	2	8.1	0.31	7.8	23.3	7	9.8	11.4	1.4	2.2	1.8	0.3
BH-053	0	3.5		0.09	< 2.04			1.11	1.55	0.76	< 0.112		0.0
BH-053	0	9.5	4.4	0.44	5.6	19.9	3.2	2.8	5.3	1.4	1.2	1.6	0.0
BH-053	0	13.5	2.7	0.08	2.6	10.1	1.3	1.1	3.2	0.88	1.2	1	0.0
BH-054	0	1.5	30.9	1.6	30.8	84.1	25.2	192	55.3	3.8	6.3	4.9	6.5
BH-054	0	4.5		0.92	10.7			< 1.18	10.9		2.91		0.1
BH-054	0	5.5	4.1	0.17	4.4	17.2	1.8	1.6	10.2	0.97	1.6	0.81	0.0
BH-054	0	7		0.23	3.86			< 0.535	2.9		1.61		0.0
BH-054	0	9.5		0.09	< 3.81			2.14	0.96		2.39		0.0
BH-054	0	11.5		< 0.0375	< 2.1			< 0.66	1.83		1.39		0.0
BH-054	0	12.5		0.13	< 2.72			1.6	1.51		1.34		0.0
BH-054	0	14.5		0.27	3.69			2.26	2.2		0.58		0.0
BH-054	0	15.5	8.7	0.36	9.2	29.2	2	9.8	9.3	0.89	1.6	1.2	0.3
BH-054	0	19.5		0.09	< 3.42			< 0.787	1.28		2.89		0.0
BH-054	0	20.5	1.6	0.05	1.3	4.2	1.8	1.3	< 3.8	1.3	1.4	1.1	0.0
BH-055	0	3	10.2	0.54	13.8	23.5	1.8	2	12	0.7	0.98	0.86	0.0

Table 4-7, Analytical Results of Columbium-Tantalum Characterization Plan Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-055	0	4.5		0.23	4.39			2.06	1.27		2.07		0.0
BH-055	0	5.5		0.17	< 2.92			1.48	2.19		2.13		0.0
BH-055	0	7		0.19	< 2.58			2.63	2.2		3.32		0.1
BH-055	0	9.5	37.9	2.9	242.7	1321	1.5	2.5	679.7	0.9	1.6	1.2	0.2
BH-055	0	11	16.7	1	17.5		4.3			1.3		1.7	1.6
BH-055	0	12.5	16.1	0.84	16.7		6.3			2.9		2.7	1.6
BH-055	0	15	13.5	0.49	18.7	47.6	9.6	60.7	30.5	2.2	6.6	4.2	2.1
BH-055	0	19		0.14	< 2.69			2.97	1.77		3.23		0.1
BH-055	0	20.5		0.15	< 3.55			2.5	1.66		3.18		0.1
BH-056	0	3		0.05	< 3.07			0.79	0.95	0.7	0.77		0.0
BH-056	0	4.5	3.5	0.1	3.9	9.5	2.1	3.1	5.8	1.1	2.8	1.5	0.1
BH-056	0	11.5	6.3	0.21	6.2	14.8	4.1	4.8	9.2	0.96	1.8	1	0.1
BH-056	0	14.5	8.7	0.32	8.7	24.1	3.8	4.4	12.3	0.81	1.7	1	0.1
BH-056	0	29			1.17	3.5	0.97	0.69	0.01	0.74	< 0.45	0.97	0.0

Table 4-8, Analytical Results of Soil Samples at Building 245

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-062	0.5	1		0.61	10.8			3.04	5.7	1.24	1.15		0.0
BH-062	1	2	30.28	1.64	29.34		3.81	3.45		0.77	1.34	0.93	0.1
BH-062	4	5		0.25	5.07			1.52	4.62	1.07	1.09		0.0
BH-062	6	7		0.35	6.24			2.92	5.54	1.25	1.27		0.0
BH-062	7	8	4.63	0.29	4.95		4.48	6.15		2.35	3.18	2.22	0.2
BH-062	15	16	28.16	2.09	29.97		3.33	5.85		0.78	2.5	0.93	0.2
BH-063	1	2	6.87	0.45	7.62		5.25	4.77		1.42	1.46	1.38	0.1
BH-063	4	6	7.2	0.63	6.45		2.67	2.25		1.26	1.32	1.12	0.0
BH-063	12	13	26.73	1.48	28.49		5.99	4.08		1.8	4.32	2.15	0.2
BH-064	1	2	11.95	0.78	11.88		4.27	4.19		0.84	1.6	1.04	0.1
BH-064	4	5	5.83	0.39	5.06		3.4	4.07		0.87	1.54	1.03	0.1
BH-064	11	12	3.35	0.22	3.75		2.42	2.58		1.52	1.36	1.48	0.0
BH-065	0	0.5	6.4	0.49	5.92		3.78	5.35		1.01	1.98	1.03	0.1
BH-065	0	3.5	2.02	0.19	1.68		1.93	4.18		1.53	2.36	1.1	0.1
BH-066	0	1.5	60.12	3.52	66.01		77.9	3.56		1.31	0.97	1.11	0.2
BH-066	0	3.5	5.67	0.3	5.69		3.8	4.19		1.18	1.4	0.97	0.0
BH-066	2	3		0.91	18.9			3.07	5.73	1.03	1.04		0.1
BH-067	1	2	9.45	0.5	9.81		5.5	4.07		0.85	1.83	1.26	0.1
BH-067	4	6	6.12	0.2	6.47		4.47	4.66		1.03	1.98	1.19	0.1
BH-067	15	16	4.08	0.17	3.9		2.51	7.37		0.83	2.14	0.73	0.2
BH-068	0	1.5	12.03	0.48	11.63		4.92	3.74		1.12	1.41	1.14	0.1
BH-068A	5	6	7.82	0.31	7.89		5.38	6.45		1.29	1.95	1.15	0.2
BH-069	0.5	1	16.96	0.86	17.31		5.91	5.05		0.85	1.36	0.78	0.1
BH-069	2	3	10.6	0.81	11.09		5.39	4.82		0.94	1.52	1.26	0.1
BH-069	2	3	11.15	0.69	11.47		7.08	3.51		0.81	1.28	0.76	0.0
BH-120	0	9	2.26		2.4		4.18	3		1.04		1.13	0.0

Table 4-9, Analytical Results of Soil Samples at Building 200 West

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-095	0	3	2.2		2.1		4.54	3.48		1.14		1.17	0.0
BH-095	3	5	1.7		1.8		3.16	1.61		0.99		0.97	0.0
BH-096	0	3	5.6		4.3		4.93	4.32		1.42		1.27	0.1
BH-096	3	5.5	< 0.12		< 0.12		1.85	1.52		1.16		1.03	0.0
BH-097	0	3	2		1.7		2.33	1.39		0.61		0.81	0.0
BH-097	3	6	0.88		1.2		1.36	2.17		< 0.75		0.6	0.0
BH-098	0	3	3.3		2.7		3.92	1.27		1.01		1.04	0.0
BH-098	3	5	4.7		3.5		4.76	2.27		1.17		1.42	0.0

Table 4-10, Analytical Results of Soil Samples at Plant 5 Tank Farm

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-099	0	3	1.95		2.25		1.69	1.01		6.49	0.8	7.06	0.2
BH-099	3	6	1.79		1.69		1.66	2.04		4.79	1.24	7.63	0.2
BH-099	6	9	1.3		1.43		1.26	0.87		4.5	0.88	3.56	0.1
BH-100	0	3	9.73		9.26		8.86	0.86		2.84	1.75	2.84	0.1
BH-100	3	6	1.89		2		1.95	1.06		6.12	1.53	9.04	0.2
BH-100	6	8.5	9.8		7.02		5.61	1.46		2.61	2.21	1.98	0.0
BH-101	0	3	7.95		8.06		1.01	2.09		8.15	1.75	7.75	0.2
BH-101	3	6	1.72		1.9		1.09	1.92		2.61	2	4.27	0.1
BH-101	6	9	9.13		1.07		4.39	1.97		4.31	0.9	3.7	0.1
BH-102	0	3	9.52		7.62		9.1	1.54		5.73	0.84	1.11	0.0
BH-102	3	6	1.48		1.2		6.38	2.04		3	0.54	3.19	0.1
BH-102	6	9	1.98		1.79		1.34	2.38		3.6	0.49	-1.03	0.0

Table 4-11, Analytical Results of Soil Samples at Buildings 201/215

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-103	0	2	7.7		6.72		4.01	0.86	6.29	1.34			0.0
BH-103	2	4	6		5.94		4	0.85		1.06			0.0
BH-104	0	2	5.58		6.18		3.57	1.04		1.1			0.0
BH-104	2	4	3.53		3.53		1.85	0.87	3.74	1.23			0.0
BH-104	4	6	2.71		2.67		1.33	1.05		1			0.0
BH-105	0	2	4.7		3.92		2.23	0.53		0.77			0.0
BH-105	2	4	0.4		0.3		0.55	0.2		0.34			0.0
BH-105	4	5.5	0.43		0.41		0.65	0.1		0.36			0.0
BH-106	0	2	10.4		11.85		3	0.63	3.36	1.04			0.0
BH-106	2	4	10.8		12.34		2.64	0.88	7.25	1			0.0
BH-106	4	6	0.72		0.71		0.7	0.18		0.35			0.0
BH-107	0	2	1.91		2.35		1.98	0.39		0.75			0.0
BH-107	2	4	3.11		2.41		1.39	0.37		0.44			0.0
BH-107	4	6	1.9		1.81		1.51	0.58		0.79			0.0
BH-108	0	2	2.22		2.15		2.27	0.43	8.07	0.7			0.0
BH-108	2	4	3.52		3.3		2.3	0.42		0.74			0.0
BH-108	4	6	1.52		1.6		1.57	0.34	1.62	0.53			0.0
BH-108	6	8	2.51		2.37		2.2	0.55		0.47			0.0
BH-108	8	10	1.55		1.61		1.01	0.26		0.48			0.0
BH-109	0	2	5.78		5.27		3.94	0.19		0.97			0.0
BH-109	2	4	4.29		3.74		2.69	0.33		0.88			0.0
BH-109	4	6	3.91		4.38		2.77	0.26	4.02	0.97			0.0
BH-109	6	8	3.43		3.38		2.25	0.17		0.82			0.0
BH-109	8	10	3.02		3.01		2.08	0.36		0.48			0.0
BH-110	0	2	6.35		6.5		3.87	0.65	10.05	1.05			0.0
BH-110	2	4	3.58		3.06		2.39	1.02		0.99			0.0
BH-110	4	6	4.54		5.04		2.61	0.57	4.86	0.89			0.0
BH-110	6	8	5.86	0.47	6.74		2.58	0.88		0.36			0.0
BH-111	0	2	7.68		7.68		1.91	0.81	7.72	1.05			0.0

Table 4-11, Analytical Results of Soil Samples at Buildings 201/215

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-111	2	4	9.76		10.53		3.5	1.39	10.34	1.65			0.1
BH-111	4	6	2.83		3.43		0.84	0.44		0.86			0.0
BH-121	0	1	4.26	0.12	4.07		6.73	82.5		1.24	-0.44	1.54	2.6

Table 4-12, Analytical Results of Soil Samples at Building 250

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-094	0.8	4	6.78		3.14		4.78	1.93		2.35		3.67	0.1
BH-112	0	2	25.68	0.9	26.54		11.5	6.06	21.36	0.88			0.1
BH-112	2	4	5.46	0.36	4.29		1.98	2.4	3.07	1.09			0.0
BH-112	4	6	1.47	0.07	1.15		1.52	2.35	1.83	1.55			0.1
BH-113	0	2	15.08	0.59	15.31		3.75	3.23	6.68	0.61			0.0
BH-113	2	4	9.48	0.46	8.48		5.45	2.22	5.16	0.88			0.0
BH-113	4	6	3.4	0.37	3.66		1.34	0.67	2.51	0.65			0.0
BH-114	0	2	18.71	0.84	19.17		10.03	3.92	13.79	1.42			0.1
BH-114	2	4	32.85	1.34	36.74		30.43	5.6	14.95	1.11			0.2
BH-114	4	6	3.43	0.28	3.12		2.96	1.51	0.16	1.11			0.0
BH-115	0	2	15.77	0.65	17.28		2.37	2.59	10.44	1.01			0.0
BH-115	2	4	20.84	1.61	21.63		2.77	2.99	11.28	1.21			0.1
BH-115	4	6	13.63	0.62	12.98		2.44	1.89	8.04	0.67			0.0
BH-116	0	2	8.99	0.32	9		7.06	3.61	8.33	1.41			0.1
BH-116	2	4	3.34	0.37	2.97		2.8	3.66	6.42	0.71			0.0
BH-116	4	6	5.62	0.14	5.49		2.04	2.06	3.73	1.17			0.0
BH-117	4	6	2.09		1.87		2.09	0.27	1.14	0.7			0.0
BH-117	6	9	3.42		3.39		2.2	0.38	0.44	0.54			0.0
BH-117	9	12	3		2.83		2.68	0.22	3.05	0.92			0.0
BH-118	4	6	2.3		2.37		1.7	0.16	1.79	0.89			0.0
BH-118	6	9	1.72		1.46		1.58	0.42	0.7	0.96			0.0
BH-118	9	12	1.27		1.23		1.86	0.56	0.29	1.14			0.0
BH-119	4	6	1.35		0.98		1.56	0.31	1.86	0.85			0.0
BH-119	6	9	1.38		2.11		2.05	0.62	1.07	1.54			0.0
BH-119	9	12	1.46		1.07		1.76	0.58	0.07	1.53			0.0
BH-119	12	15	0.96		1.46		1.54	0.44	1.46	1.04			0.0
BH-119	15	18	1.3		1.13		1.73	0.66	1	1.12			0.0
BH-119	18	21	1.34		1.3		1.89	0.46	1.04	1.33			0.0

Table 4-13, Analytical Results of Soil Samples at Building 235

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-Z-01	0	1	4.39		4.18		3.18	0.39	3.25	0.82			0.0
BH-Z-01	1	3	5.24		5		4.01	0.78	3.48	1.56			0.0
BH-Z-01	3	6	4.28		4.02		3.28	0.41	2.2	1.56			0.0
BH-Z-01	6	9	4.59		4.77		3.73	0.34	2.9	1.48			0.0
BH-Z-01	9	12	3.48		4.14		3.44	0.14	0.74	0.86			0.0
BH-Z-02	0	1	6.45		6.25		4.36	0.27	2.92	1.16	0.49	1.42	0.0
BH-Z-02	1	3	7.88		7.21		3.48	0.38	3.7	1.01	0.76	0.95	0.0
BH-Z-02	3	6	4.01		3.8		5.13	0.21	3.1	1.27	0.73	0.98	0.0
BH-Z-02	6	9	4.78		4.27		3.66	0.23	3.13	1.31	0.76	1.36	0.0
BH-Z-02	9	12	5.38		5.36		4.68	0.19	2.28	1.65	0.81	1.18	0.0
BH-Z-03	0	1	7.6		7.52		3.43	0.25	3.35	1.01	0.53	0.76	0.0
BH-Z-03	1	3	7.25		7.58		4.49	0.13	2.92	1.05	0.65	1.12	0.0
BH-Z-03	3	6	4.94		4.36		4.76	0.37	3.44	1.08	0.79	1.12	0.0
BH-Z-03	6	9	5.99		4.66		4.36	0.41	3.73	1.13	0.82	1.03	0.0
BH-Z-03	9	12	2.94		3.49		3.3	0.29	1.94	0.94	1.13	0.7	0.0
BH-Z-04	0	1	16.18		17.07		4.07	2.13	13.22	2.34	3.01		0.1
BH-Z-04	1	3	7.84		8.16		2.47	1.16	2.74	1.64	1.39		0.0
BH-Z-04	3	6	6.68		7.27		4.29	1.02	0.69	0.87	0.66		0.0
BH-Z-04	6	9	5.64		4.44		5.71	0.64	2.46	1.4	0.97		0.0
BH-Z-04	9	12	5.8		5.24		5.22	0.48	1.86	1.18	0.92		0.0
BH-Z-05	2.5	3.5	3.32		3.17		2.79	0.64	1.55	1.03			0.0
BH-Z-05	3.5	5.5	2.78		2.6		3.73	0.41	0.49	1.3			0.0
BH-Z-05	5.5	8.5	4.7		4.82		5.16	0.63	3.63	1.59			0.0
BH-Z-05	8.5	11.5	4.13		4.43		2.52	0.34	1.75	0.84			0.0
BH-Z-05	11.5	14.5	4.45		3.68		2.85	0.53	1.19	0.93			0.0
BH-Z-06	3	4	4.53		4		4.74	0.61	3.49	1.67			0.1
BH-Z-06	4	6	4.06		3.66		4.17	0.79	2.68	1.14			0.0
BH-Z-06	6	9	3.08		3.53		2.64	0.48	1.39	0.92			0.0
BH-Z-06	9	12	4.53		4.13		4.52	0.42	1.85	1.05			0.0

Table 4-13, Analytical Results of Soil Samples at Building 235

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-Z-06	12	15	4.76		5.09		5.82	0.09	2.68	1.24			0.0
BH-Z-07	0	1	16.35		15.9		5.06	0.57	14.93	1.1	1.13		0.0
BH-Z-07	1	3	22.72		25.38		3.47	0.74	10.77	0.93	0.66		0.0
BH-Z-07	3	6	10.67		10.38		2.3	0.3	6.42	0.77	0.68		0.0
BH-Z-07	6	9	2.37		1.78		2.26	0.52	2.52	1.06	0.71		0.0
BH-Z-07	9	12	4.05		4.62		3.27	0.22	3.8	1	0.82		0.0
BH-Z-08	0	1	1.54		1.99		0.94	0.2	0.89	0.27	0.16	0.03	0.0
BH-Z-08	1	3	4.25		3.75		3.07	0.54	2.17	0.75	0.41	0.79	0.0
BH-Z-08	3	6	5.39		5.12		4.24	0.3	1.73	1.47	0.64	1.26	0.0
BH-Z-08	6	9	3.69		3.89		3.71	0.25	1.98	0.9	0.57	1.2	0.0
BH-Z-08	9	12	3.25		3.47		3.41	0.15	-0.29	1.45	0.77	0.88	0.0
BH-Z-09	0	1	12.01	0.41	11.24	0.41	4.64	0.27	7.33	0.89	0.49	0.55	0.0
BH-Z-09	1	3	6.16		7.36		3.99	0.26	2.07	1.15	0.66	0.88	0.0
BH-Z-09	3	6	4.3		4.59		3.14	0.3	2.86	1.07	0.69	1.07	0.0
BH-Z-09	6	9	4.24		4.19		2.88	0.45	1.87	0.6	0.47	0.73	0.0
BH-Z-09	9	12	3.75		4.3		3.33	0.25	3.08	0.94	0.69	1.02	0.0
BH-Z-10	0	1	1.33		1.45		1.12	0.35	0.25	0.48	0.5	0.48	0.0
BH-Z-10	1	3	1.01		1.05		1.03	0.42	1.1	0.78	0.73	0.73	0.0
BH-Z-10	3	6	2.15		1.66		2.71	0.41	1.08	1.06	0.62	1	0.0
BH-Z-10	6	9	3.69		4.16		3.97	0.32	1.38	1.05	0.82	0.75	0.0
BH-Z-10	9	12	4.91		4.43		3.51	0.12	3.18	0.99	0.87	0.93	0.0
BH-Z-11	0	1	11.18		10.91		4.63	0.51	4.67	1.05			0.0
BH-Z-11	1	3	9.49		10.04		4.31	1.26	7.98	0.98			0.0
BH-Z-11	3	6	3.66		3.83		2.17	0.69	1.96	1.17			0.0
BH-Z-11	6	9	2.96		2.8		2.97	0.2	1.22	0.86			0.0
BH-Z-11	9	12	5.3		4.94		5.87	0.46	2.98	1.41			0.0
BH-Z-12	0	1	6.18		6.34		4.45	0.43	5.03	1.19	0.97		0.0
BH-Z-12	1	3	2.73		2.39		2.26	0.69	1.39	1.19	0.91		0.0
BH-Z-12	3	6	3.85		2.66		4.03	0.33	1.87	0.94			0.0

Table 4-13, Analytical Results of Soil Samples at Building 235

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-Z-12	6	9	6.74		7		3.8	0.23	1.62	0.86			0.0
BH-Z-12	9	12	2.96		2.14		1.57	0.15	0.25	0.41			0.0
BH-Z-13	0	1	1.39		1.26		2.24	0.28	2.17	0.35			0.0
BH-Z-13	1	3	4.21		4.08		2.81	0.3	2.78	1.1			0.0
BH-Z-13	3	6	3.74		3.79		3.86	0.67	3.4	0.94			0.0
BH-Z-13	6	9	2.96		3.13		2.92	0.52	3.77	1.29			0.0
BH-Z-13	9	12	4.01		3.47		3.8	0.84	1.96	1.05			0.0
BH-Z-14	0	1	3.65		3.12		2.86	0.78	1.81	0.74			0.0
BH-Z-14	1	3	4.5		4.41		3.59	0.67	3.15	0.88			0.0
BH-Z-14	3	6	3.11		3.17		2.34	0.42	1.74	0.62			0.0
BH-Z-14	6	9	4.03		3.54		2.89	0.39	2.41	0.92			0.0
BH-Z-14	9	12	5.5		5.65		4.51	0.4	5.38	0.99			0.0
BH-Z-15	0	1	14.21		12.45		2.15	1.71	5.6	0.74	0.57		0.0
BH-Z-15	1	3	10.64		9.43		2.4	0.93	5.66	0.63	0.61		0.0
BH-Z-15	3	6	6.72		6.22		2.94	0.9	4.04	0.81	0.91		0.0
BH-Z-15	6	9	4.8		4.16		2.3	1.04	1.66	0.58	0.52		0.0
BH-Z-15	9	12	6.02		6.24		3.21	0.75	3.76	0.84	0.81		0.0
BH-Z-16	0	1	10.51		10.67		2.14	1.13	13.94	0.56	0.81		0.0
BH-Z-16	1	3	14.2		14.11		2.8	0.72	8.9	0.42	0.79		0.0
BH-Z-16	3	6	10.33		9.64		2.45	0.73	3.91	0.8	0.73		0.0
BH-Z-16	6	9	9.72		9.82		2.74	0.77	8.02	0.85	0.81		0.0
BH-Z-16	9	12	6.78		4.94		3.29	0.97	2.65	1.25	0.99		0.0
BH-Z-17	0	1	3.41		2.97		1.5	0.54	-0.31	0.73	1.36		0.0
BH-Z-17	1	3	4.06		3.67		4	0.55	4.76	1.37	1.61		0.0
BH-Z-17	3	6	5.78		5.22		4.31	0.38	3.41	1.52	0.81		0.0
BH-Z-17	6	9	4.59		4.57		3.46	0.46	3.15	1.34	0.67		0.0
BH-Z-17	9	12	4.34		4.76		2.8	0.19	2.01	1.1	1.22		0.0
BH-Z-18	0	1	4.6		4.83		1.98	0.41	5.21	0.61	0.89		0.0
BH-Z-18	1	3	2.96		2.71		1.71	0.28	1.98	0.68	0.53		0.0

Table 4-13, Analytical Results of Soil Samples at Building 235

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-Z-18	3	6	3.34		3.18		2.94	0.35	1.79	0.8	0.68		0.0
BH-Z-18	6	9	4.9		4.5		4.31	0.48	-0.23	1.29	0.8		0.0
BH-Z-18	9	12	4.87		4.27		2.69	0.43	1.39	0.91	0.93		0.0
BH-Z-19	9	12	3.72		3.5		5.93	0.49	2.13	1.3			0.0
BH-Z-19	12	15	9.41		9.94		4.76	0.2	5.3	1.42			0.0
BH-Z-19	15	18	6.35		6.56		6.87	0.74	6.04	1.59			0.1
BH-Z-20	9	12	5.77		6.02		6.25	0.21	2.4	1.15			0.0
BH-Z-20	12	15	4.3		5.29		2.9	0.13	1.55	1.1			0.0
BH-Z-20	15	18	7		8.87		2.94	0.28	3.85	1.03			0.0
BH-Z-21	0	3	3.87		3.59		3.4	0.56	5.08	0.85			0.0
BH-Z-21	3	6	5.14		5.15		3.87	0.63	3.12	1.11			0.0
BH-Z-21	6	9	4.21		4.43		3.88	0.4	2.64	1.17			0.0
BH-Z-21	9	12	7.53		8.46		4.79	0.2	6.96	1.15			0.0
BH-Z-21	12	15	6.46		7.47		3.9	0.33	5.66	1.19			0.0
BH-Z-22	0	3	10.78		11.48		11.14	0.83	6.02	0.81			0.0
BH-Z-22	3	6	23.84		24.43		6.62	0.86	13.7	0.99			0.0
BH-Z-22	6	9	13.17		12.37		2.86	0.31	7.78	1.18			0.0
BH-Z-22	9	12	2.3		3.58		2.08	0.1	1.26	0.96			0.0
BH-Z-22	12	15	9		9.68		4.47	0.06	8.34	0.99			0.0
BH-Z-23	0	3	10.56		10.48		8.12	1.14	6.97	0.88			0.0
BH-Z-23	3	6	12.64		15.55		3.96	0.61	4.78	1.17			0.0
BH-Z-23	6	9	6.03		5.88		3.42	0.25	4.86	1.35			0.0
BH-Z-23	9	12	12.22		13.12		4.61	0.12	9.28	1.56			0.1
BH-Z-23	12	15	11.24		11.96		3.41	0.23	16.33	0.99			0.0

