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October 14, 2008

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Mr. John Buckley, Project Manager
Low-Level Waste and Decommissioning Projects Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Ref: Docket No. 40-6563; License No. STB-401
Mallinckrodt, Inc., C-T Phase II Decommissioning Plan – Final

Dear Mr. Buckley:

In accordance with Materials License STB-401, Mallinckrodt, Inc. is submitting its Final Phase II Decommissioning Plan herewith. Phase II will complete decommissioning of grade-level and below-grade building slabs, paved surfaces, and subsurface materials affected by former C-T operations in order that they may be released for unrestricted use. Mallinckrodt's goal is to remediate regulated, radioactive material associated with C-T processing to the extent required to terminate Materials License STB-401.

Mallinckrodt requests that the NRC amend Materials License No. STB-401 to authorize C-T decommissioning as proposed in Phase II of its Decommissioning Plan, submitted herewith.

Remediation of radioactive residues remaining from MED-AEC activity in other areas of the St. Louis Plant has previously been performed by the U.S. Department of Energy and is currently being performed by the U.S. Army Corps of Engineers under the Formerly Utilized Sites Remedial Action Program. Delineation of responsibility for remediation, particularly in the area of the wastewater ponds within Plant 7 of the St. Louis Plant, remains to be decided between Mallinckrodt and the U.S. Army Corps of Engineers. Mallinckrodt requests to address its responsibility for any C-T residue remediation in the ponds area in an additional phase of the decommissioning activities identified as Phase IIa.

NMSS01

If additional information is needed to enable approval of the decommissioning plan, please contact me at (314) 654-5838.

Sincerely yours

Karen Burke

Karen Burke
C-T Decommissioning Project Manager

Cc: NRC Document Control Desk
Mr. John Buckley, U.S. NRC
Mr. Tom Youngblood, U.S. NRC
Mr. Gene Bonano, U.S. NRC Region III
Mr. Brenden Doster, MDNR (CD)
Ms. Sharon Cotner, USACE (CD)

Official Project Documents

C-T Phase II Decommissioning Plan

Revision 2
August 12, 2008

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

Controlled Copy Number: 1
Issued to: NRC Document Control

Official Project Documents

C-T Phase II Decommissioning Plan

Revision 2
August 12, 2008

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

Controlled Copy Number: 1
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Revisions in August 12, 2008 Version of the C-T Phase II Decommissioning Plan

This tabulates revisions of C-T Phase II Decommissioning Plan occasioned by responses to NRC Requests for Additional Information. Other revisions are identified following RAI at the end of this tabulation. Revisions in the text are marked by a vertical line in the margin adjacent the line(s) revised.

RAI number	CT2DP section revised	Comment
		RAI set 1
1.1	9.5	Done. P 9
1.1	14.4.3.4	Revised. p 12 & p 13
1.1	14.4.3.5	Revised. p 15
1.1	14.4.3.9	Revised. p 27 [*Contingencies* is designated as a new section, §14.4.3.9]
1.2	9.5	§9.5, items K & L. p 9
1.2	14.4.3.8	Done
1.2	14.4.3.9	Revised.
1.3	9.5	§9.5, item m. p 9
1.3	14.4.3.3	Done
1.3	14.4.3.4	Done
1.3	14.4.3.9	Done
2	Table 4-7	Revised.
3	Table 4-8	Revised.
4	5.9.1 Table 5-3	Revised. p 24 & p 25 Revised. p. 18
4	Table 5-4	Revised. p. 22
5	7.4.2 7.5.1 7.5.2	Done done done
6	7.4.3	revised
7	8.4.3	Revised according to RAI set 1, items 7 and 46, and as superceded by RAI set2 items 51, 58, 62, 69, 81, 82, and 86.
8	8.7	Revised. p 9
9	8.5.1 14.4.3.7	Revised. p 7 §14.4.3.7 Surveys, ¶ Soil is revised to incorporate response to RAI 9.
10	14. 14.4.3.7	Revised footnote 2, p 1. §14.4.3.7 Surveys, ¶Foundations is revised.
11	14.2	14.2, footnote 3 is revised.
12	14.2	14.2 is revised. p 3
13	14.3	14.3 is revised
14	14.4.1	Revised. p 5
15	14.4.3.2	Revised. p 11
16	14.4.3.3	Revised. p 11
17	9.5	Revised.

17	14.4.3.4 14.4.3.5 14.4.3.8	Revised. p 12 & p 13 Revised. Revised.
18	14.4.3.5 14.4.3.7	Revised. p 16 Revised, p 20.
19	14.4.3.5	Footnote 22 revised. P 17
20	14.4.3.7 14.4.3.8	Pp 19 & 20 revised Revised. P25
21	14.4.3.8 14.4.3.8 14.4.3.9	Revised. p 22 Revised. P26 Revised. P 31
22	14.4.3.8, Table 14-5	Revised Table 14-5. P 14-27
23	14.4.3.8 Table 14-5 14.4.3.8	Revised. p 22 Revised. p 23 Revised. P 26
24	14.4.3.8	Revised. p 24 & P 28
25	14.4.3.8, Table 14-6	No revision needed. No revision needed.
26	9.5 14.4.3.4 14.4.3.5 14.4.3.9	Revised item j. p 9 Revised. P 12, p 13 Revised. P 15 Revised. P 31
27	14.4.3.9	Revised. P 31
28	14.4.3.9	Revised. P 32
29	5.8.7 and Figure 5-3.	Revised to represent later RAI in which DCGL is derived probabilistically. Response to RAI 29 in §5.8.1.2 and §5.8.3.2 are superceded by §5.8.7.
30	14.4.3.9 Appendix H	Revised. p 32 Added Appendix H to CT2DP. Appendix H was labeled Appendix 30 in response to RAI set 1.
31	14.4.3.9	Revised. p 31
32	14.4.3.9	Revised. p 30 & p. 32
33	14.4.3.7 14.4.3.8 14.4.3.9	Revised. P 20 Revised. p 28 Revised. p 31, p 32, and p 33.
34	14.4.3.8 14.4.3.9	Revised equation 14-7, p 28 Revised equation 14-9, p 32. Add equation 14-10, p 33
35	14.4.3.9	Revised. p 32
36	14.4.3.9	Revised. p 32
37	14.4.3.9	Revised. pp 32
38	14.4.1	Revised. p 5
39	9.4 9.4.2	Revised. p 6 Revised. p 7
40	Appendix E, §E.1.1.6	Revised. p E-2

41	5.7.1.2	Revised. p 7 & p 8
42	5.7.1.7	Revised. p 10, p 11, & p 12
43	5.7.1.9	Revised. p 13 & p 14
44	5.7.1.5 5.7.1.8	Revised. p 9 Revised. p 13. Soil ingestion rate in construction work scenario was omitted.
45	5.8.1 5.8.2 5.8.3 5.8.4 5.8.5	Revised. p 16 RAI 45 was superceded by RAI in set 2 about $DCGL_W$ Revised. p 18 These sections and pages were affected. Revised. p 19. §5.8, pp. 5-16 thru 5-19 later revised in response to RAI set 2.
46	14.4.3.7 14.4.3.7 14.4.3.7	§14.4.3.7 referenced §14.4.3.1 §14.4.3.7 referenced §14.4.3.2 Revised. p 19, p 20, p 22, p 23
47	14.4.3.7	Revised. p 23
48	5.9.1 Appendix G	Revised. p 24 & p 25 Added Appendix G, §3.4 to document response to RAI 48.
49	5.8.5 Table 5-3 5.8.7 Figure 5-3 5.9.1 Figure 5-4 5.8.8.2	Revised Table 5-3, p 5-18 and in response to RAI set 2. Revised again to §5.8.7, pp 19 & 20 in response to RAI set 2 Revised to §5.9.2, Fig. 5-4, p. 5-24. Revised. p. 28. [Later renamed to 5.9.2. and revised p. 5-23 & 5-24 in response to RAI set 2.]
	RAI set 2	
50		Revised §5.9.1 p 24 & p 25 to allocate pavement and soil in response to RAI set 1, item 4.
51	Table 2-2	Table 2-2 added to §2.
52	2.4.2	Revised. p 9
53	8.1	Revised. p 2 & p 3
54		No revision needed.
55	8.9 Figure 8-1	Revised. p 10. Note: We need to update Figure 8-1, the schedule to do Phase 2 decommissioning.
56		DP revision not needed.
57	4.2	Revised. p 1, footnote 2
58	8.4.1 8.4.2 8.4.3 14.4.3.7	Revised. p 5 Revised . p 5 Revised. p 6 Revised. p 22 & p 23 [See also response to RAI 62]
59	14.4.3.2 14.4.3.7	Revised. p 12 Revised. p 21 & p 22
60	4.4.2 14.4.3.7	P 3 describes wastewater neutralization characterization survey. Revised. p 23
61		No revision of CT 2 DP needed.
62	8.4.1 8.4.2	Revised. p 5. Refer to characterization data in §4.8 Revised. p 5.

62	8.4.3 14.4.3.7	Revised. p 6. Revised. p 22 & p 23
63	14.3	Revised. p 4
64		DP revision not needed.
65	8.1	Revised. p 2
66	14.4.3.7	Revised. p 21 & p 22
67	8.9	Revised. p 10
68		DP revision not needed.
69	8.4.2	Revised. p 5 & p 6
70	8.5.2 12.1.6	Revised. p 7 Revised. p 4
71	8.5.3 12.1.3	Revised. p 8. Revised. p 2 & p 3.
72	8.5.3	Revised. p 8.
73	12.2	Revised. p 5
74		DP revision not needed.
75	10.1.1.1 10.1.1.2 11.2.5.2	Revised. p 1 Revised. p 2 Revised. p 3 Appendix 77, referenced in RAI set 2, is added to CT2 DP as Attachment 3.
76	10.1.2	Revised. p 2
77	Attachment 3	Added new Attachment 3, previously provided with RAI set 2 as Appendix 77.
78	10.1.2.3	Revised. p 3.
79	10.1.1.2	Revised. p 2.
80	14.4.3.7	Revised. p 20.
81	14.4.3.7	Revised. p 21, p 22, & p 23
82		DP revision is not needed.
83	5.8.6 5.9.1 Appendix D, §4 thru §7	Revised. p. 18. Revised. p 22 & p. 23 Apx D, §4 thru §7 explains the compliance model.
84		DP revision not needed. [Ref. DP §14.4.3.8.]
85		DP revision not needed. Ref. DP §14.5
86	14.4.3.9	Revised. p 33
87	14.5	Revised. p 34
88		DP revision is not needed.
89	4.8.4 Table 12-1 Table 12-2	Revised. p 10 Revised. §12, Table 12-1 volume Revised. §12, Table 12-2 radioactivity
90		DP revision is not needed.
91	12.1.3 12.1.5	Revised. p 2, footnote Revised. p 4

91	12.1.6	Revised. p 4
92	12.1.6	Revised. p 4
93	Figure 9-1 9.2.2	[Do we need an updated organization chart, Figure 9-1 and attendant revision to text in §9.1?] Revised. p 4
94		DP revision not needed.
95	9.3	Revised. p 5
96	9.1.3 9.3.2	Revised. p 2 Revised. p 5 *[RAI 96 asks about qualifications of Mallinckrodt's Radiation Safety Officer specified in §9.3.2. Response to the RAI mentioned Tim Woodford as the RSO. The response will need to be revised. If we accede to NRC interest in specifying that the RSO "... be qualified by training and experience for the types and quantities of radionuclides that will be encountered during decommissioning operations, as well as the operations that will be undertaken to decommission the facility. In addition, the RSO must be qualified to implement the radiation protection program." then I think we would not have to name the RSO at this time. This would cause DP §9.3.2 to be revised]*
97		DP revision is not needed.
98	9.2.6	Revised. p 5. Ref. DP §9.1 and Fig. 9-1 also.
99		DP revision is not needed. Ref. DP §9.1.2, §9.1.3, and §9.1.4.
100		DP revision not needed. Ref. DP §9.4 and §9.1.7.
101		DP revision is not needed. Ref. DP §9.1.5 and §9.1.6
		Other Revisions
	Table of Contents	Revised.
	1.0	Revised. p 1-3. Table 5-1 to Table 5-3 and Table 5-2 to Table 5-4.
	1.0	Revised. p 1-4.
	10.1.4	Included "or optically-stimulated luminescence dosimeter"
	10.1.6.2	Table 10-1, maximum areal contamination limit on surface of items of equipment to be released from a restricted area without restriction on use, was added. Ref. p 7
	11.2.5.2	Revised. p 3.
	Appendix D	Replace original Appendix D "Record of RESRAD Computations for DCGL Derivation" with new Appendix D "Probabilistic Derivation of Radiological Dose Factors and $DCGL_W$ Applicable to C-T Soil." New appendix incorporates responses to NRC:EPAB RAI in RAI set 1. Appendix D includes dose modeling parameters in its Attachment A, Th^{230}-to-Ra^{226} ratios in its Attachment B, and key dose modeling (RESRAD) cases in its Attachment C.
	Appendix G	Insert new Appendix G. It includes key dose modeling (RESRAD) cases in its Attachment G-A and Attachment G-B.

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

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SECTION 1

EXECUTIVE SUMMARY

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 2
August 12, 2008

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 5-3. The RESRAD-computed dose factors and corresponding $DCGL_W$ applicable to surfaces of pavement, process building slabs, and wastewater basins are in Table 5-4. 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 **A**s **L**ow **A**s is **R**easonable. 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 24 months after NRC approval of the CT Phase II Decommissioning Plan.

SECTION 2

FACILITY OPERATING HISTORY

Mallinckrodt Inc.

C-T Phase II Decommissioning 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.

Legal Basis of FUSRAP Remedial Action. The following are documents that define USACE's authority and clean-up scope of work.

- The USACE is administering and executing cleanup at FUSRAP sites pursuant to a March 1999, Memorandum of Understanding with the Department of Energy and the provisions of the Energy and Water Development Appropriations Acts for Fiscal Years 1998-2001 (Public Laws 105-62, 105-245, 106-377, respectively). Section 611 of Pub. L. 106-60 requires the USACE to remediate FUSRAP sites, in accordance with, and subject to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 U.S.C. 9601 et seq., and the National Oil and Hazardous Substance Pollution Contingency Plan (NCP), Chapter 1, Part 300.
- USEPA Region VII. Federal Facility Agreement in the matter of the United States Department of Energy's FUSRAP Sites, St. Louis and Hazelwood, Missouri. Docket VII-90-F-0005. June 26, 1990
- U.S. Army Corps of Engineers, Record of Decision for the St. Louis Downtown Site, St. Louis, Missouri, July 1998.

  The CERCLA process provides for a Record of Decision (ROD) of the selected remedial action for cleanup of the wastes related to the Manhattan Engineering District/Atomic Energy Commission (MED/AEC) on the Mallinckrodt Chemical Works Site and Vicinity Properties. A Record of Decision was agreed to by the USACE and the USEPA and was concurred to by the Missouri Department of Natural Resources (MDNR).[2]

  This ROD applies to cleanup of MED/AEC wastes in accessible soils by excavation and off-site disposal, for monitoring ground water in the Mississippi River alluvial aquifer, and for periodic reviews to evaluate need for ground water remediation at the St. Louis Downtown Site.

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[2] USACE and USEPA. Declaration for the Record of Decision, August 1998, in U.S. Army Corps of Engineers, Record of Decision for the St. Louis Downtown Site, St. Louis, Missouri, July 1998.

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.

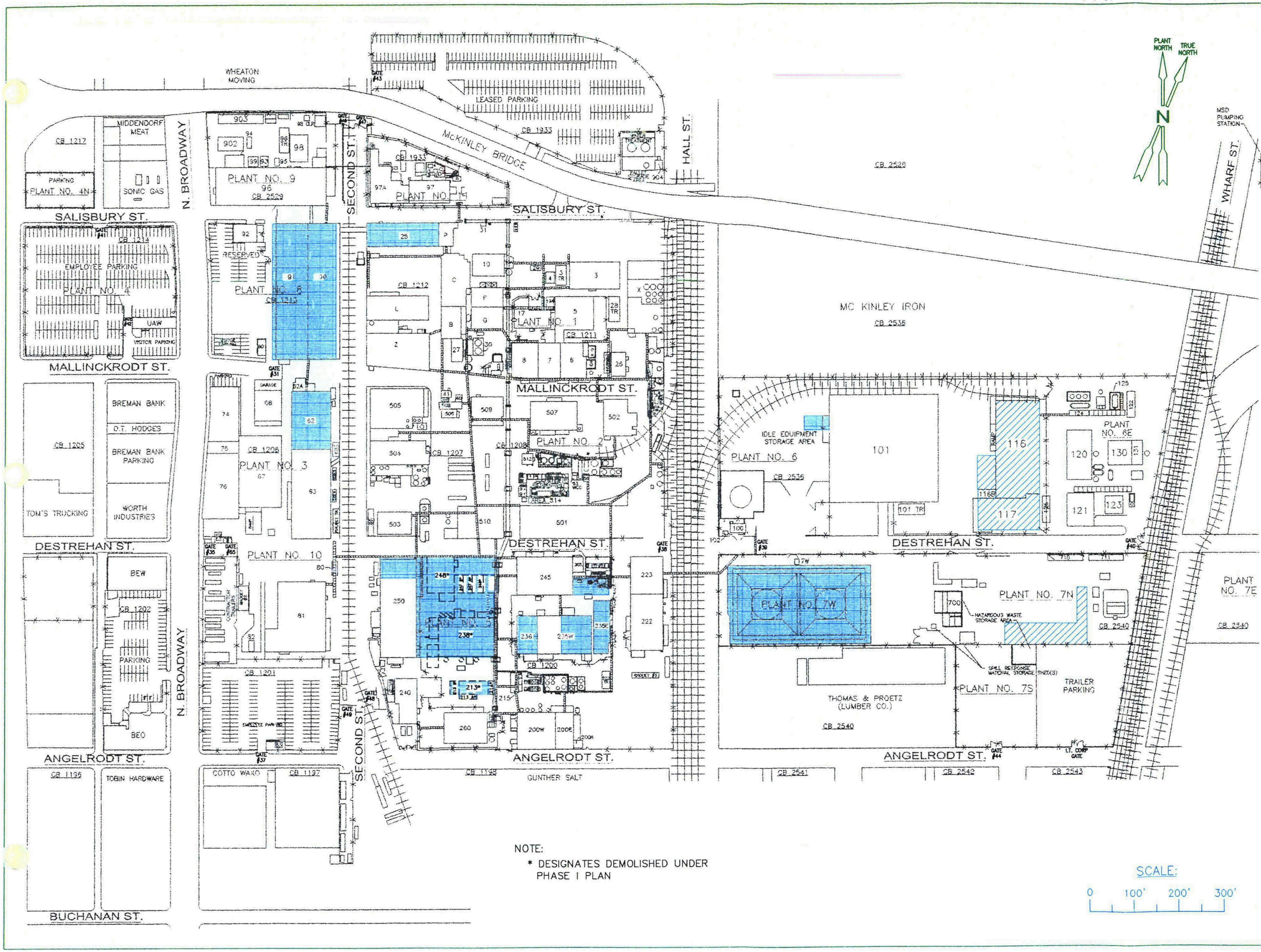
TABLE 2-1
C-T PROCESS AND SUPPORT BUILDINGS

Building No. and Location	C-T Process and Support Areas
<u>Plant 1 Area</u>	
Building 25 (FUSRAP)*	Laboratory
<u>Plant 3 Area</u>	
Building 62	Change Rooms (Lockers)
<u>Plant 5 Area</u>	
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
<u>Plant 6 Area</u>	
C-T Incinerator	C-T Incinerator
Building 116 (FUSRAP)	Receipt/Unloading of C-T Ore
Building 117 (FUSRAP)	URO Drum Preparation and Staging
<u>Plant 7 Area</u>	
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
<u>Plant 8 Area</u>	
Building 90/91	Maintenance Areas

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

Table 2-2. Potentially Contaminated C-T Areas

Item	Location	Reference to Decommission Plan	Remediation Strategy	Waste Volume Estimate (ft^3)
Plant 5 pavement	Fig. 14-1A	CT 2 DP §4.8.3	Decontamination or removal and disposal off-site.	4100.
Plant 5 building slabs	Bldgs 238 & 248	CT 2 DP §4.8.3	Decontamination or removal and disposal off-site.	13000.
Plant 5 soil and subsurface material	Figs. 4-17,18,19	CT 2 DP §4.8.4	Excavation and disposal off-site.	42000.
Sewerage from Plant 5 to wastewater basins	Fig. 4-1	CT 2 DP §4.8.2	Expected to meet release criteria. Else, removal and disposal of sediment or removal of sewerage and disposal of debris.	0
Wastewater lift station	Fig. 4-5	CT 2 DP §4	Expected to meet release criteria. Else, decontamination, with waste disposal off-site	0
Wastewater Neutralization Basins in Plant 7W	Fig. 4-5	CT 2 DP §4	Expected to meet release criteria. Else, decontamination, with waste disposal off-site	0
URO buried in Plant 6W	Fig. 2-5	CT 2 DP §2.6	Excavation and disposal off-site	81500



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

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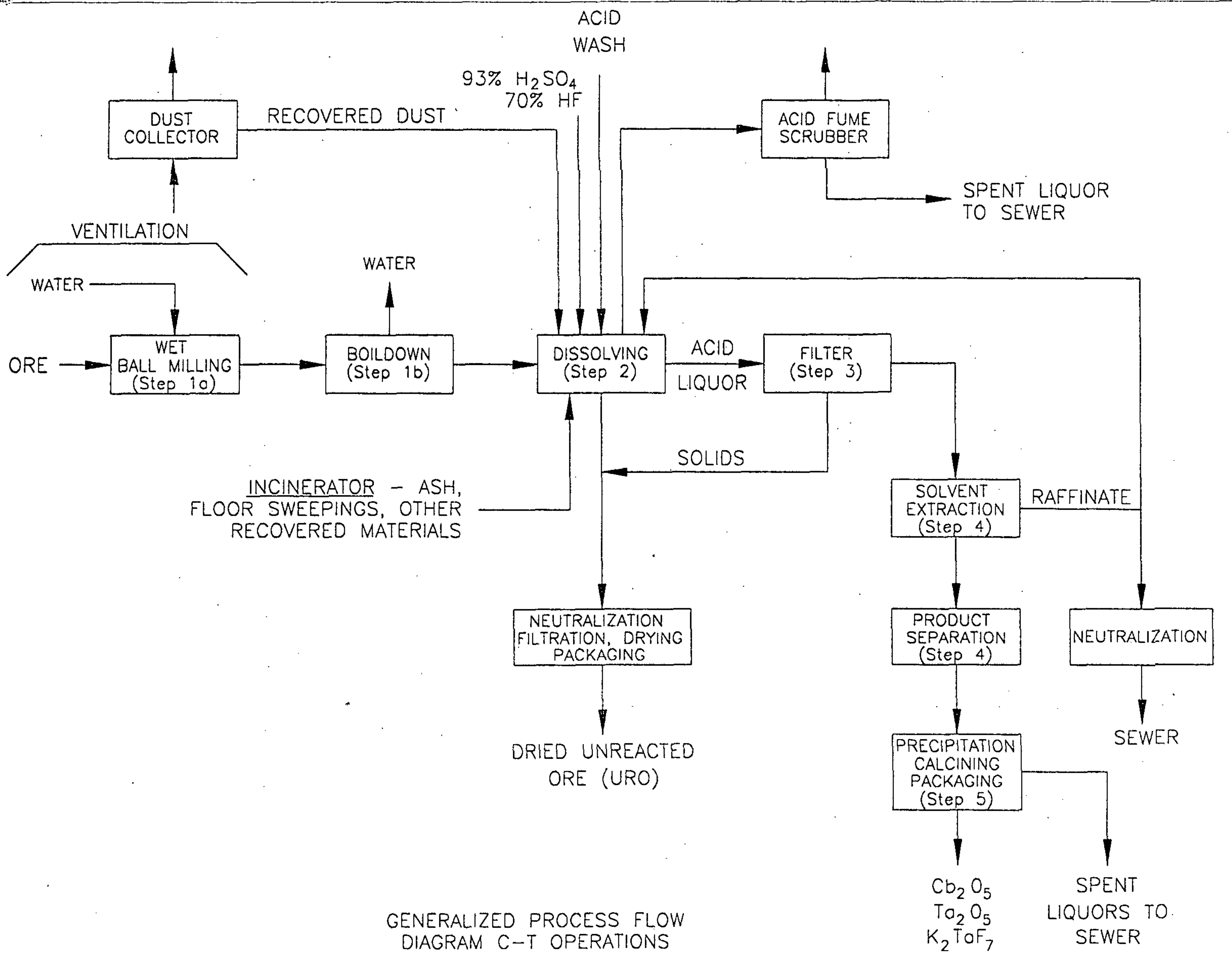
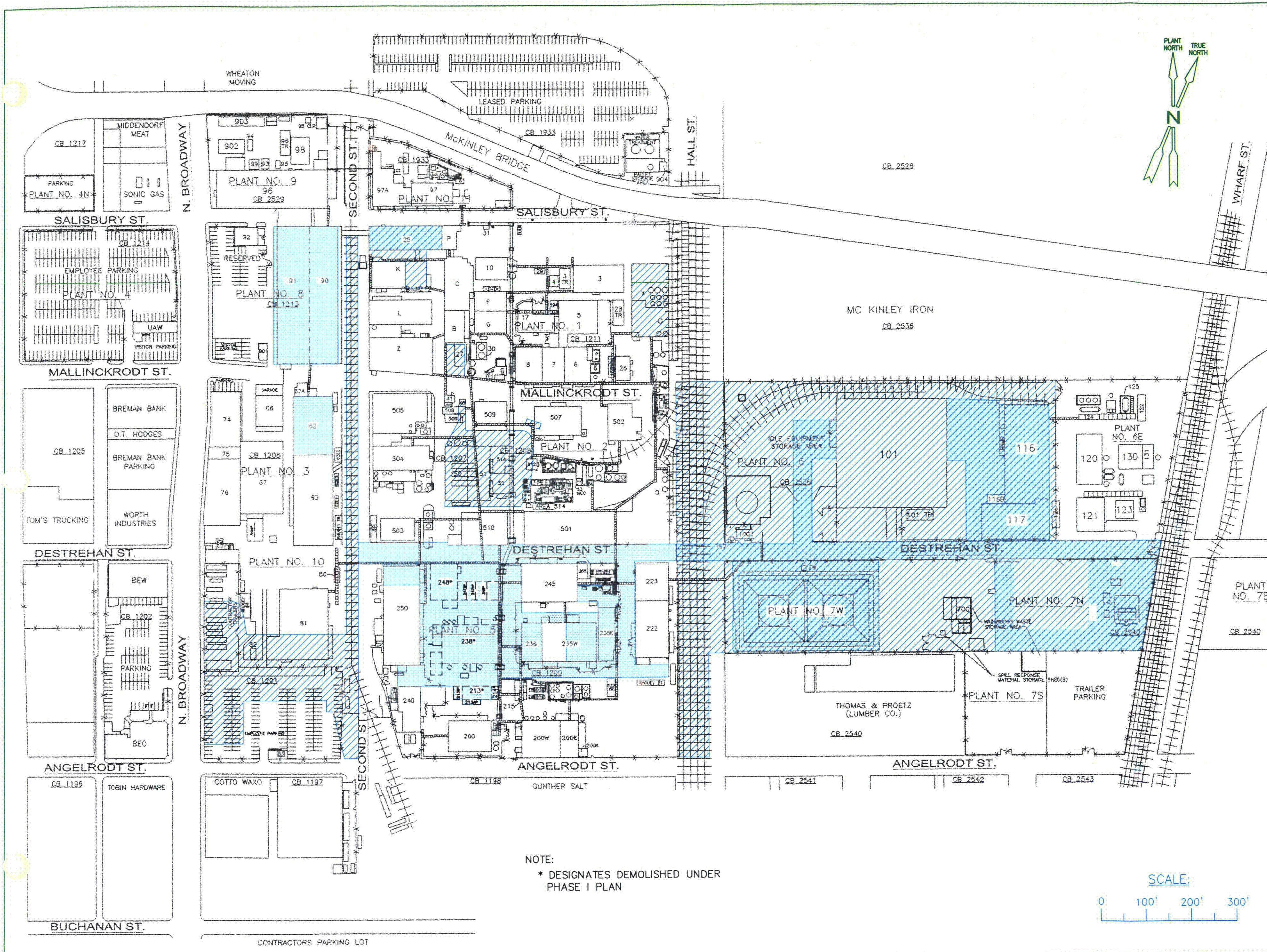


FIGURE 2-2
GENERALIZED PROCESS FLOW DIAGRAM
C-T OPERATION
REV. 0

fn = Gen_proc 8/6/97



NOTE:

* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

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

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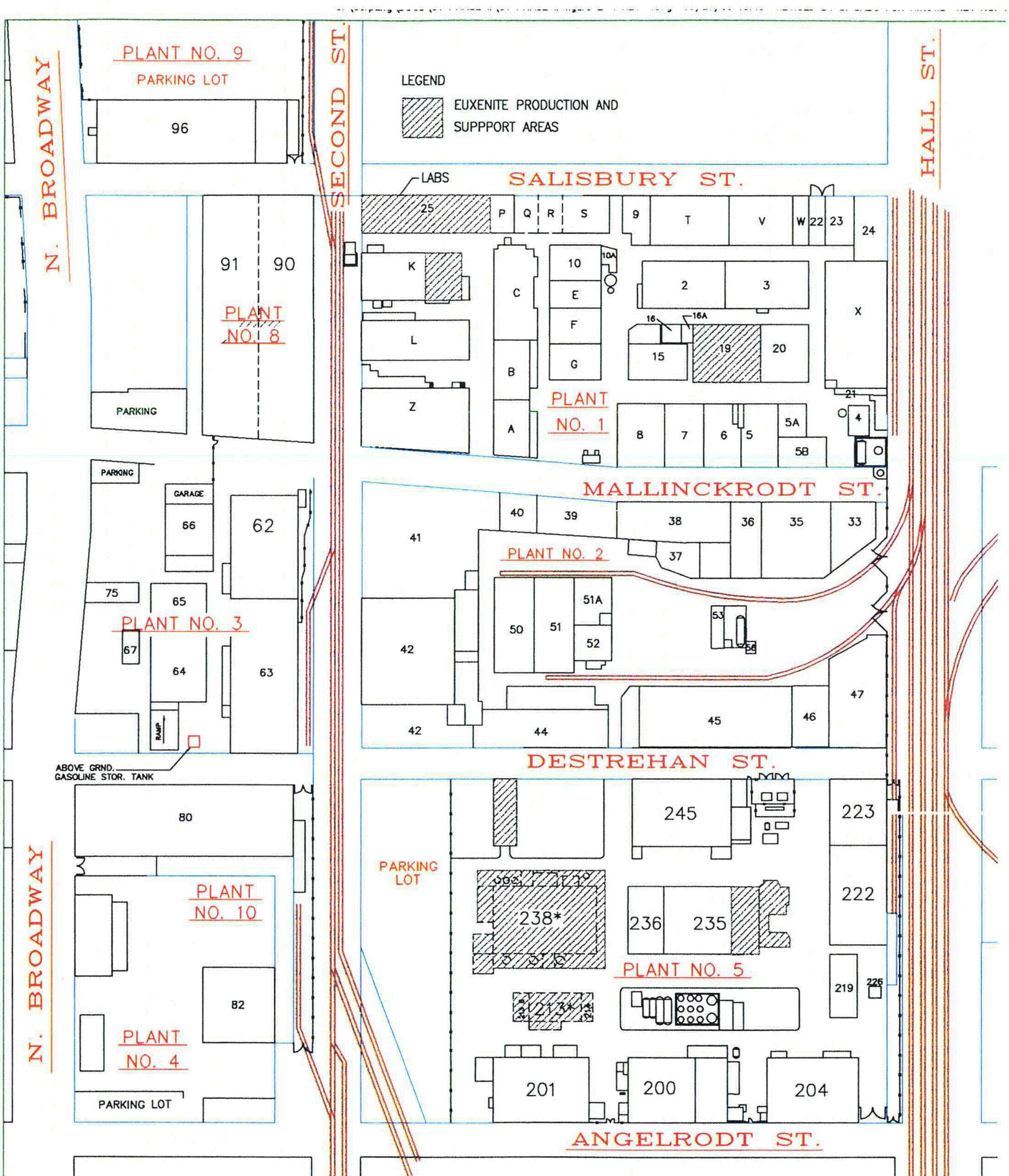
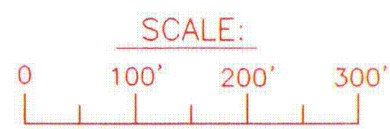


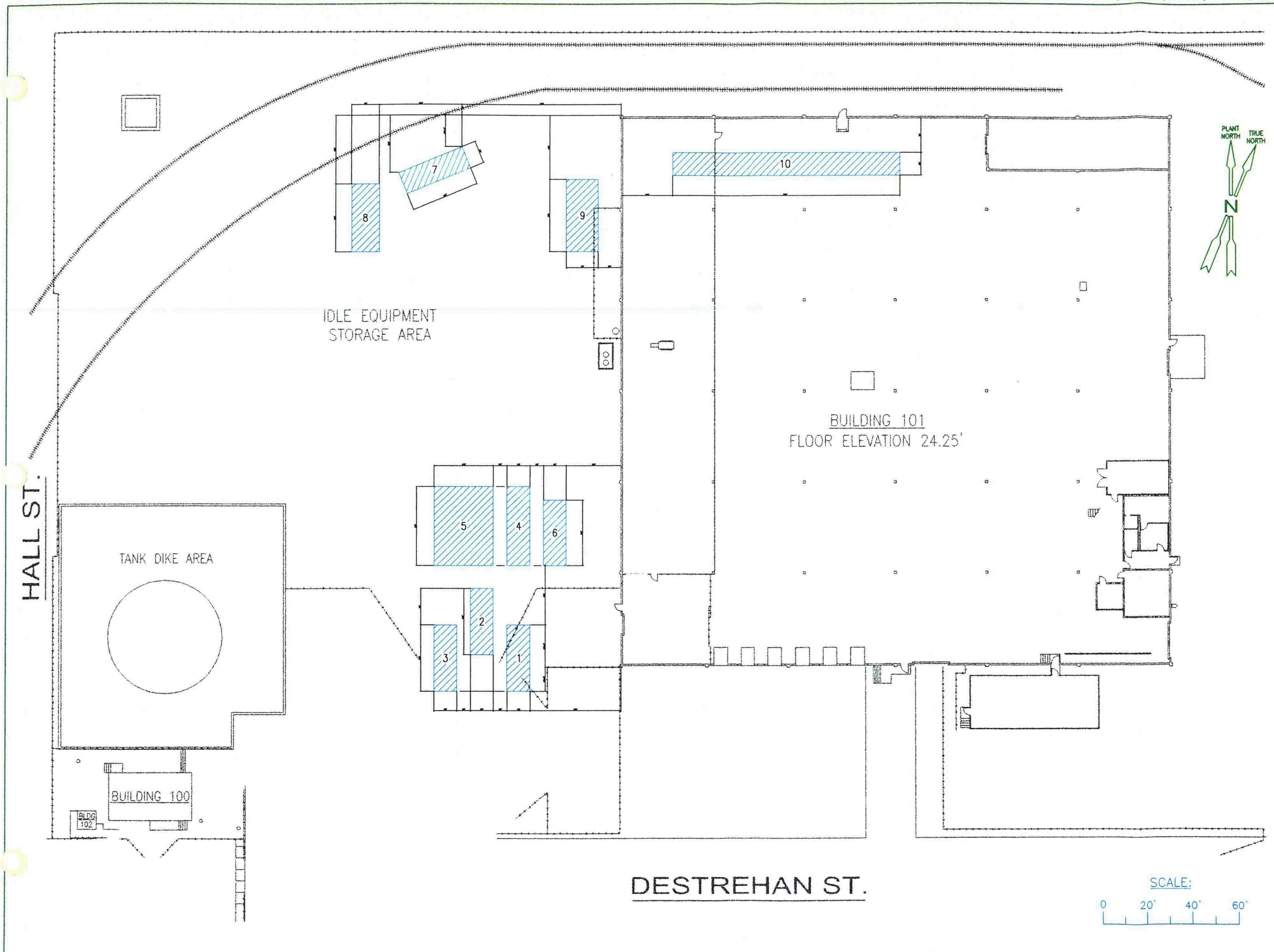


NOTE:

* DESIGNATES DEMOLISHED UNDER PHASE I PLAN

FIGURE 2-4
FORMER EUXENITE SUPPORT AREA
REV. 0

S:\CorpEng\DOCS\CT PHASE II\CT PHASE II figure 2-5.dwg 03/19/03 14:39 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 Decommissioning 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

[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 1.8×10^6 km^2 (700,000 sq. miles). The average flow for a 114-year period is 5×10^6 m^3/s [177,000 cubic feet per second (cfs), 114390 million gallons per day (MGD)]. The minimum flow recorded in this period is 5×10^5 m^3/s (18,000 cfs), and the maximum measure flow is 3×10^7 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			

[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.

[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

[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 NFPO TFS	DTSVNWG	DIST km
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

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

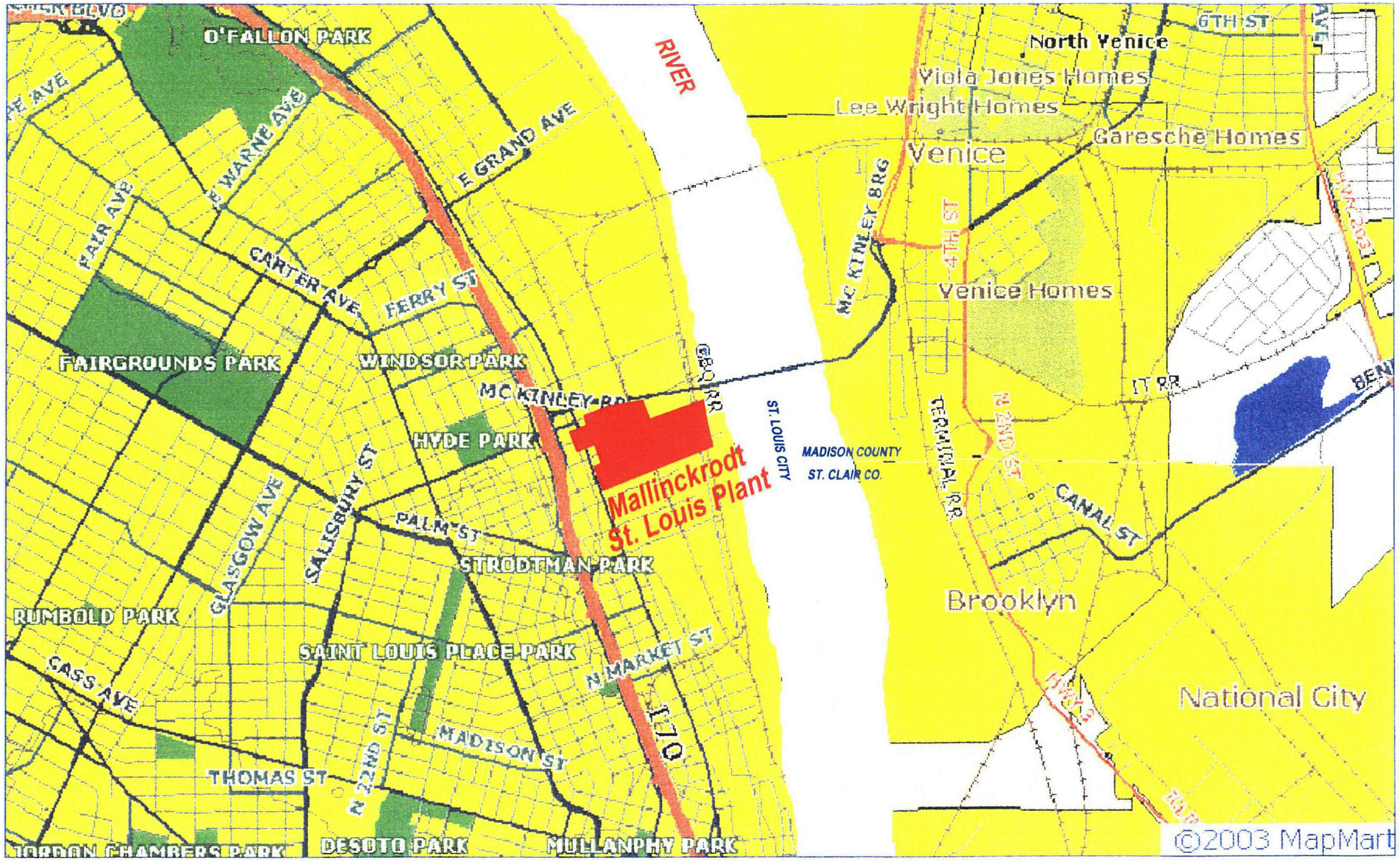
Table 3-6. Probabilistic Ground Motion Hazard Values

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



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

DRAWING REVISIONS

JOB NO. PROJECT NO.

MALLINCKRODT

ST. LOUIS, MO.