Table 4-14, Analytical Results of Soil Samples at Building 204

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-070	0	4	3.43	0.28	3.37		3.03	2.42		1.41	1.44		0.0
BH-070	4	8	5.9	0.24	5.5		4.8	5.23		1.44	1.01		0.1
BH-070	8	12	2.22	0.146	2.38		2.77	2.7		1.23	0.84		0.0
BH-071	0	4	4.15	0.33	4.31		3.23	3.84		1	0.71		0.0
BH-071	4	8	2.12	0.108	2.09		2.21	0.91		0.95	1.09		0.0
BH-071	8	12	2.36	0.144	2.04		2.68	1.82		0.89	0.88		0.0
BH-072	0	4	9.5	0.57	9.9		3.63	2.48		1.26	1.26		0.0
BH-072	4	8	4.6	0.22	4.4		2.15	1.55		0.71	0.77		0.0
BH-072	8	12	6.8	0.45	6.5		3.11	4.37		1.08	0.64		0.1
BH-073	0	4	1.46	0.053	1.58		1.79	1.15		0.99	0.85		0.0
BH-073	4	8	3.64	0.28	3.73		3.72	3.23		1.02	0.87		0.0
BH-073	8	12	1.75	0.112	1.82		1.9	3.38		1.01	0.53		0.0
BH-074	0	4	3	0.25	3.14		3.47	3.74		1.17	0.98		0.0
BH-074	4	8	4.5	0.58	4.9		5.3	4.13		1.33	1.24		0.1
BH-074	8	12	2.29	0.104	2.39		2.76	3.04		1.23	1.12		0.0
BH-075	0	4	1.12	0.16	1.4		1.59	2.81		0.9	0.71		0.0
BH-075	4	8	1.64	0.104	1.82		1.88	2.18		0.8	0.92		0.0
BH-075	8	12	2.3	0.35	2		2.25	3.56		0.54	0.72		0.0
BH-076	0	4	2.21	0.24	2.42		2.01	2.01		0.86	1.24		0.0
BH-076	4	8	2.98	0.17	3.17		2.82	4.34		1.08	1.35		0.1
BH-076	8	12	1.08	0.03	0.58		0.8	1.69		0.44	0.4		0.0
BH-077	0	4	2.73	0.17	2.55		3.01	1.71		1.31	1.71		0.0
BH-077	4	8	2.54	0.18	2.86		3.08	3.46		1.25	1.37		0.0
BH-077	8	12	6	0.5	6.6		3.54	4.34		0.67	0.38		0.1
BH-078	0	4	2.2	0.16	2.37		2.72	3.89		0.72	0.24		0.0
BH-078	4	8	2.23	0.154	2.08		2.34	2.46		1.06	1.05		0.0
BH-078	8	12	1.69	0.141	1.96		1.77	3.24		0.81	0.6		0.0
BH-079	0	4	1	0.046	1.14		1.45	1.09		0.97	0.71		0.0
BH-079	4	8	0.92	0.061	0.98		1.07	1.23		0.81	0.66		0.0

Table 4-14, Analytical Results of Soil Samples at Building 204

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-079	8	12	2.78	0.19	3.36		3.39	3.8		1.01	0.68		0.0
BH-080	0	4	3.21	0.19	3.21		2.73	2.05		1.16	1.22		0.0
BH-080	4	8	2.91	0.148	3.08		2.08	1.78		1.22	1.13		0.0
BH-080	8	12	2.67	0.21	3.05		2.76	1.39		1.03	0.9		0.0
BH-081	0	4	1.11	0.066	1.14		4.4	1.05		1.08	0.98		0.0
BH-081	4	8	3.26	0.15	3.22		1.88	4.31		1.19	0.94		0.1
BH-081	8	12	5.1	0.44	4.7		5.2	3.68		1.2	1.21		0.1

Table 4-15, Analytical Results of Soil Samples at Plant 5

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-082	0.5	1.5	15.6	0.9	15		9.8	3.67	7.6	1.6	1.1	1.33	0.1
BH-082	3	4.5	11.8	0.62	11.2		4.8	2.4	6.4	1.24	0.76	1.09	0.0
BH-082	6	7.5	2.33	0.15	2.68		1.88	2.06	2.3	0.89	0.59	1.04	0.0
BH-082	9	10.5	1.08	0.051	1		1.46	1.07		0.97	0.68	1.03	0.0
BH-082	12	13.5	2.21	0.104	2.32		2.6	2.02		0.97	0.23	0.92	0.0
BH-082	15	16.5	0.95	0.047	0.9		1.44	1.12		1.34	0.99	1.32	0.0
BH-083	0.5	1.5	23.8	1.06	23.9		24.4	1.95	18.7	0.72	0.49	0.66	0.0
BH-083	3	4.5	99	4.8	97		8.4	2.65	105	1.46	1.64	1.77	0.2
BH-083	6	7.5	30.5	1.96	30.1		2.26	2.92	23.1	0.76	1.6	1.02	0.1
BH-083	10.5	12	1.35	0.068	1.35		0.94	1.46		0.91	0.85	0.93	0.0
BH-083	13.5	15	1.82	0.059	1.89		0.86	0.92		0.75	0.79	0.76	0.0
BH-083	16.5	18	0.77	0.052	0.83		1.2	1.02		1.24	0.83	1.32	0.0
BH-084	0.5	1.5	2.99	0.174	2.85		2.69	2.1		0.96	0.68	1.08	0.0
BH-084	3	4.5	2.43	0.108	2.58		2.34	1.14		1.05	0.65	1.05	0.0
BH-084	6	7.5	0.67	0.069	0.82		1.48	1.41		1.04	0.86	1.16	0.0
BH-085	1	1.5	1.98	0.14	2.1		1.42	1.48		0.69	0.68	0.72	0.0
BH-085	3	4.5	3	0.134	2.89		2.64	1.6		0.96	0.79	1.16	0.0
BH-085	6	7.5	0.62	0.038	0.63		0.62	0.54		0.45	0.75	0.52	0.0
BH-085	7.5	9	0.93	0.061	0.93		1.05	0.55		0.93	1.14	0.9	0.0
BH-086	1	1.5	13.2	0.72	12.9		4.43	3.63	12.2	1.08	1.01	1.25	0.1
BH-086	3	4.5	4.34	0.168	4.37		4.21	1.71		8.6	2.98	7.9	0.2
BH-086	6	7.5	7.2	0.43	7.7		11.4	7.1		27.5	17	29.2	1.3
BH-086	7.5	9	1.41	0.079	1.63		1.29	1.36		2.22	1.54	2.09	0.0
BH-087	1	1.5	30.9	1.66	31.6		13.3	4.46	44.5	1.46	1.71	1.46	0.1
BH-087	3	4.5	27.4	1.3	27.4		7	2.46	21.9	1.32	1.07	1.18	0.0
BH-087	6	7.5	7.8	0.46	7.6		1.81	0.047	0.69	0.64	-0.17	0.7	0.0
BH-087	9	10.5	7.3	0.45	7.5		1.91	1.03	2.6	1.12	0.83	1.28	0.0
BH-087	12	13.5	7.2	0.35	7		1.33	0.75	6	1.04	1.16	1.11	0.0
BH-088	1.5	3	9.4	0.59	9.9		27.8	3.23	6.6	0.9	1.16	0.73	0.0

Table 4-15, Analytical Results of Soil Samples at Plant 5

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-088	3	4.5	19.2	0.97	18.8		11.7	1.73	12.9	0.84	0.3	0.8	0.0
BH-088	6	7.5	16.4	0.78	17		5.02	3.26	13.6	7.4	4.9	6.7	0.3
BH-088	12	13.5	1.41	0.062	1.53		1.27	0.74		1.22	1.19	1.27	0.0
BH-089	1	1.5	4.42	0.261	4.36		4.8	21.4		0.79	0.54	0.85	0.6
BH-089	3	4.5	3.2	0.161	3.13		2.24	9.1	3.18	0.96	0.86	1.02	0.2
BH-089	6	7.5	4.27	0.247	4.15		3.3	15.7		1.1	0.09	1.09	0.4
BH-089	9	10.5	6	0.309	6.2		3.14	5.25		1.45	1.19	1.5	0.1
BH-089	15	16.5	8.7	0.45	9		7.2	1.04		4.05	1.46	4.53	0.1
BH-089	18	19.5	1.12	0.053	1.23		1.43	1.4		1.33	0.67	1.4	0.0
BH-090	0.75	1.5	17.2	0.84	17.2		5.4	3.39	8.8	0.87	0.38	0.9	0.0
BH-090	3	4.5	7	0.47	7.2		2.06	1.7	5.7	0.98	1.25	1.3	0.0
BH-090	6	7.5	3.58	0.189	3.65		1.73	1.52		1.12	0.79	1.16	0.0
BH-090	9	10.5	5.4	0.32	5.4		0.94	2.4	3	0.61	0.7	0.86	0.0
BH-090	12	13.5	18.5	1.02	18		9.7	11.1	18.2	3.04	2.5	2.99	0.4
BH-090	16.5	18	1.96	0.125	1.93		2.28	0.98		1.65	0.9	1.47	0.0
BH-091	1	1.5	6.7	0.26	6.6		4.7	5.08	5.3	1.45	1.72	1.41	0.1
BH-091	3	4.5	2.14	0.084	2.05		2.21	1.86		0.93	1	0.92	0.0
BH-091	6	7.5	1.81	0.096	1.84		1.34	1.62		0.49	0.89	0.58	0.0
BH-091	9	10.5	3.37	0.202	2.96		1.5	1.06		0.55	0.17	0.68	0.0
BH-091	12	13.5	34.4	1.76	36.5		28	24.3	23.3	7.7	4.8	7.3	1.0
BH-091	13.5	15	2.22	0.18	2.13		1.89	1.19		1.31	1.14	1.36	0.0
BH-092	1	1.5	5.2	0.34	5.4		3.51	2.18	3.04	0.79	0.68	0.77	0.0
BH-092	3	4.5	3.25	0.167	3		4.34	3.85	5.1	1.07	0.84	1.24	0.0
BH-092	6	7.5	1.42	0.039	1.37		1.6	1.56		0.67	0.75	0.83	0.0
BH-092	9	10.5	2.56	0.221	2.23		1.52	1.59		0.59	0.73	0.9	0.0
BH-092	12	13.5	17.6	1.03	18		10.8	5.36	15.8	3.01	2.42	3.25	0.2
BH-092	15	16.5	4.06	0.267	4.19		3.28	1.22		0.94	1.16	0.92	0.0
BH-093	0.5	1.5	7.1	0.43	6.9		4	3.32	4.25	1.3	1.14	1.22	0.0
BH-093	3	4.5	5.6	0.33	5.4		1.7	1.48	4.7	0.96	0.76	0.92	0.0

Table 4-15, Analytical Results of Soil Samples at Plant 5

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
BH-093	6	7.5	2.15	0.107	2.14		1.14	0.84	2.7	0.48	0.64	0.41	0.0
BH-093	9	10.5	3.89	0.21	4.07		3.89	2.66		1.21	0.4	1.29	0.0

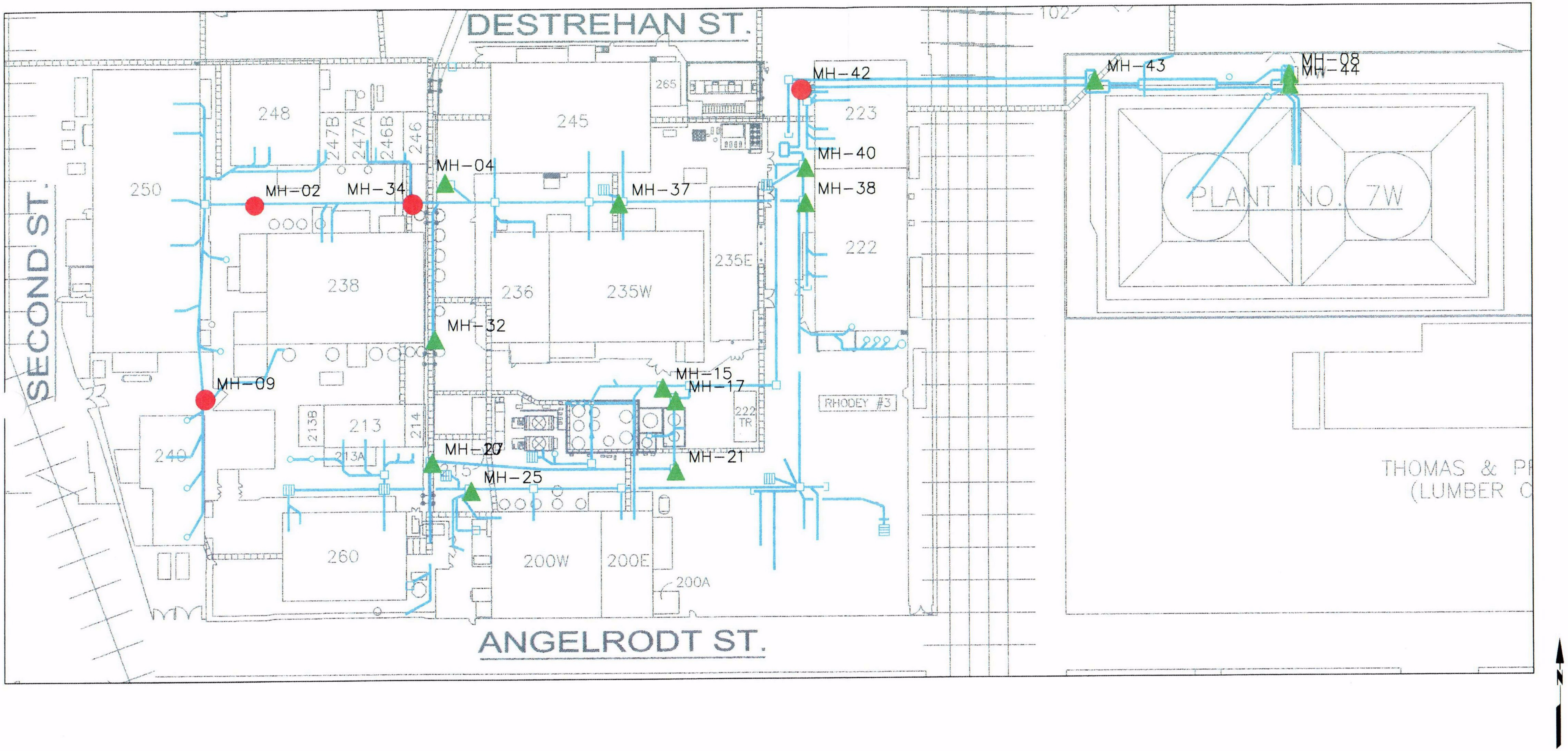
Table 4-16, Analytical Results of Mallinckrodt Biased Soil Samples

	Sample Depth (ft)		Radionuclide Concentration										
Location ID	Top	Bottom	U-234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	U-Tot (µg/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-234 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)	Sum of Fractions
JA-01	0	5			216.06		43.72	1.87		1.87			0.2
JA-02	0	1			89.96		60.72	13.44		2.16			0.5
JA-03	0	1			28.39		41.14	28.08		3.07			1.0
JA-04	0	1			33.46		79.74	132.8		8.24			4.8
JA-05	0	1			26.87		50.32	4.79		1.95			0.2
JA-06	0	1			36.27		53.73	242.7		5.88			8.3
JA-07	0	1			51.91		60.64	2.49		2.5			0.2
JA-08	0	1			33.08		32.39	2.76		2.17			0.1
JA-09	0	1			69.76		50.47	2.71		1.9			0.1
JA-10	0	1			70.7		81.27	2.56		2.34			0.2
JA-11	0	1			172.48		123.1	3.97		2.02			0.2
JA-12	0	1			166.5		19.3	2.9		2.1			0.2
JA-13	0	0.5			2.7		5.5	0.66		0.4			0.0
JA-14	0	0.5			9.2		7.4	2		1.7			0.1
JA-15	0	2			5.2		8.5	1.8		1			0.0
JA-16	0	4.25			8		7.3	2		1.9			0.1
JA-17A	0	3			14.5		19.6	3.79		2.32			0.2
JA-19	0	0.5			4.94		23.3	1.63		5.08			0.3
JA-20	0	0.5			1.76		11.3	0.43		2.94			0.1
JA-21	0	4	4.5		3.3		3.32	3.96		0.68		1.7	0.1
JA-22	0	4	5.04		4.69		3.07	1.91		1.19		1.07	0.0
JA-23	0	4	2.96		2.37		2.39	2.29		0.7		1.9	0.0
JA-24	0	0.5			3.5		1.8	2.5		1.3			0.0
JA-25	0	3			3.4		0.5	2.1		< 0.1			0.0
JA-30	0	10	4.35		4.01		3.27	2.49		0.62		0.58	0.0
JA-31	0	6	11.6		13.8		2.65	1.49		0.59		1	0.0

Table 4-17, Background Concentrations of Key Radionuclides in Cinder/Fill

Radionuclide	Number of Measurements	Mean Concentration[a] (pCi/g)	Standard Deviation[a] (pCi/g)	95% confidence limits[a] (pCi/g)
U-238	130	4.4	2.3	4.1 to 4.9
U-235	n/a	0.2	n/a	n/a
Th-230	130	3.4	2.2	1.8 to 2.6
Ra-226	130	2.5	2.3	1.9 to 2.7
Th-232	130	1.3	0.7	1.2 to 1.4
Ra-228	129	1.2	0.6	1.2 to 1.4
Th-228	129	1.3	0.8	1.2 to 1.5

[a] Derived from the Weibull probability distribution.
The Mean Concentration of U-235 is 0.0455 times U-238; i.e. assume natural uranium.



KEY

□ -Manhole

▤ -Surface Drain

○ -Downspout

▬ -Sewer Line

▲ - Location Identification: Sample Less than or Equal to DCGL Sum-of-Fractions

● - Location Identification: Sample Greater than DCGL Sum-of-Fractions

TITLE:

Figure 4-1
Locations of Manhole Samples
and Sewer Lines

PROJECT: C-T Phase 2 DP	DATE: April 2003	DRAWING:	REVISION: △
SCALE:	ACAD FILE: manholesewer.dwg		

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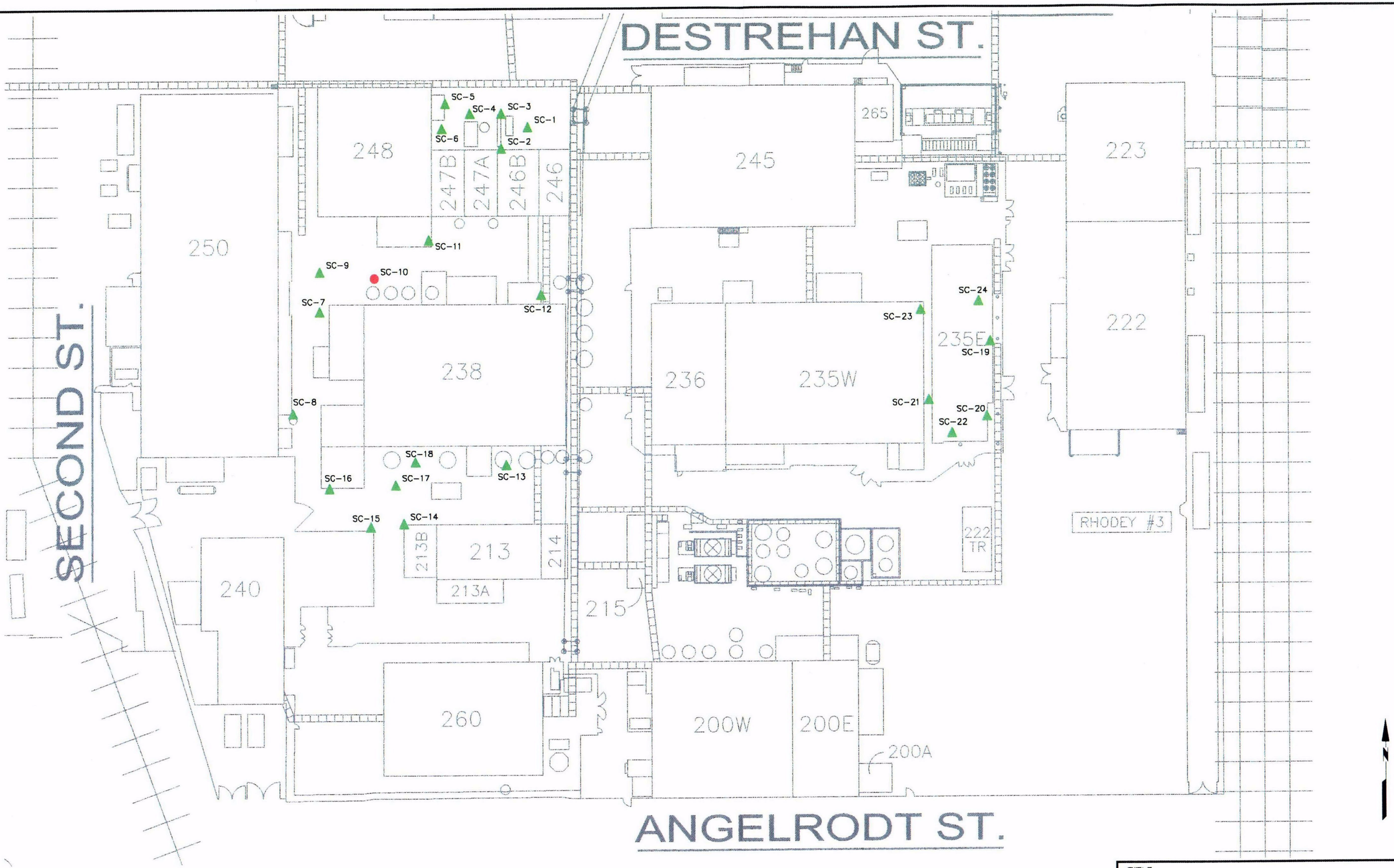
C-06



KEY

▲ - Location Identification: Less than 0.05 % weight source material.

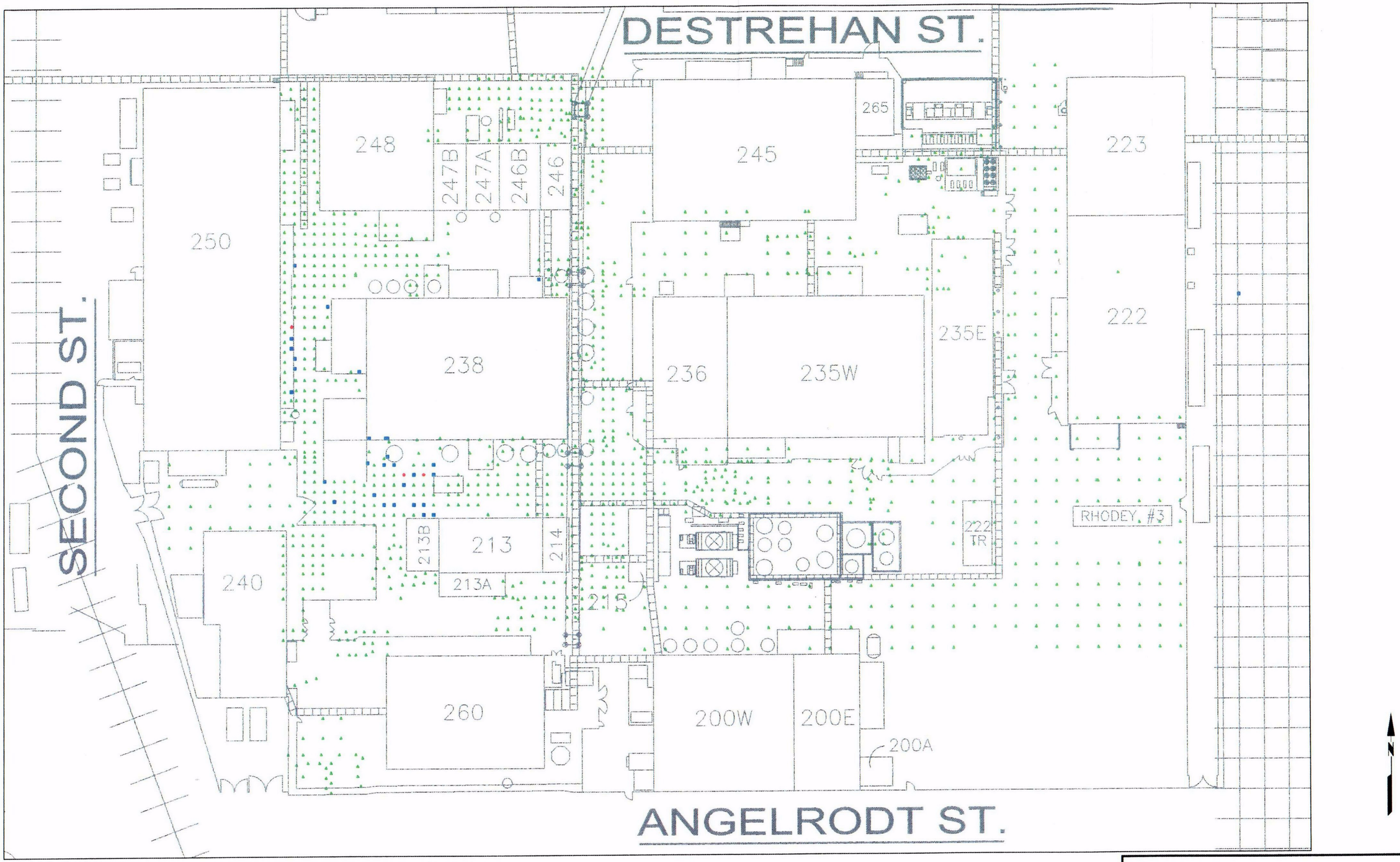
● - Location Identification: Greater than 0.05 % weight source material.

TITLE:

Figure 4-2
Locations of Scabble Samples from
Street Surfaces

PROJECT:	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE:		ACAD FILE	scabble.dwg		△

C-07



KEY

- 🟩 - Location Identification: Measurement Less than or Equal to 2400 atomic transformations per miniute per 100cm² (tpm/100cm²)
- 🟦 - Location Identification: Measurement Between 2400 and 24000 tpm /100cm²
- 🔴 - Location Identification: Measurement Greater than 24000 tpm /100cm²

TITLE:

Figure 4-3
Location of Direct Measurements
of Street Surfaces

PROJECT	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE		ACAD FILE	streetatomic.dwg		△

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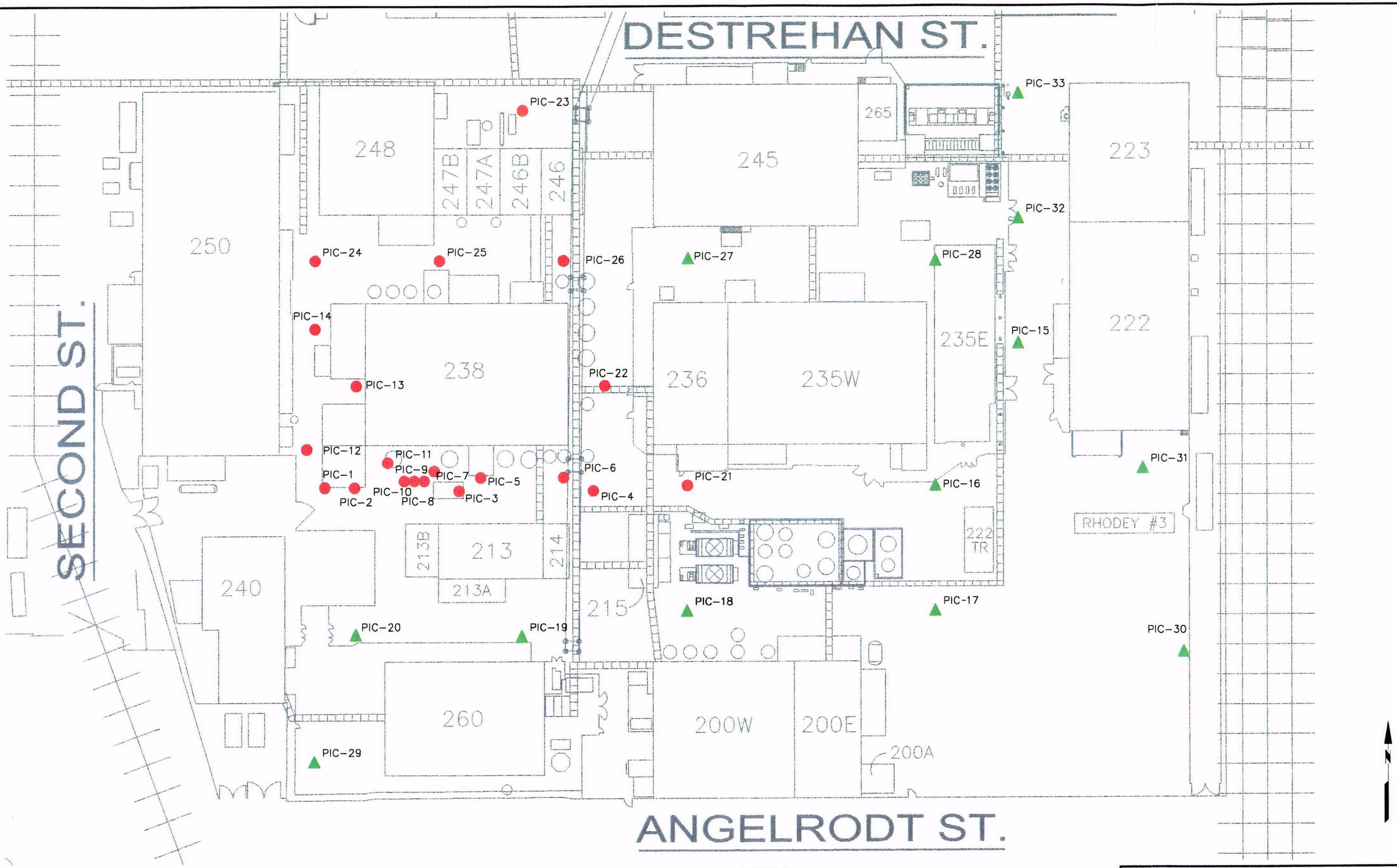
C-08



KEY

▲- Location Identification : Less than or Equal to 10 µR/h

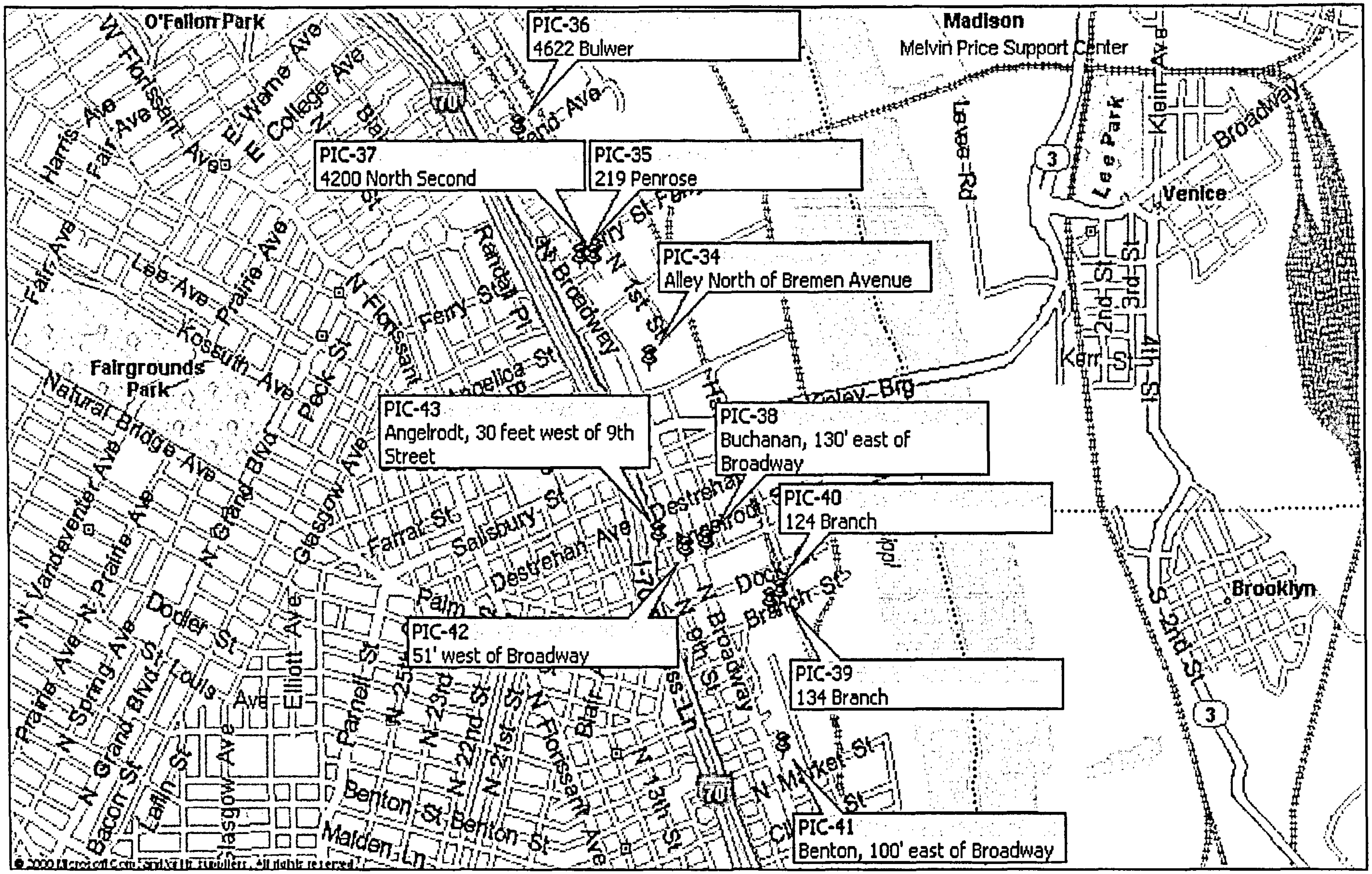
●- Location Identification : Greater than 10 µR/h

TITLE:

Figure 4-4A
Locations of Exposure Rate Measurements on Site

PROJECT:	C-T Phase 2 DP	DATE:	April 2003	DRAWING:	REVISION:
SCALE:		ACAD FILE:	PICon.dwg		△

C-09



PIC-36
4622 Bulwer

PIC-37
4200 North Second

PIC-35
219 Penrose

PIC-34
Alley North of Bremen Avenue

PIC-43
Angelrodt, 30 feet west of 9th Street

PIC-38
Buchanan, 130' east of Broadway

PIC-40
124 Branch

PIC-42
51' west of Broadway

PIC-39
134 Branch

PIC-41
Benton, 100' east of Broadway

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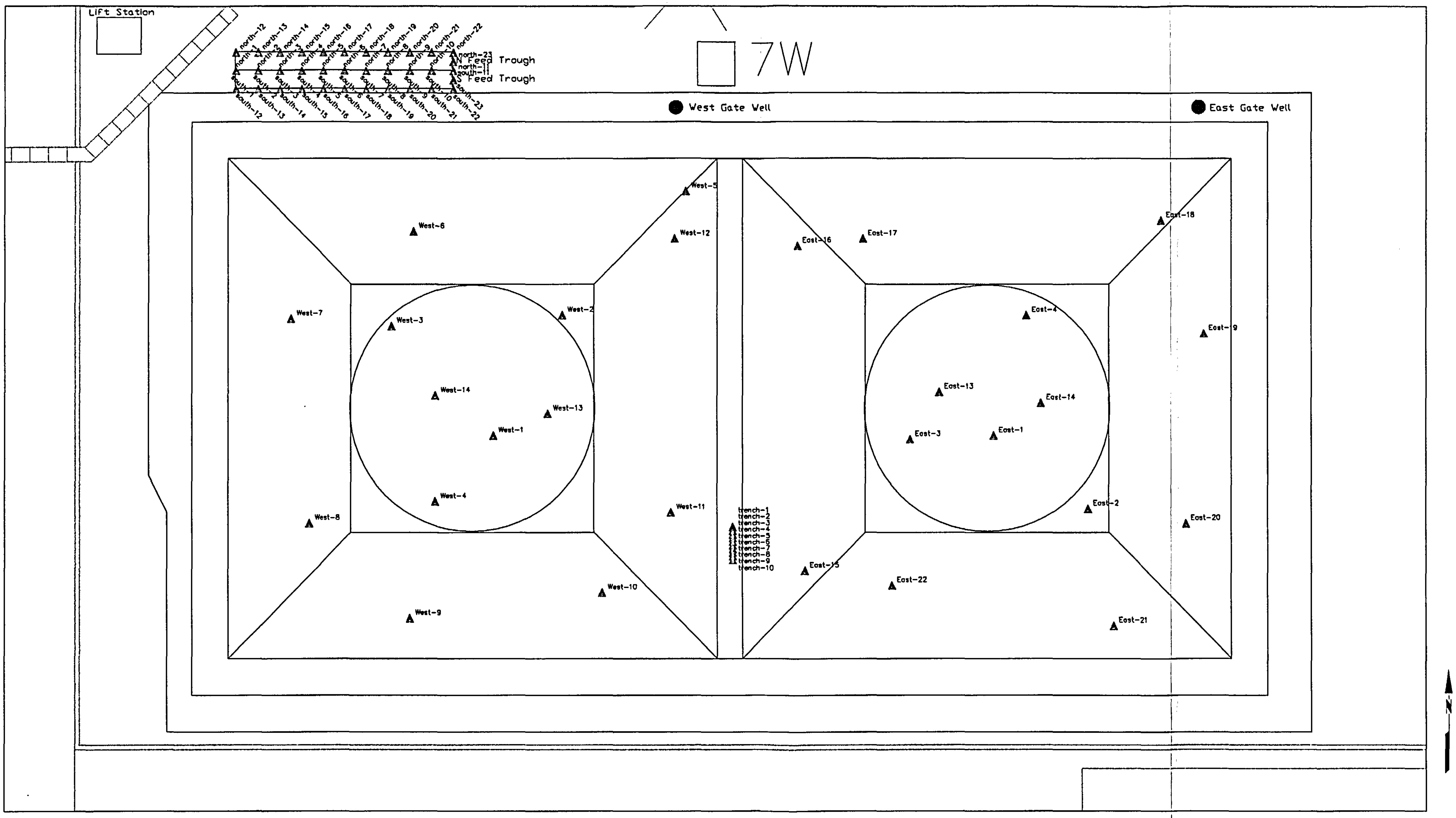
Figure 4-4B
Offsite PIC Measurement Locations

Date: April 2003
Project: CT Phase 2 DP
File: offsite locations.ppt



KEY

▲ - Location Identification: Measurement Less than or Equal to 2400 atomic transformations per minute per 100 cm² (tpm/100 cm²)

TITLE:

Figure 4-5
Location of Direct Measurements
in Plant 7W Wastewater Neutralization Basins

PROJECT:	C-T Phase 2 DP	DATE:	April 2003	DRAWING	REVISION
SCALE		ACAD FILE:	wwbasin.dwg		△

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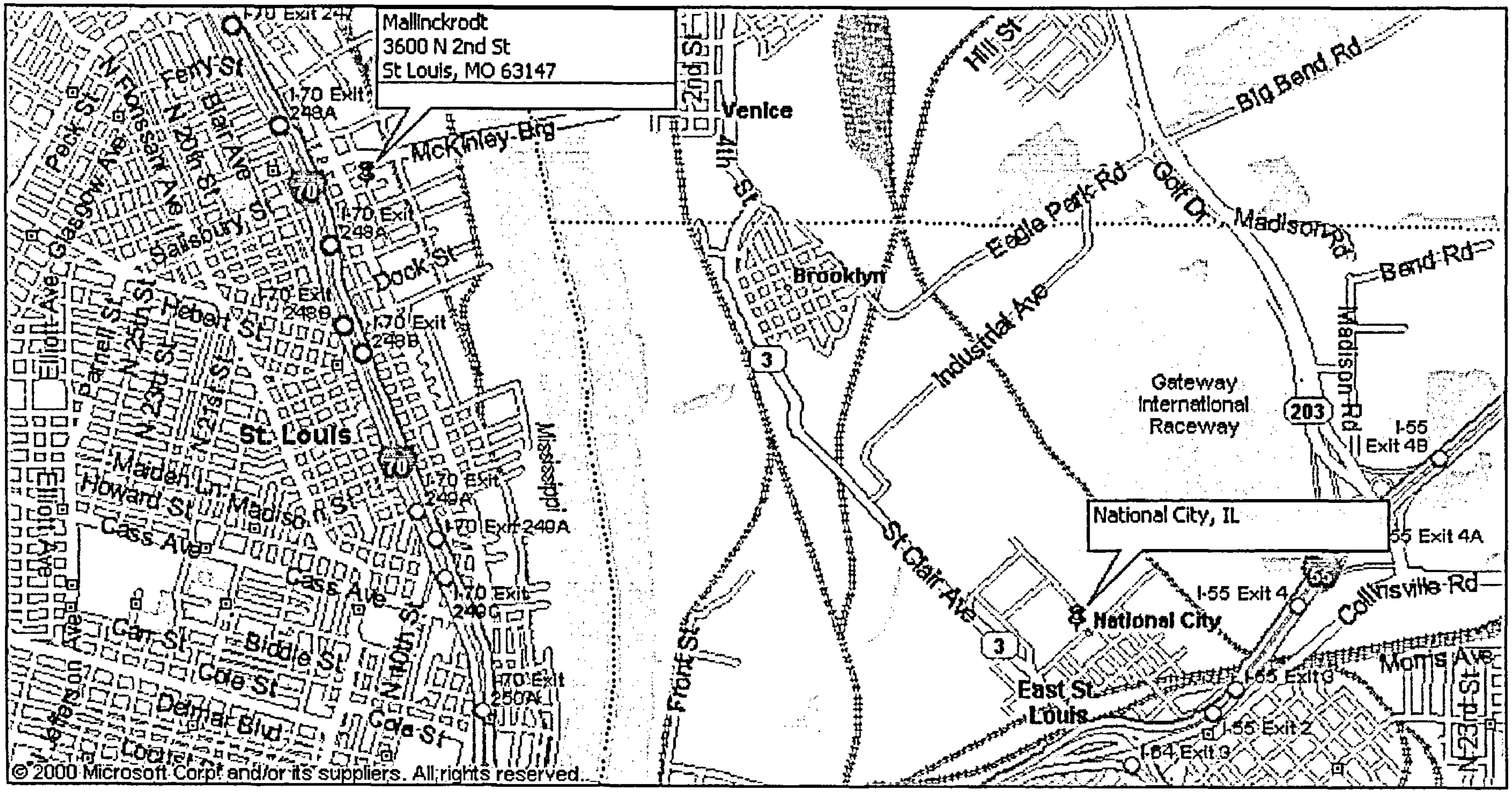

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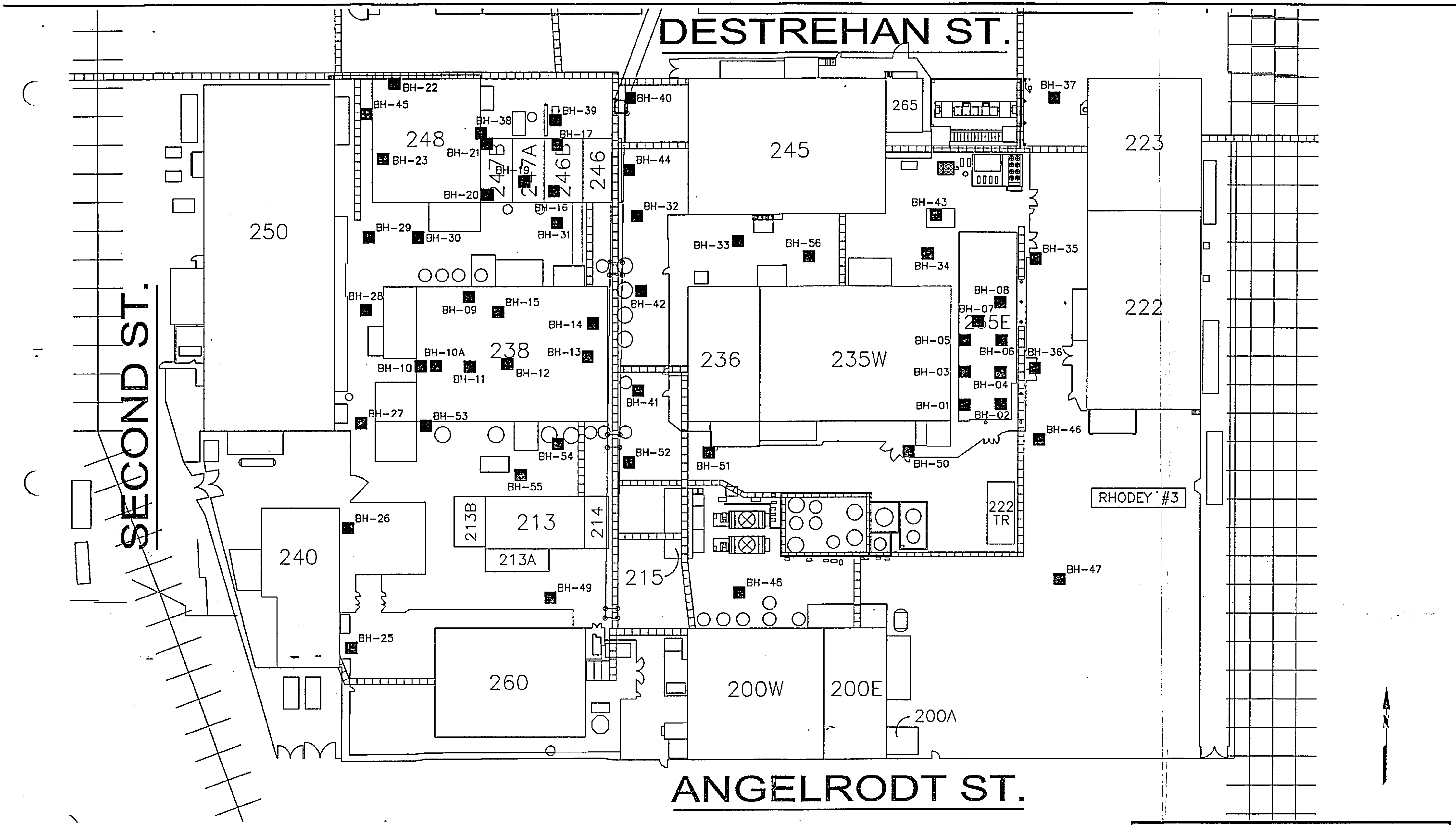
Figure 4-6
Location of Pre-Phase I Background Soil Characterization

Date: April 2003

Project: CT Phase 2 DP

File: offsite locations.ppt



KEY

▨ -Location Identification

Note: BH-18 and BH-24 are not shown. They were terminated prior ro sample collection.

TITLE:

Figure 4-7
Locations of Columbium-Tantalum
Characterization Plan Boreholes

PROJECT:	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE		ACAD FILE	BH01_56.dwg		△

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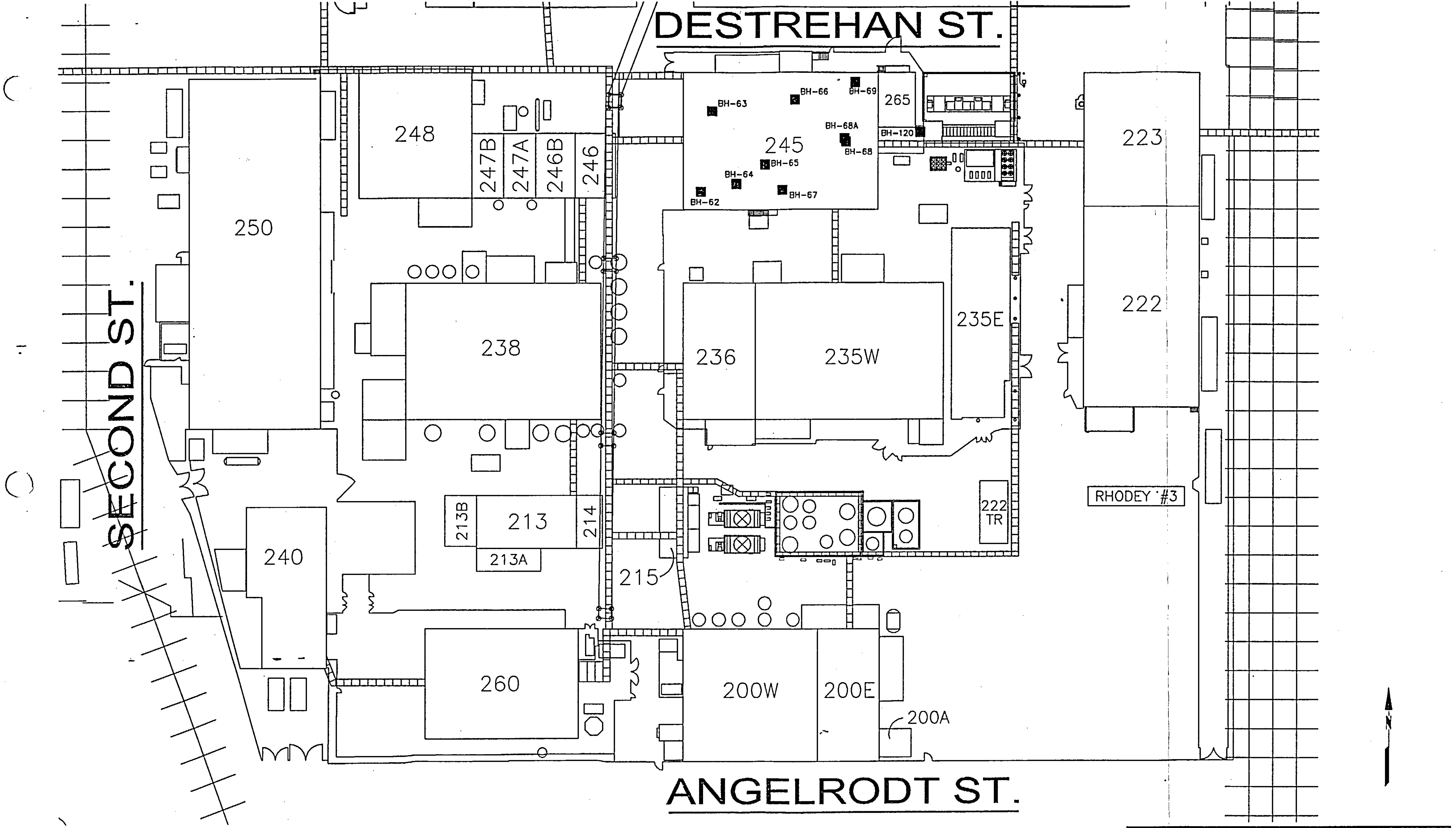

KEY

▨ -Location Identification

TITLE:

Figure 4-8
Locations of Building 245 Boreholes

PROJECT:	C-T Phase 2 DP	DATE:	April 2003	DRAWING:	REVISION:
SCALE:		ACAD FILE:	BH62_69 & 120.dwg		△

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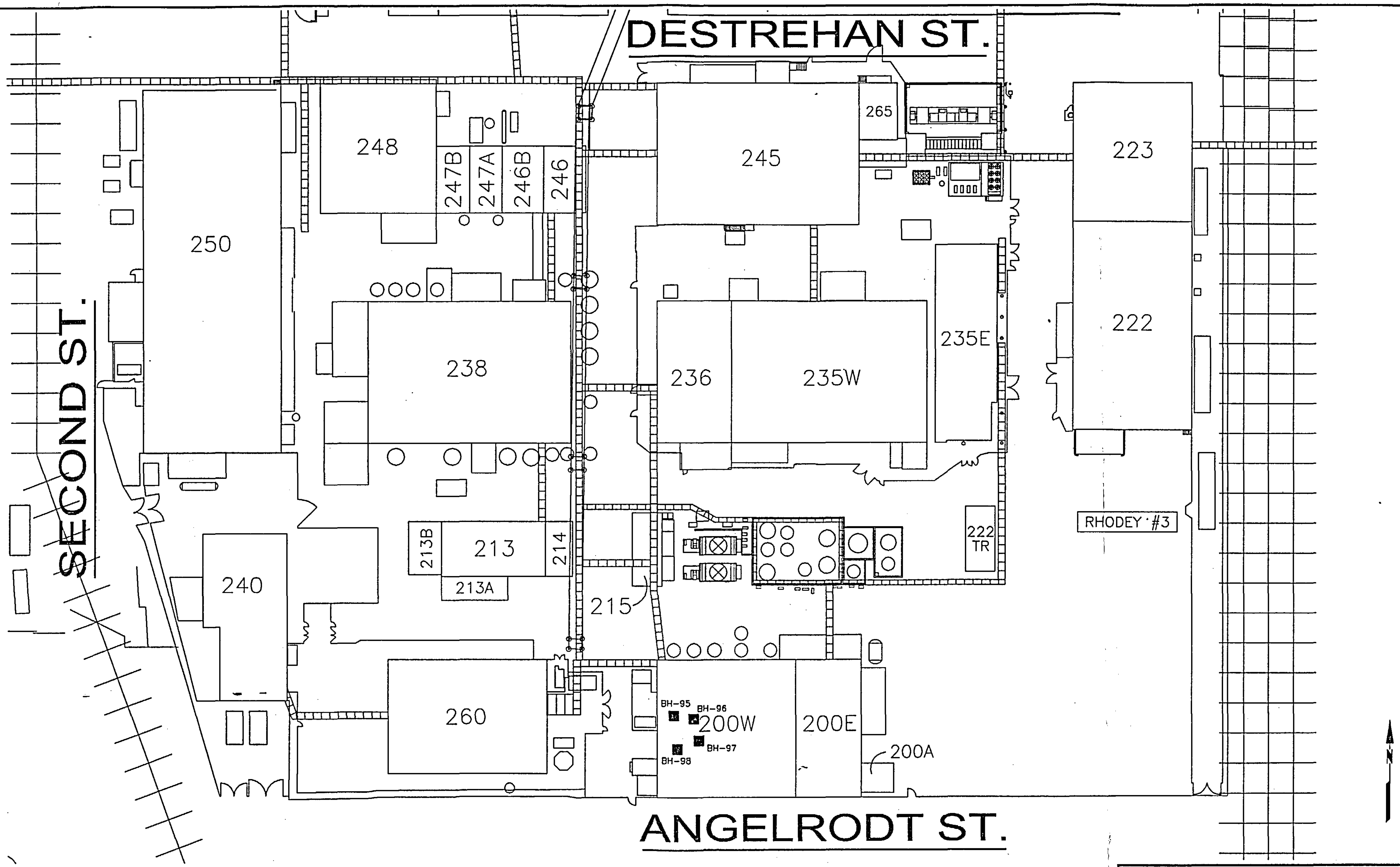