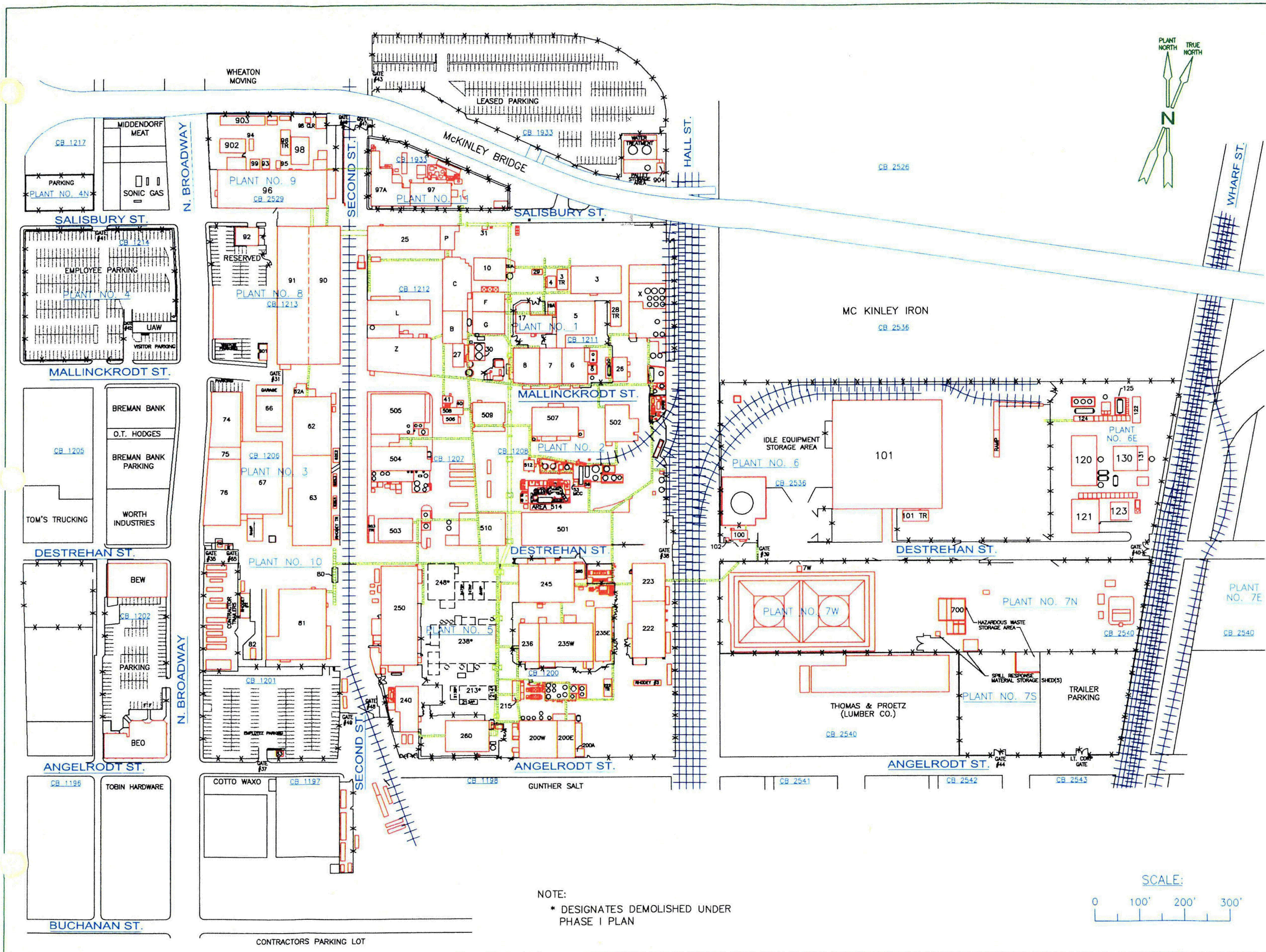
ST. LOUIS PLANT
SITE LOCATION MAP
FIGURE 3-1

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

T_BLK25.DWG

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



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
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

T_BLK25.DWG

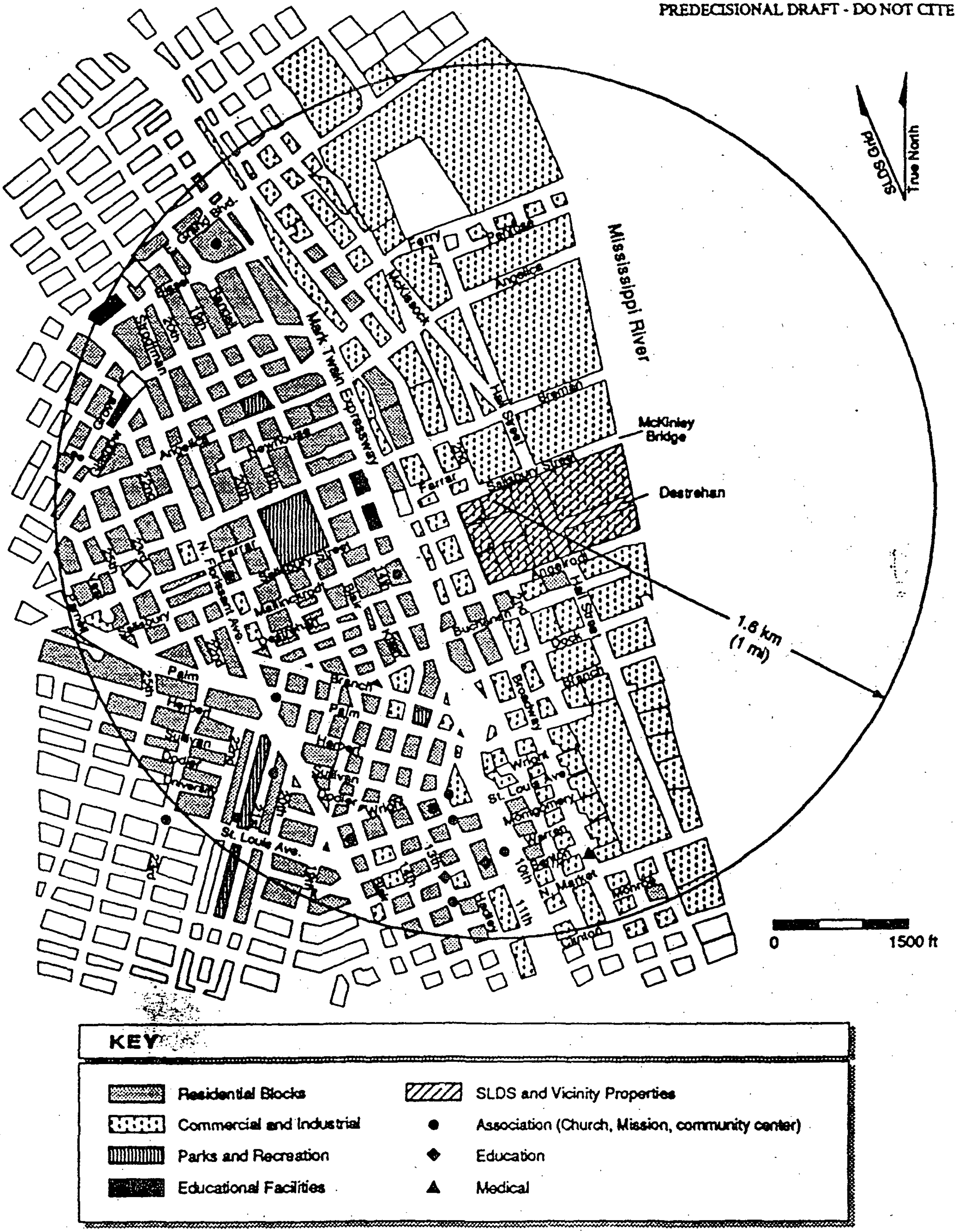


Figure 3-3. Land Use Within a 1.6-km (1-mi) Radius of SLDS
(St. Louis Community Development Agency 1992)

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:
"GEOLOGIC MAP
OF
ST. LOUIS CITY AND COUNTY,
MISSOURI."
FIGURE 3-4

WITHIN THIS PACKAGE... OR
BY SEARCHING USING THE

D-01

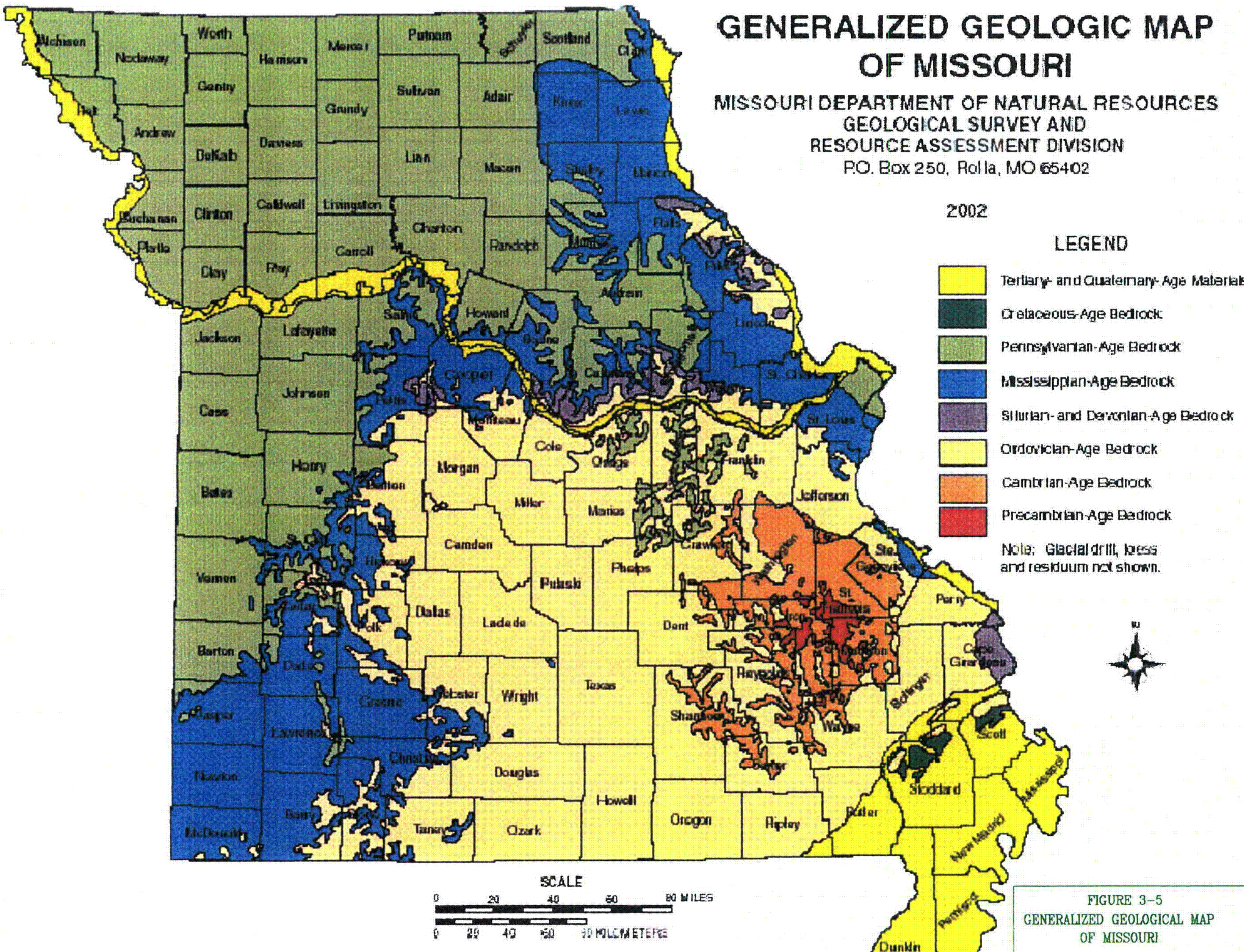
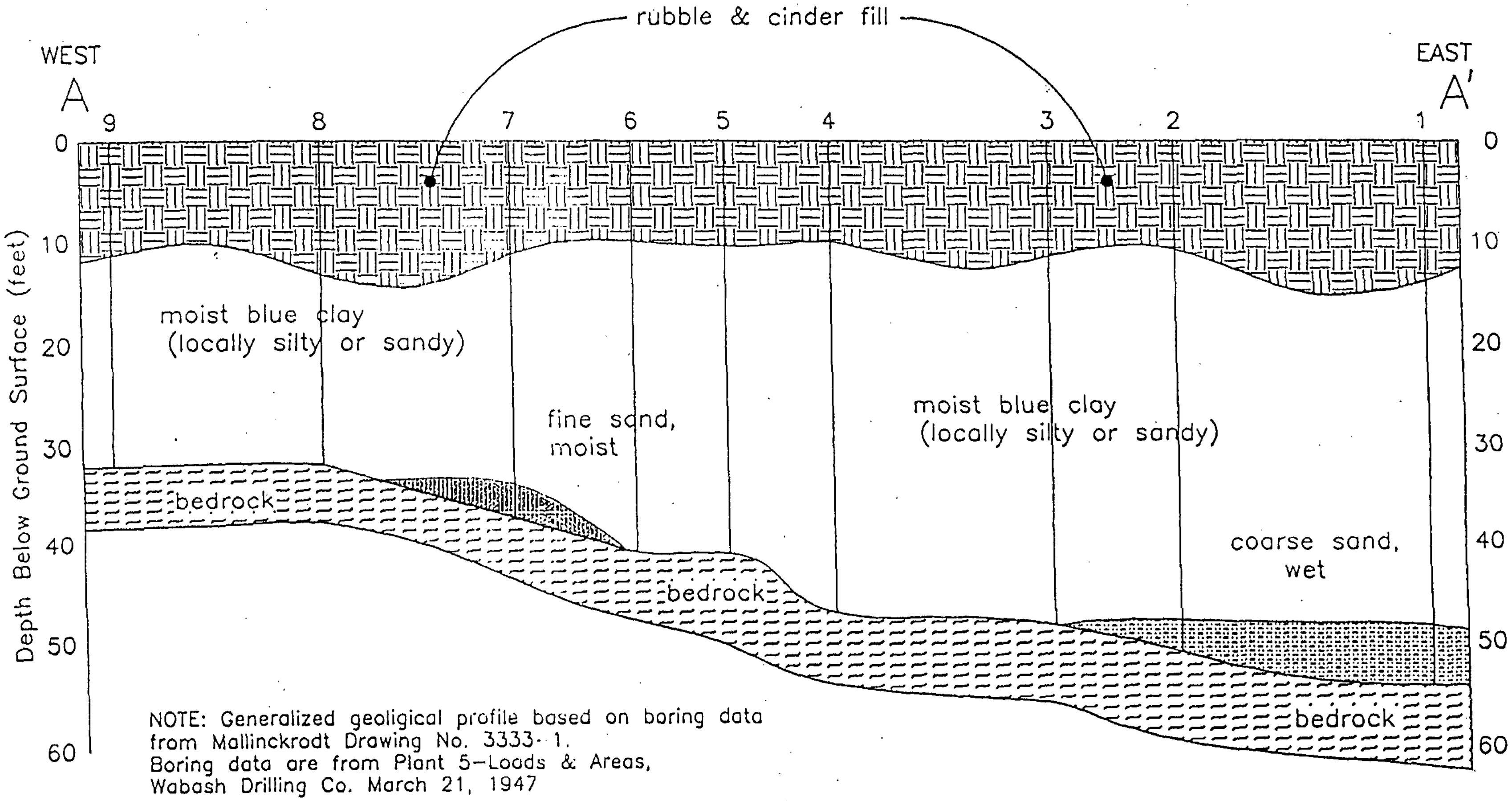


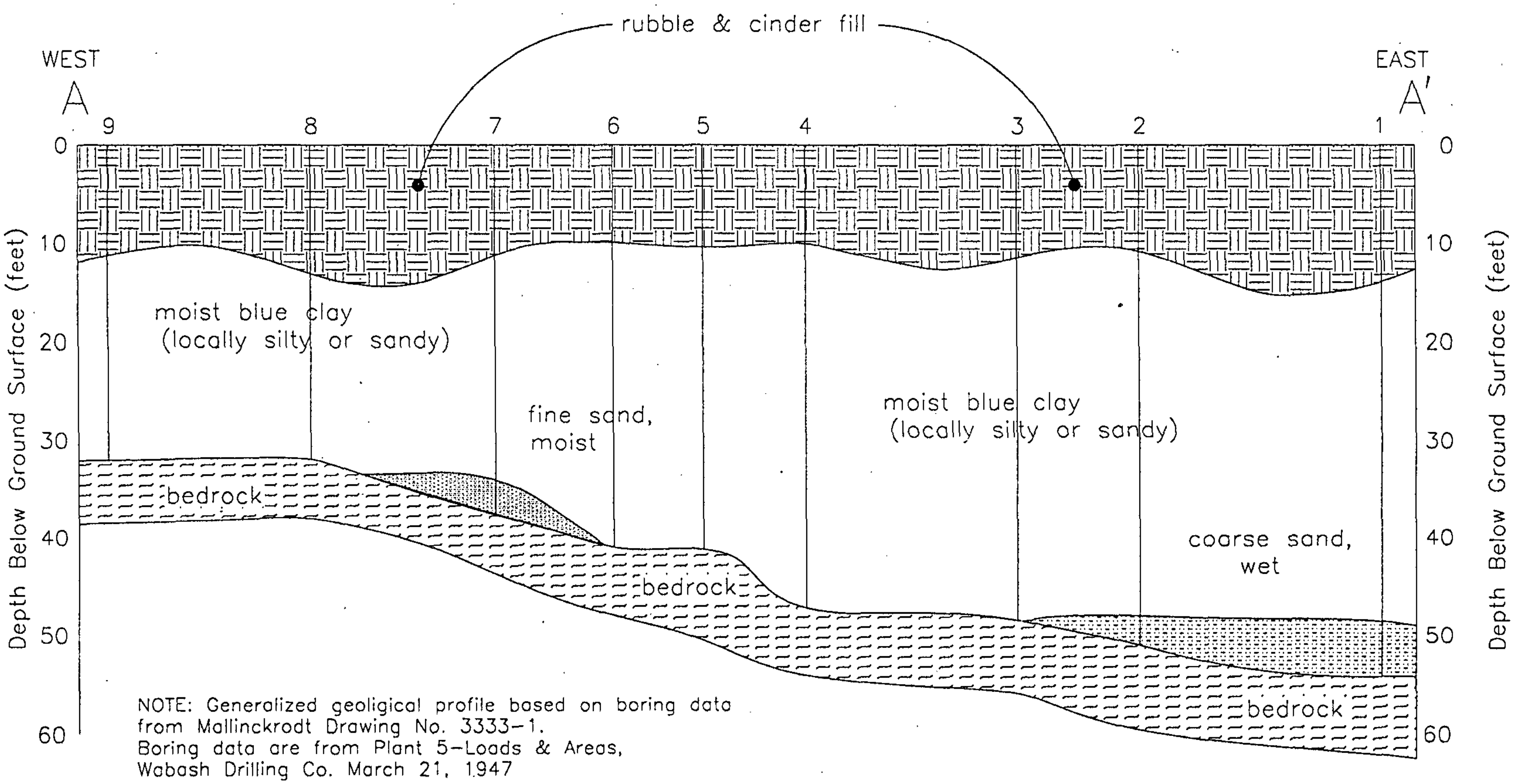
FIGURE 3-5
GENERALIZED GEOLOGICAL MAP
OF MISSOURI



GENERALIZED GEOLOGICAL PROFILE
PLANT 5

FIGURE 3-6
GENERALIZED GEOLOGIC
PROFILE

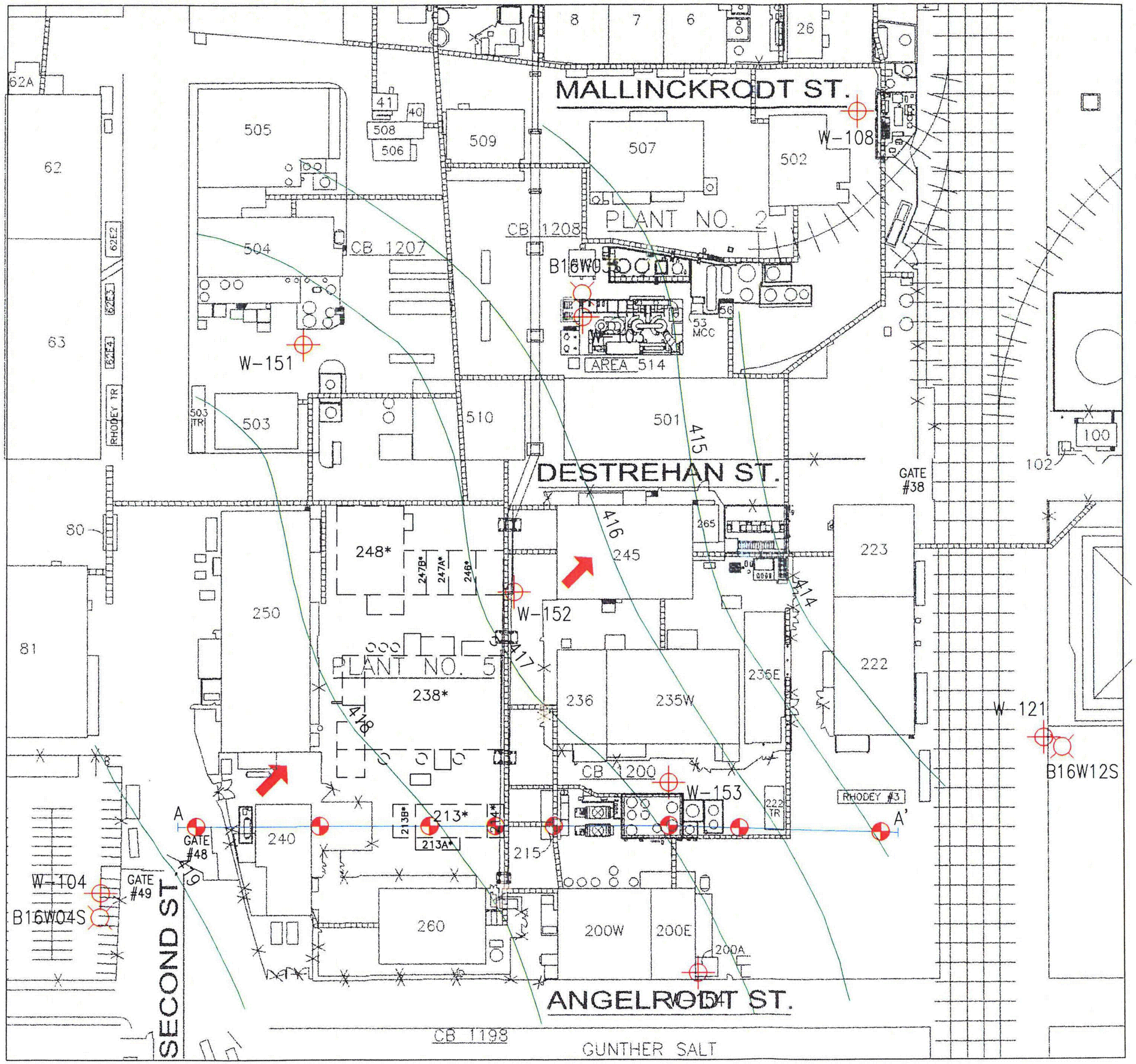
S:\CorpEng\DOCS\CT [illegible] II\CT PHASE II FIGURE 3-7.dwg 03/19/03 14:01 REVISED BY S. SABO FOR R.ROWE R[illegible] 0

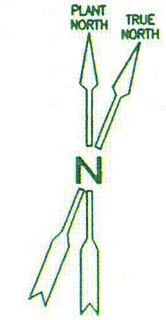


GENERALIZED GEOLOGICAL PROFILE
PLANT 5

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

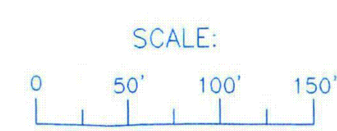
fn = Geo_prof 8/6/97





NOTE:

* DESIGNATES DEMOLISHED UNDER PHASE I PLAN



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

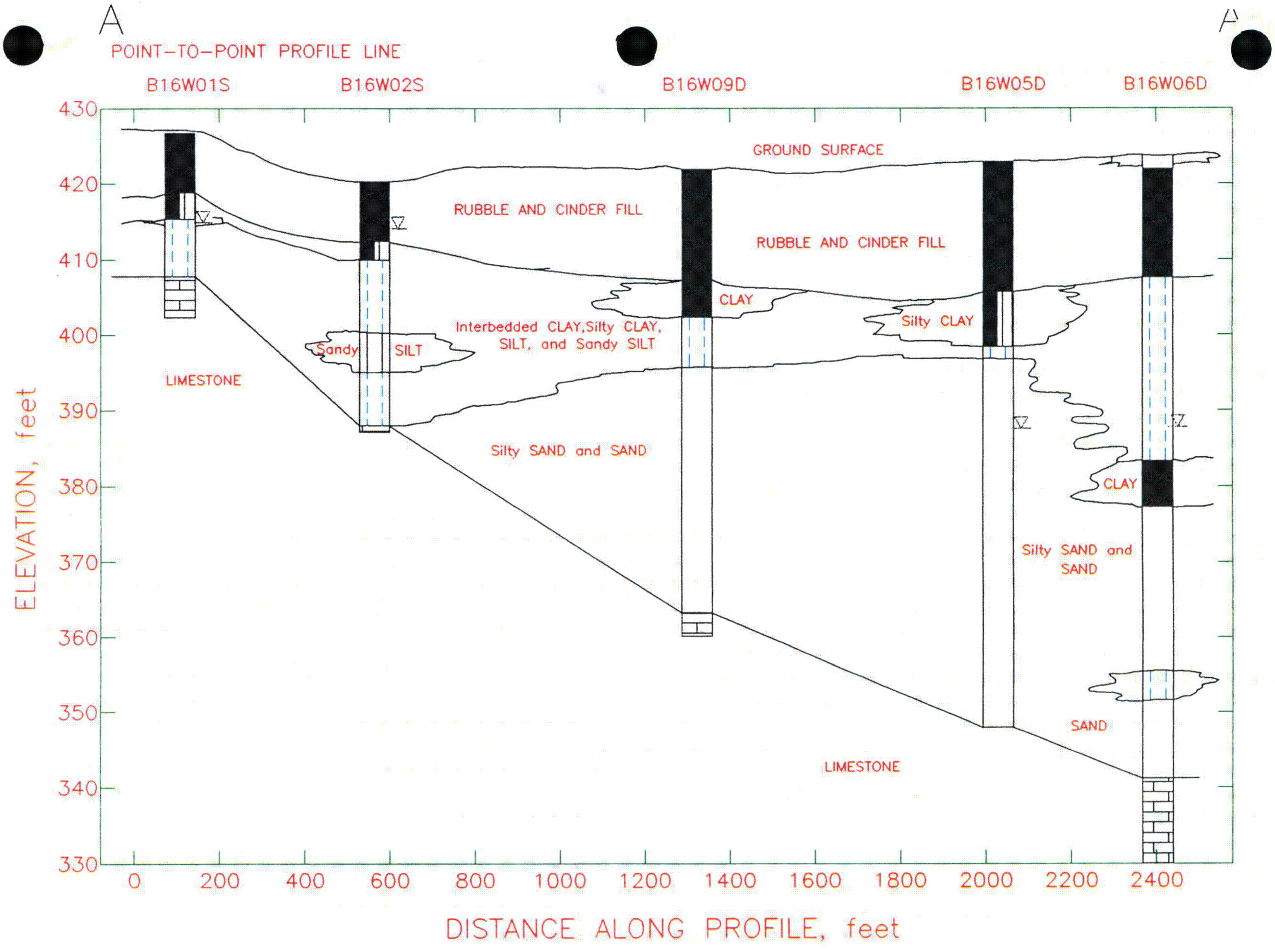
ST. LOUIS, MO.

ST. LOUIS PLANT
MONITORING WELL LOCATIONS
FIGURE 3-8

SITE STL	PLANT ALL	BLDG. ALL	FLOOR N/A
SCALE 1"=50'		DATE 12/08/00	
DR. BY: J. MCMAHON		ENGR.	
CHECKED			

DRAWING NO. FIGURE 3-8 REV. 1

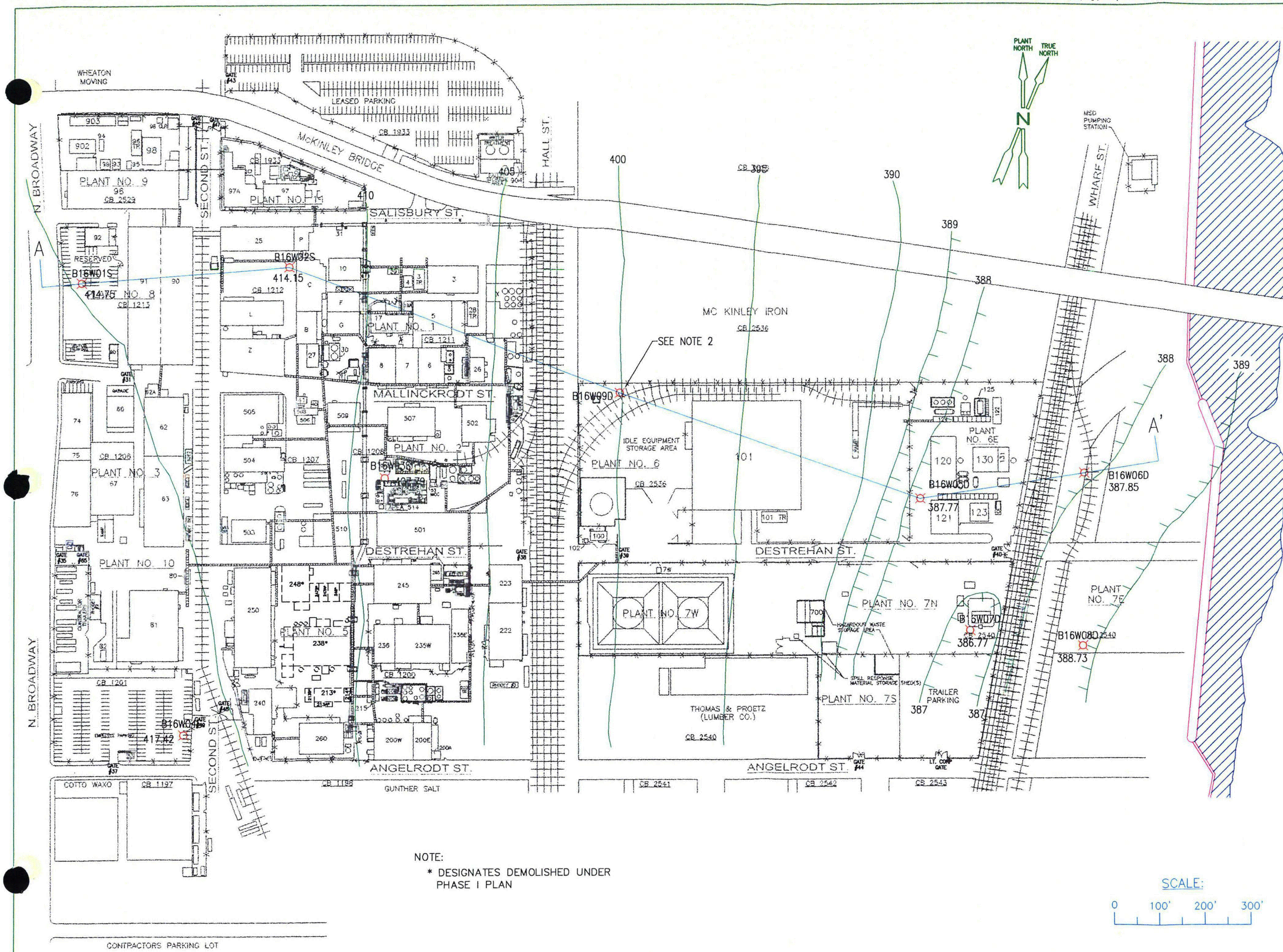
T BLK25.DWG



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

fn = HYDRO_XN 10/16/97



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

T_BLK25.DWG

SECTION 4

RADIOLOGICAL STATUS OF FACILITY

Mallinckrodt Inc.

C-T Phase II Decommissioning 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[2] 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)[3], describes the activities involving above-grade decommissioning of the buildings. The

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

[2] *Structure* is intended to refer to a building or other structure above ground.

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

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.[4]

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.[5] 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.

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

[5] 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.[6] 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.

[6] 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.[7] 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.[8] 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.[9] 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.

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[7] 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.

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

[9] 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.[10] 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.[11] 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).[12] In July and September 1999, sampling of subsurface soils was completed in southwest of Building 250.[13] 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.[14] 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.

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

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

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

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

[14] 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.[15] 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,[16] 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.[17] 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.[18] 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.

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

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

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

[18] 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[19]. 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[20].

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

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

[20] *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[21]. 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[22].

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[23]. 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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[21] 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.

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

[23] 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."[24] 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. <u>Sewers (Manholes)</u>

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. <u>Pavement</u>

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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[24] 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. Approximately 70300 ft^3 of unreacted C-T ore buried in Plant 6W is estimated to be candidate for excavation. The total volume of potentially contaminated solid waste in C-T Phase II is estimated to be 129000 ft^3. (ref. Table 12-1).

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			4.59	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			4.054	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	531	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 minut

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	

[a] dpm = atomic transformations per minute

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

Borehole Number	Average Depth (ft)	Radionuclide Concentration 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

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-008	17.5	18.5					3.1	2.2	5.2	1.5	1.3	1.7	0.0
BH-009	2	3	3.5	0.24	3.8	9	27.6	16.3	< 3.7	5.5	6.3	6.4	0.7
BH-010	2	3	19.6	1.2	21.5	50.9	262	239.3	< 10.7	51.1	81.5	64.6	< 11.3
BH-010	4	5	19	1.1	20		18	31.8	11.1	2.9	17.1	3.3	1.4
BH-010	5	6	15	0.68	15		3.1	2.84	14.6	0.45	4.48	0.35	0.1
BH-010A	6	7	6.8	0.29	7.1	25.4	11.2	22.5	33.4	10.8	28.2	14.2	1.6
BH-010A	9	10		0.19	< 3.98			2.81	0.97	3.1	3.42		0.1
BH-010A	13	14	1.3	0.04	1.3	5.3	2.4	1.3	1.1	1	1	1.1	0.0
BH-011	2	3	1.1	< 0.1	0.65		0.16	2.12	3.23	0.24	1.53	0.23	0.0
BH-011	3	4	2.4	0.15	2.3	748.3	238	115.2	225.6	25.9	47.4	28.1	5.5
BH-011	9	10	32.2	1.2	30.4	108	24.8	40.4	47.8	15.3	33.3	19.3	2.5
BH-011	13	14	2.5	0.05	2.8	6.5	3.6	2.2	3.7	2.7	1.6	2.4	0.1
BH-011	22	23	1.1	0.05	1.2	3.1	1.8	1.4	2.5	1.5	1.1	1.4	0.0
BH-012	5	6	9.9	0.49	10.4	30.4	24.3	250.2	28	33.8	40.3	38.3	10.0
BH-012	9	10	9.4	0.54	10	24.9	16.3	208.7	< 15.8	8.3	23	12.5	7.5
BH-012	11	12		0.55	8.03			17.6	8.56	5.95	5.99		0.8
BH-012	12	13		0.96	< 4.88			1.51	< 0.7	1.1	1.14		0.0
BH-012	13	14		0.62	7.68			8.07	9.93	1.62	1.73		0.3
BH-012	14	15	3.1	0.17	3.4	12.3	4.7	4.8	3.8	2.5	0.85	2.9	0.2
BH-012	15	16	2.9	0.23	2.8	5	2.8	3.3	3.8	0.92	1.1	1.4	0.1
BH-013	3	4		0.39	7.05			2.85	7.23	1.28	1.45		< 0.0
BH-013	5	6	4.2	0.16	4.5	12.7	2.4	1.1	5.6	1.6	1.2	1.3	0.0
BH-013	9	10	4	0.16	4.4	10.2	1.7	3.4	4.6	1.1	1.6	1	0.0
BH-013	16	17	1.4	0.02	1.7	4.9	1.5	1.8	2.8	0.95	1	1.1	0.0
BH-014	1	2	6.6	0.25	7.2	20.6	4.5	0.49	20	1.4	5.5	2.7	0.1
BH-014	2	3		0.67	11.1			2.97	23.6	2.48	2.38		0.1
BH-014	3	4		1.47	30.9			3.37	25.7	1.99	2.09		0.1
BH-014	4	4.5	27.9	1.2	28.7	70.3	20.2	16.4	27.9	11.9	8.5	16.9	1.1

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-015	5	6	14.9	0.56	16.3	27.5	98.8	327.4	< 10.9	11.1	78	32	13.1
BH-015A	9	10	69.3	3.1	71.7	180.6	261.9	744.6	< 44.7	48.2	193.3	60.9	30.2
BH-015A	11	12	210	6.9	210		6.1	667	< 10.6	0.93	117	2.1	24.5
BH-015A	14	15	72	3.8	75		14	462	3.08	2.2	92.4	5.1	17.3
BH-015A	15	16	8.5	0.28	9.7	16.7	5.9	< 0.43	< 2.3	2.2	0.67	2.3	0.0
BH-016	4	5		< 0.08	< 4.26			1.33	< 0.6	2.74	2.57		0.1
BH-016	6	7	5.4	0.29	5.9	16.6	6.3	7.8	8.7	3.5	4.5	3.5	0.3
BH-016	6	7			8.92								< 0.7
BH-017	0.75	1.2	4.8	0.27	5	13.2	11.5	122.5	11.7	4.9	2.1	11.8	< 4.2
BH-017B	4	5		0.07	< 4.47			1.91	0.88	1.35	1.33		0.0
BH-019	2	3		0.079	< 4.25			1.39	0.87	1.12	1.07		0.0
BH-019	9	10	3.4	0.14	4.8	5.6	1.5	2.8	6.9	1.1	2.9	1.4	0.0
BH-020	2	3		0.18	< 4.89			1.68	2.56	1.01	0.98		0.0
BH-020	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	9	10	4.8	0.18	4.9	12.2	5	2.9	11.5	9.4	11.3	8.3	0.4
BH-021	2	3	13.1	0.58	16.6	30.4	10.4	9	17.5	0.78	1	1.1	0.2
BH-021	5	6	11	0.45	14.4	37.1	3.1	2.9	20.2	0.63	1.1	0.92	0.0
BH-022	0.75	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	5	6	36.1	1.2	34.8	107.1	54.3	9.3	37.5	1.4	1.9	1.6	0.3
BH-022	6	7	29	1.4	31		0.58	4.86	17	< 0.07	1.35	< 0.1	0.1
BH-022	7	8	17	0.76	17		4.6	4.22	23.4	0.29	1.15	0.28	0.1
BH-022	9	10	12.8	0.48	13	39.4	17.3	4.7	15.4	1.6	1.7	1.8	0.1
BH-023	9	10	6.6	0.6	6.6	14.1	1.8	0.13	9.1	0.61	1.1	0.64	0.0
BH-023	14	15	2.3	0.15	2.5	5.6	2.1	< 0.24	3.1	1.1	1.2	1.4	0.0
BH-025	2.5	3.5	81.7	4.7	81.8	225.2	8.9	4.1	74.5	0.66	1.2	0.9	0.2
BH-025	4	5		2.68	65.1			2.33	20.4	0.71	0.56		0.1
BH-025	8	9	71.3	2.9	76	226.2	1.9	1.6	100.9	0.76	1.6	0.51	0.1
BH-026	3	4		0.55	8.15			13.7	8.33		1.14		0.4

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

Location ID	Sample Depth (ft) Top	Bottom	Radionuclide Concentration 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	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	5	6		0.56	13.3			1.29	3.43		2.6		0.0
BH-026	7	8		0.56	11.3			< 0.642	1.64		2.49		0.0
BH-026	9	10		0.1	< 2.23			1.21	0.82		2.9		0.0
BH-026	12	13	7.8	0.35	8.2	23.9	6.8	8.5	7.1	0.96	1.1	1.1	0.2
BH-026	15	16	1.1	0.03	1	3.5	1.5	1.2	< 4.2	1.1	1.5	1.2	0.0
BH-027	2.5	3.5		0.22	< 4.76			2.16	3.31	0.97	0.98		0.0
BH-027	4	5		0.09	< 4.77			1.44	1.67	0.99	0.86		0.0
BH-027	5	6	3.7	0.08	3.6	11.7	3.2	1.5	3.5	2.1	1.8	2.1	0.0
BH-027	8	9	6.8	0.19	7.1	21.7	7.3	4.6	8.1	2.9	2.4	2.9	0.1
BH-027	11	12	2.4	0.05	2.5	6.5	2.6	1.4	1.8	1.9	2	1.9	0.0
BH-027	22.5	23.5	1.1	0.08	1.1	2.9	1.5	1.1	< 3.1	1.3	< 0.62	1.3	0.0
BH-028	0.7	2		1.16	27.9			4.34	4.16	1.42	1.26		0.1
BH-028	2	3	23.5	1	23.5	49.8	3.5	5.1	25.2	1.1	1.9	2.7	0.2
BH-028	3	4		0.59	13.8			3.63	7.45	1.35	1.23		0.1
BH-028	10	11	3.5	0.08	3	7.7	2.8	1.7	3.2	1	0.81	1.4	0.0
BH-028	13	14	4.2	0.2	4.1	14.8	5.6	3.3	5.4	1.7	1.2	1.2	< 0.1
BH-029	2	3	54.8	1.4	53.4	91	16.9	4.5	75.3	1.6	1.2	1.6	0.1
BH-029	3	4		0.34	5.59			1.84	4.08	0.93	0.92		0.0
BH-029	10	12	5.1	0.33	5.5	14.6	7.8	4	12.8	1.9	1.5	1.5	0.1
BH-029	15	16	1.9	0.13	1.6	4.2	1.5	1.4	1.9	0.9	1.2	1.5	0.0
BH-030	2	3	24	3.9	28.2	43.6	18.6	3.5	20.3	1.6	1.8	1.1	0.1
BH-030	3	4		0.18	< 4.03			2.52	1.82	0.77	0.76		0.0
BH-030	4	5		0.33	5.79			2.2	5.98	0.84	0.94		0.0
BH-030	10	11		0.48	9.76			1.29	1.67	0.69	0.54		0.0
BH-030	12	13	14.3	0.71	14.6	42	8.3	1.3	3.3	2.6	0.83	3.2	0.1
BH-030	14	15	6.1	0.17	6.3	23.9	3.2	0.84	7.3	1.4	1.2	1.2	0.0
BH-031	0.75	2		0.31	5.06			2.72	5.64	1.11	1.19		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-031	4	6		0.15	< 4.69			1.68	3.05	1.74	1.74		0.0
BH-031	6	8		0.16	< 4.08			3.04	2.46	1.63	1.53		0.0
BH-031	8	10		0.64	6.29			22.7	5.23	6.86	6.97		1.0
BH-031	10	12	3.8	0.1	4.2	12	9.7	26.5	11.4	2.7	4.7	4	0.9
BH-031	12	14	1.5	0.07	1.4	6.3	1.5	1.7	3.1	0.67	1.4	0.72	0.0
BH-031	16	18	1.1	0.06	1.5	3.9	2.4	1.5	< 3.5	1.1	< 0.35	1.6	0.0
BH-032	1	3	11.7	0.52	12.6	30.2	6.6	6.3	16.7	0.82	2.1	1	0.2
BH-032	3	5		0.45	9.96			2.18	8.21	0.88	0.73		0.0
BH-032	5	7		0.18	< 4.93			1.03	2.74	0.66	0.79		0.0
BH-032	13	15	16	0.96	16.8	42.5	3	1.6	20.1	1.5	1.9	1.4	0.0
BH-032	17	19	7.1	0.26	7	18.2	3.7	1.4	7.9	2.4	1.4	2.2	0.0
BH-032	27	29	0.88	0.04	1.3	3.2	1.3	0.98	< 3.2	1.1	0.89	1.3	0.0
BH-033	0.75	2	21.1	0.87	20.7	77.5	15.4	2.6	22.6	1.9	0.86	1.9	0.0
BH-033	2.5	3.5		1.52	31.6			< 0.891	9.17		2.79		0.1
BH-033	6	7		0.24	3.61			1.74	0.69	0.764	0.78		0.0
BH-033	10.5	11.5		0.58	13.1			2.67	0.61	2.49	2.35		0.1
BH-033	12	13	46.6	2	49.7	126.1	4.2	2.9	46.7	1.4	1.2	1.4	0.1
BH-033	16	17	33.4	1.7	33.1	87.3	6.9	1.4	19.8	3.2	2.1	3.4	0.1
BH-034	3	4	5.9	0.24	5.2	13.9	6.3	6.9	7.4	1.2	1.5	1.3	0.2
BH-034	9	10	4.4	0.11	4.2	12.1	5.8	4.6	5.1	2.6	1.8	2.9	0.1
BH-034	15	16	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	0.75	14.9	0.75	15.2	47.3	13	3.9	9.4	1.8	1.5	2.8	0.1
BH-035	0.75	2		0.26	5.5			3.7	3.35	1.15	1.25		0.0
BH-035	3	4		0.15	< 2.21			2.46	2.05	0.895	0.99		0.0
BH-035	5	6		0.25	< 3.42			3.17	3.24	1.05	1.1		0.0
BH-035	7	8	3.1	0.18	3.5	14.1	4.7	36.3	36.4	1.2	8.4	1.1	1.3
BH-035	16	17	1.6	0.04	1.4	5.6	1.8	1.5	2.8	1.2	1.5	1.6	0.0
BH-035	28.5	29.5	1	0.06	0.92	3	1.3	0.86	1.4	1.1	1.2	1.3	0.0

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

Location ID	Sample Depth (ft) Top	Bottom	Radionuclide Concentration 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-036	0	0.75	2.8	0.14	3	8.3	3.6	3.2	< 5.6	0.99	1.6	1.3	0.0
BH-036	5	6	2.7	0.14	3.4	7.8	3.9	4.5	5	1	1.6	1.1	0.1
BH-036	16	17	5.6	0.26	6	12.1	3.5	2.4	7.3	1.2	1.2	1.2	0.0
BH-037	0.7	2	10.4	0.41	9.9	19	6.5	< 0.44	< 2.4	1.4	< 0.47	1.4	0.0
BH-037	6.5	7.5	5.2	0.1	5.3	8.9	6.1	4.3	4.7	1.7	< 0.55	1.9	0.1
BH-037	11	12	4.2	0.2	4.4	8.4	2.9	6	1.1	1.7	1.7	1.4	0.1
BH-038	0.5	2	55.9	3	56.9	168.5	138.6	16.7	72	3.8	8	4.2	0.8
BH-038	2	4	62	3.1	61		3.2	4.73	56.6	< 0.1	2.06	< 0.2	0.2
BH-038	5	6	13	0.66	13		0.085	3.03	24.4	< 0.02	1.65	0.039	0.0
BH-038	6	7	9.9	0.41	10.3	34.2	22.4	3.8	8.9	1.3	1.3	1.3	0.1
BH-038	15	16	1.7	0.04	1.9	4.8	1.8	3.2	1.8	1.4	1.7	1.6	0.1
BH-039	0.4	2	22.6	1.2	29.7	50.9	23.3	21.1	20.4	1.2	1.8	1.5	0.7
BH-039	2	4		0.21	< 4.12			3.93	1.83	0.86	0.85		0.0
BH-039	4	5		< 0.14	5.39			5.56	2.98	0.8	0.86		0.1
BH-039	6	7		0.25	3.46			3.7	1.28	0.91	0.9		0.0
BH-039	8	9	2.7	0.17	3	8.9	7.7	5	0.95	1	1.3	1.2	0.1
BH-039	17	18	1.2	0.09	1.6	4.7	1.8	1	< 3.6	1.3	1.5	1.2	0.0
BH-039	30	31	1.5	0.06	1.3	3	2.2	0.96	1.8	1.4	< 1.2	1.5	0.0
BH-040	0.5	2		0.11	< 3.97			0.87	1.42	0.28	0.31		0.0
BH-040	2	3		0.28	< 5.91			2.28	4.31	1.36	1.37		0.0
BH-040	3	4	3.1	0.08	3.3	9.3	2.8	2.8	4.4	1.3	1.6	1.4	0.0
BH-040	11	12	6.1	0.4	8	20.2	4.3	1.7	11.3	2.3	2.9	2	0.1
BH-040	17	18	0.97	0.08	1.1	3.6	1.3	1.1	0.67	1.3	1.1	1.1	0.0
BH-041	3	4	15.8	1	17.5	94.4	61.5	5.9	20.6	1.5	1.6	1.3	0.2
BH-041	4	5	6.2	0.29	6.1		0.3	3.04	11.2	< 0.05	1.24	0.17	0.0
BH-041	6	7	0.72	< 0.03	0.85		0.07	1.37	1.45	< 0.03	1.03	< 0.05	0.0
BH-041	8	9	4	0.19	3.9		0.095	1.35	6.03	< 0.02	1.01	< 0.02	0.0
BH-041	11.5	13.5	4.1	0.09	3.9	15.5	2.6	5.6	7.4	1	2.8	2.6	0.2

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

Location ID	Sample Depth (ft) Top	Bottom	Radionuclide Concentration 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-041	16	17	3.9	0.24	4.2	11	2.3	3.9	3.8	1	1.5	1.2	0.1
BH-042	0.6	2	10.1	0.47	11.1	47.5	32	5	14.6	1.5	2.1	1.6	0.1
BH-042	2	3		0.16	< 4.98			1.12	2.43	1.12	1.25		0.0
BH-042	4.5	5.5		0.24	< 4.57			2.38	4.85	1.31	1.47		0.0
BH-042	7	8		0.25	6.11			2.23	5.61	0.992	0.94		0.0
BH-042	9	10		0.76	20.9			2.09	7.37	0.77	0.8		0.0
BH-042	10.5	11.5	18.1	0.85	19	41	9.7	5.3	11.2	3	4	3.8	0.2
BH-042	16	17	2.1	0.04	2.2	5.9	2.9	1.9	3.9	1.3	1.9	1.4	0.0
BH-043	0.5	1	4	0.13	3.7	12.6	3	50.5	4.6	1.2	3.1	1.4	1.6
BH-043	2	3		0.4	10.2			24.8	< 0.676	1.67	1.83		0.8
BH-043	3	4		0.19	< 4.1			2.21	3.35	1.62	1.9		0.0
BH-043	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	10	11	5.1	0.26	5.2	12.5	7.7	0.91	5.2	1	1.2	1.7	0.0
BH-044	0.6	1	5	0.39	5.4	16.5	4.1	16.7	13.3	1.4	1.8	1.4	0.5
BH-044	1	2		0.17	< 6.01			1.1	0.91	0.48	0.48		0.0
BH-044	2	3		0.33	6.71			7.92	5.4		1.02		0.2
BH-044	8	9		0.28	7			1.74	3.82	0.9	0.8		0.0
BH-044	10.5	11.5	4.1	0.22	4.8	11.5	6	3	4.7	3.1	2.8	3.1	0.1
BH-044	17	18	1.6	0.04	2.4	3.6	1.7	1.3	3.9	1.2	1.5	1.3	0.0
BH-045	1.5	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	9	10	1.3	0.04	1.5	3.5	1.6	1.1	1.8	0.81	1	0.71	0.0
BH-045	13	14	1.6	0.11	2.1	5.1	8.3	1.2	1	0.71	0.72	0.65	0.0
BH-046	2	3	1.8	0.06	2	5.3	2.2	1.4	3.3	1.4	0.67	0.85	0.0
BH-046	9	10	5.3	0.31	6.5	13.5	5.4	3.5	5.5	< 0.61	1.1	2.3	0.1
BH-046	13	14	5.2	0.12	5.5	14.3	3	7.4	14.6	2.6	1.6	3.8	0.2
BH-047	3	4	6	0.45	6.2	14.3	4.6	2.9	11.9	1.1	1.7	1.3	0.0
BH-047	7	8	3.4	0.19	5.8	13.6	2.5	2.3	2.5	1.3	1.6	1.4	0.0
BH-047	19	20	1	0.04	1.5	3	1.5	1.3	< 3.9	1	1.2	1.1	0.0

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

Location ID	Sample Depth (ft) 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
			Radionuclide Concentration										
BH-048	3	4	1.3	0.11	1.3	3.3	1.5	1.6	< 4.1	1	1.3	1.5	0.0
BH-048	9	10	2.1	0.03	2.6	6	1.6	2.4	3.6	1.1	1	0.94	0.0
BH-048	16	17	1	-0.01	0.79	2.6	0.94	1.4	1.5	0.59	1	0.82	0.0
BH-049	2	3	4.7	0.33	4.9	9.2	3.5	4.8	5.9	1.1	1.9	1.1	0.1
BH-049	10	11	6.5	0.32	6.8	10.9	3.4	4.8	10	1.2	1.5	0.85	0.1
BH-049	13	14	1.3	0.09	1.1	4.2	1.6	1.2	< 4.2	1.2	1.3	1.3	0.0
BH-050	2.5	3.5	13.3	0.79	60.9	196.8	2.1	2.4	79.2	1.1	1.3	1.2	0.0
BH-050	5	6	1.7	0.21	1.5		1.5			0.81		0.85	0.1
BH-050	14	15	16.9	0.8	22.9	31.1	3.4	4.1	25.4	0.87	1.6	0.77	0.1
BH-050	18	19	6.4	0.38	10.6	23.2	1.4	1.4	14.3	1.2	1.1	1.1	0.0
BH-051	2	3	7.3	0.41	8.6	25.7	4.3	3.6	12.4	0.99	1.4	1	0.0
BH-051	6	7	2.1	0.06	1.9	6.3	0.18	2.5	2.4	0.66	1	0.85	0.0
BH-051	13	14	5.6	0.19	5.8	17.3	8.3	7.9	12.8	2.2	2.6	1.8	0.2
BH-051	18	19	5.2	0.33	5.6	15.4	2.3	1.4	15.8	1	5	1.1	0.1
BH-052	3.5	4.5	27.3	0.98	28.5	94	29.4	1511	< 65.8	7	13.3	19	50.3
BH-052	7	8		0.49	6.66			19.3	5.25	2.43	2.5		0.6
BH-052	9	10		0.2	< 3.74			3.73	1.8	0.58	0.59		0.0
BH-052	10	11		0.11	< 2.63			1.62	1.64	0.306	0.32		0.0
BH-052	13	14	8.8	0.33	9.5	29.7	2.3	18.4	5.2	0.62	1.3	1.2	0.5
BH-052	19	20	1.2	0.04	1.4	5.6	2.2	2.1	3.7	1.5	1.6	1.8	0.0
BH-053	0.5	2	8.1	0.31	7.8	23.3	7	9.8	11.4	1.4	2.2	1.8	0.3
BH-053	3	4		0.09	< 2.04			1.11	1.55	0.76	< 0.112		0.0
BH-053	9	10	4.4	0.44	5.6	19.9	3.2	2.8	5.3	1.4	1.2	1.6	0.0
BH-053	13	14	2.7	0.08	2.6	10.1	1.3	1.1	3.2	0.88	1.2	1	0.0
BH-054	0.75	2	30.9	1.6	30.8	84.1	25.2	192	55.3	3.8	6.3	4.9	6.5
BH-054	4	5		0.92	10.7			< 1.18	10.9		2.91		0.1
BH-054	5	6	4.1	0.17	4.4	17.2	1.8	1.6	10.2	0.97	1.6	0.81	0.0
BH-054	6.5	7.5		0.23	3.86			< 0.535	2.9		1.61		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-054	9	10		0.09	< 3.81			2.14	0.96		2.39		0.0
BH-054	11	12		< 0.038	< 2.1			< 0.66	1.83		1.39		0.0
BH-054	12	13		0.13	< 2.72			1.6	1.51		1.34		0.0
BH-054	14	15		0.27	3.69			2.26	2.2		0.58		0.0
BH-054	15	16	8.7	0.36	9.2	29.2	2	9.8	9.3	0.89	1.6	1.2	0.3
BH-054	19	20		0.09	< 3.42			< 0.787	1.28		2.89		0.0
BH-054	20	21	1.6	0.05	1.3	4.2	1.8	1.3	< 3.8	1.3	1.4	1.1	0.0
BH-055	2.5	3.5	10.2	0.54	13.8	23.5	1.8	2	12	0.7	0.98	0.86	0.0
BH-055	4	5		0.23	4.39			2.06	1.27		2.07		0.0
BH-055	5	6		0.17	< 2.92			1.48	2.19		2.13		0.0
BH-055	6.5	7.5		0.19	< 2.58			2.63	2.2		3.32		0.1
BH-055	9	10	37.9	2.9	242.7	1321	1.5	2.5	679.7	0.9	1.6	1.2	0.2
BH-055	10.5	11.5	16.7	1	17.5		4.3			1.3		1.7	1.6
BH-055	12	13	16.1	0.84	16.7		6.3			2.9		2.7	1.6
BH-055	14.5	15.5	13.5	0.49	18.7	47.6	9.6	60.7	30.5	2.2	6.6	4.2	2.1
BH-055	18.5	19.5		0.14	< 2.69			2.97	1.77		3.23		0.1
BH-055	20	21		0.15	< 3.55			2.5	1.66		3.18		0.1
BH-056	2	3		0.05	< 3.07			0.79	0.95	0.7	0.77		0.0
BH-056	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	11	12	6.3	0.21	6.2	14.8	4.1	4.8	9.2	0.96	1.8	1	0.1
BH-056	14	15	8.7	0.32	8.7	24.1	3.8	4.4	12.3	0.81	1.7	1	0.1
BH-056	28.5	29.5			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

Location ID	Sample Depth (ft)		Radionuclide Concentration										Sum of Fractions
	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)	
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	1	6.4	0.49	5.92		3.78	5.35		1.01	1.98	1.03	0.1
BH-065	3	4	2.02	0.19	1.68		1.93	4.18		1.53	2.36	1.1	0.1
BH-066	1	3	60.12	3.52	66.01		77.9	3.56		1.31	0.97	1.11	0.2
BH-066	3	4	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

Location ID	Sample Depth (ft) 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
			Radionuclide Concentration										
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

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	9	12	4.53		4.13		4.52	0.42	1.85	1.05			0.0
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

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	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
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

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-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
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

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

Location ID	Sample Depth (ft) Top	Bottom	Radionuclide Concentration 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	4	8	0.92	0.061	0.98		1.07	1.23		0.81	0.66		0.0
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

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	1.5	3	9.4	0.59	9.9		27.8	3.23	6.6	0.9	1.16	0.73	0.0
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

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	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
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

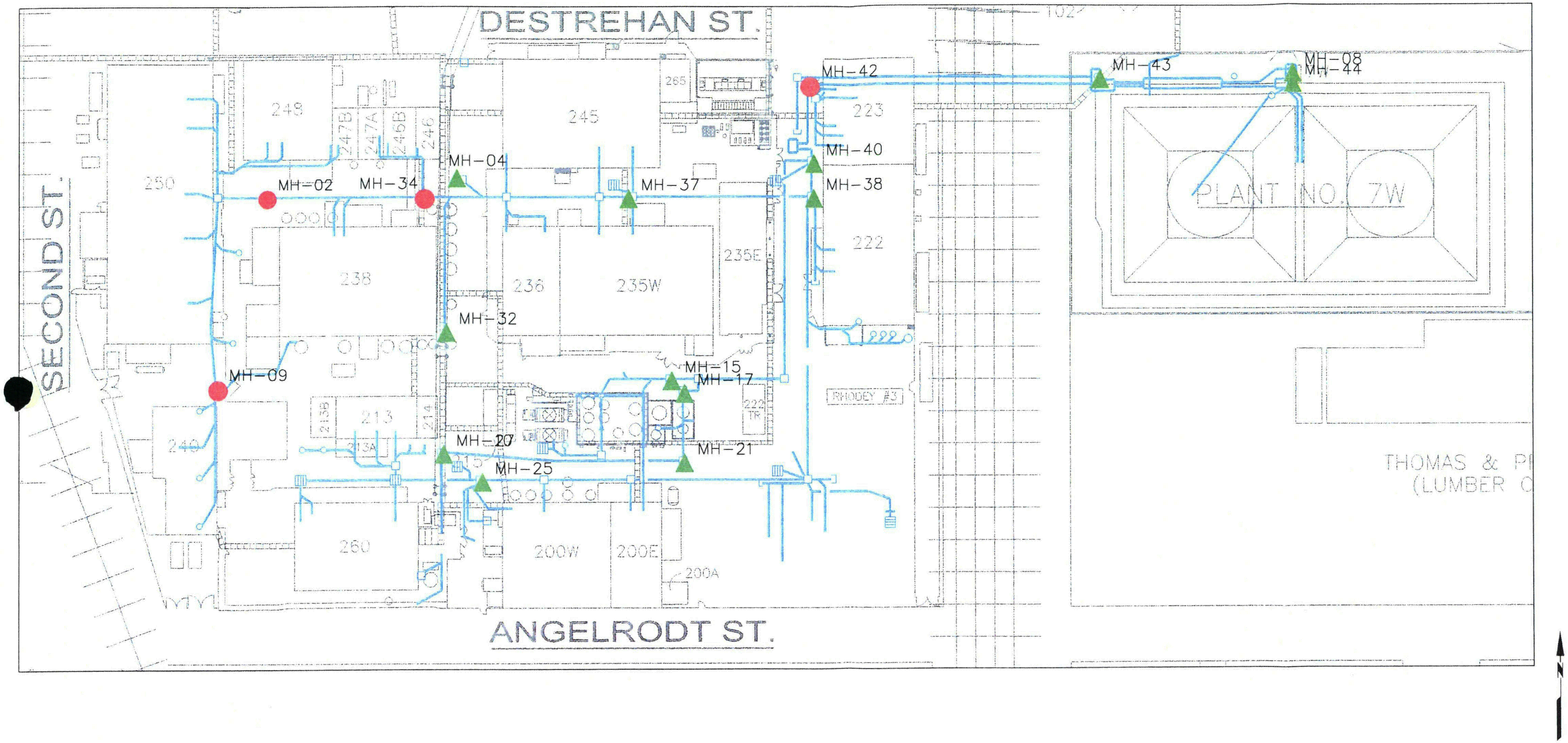
Table 4-16, Analytical Results of Mallinckrodt Biased Soil Samples

	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			216.1		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			172.5		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

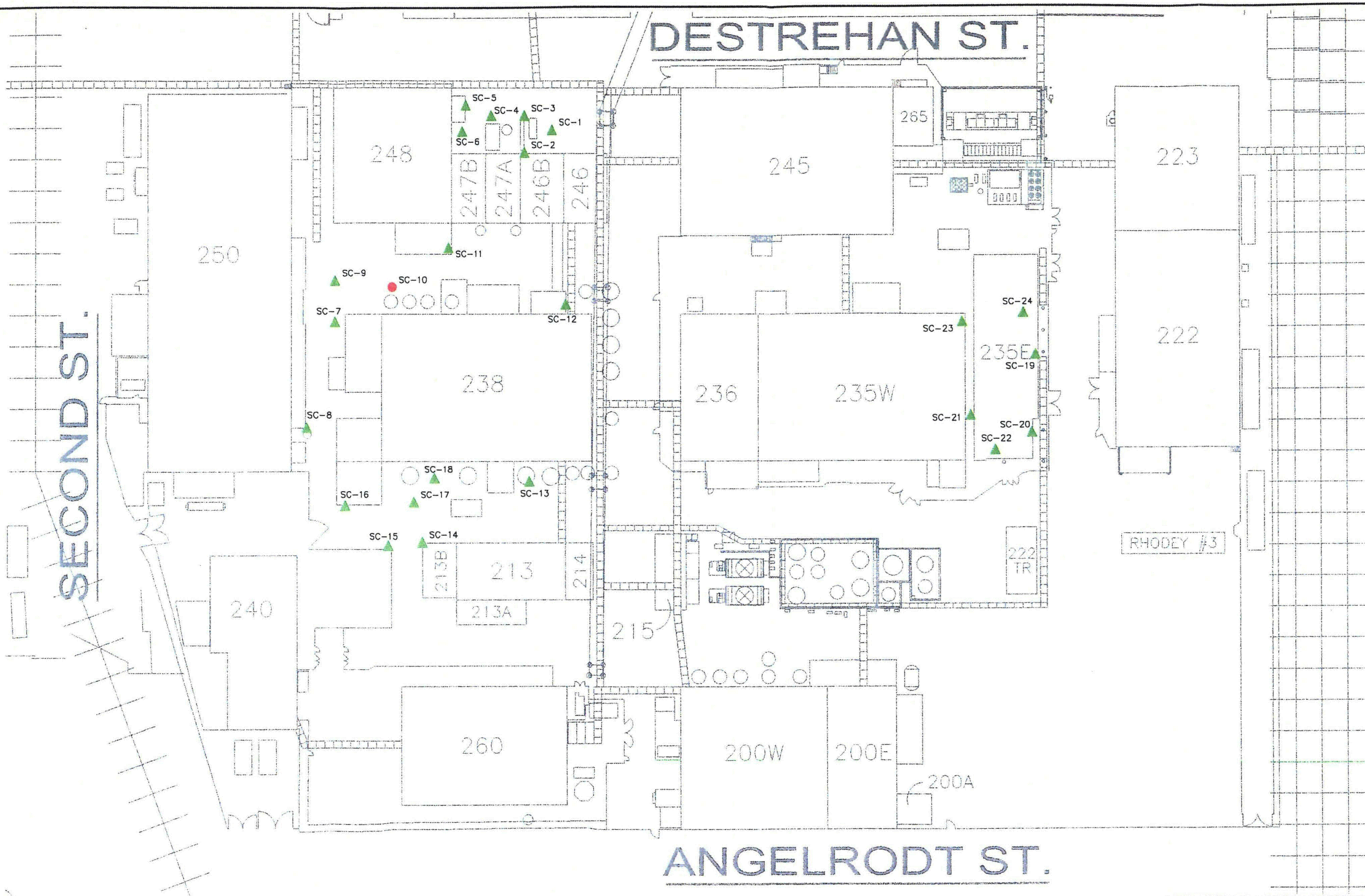
- -Manhole
- -Surface Drain
- -Downspout
- -Sewer Line

▲ - 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		

omega PROJECT SERVICES LLC



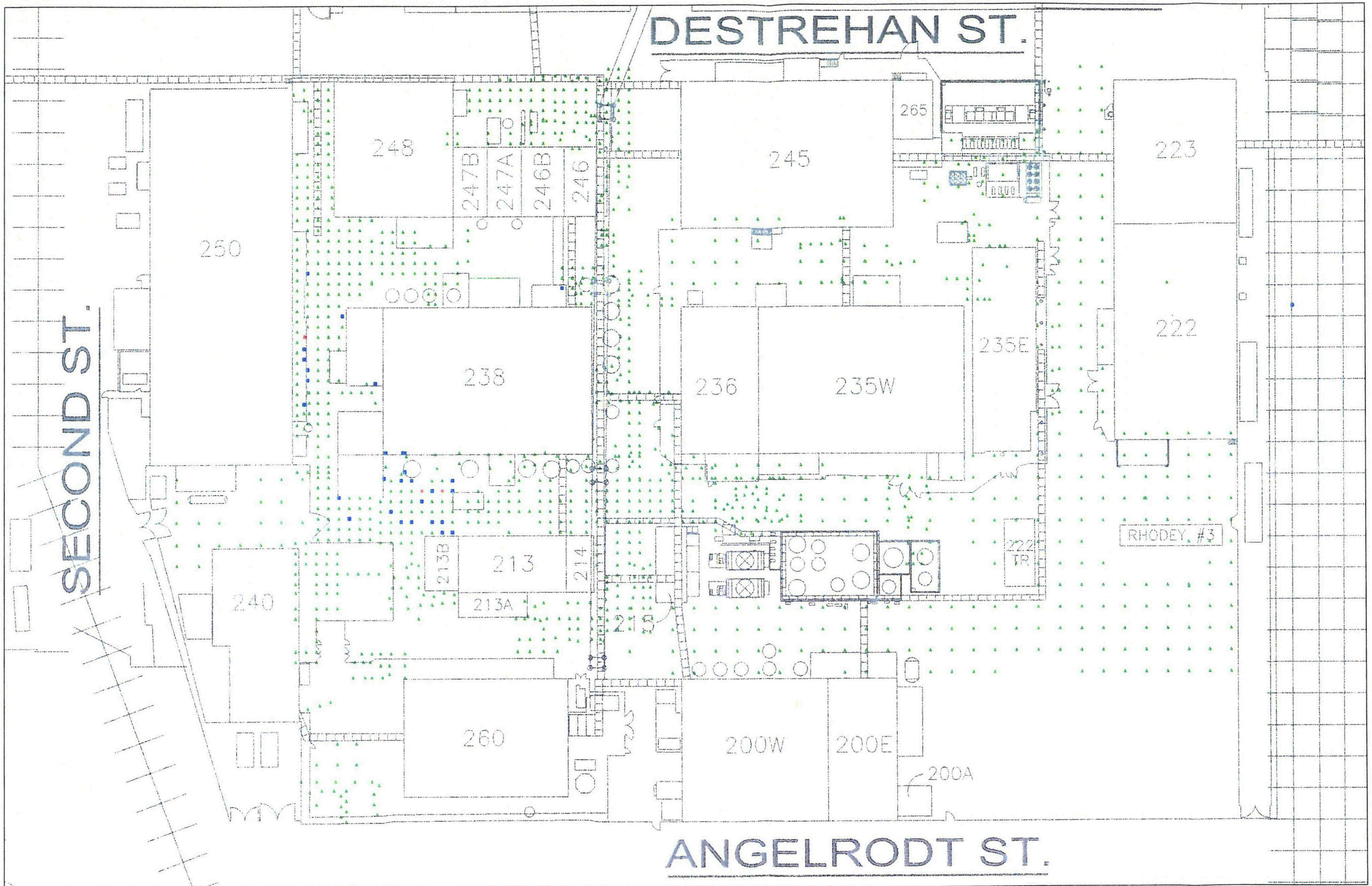
KEY

▲ - 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		

omega PROJECT SERVICES LLC



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

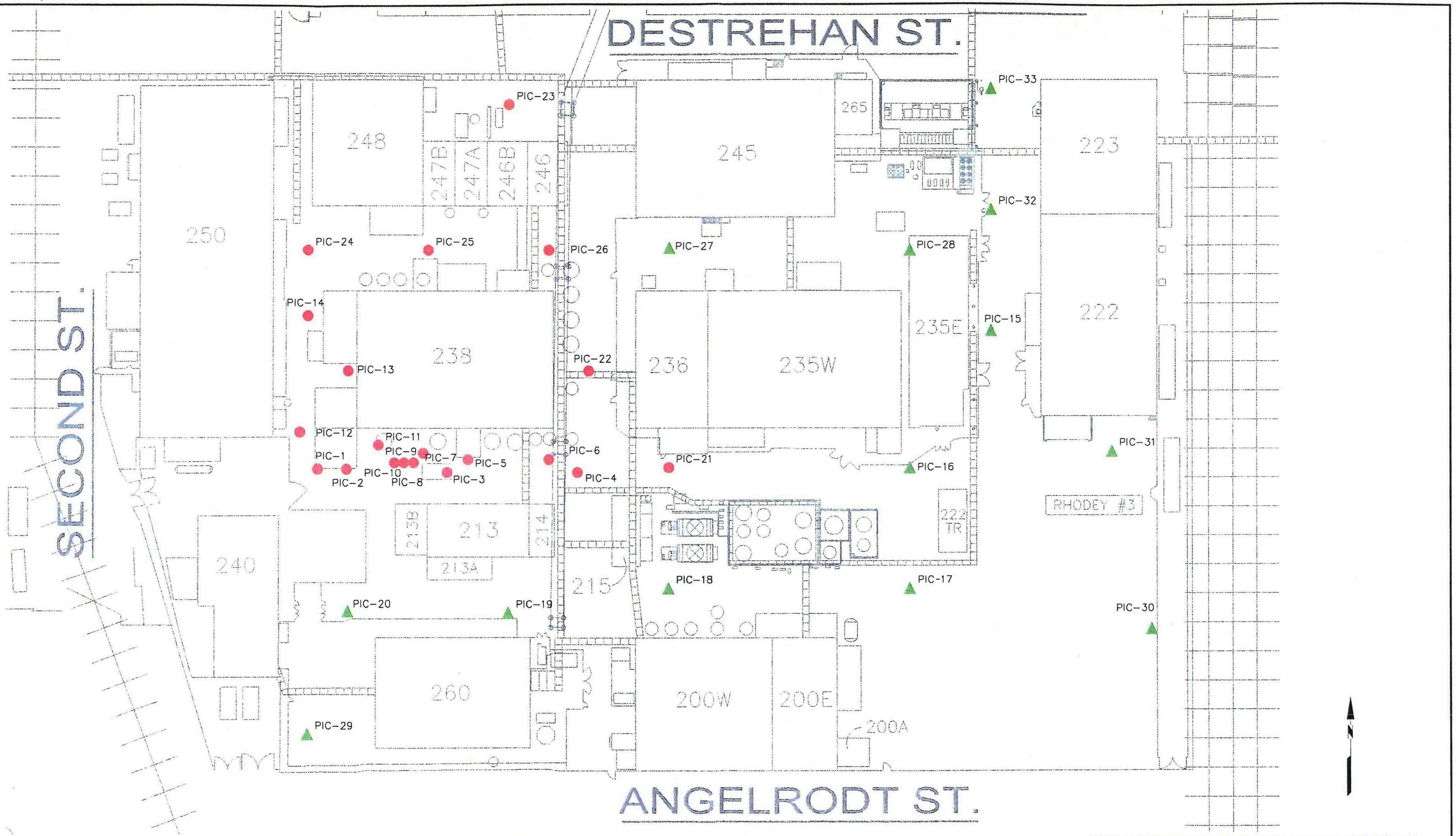
● - Location Identification: Measurement Greater than 24000 tpm /100cm²

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		

omega PROJECT SERVICES LLC



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

omega PROJECT SERVICES LLC

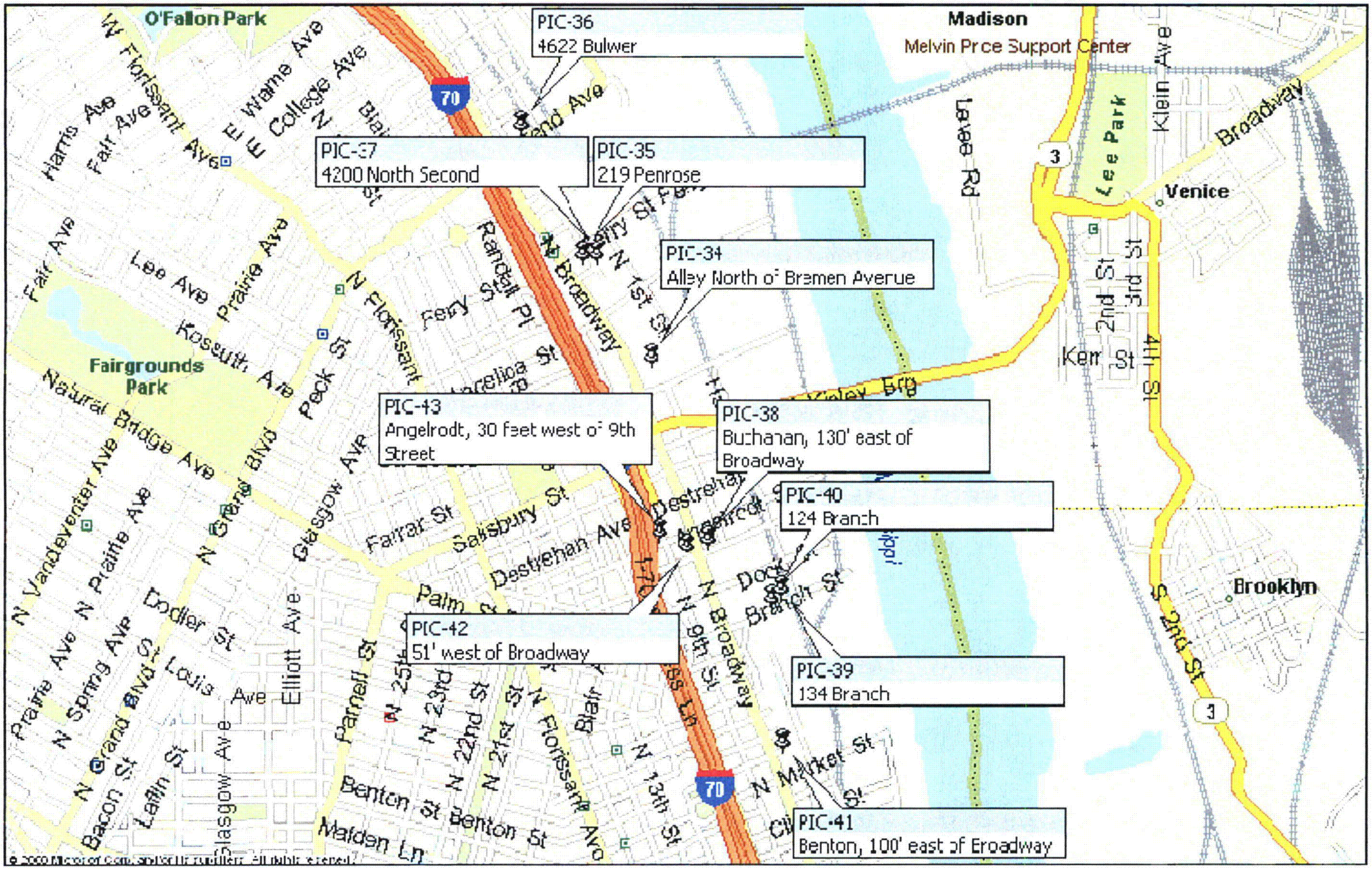


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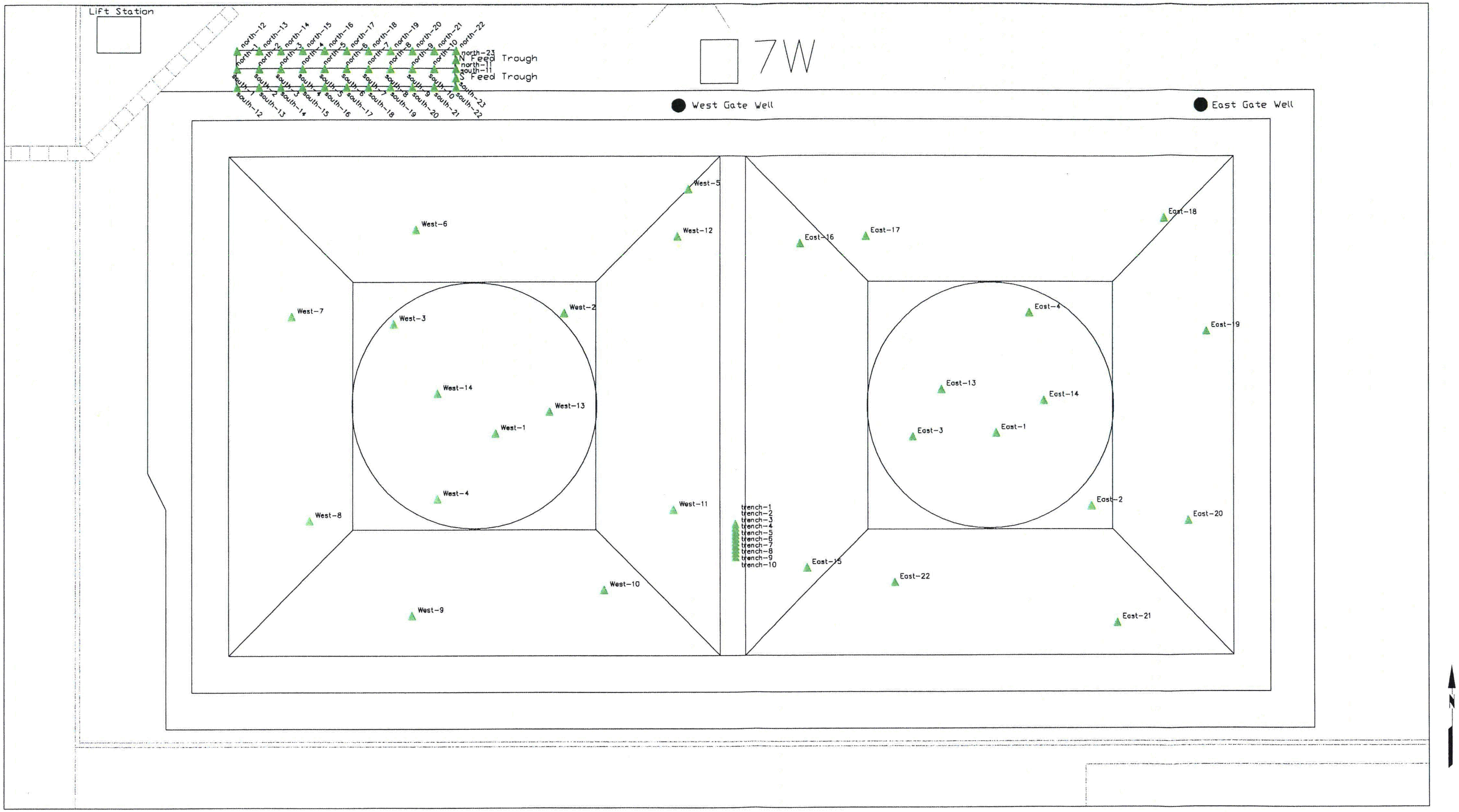
Figure 4-4B
Offsite PIC Measurement Locations