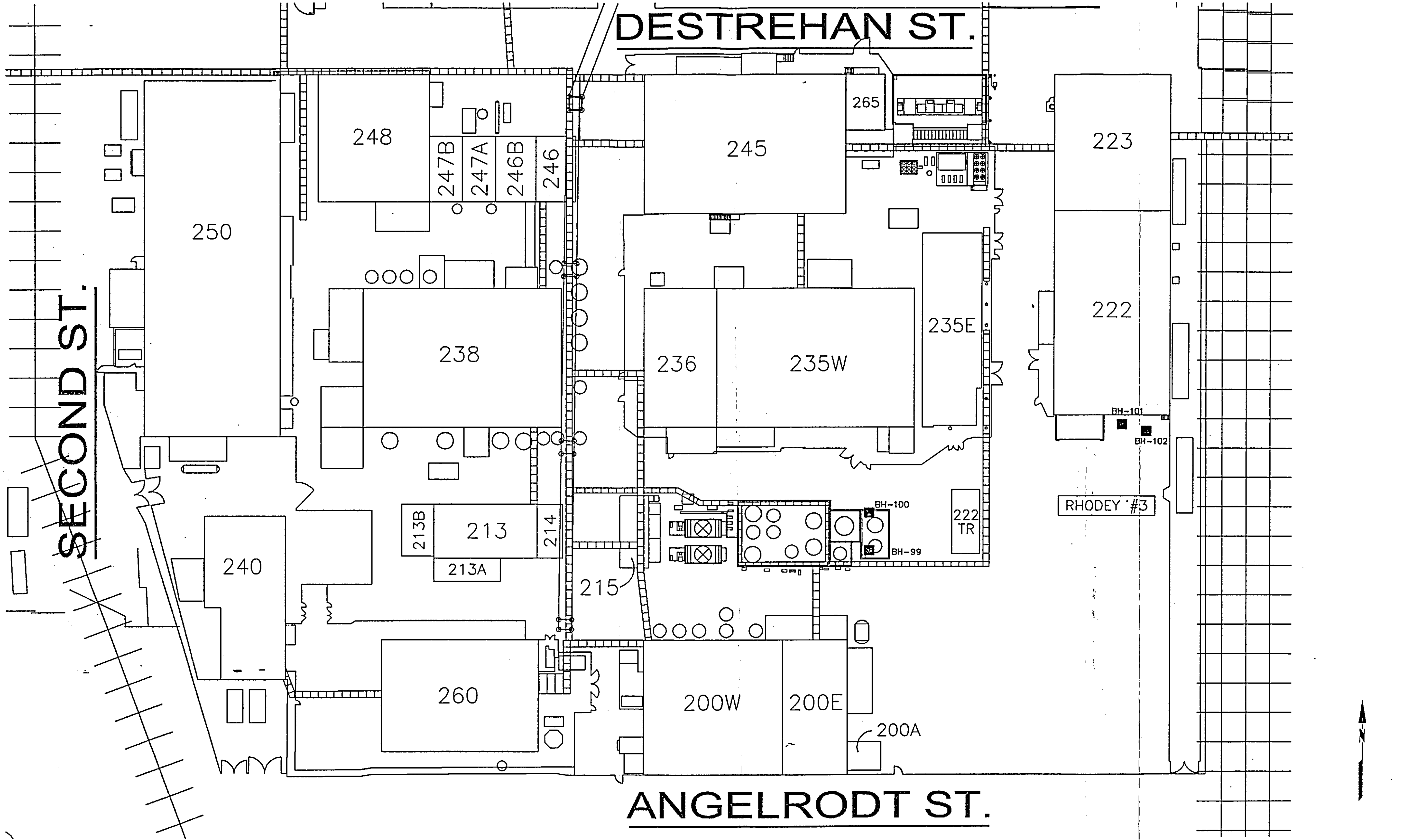
KEY

▨ -Location Identification

TITLE:

Figure 4-9
Locations of Building 200 West Boreholes

PROJECT	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE		ACAD FILE	BH95_98.dwg		△



KEY

▨ -Location Identification

TITLE:

Figure 4-10
Locations of Plant 5 Tank Farm Boreholes

PROJECT:	C-T Phase 2 DP	DATE:	April 2003	DRAWING:	REVISION:
SCALE:		ACAD FILE	BH99_102.dwg		△

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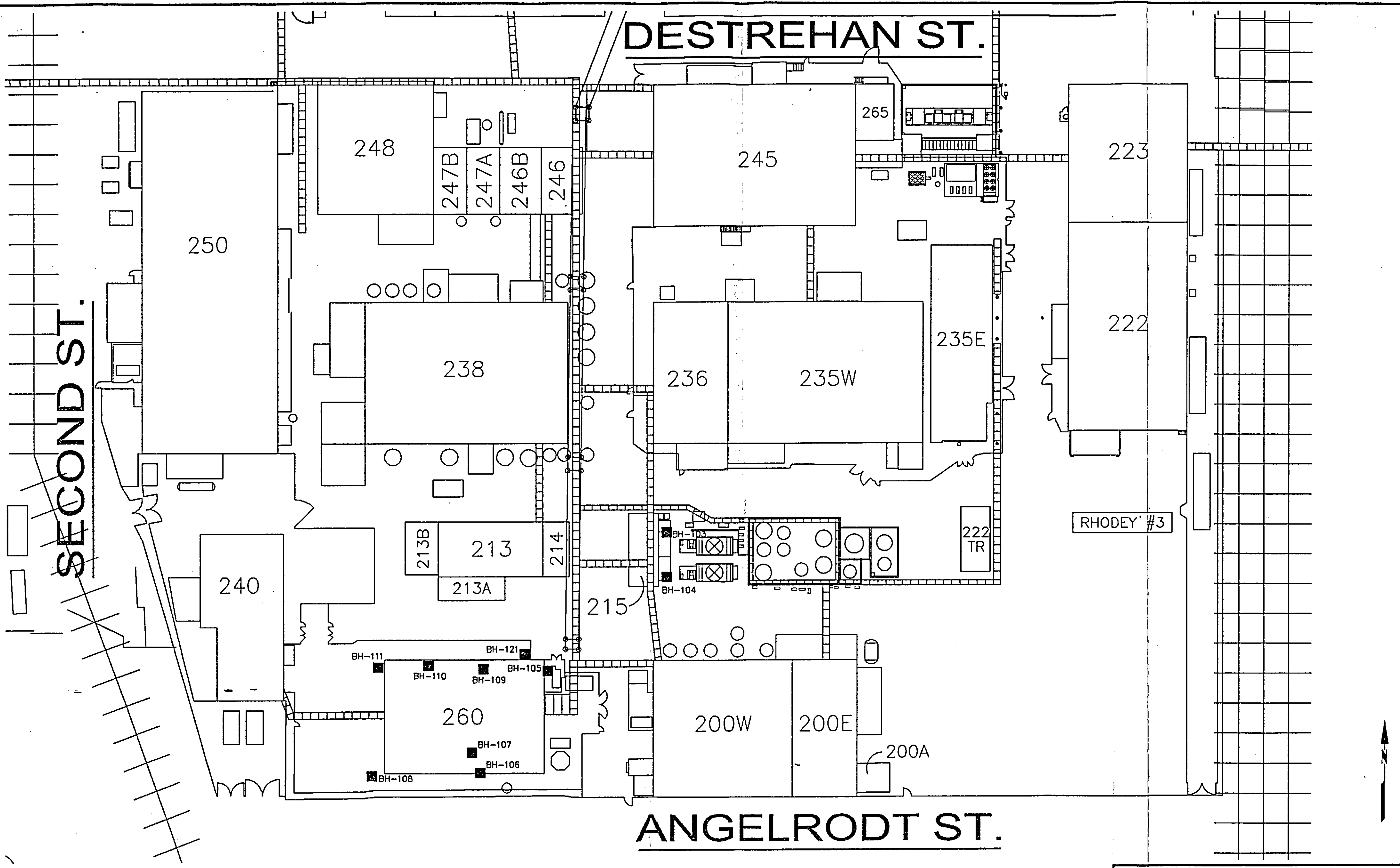

KEY

▨ -Location Identification

TITLE:

Figure 4-11
Locations of Building 201/215 Boreholes

PROJECT.	C-T Phase 2 DP	DATE:	April 2003	DRAWING	REVISION
SCALE.		ACAD FILE.	BH103_111 & 121.dwg		△

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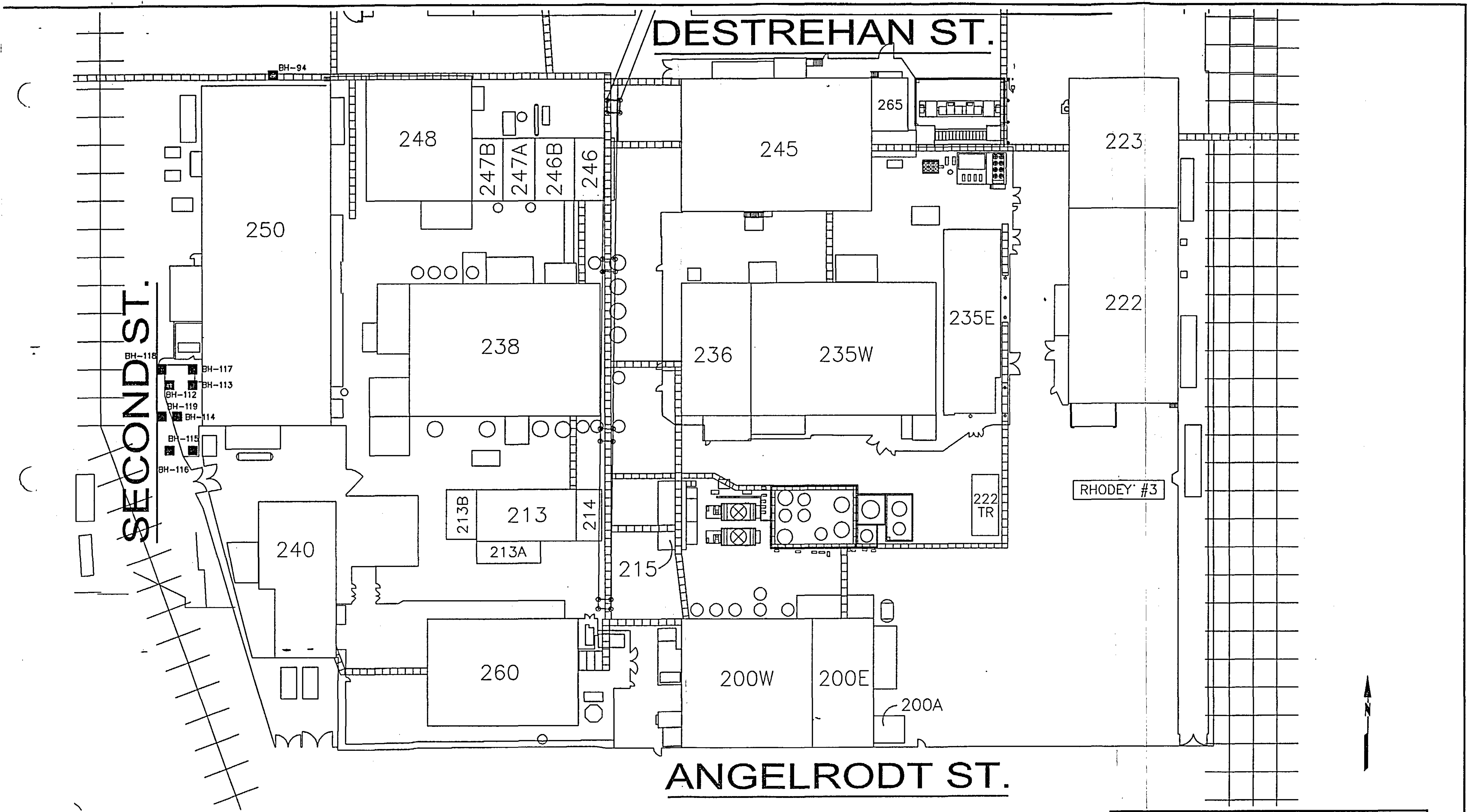


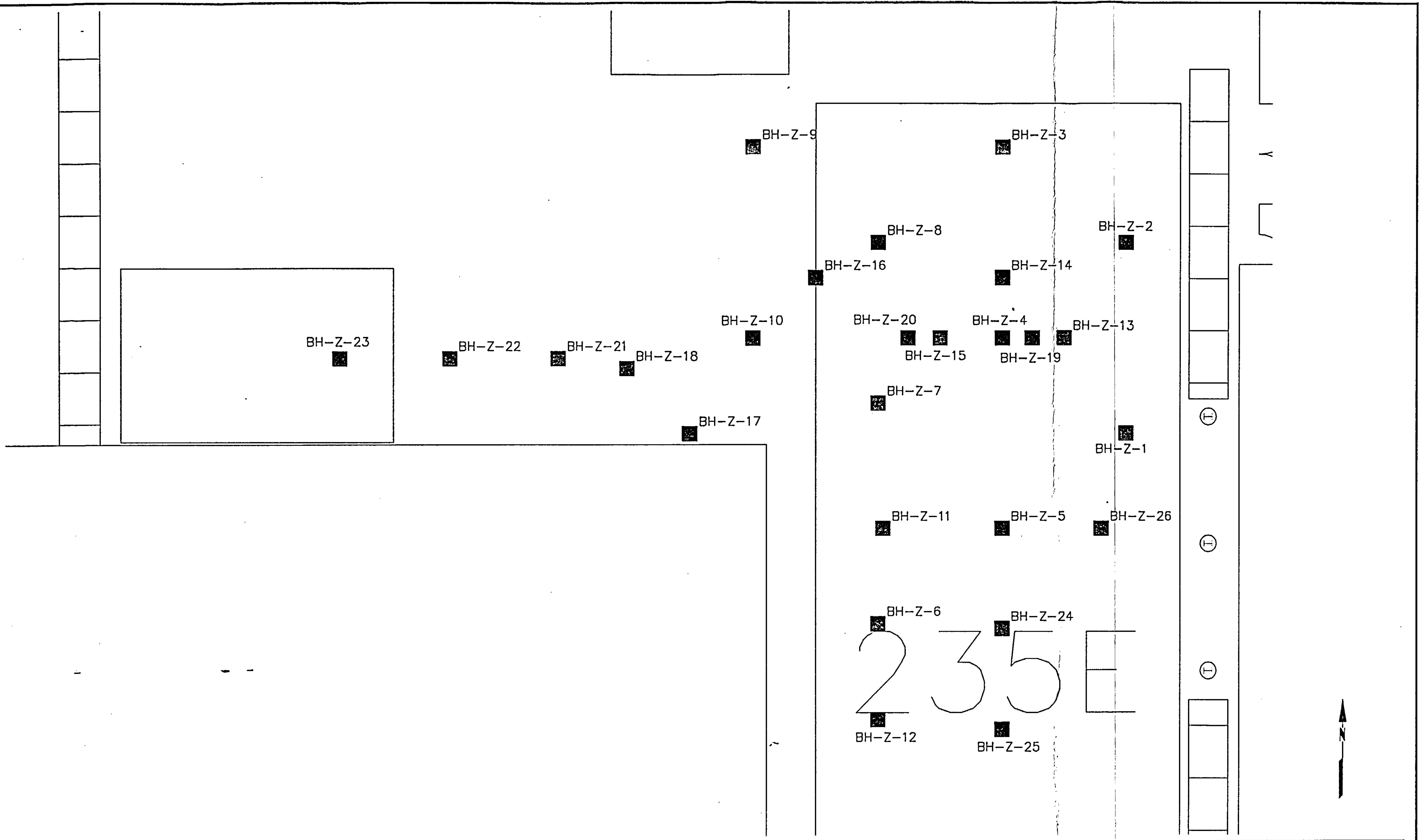
KEY

▨ -Location Identification

TITLE:

Figure 4-12
Locations of Building 250 Boreholes

PROJECT C-T Phase 2 DP
DATE: April 2003
DRAWING:
REVISION △
SCALE
ACAD FILE: BH94 & 112_119.dwg



KEY

■ -Location Identification

TITLE:

Figure 4-13
Locations of Building 235 Boreholes

PROJECT	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION.
SCALE		ACAD FILE	BHZs.dwg		△

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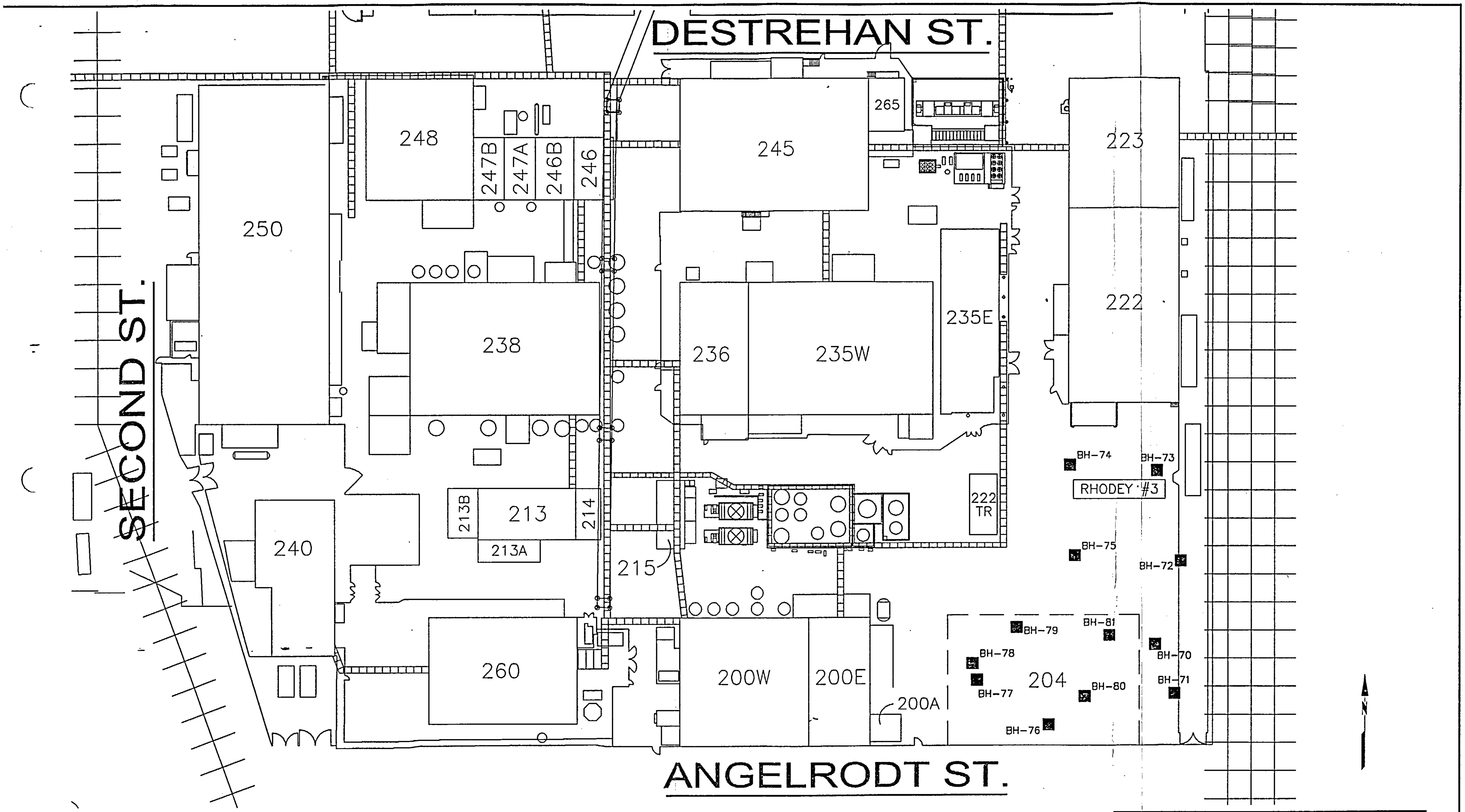

KEY

▨ -Location Identification

Building 204 does not exist.
Building 204 outline is shown for reference.

TITLE:

Figure 4-14
Locations of Building 204 Boreholes

PROJECT:	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE		ACAD FILE:	BH70_81.dwg		△

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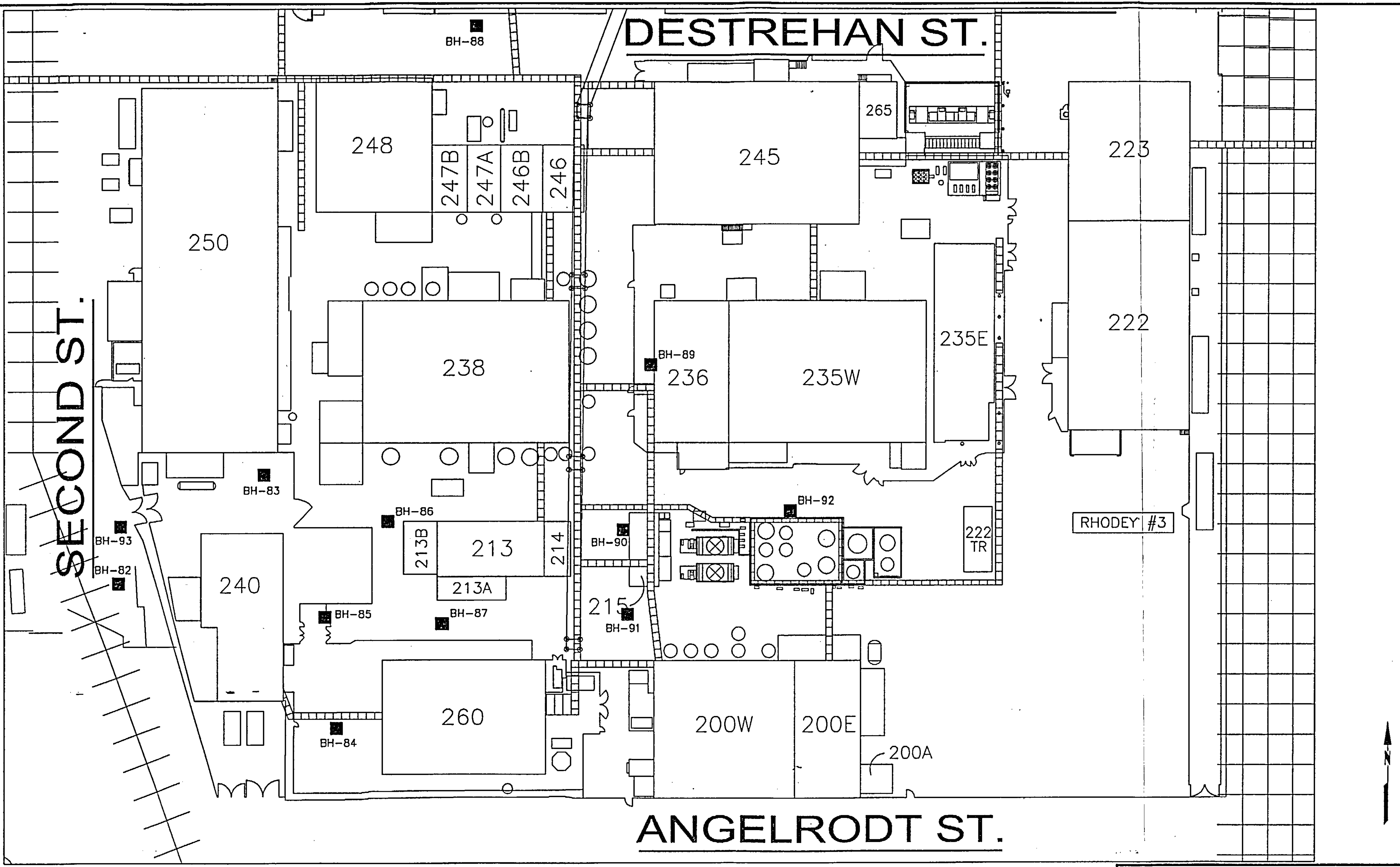


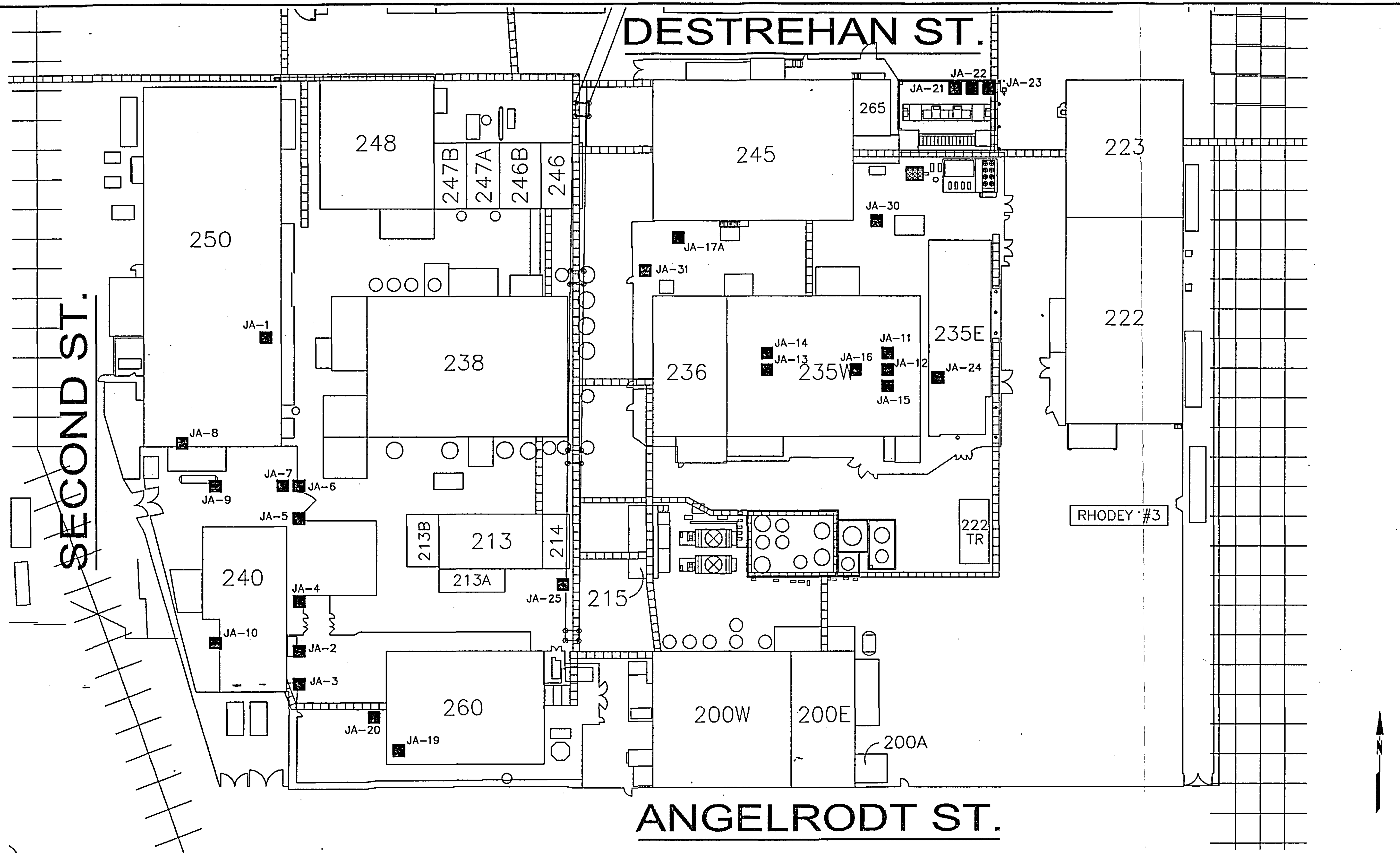
KEY

▩ -Location Identification

TITLE:

Figure 4-15
Locations of Plant 5 Boreholes

PROJECT:	C-T Phase 2 DP	DATE	April 2003	DRAWING:	REVISION: △
SCALE		ACAD FILE	BH82_93.dwg		



KEY

▨ -Location Identification

TITLE:

Figure 4-16
Locations of Mallinckodt Biased Samples

PROJECT C-T Phase 2 DP	DATE: April 2003	DRAWING	REVISION △
SCALE	ACAD FILE: JAdams.dwg		

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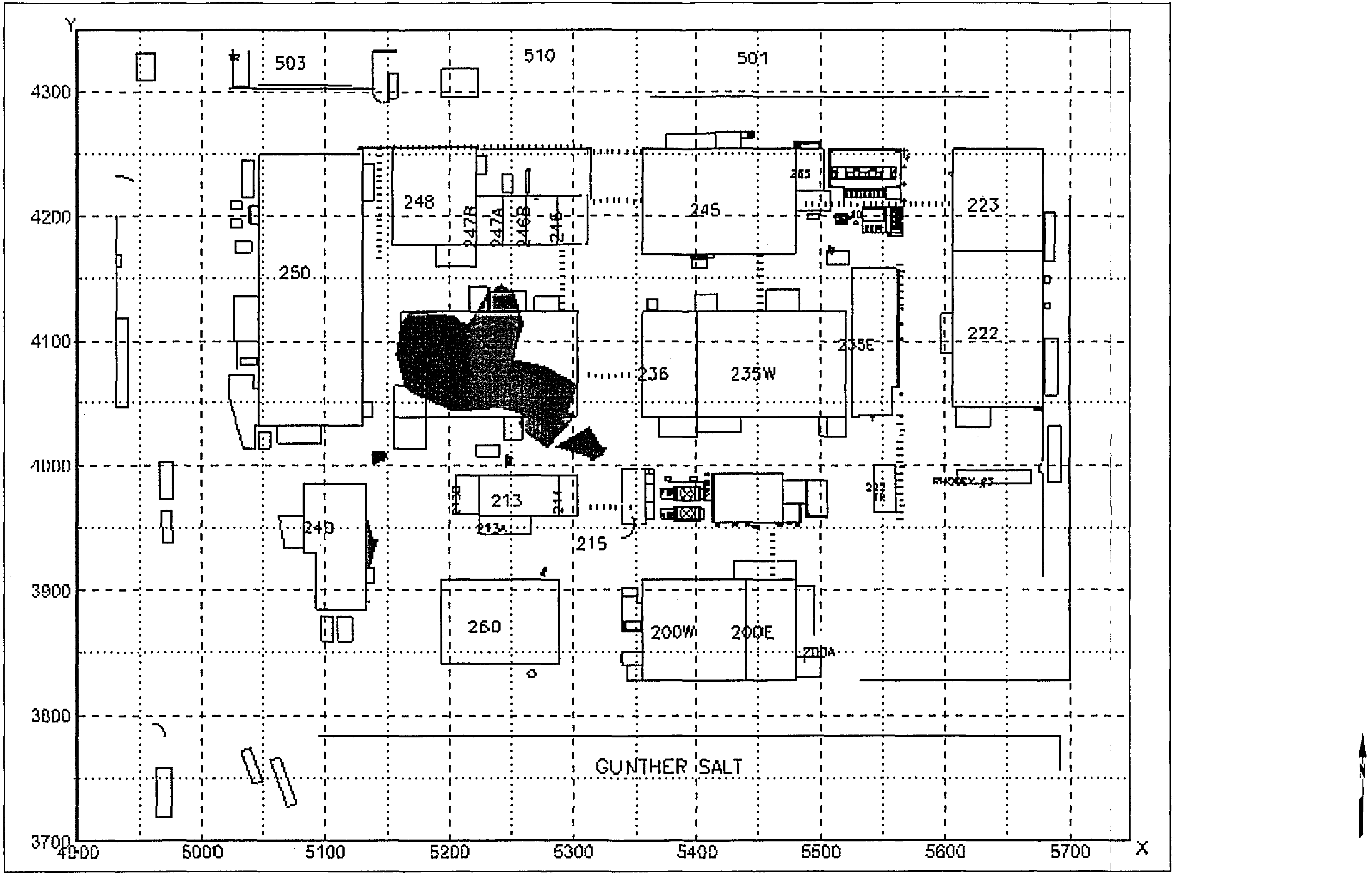

TITLE:

Figure 4-17
Plan View of Contaminated Soils in Plant 5

PROJECT: C-T Phase 2 DP	DATE: April 2003		DRAWING	REVISION △
SCALE:	ACAD FILE: Plant5Top.dwg			

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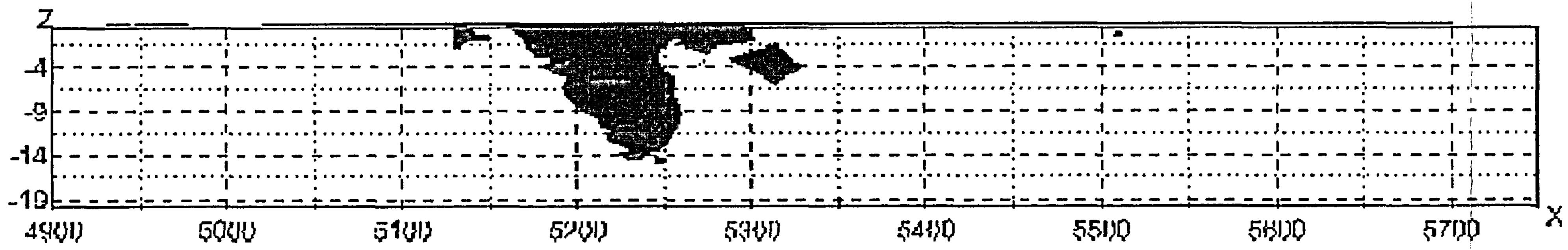
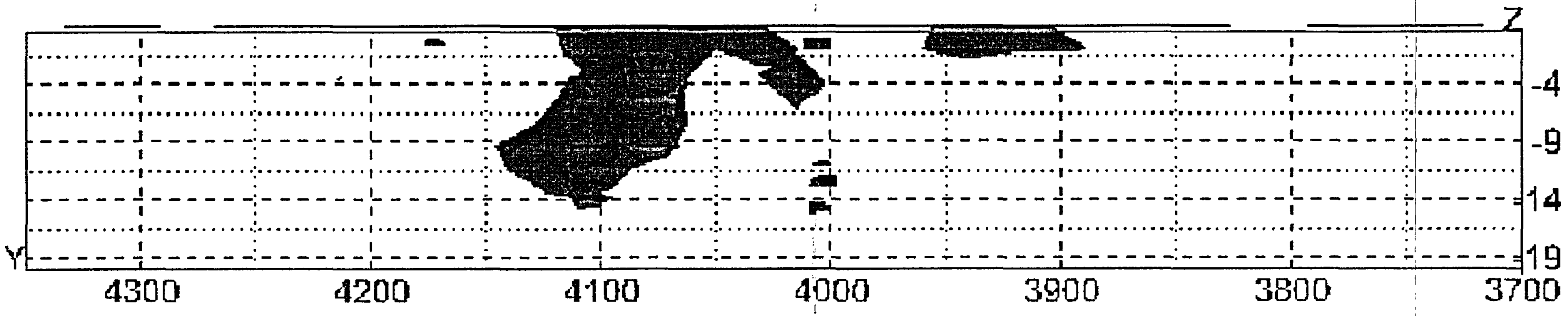


TITLE:

Figure 4-18
Side View of Contaminated Soils in Plant 5
South Side Looking North

PROJECT: C-T Phase 2 DP
DATE: April 2003
DRAWING:
REVISION: △
SCALE:
ACAD FILE: Plant5Front.dwg



TITLE:

Figure 4-19
Side View of Contaminated Soils in Plant 5
West Side Looking East

PROJECT:	C-T Phase 2 DP	DATE:	April 2003	DRAWING:	REVISION:
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omega
PROJECT SERVICES LLC

SECTION 5

DOSE MODELING

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

5. DOSE MODELING

5.1. INTRODUCTION

Radiological dose criteria for decommissioning lands and structures[1] provide the basis of determining maximum acceptable residual radionuclide concentration for remediation of residual radioactivity at nuclear facilities undergoing decommissioning. These criteria determine the extent to which lands and structures must be remediated before decommissioning of a site can be considered complete and the license terminated. This chapter describes the derivation of soil concentration guideline levels, $DCGL_W$ [2] and $DCGL_{EMC}$ [3], for land affected by C-T process operation and areal contamination guideline levels for surficial contamination on pavement affected by C-T process operation. Criteria for buildings and structures were derived in the C-T Phase I Decommissioning Plan (Phase I Plan).

To help decide what actions are reasonable to mitigate potential exposure to residual radionuclides in soil and to assure the radiological dose limit is met, maximum acceptable levels of residual radioactivity concentration in soil must be derived for soil remaining after decommissioning. To do this one must estimate the quantitative relation between radionuclide concentration in the soil and potential radiation dose to an average person in the group who might be exposed the most to residual radionuclides in land in Plant 5. Radiological dose modeling by mathematical simulation is a way to describe this source-to-dose relation, thereby enabling one to derive maximum acceptable radionuclide concentration to guide decommissioning and/or decide compliance with the decommissioning regulation. Dose modeling involves:

1. the radioactive source term;
2. an exposure scenario considering the site environment and pathways of exposure;
3. relation of the source term and potential radiological dose; and
4. parameters in the model.

Assessment Methodology. An objective of an environmental exposure pathway analysis is to derive a maximum acceptable average concentration of residual, licensed radioactive material ($DCGL_W$) that will assure conformance with regulatory limit(s) on radiological dose. To derive a $DCGL_W$, one describes land use scenarios based on anticipated site conditions and uses. For each land use scenario, reasonably anticipated environmental radionuclide exposure pathways are described. A mathematical model with simplified representations of site physical conditions and the potentially maximally exposed group of people is used to calculate future exposures and radiation doses as a function of time and concentration of nuclides in the soil. The relationship between dose and radionuclide concentration in soil is computed with the mathematical model.

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[1] 10 CFR Part 20, subpart E

[2] $DCGL_W$ = derived concentration guideline level corresponding to the release criterion for the nonparametric statistical test. ref. MARSSIM.

[3] $DCGL_{EMC}$ = derived concentration guideline level corresponding to the acceptance criterion for elevated measurements comparison ref. MARSSIM.

Reasonable remediation alternatives are posed to clean the site to comply with the DCGL.

Under NRC regulation for decommissioning, pathway analysis includes the estimation of radiation doses that might be received by a typical member of a small group of people from future uses of the site as much as 1,000 years into the future. Thus, this analysis considers not only the current conditions at the site, but projected conditions as well. The analysis evaluates potential uses of the site and potential migration of radioactive materials through the environment over time, accounting for both natural processes and human activities that could be expected to alter the patterns or rates of contaminant movement. The primary objectives of the environmental radiation exposure analysis is to derive the concentration of uranium series and thorium series radionuclides in soil in Plant 5 that potentially produce a 25 mrem/yr radiological dose equivalent to an average member of the critical group.

5.2. SOURCE TERM

Residual radioactive sources from C-T processing are the thorium series, the uranium series, and the actinium (U^{235}) series. The thorium decay series may be assumed to be in secular radioactive equilibrium because Th^{232} progeny are relatively short-lived. U^{238} and U^{235} are presumed to be present at the ratio present in natural uranium ore.

The existing distributions of residual source material in soil and on pavement in Plant 5 are described in Section 4 of the C-T Phase II Decommissioning Plan (Phase II Plan). A remediation goal is that radioactivity concentrations exceeding the DCGL will be removed.

By deriving nuclide-specific concentration limits equivalent to the dose limit, *i.e.*, DCGL, and by removing soil containing more radioactivity than the DCGL, acceptable spatial variability of any remaining radioactive residue will be achieved by remedial action and confirmed by a final radiation status survey. This provides the best assurance before the fact that acceptable spatial variability of radioactive residue will be achieved.

5.3. LAND USE SCENARIO

Mallinckrodt's site is in an urban industrial area. Manufacturing and support buildings cover a large portion of the site, and the remainder of the area is typically paved with asphalt or concrete. Mallinckrodt has owned the site and has operated chemical manufacturing facilities on the site since 1867. It intends to continue industrial use of the site, including Plant 5 where C-T facilities are being decommissioned.

The site is in an area whose zoning by the City of St. Louis allows all uses except new or converted dwellings. Some uses allowed within this zone under conditional use permit are acid manufacture, petroleum refining, and stockyards.[4] Land use within a 1.6 km (1-mi) radius of the site reflects a mixture of commercial, industrial, and residential uses. The closest residential

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[4] St. Louis City Revised Code, Chapter 26.60, K UNRESTRICTED DISTRICT

dwelling is located on North Broadway, approximately 60 m (200 ft) south of the site.[5] The long-term plans for this area are to retain the industrial uses, encourage the wholesale produce district, and phase out any junkyards, truck storage lots, and the remaining marginal residential uses.

The foreseeable use of Mallinckrodt's St. Louis downtown site where C-T facilities are being decommissioned is for continued industrial or commercial use. This is reasonably assured without additional restrictions. Residential use is not expected because of historical and current land use and because of government land use zoning. Agricultural usage is not expected or likely because of the poor soil quality and the prevailing land use in the area.

5.4. CRITICAL GROUP

As a result of the land use scenario, workers are potentially subject to the most exposure in the future. Mallinckrodt limits access to its facilities to employees, subcontracting construction workers, and authorized visitors and maintains 24-hour security at the property. Labor laws prohibit employment of minors. The maximum exposure could occur in two circumstances, either 1) to a typical production worker who spends most of their time in a building and some time out-of-doors or 2) to a construction or maintenance worker who spends a minor fraction of a work year in an excavation on-site.

Radioactive contamination on interior and exterior surfaces of the buildings has been addressed in the Phase I Plan. The regulated sources of radiation exposure in the Phase II Plan would be in soil and or on pavement in Plant 5. An industrial work scenario involves employees who spend most of their time in a building and some time out-of-doors. This critical group could potentially be exposed to outdoor sources by direct irradiation, by ingestion of soil, and by inhalation of airborne dust. While indoors, they could be exposed to radiation penetrating the floor of a building or to airborne dust that enters the building.

Occasionally, subsoil may need to be accessed for maintenance, to construct a structural foundation, or to install an underground utility line. During that time, construction or maintenance workers may need to spend time on bare ground and or in an excavation. Consequently, construction or maintenance workers are evaluated as a possibly critical exposure group.

5.5. ENVIRONMENTAL EXPOSURE PATHWAYS

Whereas decommissioning criteria for buildings was addressed in the C-T Phase I Plan, the Phase II Plan addresses decommissioning criteria for soil, pavement, and building slabs. Thus, environmental pathways from residual source material in soil or on surfaces of pavement or building slabs to potential exposure of people in the critical group of workers are of interest to derivation of DCGL.

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[5] Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, U.S. Army Corps of Engineers, St. Louis District, Formerly Utilized Sites Remedial Action Program, April 1998, page 2-4.

5.5.1. Pathways to Industrial Worker

A typical production or maintenance worker will spend most of their time in a building and some time out-of-doors. Such an *industrial worker* might be exposed to radionuclides in soil or on the surface of pavement or a building slab in the following ways.

1. Gamma radiation emitted by contaminated soil might irradiate a worker directly while out-of-doors.
2. Contaminated soil might be suspended as airborne dust and inhaled by a worker while out-of doors.
3. Contaminated soil might get on a worker's clothing and/or hands and be eaten inadvertently.
4. Gamma radiation emitted by contaminated soil might penetrate the floor and or walls of a building and irradiate a worker while indoors.
5. Contaminated soil might be suspended as airborne dust; some fraction of that dust might enter a building in ventilation air, and be inhaled by a worker while inside a building.

Although credit was not taken in dose modeling to derive DCGL for contaminated soil, a mitigating factor is that pavement shields an industrial worker from some direct radiation from soil and from creation of airborne dust from soil beneath the pavement. Most of Plant 5 is covered by buildings or is paved with concrete or macadam. Characterization surveys have identified some radioactivity on pavement that is elevated above expected background. As a practical matter, a worker would not be exposed simultaneously to bare ground and to pavement. Thus, separately an industrial worker might be exposed by:

- direct irradiation by the surficial source while out-of-doors;
- inhalation of dust suspended from the surface while out-of-doors;
- ingestion of dust;
- direct irradiation while indoors; and
- inhalation while indoors of dust suspended from a surficial source on pavement.

5.5.2. Pathways to Construction Worker

Occasionally, subsoil may need to be accessed to construct a structural foundation, to install an underground utility line, or to perform repair. In that event, *construction workers* would be subject to exposure to any residual source in the soil during a fraction of year during the construction. Exposure pathways would be relatively direct, including external irradiation from soil, inhalation of suspended dust, and inadvertent ingestion of dust from hands and clothing, all while out-of-doors.

5.5.3. Pathways Not Present

5.5.3.1. Surface Water.[6]

Site wastewater, storm water, and all other surface drainage flow via site sewers and drains to a combined municipal sewer system and then to the Metropolitan St. Louis Sewer District (MSD) Bissell Point Treatment Plant. The Bissell Point Plant is located approximately 1 km (0.7 mi.)

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[6] C-T Phase II Plan §3.6 Surface Water Hydrology.

north (upstream) of the site. Treated water is discharged to the Mississippi River. During storm periods, the combined sewer system serving the site is diverted directly to the Mississippi River. There are no surface streams or lakes on-site; industrial or commercial use would not be conducive to creation of either, thereby eliminating any reasonable anticipation of surface water use on-site to become a potential exposure pathway.

5.5.3.2. Groundwater.[7]

The groundwater beneath the site is not a current source of drinking water, nor will it be a source of drinking water in the future for the following reasons.[8, 9]

1. All of the drinking water for the City of St. Louis is derived from the Mississippi and/or Missouri Rivers, and all of the drinking water intakes for the City of St. Louis are located upstream of the facility.

2. St. Louis City Ordinance 13,272, Section 3 (dated March 25, 1885), states that drinking water supply wells are prohibited within the City of St. Louis. The ordinance has restricted drinking water supply well installation in the City of St. Louis for over 100 years and will continue to restrict well installation for the foreseeable future.

3. There is no known drinking water well in the vicinity of the plant (DOE, 1990). According to information obtained from the Missouri Department of Natural Resources Division of Geology and Land Survey, two wells are located within a ½-mile radius of the facility (EPA, 1993). Neither of the wells is a drinking water well. Well No. 2798 is located in the SE¼ of Township 45N Range 7E. It was installed in 1933 to a depth of 185 feet and produced 30 gallons per minute. Fisher Chemical Company is listed as the well owner. Well No. 19835 is located in the SE¼ NE½ Township 45 N Range 7E and was installed in 1961. It is 180 feet deep and screened in the Mississippian alluvium. Well No. 19835 has produced 260 gallons per minute, but is located at an abandoned site.

4. The quality of perched groundwater in fill historically placed along the riverfront in the St. Louis area is naturally poor due to the presence of brick, glass, concrete rubble, coal cinder, and slag, and associated metals and PAH compounds (DOE, 1990). The perched zone is intermittent in nature and limited in its lateral continuity, saturated thickness, and transmissivity, which results in low water producing quality. For these reasons, the perched zone is not a realistic source of potable groundwater even in the absence of any contamination derived from the Mallinckrodt facility.

5. Groundwater in the lower zone (sandy alluvial unit) is locally saline and generally very hard, with high iron and manganese content. Groundwater found in the underlying bedrock is generally saline and non-potable. Groundwater in the site area is not withdrawn for potable, industrial, or agricultural purposes, and groundwater use is not anticipated to change in the future. Considering these unfavorable groundwater characteristics and that St. Louis has a

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[7] C-T Phase II DP §3.7 Groundwater Hydrology.

[8] Mallinckrodt. *RCRA Facility Investigation Report for AOC I (Site-Wide Groundwater)*, Mallinckrodt, Inc., St. Louis Facility, p. 5. April 6, 2001; prepared by URS Corporation.

[9] Ref. Appendix A herein.

municipal water system that serves this region, installation of a domestic water well is not reasonably foreseeable. Since the land is unsuitable for agriculture because it is coal cinder fill, withdrawal of groundwater for agricultural irrigation also is not a reasonable expectation.

6. Groundwater in the St. Louis area is generally of poor quality and does not meet drinking water standards without treatment. The expected future use of groundwater at the SLDS is minimal since in the Mississippi and Missouri Rivers constitute high-quality, large-quantity, readily available sources.[10]

5.6. CONCEPTUAL AND MATHEMATICAL MODELS

Each environmental scenario and pathway of exposure can be described by a conceptual model and a mathematical model. A *conceptual model* is a simplified description of the environmental system, including the radioactive source, its movement in the environment to a receptor, and habits of the receptor of the exposure. A *mathematical model* reduces the conceptual model into equations that can quantify the relations between radioactive source and radiological dose.

5.6.1. Soil

The RESRAD computer program implements mathematical models that calculate total effective dose equivalent to an average member of the critical group from residual radionuclides in soil. RESRAD models simulate environmental pathways including transport in air, water, and biological media to an exposed person. Exposure is translated to radiological dose with ICRP models (ICRP 26, 30, and 48) for estimating total effective dose equivalent, which are the bases of NRC regulations. Mathematical models implemented in RESRAD v.6 have been described.[11] RESRAD v.6 includes perhaps the best available set of mathematical models to describe the environmental scenario and exposure pathways that might be anticipated in Plant 5 after C-T decommissioning.

5.6.2. Pavement

Land in Plant 5 that is not covered by a building is practically all paved with concrete or macadam. Characterization surveys have identified some radioactivity on pavement that is elevated above expected background. A conceptual model of this surficial source is described as 0.1 cm thick layer of contaminated soil at land surface. An industrial worker might be exposed to surficial contamination on pavement by:

- direct irradiation by the surficial source while out-of-doors;
- inhalation of suspended dust while out-of-doors;
- ingestion of dust;
- direct irradiation while indoors; and
- inhalation of suspended dust while indoors.

These potential exposure pathways are simulated by mathematical models in RESRAD v.6. An advantage of using RESRAD for exposure to contamination on pavement is consistency with the

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[10] USACE. Record of Decision for St. Louis Downtown Site. p. 6, July 1998.

[11] Yu, C., *et. al.*, *User's Manual for RESRAD* Version 6. ANL/EAD-4. July 2001.

simulation of the conceptual model for exposure to bare soil. This is significant because the airborne dust loading model is used to estimate airborne concentration of respirable particulate for both the outdoor sources, soil and pavement.

5.7. INPUT PARAMETERS

Default values of parameters in RESRAD v. 6 have been developed and described.[12] Unless described herein, default values of parameters in RESRAD v.6 have been retained in the derivation of DCGL. The influence of parameters most pertinent to the scenario have been considered for appropriateness of value.

5.7.1. Industrial Worker and Construction Worker Exposed to Soil

5.7.1.1. Area of Contaminated Zone

For the purpose of deriving, DCGL in soil, the area of a contaminated zone should not be smaller than 2,000 m^2 the maximum area of a Class 1 survey unit; nor should it be larger than 10,000 m^2, the maximum area of a Class 2 survey unit. The RESRAD v.6 default value is 10,000 m^2. The larger assumed potential area increases dose by airborne dust inhalation and thereby diminishes the DCGL. Thus, the default value, 10,000 m^2 is retained.

5.7.1.2. Thickness of Contaminated Zone

The thickness of the contaminated zone is the depth distance between the uppermost and lowermost soil samples that have radionuclide concentration above background. The default value recommended for use in RESRAD, 2 meters, will be used in calculations to derive DCGL.

5.7.1.3. Cover Depth

Cover depth is the distance from ground surface to the contaminated zone. The default value in RESRAD is zero meters. Although Plant 5 is covered by pavement, when evaluating potential exposure to contaminated soil, it will be modeled as if there were no pavement and the land were bare.

5.7.1.4. Soil Mixing Layer Thickness

The soil mixing layer thickness is the thickness of the uppermost soil layer in which radioactive residue is mixed. It is estimated[13] to range from 0 to 0.6 meter, with the most likely thickness being 0.15 m. Since 0.15 m is also the default value, it will be assumed in DCGL calculations.

5.7.1.5. Occupancy Time

Occupancy times are described as the fraction of a year spent indoors and the fraction of a year spent outdoors in an area on-site that was previously contaminated. That would be the fraction of an 8766 hour year spent in an industrial or construction scenario within an affected area of

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[12] Biwer, B.M., *et. al.*, "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch. C in *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes.* NUREG/CR-6697. Dec. 2000.

[13] *op. cit.*, Biwer, B.M., *et. al.*, pp. 3-42 & 3-43.

Plant 5 or where the C-T incinerator or URO burials had been located.

An *industrial or commercial work* year is estimated to be 50 weeks x 40 hr/wk = 2000 hr. 0.8 of that time is estimated to be indoors and 0.2 is estimated to be out-of-doors. These amount to 0.1825 of time indoors and 0.04566 of time out-of-doors. By comparison, the USACE estimated industrial worker occupancy 0.1969 of time indoors and 0.04566 out-of-doors on nearby Plant 2;[14] while the ANL staff estimated industrial worker occupancy indoors to be 0.17 of the time and occupancy out-of-doors to be 0.06 of the time.[15]

The USACE estimated that on adjacent land remediated under the FUSRAP,[16] a construction worker might work two weeks (80 hr) during a work year on excavated, remediated land without cover. It is reasonable that this time apply to a *construction work* scenario in Plant 5 after it is decommissioned.