Date: December 2002
Project: Phase 2 DP
File: offsite locations.ppt

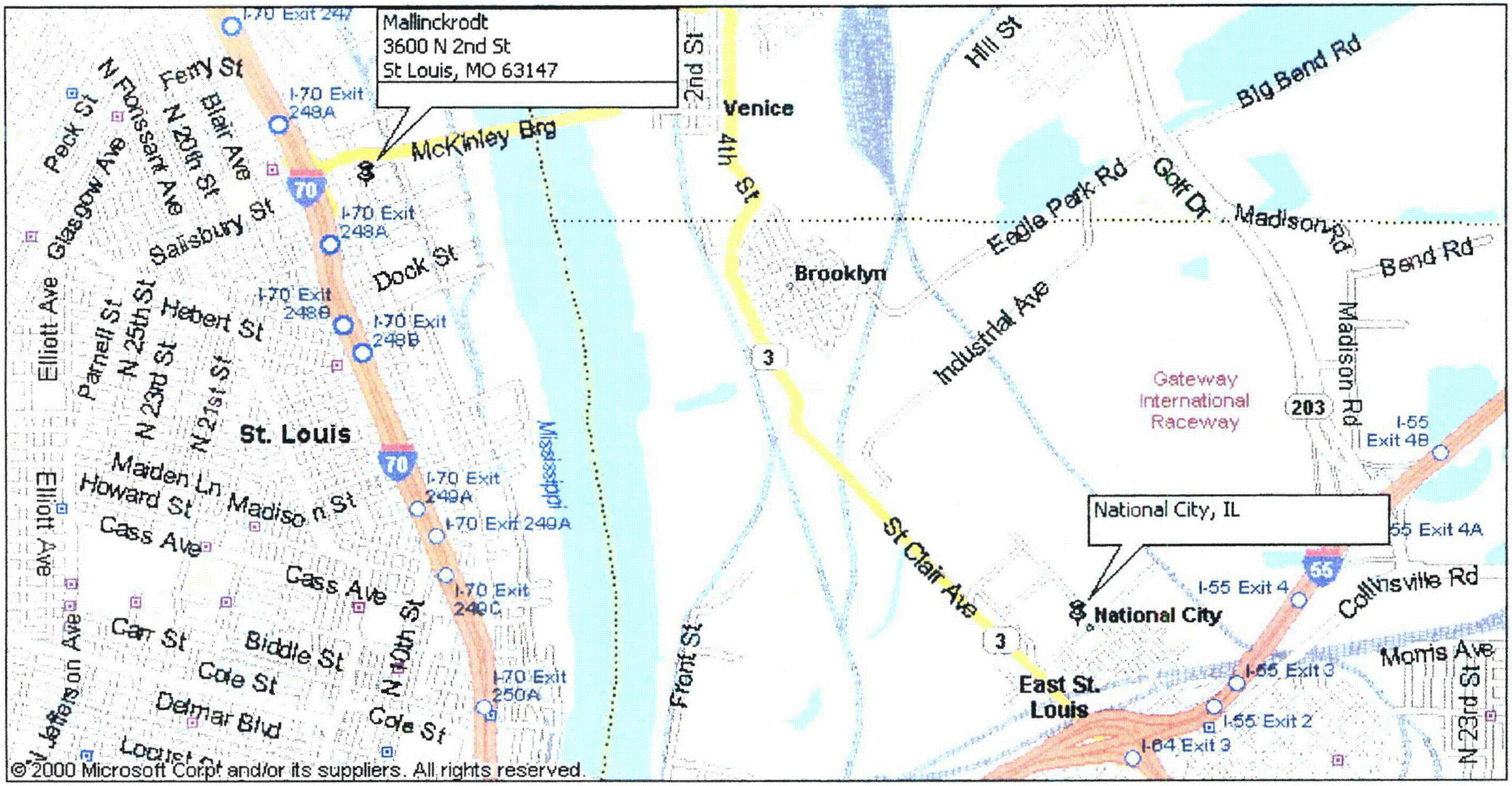


KEY

▲ - 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		

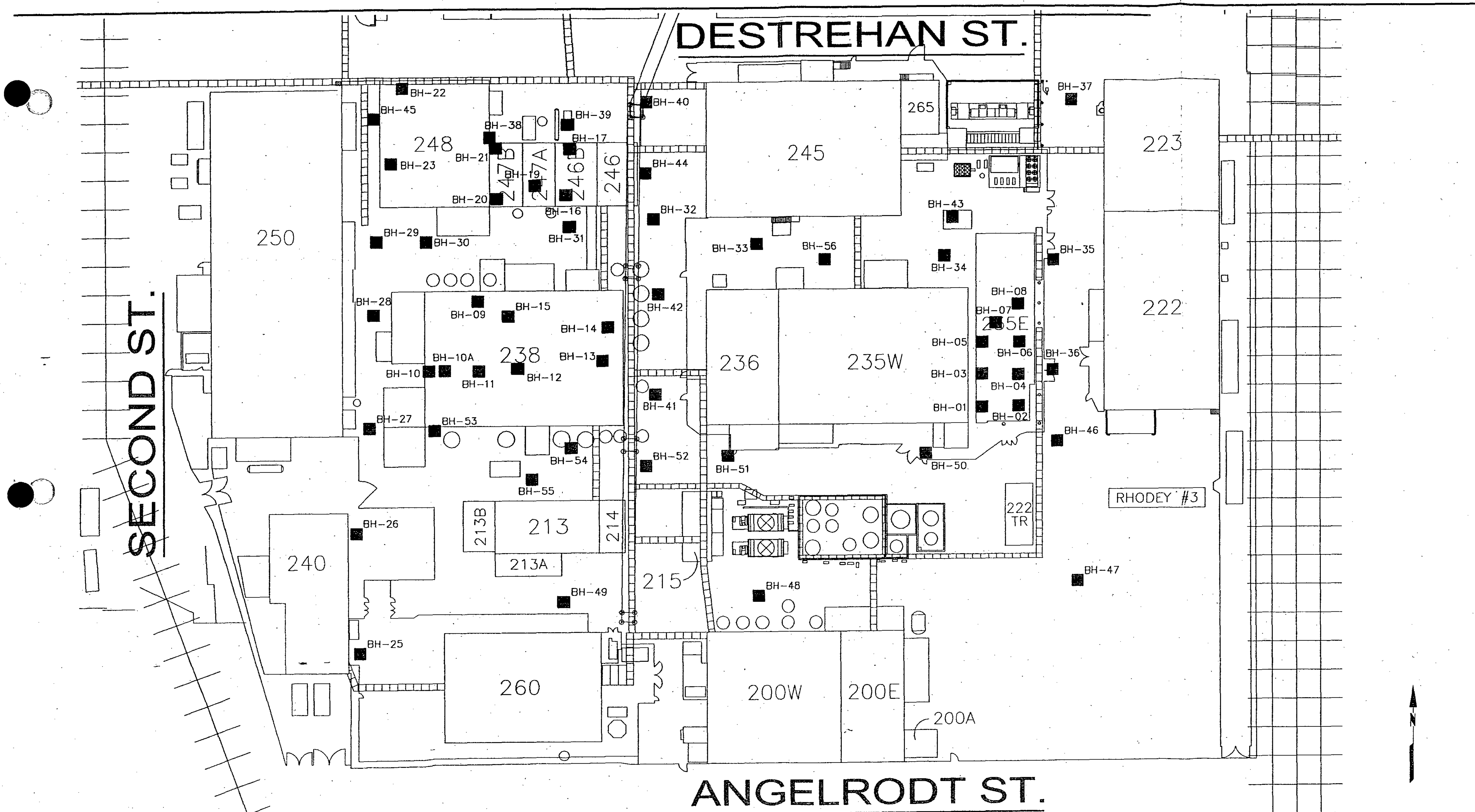
omega PROJECT SERVICES LLC



omega PROJECT SERVICES LLC

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

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



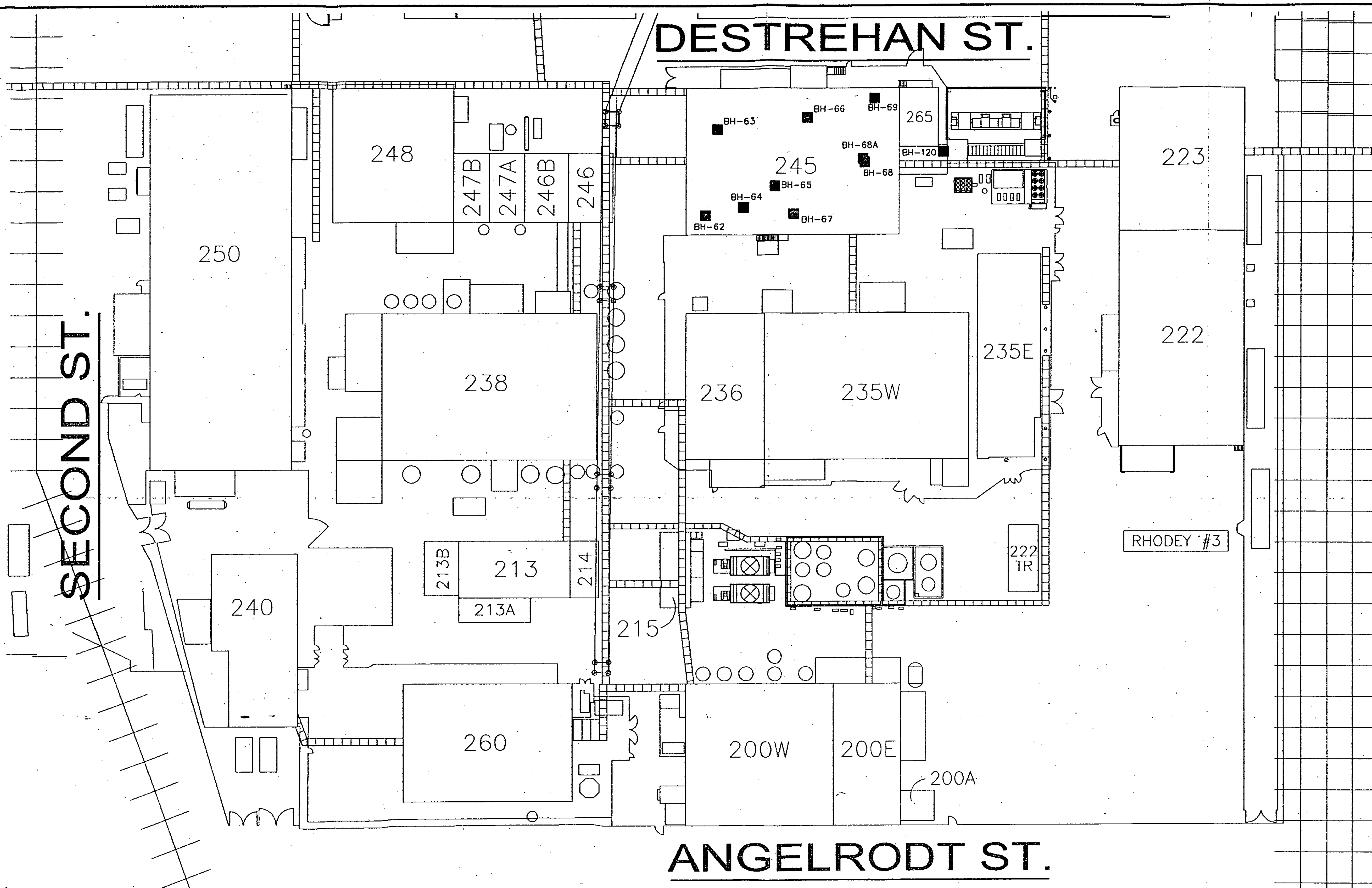
KEY

■ -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		

omega PROJECT SERVICES LLC



KEY

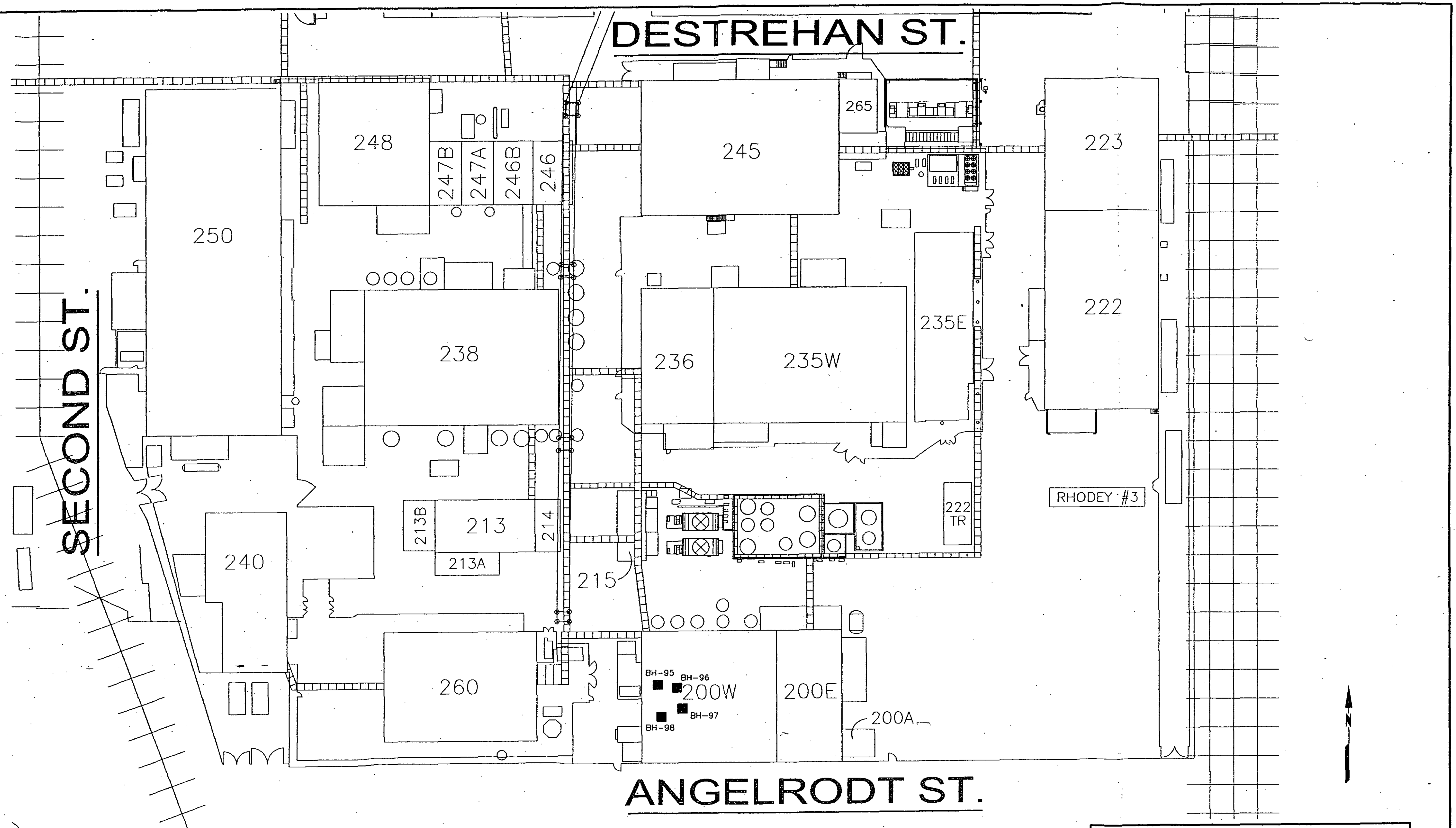
-Location Identification

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		

omega PROJECT SERVICES LLC



KEY

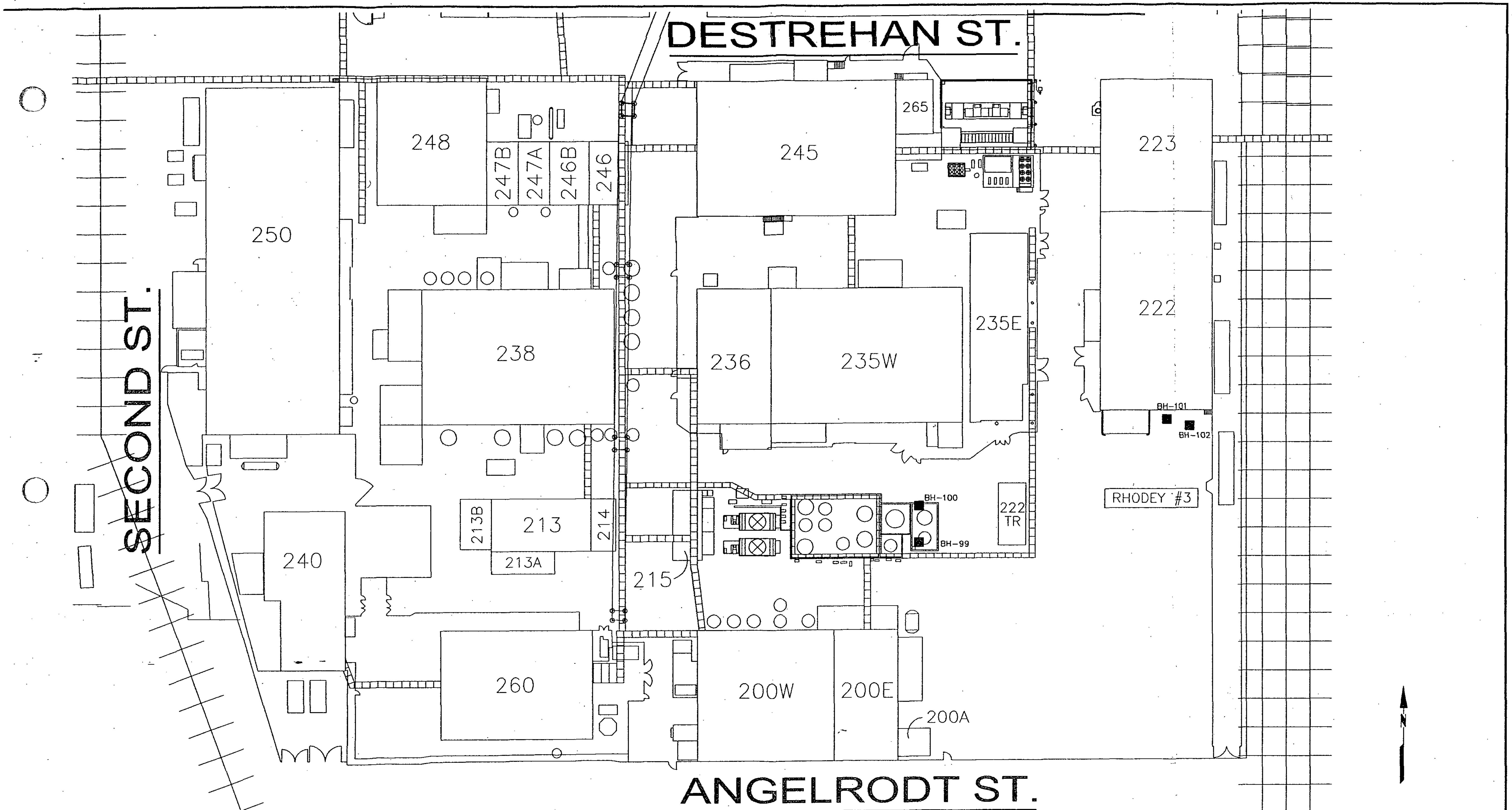
■ -Location Identification

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		

omega PROJECT SERVICES LLC



KEY

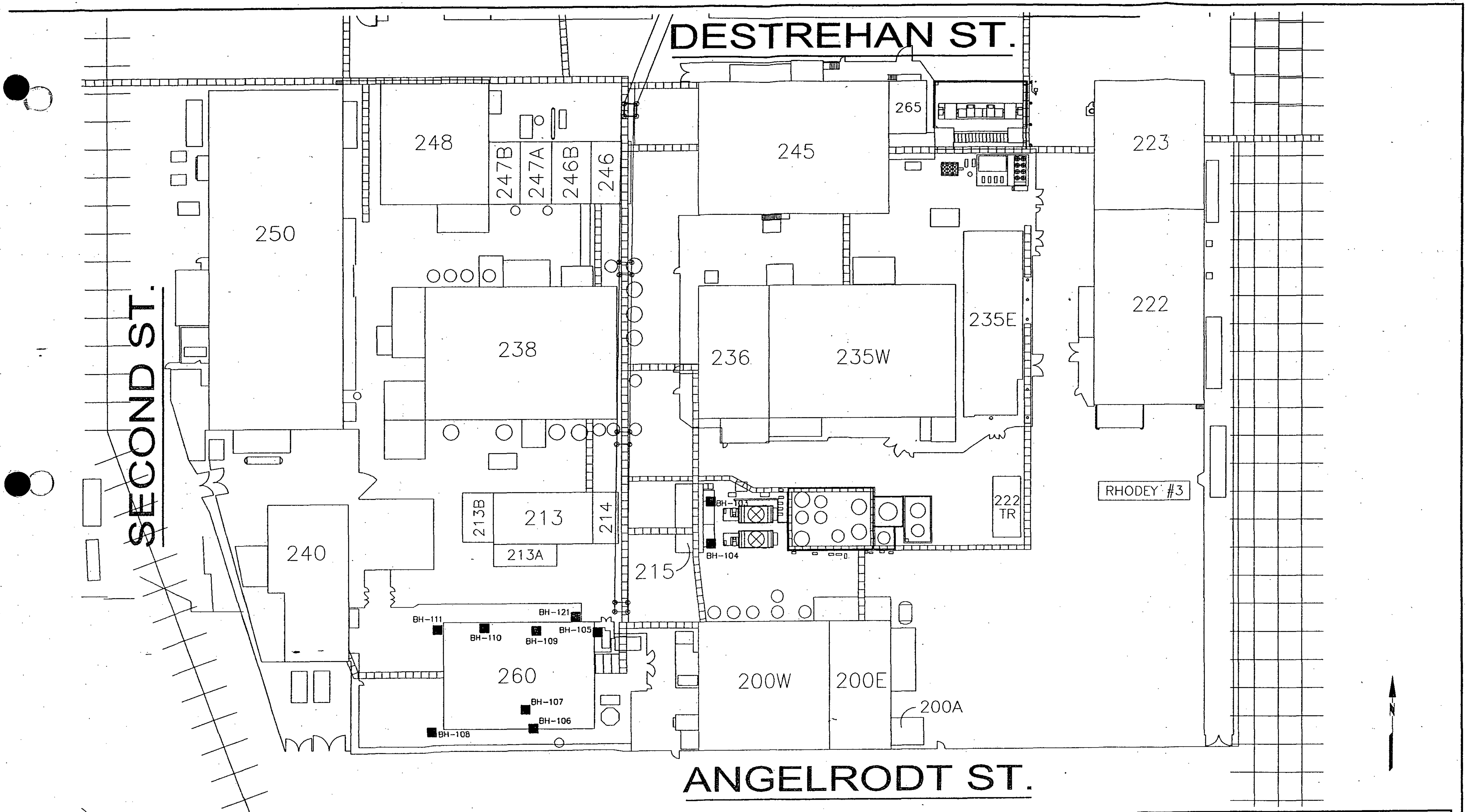
■ -Location Identification

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		△

omega PROJECT SERVICES LLC



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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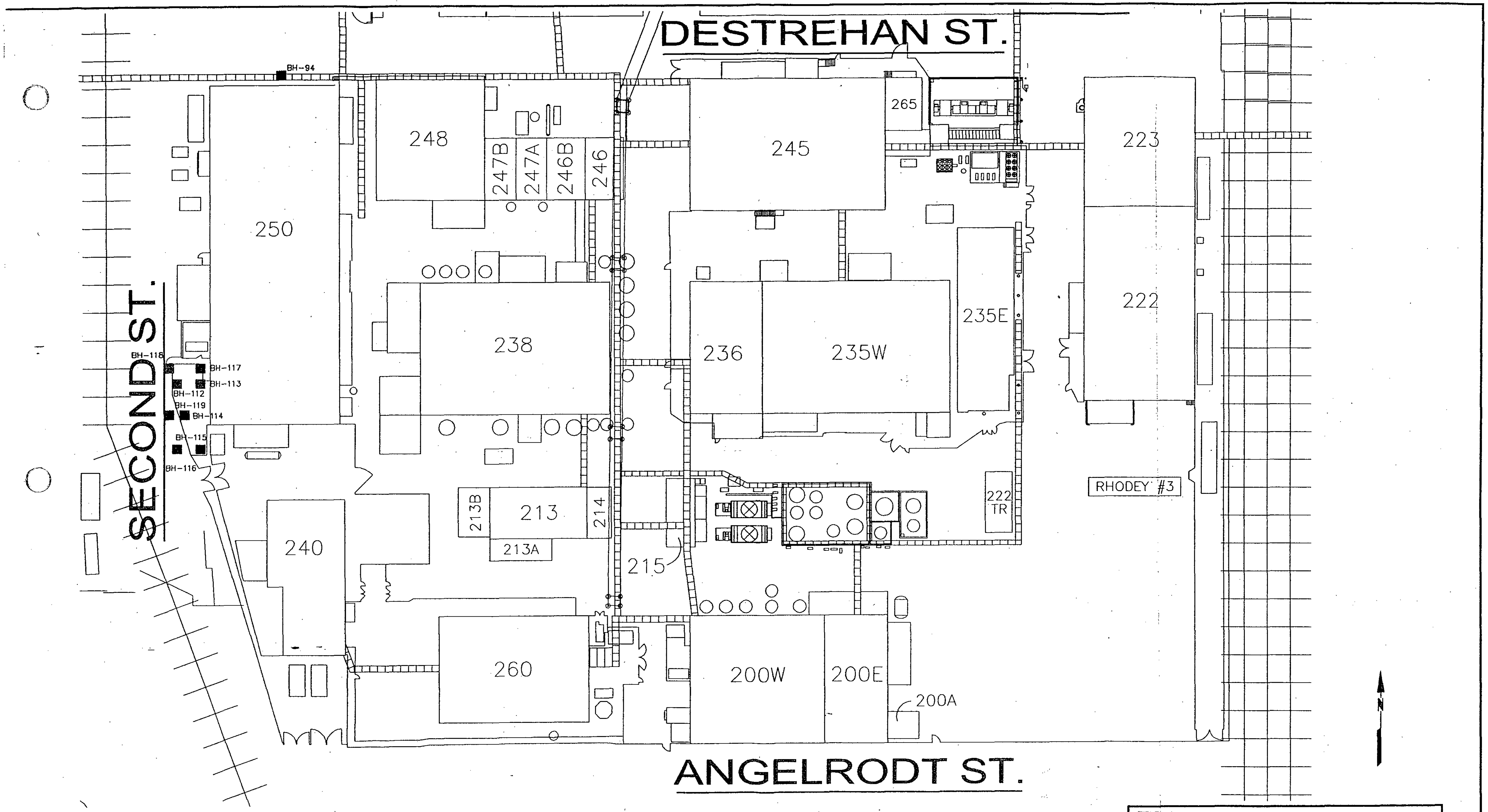


KEY

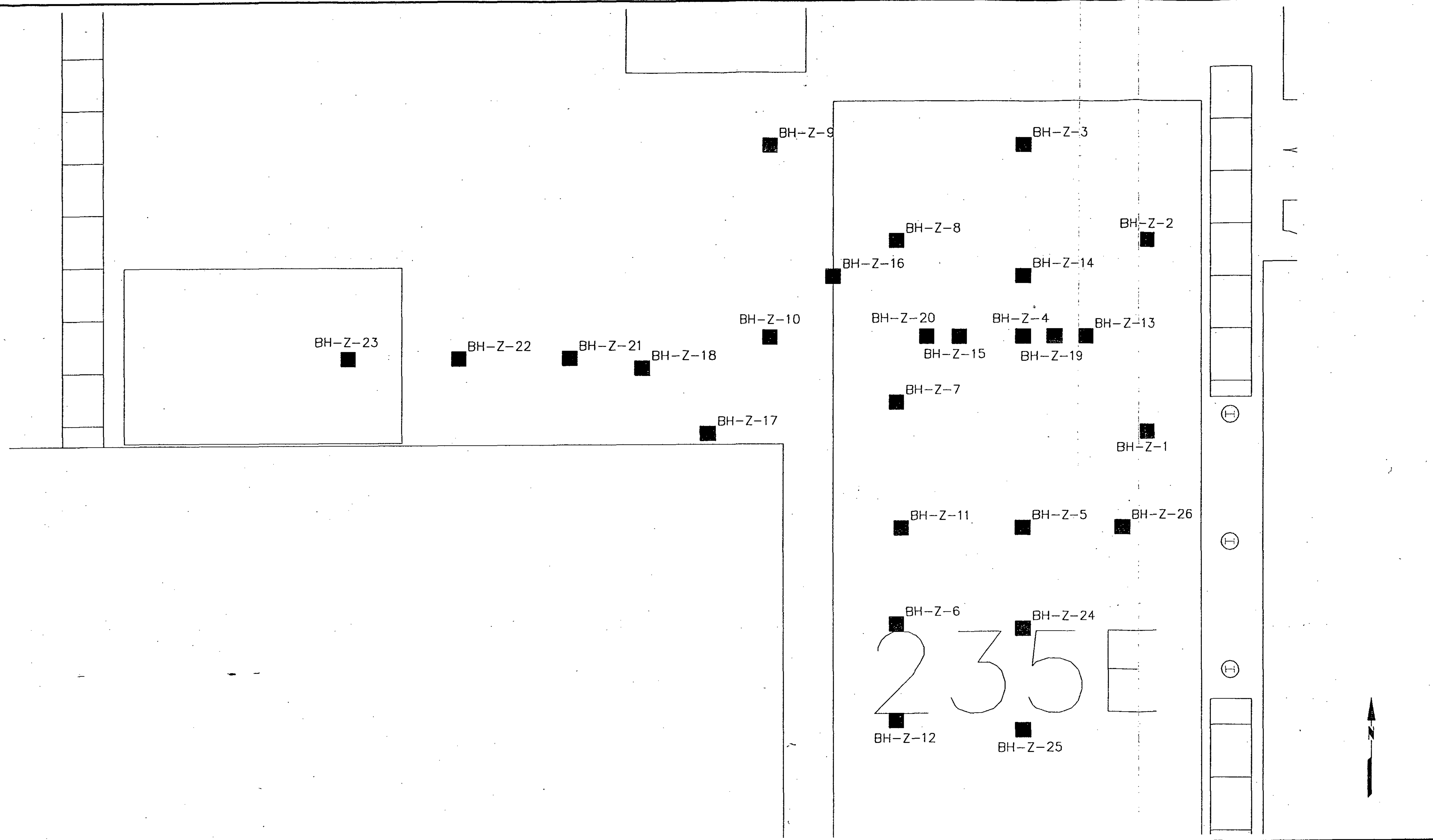
■ -Location Identification

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				

omega



KEY

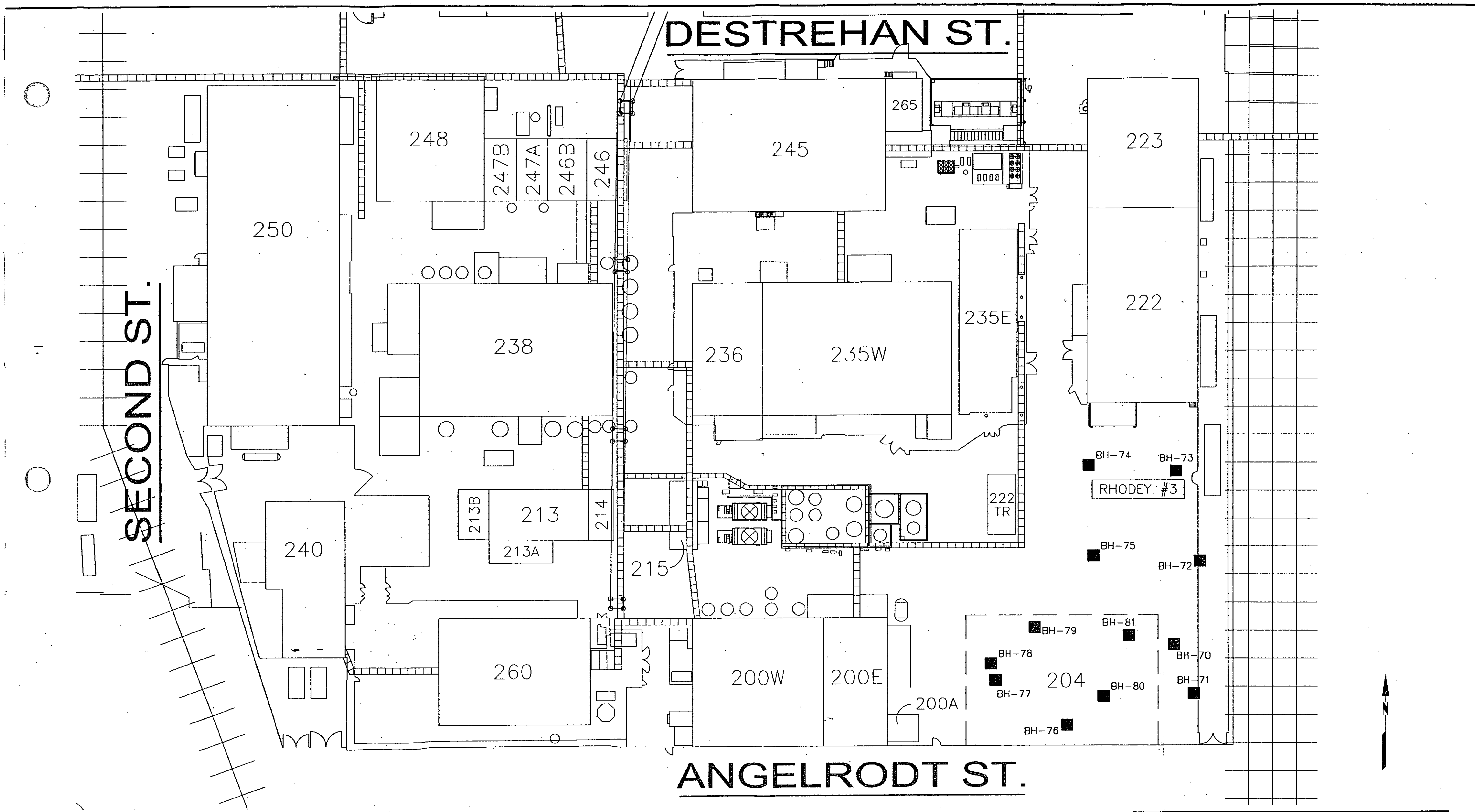
■ -Location Identification

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		

omega PROJECT SERVICES LLC



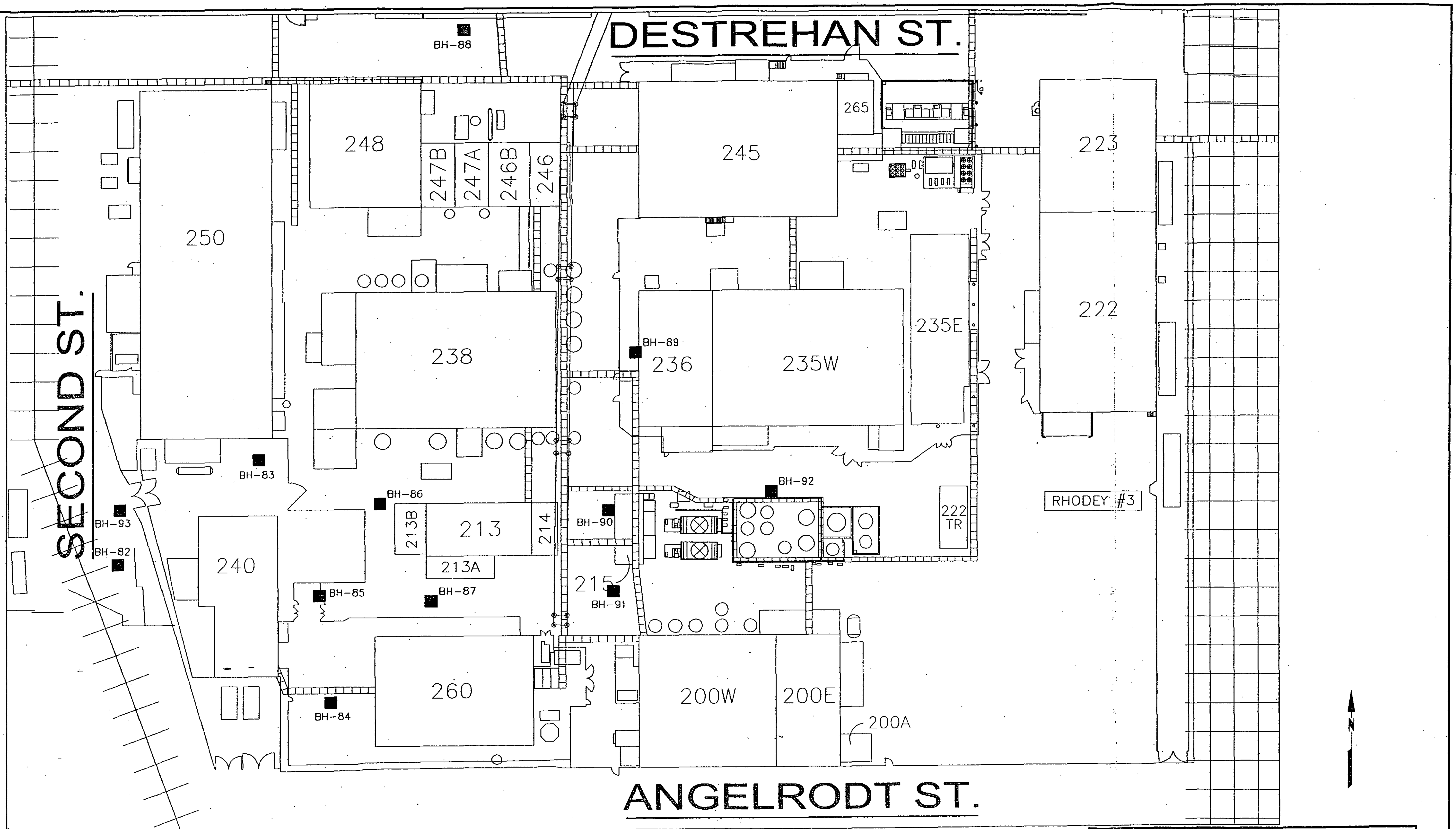
KEY

■ -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	

omega PROJECT SERVICES LLC



KEY

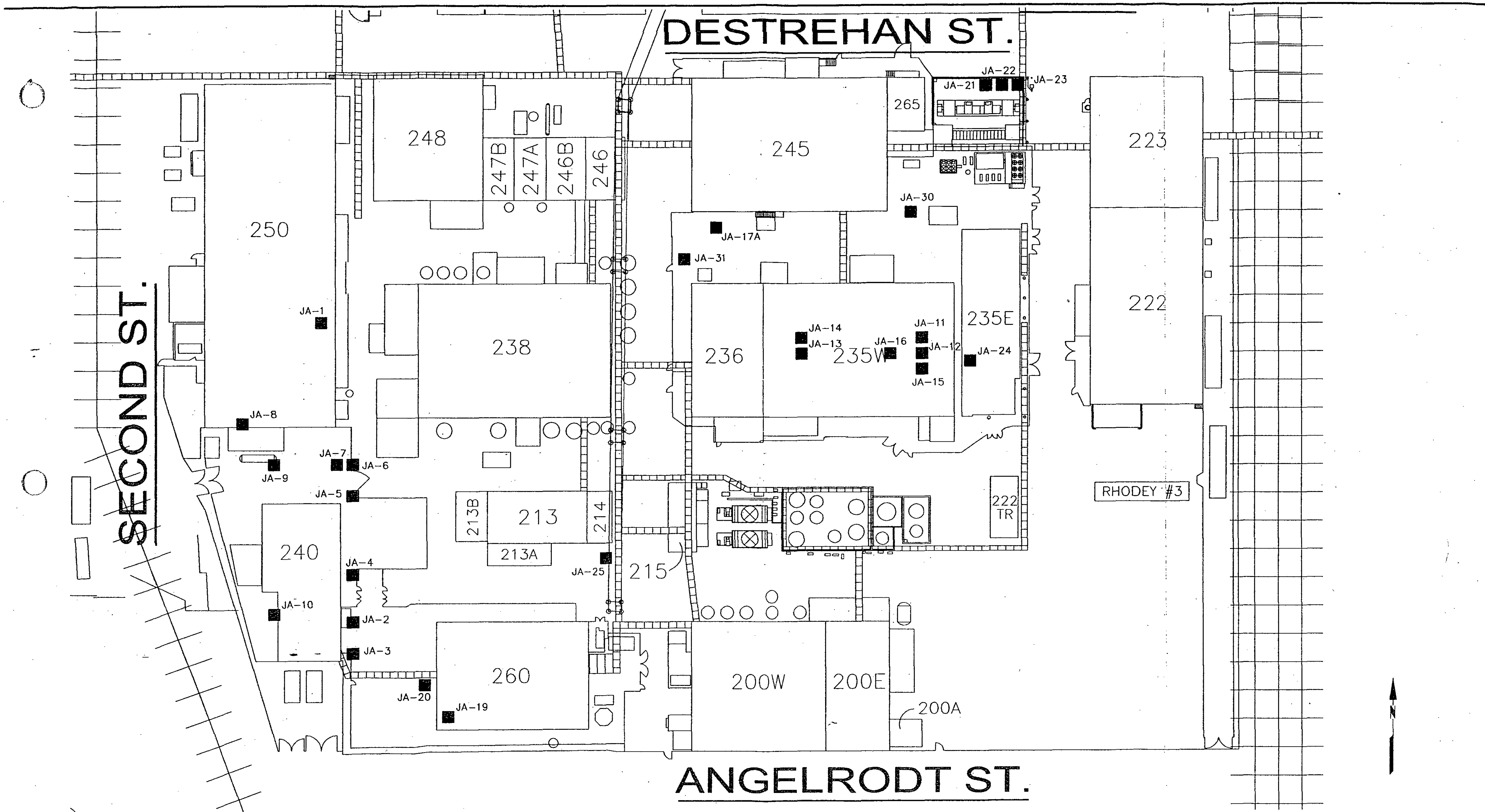
■ -Location Identification

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		

omega PROJECT SERVICES LLC



KEY

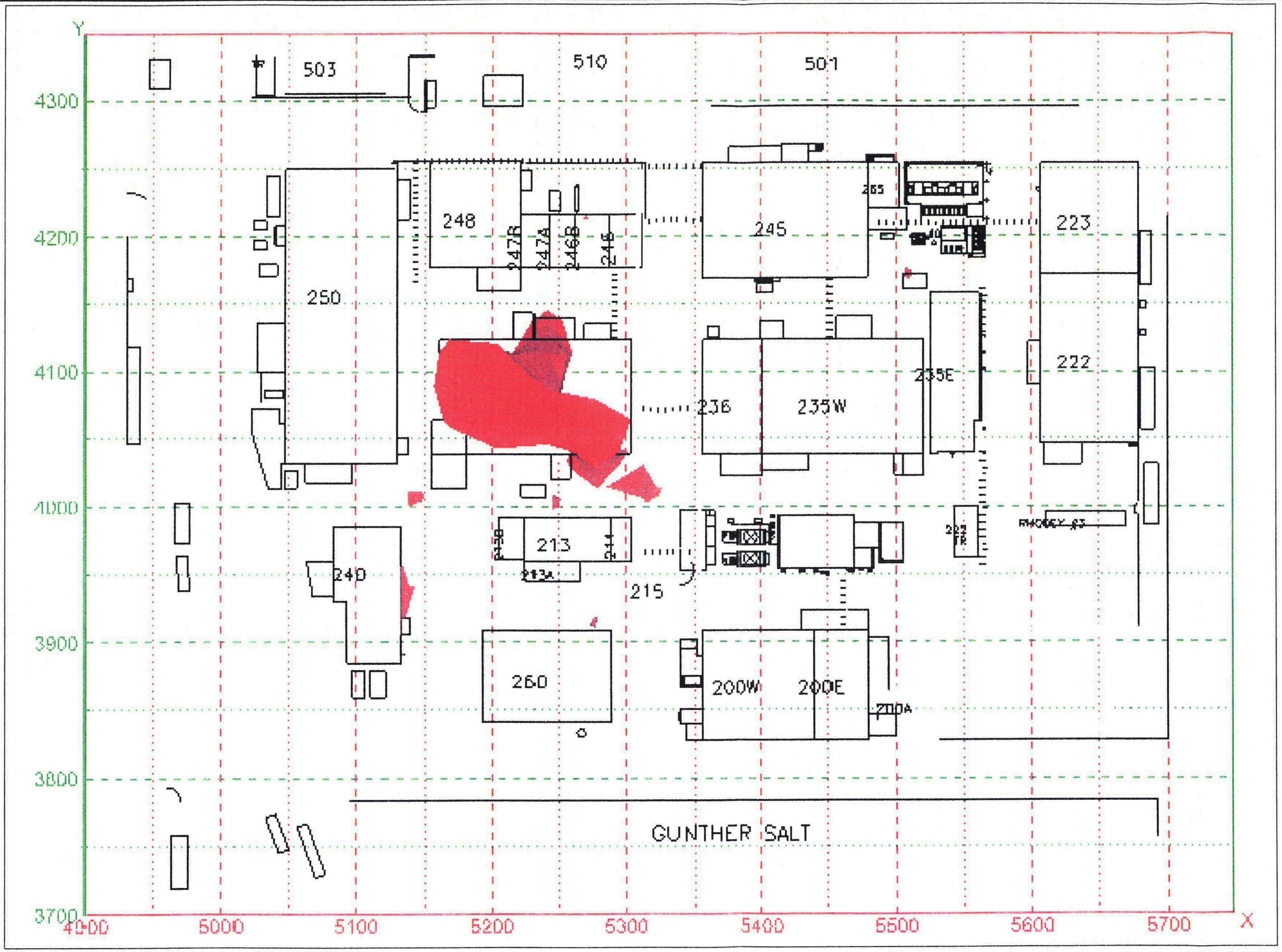
■ -Location Identification

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		

omega PROJECT SERVICES LLC

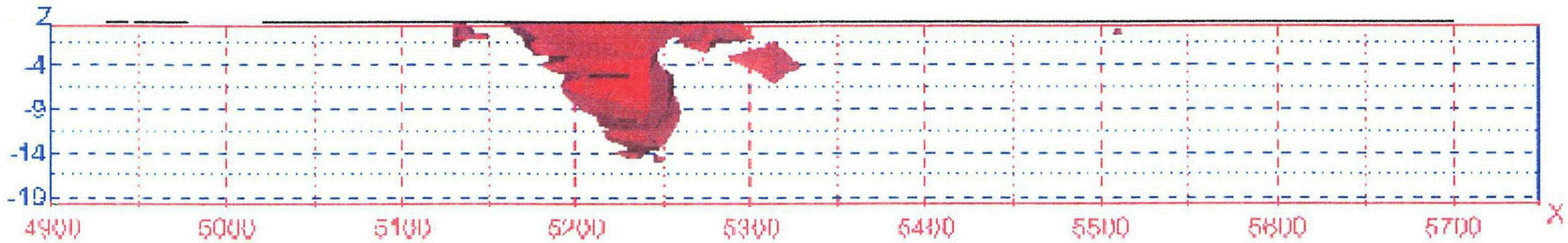


TITLE:

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		

omega PROJECT SERVICES LLC

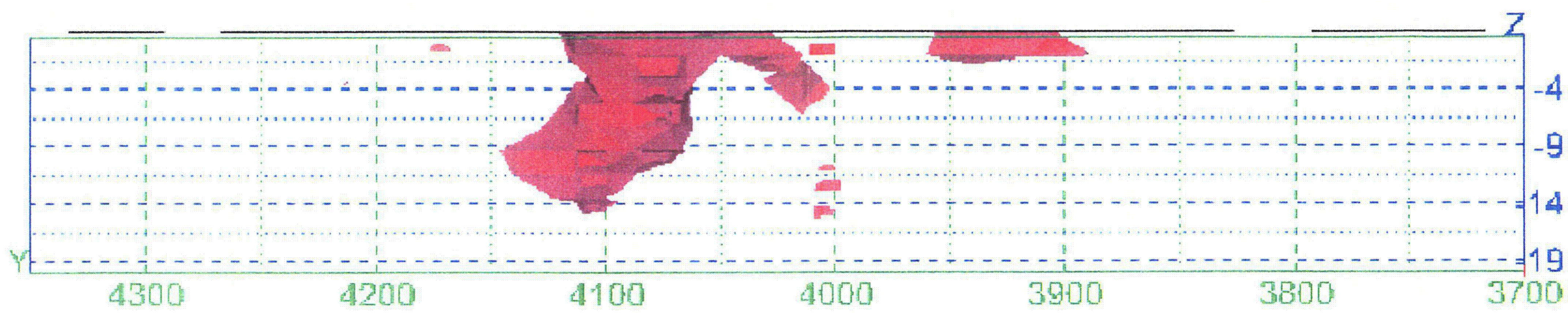


TITLE:

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		

omega PROJECT SERVICES LLC



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:
SCALE:		ACAD FILE:	Plant5Side.dwg		

omega PROJECT SERVICES LLC

SECTION 5

DOSE MODELING

Mallinckrodt, Inc.

C-T Phase II Decommissioning Plan

June 6, 2006

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.

---

[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 above background 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

[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 to a typical industrial worker who spends most of their time in a building and some time out-of-doors.

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.

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.

5.5.1 Pathways to Industrial Worker

A typical industrial 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.

---

[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.

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.

5.5.2 Pathways Not Present

5.5.2.1 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.) 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.

5.5.2.2 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]

---

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

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.

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 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]

---

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

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 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.

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

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 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.

Probabilistic. An analysis of the effect of contaminated zone thickness on radiological dose during industrial land use was done to interpret the depth beyond which additional contribution from a representative source in soil to irradiation dose to a person would become negligible. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together.
- bare land in which residual source contamination extends from land surface downward into the soil;
- indoor time fraction = 0.0 in order to simulate effect of irradiation on bare land;
- the same industrial land use scenario modeled to derive $DCGL_W$ originally, except absent ingestion of soil and inhalation of dust; (for the origin of inadvertently ingested dust and of dust suspended into air is surficial topsoil); and
- deterministic simulation using RESRAD to derive the effect of increasing contamination depth in soil on exposure to direct irradiation.

The result of this analysis is summarized graphically in Figure 5-1. It determined that, in representative simulation, maximum dose rate by direct irradiation is reached asymptotically when the depth of the contaminated zone in topsoil reaches about 30 cm. Additional source thickness would not produce significantly greater dose rate.

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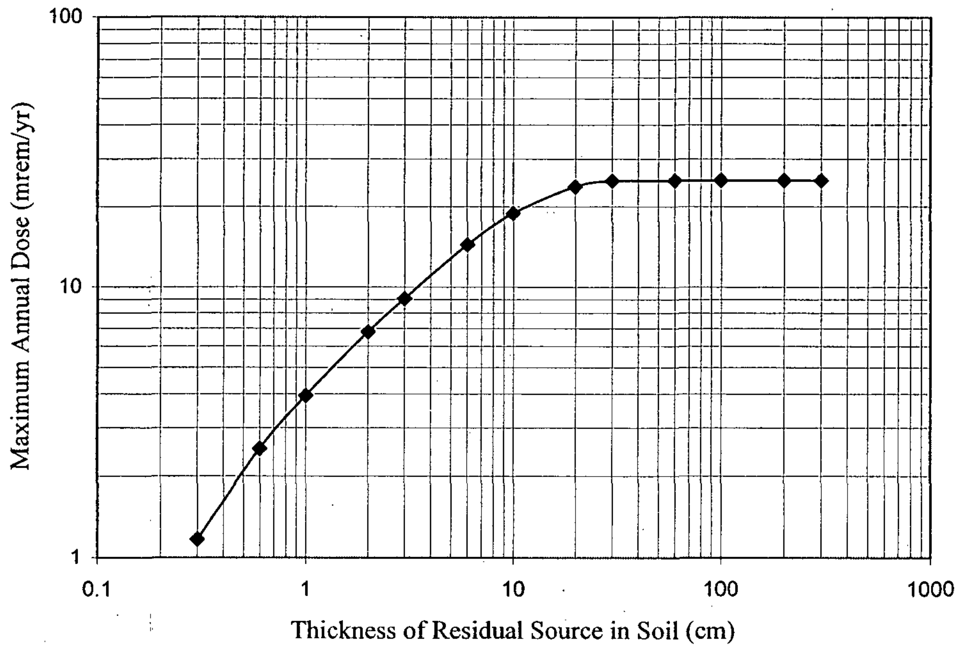
[12] Biwer, B.M., *et. al.*, "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch. C in *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*. NUREG/CR-6697. Dec. 2000.

Figure 5-1. Maximum Annual Radiological Dose Versus Source Depth in Soil (infinitely-thick source ratio 3 U series + 1 Th series produces 25 mrem/yr)



As a result of this analysis, the thickness of contaminated zone parameter will be represented as a variable in probabilistic dose modeling. It is being represented as a uniform distribution ranging from 0 to 1 meter thick since characterization survey soil sampling intervals are insufficient to resolve a well-defined gradient within this range. A maximum depth of 1 meter is more than sufficient to be a conservative representation insofar as direct irradiation is concerned.

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

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

of an 8766 hour year spent in an industrial scenario within an affected area of 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. These fractions, 0.1825 of time indoors and 0.04566 of time out-of-doors, are based on an estimated 2000 working hours per year and are entered into RESRAD as deterministic estimates of indoor and outdoor time fractions of 8766 hr/yr.

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]

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.

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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.

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

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

Deterministic. 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.)

Probabilistic. The model of radionuclides in outdoor air subject to inhalation is the product of the radionuclide concentration in surface soil and the airborne density of particulates of respirable size in ambient air. Biwer, *et.al.*,[33] summarized the distribution of respirable particulate in ambient air reported by the EPA[34] for about 1790 air monitoring stations in a range

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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.

[33] Biwer, *et.al.* "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch C, pp. C4-15 & C4-16 in NUREG/CR-6697. Dec. 2000.

[34] USEPA. Aerometric Information Retrieval System. internet site http://www.epa.gov/airs/airs.html. 1999.

of environments. At cumulative probability = 0.50, the most frequent respirable particulate density in the EPA distribution occurs at about 23 μg/m^3 air.[35]

Three other sources of data were examined to get more comprehensive information about airborne particulate density in urban air. 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[36] and 33 to 254 by Gilbert, *et.al.*[37] Their respective geometric means are approximately 115 and 92 μg/m^3. Airborne particulates measured in 14494 urban and 3114 non-urban air samples in the National Air Sampling Network exhibited a geometric mean of 98 μg/m^3.[38] A best geometric estimate of those is about 102 μg/m^3.

Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil, that is respirable. About 0.28 to 0.33 of airborne particles have been found to be respirable, *i.e.,* less than 10 μm in diameter.[39, 40, 41, 42] 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. Thus, a reasonable estimate of the geometric mean of respirable mass loading for inhalation in an urban, industrial area is about 0.3 x 102 μg/m^3 = 31 μg/m^3.

A distribution representing airborne particulate loading in urban air may be estimated by the shape of the distribution in NUREG/CR-6697, Table 4.6-1 and shifted upward by an increment representing the increase in dust in urban air relative to all ambient air. The result, in Figure 5-2, becomes the probabilistic distribution to replace the default distribution in RESRAD v. 6.3. This distribution represents careful, reasonable appraisal of values of airborne mass loading in an urban environment.

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35 Biwer, *et.al.*, Table 4.6-1 and Fig. 4.6-1 in NUREG/CR-6697.

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

37 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.

38 Stern, A.C., ed. *Air Pollution.* 2nd ed. Academic Press. NY. 1968.

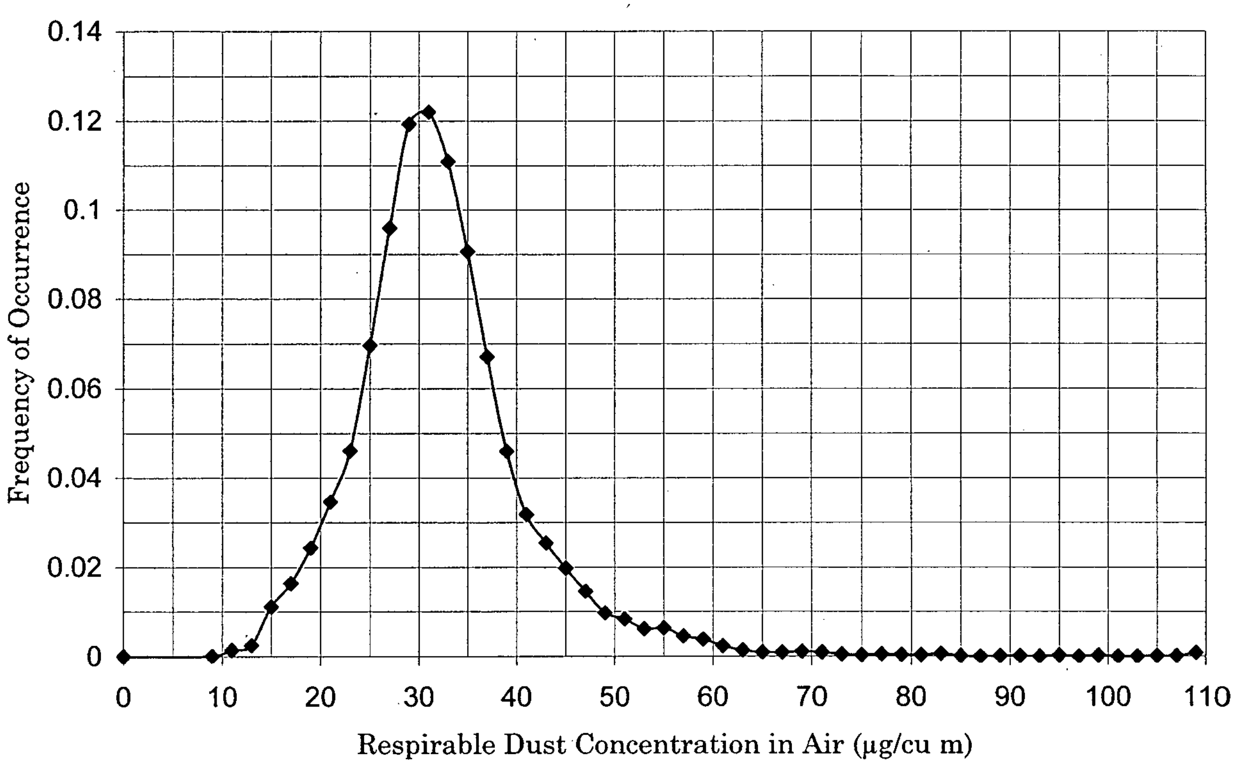
39 USEPA. *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment.* EPA 520/4-77-016. pp. 31-32. Sept. 1977.

40 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

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

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

Figure 5-2. Frequency Distribution of Respirable Dust in Urban Air
(EPA AIRS PM-10 data normalized to urban environment)



It is represented in RESRAD as a continuous linear distribution with entries in Table 5-1.

Table 5-1. Respirable Particulate in Urban Air

Respirable Particulate Concentration (µg/m^3)	Frequency
0.	0.0
15.	0.0151
23.	0.1365
37.	0.8119
47.	0.9495
67.	0.9937
83.	0.9983
107.	0.9992

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.[43] The most likely amount is estimated to be 18.3 g/yr.[44] The recommended default value[45], 36.5 g/yr, is entered into RESRAD to represent an industrial worker.

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.

Probabilistic. An analysis of the effect of radiation attenuation by a building, especially floor thickness, on radiological dose for the portion of time a worker spends indoors during industrial occupation has been performed. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together;
- residual source contamination extends from land surface downward one meter into the soil;
- outdoor time fraction = 0.0 in order to simulate effect of irradiation indoors;
- the same industrial land use scenario modeled to derive $DCGL_W$ originally, except absent ingestion of soil and inhalation of dust;
- deterministic simulation using RESRAD to derive the fraction of gamma dose rate as a function of concrete floor thickness; and
- combination of probable distribution of floor thickness and indoor gamma shielding factor to derive a probability distribution of indoor gamma shielding factor.
- The result of this analysis is summarized in Table 5-2 where indoor gamma shielding factor probability distribution is tabulated.

On the premise that a floor construction is likely to be specified in an integer thickness in units of inches, a *discrete cumulative* probability distribution of these data has been specified in RESRAD. Table 5-2 depicts the cumulative probability and indoor gamma shielding factor data entered into RESRAD for probabilistic evaluation of the effect of this parameter on radiological dose rate.

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

44 *ibid.*

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

Table 5-2. Indoor Gamma Shielding Factor Distribution

Shielding Thickness (cm)	(in)	Shielding Factor ("value")	Fractional Occurrence	Cumulative Distribution Indoor Only (cdf)
25.4	10	0.0084	0.01	0.01
20.3	8	0.022	0.08	0.09
17.8	7	0.035	0.12	0.21
15.2	6	0.055	0.18	0.39
12.7	5	0.088	0.24	0.63
10.2	4	0.14	0.25	0.88
7.6	3	0.23	0.07	0.95
0	0	1.0	0.05	1.0

5.7.1.10. Indoor Airborne Dust Filtration

The fraction of airborne dust out-of-doors that is available indoors has been reviewed.[47] When considering outdoor sources of respirable particulate indoors, Wallace[48] 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.*,[49] 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);[50] 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.

5.7.2 <u>Industrial Work on Pavement</u>

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 mentioned below, 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

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

48 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.

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

50 C-T Phase II Decommissioning Plan, §3.4, Table 3-2.

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, an areal density of soil equivalent to 0.3 cm thickness of soil would adequately represent areal contamination on pavement for the purpose of estimating potential exposure of an industrial worker. Areal contamination on pavement is thus represented by 0.3 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);[51] 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 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 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.

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 that is a probabilistic fraction 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.

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

5.8. DCGL FOR INDUSTRIAL WORK ON SOIL

5.8.1 Radiological Dose Modeling

Models simulating environmental exposure pathways to estimate potential radiological dose to people are coded in the RESRAD computer program. With the aid of RESRAD, probabilistic modeling has been done to derive dose factors and DCGL at the *peak of the mean* dose as NRC guidance suggests.[52]

RESRAD is able to compute and tabulate the time of peak mean dose rate and the peak mean dose rate (mrem/yr). One may derive a composite dose factor for a related series of radionuclides by summing the average dose of each source radionuclide in the series at the time of the peak of the mean dose. Then one may derive the dose factor as the quotient of that sum and the concentration of the radionuclides to which it is referenced. For example, the composite dose factor of the thorium series would be the sum of doses of the principal radionuclides, including their short-lived progeny, at the time of the peak of the mean dose divided by the initial concentration of the reference, or parent Th^{232}.

In the probabilistic total dose summary, one can read the contribution by each long-lived radionuclide entered in the source term column corresponding to the time of peak mean dose. The *average (avg)* dose of each source radionuclide at the time of peak mean dose, summed over all of the source radionuclides, equals the peak of the mean dose. Having identified the contribution of each source radionuclide to the peak of the mean total dose, one may derive an appropriate probabilistic dose factor (mrem/yr per pCi/g) as the quotient of the average dose of each source radionuclide at the time of peak mean total dose and the concentration of that radionuclide entered into the source term in RESRAD.

5.8.2 Derivation of Thorium Series Dose Factor and $DCGL_W$

Thorium series nuclides associated with C-T processing have grown or decayed within about 0.20 of radioactive equilibrium. Considering that C-T feed was ore and that alpha spectrometry of separate radioelements poses some uncertainty at low concentration, the thorium series might rationally be assumed to be in radioactive equilibrium in Plant 5 soil samples. Especially for future estimation, the shorter radioactive half-lives of Ra^{228}, 6.7 yr, and of Th^{228}, 1.9 yr, imply that Th^{232} parent concentration is controlling. Characterization survey data also indicate the thorium series occurs at about a 1/3 of the uranium series concentration in soil.

Assuming the thorium series to be in radioactive equilibrium, a composite dose factor representing the series was derived probabilistically with RESRAD (ref. case 408guti in Appendix D). Equal concentrations of principal radionuclides, Th^{232}, Ra^{228}, and Th^{228}, entered into RESRAD, produce peak of the mean annual dose at year zero and corresponding peak of the mean composite dose factor, DF = 1.05 (mrem/yr)/(pCi Th^{232}/g soil). The corresponding $DCGL_W$ = 23.8 pCi Th^{232}/g soil for industrial land use.

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[52] NUREG-1757, 2, §5.

5.8.3 Derivation of Uranium Dose Factor and $DCGL_W$

Since C-T residue includes natural uranium, it would be logical to consider U^{238} through U^{234} and include the actinium, or U^{235}, series in its naturally-occurring proportion to the uranium series. When these radionuclides are the source in a RESRAD probabilistic simulation of an industrial land use scenario, the peak of the mean annual dose occurs in the first year of exposure (ref. case 407guti in Appendix D). The composite dose factor,[53] corresponding to the peak of the mean annual dose rate = 0.0347 mrem/yr per pCi U^{238}/g soil. The corresponding $DCGL_W$ = 721 pCi U^{238}/g soil for industrial land use.

5.8.4 Derivation of the Dose Factor and $DCGL_W$ of Th^{230} and Ra^{226}

Since Th^{230} transmutes into Ra^{226}, is observed together with Ra^{226} in soil samples, and since the dose factor of Ra^{226} and its progeny, including Pb^{210}, exceed other radionuclides in the uranium series, it is logical to associate Th^{230} and Ra^{226} in dose estimation. Measurement of Th^{230} requires analysis that is slow, expensive, and separate from other key radionuclides. To the extent its presence in excess of uranium or Ra^{226} does not increase potential annual dose substantially and specific measurement is unnecessary, remediation can be done without undue delay. It would be desirable to adopt a conventional association that does not underestimate potential radiological dose and that allows measured Ra^{226} to represent the subseries. For this reason, it would be logical and useful to link Th^{230} with Ra^{226} in lieu of further measurement of Th^{230} itself.

A subseries beginning with Th^{230} and including Ra^{226}, Pb^{210}, and their short-lived progeny is a logical grouping. In soil, it would be reasonable to assume Ra^{226}, Pb^{210}, and their short-lived progeny are in radioactive equilibrium; although exhalation of Rn^{222} could even leave progeny below equilibrium. The relatively short half-life of Pb^{210}, 21 years, and its lower dose factor than of Ra^{226} justifies compositing the contributions of Ra^{226}, Pb^{210}, and their short-lived progeny to radiological dose.

A series of probabilistic dose modeling was computed with RESRAD to determine conditions in which a composite dose factor including principal radionuclides, Th^{230}, Ra^{226}, and Pb^{210} as the source, would not significantly underestimate radiological dose when applied to the range of characterization survey data. Within a population of more than 500 soil characterization samples and among the 41 pairs in which Ra^{226} and Th^{230} are above background mean by more than 1 standard deviation, only 3 samples, or 0.6 %, exhibit Th^{230} -to- U^{238} > 6. Adopting the composite dose factor representing Th^{230}, Ra^{226}, Pb^{210}, and their progeny, with Th^{230}/Ra^{226} ratio = 6, would be expected to encompass more than 99% of soil samples. The peak of the mean dose as a function of increasing Th^{230} -to- the peak of the mean dose when Th^{230} concentration equals Ra^{226} concentration only exceeds 1.1, or increases by as much as 11 percent only when the Th^{230} -to- U^{238} ratio exceeds 6. Thus, radiological dose is not very sensitive to increasing Th^{230} -to- Ra^{226} ratio.

[53] including all the principal radionuclides and their short-lived progeny

Thus, it is reasonable to apply a composite dose factor = 0.852 (mrem/yr)/(pCi Ra^{226}/g soil) and a $DCGL_W$ = 29.4 pCi Ra^{226}/g soil to represent the subseries including Th^{230}, Ra^{226}, and Pb^{210} for industrial land use.

5.8.5 Composite Dose Factors and $DCGL_W$

From the separate cases and source terms, recorded in Appendix D, composite dose factors and $DCGL_W$ in Table 5-3 were derived.[54]

Table 5-3. Composite Dose Factor and DCGLw Derived Separately

Radionuclide Group	Composite Dose Factor (mrem/yr)/(pCi/g)	$DCGL_W$ (pCi/g)	RESRAD case
Th series	1.05	23.9	408guti
Natural Uranium	0.0347	721.	407guti
6 Th^{230} + Ra^{226} + Pb^{210}	0.852	29.4	399guti

Dose factor and $DCGL_W$ of the thorium series is referenced to Th^{232}.
Dose factor and $DCGL_W$ of natural uranium is referenced to U^{238}.
Dose factor and $DCGL_W$ of Th^{230}, Ra^{226}, and Pb^{210} is referenced to Ra^{226}.

5.8.6 Compliance Model for Soil

In the uranium series, U^{238} through U^{234} will be assumed to be in radioactive equilibrium and will be represented by measurement of uranium isotope(s) or surrogate progeny. The actinium (U^{235}) series will be assumed to exist in its naturally-occurring proportion to the uranium series.

Radium-226 and its progeny, including Pb^{210}, will be assumed to be in radioactive equilibrium and will be referenced to measured Ra^{226} concentration. Th^{230} will be associated with Ra^{226} and Pb^{210} because the Ra^{226}, to which it decays, presents the dominant dose factor.

Thorium series radionuclides will be assumed to be in radioactive equilibrium and will be represented by measurement of a surrogate radionuclide, Ac^{228}, in the series.

Radiological **dose factors** of individual radionuclides in each subseries may then be composited and stated simply as

$$DF_U = [D(U^{238}) + D(U^{234}) + D(U^{235} + Ac^{227} + Pa^{231})] \div C(U^{238}) \quad \text{eqn 1}$$

$$DF_{Ra226\ \&\ Th230} = [D(Ra^{226}) + D(Pb^{210}) + D(Th^{230}{=}6\cdot Ra^{226})] \div C(Ra^{226}) \quad \text{eqn 2}$$

$$DF_{Th\ series} = [D(Th^{232}) + D(Ra^{228}) + D(Th^{228})] \div C(Th^{232}) \quad \text{eqn 3}$$

where D_i = annual dose rate of principal radionuclide *i* and its short-lived progeny at the time of the peak of the mean dose rate posed by the related group of radionuclides (mrem/yr)

C_i = concentration of reference radionuclide *i* in soil (pCi/g soil)

DF = radiological dose factor (mrem/yr)/(pCi/g soil)

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

Dose factors include long-lived radionuclides mentioned and their short-lived progeny.

The **derived concentration guideline level** may then be stated as

$$DCGL_{W\ U} = \frac{25}{DF_U} \qquad \text{eqn 4}$$

$$DCGL_{W\ Ra226} = \frac{25}{DF_{Ra226+Th230}} \qquad \text{eqn 5}$$

$$DCGL_{W\ Th\,series} = \frac{25}{DF_{Th\,series}} \qquad \text{eqn 6}$$

where 25 = maximum acceptable annual radiological dose (mrem/yr)
$DCGL_W$ = derived concentration guideline level of reference radionuclide (pCi/g soil)

This permits a simplified statement of the **sum-of-fractions** of the radionuclides encountered in C-T decommissioning to be:

$$SOF = \frac{C_{U238}}{DCGL_{W\ U}} + \frac{C_{Ra226}}{DCGL_{W\ Ra226}} + \frac{C_{Th232}}{DCGL_{W\ Th\ series}} \qquad \text{eqn 7}$$

where:
SOF = sum-of-fractions of $DCGL_W$
C_{U238} = concentration of U^{238} in soil (pCi/g)
C_{Ra226} = concentration of Ra^{226} in soil (pCi/g)
C_{Th232} = concentration of Th^{232} in soil (pCi/g)
$DCGL_{W\ U}$ = $DCGL_W$ of U^{238} + U^{234} + actinium (U^{235}) series in its naturally-occurring ratio to the uranium series (pCi/g)
$DCGL_{W\ Ra226}$ = $DCGL_W$ of 6 Th^{230} + Ra^{226} and its progeny, including Pb^{210}, in radioactive equilibrium (pCi/g)
$DCGL_{W\ Th\ series}$ = $DCGL_W$ of Th^{232} and its progeny, including Ra^{228} and Th^{228}, in radioactive equilibrium (pCi/g)

The index, or SOF, determined for each soil sample or location measured, will be the basis of testing compliance with population statistics and elevated measurements criteria.

5.8.7 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*.[55] It may be calculated as the ratio

$$\text{Area Factor} = \frac{\text{composite dose factor for survey unit area}}{\text{composite dose factor for local area of contamination}} \qquad \text{eqn 8}$$

Figure 5-3 is the *area factor* as a function of a localized area of radioactive contamination consisting separately of

- thorium series;
- natural uranium, including U^{234}, U^{235}, and actinium series in which uranium isotopes are in the ratio occurring in natural uranium; and

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

- Ra^{226}, Pb210, and 6 Th^{230}.

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

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

where the maximum area factor considered corresponds to 10 m^2 area of elevated contamination.

An index representing radioactivity in a small area may be calculated with the sum-of-fractions relation:

$$\text{Index} = \frac{C_{U238}}{(AF \times DCGL_W)_U} + \frac{C_{Ra226}}{(AF \times DCGL_W)_{Ra226}} + \frac{C_{Th232}}{(AF \times DCGL_W)_{Th\,series}} \qquad \text{eqn 9}$$

where $DCGL_W$ are read from Table 5.1 and AF_U, AF_{Ra226}, and $AF_{Th\,series}$ are read from Figure 5-3. This Index represents the fraction or multiple of the $DCGL_{EMC}$. In effect, $DCGL_{EMC}$ occurs when this Index = 1 and is exceeded when the Index > 1.

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 radioactivity concentration is elevated above the $DCGL_W$.

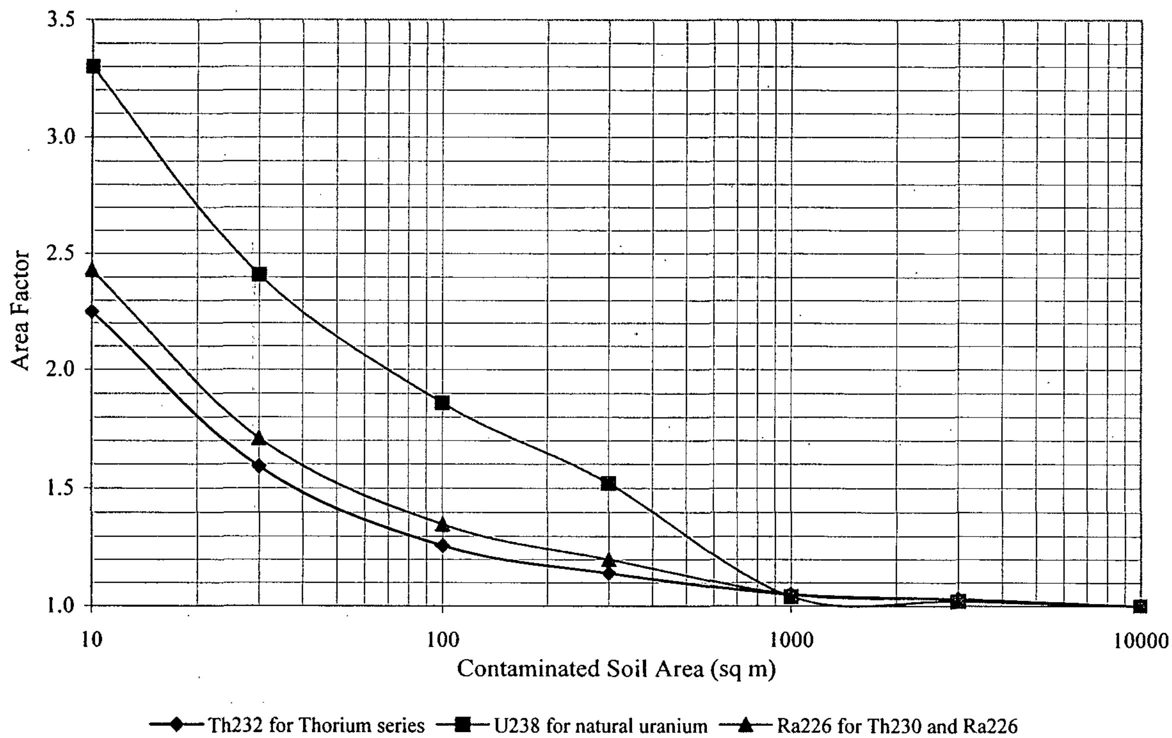


Figure 5-3. Area Factors for Elevated Measurements Criterion in Soil

5.9. INDUSTRIAL WORK ON PAVEMENT

5.9.1 DCGL$_W$ on Pavement

Dose factors were computed by RESRAD for an industrial work scenario on pavement. 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 maximum acceptable potential radiological dose equivalent.

Exposure to bare soil and to pavement cannot occur simultaneously. The scenario assuming bare soil necessarily excludes pavement and any exposure to it. Thus, derivation of DCGL for work on soil is independent of exposure to pavement.

On the other hand, pavement would exist atop soil. When so, it would be a complete barrier against airborne and ingestion pathways of exposure to conceivable residue in the soil and an incomplete shield against gamma radiation penetrating from conceivable residue in the soil. With the aid of dose modeling of outdoor exposure to gamma radiation penetrating nominal 4-inch-thick pavement by RESRAD, a meter of soil containing a spectrum of radionuclides observed in soil [ref. Appendix C, §C.3.2] at the concentration corresponding to DCGL$_W$ in soil would be estimated to contribute 5.0 mrem/yr through the pavement. Subtracting that from 25 mrem/yr allotted to DCGL would imply reduction of conceivable contribution from residue on pavement itself to 20 mrem/yr, or 0.80 of the DCGL$_W$ derived and proposed for pavement.

Although it is unlikely that both soil and pavement would be contaminated to more than 0.80 of either DCGL$_W$, and thus are practically independent, DCGL$_W$ in Table 5-4 and consequently DCGL$_{EMC}$ are reduced to 0.80 of values that would produce 25 mrem/yr. Corresponding DCGL$_W$ were then derived as the quotient of 20 mrem/yr and each dose factor. They may be composited into logical groups, each of which may be represented by a practically measurable radionuclide:

U_{nat}	represents U^{238} thru U^{234} and the actinium (U^{235}) series in natural proportion to U^{238}; U^{238} is the reference radionuclide.
Th^{230} subseries	represents Th^{230}, Ra^{226}, Pb^{210}, and their short-lived progeny, with Th^{230} and Ra^{226} in proportions measured in cinder fill samples and with Pb^{210} and its short-lived progeny assumed in radioactive equilibrium with Ra^{226}. Ra^{226} is the reference radionuclide.
Th series	represents the thorium series in radioactive equilibrium. Th^{232} is the reference radionuclide.

The adjusted DCGL$_W$ applicable to pavement are in Table 5-4. Derivation of Table 5-4 is explained in Appendix G of this Plan. Application of DCGL$_W$ in Table 5-4 absorbs any need to allocate potential radiological dose among soil and pavement later.

Table 5-4. Radioactivity on Pavement Surface Producing 20 mrem/yr

Radionuclide	Dose Factor	Areal Density Equal to 20 mrem/yr	
	(mrem/yr)/(pCi/g)	(pCi/100 sq cm)	(dpm/100 sq cm)
U-238	8.57E-04	1.05E+06	2.33E+06
U-234	7.02E-05	1.28E+07	2.85E+07
U-235+DI	2.16E-02	4.17E+04	9.26E+04
Th-230	1.51E-04	5.94E+06	1.32E+07
Ra-226	4.54E-02	1.98E+04	4.41E+04
Pb-210	1.28E-03	7.04E+05	1.56E+06
Th-232	2.37E-03	3.80E+05	8.43E+05
Ra-228	2.98E-02	3.02E+04	6.70E+04
Th-228	3.20E-02	2.82E+04	6.25E+04
U nat [b, c]	1.91E-03	4.71E+05	1.05E+06
$Th^{230}+Ra^{226}+Pb^{210}$ [d]	4.67E-02	1.93E+04	4.28E+04
Th series [a]	6.42E-02	1.40E+04	3.11E+04

[a] Th^{232} series is the limit for Th^{232} with all its progeny nuclides present in equilibrium concentration (*i.e.*, radioactivity 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 nat is the limit for U^{238} with U^{234}, and their short-lived progeny present in equilibrium and the U^{235} series is present in equilibrium in the proportion occurring in natural uranium.

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

[d] Th^{230} series includes Th^{230}, Ra^{226}, Pb^{210}, and their short-lived progeny and is referenced to Ra^{226} radioactivity concentration.

Radioactive contamination on surfaces is often surveyed by gross activity detection. It is practical, then, to state the contamination limit in units consistent with the measurement. A method of interpreting a surface radioactivity limit and gross beta measurement in comparable units is described in C-T Phase I Decommissioning Plan, Appendix D. The maximum acceptable average areal radioactivity density on a surface, or $DCGL_W$, is expressed in units, pCi/ 100 cm^2, and in units, disintegrations/(min·100 cm^2) in Table 5-4 for components of the source.

Principal radionuclides in the uranium series, thorium series, and actinium series were measured in 24 samples scabbled on pavement in Plant 5. Lognormal distribution graphics of the analytical data in Table 4-2, indicate that the log mean radioactivity ratios are as in Appendix G, Tables G-4 and G-5 and in Table 5-5.

Table 5-5. Ln Mean Ratio on Pavement

Radionuclide	Relative Concentration
U_{nat}/Th series	3
Th^{230}/U_{nat}	0.78
Ra^{226}/U_{nat}	1.4
Th^{230}/Ra^{226}	0.6

Applying this distribution to the areal density equal to 20 mrem/yr, or $DCGL_W$, in Table 5-4 yields composite limits:

$$DCGL_W = 6.2 \times 10^4 \text{ dis/(min}\cdot 100 \text{ cm}^2)$$

or the corresponding β radiation limit:

$$\beta_{limit} = 1.8 \times 10^5 \ \beta\text{/(min}\cdot 100 \text{ cm}^2)$$

Derivation of these composite limits is explained in Appendix G.

To enable practical survey of the radionuclide spectrum observed on pavement by measuring gross beta radiation, $DCGL_W = 1.8 \times 10^5 \ \beta/(\text{min}\cdot 100 \text{ cm}^2)$ is proposed. Measurement methodology is described in C-T Phase I Decommissioning Plan, Appendix D, §3 "Beta Radiation Measurement."

5.9.2 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*.[56] Figure 5-4 provides the *area factor* separately for U series (including actinium series present in natural uranium) Th series, and the ratios of principal radionuclide in pavement scabble samples as a function of a localized area of radioactive contamination on pavement. The actinium series is assumed present with the uranium series at the radioactivity ratio, U^{235}-to-U^{238} = 0.0455, that occurs naturally.

A composite area factor is calculated as the ratio of composite areal density limits, *i.e.*, DCGL, applicable to radionuclides in pavement scabble samples in ratios of principal radionuclides observed therein and reported in Table 5-4 and Appendix G, Tables G-4 and G-5.

$$\text{Area Factor} = \frac{\text{composite areal DCGL for survey unit area}}{\text{composite areal DCGL for local area of contamination}} \quad \text{eqn 13}$$

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

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

$$DCGL_{EMC} = \text{Area Factor} \times DCGL_w \qquad \text{eqn 14}$$

where the maximum area factor considered corresponds to 10 m^2 area of elevated contamination. Since the area factors curves in Figure 5-4 are nearly coincident, it is reasonable to adopt the area factor curve representing the composite of the radionuclide distribution observed in scabble samples of pavement to apply to the $DCGL_W$ derived in §5.9.1.

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 $DCGL_w$. Measurement of gross beta radiation and interpretation as described in the CT Phase I Decommissioning Plan would be acceptable. .

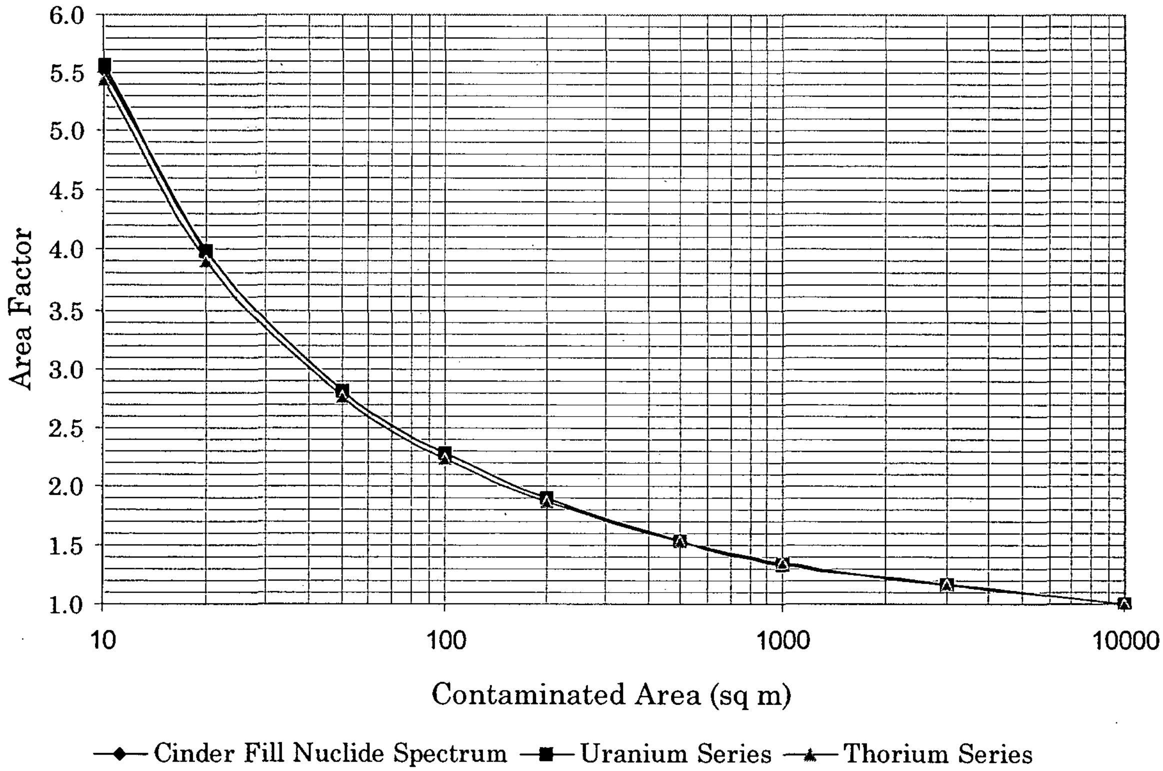


Figure 5-4. Area Factor for Elevated Measurements on Pavement

5.10. SENSITIVITY ANALYSIS

5.10.1 Ranking Parameters

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,[58] 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.

Yu, *et. al.*,[59] 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 5-6. 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 5-6. 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	

[58] NUREG-1727, Apx. C, §6.3.3, p. C60.
[59] Yu, *et. al.*, NUREG/CR-6697. Table 4.2, p. 55.

Table 5-6 continued:

Priority 1 (higher)	Priority 2 (mid)	Priority 3 (lower)
	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.

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 5-6 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 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.

5.10.2 Radionuclide Variability

The $DCGL_W$ of C-T source residue on pavement is not very sensitive to radionuclide variability. To evaluate this, boundary conditions could be reasonably represented by assumptions that the source were either all natural uranium series and actinium series in naturally-occurring proportion, or all thorium series, or all Th^{230} subseries. If, for instance, the source were entirely uranium series in equilibrium, the β limit equivalent to $DCGL_W$ would = 2.2×10^5 β/(min·100 cm^2); or if the source were entirely thorium series in equilibrium, the beta limit equivalent to $DCGL_W$ would = 1.1×10^5 β/(min·100 cm^2); or if the source were entirely the Th^{230} subseries mix represented in its $DCGL_W$, the beta limit equivalent to that $DCGL_W$ would = 1.4×10^5 β/(min·100 cm^2).

The radionuclide spectra in a set of 24 scabble samples collected on pavement are a mix of uranium series[60] and thorium series. The β limit equivalent to the $DCGL_W$ of the radionuclide spectrum (radionuclides in their relative concentrations) observed in this set of scabble samples is 1.8×10^5 β/(min·100 cm^2). Thus, the β limit equivalent to the $DCGL_W$ of the most representative radionuclide spectrum in these samples is a value between the extremes of all uranium series or all thorium series. In perspective, these boundary conditions indicate that the β limit to which measurements will be compared to assess compliance with the DCGL will not be very sensitive to variability in the spectrum of radionuclides on pavement.

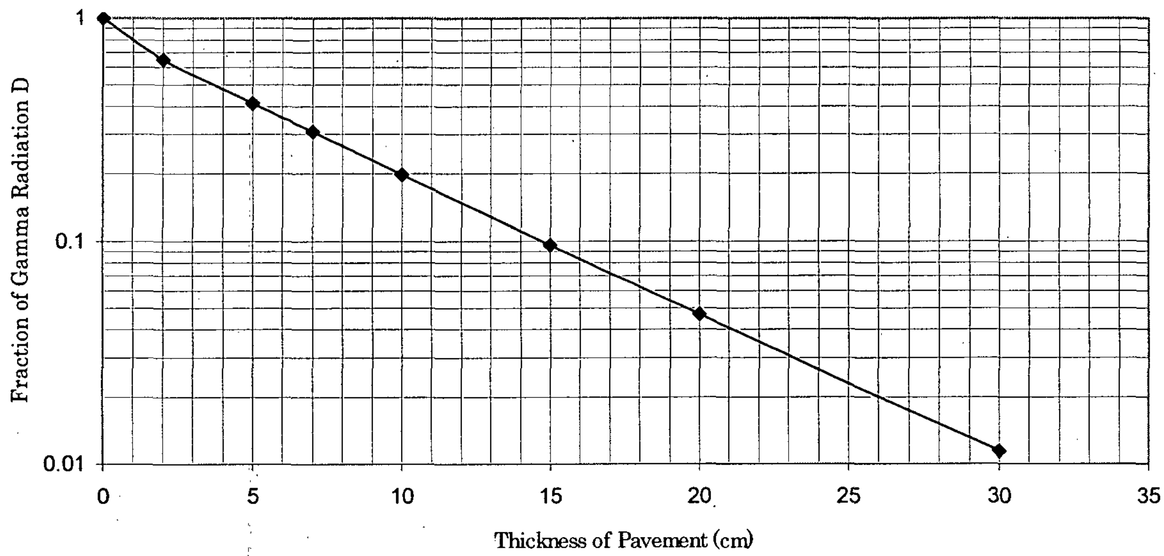
5.10.3 Pavement

Radiological dose is sensitive to cover depth and density of cover material. The industrial/commercial work scenario assumes 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 source spectrum observed in cinder fill samples it would diminish potential dose and increase the composite $DCGL_W$ derived by RESRAD for an industrial worker about 5 times more than if no pavement were present.

Thus, radiological dose from cinder fill would diminish with increasing depth and density of a pavement cover zone. This is evident in Figure 5-5.[62] 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 in cinder fill.

[60] including actinium series in naturally-occurring proportion to the uranium series
[62] CT 2 DP, Appendix G, Fig. G-2.

Figure 5-5. Fraction of Gamma Radiation Penetrating Pavement
Source Spectrum is Ln Mean Radionuclide Concentration in Cinder Fill
Dose Modeling by RESRAD v. 6.3



5.11. 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 §5.8.5 as interpreted in §5.8.6 and $DCGL_{EMC}$ in §5.8.7 are not exceeded in soil affected by C-T operation, and separately that
- $DCGL_W$ in §5.9.1 and $DCGL_{EMC}$ in §5.9.2 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 Decommissioning 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 background for Ra^{226}, Ra^{228}, Th^{232}, and Th^{230} specified in 40 CFR Parts192.12(a) and 192.41,

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

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.

<u>Supplemental Criteria (Deeper than 4 or 6 Feet)</u>. 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:

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

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. Alternative # 4, Restricted Release

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. <u>Rationale for Selecting the Preferred Alternative</u>

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. <u>NRC License STB-401</u>

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

6.3.2. <u>Metropolitan St. Louis Sewer District Discharge Permit No. 21120596-00</u>

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 Decommissioning Plan

Revision 1
May 15, 2005

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 **A**s **L**ow **A**s is **R**easonably **A**chievable 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

[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 Reduction in Public Opposition	Transportation Risks
	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 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 = $0.2(528\ ft)^2 = 5.6 \times 10^4\ ft^2$, 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.

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

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

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 \$367400.

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.

[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 $395500.

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.

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

$$Cost_{ACC} = \$\ 222.$$

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

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

= 4.2×10^{-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.

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

$$Cost_{TF} = \$13200.$$

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

W_A = incremental weight of soil shipped (tons)

[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.

$$Cost_{Wdose} = \$2000 \times D_R \times T \qquad \text{eqtn 7.5}$$

$$Cost_{Wdose} = \$\ 176.$$

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

[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 **A**s **L**ow **A**s is **R**easonably **A**chievable 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.

$$\mathrm{Cost_T} = \mathrm{Cost_R} + \mathrm{Cost_{WD}} + \mathrm{Cost_{ACC}} + \mathrm{Cost_{TF}} + \mathrm{Cost_{Wdose}} \quad \text{eqtn 7.6}$$

$$\mathrm{Cost_T} = \$367400 + \$395500 + \$222 + \$13200 + \$176$$

$$\mathrm{Cost_T} = \$\,776498.$$

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 \$776000 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. <u>$\mathrm{DCGL_{EMC}}$ Baseline</u>

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.

$$\frac{\mathrm{Conc}}{\mathrm{DCGL_W}} = \frac{\mathrm{Cost_T}}{2000 \times P_D \times 0.025 \times F \times A} \times \frac{r + \lambda}{1 - e^{-(r+\lambda)N}} \quad \text{eqtn 7.7}$$

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 $\frac{\mathrm{Conc}}{\mathrm{DCGL_W}} = 34$. Thus, according to this logic, it would be cost-effective to excavate soil containing more than 34 times the $\mathrm{DCGL_W}$ in order to reduce residual radioactivity concentration, but not if it contains less than 34 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 34 times the $DCGL_W$. Yet since the maximum value of $DCGL_{EMC}$ in soil will be about 0.1 of 34 times the $DCGL_W$, decontamination to satisfy $DCGL_{EMC}$ in localized areas will also yield cleanup that is ALARA.

SECTION 8

PLANNED DECOMMISSIONING ACTIVITIES

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
April 11, 2006

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

8. PLANNED DECOMMISSIONING ACTIVITIES

8.1. INTRODUCTION

C-T Process and support buildings and all other affected above-ground areas at the site were or will be demolished or decontaminated in accordance with the C-T Phase I Decommissioning Plan (Phase I Plan). Activities in the Phase I Plan are authorized under license STB-401, as amended May 3, 2002. Under the C-T Phase II Decommissioning Plan (Phase II Plan), authorization to perform activities described in this section 8 is being sought. The Phase II Plan addresses remediation of C-T Process and Support Building floor slabs, subsurface sewer system, contaminated soils, and the wastewater neutralization basins.

Most of the activities required to decommission the C-T project site will take place within Plant 5. However, wastewater neutralization basins outside Plant 5 supported C-T operations and will also be decommissioned. Within Plant 5, the C-T Project remediation area boundaries have been defined as:

- everything south of the south edge of Destrehan Street,
- everything north of a line drawn along the south sides of Buildings 200 and 260,
- everything west of a line drawn on the east side of Bldgs. 222 and 223, and
- everything east of a line drawn along the west sides of Buildings 240 and 250.

Certain Plant 5 areas outside of these limits contain residues of uranium processing under MED/AEC and are the responsibility of USACE under the FUSRAP. The FUSRAP is responsible for evaluation and remediation of all areas containing MED/AEC residues, including any areas where such residues are commingled with other radioactive materials such as C-T materials.[1]

The following C-T support areas outside of Plant 5 will be remediated during Phase II:

- Building 91 sewers (if contamination of drains is identified in Phase I),
- Wastewater basins in Plant 7.
- Figures 14-1A, 14-1B, and 14-2 are maps of the St. Louis Plant C-T process and support areas to be addressed in Phase II.

An Occupational Dose Evaluation was performed to provide a conservative estimate of the radiological dose to a worker under normal conditions. This evaluation is included as Attachment 1.

An Accident Analysis was performed to assess the radiological dose to a worker under the maximum credible accident conditions. This analysis is included as Attachment 2.

During the planning stages, Mallinckrodt has evaluated several alternative methods for decommissioning the C-T project site including, but not limited to various options for decontaminating or demolishing pavement and building slabs, excavation of subsurface sewerage, and excavation of contaminated soils. Phase II activities are complicated by the fact

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[1] USDOE and USEPA. *DOE FUSRAP Sites, St. Louis and Hazelwood, Missouri Federal Facilities Agreement,* EPA Docket No. VII-90-F-0005. June 26, 1990.

that the facility will continue to perform routine manufacturing while decontamination and remediation are performed. After careful review of site and facility characterization data, research program results, and engineering cost analyses, Mallinckrodt selected the following decommissioning strategy. During Phase I, Mallinckrodt contractor(s):

(a) demolished C-T process buildings (Buildings 238, 246B, 247, 248) and immediately adjacent support buildings (Buildings 213, 214, 246A), and
(b) surveyed and decontaminated other C-T support areas.

During Phase II, Mallinckrodt will, as may be necessary

(a) remediate remaining floor slabs and subsurface soils and systems by decontamination or excavation and disposal followed by a final survey,
(b) remediate former wastewater neutralization basins by decontamination or demolition and disposal followed by final surveys where appropriate, and
(c) Remediate sewerage.

Decontamination and volume reduction methods were selected to minimize the volume and cost of radioactive waste requiring disposal. Mallinckrodt and its contractor(s) will determine whether decontamination and final survey of individual materials is preferred over excavation and disposal. The Phase II Plan is based on the following preferences:

- excavation or demolition and disposal when it is cost-effective,
- decontamination when it is judged to be cost-effective compared to disposal, and
- decontamination or removal of selected contaminated areas of pavement to < DCGL specified in §5.9 and subsurface material to < DCGL in §5.8 and to reduce the average mass concentration activities below disposal criteria and therefore minimize the cost of disposal.

The general technical approach for decommissioning during Phase II is as follows:

- decontamination, if necessary, or removal of remaining C-T building floor slabs and foundations,
- removal or plugging of contaminated sewers and soils;
- packaging and shipping of contaminated materials for transfer to an appropriate facility,
- final radiation status survey,
- backfilling and compaction of remediated areas, and
- final grading and paving.

Mallinckrodt will ensure that areas that have been cleaned will not be cross-contaminated due to ongoing remediation activities by:

- planning the progression of remedial actions involving decontamination and or excavation to minimize likelihood of cross-contamination;
- planning progression of final status surveys to improve likelihood of discovering inadvertent cross-contamination.
- establishing a controlled area boundary around a remediation location;
- employing water misting to suppress airborne dust if needed;
- implementing a contamination control procedure for haul vehicles;
- specifying and monitoring the haul route from excavation site to rail car loading site;
- routine surveillance of the haul route;
- establishing a controlled area boundary around the rail car loading area;
- surveying, and if necessary decontaminating rail car surfaces before shipment; and

- employing administrative controls, including procedures, field instructions, and safety work permits to control activities involving radioactive material.

The activities to be performed during Phase II decommissioning are grouped below in several categories of similar work.

8.2. STRUCTURES

C-T process and support buildings, above-grade structures, were subject to the Phase I Plan.

8.3. PAVEMENT AND SLABS

8.3.1. Street Pavement

Plant 5 is paved with macadam or concrete. In compliance with the Phase I Plan, floor slabs of process and support building that were removed and some pavement have been sealed.[2] A seal-coat of macadam was applied. Prior to the FSS, this temporary pavement will be removed from areas subject to survey to permit accurate survey of the pavement and slab surfaces of interest. Debris of the seal-coat will be confirmed to be contamination-free by bulk survey before disposing of it in an industrial waste landfill or recycling it in ready-mix asphalt pavement.

8.3.2. Building Slabs and Foundations

C-T process and support building floor slab and foundation surfaces exposed above grade that are subject to decommissioning include the floor slabs of former Buildings 213, 213A, 213B, 214, 238, 246, 246B, 247A, 247B, and 248. If a floor slab or foundation surface were to fail a final status survey, it would either be decontaminated, *e.g.*, by scabbling, and be subject to survey again in accordance with section 14 of this Plan or would be removed. In the event a floor slab or foundation were removed, its debris would be characterized for disposal and would be managed in accordance with provisions of section 12.1 of this Plan.

If access to contaminated subsoil is necessary, pavement or floor slab would be removed. Otherwise, if pavement or a floor slab passes a final status survey, it may be left in place. Where gross removal is necessary, it will be completed using standard construction equipment such as excavators, bulldozers, front-end loaders, dump trucks, compactors, water trucks, forktrucks, and miscellaneous small tools. Debris size reduction will be performed during excavation as required for transportation and disposal. Excavated pavement and associated soil and debris will either be loaded into shipping containers at the excavation site or will be transported to the soil handling area for characterization, segregation, staging and shipment.

8.3.3. Wastewater Neutralization Basins

The former wastewater neutralization basins in Plant 7W will remain after completion of Phase I decommissioning. During Phase II, the basins may either be removed and disposed by NRC-

[2] C-T Phase I Decommissioning Plan, §2.3.1

authorized transfer to a disposal facility off-site or be decontaminated if necessary, left in place, and subjected to a final status survey. The wastewater neutralization basins and surrounding areas will be remediated by the remediation contractor(s) as follows:

- Basin liners will be removed and packaged for shipment and disposal.
- Exposed concrete surfaces will be surveyed either for the purpose of establishing cost-effective disposal or final radiation status to compare with DCGL.
- Exposed surfaces of concrete structures may be decontaminated as appropriate by scabbling, grit blasting or similar techniques, broken into appropriate size pieces, and loaded into transport containers using conventional demolition equipment and techniques.

8.3.4. General

In the event of pavement, building slab, foundation, or basin decontamination and/or demolition, it will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan.

Decontamination and demolition of the pavement, building slab, foundation, or wastewater neutralization basins does not entail unique construction or remediation safety issues. Mallinckrodt has safely and effectively performed such activities during the ongoing operation and maintenance of the facility.

Water misting or similarly effective dust control methods will be used as necessary to prevent the release of airborne dust during excavation and materials handling activities. In the event erosion or dispersion of staged or stockpiled soil were to become problematic, active confinement, *e.g.*, by straw bale berm or tarpaulin cover, would be considered.

Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

8.4. SEWERAGE SYSTEMS

8.4.1. Description and History

Above-grade C-T process systems and equipment have been decontaminated and disposed of through implementation of the Phase I Plan. C-T process buildings and some support areas were served by subsurface sewer systems that are addressed in this Phase II Plan.

Prior to December 1970, all site wastewater was discharged to the Mississippi River through a combined (wet and dry weather) sewer system. Sewerage serving Plant 5 discharged to the Mississippi River through the Destrehan Street outfall structure. This structure was constructed by MED/AEC to support the Destrehan Street Plant and was located at the foot of Destrehan Street east of the plant.

Wastewater from the MED/AEC Destrehan Street Plant was discharged to the MSD Salisbury Street Sewer and the Destrehan Street outfall. The U.S. Army Corps of Engineers is addressing radioactivity contamination in these sewer systems under the FUSRAP program.[3]

Results of extensive soil core sampling and of sediment sampling taken via manholes in sewerage are reported in CT 2 DP §4.8.2 Sewers and §4.8.4 Subsurface Material.

8.4.2. <u>Drains and Subsurface Sewerage That Served C-T Process Buildings</u>

These drains and sewers are the most likely to contain C-T residues of licensed radioactive material. Interpretation of the manhole samples indicates radioactive contamination in sewerage to be confined to segments immediately southwest, west, and north of Building 238. [ref. CT 2 DP, §4.8.2] Drains and sewerage that served C-T process buildings (238, 246B, 247A&B, 248) will either be plugged to prevent use or will be removed during removal of building floor slabs and shallow soil, if any.

Main sewer lines immediately to the west and north of Building 238 will be removed or plugged in the process of remediation of subsurface soils beneath Building 238. If they are removed, the sewers and the sludge in them will be treated as radioactive waste, as described in Section 12 of the Phase II Plan. Else, if plugged, they may be released for unrestricted use if warranted by a Final Status Survey as described in Section 14 of the Phase II Plan. It is anticipated that sewers remaining downstream of Building 238, beginning about even with west ends of Buildings 236 and 245 and extending to the Waste Water Treatment Basin area, will remain in service after a Final Status Survey as described in Section 14 of the Phase II Plan and release for unrestricted use.

The sewerage involved is clay or concrete composition, is buried in ground, and would be impractical to salvage intact. If future excavation were to intrude into it or even intend to remove it, one would expect it to be broken into debris during excavation. While being excavated and brought to the surface, the debris and nearby excavate would be expected to be mixed as excavation spoil. This is equivalent to the scenario in which inadvertently excavated subsoil would be mixed as excavation progresses from land surface downward, and the resulting mixture average concentration would be compared with $DCGL_W$ derived for topsoil. Thus, the appropriate scenario and model on which to derive $DCGL_W$ would be the same as for soil.

To plug a drain, a contractor would access the drain or sewer via the drain opening, storm drain opening, or manhole into the sewer. In a manner similar to grouting a well to plug it, the contractor would pump cement or a cement-bentonite mixture into the drain or sewer to plug it at these strategic segments to preclude further use and to preclude further drainage of wastewater in the line.

Objectives of plugging sewerage would be to prevent future use, to contain sediment that might be in it, and to prevent backflow from sewers remaining in use downstream, especially at the juncture of a sewer line upstream to be removed. If sewerage north and west of Building 238 is to be removed, the juncture in sewerage will be plugged before sewer line upstream of the plug will be removed in order that sewerage downstream may remain in use. Any sewerage north and west of Building 238 to be plugged rather than removed would be plugged at strategic points

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

before excavation to remove connected sewer lines in order to prevent backflow from downstream. Final status survey of sewerage downstream remaining in use would be done after plugging upstream and after building slab, foundation, and soil remediation.