5.7.1.6. Inhalation Rate

It is necessary to estimate the volume of air inhaled by a worker while in an area on-site that was previously contaminated in order to estimate potential radiological dose to an industrial worker after C-T decommissioning. That volume is the product of occupancy time and inhalation rate. Resource data on inhalation rate have been reviewed.[17]

For the purpose of deriving DCGL in soil, industrial workers are assumed to spend time out-of-doors on affected land as well as indoors. The RESRAD model accepts a single inhalation rate, which should be weighted to represent both circumstances. The USACE[18] estimates an industrial worker breathes at an average rate of 1.2 m^3/hr. The ANL staff estimates that an industrial worker breathes at an average rate of 1.3 m^3/hr.[19] Short-term inhalation rates of adults[20] at 1.0 m^3/hr during light activity 1/3 of the time and at 1.6 m^3/hr during moderate activity 2/3 of the time produce a time and activity weighted inhalation rate of 1.4 m^3/hr. Similarly, if an outdoor worker[21] breathes 1.1 m^3/hr during slow activity 0.25 of the time and 1.5 m^3/hr during moderate activity 0.75 of the time, the weighted inhalation rate would also be estimated to be 1.4 m^3/hr. An inhalation rate of 1.4 m^3/hr has also been recommended as the default rate for commercial or industrial building occupancy.[22] An inhalation rate representing an *industrial* worker who spends some time out-of-doors and the majority indoors is represented by 1.4 m^3/hr in the industrial work scenario.

Construction worker activity would seem to be most nearly similar to gardening, for which the

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[14] USACE. Post-Remedial Action Report for the St. Louis Downtown Site Plant 2 Property. Table B-3. June 2001.

[15] Yu, C., *et. al.*, ANL/EAD-4, Table 2-3, p. 2-22.

[16] *ibid.*, USACE.

[17] Biwer, B.M., *et. al.*, atch C, pp. 5-1 thru 5-5 in NUREG/CR-6697.

[18] USACE. Post-Remedial Action Report for the St. Louis Downtown Site Plant 2 Property. Table B-3. June 2001.

[19] Yu, C., *et. al.*, *User's Manual for RESRAD Version 6. ANL/EAC-4. p.2-22. July 2001.*

[20] Biwer, B.M., *et. al.*, p. 5-4, Table 5.1-2.

[21] Biwer, B.M., *et. al.*, p. 5-4, Table 5.1-2.

[22] Biwer, B.M., *et. al.*, atch C, p. 5-3 in NUREG/CR-6697

recommended[23] default inhalation rate is 1.7 m^3/hr. This would correspond to an outdoor worker[24] whose activity is 0.8 moderate exertion at 1.5 m^3/hr breathing rate and 0.2 heavy exertion at 2.5 m^3/hr breathing rate. Since *construction* workers are assumed to work out-of-doors entirely, the inhalation rate of this critical group is estimated to be 1.7 m^3/hr without adjustment for any time indoors.

By comparison, the USACE estimates a breathing rate of 1.2 m^3/hr represents both industrial workers and construction workers on portions of Mallinckrodt's site being remediated under the FUSRAP.

5.7.1.7. Mass Loading for Inhalation

Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil, that is respirable. Respirable particles are those less than 10 μm in diameter. About 0.28 to 0.33 of airborne particles have been found to be respirable.[25, 26, 27, 28] The mass loading of respirable particulate in air may be estimated as the product of the total mass loading of airborne dust and the respirable fraction.

The total mass loading of airborne dust in an urban area has been estimated to range from 60 to 220 μg/m^3 by USHEW[29] and 33 to 254 by Gilbert, *et.al.*[30] A best geometric estimate is about 115 μg/m^3. Thus, a reasonable estimate of respirable mass loading for inhalation in an urban, industrial area is 0.3 x 115 μg/m^3 = 35 μg/m^3. (This is about the upper 90th percentile recommended for use in RESRAD in a residential environment.[31] Long-term measurements of mass loading in ambient air are 23 μg/m^3 at the 50th percentile.)

Airborne dust in the vicinity of excavation may be reasonably similar to that during tilling bare land. 136 μg/m^3 has been measured while tilling a bare field;[32] gardening has been assumed to produce 500 μg/m^3 of airborne dust. A best geometric estimate is about 260 μg/m^3. Thus, a reasonable estimate of respirable mass loading for inhalation in a construction/excavation area is 0.3 x 260 μg/m^3 = 80 μg/m^3.

Thus, a mass loading of respirable dust in air = 35 μg/m^3 has been entered into RESRAD to

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[23] Biwer, B.M., *et. al.*, p. 5-4, Table 5.1-3.

[24] Biwer, B.M., *et. al.*, p. 5-4, Table 5.1-2.

[25] USEPA. *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment.* EPA 520/4-77-016. pp. 31-32. Sept. 1977.

[26] Chepil, W.S., "Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust." Am. J. Sci., 225, p. 206, 1957. in EPA 520/4-77-016, p. 57

[27] Sehmel, G.A., *Radioactive Particle Resuspension Research Experiments on the Hanford Reservation,* BNWL-2081, 1977.

[28] Willeke, K. *et.al.*, "Size Distribution of Denver Aerosols - A Comparison of Two Sites," Atm. Env., 8, p. 609, 1974.

[29] USHEW. *Air Quality Criteria for Particulate Matter.* 1969. in NUREG/CR-5512, 1, p. 6.11.

[30] Gilbert, T.L., *et.al., Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites.* ORO-832 rev. Jan 1984. in Yu, C. *et.al., Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil.* ANL/EAIS-8. pp. 110-111, Apr. 1983.

[31] Biwer, *et.al.* atch C, p. c4-16 in NUREG/CR-6697.

[32] NUREG/CR-5512, 1, p. 6.11.

simulate an *industrial* work scenario, and 80 μg/m^3 has been entered for *construction* work.

5.7.1.8. Soil Ingestion Rate

The quantity of contaminated soil ingested incidentally from outdoor activities annually is estimated to range from 0 to 36.5 g/yr.[33] The most likely amount is estimated to be 18.3 g/yr.[34] The recommended default value[35], 36.5 g/yr, is entered into RESRAD to represent an industrial worker.

Because a construction scenario is on exposed land, the inadvertent soil ingestion rate will be assumed to increase to 73 g/yr.

5.7.1.9. Building Shielding Against Gamma Irradiation

The floor and walls of a building shield an occupant against some gamma rays entering from soil outside. Buildings in Plant 5 have concrete slab floors and brick or concrete block walls with few windows. They would be similar to a brick house on a concrete slab or with a basement. In that environment, the building shielding factor for external gamma radiation is estimated to be 0.17.[36] In the *industrial work* scenario, a gamma shielding factor = 0.17 is assumed to represent building flooring and walls in Plant 5.

When a *construction work* scenario is evaluated, workers are assumed to be out-of-doors on bare ground; hence a gamma shielding factor = 1.0 is entered into RESRAD in that circumstance.

5.7.1.10. Indoor Airborne Dust Filtration

The fraction of airborne dust out-of-doors that is available indoors has been reviewed.[37] When considering outdoor sources of respirable particulate indoors, Wallace[38] estimated the indoor-to-outdoor fraction to be close to 0.5. In residential housing, Wallace estimated the indoor-to-outdoor fraction of respirable particulate to average about 0.57. Biwer, *et. al.*,[39] estimated the same fraction to be 0.54. A value of 0.6 will be assumed when deriving DCGL for an industrial worker scenario.

5.7.1.11. Wind Speed

The average wind speed reported for St. Louis is 4.3 m/s (9.5 mi/hr);[40] whereas the default value in RESRAD v. 6 is 2 m/s. Although it makes little difference in dose modeling, an average wind speed = 4. m/s is entered into RESRAD to derive DCGL for C-T decommissioning.

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[33] Biwer, *et.al.* atch C, pp. c5-19 thru c5-25 in NUREG/CR-6697.

[34] *ibid.*

[35] Yu, C., *et. al.*, NUREG/CR-6697, p. 18, Table 2.1.

[36] Biwer, *et.al.* atch C, p. c7-36 in NUREG/CR-6697

[37] Biwer, *et.al.* atch C, pp. 7-1 thru 7-4 in NUREG/CR-6697

[38] Wallace, L., "Indoor Particles: A Review." J. Air & Waste Mgt. Assoc., 46, pp. 98-126. 1996 in Biwer, *et.al.* atch C, pp. 7-1 thru 7-4 in NUREG/CR-6697.

[39] Biwer, *et.al.* atch C, pp. 7-3 & 7-4 in NUREG/CR-6697.

[40] C-T Phase II Decommissioning Plan, §3.4, Table 3-2.

5.7.2. Industrial Work on Pavement

The influences of parameters most pertinent to industrial work on pavement scenario are discussed below. Industrial worker characteristics are assumed to be the same whether the source is in soil or on pavement. Aside from parameters mentionedbelow, default values of parameters in RESRAD v.6 have been retained when deriving DCGL for surficial contamination on pavement.

5.7.2.1. Contaminated Zone

Surficial contamination on pavement may be simulated in RESRAD as a thin contaminated layer of soil without cover and with zero erosion rate. Inhalation and ingestion models in RESRAD depend more on radionuclide concentration in soil than on thickness; while direct irradiation is more closely related to thickness, particularly when the source is thin. Physically, one would not expect as much as 0.1 cm of soil, on average, on pavement in Plant 5.

Consequently, a 0.1 cm thickness of soil adequately represents areal contamination on pavement for the purpose of estimating potential exposure of an industrial worker. Areal contamination on pavement is thus represented by 0.1 cm thick contaminated zone, zero cover depth, and zero erosion rate.

Although characterization survey data suggest surface contamination is unlikely to exceed an appropriate areal DCGL, assumption of 10,000 m^2 area of contamination will tend to maximize the dose factor and minimize the DCGL. Hence, the default value of the contaminated area, 10,000 m^2, is retained for pavement.

5.7.2.2. Wind Speed and Mass Loading for Inhalation

The average wind speed reported for St. Louis is 4.3 m/s (9.5 mi/hr);[41] whereas the default value in RESRAD v. 6 is 2 m/s. Thus, an average wind speed = 4. m/s is entered into RESRAD to derive an areal DCGL for decommissioning pavement affected by C-T.

A mass loading of respirable dust in outdoor air = 35 $\mu g/m^3$ has been entered into RESRAD to simulate an industrial work scenario in which the radioactive source is surficial contamination on pavement. The rationale of a dust concentration, 35 $\mu g/m^3$, in outdoor air is discussed in section 5.7.1.7.

While a worker is indoors, an indoor dust filtration factor = 0.6 will be assumed when deriving DCGL. The rationale for estimating this value is discussed in section 5.7.1.10.

5.7.2.3. Worker Characteristics

Industrial workers spend most of their time indoors. In Plant 5, an industrial worker is conservatively assumed to be on contaminated pavement 0.20 of their work time, which is an outdoor time fraction = 0.04563, and their remaining time indoors, an indoor time fraction = 0.1825. These estimates are discussed in section 5.7.1.5.

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[41] C-T Phase II Decommissioning Plan, §3.4, Table 3-2.

Where the source of contamination is on the surface of pavement, an industrial worker is assumed to ingest contaminated material at RESRAD's default rate, 36.5 grams per year.

A breathing rate representative of indoor and outdoor activities is estimated to be 1.4 m^3/hr, or 12270 m^3 during a 2000 work year. While indoors, an external gamma shielding factor = 0.17 of the outdoor gamma exposure rate is estimated to apply in Plant 5 buildings, which typically are constructed with a concrete slab floor and brick walls. These estimates are discussed in sections 5.7.1.6, 5.7.1.9, and 5.7.1.10.

5.8. RESRAD CALCULATIONS

Dose modeling was performed with the RESRAD v.6 program for each major nuclide: U^{238}, U^{234}, Th^{230}, Ra^{226}, and Pb^{210} in the uranium series, U^{235}, Pa^{231}, and Ac^{227} in the actinium series, and Th^{232}, Ra^{228}, and Th^{228} in the thorium series. The RESRAD code included dose contributions from short-lived daughters of each of these nuclides.

5.8.1. Industrial Work on Soil

5.8.1.1. DCGL$_W$

The input and output for the RESRAD runs in this analysis are in Appendix D. The RESRAD output for each radionuclide can be interpreted as a dose factor (mrem/y per pCi/g soil), which in turn may be interpreted as a maximum acceptable concentration of the radionuclide in soil, also called the DCGL$_w$, corresponding to a potential radiological dose equivalent of 25 mrem/yr. The RESRAD-computed dose factors and corresponding DCGL$_W$ are in Table 5-1.

These DCGL$_W$ for individual radionuclides or for the U series and or Th series may be combined into a composite DCGL$_W$ representing a mixture of U series and Th series radionuclides. A composite limit,[42] accounting for the proportions of U series and Th series, is derived in accordance with the sum-of-fractions equation:

$$\text{Limit}_{\text{composite}} = \frac{\sum_i F_i}{\sum \frac{F_i}{Lm_i}}$$

where

Limit$_{\text{composite}}$ = maximum acceptable average concentration of U series and Th series combined in soil, referenced to parents of series(pCi/g).

Lm_i = maximum acceptable average concentration of U series or Th series in radioactive equilibrium in soil, referenced to parent of series (pCi/g)

F_i = fraction of radioactivity represented by U series, referenced to U^{238} parent, or Th series referenced to Th^{232} parent.

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[42] Composite limit is also referred to as the derived concentration guideline level for the Wilcoxon test (DCGL$_W$).

Table 5-1 Radionuclide Limits in Soil for Industrial Scenario

Radionuclide	Dose Factor mrem/yr per pCi/g	DCGLw[d] pCi/g
U-238	1.286e-2	1.944e+3
U-235 +DI[c]	4.785e-1	5.225e+1
U-234	3.193e-3	7.830e+3
Th-230	6.826e-3	3.662e+3
Ra-226	8.204e-1	3.047e+1
Pb-210	6.019e-2	4.154e+2
Th-232	6.331e-2	3.949e+2
Ra-228	5.328e-1	4.692e+1
Th-228	6.257e-1	3.996e+1
U-238 +DI[b]	9.252e-1	2.702e+1
Th-232 +DI[a]	1.222e+0	2.046e+1

[a] Th-232 +DI is the limit for Th-232 in the situation in which all progeny nuclides are present in equilibrium concentration (*i.e.*, concentration of each equal to the Th-232 concentration). Because Th-232 progeny grows in to equilibrium within about 30 years, and because the C-T facilities have existed for nearly that long, Th-232 progeny can be expected to be near equilibrium.

[b] U-238 +DI is the limit for U-238 in the situation in which all progeny nuclides are present in equilibrium and the U^{235} series is present in equilibrium as in natural uranium.

[c] Radioactivity ratio of U^{235} -to- U^{238} = 0.0455 in natural uranium.

[d] per pCi parent nuclide/g soil

DI = radioactive progeny included and assumed in radioactive equilibrium with parent

5.8.1.2. Area Factor for Elevated Measurements in Soil

It is desirable to discover any small area of contamination that could cause more than 25 mrem/yr radiological dose. The magnitude by which the concentration within a small area of elevated radioactivity can exceed the $DCGL_W$ while maintaining compliance with the release criterion is defined as an *area factor*.[43] It may be calculated as the ratio

$$\text{Area Factor} = \frac{\text{composite dose factor for survey unit area}}{\text{composite dose factor for local area of contamination}}$$

Figure 5-1 is the *area factor* as a function of a localized area of radioactive contamination consisting separately of thorium series and of uranium series + actinium series in which uranium isotopes are in the ratio occurring in natural uranium. A composite of U series and Th series would be derived by a sum-of-fractions equation. An illustration of the composite effect is presented in Figure 5-1 for U series + Th series in a 3 -to-1 parent ratio. The maximum tolerable

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[43] MARSSIM, p. 5-36. Dec. 1997.

areal density of residual radioactive contamination, above background, within a small area of elevated radioactivity is derived by the relation

$$DCGL_{EMC} = \text{Area Factor} \times DCGL_w$$

Systematically distributed measurements and soil characterization survey measurements, together, are employed in each Class 1 survey unit to find such an area of contamination whose areal radioactivity density is elevated above the $DCGL_W$.

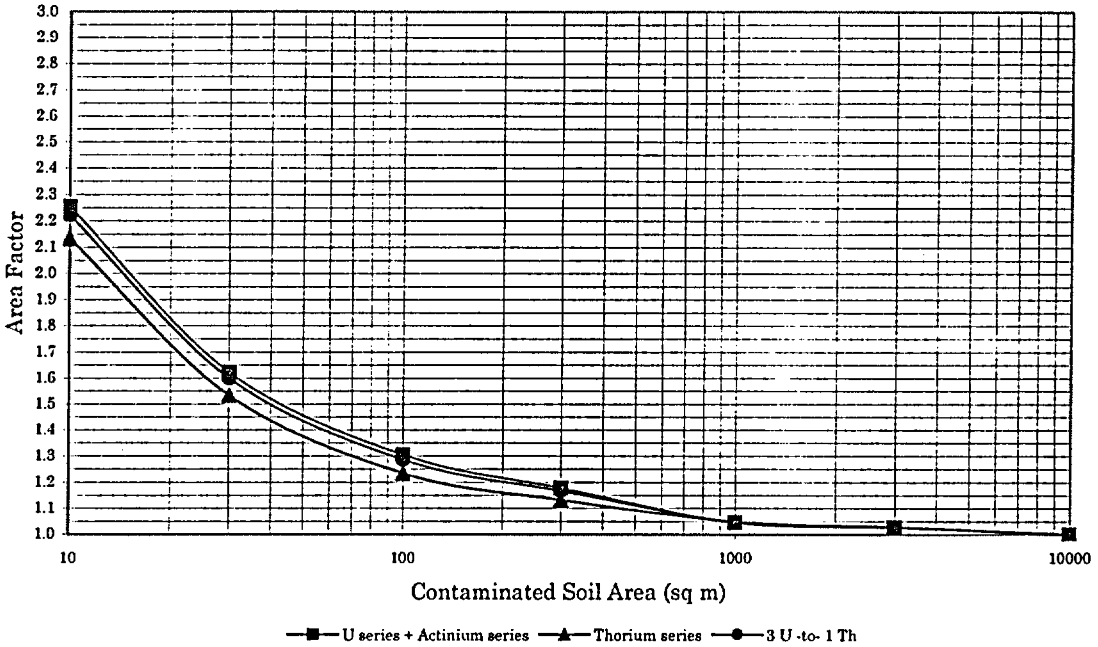

Figure 5-1. Area Factors for Elevated Measurements Criterion for Soil

5.8.2. Construction Work on Soil

Dose factors were computed by RESRAD for a construction work scenario. Corresponding $DCGL_W$ were then derived as the quotient of 25 mrem/yr and each dose factor. The results, in Table 5.2, are lower dose factors and higher $DCGL_W$ than for the industrial work scenario. For a given residual radioactivity concentration, a construction work scenario poses a potentially lower radiological dose than an industrial work scenario. Consequently, evaluation of a construction work scenario is not pursued further.

Table 5-2 Radionuclide Limits in Soil for Construction Scenario

Radionuclide	Dose Factor mrem/yr per pCi/g	$DCGL_W$[d] pCi/g
U-238	1.768e-3	1.414e+4
U-235 +DI[c]	6.086e-2	4.108e+2
U-234	3.789e-4	6.598e+4
Th-230	8.382e-4	2.983e+4
Ra-226	1.172e-1	2.133e+2
Pb-210	6.051e-3	4.132e+3
Th-232	8.349e-3	2.994e+3
Ra-228	7.588e-2	3.295e+2
Th-228	8.969e-2	2.787e+2
U-238 +DI[b]	1.290e-1	1.938e+2
Th-232 +DI[a]	1.739e-1	1.438e+2

[a] Th-232 +DI is the limit for Th-232 in the situation in which all progeny nuclides are present in equilibrium concentration (*i.e.*, concentration of each equal to the Th-232 concentration). Because Th-232 progeny grows in to equilibrium within about 30 years, and because the C-T facilities have existed for nearly that long, Th-232 progeny can be expected to be near equilibrium.

[b] U-238 +DI is the limit for U-238 in the situation in which all progeny nuclides are present in equilibrium and the U^{235} series is present in equilibrium as in natural uranium.

[c] Radioactivity ratio of U^{235} -to- U^{238} = 0.0455 in natural uranium.

[d] per pCi parent nuclide/g soil

5.8.3. Industrial Work on Pavement

5.8.3.1. $DCGL_W$ on Pavement

Dose factors were computed by RESRAD for an industrial work scenario on pavement. Corresponding $DCGL_W$ were then derived as the quotient of 25 mrem/yr and each dose factor. The results are in Table 5-3. The input and output for the RESRAD runs used in this analysis are listed in Appendix D. The RESRAD output for each radionuclide can be interpreted as a dose factor (mrem/y per pCi/m^2), which in turn may be interpreted as a maximum acceptable average areal density of the radionuclide on a surface, also called the $DCGL_w$, corresponding to a potential radiological dose equivalent of 25 mrem/yr.

Table 5-3. Uranium Series and Thorium Series Limits on Pavement Surface

Radionuclide	Dose Factor mrem/yr per pCi/g	Areal Density Equal to 25 mrem/yr pCi/100 cm^2	 dpm/100 cm^2
U-238	1.276 e-4	2.94e+6	6.52e+6
U-235 +DI[c]	5.779e-3	6.49e+4	1.44e+5
U-234	1.125e-5	3.33e+7	7.40e+7
Th-230	5.296e-5	7.08e+6	1.57e+7
Ra-226	1.628e-2	2.30e+4	5.11e+4
Pb-210	4.155e-4	9.03e+5	2.00e+6
Th-232	4.852e-4	7.73e+5	1.72e+6
Ra-228	3.219e-3	1.16e+5	2.59e+5
Th-228	1.177e-2	3.19e+4	7.07e+4
U-238 +DI[b]	1.72e-2	2.19e+4	4.85e+4
Th-232 +DI[a]	1.55e-2	2.42e+4	5.38e+4

[a] Th-232 +DI is the limit for Th-232 in the situation in which all progeny nuclides are present in equilibrium concentration (*i.e.*, concentration of each equal to the Th-232 concentration). Because Th-232 progeny grows in to equilibrium within about 30 years, and because the C-T facilities have existed for nearly that long, Th-232 progeny can be expected to be near equilibrium.

[b] U-238 +DI is the limit for U-238 in the situation in which all progeny nuclides are present in equilibrium and the U^{235} series is present in equilibrium as in natural uranium.

[c] Radioactivity ratio of U^{235} -to- U^{238} = 0.0455 in natural uranium.

5.8.3.2. Area Factor for Elevated Measurements on Pavement

It is desirable to discover any small area of contamination that could cause more than 25 mrem/yr radiological dose. The magnitude by which the concentration within a small area of elevated radioactivity can exceed the $DCGL_W$ while maintaining compliance with the release criterion is defined as an *area factor*.[44] Figure 5-2 provides the *area factor* separately for U series (including actinium series present in natural uranium) and Th series as a function of a localized area of radioactive contamination on pavement. This is the $DCGL_W$ of each decay series referenced to parent of the series when all progeny are in secular radioactive equilibrium with the parent. The actinium series is assumed present with the uranium series at the radioactivity ratio, U^{235}-to-U^{238} = 0.0455, that occurs naturally.

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[44] MARSSIM, p. 5-36. Dec. 1997. Biwer, *et.al.* atch C, pp. 7-1 thru 7-4 in NUREG/CR-6697

Since a gross radiation measurement is commonly used to assess compliance with areal density DCGL, a composite limit,[45] accounting for the proportions of U series and Th series, is derived in accordance with the sum-of-fractions equation:

$$\text{Limit}_{\text{composite}} = \frac{\sum_i F_i}{\sum \frac{F_i}{Lm_i}}$$

where

$\text{Limit}_{\text{composite}}$ = maximum acceptable average areal radioactivity density limit of U series and Th series combined, referenced to parents of series(dis/(min·100 cm^2)).

Lm_i = maximum acceptable average areal radioactivity density limit of U series or Th series in radioactive equilibrium, referenced to parent of series (dis/(min·100 cm^2))

F_i = fraction of radioactivity represented by U series, referenced to U^{238} parent, or Th series referenced to Th^{232} parent.

A composite area factor is calculated as the ratio of composite areal density limits, *i.e.*, DCGL, applicable to U series and Th series combined.

$$\text{Area Factor} = \frac{\text{composite areal DCGL for survey unit area}}{\text{composite areal DCGL for local area of conta min ation}}$$

The maximum tolerable areal density of residual radioactive contamination, above background, within a small area of elevated radioactivity is derived by the relation

$$\text{DCGL}_{\text{EMC}} = \text{Area Factor} \times \text{DCGL}_{w}$$

Systematically distributed measurements and scanning, together, are employed in each Class 1 survey unit to find such an area of contamination whose areal radioactivity density is elevated above the DCGL_W.

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[45] Composite limit is also referred to as the derived concentration guideline level for the Wilcoxon test (DCGL_W).

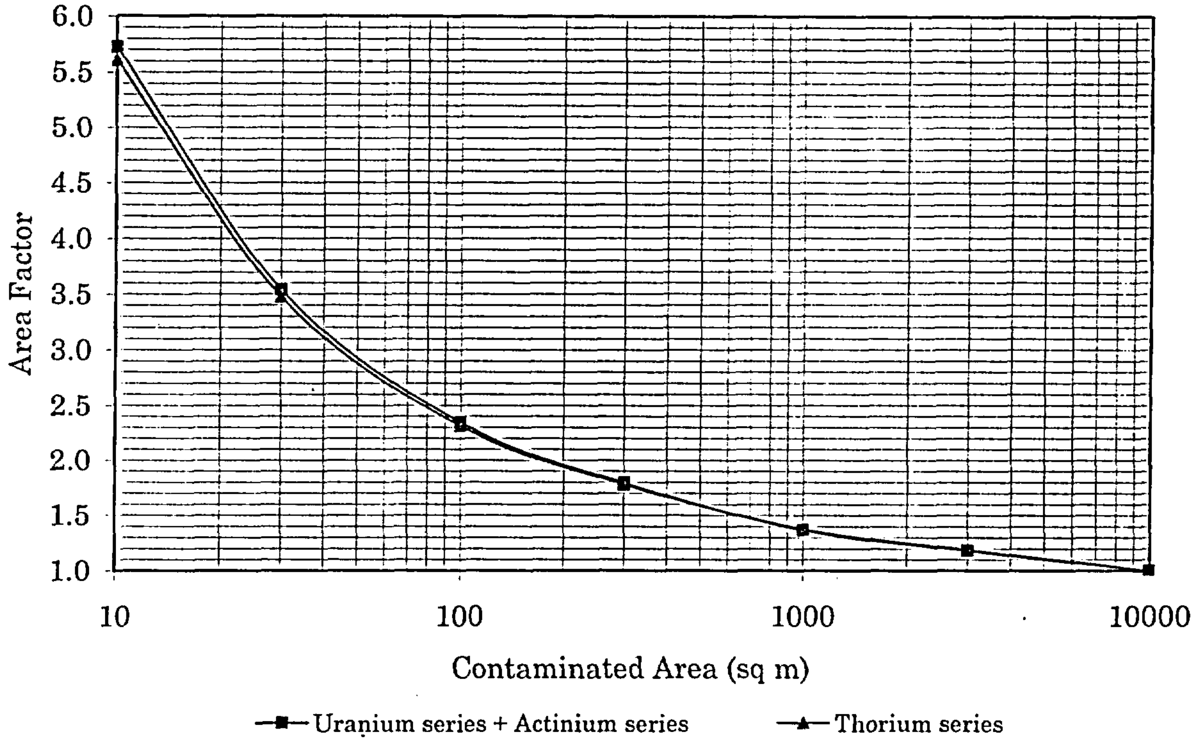

Figure 5-2. Area Factor for Elevated Measurements on Pavement

5.8.4. Sensitivity Analysis

An aim of conceptual and mathematical modeling to derive a DCGL is confidence that the modeling is unlikely to overestimate future radiological dose to an average member of the critical group of people exposed. That confidence is built on conceptual and mathematical simulation in which projected land use scenarios, environmental exposure models, and values of parameters in the models, compounded together, are unlikely to overestimate dose consequence of residual radioactive material.

It is important to understand the effect on dose of values used in the assessment to represent the key parameters. In deterministic modeling,[46] sensitivity analysis calculates the change in the radiological dose, with respect to a small change in the independent variables, one at a time. In a deterministic analysis, it is recognized that the reported dose is one of a range of possible doses that could be calculated for the site. It is important to build confidence that the single reported estimate of the peak dose is likely to be an overestimation of the actual peak dose.

The primary aim of sensitivity analysis is to identify the important assumptions and input parameters that cause variation in the estimated dose. This helps a modeler to identify conservative land use scenarios, models, and values in order to make a convincing case for the acceptability of the DCGL.

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[46] NUREG-1727, Apx. C, §6.3.3, p. C60.

Yu, *et. al.*,[47] have ranked RESRAD input parameters with respect to potential for affecting radiological dose, tendency to vary from site to site, parameter type, and ease of characterization using available literature. The impact on the radiation dose resulting from a change in a parameter value was a major factor in ranking the parameters for analysis.

Ranking of parameters in models used to derive DCGL for soil are in Table 5-4. Parameters ranked Priority 1 were expected to have the greatest potential for affecting radiological dose, tend to vary more from site to site, and are able to be characterized more easily than parameters of lower priority.

Table 5-4. ANL Ranking of Parameters in RESRAD That Are Used to Derive DCGL Herein

Priority 1 (higher)	Priority 2 (mid)	Priority 3 (lower)
Density of cover material *	Nuclide concentration	Time since placement of material*
Density of contaminated zone*	Area of contaminated zone*	Inhalation rate
	Thickness of contaminated zone*	Indoor time fraction
	Cover depth	Outdoor time fraction
	Cover erosion rate	Building foundation thickness*
	Wind speed	Building foundation density*
	Mass loading for inhalation	
	Indoor dust filtration factor	
	External gamma shielding factor	
	Soil ingestion rate*[A]	
	Depth of soil mixing layer*	

* Default value used for DCGL.

*, A Default value used for industrial worker. 2 times the default value is estimated a for construction worker.

In a particular scenario the sensitivity of derived dose to a change in parameter value depends on the influence of that parameter in each exposure pathway model and on the relative contribution of each pathway to total dose. Some parameters, like radionuclide concentration affect every pathway, whereas other parameters, such as mass loading of airborne dust affect only one or two inhalation pathways.

The Table 5-4 ranking of parameters and the fractional contribution by each pathway to total dose offer an efficient way to judge which are the most influential parameters.

In the industrial/commercial work scenario, most of potential dose would be caused by gamma

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[47] Yu, *et. al.*, NUREG/CR-6697. Table 4.2, p. 55.

irradiation directly from radionuclides in the soil. Minor fractions would be attributable to inadvertent ingestion of soil and inhalation of dust suspended from the soil. Parameters in RESRAD's direct radiation model to which dose is most sensitive to variation would be:

- density of cover material,
- density of contaminated zone,
- nuclide concentration in the contaminated zone,
- area of contaminated zone
- thickness of contaminated zone
- cover depth, and
- external gamma shielding factor while indoors.

Radiological dose by gamma irradiation directly from contaminated soil would be a direct, one-to-one, function of radionuclide concentration in the contaminated zone.

DCGL herein is derived on the basis of the default soil density, 1.5 g/cm^3, in the contaminated zone. Soil density in the contaminated zone does not affect source self-shielding because the contaminated zone is initially assumed to be an infinitely thick source relative to first collision of gamma rays and secondary photon buildup. The thickness of the contaminated zone, assumed to be 2 meters, is effectively an infinitely thick source, given the default soil density. That is, radiological dose would not be increased significantly by increasing the contaminated zone density or diminishing soil density within realistic bounds.

While radiological dose by direct irradiation is a function of the area of the contaminated zone, the 10000 m^2 default area assumed in deriving DCGL$_W$ is effectively infinite in areal extent.

Radiological dose is sensitive to cover depth and density of cover material. Both the industrial/commercial work scenarios assume outdoor exposure to bare, contaminated land, *i.e.*, without cover on the contaminated zone. Whereas, practically all land in Plant 5 is paved or is covered by a concrete slab. Together, they conceptually exclude inhalation and ingestion of contaminated soil and would shield an industrial worker from most direct gamma radiation. If one were to assume 4-inch-thick pavement instead of bare land containing typical 3 parts uranium series -to- 1 part Th series,[48] it would increase the composite DCGL$_W$ derived by RESRAD for an industrial worker about 5 times more than if no pavement were present.

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[48] 3 -to- 1 parts radioactivity (pCi) referenced to parent U^{238} and Th^{232}.

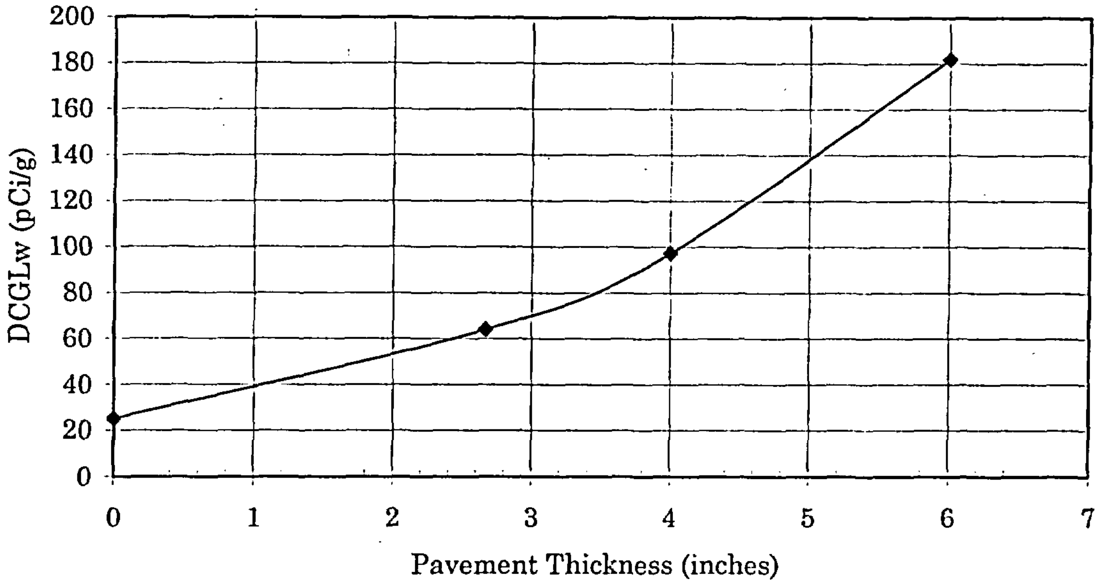

Figure 5-3. Effect of Pavement on DCGLw

Thus, radiological dose would be quite sensitive to depth and density of a pavement cover zone. This is evident in Figure 5-3. Having assumed no pavement when deriving the DCGL in soil tended to overestimate radiological dose and conservatively estimate the $DCGL_W$ in the industrial/commercial scenario herein by a factor of about 5 for typical U series + Th series combined.

5.8.5. Compliance with Regulatory Criteria

Mallinckrodt proposes to satisfy unrestricted release provisions of 10 CFR Part 20, Subpart E by evaluating final status survey data to demonstrate that

- $DCGL_W$ in §5.8.1.1 and $DCGL_{EMC}$ in §5.8.1.2 are not exceeded in soil affected by C-T operation, and separately that
- $DCGL_W$ in §5.8.3.1 and $DCGL_{EMC}$ in §5.8.3.2 are not exceeded on pavement affected by C-T operations.

Final radiation status survey methods to assess compliance are described in §14, *Facility Radiation Surveys.*

SECTION 6

CONSIDERATION OF ALTERNATIVES

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

6. CONSIDERATION OF ALTERNATIVES

This section identifies and evaluates reasonable alternatives that could accomplish their objective. The information provided includes descriptions of the alternatives evaluated; the impacts of each alternative; and the rationale for selecting the preferred alternative, *i.e.*, the proposed action. The environmental media that are subject to the essential scope of alternatives development are:

- accessible soils, and
- surfaces of pavement and slabs.

The general types of actions around which the following alternatives were developed are to:

- leave conditions as they currently exist (no action);
- reduce residual radioactivity within unrestricted release criteria by removing materials exceeding the criteria from the site (remediation and off-site disposal), and
- restrict exposure to residual radioactive materials on site (institutional controls).

6.1. ALTERNATIVES CONSIDERED

6.1.1. Alternative # 1, No Action

6.1.1.1. Description of the Facility if the No Action Alternative is Employed

Under this alternative, any residual radioactive material would remain on site as it exists. That is, no remedial decontamination of pavement or soil would be undertaken.

If a no action alternative were adopted, any residual radioactive material would be presumed to remain as described in C-T Phase II Decommissioning Plan (Phase II Plan) §4, "Radiological Status of Facility".

6.1.1.2. Summary of the Health Effects on Adjacent Communities if the No Action Alternative is Employed

Under current conditions described in Phase II Plan §4, "Radiological Status of Facility", residual source material in localized areas might cause more than 25 mrem/yr to a worker on the plant site. Without localized decontamination of C-T process building slabs and localized removal of soil, beneficial reuse of land where the process buildings were located would be hindered. Continuing surveillance to protect against undue exposure to residual radioactive material may be needed if no remedial decontamination were performed. Due to the limited amount of contamination, and the low specific activity of the contamination, no adverse health effects would be anticipated off-site.

6.1.1.3. Summary of the Impacts on Community Resources Such as Land Use and Property Values

The St. Louis Downtown Site (SLDS) is inherently an industrial use site, and has been for over 100 years. The No Action alternative would have little or no impact on the land use or property value in the area of the site. There would also be no additional impact due to increased traffic in the vicinity of the site due to decommissioning activities.

6.1.1.4. Summary of the Impacts on Geology, Hydrology, Air Quality and Ecology in and Around the Site

The No Action alternative leaves the current residual radioactive material in place. This means there is a long-term potential for migration of the radioactive material, with ultimate discharge to the Mississippi River. Given the high flow volume of the river compared to the discharge rate of groundwater into the river, the environmental impact would be negligible.

There is also a potential for airborne contamination. This would be primarily related to construction or excavation activities, and the probability for off-site impact is low.

6.1.1.5. Description of Impacts on Minority or Low-income Populations

Under the No Action alternative the SLDS would continue as an industrial use site, with minimum impact on minority or low-income populations.

6.1.1.6. Summary of the Irreversible and Irretrievable Commitment of Resources

The No Action alternative would require expenditure of funds for continued radiological monitoring. An additional expenditure of funds would be required for radiological controls and radiological waste management for any future excavation or building demolition. No additional irreversible impact or irretrievable commitment of resources would be anticipated. In the event construction activities were to remove affected pavement or soil, surveillance to provide radiation protection and radioactive waste management might be needed.

6.1.2. Alternative # 2. Remediate to Derived Radioactivity Concentration Guideline Levels

6.1.2.1. Description of the Facility if the DCGL Remediation Alternative is Employed

Under this alternative, maximum acceptable residual radioactivity concentration in soil and on pavement and slabs, *i.e.*, Derived Concentration Guideline Levels (DCGL), corresponding to NRC radiological dose criterion in 10 CFR Part 20, Subpart E, would be derived (ref. §5 Dose Modeling herein). Soil, streets, and slabs would be decontaminated or removed to achieve the DCGL.

If this alternative were employed, C-T production and support areas would be remediated to the DCGL in §5, Dose Modeling, criteria herein. Material found to contain less than the DCGL upon or after excavation or removal might be deposited in an excavation on Mallinckrodt's SLDS. These remediated areas would remain in beneficial use in Mallinckrodt's manufacturing plant along with the remainder of the SLDS.

Decommissioning to attain DCGL for unrestricted use would be achieved by cleanup and removal of soil or other contaminated material containing elevated radioactivity concentration. Remediation will be performed to reduce radioactive residue to *as low as reasonably achievable* (ALARA).

For soils, levels less than 25 mrem/y generally result in a cost-benefit ratio not considered reasonably justifiable under NRC's regulatory framework as described in NUREG/BR-0058.[1]

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[1] USNRC. *Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities.* NUREG-1496, 1. §6.2, p. 6-3. July 1997.

By remediating to a 25 mrem/y standard, reasonable alternatives will have been exercised to reduce and to avoid adverse effects.

6.1.2.2. Summary of the Health Effects on Adjacent Communities if the Alternative is Employed

This alternative increases protection of human health and the environment by reducing residual radioactive material from potential contact with industrial and construction worker occupants in comparison to existing conditions.

Residual radioactivity concentration or areal density guidelines, derived to satisfy NRC decommissioning regulations in 10 CFR Part 20, subpart E, must not cause any more than 25 mrem/yr to an average member of the most exposed group of people. In this situation, that group would be industrial workers on Mallinckrodt's St. Louis Downtown Site (SLDS). Potential exposure of members of the public nearby the SLDS would be insignificant.

If remediation waste is sent to a disposal site in accordance with an NRC-authorized transfer of unimportant quantity of source material, its potential radiological impact will be less than 25 mrem/yr and in no event more than 100 mrem/yr. In the event remediation waste is transferred to a licensed disposal site, its safety will be controlled by the conditions of the disposal site license.

6.1.2.3. Summary of the Impacts on Community Resources Such as Land Use and Property Values

All slabs, pavement, and soil subject to Phase 2 of C-T decommissioning are on Mallinckrodt's St. Louis Downtown Site. Any impacts on adjacent land and nearby population would be mainly due to transportation of remediation workers on local roadways and of solid waste shipments on the railroad that bisects the SLDS.

When C-T decommissioning is completed, C-T production and support buildings will have been dismantled or decontaminated. Streets and soil will have been remediated to satisfy NRC cleanup criteria. Afterward, Mallinckrodt can return the land and remaining support facilities to productive industrial use. The value of land and buildings to be decommissioned will be improved by return to beneficial use. Thereby, the adjacent community will benefit indirectly by continuing renewal and operation of the SLDS.

6.1.2.4. Summary of Impacts on the Geology, Hydrology, Air Quality and Ecology in and Around the Site

The environmental consequences of this alternative would be to remove or decontaminate soil, pavement, and slabs in or on which the DCGL is exceeded and to ship that which exceeds the DCGL to an off-site disposal facility in accordance with an NRC-authorized transfer or to a licensed disposal site.

An objective of decommissioning is to safely reduce residual, licensed, radioactive material from C-T facilities to a level that permits the land to be used without restriction to assure radiological safety.

Geology. C-T production and support facilities have concrete slab floors and are built on cinder-fill material.[2] Most of the surrounding land in Plant 5 is paved. Any excavation pit resulting from removing cinder-fill soil that exceeds release criteria would be filled with soil or cinder-fill whose radioactivity concentration is less than the release criteria. Beginning with cinder-fill soil and reducing radioactive residue by remediation would not affect local geology adversely.

Hydrology. Site wastewater, storm water, and all other surface drainage flow via site sewers and drains to a combined municipal sewer system. Treated water is discharged to the Mississippi River. During storm periods, the combined sewer system serving the site is diverted directly to the Mississippi River.[3]

Groundwater hydrology in the site area is influenced by site stratigraphy (the presence of fill, alluvial deposits, and limestone bedrock) and the Mississippi River. Groundwater is present in each of these units. Groundwater in the sandy alluvial unit is locally saline and generally very hard, with high iron and manganese content. Groundwater found in the underlying bedrock is generally saline and non-potable. Groundwater in the site area is not withdrawn for potable, industrial, or agricultural purposes.[4] Ground-water use is not anticipated to change in the future. Reduction of radioactive residue attributable to C-T activities will likewise diminish potential presence in groundwater, aside from anticipation that groundwater will not be withdrawn for beneficial use.

Neither surface water nor ground-water discharge into the Mississippi River would affect water quality substantially in the river because of the large amount of dilution afforded by the river flow.

Air Quality. Most of Plant 5 is paved and thereby mitigated against soil erosion and suspension of dust into the air. Decommissioning activities involving materials excavation, handling, and potentially producing airborne particulate will be subject to dust control measures such as water misting and monitoring as needed to assure that local air quality is controlled to NRC standards. As a result, air quality off-site would be expected to be controlled to a small fraction of NRC standards.

Ecology. The St. Louis Downtown Site is in an urban industrial zone. Land on-site and nearby is occupied mainly by buildings and streets or is otherwise paved. Current land uses are expected to continue foreseeably. Restoration by decommissioning and return to commercial, industrial use would not affect the environment adversely with respect to its current use.

6.1.2.5. Description of Impacts on Minority or Low-income Populations

C-T decommissioning will restore land on a portion of approximately one-half city block of the SLDS to availability for productive use. Enabling the return of that land to development of manufacturing facilities would sustain opportunity for employment of nearby residents. It will

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[2] C-T Phase 2 Decommissioning Plan, §3.5.1 Geology.

[3] C-T Phase 2 Decommissioning Plan, §3.6 Surface Water Hydrology.

[4] C-T Phase 2 Decommissioning Plan, §3.7 Groundwater Hydrology.

not consume any land off-site and thus would not displace nearby residents nor commercial or public facilities nearby. Unrestricted release under this alternative would not require any original governmental regulation or institutional control that would affect nearby residents adversely.

An objective of decommissioning is to safely reduce residual, licensed, radioactive material resulting from C-T activities to a level that permits the land to be used without restriction to assure radiological safety.

6.1.2.6. Summary of the Irreversible and Irretrievable Commitment of Resources

This remediation alternative would consume the financial and physical resources necessary to accomplish it. Waste removed from the SLDS would also occupy space at a developed disposal site. Utilization of these resources would be irreversible, irretrievable, and unavoidable.

Although transportation of remediation workers on local roadways during decommissioning would be unavoidable, it would involve fewer than about 20 vehicles per day. Remediation waste will be transported from the SLDS to a disposal site mostly by railroad that bisects the SLDS. Primary use of rail transport would minimize any impact of use of local streets and highways.

6.1.3. Alternative # 3, Remediate to Radioactivity Concentration Guideline Levels in the FUSRAP Record of Decision

6.1.3.1. Description of the Facility of This Alternative is Employed

Criteria for remediating radioactive material of MED/AEC origin remaining in accessible soils and ground water on the St. Louis downtown site (SLDS) are stated in the USACE Record of Decision[5] and are summarized hereafter.

The remediation objectives are to comply with applicable and relevant requirements for permissible levels of residual contamination through a combination of excavation of the contaminated soil above the human health target risk range, removal of soil above 40 CFR Part 192 requirements within the depth of plausible intrusion, and institutional controls. Potential public radiological dose would be less than 25 mrem/yr as required by 10 CFR 20 Subpart E. Residual risk will be within the CERCLA target risk range.[6]

The cleanup criteria apply to accessible areas affected by the MED/AEC uranium manufacturing and processing activities.[7] MED/AEC source material included uranium (U^{238}) series, actinium (U^{235}) series, and thorium (Th^{232}) series. Remediation cleanup concentration is derived for key site contaminants Ra^{226}, Th^{230}, Ra^{228}, Th^{232} and U^{238} since remediation of these radioisotopes will assure that all radioactive contaminants are addressed concurrently.[8]

Shallower than 4 or 6 Feet. USACE remediation criteria for radioactive material specify excavation of accessible soils according to the cleanup criteria of 5 or 15 pCi/g above

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[5] USACE. *Record of Decision for the St. Louis Downtown Site.* p. 12. July 1998.

[6] *Ibid.* p. 70.

[7] *Ibid.* p. 68.

[8] *Ibid.* p. 44

background for Ra^{226}, Ra^{228}, Th^{232}, and Th^{230} specified in 40 CFR Parts192.12(a) and 192.41, and a supplemental criterion of 50 pCi/g above background for U-238 in the uppermost 1.2 or 1.8 m (4 or 6 ft) throughout the site and on vicinity properties along the perimeter.[9]

As other nuclides are also present in most cases with U^{238}, it is necessary pursuant to 40 CFR 192.21(h) to address the potential effects of multiple contaminants. To concurrently address the radionuclides of interest, a sum of the ratios calculation is applied as follows for the key radionuclides.

In the top 15 cm (6 in), the criterion is:

$$\frac{\text{greater of } Ra^{226} \text{ or } Th^{230}}{5} + \frac{\text{greater of } Ra^{228} \text{ or } Th^{232}}{5} + \frac{U^{238}}{50} < 1 \quad \text{(net above background).}$$

From 6 inches to 4 or 6 feet, the criterion is:

$$\frac{\text{greater of } Ra^{226} \text{ or } Th^{230}}{15} + \frac{\text{greater of } Ra^{228} \text{ or } Th^{232}}{15} + \frac{U^{238}}{50} < 1 \quad \text{(net above background).}$$

Soil that meets these *composite criteria* does not need to be removed.[10] Contaminated soil exceeding a *composite criterion* would be removed by excavation as deep as it occurs in the Plant 7 area and vicinity properties.

Supplemental Criteria (Deeper than 4 or 6 Feet). Under certain conditions, 40 CFR Part 192.2 1(c) provides for derivation of supplemental cleanup criteria when the estimated cost of cleaning up a site is unreasonably high in comparison to the long-term benefits and when the residual radioactive materials do not pose a clear present or future hazard.[11] The USACE concluded that, based on conditions at the SLDS, and depending upon the specific location on the Mallinckrodt property, MED/AEC-related, radioactively contaminated soils deeper than 4 or 6 feet satisfy the criteria for establishment of supplemental standards. As a result, risk-based supplemental standards were developed.[12]

Deeper than 4 or 6 feet, a site-specific target removal concentration 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} was adopted.[13] They are combined by a sum-of-ratios expression:

$$\frac{Ra^{226}}{50} + \frac{Th^{230}}{100} + \frac{U^{238}}{150} < 1 \quad \text{(net above background)}$$

Soil that meets this standard is not required to be removed.[14]

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[9] *Ibid.* p. 68.

[10] *Ibid.* p. 45.

[11] *Ibid.* p. 75.

[12] *Ibid.* p. 75.

[13] *Ibid.* p. 68.

[14] *Ibid.* p. 48.

6.1.3.2. Summary of the Health Effects on Adjacent Communities

USACE Assessment. Cleanup criteria adopted for the SLDS by the USACE in the ROD, *i.e.*, 5 pCi/g in topsoil and 15 pCi/g in subsoil to 4 or 6 feet deep are the criteria in 40 CFR Part 192. Relating those criteria to radiological dose, the USEPA concluded:

> "... analysis indicates that the cleanup of UMTRCA sites using the under 40 CFR 192 is consistent with an upper bound of 15 mrem/yr EDE under a rural residential exposure scenario for radium-226, radium-228, and thorium-232, and is much more stringent for thorium-230.[15] For land uses other than residential (*e.g.*, commercial/industrial, recreational) the UMTRCA cleanup standards are more stringent for all four radionuclides. [16]

Logically according to EPA rationale, the criteria, 5 pCi/g and 15 pCi/g in soil, would pose less than 25 mrem/yr dose.

6.1.3.3. Summary of the Impacts on Community Resources Such as Land Use and Property Values

Determination of whether use restriction and institutional control is necessary to assure dose criteria are met for an area having a residual concentration of contaminants unsuitable for unrestricted use will be based on calculations of post-remedial action conditions.[17] If restriction against use of an exposure pathway is necessary to assure potential dose is below 25 mrem/yr, land use restriction assured by institutional control would be indicated.

Institutional control would aim to ensure continued protectiveness through restriction against digging and adherence to federal and state worker safety regulations.[18] Exposure to residual material left deeper than 1.2 or 1.8 m (4 or 6 ft), as well as the contaminated soils that are inaccessible, would be managed by implementing institutional controls and a monitoring program.[19] Five year reviews will be conducted per the National Contingency Plan for residual conditions that are unsuitable for unrestricted use.[20]

6.1.3.4. Summary of the Impacts on the Geology, Hydrology, Air Quality and Ecology in and Around the Site

Groundwater - Under the USACE ROD, sources of soil contamination within groundwater in shallow, perched groundwater (designated Unit A) would be removed and water that must be managed as part of the excavation will be treated and disposed of appropriately. Federal and

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[15] USEPA. *Reassessment of Radium and Thorium Concentrations and Annual Dose Rates*. EPA:ORIA, July 22, 1996.

[16] USEPA. "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination." OSWER Directive 9200.4-18, Attachment B. Aug. 20, 1997.

[17] *Ibid.*

[18] *Ibid.* p. 71.

[19] *Ibid.*

[20] *Ibid.* p. 69.

State laws and regulations related to drinking water are not considered to be applicable or relevant and appropriate to currently impacted groundwater in Unit A beneath the SLDS because unit A is not considered a potential source of drinking water.