8.4.3. Drains and Subsurface Sewerage That Served C-T Support Buildings

Mallinckrodt does not anticipate that drains and subsurface sewerage that served C-T support buildings will contain C-T related contamination in excess of sewerage contamination criteria. Access points, including such drains, traps, and other at-grade locations that may have been exposed to C-T materials will be identified and surveyed for radioactivity. If these surveys identify contamination, interior surveys, *i.e.*, sediment sampling, will be performed. The access points, sampling locations, and survey findings will be recorded. If surveys in access points do not identify the presence of radioactivity above criteria, downstream sewerage will reasonably be assumed to be non-contaminated.

8.4.4. Drains and Subsurface Sewerage That Served C-T Yard Areas

Drains and subsurface sewerage that served C-T yard areas will be addressed in a manner similar to that employed for drains and subsurface sewerage that served C-T support buildings.

8.4.5. Plant 7 Lift Station

The Plant 7 Neutralization basin is described in Section 8.4.3 above. Lift station interior surfaces will be surveyed for radioactivity contamination, including any exposed joints. Areas exceeding the DCGL for pavement, stated in DP Section 5 will be decontaminated using scabbling, grit blasting, or other techniques or will be removed. A final status survey will be performed on surfaces that are left in place.

8.4.6. Sewerage That Served MED/AEC Operations

USACE is addressing sewerage serving MED/AEC operations under the FUSRAP program, including sewerage that may contain commingled C-T residue. Those sewers are not subject to this Phase II Decommissioning Plan.

8.4.7. Sewerage That Served Neither C-T Nor MED/AEC Operations.

No decommissioning activity will be performed in other sewers as they cannot reasonably be expected to contain C-T contamination in excess of criteria.

8.4.8. Other Sewerage Remediation Issues

Sewer decontamination and/or excavation will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan. Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

Water misting or similarly effective dust control methods will be used as necessary to prevent the release of airborne dust during excavation and materials handling activities.

Surveying, decontamination, excavation, and removal of drains and subsurface sewerage does not entail unique construction or remediation safety issues. Mallinckrodt has safely and effectively performed such activities during the ongoing operation and maintenance of the facility.

8.5. SOIL

The estimated radioactivity concentration profile observed by characterization survey that exceeds the $DCGL_W$ in soil in Plant 5 is described in Section 4 of the Phase II Plan. Characterization data indicate that radioactive residue in some soils beneath and adjacent C-T process Building 238 exceeds criteria. Demolition of the above-grade portions of C-T process and support buildings was accomplished during Phase I. Contaminated building floor slabs, foundations, and contaminated soils exceeding the DCGL will be addressed during Phase II.

8.5.1. Soil Remediation

Soil remediation will generally be performed as follows:

- Three-dimensional modeling of characterization data will define the gross outline of areas exceeding soil criteria.
- The areas where criteria are exceeded will be excavated using conventional construction equipment.
- Radiation measurements will be employed to guide remedial excavation.
- Excavated soils will be loaded into trucks or containers at the site of remediation and moved to the material handling area or shipped in accordance with NRC-authorized transfer to a state-regulated disposal facility.
- A final radiation status survey will be performed in each remediated area. [ref. §14.4.3.4]
- Excavated soil demonstrated to contain lower radioactivity concentration than the DCGL by radioactivity survey performed to specifications in section 14 may be returned into an excavation pit.
- Remediated areas will be backfilled, compacted, graded, and resurfaced as appropriate.

In the event groundwater were to prevent direct access to survey the bottom of an excavation cavity, an alternative would be to backfill as much as one meter and do final status core sampling through the backfill into the unexcavated bottom. Adjacent land not requiring excavation in the same survey unit will be subject to soil core sampling and analysis to complement the final status survey.

8.5.2. Soils and Materials Management

Solid waste, including soil and pavement, slab, and foundation debris, will be managed as specified in Section 12.1.

In order to qualify for deposition into an excavation pit, soil, concrete, or pavement rubble must be either be imported from a non-impacted source off-site, or be indistinguishable from background radioactivity. Else, it must contain less than the DCGL for soil specified in DP §5 and be certified so by survey equivalent in quality to final status survey specifications in DP §14. Sampling or in-situ analysis of material originating on-site would be done in stockpile before deposition into an excavation pit. Measurement quality would be equivalent to that required for a final status survey to assure that the radioactivity concentration in backfill, when evaluated together with final status survey measurements of the excavation cavity, will satisfy the requirements of a final status survey of the combination.

8.5.3. General Information

These activities will be controlled administratively by directives, *e.g.*, field instruction, safety work permit, and or procedure, in accordance with an Administrative Controls Plan, to control operations and safety.

Soil radioactivity surveys will be performed as appropriate during excavation and soil management to minimize the intermixing of contaminated and uncontaminated soils and debris. Excavation will be guided by radiation survey of the cavity bottom and side and or of soil as it is removed by excavation. Additional soil sampling for analysis or direct measurement will be done to determine for which approved disposition it qualifies; that may necessitate sorting and short-term staging nearby the excavation. However, some incidental intermixing of contaminated and uncontaminated soils is unavoidable because of the heterogeneity of the contamination and the nature of excavation operations.

Techniques such as water misting and tarps may be used to minimize dust emissions during soil excavation, loading, transport, and handling.

Soil remediation and removal will be performed using standard construction equipment such as excavators, bulldozers, front-end loaders, dump trucks, compactors, water trucks, forktrucks, and miscellaneous small tools.

Slope stability will typically be maintained using conventional excavation sloping techniques. Shoring will be used when required to minimize the excavation area or maintain the stability of adjacent structures or other critical areas.

The excavation and remediation activities described above do not entail unique safety or remediation issues. Mallinckrodt has safely and effectively performed such activities as part of the ongoing operation, maintenance, and expansion of the facility.

Activities will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan. Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

Water misting of other similar techniques will be used as appropriate to prevent the release of airborne dust during excavation and materials handling activities. In the event erosion or dispersion of staged or stockpiled soil were to become problematic, active confinement, *e.g.*, by straw bale berm or tarpaulin cover, would be considered.

8.6. SURFACE AND GROUNDWATER

No surface water groundwater remediation is warranted or will be performed. Surface water and groundwater monitoring has been performed at the site by Mallinckrodt, DOE and USACE and is described in Appendix A. There is not a complete groundwater exposure pathway at the site. As indicated previously, the City of St. Louis operates and maintains a municipal water system and there are no groundwater withdrawal wells in the site vicinity. Furthermore, a City ordinance[4] prohibits installation of drinking water wells in areas such as the Mallinckrodt site, and groundwater discharges to the Mississippi River immediately downgradient of the site.

8.7. FINAL RADIATION SURVEY

Section 14 describes specifications for the final radiation survey that will be performed after soil remediation tasks are completed. Following successful completion of the final radiation survey of a survey unit, soil replacement, compaction, and grading will be performed. Minimal time is planned for the NRC response following final survey because of the increased risk to worker health and safety of leaving excavations unfilled for extended periods of time. If timely response from the NRC Project Manager is not received within two business days after notification, excavations may be surveyed (*e.g.*, geographically) or otherwise delineated (*e.g.*, with a marker layer) and backfilled.

8.8. SITE RESTORATION

At completion of excavation activities, the site grade will be reestablished and remediated areas other than where the basins are will be paved. The site will continue to be an active and expanding industrial facility for the foreseeable future. New manufacturing or support operations may be constructed on previously remediated areas.

8.9. SCHEDULE

Because the C-T production and support areas are located within an active manufacturing facility, completion of decommissioning activity within a 24-month period is technically infeasible without causing serious 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 quickly as practicable.

A preliminary schedule for Phase II decommissioning activities is presented in Figure 8-1 and is described below. The project schedule references project milestones and other dates to receipt of NRC approval of the decommissioning plan (Project Start Date = 0). The key elements forming the bases for the schedule are:

- Removal or decontamination of pavement and building slabs will take approximately 3 months,
- Removal of contaminated subsurface material will take approximately 10 months,
- Demolition of the waste water basins, if necessary, will take approximately 4 months,
- Relocation of water utility and site refurbishment will take place after the remediation, and
- Completion of final radiation surveys and NRC verification that the residual radioactivity limits have been met will occur concurrently with other activities and not impact the length of the Phase II schedule.

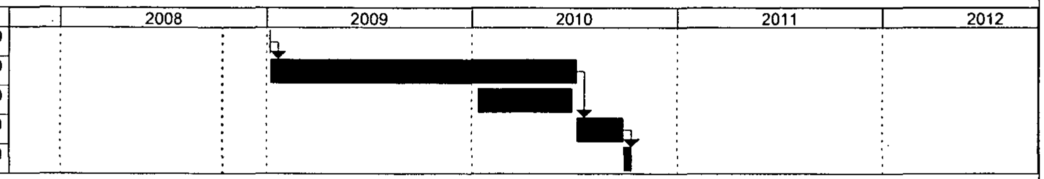
[4] St. Louis City Ordinance 13,272, Section 3. March 25, 1885.

The project schedule is based on information available during plan preparation. Mallinckrodt will provide an updated schedule to NRC if it is determined that decommissioning cannot be completed as outlined in the schedule.

Upon request, Mallinckrodt will provide the NRC an updated schedule that represents progress and work completed toward decommissioning.

Figure 8-1
Conceptual Decommissioning Schedule for CT Phase II

ID	Task Name	Duration	Start	Finish
1	NRC Approval of Decommissioning Plan (See Note)	1 day	Tue 1/6/09	Tue 1/6/09
2	Remediate Floor Slabs and Subsurface Soils	13 mons	Wed 1/7/09	Tue 7/6/10
3	Remediate Former Wastewater Neutralization Basin	4 mons	Tue 1/12/10	Mon 6/28/10
4	Final Staus Survey/Sampling & Analysis (FSS)	2 mons	Wed 7/7/10	Tue 9/28/10
5	Complete FSS Report for CT Phase II	2 wks	Wed 9/29/10	Tue 10/12/10



Project: C-T Phase II Decommissionir
Date: Mon 10/13/08

Task		Progress		Summary		External Tasks	
Split		Milestone	◆	Project Summary		External Milestone ◆	
Deadline							

NOTE: The actual start date and subsequent dates are dependent on the NRC approval date.

SECTION 9

PROJECT MANAGEMENT AND ORGANIZATION

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
April 11, 2006

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

9. PROJECT MANAGEMENT AND ORGANIZATION

This section describes the project organization that will become effective upon NRC approval of the C-T Phase II Decommissioning Plan (Phase II Plan). As the project moves forward, changes to the project organization may be justified in response to the varying level of site activities. Effective with NRC approval of this plan, the licensee may make changes to the organizational structure provided that the safety and quality functions maintain an independent reporting relationship from that of operations, and that the persons responsible for safety functions satisfy the educational and experience qualifications in provided below.

9.1. DECOMMISSIONING MANAGEMENT ORGANIZATION

9.1.1. Organization

Implementation of the Phase II Plan will be managed by a team comprised of management, radiation safety, and occupational safety personnel from the Mallinckrodt and decommissioning contractor organizations. The C-T project decommissioning organization is illustrated in Figure 9-1.

While Mallinckrodt is responsible for ensuring overall successful implementation of the Phase II Plan, it will contract the services of a remediation contractor to perform the decommissioning tasks required by the Plan.

The contractor will develop and/or implement the radiological safety, occupational safety, and environmental protection programs and the procedures required by this Phase II Plan. The contractor will provide the equipment, materials, and a trained and experienced labor force to perform the decommissioning activities. The contractor will also provide an independent quality assurance program as required by the Phase II Plan.

Mallinckrodt will use various project management and decommissioning consultants to assist in the management of decommissioning activity. These persons and/or organizations take their direction from the Mallinckrodt Project Manager and may interact directly with the contractor Project Manager and personnel at the request of the Mallinckrodt Project Manager.

Mallinckrodt managers responsible for site contract administration, quality assurance, and project engineering and corporate environmental affairs and legal will support the Mallinckrodt Project Manager. These support functions will be utilized as appropriate and are not identified on Figure 9-1.

The responsibilities of the primary managers and the minimum qualifications for managers with safety-related responsibilities are provided below.

9.1.2. Mallinckrodt C-T Project Manager

The Mallinckrodt C-T Project Manager will provide overall leadership and management of C-T project decommissioning. He or she reports to the Site General Manager. The Radiation Safety

Officer (RSO), Site Safety Manager, and project management and decommissioning consultants will support the Project Manager.

The C-T Project Manager is responsible for ensuring that the overall C-T decommissioning project, including the work performed by contractors and subcontractors, is accomplished in conformance with this Phase II Plan and with applicable health, safety, quality, technical, and contractual requirements. The Mallinckrodt Project Manager is responsible for assuring that NRC requirements are met. He or she also is responsible for coordinating activities between plant operations and the decommissioning contractor. He or she will use other Mallinckrodt staff or consultants as appropriate to perform this coordination. The Mallinckrodt Project Manager has full authority to halt any operation that he or she believes has the potential to threaten the health and safety of site or contractor personnel, the public, or the environment, is not in conformance with this Phase II plan, or is otherwise not meeting NRC requirements. He or she is also responsible for ensuring that established environmental programs and contractor environmental programs are in compliance with applicable and relevant laws and regulations. The C-T Project Manager is the designated contact with the NRC.

9.1.3. Mallinckrodt Radiation Safety Officer

The Mallinckrodt Radiation Safety Officer (RSO) is responsible for ensuring that radiation safety programs are in compliance with applicable and relevant laws and regulations and for auditing the contractor's compliance with these programs. Procedures addressing radiation safety issues with be reviewed and approved by the RSO. The RSO advises the Mallinckrodt Project Manager on matters pertaining to radiation safety and is supported by the Contractor Radiation Protection, Health, and Safety Manager. The RSO reports to the Site Safety Manager. The Mallinckrodt RSO has the authority to halt any operation which he believes has the potential to threaten the health and safety of personnel, the public, or the environment.

9.1.4. Mallinckrodt Site Safety Manager

The Site Safety Manager is responsible for ensuring that the C-T Phase II occupational safety program is in conformance with applicable and relevant laws, regulations, and NRC requirements. He or she will also audit contractor performance to ensure compliance with this Phase II Plan and other generally applicable requirements. The Site Safety Manager reports to the Plant Manager. The Site Safety Manager advises the Mallinckrodt C-T Project Manager on matters pertaining to occupational safety. The Site Safety Manager has the authority to halt any operation that they believe has the potential to threaten the health and safety of personnel, the public, or the environment.

9.1.5. Contractor Project Manager

The contractor's Project Manager is responsible for the execution of all of the Phase II Plan decommissioning activities. He is the primary interface with the Mallinckrodt C-T Project Manager. The contractor's Project Manager is directly responsible for all field work being performed by the contractor. As such, he is responsible for field work being conducted in accordance with applicable health, safety, quality, and technical requirements, including

Mallinckrodt procedures. The contractor's Project Manager has full authority to halt any operation when he believes these requirements are not being met.

9.1.6. Contractor Radiation Protection, Health, & Safety Manager

The contractor Radiation Protection, Health & Safety Manager (RPHS Mgr), alternatively referred to as the contractor ES&H Representative, is responsible for implementation of safety and environmental protection, including radiation protection, environmental protection, and occupational health and safety in the Phase II Decommissioning. The contractor RPHS Manager reports directly to the contractor Project Manager and is functionally independent of decommissioning Operations, thus assuring independence of action in matters pertaining to decommissioning radiation and environmental protection, health, and safety. The contractor RPHS Manager has the authority to halt any operation that they believe has the potential to threaten the health and safety of personnel, the public, or the environment.

9.1.7. Contractor Operations Manager

The contractor's Operations Manager reports directly to the contractor's Project Manager and receives program and task directives directly from the contractor's Project Manager. The contractor's Operations Manager is responsible for nuclear materials accounting, field engineering, waste management, daily work assignments for all field personnel and the physical execution of the decontamination and decommissioning activities for the implementation of Phase II decommissioning project. The Operations Manager will ensure that all personnel are properly trained to perform assigned decommissioning tasks and that the training is appropriately documented. The contractor Operations Manager has the direct responsibility to ensure that all field activity is protective of the health and safety of personnel, the public, and the environment and has the responsibility and authority to halt work in the event they are put at risk.

9.1.8. Contractor Quality Assurance Manager

The contractor's Quality Assurance Representative is responsible for establishing and assuring implementation of the contractor quality assurance program, including periodic audits. This function is independent of Operations and will report directly to the Mallinckrodt Project Manager with copies of audits provided to the contractor's Project Manager.

9.2. DECOMMISSIONING TASK MANAGEMENT

Decommissioning activities for the C-T Project will be performed in accordance with written instructions. There will be four general types of written instructions in use for the C-T Project: Plans, Procedures, work plans, Safety Work Permits (e.g., Hot Work Permits, Excavation Permits, etc.). These written instructions and their approval are described below.

9.2.1. Administrative Control Plan

The project will develop and implement an Administrative Control Plan that establishes guidelines for creation, use, and control of these administrative controls to ensure that C-T decommissioning is performed safely and in conformance with governing regulations, the NRC license, and the Phase II Plan.

Specific procedures and safety work permits, as discussed below, will be implement under this Decommissioning Plan and the Administrative Control Plan.

9.2.2. Procedures

Procedures are essential, written instructions and specifications to provide the controls needed to ensure safety and other objectives of the procedure are achieved. A procedure is ordinarily appropriate for repetitive activities such as defining how to operate equipment, calibrate instruments, or other routine work activities. Procedures are typically prepared by the contractor and issued by the contractor project manager. All Procedures will be reviewed and approved by the Mallinckrodt Project Manager. Procedures addressing radiation safety issues with be reviewed and approved by the RSO. Procedures addressing occupational or construction/remediation safety will be reviewed and approved by the Site Safety Manager. In the event that existing Mallinckrodt Procedures are used in Phase II activity, they will be reviewed and their use approved by the contractor and Mallinckrodt Project Managers and, as appropriate, by the RSO and Site Safety Manager.

9.2.3. Work Plan

A Work Plan is a plan to guide decommissioning work activities requiring a disciplined approach. It provides logical guidance without necessarily being procedural. Work Plans are typically prepared and issued by the contractor Operations Manager. A Work Plan depends on associated safety work permits for safety specifications that apply to the work activity covered. Each Work Plan will be prepared, reviewed, and approved in accordance with the Administrative Control Plan. Safety Work Permits and Daily Safety Permits (see below) required to perform the work will be identified. Each work plan will be reviewed and approved by the contractor Project Manager and/or the RPHS Manager, as appropriate depending upon the subject of the Work Plan. Any revision or termination will be communicated to decommissioning personnel in accordance with the Administrative Control Plan.

9.2.4. Safety Work Permits

Safety Work Permits (SWP) specify industrial and radiation safety controls, including personnel monitoring, monitoring devices, protective clothing, respiratory protection equipment, special air sampling, and additional precautionary measures required to be used when performing decommissioning tasks. SWP are prepared in conformance with the SWP Procedure and are typically prepared in concert with a work plan. SWP are issued for non-routine activities where there is a need to prescribe the conditions under which the work may be done in order to assure adequate protection of workers and the public from the potential hazards that may be encountered. Safety Work Permits will be reviewed and approved by the contractor RSO or contractor environmental health and safety representative as appropriate. SWP will remain in force until they are revised or terminated by the Operations Manager. Any revisions or terminations will be communicated to decommissioning personnel in accordance with the Project Communications Procedure.

9.2.5. Daily Safety Permits

Daily Safety Permits check for hazardous conditions, allow use of spark-generating tools and equipment, ensure adequate ventilation, etc. The Daily Safety Permit procedure describes the conditions under which a Daily Safety Permit must be issued prior to the initiation of work. The contractor environmental health and safety representative will issue Daily Safety Permits. Daily Safety Permits expire eight hours after issuance and must be reissued prior to continuation of work.

9.2.6. Operations and Safety Communications

The Mallinckrodt and contractor decommissioning organizations will be small. Mallinckrodt and contractor management teams will have routinely scheduled meetings to review project status, decommissioning performance, safety performance, and issues for which action is required. Project teams may be established as deemed appropriate by the Mallinckrodt or Contractor Project Managers. The Contractor Project Manager will be responsible for establishing project teams, monitoring their performance, and ensuring timely completion and reporting of findings and recommendations. The Contractor Project Manager will report at least monthly on project status and activities.

9.3. DECOMMISSIONING MANAGEMENT POSITIONS AND QUALIFICATIONS

Minimum qualifications for C-T decommissioning management positions are specified hereafter. In the event a person having equivalent although not exact qualifications[1] were to occupy one of the positions, Mallinckrodt would inform the NRC Project Manager.

9.3.1. Mallinckrodt CT Project Manager

Minimum qualifications for C-T decommissioning management positions are specified hereafter. In the event a person having equivalent although not exact qualifications were to occupy one of these positions Mallinckrodt would inform the NRC. This person must hold a baccalaureate degree in science or engineering and have a minimum of five years of project management experience.

9.3.2. Mallinckrodt Radiation Safety Officer

Mallinckrodt's Radiation Safety Officer (RSO) must have completed a basic health physics course, must have a minimum of five years experience in health physics and radiation safety, and must be familiar with NRC radiation protection standards. This person must have sufficient cognition of the types of radionuclides to be encountered and of decommissioning operations to perform duties of the RSO.

[1] The import of *equivalence* of qualification of an occupant of a position is that the occupant, by knowledge, skill, and or experience, be capable of performing the duties of the position.

9.3.3. Mallinckrodt Safety Manager

This person must hold a baccalaureate degree in science or engineering and have a minimum of five years experience in nuclear safety, health physics, industrial safety, or environmental protection.

9.3.4. Contractor Project Manager

This person must hold (a) a baccalaureate degree in science or engineering and have a minimum of five years of experience in the nuclear industry, including five years of project management experience or (b) a baccalaureate degree in science or engineering and have a minimum of five years of construction experience with at least five years of experience in nuclear activities as well as five years of project management experience.

9.3.5. Contractor Radiation Protection, Health, and Safety Manager

This person must have a baccalaureate degree in science or engineering, must have completed a basic health physics course, must have a minimum of five years experience in occupational and environmental radiation protection industrial safety, and decommissioning, and must be familiar with NRC radiation protection standards.

9.3.6. Contractor Quality Assurance Manager

This person must hold a baccalaureate degree in engineering, chemistry, or the physical sciences with at least two years experience in quality assurance or quality control.

9.3.7. Contractor Operations Manager

This person must have a minimum of five years construction management experience with a minimum of two years radioactivity or chemical remediation management experience.

9.4. TRAINING

All decommissioning activity will be performed in accordance with license STB-401, the C-T Phase II Decommissioning Plan, and the Administrative Control Plan. With the exception of the Mallinckrodt site-wide industrial safety training program described in Section 9.4.1 below, all required training will be provided by the contractor. Training subcontractors will be used as appropriate to provide timely and cost-effective training.

Construction workers performing decommissioning will be trained as radiation workers commensurate with the radiological dose and risk estimated and observed.

9.4.1. Industrial Safety Training

All decommissioning personnel will be required to successfully complete the existing Mallinckrodt St. Louis Plant site-wide industrial safety training program before starting physical activity or unescorted access to the site. The purpose of the program is to promote an awareness of the potential risks, and to provide knowledge and proficiency in industrial safety consistent with the assigned tasks. Training takes place on a routine and frequent basis.

Personnel involved in the C-T Project will be trained to perform their assigned responsibilities safely. On-the-job training and equipment-specific training will supplement the Mallinckrodt site-wide training program. Training in the proper use of specialized equipment is given before the person uses that equipment. Credit may be given for applicable training received off-site.

The primary objectives of the C-T Project industrial safety training program are to:

- provide information on the industrial safety and hygiene hazards associated with working at the St. Louis Plant and on the C-T Project and the steps to be taken to provide a safe work environment, including those hazards unique to excavation and management of soil and debris;
- enable each person to comply with plant rules and respond properly to warnings and alarms under normal and accidental conditions; and,
- enable persons to recognize potential site specific hazards and to take appropriate measures to prevent personal injury or damage to facilities and equipment.

The industrial safety training program will be reviewed and revised as needed to meet changing conditions and ensure that instructions are sufficiently well understood to permit practical application. The status and extent of the training of each person will be documented to verify that each worker is adequately trained for each job he will perform.

9.4.2. Radiation Safety Training

All unescorted persons involved in decommissioning activities for the C-T Project will be required to complete the Mallinckrodt radiation safety training course or the contractor equivalent course. Construction workers who perform decommissioning will be trained as radiation workers commensurate with the radiological dose estimated and observed. The purpose of the training is to increase awareness of the potential radiation risks during decommissioning, and to provide a level of proficiency in personal radiation protective measures consistent with assigned tasks. On-the-job training, as deemed necessary by the contractor ES&H personnel, will be used to complement the formal radiation safety training.

Each person will be trained before entering a controlled area to perform work. The safety performance of each person will be reviewed annually, and workers will be retrained every two years. Credit may be given for applicable training received off-site, but plant-specific training is required for all decommissioning personnel. Training and examination results will be formally documented.

The primary objective of the radiation safety training program is to enable workers to work safely and comply with the instruction requirements of 10 CFR 19.

The radiation safety training will be reviewed and revised as appropriate to meet changing conditions and ensure that instructions are sufficiently well understood to permit practical application.

The radiation safety training program includes the following topics:

- radiation fundamentals - basic characteristics of radiation and contamination;
- radiation exposure limits, administrative control levels, and controls - external radiation exposure control methods, procedures, and equipment;
- radiation contamination limits and controls - contamination and internal radiation exposure control methods, procedures, and equipment;
- contaminated materials associated with decommissioning work - potential radiological problems;
- radiological work planning - integrating radiation safety and operational requirements to ensure safe conduct of work;
- application, use, and maintenance of personal protective equipment and devices;
- emergency procedures and systems - work related information and actions;
- biological effects of radiation - basic understanding of biological effects and methods of assessment; and,
- the Radiation Protection Program.
- workers rights and responsibilities
- radiation exposure reports which workers may request pursuant to 10 CFR 19.13
- ALARA

9.4.3. Training Documentation

Training will be documented in each person's training record, including Mallinckrodt, contractor, and subcontractor personnel. Training received prior to employment on the C-T project, *e.g.*, initial or annual HAZWOPER training, will be verified and included in the person's record before physical work is performed. All classroom training and initial on-the-job training on decommissioning procedures or the use of specialized tools, equipment, or methods will be documented. General safety awareness discussions such as daily tailgate meetings and jobsite discussions prior to or during the performance of a given task will not be documented.

9.5. ADJUSTMENTS TO THE DECOMMISSIONING PROCESS

Decommissioning is intended to remove sources, thereby diminishing the extent of controls needed to assure protection of health, safety, and the environment as it progresses. Mallinckrodt may make justified changes related to the decommissioning process without filing an application for an amendment to the license to change the decommissioning plan when the following conditions are satisfied:

a. the change does not conflict with requirements specifically stated in license STB-401 nor impair Mallinckrodt's ability to meet all applicable NRC regulations;
b. there is no degradation in safety or environmental commitments addressed in the NRC-approved decommissioning plan for the activity being performed;
c. the quality of the work, the remediation objectives, or health and safety will not be adversely affected significantly;
d. the change is consistent with the conclusions of actions analyzed in the Environmental Assessment;
e. reasonable assurance that adequate funds will be available for decommissioning remains;

f. the coverage requirements for scan measurements and/or sample density will not be reduced;
g. the derived concentration guideline levels and related minimum detectable concentrations (for both scan and fixed measurements methods) will not be increased;
h. the radioactivity level, relative to the applicable derived concentration guideline level, at which an investigation occurs will not be increased;
i. the statistical test applied to a final status survey will not be other than approved section 14 herein, or a Sign test, a Wilcoxon Rank Sum test, or those described in NUREG-1505;
j. the NRC Project Manager concurs that the Type I decision error (for Scenario A of NUREG-1505) or the Type II decision error (for Scenario B of NUREG-1505) may be increased beyond 0.05 and will not be increased beyond what is authorized in section 14 herein; and
k. a final status survey area classification will not be decreased, *e.g.*, from impacted to non-impacted; Class 1 to Class 2; Class 2 to Class 3; or Class 1 to Class 3,without NRC concurrence.
l. the NRC Project Manager concurs that a survey unit may be subdivided and reclassified; or
m. the NRC Project Manager concurs that the Scenario B hypothesis may be used to test a final status survey in lieu of the Scenario A hypothesis.

Persons having managerial responsibilities as identified in section 9 *Project Organization and Management*, including proponents of controlled documents, will be asked to report any change to the decommissioning process that would seem to violate either of conditions *a* through *k*. Determination of whether the conditions are met will be made by and each change shall require approval by Mallinckrodt's C-T Project Manager, and Radiation Safety Officer, the contractor's Project Manager, and its RPHS representative. Mallinckrodt's and the contractor's C-T Project Managers are responsible for ensuring that the project is conducted in accordance with applicable health, safety, quality, and technical requirements. Mallinckrodt's C-T Project Manager shall be responsible for approval of operational and engineering changes. The contractor's RPHS representative and Mallinckrodt's Radiation Safety Officer are responsible for assuring that each change conforms to health and safety program requirements.

Mallinckrodt shall retain records, including written safety and environmental evaluations of each authorized change, that provide the basis for determining that conditions in this §9.5 have been met. The records of each evaluation shall be retained until license termination.

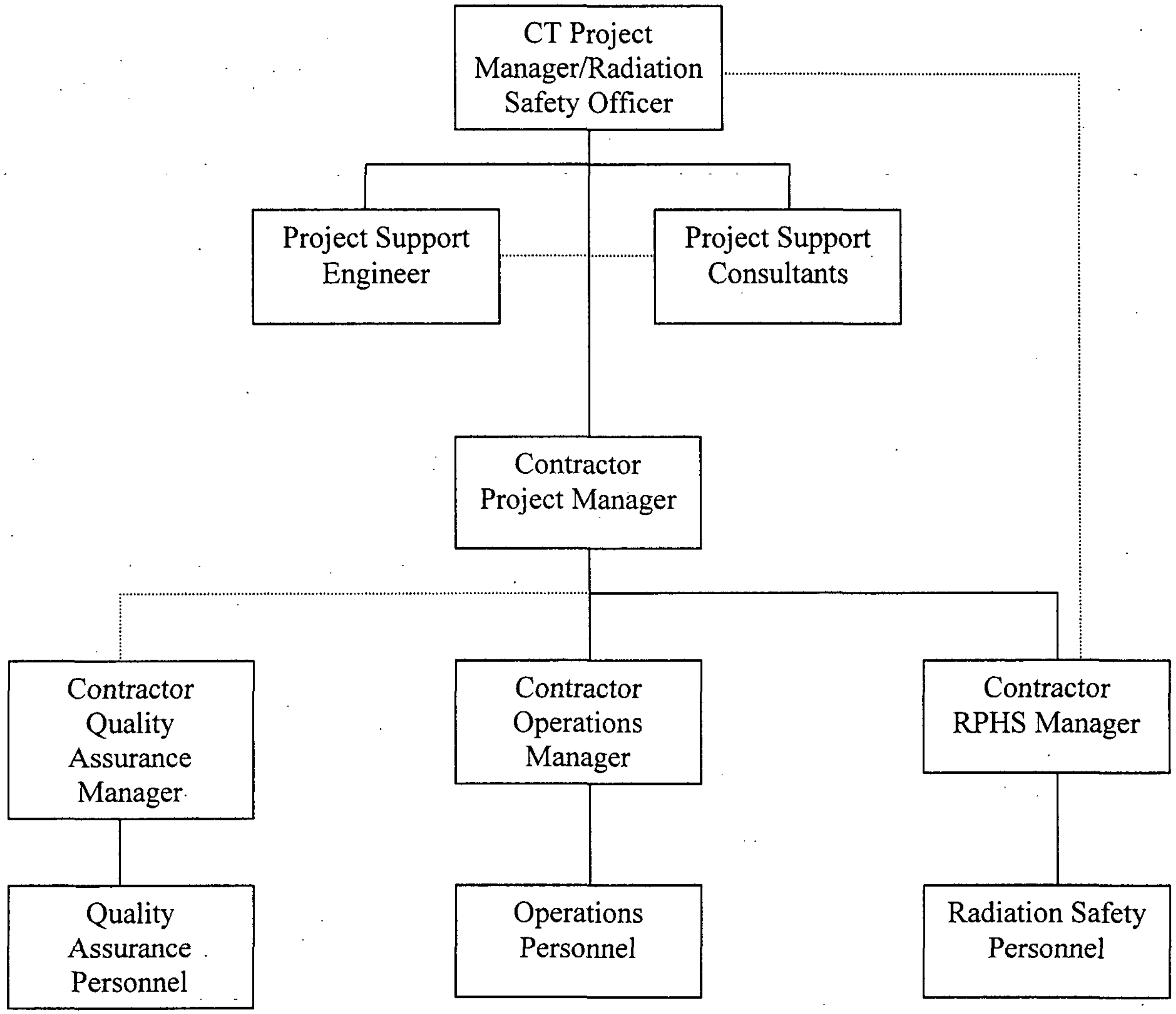


Figure 9-1 C-T Phase II Decommissioning Organization

SECTION 10

RADIATION SAFETY PROGRAM DURING DECOMMISSIONING

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
July 23, 2008

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

10. RADIATION SAFETY PROGRAM DURING DECOMMISSIONING

This chapter describes the radiation safety program for the C-T Phase II Decommissioning Plan project to ensure the safety of all Mallinckrodt employees, contractors, and visitors during decommissioning. In recognition that the amount of radioactivity and therefore associated hazards will be reduced as the project progresses, the radiation safety program may be modified to be commensurate with the activities being performed. Mallinckrodt will review and approve implementation of the radiation safety program, and any revisions that are made during the project. Any such adjustment to the requirements of the radiation safety program shall be made in accordance with Section 9 Project Management and Organization.

10.1. RADIATION SAFETY CONTROLS AND MONITORING FOR WORKERS

The Radiation Safety Program will include procedures to protect workers, the public, and the environment from ionizing radiation. The contractor will be required to implement the program with oversight by the Site RSO.

10.1.1. Air Sampling Program

10.1.1.1. Collection

Concentrations of radioactive material in air will be determined by sampling the air. Air sampling shall be conducted in accordance with or equivalent to the guidance provided in U.S. NRC Regulatory Guide 8.25, "Air Sampling in the Workplace", July 1992. Breathing zone air samples will be the primary method of monitoring the worker's intake of radioactive material. The samples will be collected under known physical conditions (*e.g.*, filter type, sample time, flow rate). The flow meters of air samplers shall be calibrated at least annually. Calibration shall also be performed after repair or modification of the flow meter.

Air samples will also be collected of general and localized areas when and/or where there is potential for generation of airborne radioactive material. These samples will be used to verify that the confinement of radioactive material is effective and provide warning of elevated concentrations for planning or response actions. In each case, the sampling point will be located in the airflow pathway near the known or suspected release point(s). As necessary, more than one air sample location may be used in order to provide a reasonable estimate of the general concentration of radioactive material in air.

This Plan for air sampling is implemented in procedures for:

- Survey requirements and frequencies
- Environmental monitoring
- Performance of radiation, contamination, and airborne radioactivity surveys
- Air sampler operation
- Survey documentation and review, and
- Air sample analyzer calibration and operation.

Considering the low radioactivity concentration observed during characterization and during Phase 1 decommissioning, the ventilation rate in outdoor air, instrumentation having instant readout, annunciator, or alarm, is not proposed for the C-T Phase II Decommissioning Project.

10.1.1.2. Action Level and Limit

An administrative action level shall be established for breathing zone air samples of one DAC; air sample results greater than this administrative action level shall be reported to the RPHS Manager or the RSO. In the event airborne radioactivity concentration is > 1 DAC or likely to be more than 12 DAC·hr in a week, the area shall be posted as an *airborne radioactivity area* with wording "Caution, Airborne Radioactivity Area" or "Danger, Airborne Radioactivity Area." An administrative limit shall be established for breathing zone air samples of 10 DAC-hours; individual exposure greater than this action level shall require the individual to be restricted from work involving potential exposure to airborne radioactive material unless approved by the Site RSO. An action level, in DAC·hr, for airborne particulate radioactivity exposure will be established, above which evaluation of internal exposure by bioassay will be required.

10.1.2. Respiratory Protection Program

The use of respiratory protection is not anticipated to be necessary during the C-T Phase II Decommissioning Project. However, in the event Mallinckrodt uses respiratory protection equipment to control inhalation of radioactive material, it will maintain and implement and administer a respiratory protection program as specified in this §10.1.2.

The respiratory protection program (RPP) provides guidance and instruction regarding protection of workers from occupational injury and illness due to exposure to airborne radioactive material. The RPP is implemented by written procedures. The RPP and implementing procedures are the primary means used to administratively establish safe respiratory protection practices and compliance with requirements of the NRC.

The RPP covers routine use of respiratory protection equipment. The functional areas of the RPP include medical evaluation, fit testing, selection, issue, inspection, cleaning, maintenance, storage, and training. The RPP incorporates specifications for respiratory protection in 10 CFR Part 20, Subpart H, to guide preparation of procedures implementing a respiratory protection program.

10.1.2.1. Medical Evaluation

Prior to the initial fit test, and at least every 12 months thereafter, an evaluation will be made of each worker required to wear respiratory protection equipment as part of the worker's duties as to whether or not the worker can wear the required respirator without physical risk. A worker will not be allowed to wear a particular type of respirator if, in the opinion of a physician, the worker might suffer physical harm due to wearing the respirator. A worker shall not be allowed to use a respirator without a current medical evaluation.

10.1.2.2. Fit Test

All workers required to wear respiratory protection equipment shall be required to successfully complete a fit test prior to initial use of the equipment. The fit test shall be repeated at least annually. A worker shall not be allowed to wear a respirator without a current successful fit test.

10.1.2.3. Selection

Respirators shall be selected from those approved by the National Institute for Occupational Safety and Health and or the Mine Safety and Health Administration for the contaminant or situation to which the worker may be exposed. The Contractor's EH&S staff shall select the respirator type. Selection shall be based on the physical, chemical, and physiological properties of the contaminant, the contaminant concentration likely to be encountered, and the likely physical conditions of the workplace environment in which the respirator will be used. The potential or observed airborne radioactivity concentration would also be considered in selecting the type of respiratory protection equipment to be issued.

10.1.2.4. Issue

Workers may be assigned respirators for their exclusive use or they shall otherwise be issued by the Contractor's EH&S staff. Respirators shall only be assigned or issued to workers qualified, with respect to the program, to use respiratory protection equipment. The type of respirator selected shall be documented on a Radiation Work Permit.

10.1.2.5. Inspection

Each respirator shall be inspected with regard to operability before, and routinely after, each use, and after cleaning.

10.1.2.6. Cleaning

Respiratory protection equipment that is used routinely shall be cleaned after each use. Respiratory protection equipment that is used by more than one worker shall be cleaned and disinfected after each use. The need for cleaning shall also be based on contamination surveys of the work area and of the respiratory protection equipment.

10.1.2.7. Maintenance

Respiratory protection equipment shall be maintained to retain its original effectiveness. Replacement or repair shall be done only by experienced persons, with parts designed for the respirator. No attempt shall be made to replace components or to make adjustments or repairs beyond the manufacturer's recommendations. Reducing valves or admission valves on regulators shall be returned to the manufacturer or equivalent for repair.

10.1.2.8. Storage

Respirators shall be stored to protect against dust, sunlight, heat, extreme cold, excessive moisture, or damaging chemicals. Respirators shall be stored in dedicated carrying cases or cartons that protect from dirt and damage.

10.1.2.9. Training

All workers required to use respiratory protection equipment shall be instructed in the content and applicability of the program and implementing procedures, and especially in the proper use of the equipment and its limitations. A worker shall not be allowed to use a respirator without current successful completion of training.

10.1.3. Internal Exposure Determination

Individual monitoring shall be provided for workers who require monitoring of the intake of radioactive material pursuant to 10 CFR 20.1502(b). Monitoring of intake shall normally be conducted by use of air samples, particularly of the breathing zone. Internal dose shall be determined by converting airborne concentrations to intakes in accordance with NRC Regulatory Guide 8.34 "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

When a potential or actual condition exists where the worker(s) could have received an unmonitored intake of radioactive material, and cannot otherwise be estimated, the intake shall be determined by measurements of quantities of radionuclides excreted from or retained in the body. These measurements shall be made consistent with the guidance provided in NRC Regulatory Guide 8.9 "Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program", July 1993.

Determination of radiation dose to the embryo/fetus shall be performed in accordance with NRC Regulatory Guide 8.36 "Radiation Dose to the Embryo/Fetus", July 1992.

Work restrictions shall be implemented for any worker with an intake in excess of 50% of the applicable limit in 10 CFR 20. Work restrictions shall be implemented for any worker with an intake in excess of 50% of the chemical toxicity limit for soluble uranium.

10.1.4. External Exposure Determination

An individual monitoring device shall be provided to each worker who requires monitoring for external exposure pursuant to 10 CFR 10.1502(a). External monitoring shall be conducted in accordance with or equivalent to NRC Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

External exposure monitoring, when required, shall be accomplished using a thermoluminescent dosimeter or optically-stimulated luminescence dosimeter worn on the front of the upper torso. Radiological surveys may be performed to supplement personnel monitoring when work is being performed where workers are required to be monitored.

Dosimeters shall be processed at least quarterly by a vendor accredited by NVLAP.

Work restriction shall be implemented for any worker reaching 50% of the annual limits of 10 CFR 20.

10.1.5. Summation of Internal and External Exposures

Results of internal and external monitoring shall be used to calculate total organ dose equivalent and total effective dose equivalent to workers for which monitoring is required. Summation of internal and external doses shall be performed in accordance with NRC Regulatory Guide 8.34 "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

10.1.6. Contamination Control Program

Contamination control shall be managed by exposure control and monitored by radiation surveys.

10.1.6.1. Exposure Control

Personnel exposure to radioactive material will be controlled by application of engineering, administrative, and personnel protection provisions. The priority of application will be descending with respect to their order of description below.

Engineering. Engineering controls will be used, as practicable, to minimize or prevent the presence of uncontained radioactive material. Engineering controls will predominantly be comprised of containment, isolation, ventilation, and decontamination.

Administrative. Administrative controls will be used to control work conditions and work practices. Administrative controls will predominantly be comprised of the following:

Access control: Routine access to work areas will be limited to personnel necessary to accomplish tasks or activities. Access to work areas will also be controlled with respect to an individuals completed level of training, and requirements for use of personnel protection equipment.

Postings and barriers: Postings will be used to inform personnel of relevant hazards or conditions and associated access requirements. Barriers may be used to prevent unauthorized access.

Procedures: Written procedures may be used to describe specific radiation safety requirements necessary for tasks that involve radioactive material.

Safety Work Permit: The requirements for a Safety Work Permit (SWP) are described in Section 9.2. SWP will be used to describe specific or special worker protection requirements for activities involving radioactive material and not covered by a procedure. SWP may also be used in conjunction with a procedure.

Contamination Control: Action levels and limits for radiation surveys, described later in this section, will be used to control the levels of radioactivity on equipment and in areas.

Personal Protective Equipment. Personal protective equipment will be used to control personnel exposure to radioactive material when administrative controls are not sufficient and engineering controls are not practicable. Personal protective equipment may include head covering, eye protection, respiratory protection, impervious outerwear, gloves, and/or protective shoes or shoe covers.

10.1.6.2. Radiation Surveys

Radiation surveys will be performed to describe the radiation types and levels in an area or during a task, to identify or quantify radioactive material, and to evaluate potential and known radiological hazards.

The types of radiation surveys and their frequency are described in the following subsections.

Contamination Measurements. Measurements will be made of removable alpha and/or beta-gamma. The measurements will be made by wiping an area with cloth, paper, or tape. The radiation levels will be measured on the wipe. Contamination surveys shall be performed at the end of each workday where invasive demolition of contaminated material was performed.

Radiation. Exposure rate measurements will be performed using an ion chamber or equivalent. Measurements will be made at 30 centimeters. Measurements may also be made at contact.

Personnel. Personnel will be frisked prior to leaving an access controlled area.

Action Levels. Action levels are established to inform facility personnel when a situation needs to be evaluated so that corrective action can be taken. Action levels are set so that corrective actions can be made before a regulatory limit is exceeded.

Exceedance of an action level requires investigation including evaluation of preventative and/or corrective action. The investigation, and documentation of such, is completed commensurate with the significance of the condition.

Radiation levels exceeding the values described in the following subsections will be reduced below the respective levels as soon as practicable.

Removable: The action level for removable alpha or beta-gamma radiation on a surface is 1000 αpm/100 cm^2 or 1000 βpm/100 cm^2.

Exposure Rate: The action level for exposure rate is two millirem per hour at 30 centimeters.

Personnel: The action level for personnel and their personal effects is three times the background count rate of the survey instrument.

Limits. Items that are to be released without restriction on use will be subject to NRC "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material', as specified in Materials License STB-401, Condition 16.

On the basis U-to-Th ratio = 3,[1] the derived maximum acceptable contamination on the surface of an item to be released for removal from a radiologically restricted area in Plant 5 during C-T

[1] The uranium-to-thorium ratios in characterization surveys of cinder fill soil in Plant 5 are lognormally distributed with a log-mean ratio = 3. When the U-to-Th ratio ≤ 3, which would diminish the release limit, only 0.06 of samples contain > 10 pCi U+Th per gram soil, *i.e.*, are substantially above background. Consequently, the areal

Phase II decommissioning without restriction on future use is specified in Table 10-1. Derivation of the maximum acceptable average radioactivity in Table 10-1 is explained in Appendix I.

Table 10-1. Maximum Acceptable Surface Radioactivity on Items to be Released for Removal from a Restricted Area Without Restriction on Use

Nuclides	Average (α/min·100 cm²)	Maximum (α/min·100 cm²)	Removable (α/min·100 cm²)
U + Th mix in Plant 5	2800	8400	600

A As used in this table, dpm α means the rate of emission of alpha rays determined by correcting instrument counts per minute for background, efficiency, and geometric factors

B Measurements of average contaminant should not be averaged over more than 1 square meter. For an object of lesser surface area, the average should be derived for each such object.