Use of the Mississippi River Alluvial Aquifer (Unit B) in this area is not likely; however, maximum contaminant levels (MCL) and the groundwater protection requirements found in 40 CFR Part 192, Subpart A, Table 1, are relevant and appropriate with regard to evaluation of the need for further study of groundwater in Unit B.[21] Groundwater in Unit B is not currently impacted by contaminants of concern (COC) identified in this remedy.[22] The goal of the groundwater portion of this remedy is to maintain protection of the potentially usable ground water (Unit B) and establish the effectiveness of the source removal action in this regard.[23]

Potential groundwater degradation would be controlled by removal of sources of soil contamination; implementing institutional controls, when applicable; and perimeter groundwater monitoring in the B Unit[24] to assure post remediation compliance.[25]

A long-term, groundwater monitoring strategy would be implemented by the USACE to evaluate expectation that significant impacts to the Mississippi Alluvial Aquifer (Unit B) would not occur.[26]

The strategy to accomplish this goal is to install and monitor perimeter wells in the Mississippi Alluvial Aquifer on a long-term basis to assess whether there is a significant impact from contaminants of concern (COC) on the Mississippi Alluvial Aquifer (Unit B). Monitoring will be conducted during and after the source term removal. If monitoring Unit B shows that the MED/AEC COC has significantly exceeded MCL or thresholds established in 40 CFR 192, a ground-water remedial action alternative assessment would be initiated.[27]

Although ground water use in this area is not anticipated, agreements would be proposed by the USACE to State and local water authorities to prevent drilling a well, which might be impacted by the surficially contaminated Unit A.[28]

6.1.3.5. Description of the Impacts on Minority or Low-income Populations

Remediation to radioactivity concentration guideline levels in the FUSRAP Record of Decision will restore land on a portion of approximately one city block of the SLDS to availability for productive use. Enabling the return of that land to development of manufacturing facilities would sustain opportunity for employment of nearby residents. It will not consume any land off-site and thus would not displace nearby residents nor commercial or public facilities nearby.

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[21] *Ibid.* p. 76.

[22] *Ibid.* p. 65.

[23] *Ibid.*

[24] B unit refers to the alluvial unit below the clay layer.

[25] USACE. ROD. p. 43.

[26] *Ibid.* p. 69

[27] *Ibid.* pp. 65 & 69.

[28] *Ibid.* p. 69.

The SLDS is inherently an industrial use site, and has been for over 100 years. Land use restrictions would have little or no impact on minority or low-income populations in the area of the site.

Although transportation of remediation workers on local roadways during decommissioning would be unavoidable, it would equivalent to that described under the unrestricted release scenario described above. Remediation waste will be transported from the SLDS to a disposal site mostly by railroad that bisects the SLDS. Primary use of rail transport would minimize any impact of use of local streets and highways.

6.1.3.6. Summary of the Irreversible and Irretrievable Commitment of Resources

This remediation alternative would consume the financial and physical resources necessary to accomplish it. Waste removed from the SLDS would also occupy space at a developed disposal site. Utilization of these resources would be irreversible, irretrievable, and unavoidable.

Although transportation of remediation workers on local roadways during decommissioning would be unavoidable, it would involve fewer than about 20 vehicles per day. Remediation waste will be transported from the SLDS to a disposal site mostly by railroad that bisects the SLDS. Primary use of rail transport would minimize any impact of use of local streets and highways.

6.1.4. <u>Alternative # 4, Restricted Release</u>

6.1.4.1. Description of the Facility if the Restricted Release Alternative is Employed

Adopting restriction(s) on land use or access to subsoil in order to assure that potential radiological dose will remain below 25 mrem/yr to personnel on the SLDS would enable removal of source material residue that is practical to remove while tolerating hard-to-reach soil to remain in place.

Under current conditions described in Phase II Plan §4, "Radiological Status of Facility", residual source material in localized areas might cause more than 25 mrem/yr to workers on the plant site. Yet it may be impractical to remove source material residues that are either deeper in the ground or adjacent the foundation of a building that is in current and foreseeable service. A deed restriction or other legally enforceable instrument to control access to such remnant residues could be a practical alternative to assure that the criteria for license termination under restricted conditions specified in 10 CFR Part 20.1403 are fulfilled.

6.1.4.2. Summary of Health Effects on Adjacent Communities

When prospective land use and access restrictions are in place, the potential radiological dose would not exceed 25 mrem/yr to the average member of the critical group, namely a worker on the SLDS. Due to the limited amount of contamination, and the low specific activity of the contamination, no adverse health effects would be anticipated off-site.

6.1.4.3. Summary of the Impacts on Community Resources Such as Land Use and Property Values

The SLDS is inherently an industrial use site, and has been for over 100 years. The restricted release alternative would have little or no impact on the land use or property value in the area of the site. There would also be no additional impact due to increased traffic in the vicinity of the site due to decommissioning activities for the restricted release alternative.

6.1.4.4. Summary of Impacts on the Geology, Hydrology, Air Quality and Ecology in and Around the Site

The restricted release alternative leaves much of the current radiological contamination in place, and implements deed restrictions governing future site use. Under this alternative there is a long-term potential for migration of the radioactive material, with ultimate discharge to the Mississippi River. Given the high flow volume of the river compared to the discharge rate of groundwater into the river, the environmental impact would be negligible.

6.1.4.5. Description of Impacts on Minority or Low-income Populations

Under the restricted release alternative the SLDS would continue as an industrial use site, with minimum impact on minority or low-income populations.

6.1.4.6. Summary of the Irreversible and Irretrievable Commitment of Resources

This alternative would require the commitment of resources to stabilize the site and to implement deed restrictions. Additional expenditure of funds would be required for continued radiation monitoring. Additionally, under the restricted release alternative, any future work on site that involved excavation or building demolition, radiation protection and radioactive waste management might be required.

6.2. SELECTION OF PREFERRED ALTERNATIVE

6.2.1. Rationale for Selecting the Preferred Alternative

The preferred alternative is the remediation of the site to derived radioactivity concentration guideline levels for an industrial use scenario, as described under Alternative 2, above. This is the most conservative decommissioning approach, and meets all regulatory requirements.

6.3. PERMITS AND LICENSES

6.3.1. NRC License STB-401

This materials license authorizes the possession and use of radioactive materials in accordance with the conditions of the license.

6.3.2. Metropolitan St. Louis Sewer District Discharge Permit No. 21120596-00

This permit authorizes the discharge of wastewater into the Metropolitan St. Louis Sewer District's sanitary or combined sewer system in accordance with the conditions of the permit. This permit was issued in accordance with the provisions of the Federal Pretreatment Regulations (40 CFR 403) and Metropolitan St. Louis Sewer District Ordinance No. 8472.

SECTION 7

ALARA ANALYSIS

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

7. ALARA ANALYSIS

7.1. INTRODUCTION

An analysis has been done to estimate what residual radioactive source material concentration in soil subject to C-T Phase II decommissioning is As Low As is Reasonably Achievable and whether it is reasonable to reduce the residual concentration in soil to a level below what is necessary to meet the dose criterion in 10 CFR 20.1402 (TEDE to an average member of the critical group that does not exceed 25 mrem/y).

NRC:NMSS decommissioning guidance provides that

> In certain circumstances, the results of an ALARA analysis are known on a generic basis and an analysis is not necessary. For residual radioactivity in soil at sites that may have unrestricted release, generic analyses (see NUREG-1496, the examples in Sections 1.4, and other similar examples) show that shipping soil to a low-level waste disposal facility is unlikely to be cost effective for unrestricted release, largely because of the high costs of waste disposal. Therefore shipping soil to a low-level waste disposal facility generally does not have to be evaluated for unrestricted release. In addition, licensees who have remediated surface soil and surfaces to the default screening criteria developed by NRC have remediated soil such that it meets the unrestricted use criteria in 10 CFR 20.1402, or if no residual radioactivity distinguishable from background, may be left at the site would not be required to demonstrate that these levels are ALARA.[1]

Mallinckrodt expects to ship soil containing residual regulated radionuclides in greater concentration than release criteria by NRC-authorized transfer to a disposal facility. Thereby, conditions of the resulting remediation are expected to be in sufficient accord with the results of a generic ALARA analysis to assure that remediation to DCGL proposed in chapter 5 *Dose Modeling* will also satisfy the NRC's generic ALARA analysis. However, in the spirit of quantification of ALARA, a simplified assessment of possible benefits and costs relating to decommissioning, and an estimate of the residual radioactivity concentration that is ALARA are presented hereafter.

7.2. BENEFITS AND COSTS

NRC guidance in NUREG-1757, §6 and Appendix N provide information outlining a simplified method to estimate when a proposed remediation guideline is cost-effective. Prospective benefits and prospective costs are to be derived and compared. In general, if the desired beneficial effects (benefits) from a remediation action are greater than the undesirable effects (costs) of the action, the remedial action being evaluated is cost-effective and should be performed. Conversely, if the benefits are less than the costs, the level of residual radioactivity is already ALARA without taking additional remedial action. Prospective benefits and costs of

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[1] NRC:NMSS. *Consolidated NMSS Decommissioning Guidance*. NUREG-1757. 2. Appendix N. Sept. 2002.

decommissioning that are expected to be the most worthy of consideration are mentioned in Table 7.1.

Table 7.1 Prospective Benefits and Costs Related To Decommissioning

Potential Benefits	Potential Costs
Collective Dose Averted	Remediation Costs
Regulatory Costs Avoided	Transport and Disposal Costs
Change in Land Value	Non-radiological Risks
Aesthetics and or	Transportation Risks
Reduction in Public Opposition	
	Worker Dose Estimates
	Loss of Economic Use of Property
	Environmental Impacts

Evaluating whether a remedial action is likely to be cost-beneficial involves estimation of the increment of cost to be expended to achieve an anticipated increment of benefit. Even if a remedial action is estimated to be cost-beneficial, realization of the anticipated benefit does not have to be guaranteed. Rather, the principle is to make a reasonable effort.

7.3. ESTIMATION OF BENEFITS

In this section, the prospective, desirable effects of removing an increment of radioactive contamination from the C-T site during Phase 2 are evaluated.

7.3.1. Collective Dose Averted

This analysis presumes that the licensee has removed licensed radioactive residue in soil that exceeds the $DCGL_W$ in order to satisfy 10 CFR Part 20.1402 concerning attainment of 25 mrem/yr. Whether attainment of the $DCGL_W$ is ALARA depends on whether collective radiological dose averted by removing additional licensed residue would be cost-beneficial. The present worth of future collective radiological dose averted, $PW(AD_{collective})$, by removing additional radioactive residue is estimated to be:

$$PW(AD_{collective}) = P_D \times A \times 0.025 \times F \frac{Conc}{DCGL_W} \times \frac{1 - e^{-(r+\lambda)N}}{r + \lambda} \qquad \text{eqtn 7.1}$$

$$PW(AD_{collective}) = 11.6 \text{ person·rem}$$

where P_D = average population density of critical group (persons/ft^2)
= 1 person / 1000 ft^2 assuming reuse as an industrial facility [ref. NUREG-1496. 2. apx B.] Current worker population density in Plant 5 is 1 person / 1700 ft^2.
A = area evaluated (ft^2)
= 0.2 of 1 city block = $0.2(528 \text{ ft})^2 = 5.6 \times 10^4 \text{ ft}^2$, estimated on the basis that no more than 0.2 of Plant 5, occupying a city block, is contaminated to more than 0.75 $DCGL_W$.
0.025 = potential annual radiological dose to an average member of the critical group from radioactive residue at the $DCGL_W$ concentration (rem/yr)

F = fraction of residual radioactivity concentration removed by the remedial action (beginning at $DCGL_W$)

= 0.25 assumed

Conc = average concentration of radioactive residue in soil in the area evaluated (pCi/g)

= $DCGL_W$ pCi/g, the baseline concentration below which a fraction, F, or increment of licensed radioactive residue is evaluated to assess whether an additional increment is reasonable, or cost-effective to remove

$DCGL_W$ = derived concentration guideline level equivalent to the average concentration of radioactive residue in soil that potentially could produce a dose of 25 mrem/yr to the average member of the critical group (pCi/g soil)

r = monetary discount rate (1/yr)

= 0.03 / yr assumed over all time [ref. NUREG-1757. 2. apx N. §N.1.1. and ref. NUREG/BR-0058.]

λ = radioactive decay constant (1/yr)

= $\ln 2/\tau_{1/2} = \ln 2/1.39 \times 10^{10}$ yr $= 5.0 \times 10^{-11}$/yr, assuming the longest-lived parent, Th^{232}, in either the uranium series, the actinide series, or the thorium series.

N = time over which collective dose is computed (yr)

= 1000 yr [ref. NUREG-1496. 2. apx B, Table A.1 and ref. NUREG-1496. 2. apx N, Table N.2]

The incremental benefit is the increment of collective radiological dose averted by remediation, B_{AD}. It is estimated by calculating the product of the present worth of the increment of future collective radiological dose averted and a factor to convert dose to monetary value.

$$B_{AD} = \$2000 \times PW(AD_{collective}) \quad \text{eqtn 7.2}$$

$$B_{AD} = \$2000 \times 11.6 = \$23200.$$

where B_{AD} = benefit from increment of collective radiological dose averted (\$)

\$2000. = valuation of collective unit of radiological dose averted[2] (\$/person·rem)

7.3.2. Regulatory Costs Avoided

The baseline of regulatory costs is assumed to be that associated with remediation to unrestricted land use criteria. No significant additional regulatory cost is assumed to occur when evaluating the prospect of additional removal of licensed radioactive residue below the unrestricted land use criterion represented by the $DCGL_W$. Thus no additional increment of regulatory cost is factored into this analysis.

7.3.3. Change in Land Value

Current and future use of land on Mallinckrodt's site, including Plant 5, is discussed in C-T Phase II Decommissioning Plan (Phase II Plan) §3.3, "Current and Future Land Use." Mallinckrodt's extensive investment in manufacturing on the site and its zoning for industrial use

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[2] BNL&NRC. *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission*. NUREG/BR-0058. 2. Nov. 1995.

assures the land will be available for industrial use for the foreseeable future. While land now occupied by unused C-T facilities will be reclaimed for beneficial industrial use, no change in land value is assumed in this analysis.

7.3.4. Aesthetics and Public Acceptance

The C-T production facilities are being demolished and the waste removed from the site in accordance with an approved C-T Phase I Decommissioning Plan (Phase I Plan). Removal of the unused C-T production facilities did not receive public opposition. Inasmuch as new industrial building may be on the reclaimed land area, neither improvement nor detriment in aesthetics is assumed in this evaluation.

7.4. ESTIMATION OF COSTS

In this section, the prospective undesirable effects, *i.e.*, costs, necessary to remove an increment of radioactive contamination from the C-T site are estimated.

7.4.1. Introduction

Costs that are the subject of this assessment are the incremental costs necessary to achieve the benefits of decommissioning the C-T facilities below the $DCGL_W$, hence below 25 mrem/yr. They include the monetary equivalent of costs and risks in sections 7.4.2 through 7.4.8 hereafter. If one or two of the costs can be shown to be in excess of the benefit, the remediation action could be shown to be unnecessary without calculating other costs.[3]

Bases of cost estimates herein are consistent with those used in §6.3 to estimate benefits. In particular, approximately an additional 24000 ft^3 of soil would be excavated to diminish remaining licensed radioactive residue concentration, beginning at the $DCGL_W$, downward to 0.75 of the $DCGL_W$, *i.e.*, a fractional reduction in concentration and potential dose of 0.25.

7.4.2. Remedial Action Costs

An estimate of incremental costs to remove an additional 24000 ft^3 of soil containing licensed radioactive residue includes the costs of excavation and measurement. On the basis of an additional 1 month to accomplish it, the incremental cost of equipment, equipment operators, laborers, health physics technicians, and administration is estimated to be $347,000.

Resource	Cost Factors	Cost ($)
Labor	11 workers x 20 da	132000.
Project Support	Contractor: 6 workers x 20 da Contractor living expenses Mallinckrodt mgt oversight	126700.
Equipment & Materials	Excavators, trucks, instruments tools, backfill	108700.
	Total =	$ 367400.

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[3] NRC:NMSS. *Consolidated NMSS Decommissioning Guidance.* NUREG-1757. 2. Appendix N. §N.1.2. Sept. 2002.

7.4.3. Transport and Disposal of the Waste

Incremental costs of rail car loading, rail transport off-site, and disposal of an additional 24000 ft^3 of soil at an acceptable disposal facility are included in this cost estimate. The total cost estimated for the additional increment of soil transport and disposal is $397,000.

Resource	Cost Factors	Cost ($)
Rail car loading	1 mo x $120000/mo	120000.
Rail transport	13 trips x $8500/trip	110500.
Disposal	24000 ft^3 soil	165000.
	Total =	$ 395500.

7.4.4. Non-radiological Risks

7.4.4.1. Workplace Risks

Prospective accidents in the workplace during decommissioning are risks counter to the benefit of decommissioning. The monetary valuation, Cost$_{ACC}$, of risks of non-radiological accidents in the workplace to excavate and remove an additional 24000 ft^3 of contaminated soil is evaluated as follows and is estimated to be about $222.

$$\text{Cost}_{ACC} = \$3 \times 10^6 \times F_W \times T_A \qquad \text{eqtn 7.3}$$

$$\text{Cost}_{ACC} = \$\ 222.$$

where $3 x 10^6 = monetary equivalent of a fatality,[4] equivalent to $2000/person·rem

F_W = fatality rate in the workplace (fatalities/hr worked)

= 4.2 x 10^{-8}/hr [ref. NUREG-1757. 2. apx N. Table N.2.]

T_A = collective worker time required for increment of remediation (person·hr)

= 11 persons x 160 hr = 1760 person·hr

7.4.4.2. Transportation Risks

Additional risk of fatality to members of the public off-site would be incurred by transporting an additional increment of 24000 ft^3 of soil to an acceptable burial facility off-site. The monetary valuation of that increment of transportation risk, Cost$_{TF}$, is estimated as in equation 7.4. In this equation, the incremental weight of soil shipped and rail car capacity are expressed in weight units because soil in a rail car reaches the weight limit before it reaches the volume limit.

$$Cost_{TF} = \$3 \times 10^6 \bullet \left(\frac{W_A}{W_{ship}} \right) \bullet F_T \times D_T \qquad \text{eqtn 7.4}$$

$$\text{Cost}_{TF} = \$13200.$$

where $3 x 10^6 = monetary equivalent of a fatality

W_A = incremental weight of soil shipped (tons)

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[4] NRC. *Reassessment of NRC's Dollar per Person-rem Conversion Factor Policy.* NUREG-1530. pp. 11-12. Dec. 1995.

= 1200 tons = 24000 ft^3

W_{ship} = weight capacity of rail car (tons)

= 100 tons

F_T = average fatality rate per train-mile

= 1.3×10^{-6} fatalities/train-mile in yr 2000 [ref. DOT: OST:Federal Railroad Admin. internet http://safetydata.fra.dot.gov/OfficeofSafety/]

D_T = distance traveled by rail (mi)

= 3400 mi = 1700 miles one-way x round trip. This assumes that 13 rail cars containing soil are in one train and that empty cars are returned to point of origin.

7.4.5. Worker Dose Estimates

The increment of collective radiological dose to workers while excavating soil below the $DCGL_W$ and loading it into rail cars may be accounted as a cost of additional remediation. The monetary valuation of radiological dose to remediation workers, $Cost_{Wdose}$, is estimated as follows.

$Cost_{Wdose}$ = \$2000 x D_R x T eqtn 7.5

$Cost_{Wdose}$ = \$ 176.

where \$2000 = valuation of collective unit of radiological dose averted[5] (\$/person·rem)

D_R = total effective dose equivalent rate (TEDE) to remediation workers (rem/hr)

= 5×10^{-5} rem/hr, assuming the maximum TEDE at the beginning of the increment of remediation persists throughout the increment of remedial action, estimated to be 160 hr of exposure to each worker.

T = collective time worked to remediate an increment of soil below the $DCGL_W$ (person·hr)

= 11 workers x 160 hr each = 1760 worker·hr

7.4.6. Loss of Economic Use of Property

Current and future use of land on Mallinckrodt's C-T site, including Plant 5, is discussed in Phase II Plan §3.3, "Current and Future Land Use." Mallinckrodt's extensive investment in manufacturing on the site and its zoning for industrial use assures the land will be available for industrial use for the foreseeable future. While land now occupied by unused C-T facilities will be reclaimed for beneficial industrial use, no change in land value and therefore no loss of economic use of the property is assumed in this analysis

7.4.7. Environmental Impacts

An assessment of the C-T Phase I Decommissioning Plan considered controls to manage and mitigate potential environmental impact consequent to decommissioning C-T process

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[5] BNL&NRC. *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission.* NUREG/BR-0058. 2. Nov. 1995.

facilities above grade.[6] The NRC staff concluded that the decommissioning plan contained sufficient controls to minimize environmental impacts consequent to decommissioning Phase I. Controls proposed during Phase II, decommissioning below grade, will be substantially effective as those during Phase I such that one may expect that environmental impacts during Phase II will also be acceptably minimized .

7.5. ALARA RESIDUAL RADIOACTIVITY

The incremental cost and benefit estimates are compared to decide what residual radioactive source material concentration in soil subject to Phase II decommissioning is As Low As is Reasonably Achievable and whether it is reasonable to reduce the residual concentration in soil to a level below what is necessary to meet the dose criterion. Such analysis compares in equivalent units the incremental cost of remediation versus incremental detriment avoided by remediation.

The essence of ALARA analysis is cost-benefit comparison to decide when the marginal, or incremental, benefit is or is not worth the marginal, or incremental, cost of achieving it. The proper focus must be on estimation of the incremental mortality reduction per incremental resources expended to attain it. The decision should rely on comparing the slope of the cost-benefit curve to a criterion, in comparable units, *e.g.*, \$/rem, derived independently of the activity being evaluated.

In the 10 CFR Part 50 rulemaking, the NRC Commissioners concluded that:

> "Such a cost-benefit analysis requires that both the costs and the benefits from the reduction in dose levels to the population be expressed in commensurate units, and it seems sound that these units be units of money. Accordingly, to accomplish the cost-benefit balancing, it is necessary that the worth of a decrease of man-rem ... be assigned monetary values.

7.5.1. DCGL$_W$ Baseline

Whether it is cost-beneficial to remove additional radioactive residue below the DCGL$_W$ corresponding to 25 mrem/person·yr may be estimated on the bases of 1) the incremental benefit of radiological avoided dose estimated in §7.3, Estimation of Benefits, herein and 2) the incremental cost of achieving that dose reduction as estimated in §7.4, Estimation of Costs, herein.

The main benefit would be the increment of collective radiological dose averted by remediation. In §7.3, its monetary valuation, B_{AD}, is estimated to be \$23200 by calculating the product of the present worth of the increment of future collective radiological dose averted and a factor to convert dose to monetary value.

The cost to achieve that reduction in radiological dose below the DCGL$_W$ is the sum of incremental costs estimated in §7.4. The total cost, $Cost_T$, is estimated to be:

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[6] NRC:NMSS. "Environmental Assessment Related to the Approval of the Mallinckrodt C-T Project Decommissioning Plan." Part 1 for Mallinckrodt Chemical, Inc. St. Louis, Missouri. License No. STB-401 Docket No. 40-6563.

$$\begin{aligned} \mathrm{Cost_T} &= \mathrm{Cost_R} + \mathrm{Cost_{WD}} + \mathrm{Cost_{ACC}} + \mathrm{Cost_{TF}} + \mathrm{Cost_{Wdose}} \\ \mathrm{Cost_T} &= \$347100 + \$395500 + \$222 + \$13200 + \$176 \\ \mathrm{Cost_T} &= \$\ 756198. \end{aligned} \qquad \text{eqtn 7.6}$$

where $\mathrm{Cost_R}$ = monetary cost of remedial action

$\mathrm{Cost_{WD}}$ = monetary cost of transport and disposal of the soil

$\mathrm{Cost_{ACC}}$ = monetary equivalent cost of workplace risk during remedial action

$\mathrm{Cost_{TF}}$ = monetary equivalent cost of transportation risk offsite

$\mathrm{Cost_{Wdose}}$ = monetary equivalent cost of potential radiological dose to workers during remediation through rail car loading

Comparison of costs and benefits consequent to removing additional radioactive residue, starting from a baseline of $\mathrm{DCGL_W}$, to achieve 0.5 $\mathrm{DCGL_W}$ demonstrates that the incremental cost is estimated to be equivalent to $756000 and the incremental benefit is estimated to be equivalent to $ 23200. Since the incremental cost is greater than the incremental benefit, it is not cost-beneficial to try to reduce residual concentration of licensed radioactive residue to any less than the $\mathrm{DCGL_W}$. Thus, when remedial action achieves the $\mathrm{DCGL_W}$, no further cleanup would be needed to satisfy the ALARA principle.

7.5.2. $\mathrm{DCGL_{EMC}}$ Baseline

Decontamination is ALARA when the benefit from additional collective dose averted becomes less than the cost of achieving it. Conceptually, the residual radioactivity concentration above which cleanup is cost-beneficial and below which it is not would be independent of the $\mathrm{DCGL_W}$. The residual radioactivity concentration that is at the ALARA balance point is that concentration at which the benefits and costs of incremental removal are equal. Whether it might be reasonable to attempt to decontaminate a localized area of residue whose concentration is greater than the $\mathrm{DCGL_W}$, but satisfies the elevated measurements criterion, *i.e.*, the $\mathrm{DCGL_{EMC}}$, can be evaluated with the aid of the following relation.

$$\frac{\mathrm{Conc}}{\mathrm{DCGL_W}} = \frac{\mathrm{Cost_T}}{2000 \times \mathrm{P_D} \times 0.025 \times \mathrm{F} \times \mathrm{A}} \times \frac{\mathrm{r} + \lambda}{1 - \mathrm{e}^{-(\mathrm{r}+\lambda)\mathrm{N}}} \qquad \text{eqtn 7.7}$$

This relation enables one to derive the concentration, as a fraction or multiple of the $\mathrm{DCGL_W}$, above which attempt to decontaminate would be cost-effective. That is, it enables one to derive the concentration, *Conc*, which, if one were to remove fraction, *F*, of it, would eliminate an increment of collective dose valued greater than the cost of removing it. The initial question is: what fraction of potential dose, *F*, would an action that costs, $Cost_T$, dollars be expected to eliminate?

This assessment assumes that the cost to excavate and dispose of an increment of radioactivity concentration when the basis is fraction, *F*, above the $\mathrm{DCGL_W}$ would be the same as if the basis is fraction, *F*, below the $\mathrm{DCGL_W}$. When so, values of parameters estimated in the evaluation of incremental benefit in §7.3 and the incremental cost in §7.4 may be entered into equation 7.7. The result is $\frac{Conc}{DCGL_W} = 33$. Thus, according to this logic, it would be cost-effective to excavate soil containing more than 33 times the $\mathrm{DCGL_W}$ in order to reduce residual radioactivity concentration, but not if it contains less than 33 times the $DCGL_W$. Actually since the volume of contaminated soil diminishes more than a linearly with increasing residual radioactivity concentration, cost-effective cleanup would occur at somewhat less than 33 times the $DCGL_W$. Yet since the maximum value of $DCGL_{EMC}$ in soil will be about 0.1 of 33 times the $DCGL_W$, decontamination to satisfy $DCGL_{EMC}$ in localized areas will also yield cleanup that is ALARA.