C The maximum contamination level applies to an area of not more than 100 cm^2.

D The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

The limits are administered such that, when exceeded, action must be taken to reduce the level or additional control must be applied.

Items will not be released for unrestricted use until the relevant limits are satisfied.

Accessible surfaces and areas outside of an access-controlled area that exceed the respective limits will be decontaminated on a timely basis. In no case will the delay to initiate control exceed one normal workday. In the case of personnel contamination, there will be no delay to initiate decontamination.

10.1.7. Instrumentation Program

Instrumentation utilized for personnel monitoring will be calibrated and maintained in accordance with radiation safety procedures. Instrument calibration will be performed by the manufacturer, or by a contractor subject to equivalent calibration requirements. Portable instruments are calibrated on a semi-annual basis or as required due to maintenance. Specific requirements for instrumentation include traceability to NIST standards, field checks for operability, background radioactivity checks, operation of instruments within established environmental bounds (*i.e.*, temperature and pressure), training of individuals, scheduled performance checks, calibration with isotopes with energies similar to those to be measured, quality assurance tests, data review, and record keeping. Where applicable, activities of sources

density of soil on an item considered for release is unlikely to produce more than maximum acceptable areal radioactivity when that limit is derived on the basis of U-to-Th ratio = 3.

utilized for calibration are also corrected for decay. All calibration and source check records are completed, reviewed, signed off and retained in accordance with Quality Assurance Program requirements. A list of typical radiation instrumentation and minimum detectable activities (MDA) for health physics application is given in Table 10-1. Typical personnel monitoring equipment is shown in Table 10-2.

In the event an instrument of the type listed in Table 10-1 is employed for the C-T Decommissioning Project, its background count rate or exposure rate and its lower limit of detection will be estimated for its application. Alternative instrumentation must also be able to measure adequately to assess compliance with radiological safety requirements.

Table 10-1. Typical Instruments for Performing Radiation Surveys

Instrument Type	Radiation Detected	Scale Range	BKG	Typical MDA 95% confidence Level
Scintillation (Ludlum 2224) Scaler/Ratemeter	Alpha Beta Beta	0-500,000 cpm	<10 cpm <300 cpm	100 dpm/100 cm^2 500 dpm/100 cm^2 4500 dpm/100 cm^2 (scan)
Micro-R Meter (Ludlum) 1" x 1" NaI Detector	Gamma	0-3,000 μR/h or 0-5,000 μR/h	7 μR/h	1-2 μR/h
Ion Chamber (Victoreen)	Gamma	0.1-300 mR/h	<0.1 mR/h	<0.2 mR/h
3" x ½" NaI Scintillation Detector Digital Scaler	Gamma	0-500,000 cpm	3,000 cpm avg shielded 9,000 cpm avg unshielded	250 cpm 500 cpm
435 cm^2 gas flow (43-27) Digital Scaler	Alpha	0-500,000 cpm	<10 cpm	20 dpm/100 cm^2
100 cm^2 gas flow (43-68) Digital Scaler	Alpha Beta Beta	0-500,000 cpm	<10 cpm <300 cpm	100 dpm/100 cm^2 500 dpm/100 cm^2 4500 dpm/100 cm^2 (scan)
60 cm^2 gas flow (43-4) Digital Scaler	Alpha	0-500,000 cpm	<10 cpm	200 dpm/100 cm^2
60 cm^2 Count Rate Meter (PRM-6)	Alpha	0-500,000 cpm	<100 cpm	350 dpm/100 cm^2
50 cm^2 Personnel Room Monitor (Ludlum 177)	Alpha	0-500,000 cpm	<100 cpm	500 dpm/100 cm^2
Ludlum 2" GM Tube (Pancake)	Beta Gamma	0-500,000 cpm 720 cpm = 0.2 mR/h	<200 cpm	70 cpm
Bicron AB-100 Scintillation Probe	Beta	0-500,000 cpm	<200 cpm	200 dpm/100 cm^2

Notes: 1) Instrument MDA are based upon static measurements, one minute count times unless otherwise noted.

2) Instrument MDA depend upon background.

Table 10-2. Typical Equipment for Performing Personnel Monitoring

Equipment Description		Purpose
Personal Air Samplers (BZ)	Gillian or equivalent	Breathing zone air monitoring
Area Air Samplers	SAIC or equiv.	High volume air monitoring
Area Air Samplers	SAIC or equiv.	Work area low volume air monitoring
Personnel Dosimetry	TLD or equiv.	Deep dose, eye dose, skin dose
Alpha Frisker	Ludlum 43-68 or equiv.	Contamination monitoring
Alpha Frisker	Ludlum 177	Contamination monitoring
Beta Frisker	Bicron AB100	Contamination monitoring
Micro-R meter	Ludlum or equiv.	Exposure rate
Ion Chamber		Dose rate

10.2. NUCLEAR CRITICALITY SAFETY

This topic is not applicable to the C-T Decommissioning Project.

10.3. HEALTH PHYSICS AUDITS, INSPECTIONS, AND RECORD-KEEPING

The radiation safety program shall be subject to an annual audit and periodic inspections. Each is performed to determine whether radiological safety activities are conducted in accordance with regulations, license conditions, and written procedures.

An audit of the radiation safety program shall be conducted annually. The audit shall be conducted by the Site RSO or designee. The audit will consider the basic functional areas of the radiation safety program; *e.g.*, Safety Work Permits, radiation safety procedures, radiological surveys and air monitoring, ALARA emphasis, individual and area monitoring results, access controls, respiratory protection program, training, *etc.*

The audit shall be conducted in accordance with a specific audit plan developed by the auditor. A written report shall be generated upon completion of the audit describing the results. The report shall be distributed to site management. As necessary, a written corrective action plan shall be prepared to address non-compliance issues. All corrective actions shall be tracked to completion. Once corrective actions have been completed, a written closure report shall be distributed to management documenting the completion of corrective actions.

Periodic inspections shall be conducted by the Contractor's EH&S staff. These inspections shall be routine reviews performed of operations and activities. The inspections shall normally be completed against a pre-established checklist. Checklists may be developed independently for differing periods; e.g. daily, weekly, monthly, etc. The checklist items shall usually be comprised of routine procedural requirements. Any findings discovered during the routine inspection shall be recorded on a tracking log. The log shall be maintained by the Contractor's EH&S Representative. The log shall include a description of planned corrective action and date of completion of corrective action.

SECTION 11

ENVIRONMENTAL MONITORING AND CONTROL PROGRAM

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
April 11, 2006

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

11. ENVIRONMENTAL MONITORING AND CONTROL PROGRAM

This section describes an environmental safety program to monitor environmental radiation, air effluent, and water effluent discharged from the C-T Decommissioning Project. The program will be reviewed and approved by Mallinckrodt prior to implementation. Samples will be routinely collected or measurements routinely made at on-site and site boundary or off-site locations to determine the extent of environmental discharges during remediation. Monitoring locations will be chosen commensurate with remediation activities.

In recognition that both the amount of radioactivity and the general environmental hazards will be reduced as decommissioning progresses, the Environmental Safety Program can be modified to be commensurate with the activities being performed by following the procedure described in Section 13.2.6.

11.1. ENVIRONMENTAL ALARA EMPHASIS

11.1.1. ALARA Emphasis for Effluent Control

The project ALARA aim for effluents is 50% of the respective value in 10 CFR 20 Appendix B. The aim is not intended to set precedent or to be applied as a limit. The emphasis may be adjusted on the basis of review with regard to what may be ALARA for the particular circumstance.

The action levels for air and water effluents are based on the levels provided in 10 CFR 20, Appendix B, Tables 2 and 3. The action levels are 0.75 for environmental air, 0.6 for effluent water, and 0.6 for sewage effluent. If exceeded, an investigation will be initiated. The results of the investigation will include identification of appropriate corrective actions.

The site Radiation Safety Officer (RSO) will be responsible for setting and periodically reviewing the ALARA emphasis. The RSO shall be responsible for conducting investigations initiated due to exceeding an investigation level.

11.1.2. Engineering Controls and Processes

A description of practices, process controls, and engineering controls to maintain concentrations of radioactive material in effluents ALARA is provided in Section 11.3.

11.1.3. ALARA Reviews and Reports to Management

The effectiveness of the ALARA emphasis for the environmental monitoring and control of effluents is evaluated through the use of surveillances and audit(s).

11.1.3.1 Surveillance

The environmental monitoring and control program will be periodically subjected to surveillance. Surveillances are intended to verify that the objectives of the program are being satisfied and that the emphasis is generally effective. The surveillances may be limited in scope.

11.1.3.2 Audit

Environmental audits are scheduled and conducted under the Quality Assurance Program described in Section 13 of this Decommissioning Plan.

11.2 EFFLUENT MONITORING

11.2.1 Expected Concentrations

Concentrations of radionuclides in effluents are not expected to increase as a result of the activities conducted under this DP. The effluent controls described in Section 11.3 are intended to realize this condition.

11.2.2 Physical and Chemical Characteristics

The physical and chemical characteristics of radionuclides in any discharges from the activities conducted under this DP are expected to be representative of the source material characterization in DP Section 4.

11.2.3 Discharge Locations

Each area of remedial activity will have a known location(s) of discharge of storm water from the area. The location(s) will be identified in written procedures or work plans.

Emissions to air may occur from specific locations of activity and therefore will vary with the progress of the project. The emissions are expected to be ground-level or from inside a structure. No discharge from a stack is planned.

11.2.4 Sample Collection and Analysis

Water samples will be collected and analyzed in accordance with the requirements of the Industrial Wastewater Discharge Permit issued by the Metropolitan St. Louis Sewer District, which is designed to be representative of the effluent discharges.

11.2.5 Sample Collection and Analysis Procedures

11.2.5.1 Effluent Air Monitoring

No effluent air monitoring is anticipated, since no point source of effluent air is expected to exist. However, in the event a decontamination process exhaust ventilation or similar point discharge of potentially radioactive effluent air were employed, its effluent air would be sampled and analyzed for regulated radioactive particulate.

11.2.5.2 Environmental Air Monitoring

Environmental sampling stations will be provided during demolition or decontamination activities as required by 10 CFR Part 20 to verify there are no adverse impacts to on-site workers and the public. Each environmental sampling station will be equipped with an air sampler.

Collection and analysis of the continuous air samples will be performed during demolition or decontamination activities as required by 10 CFR Part 20. The samples will be analyzed for gross alpha and gross beta activity as representatives of the uranium and thorium series. The analytical instruments will be calibrated using standards traceable to the National Institute of Science & Technology (NIST).

Measurement of gross radioactivity on an air sample filter enables timely evaluation and has traditional precedent for airborne natural uranium and thorium particulate.[1, 2] A representative spectrum of the key, long-lived uranium series and thorium series radionuclides in soil in Plant 5 that would be the potential source of airborne radioactive particulate has been derived from soil characterization survey data. A DAC will be derived for that spectrum of key U-series and Th-series radionuclides. That spectrum is based on premises:

- thorium series is in approximate radioactive equilibrium and is assumed so;
- key, alpha-emitting, uranium series radionuclides, U^{238}, Th^{230}, and Ra^{226}, and Th-series observed in excess of natural background
- ratio of geometric mean of U^{238}-to-geometric mean of Th-series; and ratio of geometric mean of Ra^{226}-to-geometric mean of U_{nat} or Th-series, when in excess of natural background.

11.2.5.3 Storm Water Monitoring

It will be the policy of Mallinckrodt during the C-T Decommissioning Project to minimize the production of contaminated aqueous liquids. There are three possible sources of contaminated aqueous liquids: sink and shower water, decontamination fluids, and water used for dust suppression. Mallinckrodt expects sink and shower water to contain an insignificant amount of regulated radioactive material in readily dispersible biological material, and thereby may be discharged to sanitary sewerage in accordance with 10 CFR Part 20.2003 without monitoring. Should rainwater or surface water be collected, it will ordinarily be used for dust suppression of solid waste destined for NRC-approved disposal. In the event other aqueous waste potentially containing significant concentration of regulated radioactive material were considered for discharge to sewerage, Mallinckrodt would, beforehand, filter it to remove non-dispersible solids, sample and analyze it, estimate the concentration in sewage, compare it with the 10 CFR

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[1] 10 CFR Part 20, Appendix B, Note 3, provides for gross alpha measurement of U series in ore dust prior to chemical separation.

[2] NRC Draft Regulatory Guide DG-8026, Sept. 2000. Formerly Regulatory Guide 8.30.

Part 20, Appendix B, Table 3, monthly average concentration limit, and estimate the total radioactivity inventory discharged.

11.2.6 Sample Collection Frequencies

Water samples will be collected in accordance with the requirements of the Industrial Wastewater Discharge Permit.

11.2.7 Environmental Monitoring Recording and Reporting Procedures

Water sample analyses will be recorded and reported in accordance with the requirements of the Industrial Wastewater Discharge Permit.

11.2.8 Quality Assurance Program

The Quality Assurance Program described in Section 13 is applicable to the implementation and conduct of the Environmental Monitoring and Control Program.

11.2.9 Direct Radiation Monitoring

The environmental safety program is designed to assure that direct radiation in unrestricted areas does not exceed limits in 10 CFR 20.1301. The objective of direct radiation monitoring is to verify the effectiveness of the environmental safety program in meeting the limits.

The monitoring of penetrating radiation will be performed using standard environmental thermoluminescent dosimeters that are placed at various locations around the perimeter of the restricted remediation area. These dosimeters will be collected by Health and Safety personnel and analyzed quarterly by a qualified contract vendor to measure the integrated gamma dose for each location.

11.3 EFFLUENT CONTROL

11.3.1 Practices, Process Controls, and Engineering Controls

Available process options will be considered to control the concentration of radioactive material in effluents to the environment. Examples of process controls include recycling, leakage reduction, and modification of facilities, operations, and/or procedures. If further reduction in effluent concentration is necessary, available engineering options will be considered. Examples of available engineering options include filtration, adsorption, containment, and storage.

Process and engineering options will be implemented unless a review indicates that a substantial reduction in effluent concentration would not result or costs are considered unreasonable. A determination of reasonableness may be based on a qualitative review requiring the exercise of professional judgment for factors difficult to quantify. These factors could include nonradiological social or environmental impacts, availability and practicality of alternative technologies, and potential for unnecessarily increasing occupational exposures.

Effluent controls will be described in a written procedure, work instruction, or safety permit. The primary effluent controls used are expected to be dust suppression and erosion control.

11.3.1.1 Dust Suppression

Administrative controls, such as use of less aggressive decontamination or demolition techniques, will be used to minimize generation of fugitive emissions. Engineering controls, such as water spray or filtration, will also be utilized to control fugitive emissions and minimize visible dust.

11.3.1.2 Erosion and Sediment Control

Erosion and sediment controls may be temporary or permanent, depending on the duration of the activity and any specific objectives. Controls will be provided in accordance with best management practices, regulatory guidance, manufacturer's specifications, and good engineering practices. Temporary controls serve to minimize erosion and restrict the transport of sediment within the project area. Permanent controls serve to stabilize the site with durable erosion control features to control sediment discharge, and protect nearby surface waters. Descriptions of erosion and sedimentation control practices that will be considered for use during the project include:

Stabilization Practices:

- Minimizing disturbance areas;
- Minimizing and controlling dust;
- Stabilizing surfaces after final grading; and
- Permanent vegetative cover for disturbed areas not intended for other cover.
- Pavement

Structural Features to Control Erosion and Sedimentation:

- Barriers to isolate areas of erosion and minimize sediment transport;
- Check dams in swale areas to minimize sediment transport;
- Erosion control blankets to minimize erosion due to concentrated flow prior to establishing vegetation;
- Construction of stabilized construction entrances to minimize the transport of sediment from project areas; and
- Stockpiles will be surrounded by sediment barriers.

Storm Water Management Practices

- Maintaining runoff flow patterns and discharge locations similar to existing conditions; and
- Maximizing overland flow through vegetated areas.

11.3.2 Action Levels

The action levels for implementation or revision of effluent controls are those described previously in Section 11.1.1.

11.3.3 Leak Detection Systems

Other than a pit from which contaminated soil was excavated, no impoundment is being planned for retention or processing of wastewater for the C-T Decommissioning Project. Processing systems use tanks, which can be visually inspected for leakage.

11.3.4 Release to Sewerage

Release to sewerage is described in Section 11.2.6.1.

11.3.5 Radiological Dose to Members of the Public

Based on the monitoring and controls described above, radiological dose to members of the public will be less than the applicable limits described in 10 CFR 20.

SECTION 12

RADIOACTIVE WASTE MANAGEMENT PROGRAM

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
August 12, 2008

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

12. RADIOACTIVE WASTE MANAGEMENT PROGRAM

Radioactive waste from the C-T Decommissioning Project will be managed in accordance with the requirements of this C-T Radioactive Waste Management Plan. This plan ensures that radioactive waste from the C-T Decommissioning Project will be handled, stored and disposed of in a manner protective of human health and the environment and in accordance with applicable regulatory requirements.

12.1. SOLID RADIOACTIVE WASTE

12.1.1. Solid Radioactive Waste Generation

Decommissioning activity will generate three general categories of solid waste: debris of pavement, concrete slabs, and subsurface material. Pavement includes macadam and concrete pavement removed to access subsurface materials. Concrete slabs include wastewater basin slabs and floor slabs from C-T process and support buildings demolished in Phase I. Subsurface materials will include but not be limited to soil, fill, sewer pipe, and building foundations not removed during Phase I. Subsurface foundations and other concrete, wood, or metal materials from buildings and equipment that previously occupied the site may also be encountered during Phase II. Soil and fill will be "volumetrically" contaminated. It is anticipated that sewer pipe, foundation material, and other non-soil materials will exhibit surface contamination only. In the discussions below, all subsurface material will generally be referred to as "soil".

Table 12-1 provides a summary of the type and estimated volume of radioactive wastes to be generated during Phase II. Table 12-2 provides estimates of the radionuclide activities in C-T radioactive waste. As indicated in the Table 12-2, Phase II solid wastes are projected to have average concentrations of natural uranium and natural thorium significantly below exempted quantities of source material as defined in 10 CFR 40.13.

C-T radioactive waste will not contain any of the radionuclides listed in Tables 1 or 2 of 10 CFR 61.55, except those present in background due to atmospheric fallout. All C-T radioactive waste will therefore be Class A.

12.1.2. Solid Radioactive Waste Management

Pavement and excavated subsurface materials will be loaded into roll-off containers or dump trucks at the excavation site. As discussed in Section 8, water misting or similar technique will be used as appropriate to control emissions during excavation and loading. Containers or trucks will be covered prior to movement from the excavation area. Loose material generated during excavation will remain in the excavation. Loose material generated during loading will be removed from pavement and the exterior of containers and trucks before they are moved from the excavation area. Surveys will be performed as appropriate to ensure that loose contaminated material is not carried from the excavation area on containers or vehicles.

As stated in Section 8.1, decontamination and volume reduction methods were selected to minimize the volume and cost of radioactive waste requiring disposal. Mallinckrodt and its contractor(s) will determine whether decontamination and final survey of individual materials is preferred over excavation and disposal. This Phase II Plan is based on the following preferences:

- excavation or demolition and disposal when it is cost-effective,
- decontamination when it is judged to be cost-effective compared to disposal, and
- decontamination or removal of selected contaminated areas of pavement and subsurface material to reduce the average mass concentration radioactivity below release limits and therefore minimize the cost of disposal.

12.1.3. Material Management Area

Soils and other materials that are not loaded directly into transport containers at the excavation site will be moved by truck or container to a Materials Management Area (MMA). Candidate MMA are:

1. the open area in Plant 5 would be within bounds of the
   - South side of Destrehan Street,
   - North side of Building 260,
   - East side of Buildings 240 and 250, and
   - West side of Buildings 236 and 245
2. the rail car loading area, and
3. where wastewater basins are located in Plant 7.

At either the excavation site or the MMA, radioactivity monitoring will be used to segregate solid wastes generated during Phase 2 into four categories, depending upon their radioactivity and chemical content:

- *non-impacted material*[1]
- soils and materials that are < DCGL for soil and can be returned into an excavation on-site,
- soils and materials that contain unimportant quantities of radioactive material and can be managed by NRC-authorized transfer to a state-regulated disposal facility,
- soils and materials that must be managed at a NRC-licensed disposal facility, and
- soils and materials that contain above-background radioactivity and listed or characteristic hazardous wastes and must be managed as mixed waste as described in Section 12.3.

Soils and other waste materials generated during decontamination and remediation may be temporarily stored at the MMA for sampling and analysis, to accumulate sufficient quantities for economical shipment and disposal, or to coordinate shipments between the carrier and the disposal site. Soils and materials will be stored in covered containers or in piles. If needed to control dust or erosion by wind or rain, covers, surface coatings, or functionally similar techniques will be used. Stormwater run-on and run-off controls and monitoring will be used as appropriate. Active controls will include water misting or similarly effective dust control methods as necessary to control release of airborne dust during the material handling operations of interest [ref. *e.g.*, CT 2 DP §8.3.4 & 8.5.3] In the event erosion or dispersion of

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[1] *Non-impacted material* is indistinguishable from background radioactivity and does not contain identifiable radioactive material of C-T or MED-AEC origin. That is a lower radioactivity concentration than the decommissioning criterion of background plus DCGL.

staged or stockpiled soil were to become problematic, active confinement, *e.g.*, by straw bale berm or tarpaulin cover, should be considered.

Mallinckrodt anticipates that a maximum of approximately 20,000 cubic feet (approximately 750 cubic yards) of waste materials will be in temporary storage at any given time. Storage periods will be no longer than three months. In the event that additional area storage is needed, covered roll-off containers of C-T solid waste may be temporarily stored in MMA within the facility. Positive control over waste materials will be maintained in a two-fold manner: 1) An active 24-hour security system is in place for the entire Mallinckrodt facility, and 2) the temporary radioactive material storage area will be enclosed and/or roped-off and appropriately posted as required. It is expected that radiation levels at access points to temporary storage areas will be up to several times background, with the average being less that 50 μR/hr and the maximum less than 100 μR/hr. Thus, the low radiation level beside waste in storage will ensure compliance with 10 CFR 20.1301. In addition, appropriate training will be provided to workers regarding the waste materials temporarily stored on-site.

Mallinckrodt does not anticipate treating radioactive solid wastes to any significant degree. Soils may be air dried or augmented with water to meet the disposal site moisture specifications. Size reduction of pavement and subsurface materials will be performed to the extent practical during excavation and removal. Additional size reduction may be performed in the MMA. In limited cases, small quantities of wastes exhibiting a hazardous toxicity characteristic may be treated (fixed and/or solidified) in containers to eliminate the characteristic.

12.1.4. Waste Packaging and Transportation

Wastes will be packaged, placarded and/or labeled, and transported in accordance with the requirements of the disposal site and applicable state and federal waste transportation regulations. Covers or similar devices to confine the waste and protect it from the environment will be employed as appropriate. Container liners may be used to minimize container decontamination requirements and costs at the disposal facility.

Wastes will be transported to the disposal facility by rail or truck, depending upon disposal site receiving facilities, equipment availability, cost, and other factors as appropriate. Phase II contractor personnel will load C-T radioactive wastes that will be shipped in containers or trucks into transport containers in the MMA.

C-T radioactive wastes that will be shipped by rail gondola cars will be handled differently. To the extent practical, the existing FUSRAP rail car loading facility will be used. This facility was constructed specifically to load contaminated soil and debris into rail gondola cars. Soils will be loaded into containers or trucks at the excavation site or at the MMA and be taken to the FUSRAP soils management area. Contractor personnel, working under agreement with Mallinckrodt, will load the wastes into rail gondola cars. Contractor personnel will perform the work using their health and safety procedures and protocols. In the event that the FUSRAP facility is not available, the Phase II contractor will load C-T waste into rail gondola cars at a controlled location at the facility and in accordance with the health and safety requirements of this Phase II Plan.

12.1.5. Regulatory Requirements

Processing and disposal of radioactive waste will be performed in accordance with the relevant requirements of 10 CFR 20, 10 CFR 40, 10 CFR 71, and the applicable disposal site waste acceptance criteria.

Non-impacted wastes that are indistinguishable from background radioactivity will be managed in accordance with applicable State and Federal solid and/or hazardous requirements as appropriate. This is separate from decommissioning criteria, *i.e.*, does not affect applicability of DCGL proposed in CT §5 for soil or pavement contaminated by C-T source material, nor of applicability of final status survey provisions in DP §14 to soil or pavement on-site concluding decommissioning.

Mixed waste, if any, will also be managed in conformance with State and Federal hazardous waste regulations.

12.1.6. Waste Disposition

Contaminated materials will be disposed of by transfer to a licensed disposal facility, by transfer to a disposal facility authorized to receive an unimportant quantity of source material, or may be sorted or decontaminated, surveyed, and released under criteria specified in Section 14 of this Phase II Plan.

Non-impacted material, confirmed by radiation survey to be indistinguishable from natural background radioactivity, may be released without restriction. In the event of a plan to release such unaffected, or non-contaminated material, a quality statistical survey shall be developed for that application to demonstrate that contained radioactivity is indistinguishable from background.

If equipment subject to surficial contamination that is generated during Phase II contains less regulated radioactivity than the criterion for unrestricted release specified in NRC Regulatory Guide 1.86 or in NRC Policy and Guidance Directive FC 83-23, it may be released without restriction. Before unrestricted release, that equipment or material would be subjected to a radiation survey.

Soil, debris, and or other material generated during Phase II whose radioactivity concentration is less than the DCGL specified in Section 5 may be used for backfill in on-site excavations deeper than 4 feet below grade. Excavated material or debris containing less than the DCGL proposed in DP §5.8, DCGL for Industrial Work on Soil, may either be used as backfill deeper than 4 feet in an excavation cavity; or else would be disposed, up to an *unimportant quantity*, defined in 10CFR 40.13(a), in a facility off-site subject to NRC release and State acceptance; or at greater concentration, in an NRC-licensed disposal facility. That is, DCGL, proposed in DP §5, apply to what qualifies as decommissioned and remains on-site at license termination. Whereas, disposal criteria, the focus of this §12.1.6, including application of 10 CFR Part 40.13(a), apply to what may be authorized for disposition off-site.

If waste material contains more than unrestricted release radioactivity concentration and less than the *unimportant quantity* of source material as defined in 10 CFR 40.13, it will be disposed in accordance with an NRC-authorized transfer to a disposal facility, subject to approval from the cognizant state regulatory agency(ies) in which the disposal facility is located. Waste Control Specialists in Texas or USEcology in Idaho are examples of facilities for the disposal of these materials.

If waste material contains greater than an *unimportant quantity* of source material, *i.e.*, concentration, of source material as defined in 10 CFR 40.13 it will be disposed at an NRC-regulated disposal facility authorized by radioactive materials license to receive it. Segregation from other material will be maintained.

12.2. LIQUID RADWASTE

Phase II operations will not involve use of significant quantities of liquid chemicals requiring treatment and/or disposal. Minimum use of water is anticipated for dust control during soil remediation and demolition of paved surfaces. No free water will be generated by dust control activity.

Soil management and housekeeping activities will be designed to minimize the exposure of contaminated soils to stormwater. However, stormwater from active remediation areas, decontamination areas, and the Material Management Area may contain contaminated soil particles. Management of potentially contaminated soil is described in Section 12.1 above. Stormwater will be contained, collected, and stored in temporary, dedicated aboveground tankage located in the Material Management Area. Collected water will be used for dust control or be filtered or otherwise treated prior to discharge to the plant sewer system in accordance with the facility's wastewater permit. Used filters and treatment sludge, if any, will be solidified and or dewatered and managed as a solid radioactive waste.

Water removed from excavations will be managed in a manner similar to decontamination water and stormwater runoff.

In the event water were to accumulate in an excavation cavity and impede remediation or radiation survey, Mallinckrodt would implement its water management plan to manage it in conformance with

- 10 CFR Part 20.2003
- C-T Phase II Decommissioning Plan, §12.2 Liquid Radwaste, and
- Mallinckrodt's Metropolitan St. Louis Sewer District (MSD) discharge permit no. 21120596-00

Water would be pumped from an excavation cavity into holding tanks or a tank on a truck. It would be transported to a water treatment system on-site where it would be filtered, sampled, and analyzed to verify compliance with 10 CFR Part 20, Appendix B, Table 2, column 2 effluent concentration limits and with the MSD permit before discharge into MSD sewer system.

If filtration were insufficient to assure the water discharged as effluent complies with the 10 CFR Part 20, Appendix B, effluent concentration limit, additional treatment, either by ion exchange or adding flocculant before filtration, would be done to achieve compliance. Similar practice has been used successfully by the FUSRAP contractor on-site. Used filters and treatment sludge, if any, would be managed as solid radioactive waste.

As in the case of radioactive solid waste discussed above, any aqueous radioactive waste generated during Phase II will be Class A.

12.3. MIXED WASTE

Characterization efforts performed to date have not identified any mixed wastes in the soil or other materials to be remediated during Phase II. Mallinckrodt does not anticipate that mixed waste will be generated by decommissioning efforts. In the event mixed waste is identified during remediation activities, Mallinckrodt will characterize the wastes, identify a disposal method, assess the effect on the schedule, assess related disposal costs, modify handling procedures as needed and will notify the NRC. Mallinckrodt has a RCRA Part B permit authorizing on-site storage of hazardous and mixed waste. Other than the presence of hazardous chemicals, storage in Mallinckrodt's hazardous waste storage facility, and the labeling and transportation requirements of RCRA and state hazardous waste agencies, mixed wastes will have the same radioactive character and will be managed as solid radioactive wastes described above.

As indicated above, a small quantity of radioactive waste that exhibits a hazardous characteristic may be treated in a container to eliminate the characteristic. Neutralization, stabilization, fixation, and solidification techniques may be used. Such treatment will typically be performed in the MMA.

12.4. RECORDS

Mallinckrodt will maintain records of waste material released from the C-T decommissioning area or controlled areas.

Table 12-1. Estimated C-T Phase II Solid Radioactive Waste Volumes

Waste Type	Volume[a] (ft^3)
Pavement	4100
Building slabs	13000
Subsurface material	42000
Unreacted C-T Ore	81500
TOTAL	140600

[a] Volume estimates are described in sections 4.7.2, 4.7.3, and 4.7.4.

Table 12-2. Estimated Solid Radioactive Waste Concentration and Activity

Radionuclide	Pavement[a]		Building slabs[b]		Subsurface Material[c]	
	Concentration (pCi/g)	Activity (Ci)	Concentration (pCi/g)	Activity (Ci)	Concentration (pCi/g)	Activity (Ci)
U-238	35	0.0005	18	0.0008	29	0.16
Th-230	26	0.0004	23	0.001	50	0.28
Ra-226	146	0.002	27	0.001	226	1.27
Th-232	15	0.0002	11	0.0005	11	0.062
Ra-228	16	0.0002	10	0.0004	38	0.21
Th-228	17	0.0003	15	0.0007	17	0.095

[a] The radionuclide concentrations for pavement are the respective average concentrations of scabble samples SC-07 through SC-18 (see Table 4-2). The radionuclide activity is estimated as the product of the radionuclide concentration, the area corresponding to Table 12-1 (assuming an average contamination depth of 1 cm and a density of 120 lb/ft^3).

[b] The radionuclide concentrations for building slabs are the respective average concentrations of scabble samples collected in support of the C-T Phase I Decommissioning Plan. The radionuclide activity is the product of the radionuclide concentration, the building slab area, 25000 ft^2, corresponding to Table 12-1, and assuming an average contamination depth of 1 cm and a density of 120 lb/ft^3.

[c] The radionuclide concentrations for subsurface material are the respective average concentrations of subsurface samples for which the sum-of-fractions value is greater than one. The radionuclide activity is the product of the radionuclide concentration and the subsurface material volume of Table 12-1, assuming an average density of 100 lb/ft^3. For the purpose of this estimate, radioactivity concentration in soil is also applied to URO.

SECTION 13

QUALITY ASSURANCE PROGRAM

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

May 15, 2003

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

13. QUALITY ASSURANCE PROGRAM

The major aspects of the quality assurance program for the decommissioning activities are discussed in the following sections.

13.1. ORGANIZATION

13.1.1 QA Program Management Organization

The C-T decommissioning organizational structure will consist of a management team from Mallinckrodt and the decommissioning contractor.

The Mallinckrodt C-T Project Manager will provide overall direction for the C-T Decommissioning Project. The Project Manager will be supported by managers responsible for contract administration, environmental affairs, quality assurance, project engineering, and legal.

While Mallinckrodt will be responsible for ensuring that the NRC requirements are met, Mallinckrodt intends to contract services to perform decommissioning activities.

The contractor will implement the radiological, occupational, and environmental safety programs and the procedures to implement the program requirements. The contractor will also provide an independent quality assurance program, and provide and manage a trained, experienced labor force to perform the decommissioning activities.

The contractor's Project Manager will provide day-to-day direction for the C-T Decommissioning Project, but will report directly to the Mallinckrodt Project Manager. The contractor's Project Manager will be supported by operations, environmental, safety, and health personnel who will provide technical advice, resources, and day-to-day management of the C-T Decommissioning Project workers.

13.1.2 Duties and Responsibilities

Duties and responsibilities of responsible management positions are described in Section 9.1.

13.1.2.1 Contractor's Quality Assurance Manager

The contractor's Quality Assurance Manager is responsible for establishing and assuring implementation of the contractor quality assurance program. This function is independent of Operations and will report directly to the Mallinckrodt C-T Project Manager with copies of audits provided to the contractor's Project Manager. [ref. section 9.1.8]

13.1.3 Work Performance Evaluation

Work performance is evaluated through the Corrective Action Program and through the Audit and Surveillance Program.

13.1.4 Description of Authority

The authorities of the various groups within the C-T Decommissioning Project are described in Section 9.1.

13.1.5 Organization Chart

The C-T Decommissioning Project organization, including the Quality Assurance Manager, is illustrated in Figure 9-1.

13.2. QUALITY ASSURANCE PROGRAM

13.2.1. Quality Assurance Program

Decommissioning activities will be performed in a manner to ensure the results are accurate and that uncertainties have been adequately considered. The quality assurance program will operate in all stages of decommissioning through the final survey, validation of the data, and the interpretation of the results to verify that this has occurred.

Persons or organizations responsible for ensuring that the quality assurance program has been established and verifying that activities affecting quality have been correctly performed will have sufficient authority, access to work areas, and organizational freedom to:

- identify quality problems;
- initiate, recommend, or provide solutions to quality problems through designated channels;
- verify implementation of solutions; and,
- ensure that further decommissioning activities are controlled until proper disposition of a nonconformance or deficiency has occurred.

Such persons or organizations will have direct access to responsible management at a level where appropriate action can be taken. Such persons or organizations will report to a management level such that required authority and organizational freedom are provided, including sufficient independence from cost and schedule considerations.

13.2.2. QA Policies

It is the policy of Mallinckrodt C-T Decommissioning Project management to perform its decommissioning work professionally and consistently to achieve a level of quality which meets or exceeds facility license termination and unrestricted use requirements. As part of accomplishing this management requirement, all personnel are required to comply with the elements of this Quality Assurance Program (QAP), implementing directives and project specific addenda in the day-to-day performance of their work. Suggestions on improvements to the Quality Assurance Program and its elements are encouraged and should be directed to the C-T Project Manager or the Quality Assurance Manager.

The QAP and its sub-tier functional area directives are designed to implement applicable requirements of the NRC's radiation program regulations applicable to fuel cycle facilities and their decommissioning for license termination.

All employees of the C-T Decommissioning Project and its contractors are responsible for assuring the quality of the work that they perform and for compliance with the requirements of this plan and applicable regulation.

The C-T Decommissioning Project Manager has the overall responsibility for ensuring that the Quality Assurance Program is implemented and maintained. A Quality Assurance Manager is designated as the position responsible for implementing and assessing the scope, status, implementation and effectiveness of the Quality Assurance Program.

13.2.3. Procedures

Supporting Quality Implementing Procedures (QIP) will provide step-by-step details for complying with project QA requirements. The final radiation status survey, including development of sampling plans, direct measurements, sample analyses, instrument calibration, daily functional checks of instruments, and sampling methods will be performed according to written procedures. These written procedures will be reviewed and approved by the Mallinckrodt project manager.

13.2.4. Management Reviews

Management reviews are implemented through the Corrective Action program and the Audit and Surveillance program.

13.2.5. Notification of Changes

Changes to the key elements of this Quality Assurance Program will be submitted to the NRC for review and approval prior to implementation. [ref. Sections 9.5 and 9.6]

Editorial changes or personnel reassignments of a non-substantive nature do not require NRC notification.

13.2.6. Management Assessment

The effectiveness of the Quality Assurance Program will be monitored and assessed through the Audit and Surveillance Program and the Corrective Action Program. Audit findings and deficiencies identified through the Corrective Action Program will be tracked and trended through the commitment tracking system.

Audit findings and their responses, and Condition Reports and their resolutions will be reviewed by project management.

13.2.7. Self-Assessment Program

The Self-Assessment Program is implemented through the Audit and Surveillance Program and the Corrective Action Program. Results of audits and surveillances are forwarded to the cognizant Department Manager and to the Mallinckrodt C-T Decommissioning Project Manager.

13.2.8. Independence of QA Personnel

An organizational structure, functional responsibilities and qualifications, levels of authority, and lines of communication for activities affecting quality shall be established and documented. The management organization that is responsible for assuring that decommissioning and subsequent license termination requirements are met is described in Section 9.

13.2.9. Organizational Responsibilities

Personnel performing self-assessment shall be independent of the activities being observed, and shall be qualified by education, experience and training, as appropriate.

13.2.10. Acceptance Criteria

The Self-Assessment Program is implemented through the Audit and Surveillance Program and the Corrective Action Program. Results of audits and surveillances are forwarded to the cognizant Department Manager and to the Mallinckrodt C-T Decommissioning Project Manager.

13.3. DOCUMENT CONTROL

13.3.1 Documents Included in QA Program

Documents that generate materials or data essential to the quality of decommissioning are controlled to assure that they are current, correct, are properly evaluated and audited, cite validation back-ups, and are stored and available for inspection or use in generating final project license termination materials. Standardized document control procedures are defined in the Quality Assurance Procedures (QIP).

Functional groups, when generating directives, are to identify essential quality requirements and acceptance criteria in their respective directives. Back-up records are to accompany the final data set that is to be reviewed, stored, and relied upon for license termination use.

13.3.2 Control of Documents

Documents that specify quality-related requirements and instructions are identified, reviewed, approved, issued, distributed, and maintained as controlled documents in accordance with written procedures. A listing of the types of documents to be maintained as controlled documents is contained in a Controlled Document List. The Controlled Document List will be updated as needed, to ensure it is comprehensive, current, and complete.

Changes to controlled documents are reviewed and approved by the same organization that reviewed and approved the documents originally, or by other designated, qualified persons. Disposition of a superseded or modified document is controlled in accordance with written procedure. A master list of controlled documents is maintained to identify the current revision number of instructions, procedures, specifications, and drawings important to quality. The list is distributed periodically to those individuals or organizations responsible for maintaining the applicable controlled documents, to prevent the use of outdated or obsolete documents.

Appropriate controlled documents are available in the work area before initiation of and during the performance of activities affecting quality. This availability is verified periodically by Quality Assurance. Changes or revisions to controlled documents are verbally communicated to affected individuals and a required reading program assures awareness of the change.

13.4. CONTROL OF MEASURING AND TEST EQUIPMENT

Measuring equipment will be maintained, calibrated, and tested according to Regulatory Guides 4.15 and 4.16 recommendations. Further, the procedures, responsibilities, and schedules for calibrating and testing equipment will be documented.

Proper maintenance of equipment varies; but maintenance information and use limitations are provided in the vendor documentation. Measuring and analyzing equipment will be tested and calibrated before initial use and will be recalibrated if maintenance or modifications could invalidate earlier calibrations. Field and laboratory equipment, specifically used for obtaining final radiological survey data, will be calibrated based on standards traceable to NIST or other recognized standards. In those cases where NIST-traceable standards are not available, standards of an industry-recognized organization (for example, the New Brunswick Laboratory for various uranium standards) will be used. Minimum frequencies for calibrating equipment will be established and documented.

Measuring equipment will be tested at least once on each day the equipment is used. Test results will be recorded in tabular or graphic form and compared to predetermined, acceptable performance ranges. Equipment that does not conform to the performance criteria will be promptly removed from service until the deficiencies can be resolved.

13.5. CORRECTIVE ACTION

13.5.1 Corrective Action Procedures

Conditions adverse to the quality requirements of decommissioning are those conditions that if uncorrected, could violate safety and environmental regulations, and/or license commitments. Non-conformance shall be identified promptly and corrected as soon as practical. Corrective action shall be commensurate with the seriousness of the condition being corrected.

13.5.1.1 Implementation

To ensure that only correct and current documents are in use, a Quality Assurance Procedure applicable to all functional areas is required for notification of corrective actions. This quality requirement is implemented by procedures covering Corrective Action Requests and Stop Work Orders.

13.5.2 Documentation

The effectiveness of any corrective action shall be documented before the condition is considered corrected.

13.6. QUALITY ASSURANCE RECORDS

13.6.1. Documentation

Data will be recorded and documented in a data management system. Entries will include the location of the survey or sampling point on the appropriate building grid. Data management personnel will also ensure that chain-of-custody and data management procedures are followed for decommissioning-related samples. The decommissioning contractor's procedures for proper handling, shipping and storage of samples will be used.

Both direct measurements and analytical results will be documented. The results for each survey measurement or sample and its grid block location, will be listed in tabular form (*i.e.*, result versus sample or survey location).

Data will be recorded in an orderly and verifiable way and reviewed for accuracy and consistency. Each element of the decommissioning process that is important to quality of outcome, from training personnel to calculating and interpreting the data, shall be documented in a way that lends itself to audit. Records of training to demonstrate qualification will also be maintained.

13.6.2. Data Management

13.6.2.1. Laboratory Data

Data reduction, QC review, and reporting will be the responsibility of the analytical laboratory. Data reduction includes all automated and manual processes for reducing or organizing raw data generated by the laboratory. The laboratory will provide a data package for each set of analyses that will include a copy of the raw data in electronic format, and any other information needed to check and recalculate the analytical results.

Once a data package is received from the laboratory, the analytical results and pertinent QA/QC data will be compiled onto standardized data formats. The data packages will serve as basic reference sheets for data validation, as well as for project data use.

13.6.2.2. Field Survey Data

The generation, handling, computations, evaluation, and reporting of final radiation status survey data will be as specified in the decommissioning contractor's procedures. Included in these procedures will be a system for data review and validation to ensure consistency, thoroughness and acceptability. Qualified health and safety, operations, and/or engineering personnel will review and evaluate survey data.

13.6.2.3. Data Evaluation

Prior to releasing data for use by project staff, selected data will undergo data evaluation based on intended end use of the data. Data points chosen for evaluation will be examined to determine compliance with QA requirements and other factors that determine the quality of the data.

If sample data are rejected or data omissions are identified during the data validation, those data will be evaluated to judge the impact on the project. Other corrective action may include re-sampling and analyzing, evaluating and amending sampling and analytical procedures, and accepting data acknowledging the level of uncertainty.

In the event final status survey data are processed by computer, the application program[1] and each modification thereof will be verified to perform as intended before its initial use. A knowledgeable person will verify that the algorithms are as intended and will compare an instance of computer-generated result and an independently derived result of the same process. Mallinckrodt will document the application program, including its algorithms and a listing or copy of the program.

13.6.3. Sample Chain-of-Custody

One of the most important aspects of sample management is to ensure that the integrity of the sample is maintained; that is, that there is an accurate record of sample collection, transport, analysis, and disposal. This ensures that samples are neither lost nor tampered with and that the sample analyzed in the laboratory is actually and verifiably the sample taken from a specific location in the field.

Sample custody will be assigned to one person at a time to prevent confusion of responsibility. Custody is maintained when (1) the sample is under direct surveillance by the assigned person, (2) the sample is maintained in a tamper-free container, or (3) the sample is within a controlled-access facility.

The person responsible for sample collection will initiate a chain-of-custody record using a standard form provided by the decommissioning contractor. A copy of this form will accompany the samples throughout transportation and analyses; and any breach in custody or evidence of tampering will be documented.

13.7. AUDITS AND SURVEILLANCES

Periodic audits will be performed to verify that decommissioning activities comply with established procedures and other aspects of this QA Plan and to evaluate the overall effectiveness of the QA program. Mallinckrodt and Contractor Quality Assurance personnel will verify that qualified personnel are used to conduct audits to ensure that the applicable procedures are being properly implemented. The audits will be conducted on at least a semi-annual basis, in accordance with written guidelines or checklists. Health and safety personnel will also conduct semiannual audits in their area of concern or have them performed by qualified personnel. External program audits may be used at the discretion of either Mallinckrodt or contractor management. Audit results will be reported to both Mallinckrodt and contractor management in writing; and actions to resolve identified deficiencies will be tracked and appropriately documented.

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[1] An *application program* consists of instructions and or algorithms created specifically for processing data for the CT decommissioning project. It does not pertain to generic software, including for example, a spreadsheet program such as Microsoft EXCEL™ or a database program such as Microsoft ACCESS.™

SECTION 14

FACILITY RADIATION SURVEYS

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
August 12, 2008

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

14. FACILITY RADIATION SURVEYS

This section provides a summary of facility radiation surveys primarily focused on site investigation. These surveys include characterization surveys, remedial action support surveys, and the Final Status Survey (FSS). The FSS survey will demonstrate that areas of the site subject to this decommissioning plan meet the criteria for release.

As discussed in C-T Phase II Decommissioning Plan (Phase II Plan) Sections 1 and 4, the scope of this decommissioning plan includes two types of environmental media. The first is surface slab material, either concrete or asphalt pavement or building floor, slab, or basin surface. The second type is soil, fill, and similar bulk materials. These materials are almost entirely subsurface, because the surface of the area of interest is nearly entirely covered by either building floor slabs or pavement.[1]

Information regarding the FSS is intended to satisfy Method 2 described in NUREG-1727 Section 14. That is, the decommissioning plan includes descriptions of release criteria, site characterization surveys (included by referring to the comprehensive characterization survey report), remedial action support surveys, the final status survey design principles, and Final Status Survey Report contents. The description of final status survey design principles includes a description of the method to determine the number and locations of sampling points to be used in the final radiological survey in accordance with the method described in MARSSIM. The FSS information provided here is intended to be the only information submitted for NRC approval prior to the Final Status Survey Report.

To the extent practical, guidance from the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG-1727 (Section 14 and Appendix E), and NUREG-1505 has been incorporated in this Section 14. Release criteria (denoted "derived concentration guideline level" or "DCGL" in MARSSIM) have been established, as discussed in Section 14.1. Site characterization surveys have been performed and reported earlier and are discussed briefly in Section 14.2. Remedial action support surveys are described in Section 14.3. The Final Status Survey design, based on Data Quality Objectives (DQO) is described in Section 14.4. The planned Final Status Survey Report is described in Section 14.5.

14.1. RELEASE CRITERIA

Release criteria (DCGL values) have been determined for each medium for each residual radionuclide of interest[3] regulated under the NRC license. These criteria do not apply to other

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[1] The Phase II FSS will include certain surveys designed to confirm that the Phase II activities have not invalidated certain results of the Phase I FSS. Phase I applied to structures, including a number of structures to remain in use. After Phase II and before the license is terminated, Mallinckrodt will perform a confirmatory radiation survey to assess whether buildings in Area 5 previously released by the Phase I FSS might have been contaminated as a result of subsequent Phase II decommissioning activity. The confirmatory survey would emphasize floors near entrances since re-contamination would most likely be by tracking-in. The methodology to be used in this confirmatory survey will be the methodology applied in the Phase I FSS.

[3] Radionuclides of interest exclude those regulated radionuclides contributing less than 10 percent of the total effective dose equivalent and not present in a fixed ratio to a key radionuclide (DG-4006, §2.9).

radioactive material, such as background radioactivity, for example, or to unregulated radionuclides such as K-40.

Radionuclides of interest in this plan have been identified in the review of C-T process history, described Phase II Plan Section 1, and in the evaluation of radiological characterization of the site, described in Section 4:

- U-238, U-235, and U-234, all from naturally occurring uranium (and their progeny Th-230, Ra-226, and other short-lived isotopes); and
- Th-232 from naturally occurring thorium, and its progeny (Ra-228, Th-228, and other short-lived isotopes).

Surface activity limits (activity per unit area) have been developed in Phase II Plan Section 5 for pavement or building slabs and bulk concentration limits (activity per unit mass) have been developed for subsurface materials. Two types of release criteria apply. The first, $DCGL_W$, is intended to be applied to estimates of the mean concentration in a survey unit. The second, $DCGL_{EMC}$, is intended to apply to localized, elevated measurements exceeding the $DCGL_W$. The $DCGL_{EMC}$ values are derived as the product of $DCGL_W$ and an area factor. Derivation of DCGL and area factor values is described in Phase II Plan Section 5. Values for application to volumetrically contaminated material (soil) in the FSS are listed in Table 5-1 and Figure 5-1. Values for application to areally contaminated surfaces (*e.g.*, slabs, pavement, basin surfaces) in the FSS are listed in Table 5-3 and Figure 5-2.

14.2. CHARACTERIZATION SURVEYS

An extensive radiation survey designed to characterize the radiological status of the site has been conducted in accordance with an NRC-approved plan[4] and results have been reported in detail.[5] A discussion of this effort, including a general description of methodologies employed and a summary of results obtained, is provided in Phase II Plan Section 4.

Characterization Survey results of interest in the Phase II Plan are those related to surfaces of pavement, building floor slabs, and subsurface materials. The measurements of primary importance for pavement and building slabs were direct beta/gamma measurements using large-area detectors in both scan and static mode. The measurements of primary interest for subsurface materials were laboratory analyses of key radionuclides in samples collected from boreholes.

Characterization survey results have been or will be used:

- to provide sufficient information to permit planning for site remediation that will be effective and will be performed in a way that meets regulatory requirements,
- to demonstrate that it is unlikely that significant quantities of residual radioactivity have gone undetected,

[4] Mallinckrodt Chemical, Inc., C-T Plant Characterization Plan, January 1994. Supplement May 1994.
[5] "Radiological Characterization Data Set For The Mallinckrodt Chemical C-T Plant, Thermo NUtech, Oak Ridge, TN, Revised October, 1998.

- to provide information that will be used to design the final status survey, and
- to serve as elements in the FSS (to the extent that characterization surveys can be shown to meet quality assurance requirements applied in the Characterization Survey, as described in the Characterization Survey Report).

In serving as elements in the FSS, Characterization Survey measurements may comprise the entire data set for a particular survey unit. Where Characterization Survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan[6]. Any such plan will be reviewed to ensure that it meets data quality objectives. Mallinckrodt would notify the NRC Project Manager of intent to perform double or two-stage sampling and would seek concurrence. In order to avoid delay of decommissioning activity, Mallinckrodt would expect NRC response within 4 business days.

14.3. REMEDIAL ACTION SUPPORT SURVEYS

Surveys designed to guide and monitor remedial action are planned. Methodologies to be used are those that provide adequate sensitivity to determine compliance with DCGL while minimizing the time required for measurement and reporting.

Methodologies for slab materials will include direct field measurements (both stationary and scan) of surface β-γ radioactivity. Methodologies for subsurface materials may include *in situ* measurements, such as down-hole gamma spectrometry, or measurement of radioactivity in soil samples by commonly used laboratory techniques, such as gamma spectrometry, in a radioanalytical laboratory located on-site for rapid response or off-site. The *in situ* measurement methodology is described in Appendix F, Radionuclide Analysis in Soil by In-ground Gamma Spectrometry.

Remedial action support surveys will be designed to be used as elements of the Final Status Survey where practical and where satisfaction of all FSS requirements described in this section is achieved. In serving as elements in the FSS, remedial action support measurements may comprise the entire data set for a particular survey unit. Where remedial action survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan[7]. Any such plan would be revised to ensure that it meets the data quality objectives.

Where cleanup is necessary, a survey technician will work actively with the decontamination worker or excavator operator to guide decontamination or excavation to decide when a location is decontaminated to meet the goal.

When remediating pavement, building slab, or foundation, a survey technician will:

- Perform beta or beta-gamma scanning;

[6] NUREG-1757, Appendix C.
[7] NUREG-1757, 2, Appendix C.

- Then perform beta measurement at locations judged most likely to remain contaminated in excess of DCGL. Among radiations emitted, beta is most suitable to represent contamination on a concrete slab or on pavement; for a low fraction of alpha rays escape a rough surface, while natural background gamma rays originating deeper in concrete or macadam would be detected.
- At joints or cracks, scraping, chipping, or scabbling may be used to collect a material sample to be analyzed by comparison with DCGL for a volumetric source, that derived for soil.

When remediating soil, a survey technician will:

- Rely on the extensive characterization survey data for guidance about where to begin.
- As excavation removes contaminated soil, remedial action surveys will decide whether that area has been decontaminated to the DCGL. Remedial survey measurements will be a combination of gamma scanning and point measurements on the surface or in shallow auger hole in the excavation cavity to measure the concentration of key radionuclides.
- Alternatively, sampling of soil and gamma spectrum analysis to measure the concentration of key radionuclides may be performed. This alternative would be especially useful in the event water accumulates in an excavation cavity.
- In the event caving is of concern, sampling of excavator bucket contents would enable an alternative means of measurement.
- In the event caving is of concern, sampling contents of an excavator bucket would be an alternative means of measurement.

14.4. FINAL STATUS SURVEY DESIGN

This section describes the planned Final Status Survey. This survey will demonstrate that the two types of media: pavement and subsurface material, meet the criteria for release. To the extent practical, guidance from the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NUREG-1575) has been incorporated in this Final Status Survey Plan. Measurement instrumentation is described in section 14.4.1, "Instrumentation." Background determination is described in Section 14.4.2. "Background." Section 14.4.3, "Survey Methodology," describes the statistical sampling and data evaluation methodology. Section 14.4.4 discusses quality assurance aspects of the survey.

14.4.1. <u>Instrumentation</u>

A Final Status Survey will consist of scanning, direct stationary surveying, down-hole *in situ* measurement, and or laboratory analysis of subsurface material samples. Therefore, scanning instruments, direct measuring instruments, and laboratory instruments will be used in conducting the final radiation surveys and sample analyses. All instruments will be appropriate for the type of survey and the concentration of radioactivity to be measured.

Typical instrumentation to be used in a final status survey is listed in Tables 14-1 (field methods) and 14-2 (laboratory methods), along with typical parameters and detection sensitivities for the instrumentation and survey technique. In the event an instrument not listed in Table 14-1 or 14-2 is to be used to perform final status survey measurements of record, a technical basis document demonstrating that it meets quality objectives for calibration, operability, and detection capability will be developed before it is used.[9] The combination of instrumentation and technique will be chosen to provide a detection sensitivity to satisfy survey objectives. Sensitivities for scanning techniques are based on movement of the detector over the surface at one detector-width per second and use of audible indicators to sense changes in instrument count rate.

Direct measurements for gross α activity will be performed using a scintillation or gas proportional detector. Direct surface measurements for gross beta activity will be performed using scintillation probes or gas proportional probes. Special consideration will be given to the use of large area probes on the order of 100 cm^2 or greater. Scanning shall be performed using scintillation probes or gas proportional probes such as the Bicron Surveyor M with A100 or B100 probes and gas proportional floor monitors for beta activity.

Exposure rate measurements will be performed by NaI scintillation detectors such as the Ludlum model 19 or by a pressurized ion chamber such as a Reuter-Stokes HPIC, *e.g.*, model RSS-131.

The methods of interpreting stationary and scanning sensitivity[10] to beta radiation are described in Appendix E, Lower Limit of Detection. Those methods will be used to estimate the lower limit of detection (LLD or MDA) of each instrument before it is used to perform a final status survey (*a priori* LLD). LLD are estimated in Tables 14-1 and 14-2 for instruments for which representative background data are available.

[9] Appendix E, "Lower Limit of Detection"

[10] also called lower limit of detection (LLD), minimum detectable concentration (MDC), or minimum detectable areal density (MDAD)

Table 14-1

Typical Field Methods for Performing Final Radiation Status Surveys

Instrument Type	Radiation Detected	Scale/Range	Typical Background	Typical MDA 95% confidence Level[2,3]	Usage
Scintillation (Ludlum 2224) Scaler/ Ratemeter with 43-89 probe	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	100 dpm/100 cm^2 (direct) 1600 dpm/100 cm^2 (direct) 5100 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]
Micro-R Meter (Ludlum) 1" x 1" NaI Detector	Gamma	0-3,000 μR/h or 0-5,000 μR/h	7 μR/h	1-2 μR/h	General Characterization[4]
3" x ½" NaI Scintillation Detector Digital Scaler	Gamma	0-500,000 cpm	2,500 cpm avg shielded[7] 7,000 cpm avg unshielded	250 cpm 500 cpm	General Characterization[4]
100 cm^2 gas flow (43-68) Digital Scaler[1]	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	100 dpm/100 cm^2 (direct) 1600 dpm/100 cm^2 (direct) 7100 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]
Ludlum 2" GM Tube (Pancake)	Beta Gamma	0-500,000 cpm 720 cpm = 0.2 mR/h	<200 cpm	2300 cpm	General Characterization[4]
5" plastic scintillation detector with multi-channel analyzer	Beta	N.A.	TBD[1]	TBD[1]	General Characterization[4]
2" x 2" or 3" x 3" NaI scintillation detector w/ multi-channel analyzer for down-hole *in situ* quantitative analysis	Gamma spec	N.A.	TBD[1]	TBD[1]	FSS[5]
Floor monitor with gas proportional detector and scaler/rate meter (Ludlum 239-1F with Model 2221 or 2224 alpha/beta scalar/ratemeter)	Alpha Beta	0-500,000 cpm	TBD[1]	TBD[1]	FSS[5]
Pressurized Ion Chamber (Reuter-Stokes HPIC)	Gamma	0 to 10 R/hr	Background of its environment	About 0.1 μR/hr Accuracy ± 5% at 10 μR/hr	Environmental gamma exposure rate
Bicron AB-100 Scintillation Probe	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	70 dpm/100 cm^2 (direct) 850 dpm/100 cm^2 (direct) 3900 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]

Notes: [1] TBD = to be determined prior to initial use and calibration.
[2] Instrument MDA are based upon static measurements, one minute count times unless otherwise noted.
[3] Instrument MDA depends upon background.
[4] Characterization instrument; may include non-quantitative uses
[5] FSS method, or may be used in support of FSS

Table 14-2

Typical Laboratory Methods for Performing Final Radiation Status Surveys

Instrument Type	Radiation Detected	Scale/Range	Typical Background	Typical MDA 95% confidence Level[4]	Instrument Usage
Ludlum Model 2929	Alpha Beta	0-99,999,999 cpm	0.2 cpm 45 cpm	3 dpm 50 dpm	General Characterization[2]
Tennelec LB5100 Computer Based Auto Sample Counter	Alpha Beta	0-99,999,999 cpm	<0.3 cpm 1.5 cpm	0.4 dpm 1.5 dpm	General Characterization[2]
Waste Counter – Computer Linked MCA 3" x 3" NaI (Tl) Detector	Gamma	-	TBD[1] pCi/g Total U TBD[1] pCi/g Th (Nat)	TBD[1] pCi/g U TBD[1] pCi/g Th (Nat)	Waste Characterization
5" Slide-Drawer ZnS Scintillation Counter	Alpha	0-500,000 cpm	<0.3 cpm	2 dpm	General Characterization[2]
Shielded high-resolution solid-state gamma detector with multi-channel analyzer for quantitative and qualitative analysis of gamma emitting radionuclides in soil or similar materials in Marinelli beaker or similar container	Gamma spec	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Shielded high-resolution solid state alpha detector with multi-channel analyzer for quantitative and qualitative analysis of alpha-emitting radionuclides chemically separated from sample and deposited in low self-absorption form	Alpha spec	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Photon Electron Rejecting Alpha Liquid Scintillation Counter (PERALS)[5]	Alpha	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Kinetic phosphorescence analyzer	Total uranium (mass)	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of elements of interest that are measurable by this method	General Characterization[2] FSS[3]

Notes:
1 TBD = to be determined prior to initial use and calibration.
2 Characterization instrument
3 FSS method, or will be used in support of FSS
4 Instrument MDA depends on background
5 *Photon Electron Rejecting Alpha Liquid Scintillation (PERALS)*, ORDELA, Inc., Oak Ridge, TN

The quantity determined in measurement of subsurface samples will be concentration of individual key radionuclides. Concentrations of radionuclides not measured directly will be inferred either from measurement results (*e.g.*, lead-210 assumed in equilibrium with radium-226) or, from radionuclide concentration ratios observed in characterization data. This approach will be highly accurate for short-lived progeny, which can, in fact, be assumed to be in equilibrium. The approach will also be either conservative or reasonably accurate for the one long-lived radionuclide for which concentration will be imputed rather than measured directly, thorium-230. Examination of the dose factors for thorium-230 in relation to other nuclides and the concentrations of thorium-230 in relation to concentrations of other nuclides, as measured in site characterization, demonstrates that even if even if improbably high ratios of thorium-230 to other measured nuclides are assumed, thorium-230 is not a significant contributor to dose.

A derived index, the sum over all nuclides of interest of the fraction of each nuclide's concentration to its DCGL value, may be used as a single-valued representative of a sample's suite of radionuclide concentration determinations for purposes of interpreting sample results as they relate to release criteria and investigation levels. For example, ignoring background, a single sample investigation level is not exceeded if its index value does not exceed 1. In the FSS, background radiation can be accommodated by including the index value computed for background samples in the statistical evaluation.

14.4.2. Background

The nuclides of interest are naturally occurring and are detectable using measurement methods used in the surveys described in this section. For this reason, estimates of the levels of background radiation are required so that the evaluation of survey results can properly account for the influence of background radiation.

For example, when β or γ is measured, then β or γ background values will be needed for the media to be surveyed under the Final Status Survey. As part of the Characterization Survey, described in Section 14.2, background surveys were made for building slab and pavement surface materials. Background measurements were taken on site or in the immediate vicinity of the site in areas that were not affected by site operations. Table 14-3 shows the background levels which have been determined for asphalt pavement and concrete.

Similarly, estimates of background radionuclide concentrations in subsurface material are also required. Such estimates are usually made by sampling similar materials at locations some distance from and beyond the influence of the site of interest. A complicating factor in such an approach at this site characterization is that the C-T area is not a "green field" site underlain by materials similar to those present at locations distant from the site. The site has been used for industrial purposes for over 130 years. Coal cinders and rubble were used to fill this portion of the Mississippi flood plain 100 to 125 years ago. In addition, the MED, AEC, and DOE has had an active presence at the site for about 50 years. MED-AEC radioactive material in soil is found within 100 meters of the C-T area. Consequently, an area containing sufficiently similar subsurface materials known to be free of impact from C-T operations could not be located. An alternate method of estimating background for subsurface materials is provided as Appendix B.

Table 14-3. Background Values of Pavement

Material	Number of Samples	Average Background (β/min/100 cm^2)	Standard Deviation (β/min/100 cm^2)
Asphalt	42	254	166
Concrete	70	180	79

In general, the sensitivity of a survey is greatest when the number of measurements is split between the background and the survey unit. In the event that the number of background data points acquired during characterization is insufficient, additional background data points will be taken as needed and as practicable.

14.4.3. Survey Methodology

The Final Status Survey will be designed in accordance with MARSSIM, NUREG-1727 Appendix E, and NUREG-1505 to the extent practical. The FSS is designed to provide a high degree of assurance that release criteria are met. The MARSSIM process is intended to accomplish these goals with an optimized sampling effort. First, areas will be classified according to potential for residual contamination or known contamination level, as described in Section 14.4.3.1. Next, these areas will be grouped into survey units as described in Section 14.4.3.2. Statistical analysis will then be conducted to determine the number of samples required for a survey unit. This analysis includes hypothesis formulation, determination of tolerable decision error, and determination of the number of samples required to limit decision error to tolerable levels, as described in Sections 14.4.3.3 through 14.4.3.5. Sampling locations are then determined as discussed in Section 14.4.3.6. Surveys are then conducted and results are evaluated as described in Sections 14.4.3.7 and 14.4.3.8.

14.4.3.1. Area Classification

The intent of the plan is to focus most of the survey effort on areas where the likelihood of exceeding the DCGL is greatest. Therefore, for the purposes of establishing the sample density and the sampling pattern, pavement and subsurface material will be classified according to the potential for residual contamination.

Pavement and subsurface material will first be classified as either Non-Impacted or Impacted. Non-Impacted areas are areas that have had no reasonable potential for containing residual radioactive material and do not need any level of survey coverage. These areas have not been radiologically impacted from site operations. Floor slabs of structures erected after cessation of C-T operation are included in non-impacted areas. Impacted areas are areas which have potential for containing residual radioactive material. Impacted areas will be further subdivided into one of three classifications for purposes of determining monitoring intensity.

Characterization survey data will be used in classifying areas. Characterization survey data results for building slabs and pavement represent the range of beta radiation areal density measurements on surfaces. Net beta reported is derived by subtracting open window (β+γ) minus closed window (γ). To aid statistical analysis, the measured result, even if it is a negative number, is recorded.[11] Characterization survey data and conservative release criteria from Phase II Plan Section 5 will be employed to classify the locations surveyed.

Class 1 Areas: An area that has a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radioactivity surveys) in excess of $DCGL_W$ is a candidate for Class 1. Areas containing contamination in excess of the DCGL prior to remediation shall be classified as Class 1 areas. For classification of subsurface soils, the soil concentration compared to the $DCGL_W$ is the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.).[12] Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, and 4) waste storage sites.

Class 2 Areas: These areas have, or had, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL for unrestricted release. To justify changing an area's classification from Class 1 to Class 2, the existing data shall provide a high degree of confidence that no individual measurement will exceed the DCGL. For classification of subsurface soils, as in the case of Class 1 areas, described above, the soil concentration compared to the $DCGL_W$ is the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.). Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (*e.g.*, process facilities), 2) potentially contaminated transport routes, 3) areas where low concentrations of radioactive materials were handled, and 4) areas on the perimeter of former contamination control areas.

Class 3 Areas: Any *Impacted* area that is not expected to contain any residual radioactivity resulting from CT operations, or is expected to contain levels of residual radioactivity at a very small fraction of the DCGL for unrestricted use, based on site operating history and previous radiological surveys. A nominal level of 10 percent of the applicable $DCGL_W$ is the upper level limit for classification purposes. For subsurface soils, this limit applies to the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.), following the same approach as used for Class 1 and Class 2 areas. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a *Non-Impacted* classification.

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[11] Currie, L.A., Lower Limit of Detection: Definition and Elaboration of a Proposed Position for Radiological Effluent and Environmental Measurements, NUREG/CR-4006, p. 76, 1984.

[12] Vertical averaging of subsurface soil concentrations in this manner is consistent with prior NRC-approved practice, as described in the letter dated February 13, 1997 from Mr. John T. Buckley (USNRC) to Mr. Howard A. Pulsifer (AAR Corporation) regarding NRC review of the AAR Site Remediation Plan for the Former Brooks and Perkins, Inc. Site, dated April 8, 1996.

The classification of areas of interest is delineated graphically in Figures 14-1a, 14-1b (contaminated surface classification) and 14-2 (contaminated subsurface soil classification).

14.4.3.2. Survey Unit Definition

To facilitate survey design and assure that the number of survey data points for the land areas are relatively uniformly distributed within areas of similar contamination potential, and to focus most of the survey effort on areas where the likelihood of exceeding the DCGL is greatest, the media will be divided into survey units which have a common history or other similar characteristics, or are naturally distinguishable form other portions of the site. Separate survey units will be established for pavement and subsurface material areas. Survey units will be limited in size based on classification and site-specific conditions. The maximum areas for survey units area described in Table 14-4.

Table 14-4. Typical Maximum Areas for Survey Units

Area Classification	Pavement	Subsurface Material
1	2000 m^2	3000 m^2
2	2000 m^2 to 10000 m^2	2000 m^2 to 10000 m^2
3	no limit	no limit

The maximum area specified for Class 1 subsurface material, 3,000 m^2, somewhat exceeds the MARSSIM recommendation of 2,000 m^2. It is expected that implementation of the plan will require only one Class 1 subsurface soil survey unit approximately 2,000 m^2 in area. The higher maximum area is specified to allow for slight expansion of this area without requiring creation of a separate additional survey unit.

As described in Section 8 of the Phase II Plan, main sewer lines immediately to the west and north of Building 238 will be removed or plugged in the process of remediation of subsurface soils beneath Building 238.) If the sewers are plugged, the sewers and their contents will be considered for FSS purposes a part of the subsurface survey unit in which they are located. If they are removed, the sewers and the sludge in them will be treated as potential radioactive waste, as described in Section 12 of the Phase II Plan.

Sediment in sewers remaining in use downstream of Building 238 extending to the Waste Water Treatment Basin area and other sewers in the Plant 5 area will be considered a separate Class 3 survey unit. For classification and evaluation purposes, this sediment is considered no different from other subsurface soil at the equivalent depth. At each location, a single vertical average radionuclide concentration (as described in Section 14.4.3.1) in the sewer sediments and in soils located between the ground surface and the sewer, all taken as combined, has been used to establish the basis for comparison to limits for classification, and will be used for FSS evaluation.

Certain Class 1 and Class 2 areas were covered with temporary paving material following completion of C-T Phase I Decommissioning Plan (Phase I Plan) work. All of this material in

Class 1 areas will be removed to allow FSS surface contamination measurements as part of the Phase II Plan. The material removed has very low potential for contamination, and will be considered non-impacted subject to confirmatory survey to determine that average radionuclide concentration does not depart significantly from background. Such confirmatory measurements looking for residual source material would be performed before releasing the temporary pavement rubble from the site. Such confirmatory survey will be performed as specified in written procedure. In the unlikely event that the material were to fail this test, it would be subjected to FSS as equivalent to a Class 3 subsurface soil survey unit located near the surface (*i.e.*, no vertical concentration averaging). If warranted after FSS-equivalent survey, the material may be released for unrestricted use and handled in the same way as other excavated bulk material subject to release.

14.4.3.3. Hypothesis Formulation

The decision whether the DCGL is met is based on a hypothesis test. Usually, the null hypothesis will be that the survey unit exceeds the release criterion[13]; *i.e.*, Scenario A. This will require that significant evidence exists that the residual radioactivity in the survey unit is less than the release criterion to reject the null hypothesis (and pass the survey unit). If the evidence is not significant at decision Type I error level (α) for Scenario A, the null hypothesis of a non-complying survey unit will be accepted and the survey unit will fail to comply with the release criterion, $DCGL_W$.

Alternatively, the tested hypothesis may be that measurements in a survey unit do not exceed background + $DCGL_W$, *i.e.*, Scenario B,[14] and apply alternate, appropriate statistical test(s). In the event Mallinckrodt were to intend to test compliance using Scenario B, it would notify the NRC Project Manager to seek concurrence. In order to minimize delay, it would expect a response within 4 business days before implementation.

14.4.3.4. Selection of LBGR and Tolerable Decision Error

The number of measurements in a survey unit is a function of the LBGR, Types 1 and 2 decision error rates, and standard deviation of residual radioactivity. A reasoned balance between values of these parameters and number of measurements will be sought. A decision maker should balance costs of survey design, measurements, analyses, and reporting against consequence of decision error. When estimating consequence of decision error, radiological risk is assumed to be linearly proportional to radiological dose, and dose is linearly proportional to average radioactivity concentration or areal density;

The following additional factors will be considered when deliberating selection of LBGR and Type 1 or Type 2 decision error rate, for Scenario A or Scenario B hypothesis respectively, other than default LBGR = 0.5 x $DCGL_W$ or α or $\beta > 0.05$.

- conservatism in derivation of the DCGL;
- the residual radioactivity concentration or areal density range in the survey unit;

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[13] NUREG-1505, pp. 2-14 & 2-15; MARSSIM, p 5-25.
[14] NUREG-1505, §2.5.

- cost-benefit of additional remediation, measurement, analysis, and or reporting versus concentration, dose, and risk reduction;
- physical distribution of residual source as it may affect remediation and logical survey unit boundary;
- appropriate LBGR and gray region, Δ, relative to background, variability in background, and multiple materials backgrounds in the survey unit;[15] increased α error may be tolerable when Δ is small in order to avoid an unreasonably large number of measurements;
- difficult or adverse measurement conditions;
- interference in measurements, *e.g.* K^{40} interference in beta radiation measurement;
- whether measurement error can be reduced reasonably; and
- safety considerations.

The LBGR is the minimum concentration or areal density differentiable from the DCGL, *i.e.*, the minimum increment from the DCGL where one should begin to control false negative decision error. If a Scenario A hypothesis is posed, the LBGR is bounded on the upside by the DCGL and on the downside by background.

Tolerable decision error rates are based on consideration of the consequence of making an incorrect decision about whether a survey unit complies with radiological criteria for release. The target value for Type I decision error (α) in Scenario A hypothesis[18] or alternatively if approved by NRC for use, the target value for Type II decision error (β) in Scenario B hypothesis, will be 0.05. Selection of any greater value, not to exceed 0.15, in either alternative will depend on consideration of these factors and documentation of the reasons in the survey report and will require NRC approval. It is recognized that with respect to radiological safety, any value of β would be acceptable for Scenario A, or any value of α would be acceptable for Scenario B.[19]

14.4.3.5. Determination of Number of Stationary Measurements

The number of measurements required for each survey unit will be determined by two considerations, as discussed in the subsections below. The first consideration is the sensitivity required by statistical analysis to support the hypothesis test. The second, applicable only to Class 1 pavement survey units, is the sampling density required for elevated area detection.

<u>Number of Samples Required for Central Tendency Analysis</u>. In the MARSSIM methodology, two different approaches are used for central tendency analysis. The first applies to the situation in which the radionuclides of interest are present in the background as naturally occurring radioactive material. The second applies to the situation in which they are not present in the background. Because all of the radionuclides of interest in this decommissioning plan are present in the background, only the former approach will be used here, as described below.

[15] NUREG-1505, p. 3-17.
[18] NUREG-1505, §2.3.9.
[19] DG-4006, p. 14.

The simplest situation is that in which licensed radionuclides at concentrations exceeding levels of interest are confined to the surface, such as pavement, or the uppermost shallow subsurface layer, taken to be no more than one meter thick. In that case, the number of data points required when the contaminant is present in the background will be determined in accordance with section 5.5.2.2 of MARSSIM:

1. Estimate the relative shift, Δ/σ, where σ is the expected standard deviation of the survey unit measurements[20] and Δ is the width of the "gray region." The gray region, as used in MARSSIM, can be considered as a region of central tendency nuclide concentration that corresponds to dose. Within the gray region, the probabilities of either a Type I decision error (deciding the unit meets DCGL when it does not) or a Type II decision error (deciding the unit exceeds DCGL when it does not) exceed desired limits. The upper bound of the gray region necessarily corresponds to the release criterion concentration. However, setting the boundary too low drives down the central tendency concentration below which one is highly confident in a decision that a unit exceeds DCGL. Setting the value too high drives up the number of measurements required to achieve the desired decision error probabilities. If decontamination is not performed, for purposes of estimating the number of data points, the value of σ will be estimated from characterization survey data or from background measurements, whichever is representative of the survey unit. If decontamination is performed, variability, σ, will be estimated from either 1) post-remediation survey, 2) characterization survey after deleting measurements exceeding the DCGL, or 3) background survey data. The determination of Δ/σ may be iterative.

2. Determine P_r, the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference area. P_r is determined from Table 5.1 of MARSSIM using the estimated relative shift, Δ/σ, determined in step 1.

3. Determine the decision error percentiles, $Z_{1-\alpha}$ or $Z_{1-\beta}$, corresponding to the desired error probabilities α and β using Table 5.2 of MARSSIM. Tolerable decision error, α and β, will be decided in accordance with §14.4.3.4, above.

4. Calculate the total number of measurement points (survey unit plus reference area) for the WRS Test using Equation 14-1 (Equation 5-1 from MARSSIM) with input parameter values determined in steps 1 through 3.

$$N = \frac{\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2}{3\left(P_r - 0.5\right)^2} \qquad \text{[Equation 14-1]}$$

   Where $Z_{1-\alpha}$ and $Z_{1-\beta}$ are the percentiles represented by the selected decision error levels; P_r is the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference area; and N is the total number of data points to be obtained from both the

[20] If a single-valued index is used to represent a suite of nuclides, such the sum over all nuclides of the ratio of each nuclide concentration to its DCGL value, the value of σ to be used is the standard deviation of the group of indices.

reference area and survey unit combined. Because Equation 14-1 assumes equal numbers of background and survey measurements, the number of data points from the survey unit and the number of data points from the reference area would each be *N*/2.

As noted in the discussion on background in section 14.4.2, the number of background measurements may be constrained. There will be some advantage in sensitivity achievable by collecting a larger number of measurements from the survey unit, although there will be diminishing returns as the number of measurements from the survey unit increases. To calculate the number of samples in this case, Equation 14-2 (based on NUREG-1505, Equation 9-6) is first used:

$$N = \frac{\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2}{12c(1-c)\left(P_r - 0.5\right)^2} \qquad \text{[Equation 14-2]}$$

where $Z_{1-\alpha}$ and $Z_{1-\beta}$ are the percentiles represented by the selected decision error levels; P_r is the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference unit by less than the $DCGL_W$; c is the fraction of samples from the reference area; and N is the total number of data points to be obtained from each reference area/survey unit combination.

In any survey there will be some missing or unusable data. The rate of missing or unusable measurements, R, expected to occur in survey units or reference areas will be accounted for during survey planning. To assure sufficient data points to attain the desired power level with the statistical tests and allow for possible lost or unusable data, the number of data points will be increased by 20% (R=0.2), and rounded up, over the values calculated in the final step. In the event it is not practical to collect 1.2·N measurements, as few as N measurements will be acceptable without verification by a retrospective power curve.

The required number of measurements determined in the first iteration may exceed reasonable bounds. The process can be repeated using more suitable values of Δ, α, and β as appropriate. Use of an Type 1 decision error value > 0.05 for hypothesis Scenario A or Type 2 decision error value > 0.05 for Scenario B would require NRC approval as described in §14.4.3.4.

The procedure described above is complete for the simplest situation in which licensed radionuclides at concentrations exceeding levels of interest are confined to the surface, such as pavement, or the uppermost shallow subsurface layer, taken to be no more than one meter thick. However, in some situations involving subsurface materials, radionuclides may be present deeper in subsoil: and explicit consideration of the volumetric distribution of radionuclides within the survey unit will be required. This is accomplished by extension of the procedure described above, as follows:

1. Determine the number of sampling locations (boreholes), N_B,[21] as if the survey unit were only 1 meter deep, using only characterization or remedial action survey

[21] $N_B = N \div 2$ from Equation 14-1 or $(1 - c)N$ from Equation 14-2

data from the 0 to 1 meter layer to determine the survey unit sample standard deviation.

2. Repeat the computation of the number of boreholes, N_B, using data from borehole samples vertically averaged or homogenized over either the 0 to 2 m thickness or the impacted thickness at each characterization borehole location, whichever is less. (This is intended to prevent averaging down by inclusion of non-impacted subsurface material in the survey.)

3. Repeat the computation of the number of boreholes, using vertically averaged data from 0 to 3 m deep, or the impacted thickness, whichever is less.

4. Continue computing N_B for each successively increasing thickness, until the entire volume of interest in the survey unit is captured in the analysis. The vertical limit of the volume of interest for any given borehole location will be observation of a 1-meter thick layer within which the average radionuclide concentration falls below the Class 2 survey unit stationary measurement investigation level, provided below. The application of this limit implies stopping sampling when concentrations in a 1-m thick layer fall below the DCGL on a net basis.

5. Select the maximum computed value of N_B as the minimum number of boreholes to construct and sample.

Average radionuclide concentration over each 1-m vertical increment down to the level at which concentrations fall below DCGL will be determined for each borehole. For purposes of data evaluation, each subsurface layer (averaged 0-1 m, 0-2 m, 0-3 m, etc.) will be evaluated as though it were a survey unit.

Number of Samples Required for Small Areas of Elevated Activity and Stationary Sample Spacing. The measurements addressed in previous subsection are designed to test whether the $DCGL_W$ are met based on measures of central tendency. The survey must also demonstrate that $DCGL_{EMC}$, the criterion for a small area where activity exceeds the $DCGL_W$, is also met.

Scanning measurements, where practical, are the primary method for detecting small areas of elevated contamination. To the extent that scanning measurements are not sufficiently sensitive to assure this, they are supplemented by additional stationary measurements, beyond the number needed to demonstrate compliance for the measure of central tendency. The method for determining the number stationary measurement points to demonstrate compliance with $DCGL_{EMC}$, is described below.

Scanning for the purpose of finding small areas of elevated radioactivity not detected by systematic measurements on a grid will be performed on building slab and pavement Class 1 and Class 2 survey units Scanning is not practical for subsurface soil survey units.

For Class 2 survey units, scanning is confirmatory only, because no individual measurement is expected to exceed $DCGL_W$. For Class 1 survey units, individual measurements that may exceed $DCGL_W$ are anticipated. The interest in these units is to assure that the concentration and areal extent of elevated contamination are sufficiently constrained to assure that the unrestricted release dose criteria are met.

The minimum detectable areal radioactivity density by scanning (scan MDC) needs to be less than the $DCGL_{EMC}$, the maximum acceptable areal radioactivity density for any given area of contamination smaller than the area of a grid cell for systematic measurement, determined in the previous subsection. Thus, the required scan MDC must be less than or equal the product of the $DCGL_W$ and the area factor associated with the area of a grid cell for systematic measurement. Suppose an area of elevated contamination equals a systematic grid cell area. In that instance, the required scan MDC must be less than or equal to the product of $DCGL_W$ and the area factor corresponding to grid cell area. When the scan MDC is estimated, the area factor corresponding to this estimated, or *actual* scan MDC is:

$$\text{area factor corresponding to actual scan MDC} = \frac{\text{actual scan MDC}}{DCGL_W} \qquad \text{[Equation 14-3]}$$

The contaminated area corresponding to the area factor that corresponds to the *actual* scan MDC is the largest area of elevated radioactivity potentially causing 25 mrem/yr that is detectable by that scan instrument MDC. This area is determined from the plot of area factor versus area in DP Section 5.

The maximum possible number of areas of elevated radioactivity in a survey unit that may not be detectable by scanning, n_{EA}, is derived by the equation:

$$n_{EA} = \frac{\text{survey unit area}}{\text{area corresponding to actual scan MDC}} \qquad \text{[Equation 14-4]}$$

In a Class 1 survey unit, if n_{EA} is less than $n_{wilcoxon}$,[22] no additional stationary measurement samples are required. If n_{EA} is greater than $n_{wilcoxon}$, the additional stationary measurement locations are required to supplement scanning in testing compliance with the elevated measurement criterion.

Surface locations within Class 3 building slab and pavement survey units that are judged to be most likely to be radioactively contaminated will be scanned; although $DCGL_{EMC}$ limits are not applied to a subsurface or a Class 3 survey unit.

14.4.3.6. Survey Locations

The number of data points required and the area of the survey unit will determine the location of the data points. The same approach will be taken for the pavement and subsurface material.

A scale drawing of the survey unit will be prepared, along with the overlying planar reference coordinate system or grid system. Any location within the survey area is thus identifiable by a

[22] $n_{wilcoxon}$ = number of measurements needed to provide desired confidence in a Wilcoxon Rank Sum test, equal to N/2, the number of data from a survey unit, where N is as calculated from either Equation 14-1 or 14-2

unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit are then determined.

Measurements or samples in Class 3 areas and reference areas will be taken at random locations. These locations will be determined by generating sets of random numbers (2 values, representing the X axis and Y axis distances). Each set of random numbers will be used to provide coordinates, relative to the origin of the survey unit reference grid pattern. Coordinates identified in this manner, which do not fall within the survey unit area or which cannot be surveyed, due to site conditions, will be replaced with other survey points determined in the same manner.

Class 1 and Class 2 areas will be surveyed on a random-start systematic pattern. The number of survey locations calculated to satisfy statistical tests and elevated measurement tests, will be used to determine the spacing of a systematic pattern by the following equations: Equation 14-5 for a triangular grid or Equation 14-6 for a square grid. In the equations, *L* is the spacing, *A* is the area of the survey unit. For pavement survey units, *n* is the larger number of calculated survey locations, either n_{EA}, if applicable, from Equation 14-4, or N÷2 from Equation 14-1 or (1 - c)N from Equation 14-2. For subsurface survey units, *n* is N_B, the required number of boreholes.

$$L = \sqrt{\frac{A}{0.866n}} \qquad \text{[Equation 14-5]}$$

$$L = \sqrt{\frac{A}{n}} \qquad \text{[Equation 14-6]}$$

The choice of grid pattern will be made by considering elevated area contamination potential and general shape of the survey unit. The grid which is most practical to establish, survey and evaluate will be chosen.

After L is determined, a random coordinate location will be identified, as described previously, for a survey pattern starting location. Beginning at the random starting coordinate, a row of points will be identified, parallel to the X axis, at intervals of L. For a triangular grid, a second row of points will then be developed, parallel to the first row, at a distance of 0.866•L from the first row. Survey points along that second row will be midway (on the X-axis) between the points on the first row. This process will be repeated to identify a pattern of survey locations throughout the survey unit. If identified points fall outside the survey unit or at locations which cannot be surveyed, additional points will be determined using the random process described above, until the desired total number of points is identified.

In addition to the survey locations identified for statistical evaluations and elevated measurement comparisons, it is likely that data will also be obtained from judgment locations, selected due to unusual appearance, location relative to contamination areas, high potential for residual activity, general supplemental information, *etc.* These data points selected based on professional judgment will not be included with the data points from the random-start triangular or square grid for statistical evaluations because they are not unbiased, as is assumed in the statistical analysis. These measurements will be compared to the investigation levels described in section 14.4.3.8. Characterization and or remediation survey data may serve this purpose provided they are of acceptable quality.

14.4.3.7. Surveys

After the number of required measurements or samples has been established and the location of the measurements or samples is determined, a survey strategy will be developed using the following guidelines. Final status survey of pavement and of soil will be done separately. Both scans and stationary measurements will be performed for pavement and building slabs. Pavement and building slabs will be surveyed by scans and stationary measurements for beta radiation or conservatively, $\beta + \gamma$. Subsurface materials will be subject to stationary measurements, but not scan surveys.

CT 2 DP, §4 Radiological Status of Facility, summarizes the radioactivity associated with CT Plant 5 and downstream sewerage, to and including the wastewater basins in Plant 7 West that are subject to CT Phase II decommissioning. In the event Mallinckrodt were to find substantial additional radioactive residue not accounted for in site characterization, it would provide a summary to the NRC.

Class 1 Areas. Scans will be performed over 100% of pavement and building slab surfaces. Locations of radioactive material concentration above the scanning survey investigation level will be identified, delineated, and evaluated. Stationary location measurements of radioactive material areal density will be performed on pavement at locations identified by scans and at previously determined stationary measurement locations selected to test compliance with $DCGL_W$ and $DCGL_{EMC}$, as described above in Sections 14.4.3.5. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (averaged 0-to-1 m, 0-to-2 m, 0-to-3 m, *etc*., down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test compliance with $DCGL_W$. Locations of radioactive material areal density or concentrations above the stationary measurement investigation level will be identified and evaluated. Results of initial and follow-up direct measurements and sampling at these locations where measurements exceed investigation levels will be recorded and documented in the Final Status Survey Report. Temporary pavement was applied following the completion of Phase I Plan work in some Class 1 pavement and slab areas. Prior to the FSS, this temporary pavement will be removed from areas subject to survey to permit accurate survey of the pavement and slab surfaces of interest.

Class 2 Areas. Scans will be performed on at least 10% of pavement and building slab surfaces. Locations of radioactive material concentration above the scanning survey investigation level will be identified, delineated, and evaluated. Stationary location measurements of radioactive material areal density will be performed at pavement locations identified by scans and at previously determined stationary measurement locations selected to test compliance with $DCGL_W$, as described above in Sections 14.4.3.5. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (averaged 0-to-1 m, 0-to-2 m, 0-to-3 m, *etc*., down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test compliance with $DCGL_W$. Locations of radioactive material concentrations above the stationary measurement investigation level will be identified and evaluated. Results of initial and follow-up direct measurements and sampling at these locations where measurements exceed investigation levels will be recorded and documented in the Final Status Survey Report. Temporary pavement was applied following the completion of Phase I Plan work in some Class 2 pavement and slab areas. Prior to the FSS, this temporary pavement will be removed from areas subject to survey to permit accurate survey of the pavement and slab surfaces of interest.

Class 3 Areas. Scans of surfaces will be performed at locations judged most likely to be elevated in radioactive contamination as determined through the use of historical knowledge and contractor experience. Locations of direct radiation above the scanning survey investigation level will be identified and evaluated. Stationary measurements of radioactive material concentration will be performed at locations identified by the scans and locations selected to test whether concentrations exceed more than a small fraction of $DCGL_W$. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (averaged 0-to-1 m, 0-to-2 m, 0-to-3 m, *etc.*, down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test whether concentrations exceed more than a small fraction of $DCGL_W$.

Sampling. Sampling depends on the material to be sampled. The method or reference to an applicable procedure will be specified in each final status survey design. If soil is to be sampled, collection may be by hand trowelling of topsoil, by manual core-barrel augering, by split-spoon or equivalent core sampling, or by direct measurement of the sample *in-situ*. If concrete or macadam, sample collection alternatives include core sampling, drilling or augering a sample, scabbling or scraping a shallow sample, or collecting broken pieces of the bulk material. Each sample will be put into a container, which will be then be closed and will be labeled in accordance with a formal Chain-of-custody procedure. Administrative control of final status survey samples, from initial packaging and labeling through laboratory and disposition, will be in accordance with the Chain-of-custody quality procedure. Health Physics technicians who collect and handle final status survey samples are subject to training to qualify each of them to perform the tasks and procedures that control sample collection and handling.

Pavement.[23] In revised CT 2 DP, §5.9.1 $DCGL_W$ on Pavement, $DCGL_W$ on pavement is presented in units, dis/(min·100 cm^2), and units, β/(min·100 cm^2) and the basis of derivation is explained. Measurement by beta-ray detection at pavement surface will be as described in C-T Phase I Decommissioning Plan (CT 1 DP), Appendix D, §3 Beta Radiation Measurement, as was approved for and applied to building surfaces. Calibration of beta ray-detecting survey instrumentation is described in CT 1 DP, Attachment 3 Energy Dependent Calibrations for the Bicron Model AB-100 Beta Ray Survey Probe. [also ref. CT 2 DP §14.4.1, incl. Table 14-1]. Scanning pavement will be done with a beta-detecting floor monitor or equivalent. [ref. CT 2 DP §14.4.1, incl. Table 14-1]

Survey methodology is described in CT 2 DP, §14.4.3 Survey Methodology.

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[23] Direct measurements and analyses of 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). [ref. CT 2DP §4.8.3]

Slabs. Access to process and support building slabs awaiting survey and that were sealed by temporary pavement is described in §14.4.3.2.

Foundations. Above-grade, exposed portions of a foundation are subject to the DCGL that is applicable to pavement and will be subject to final status survey. In the event the exposed portion of a foundation or adjacent portion of a slab in contact with it were contaminated above DCGL applicable to pavement, Mallinckrodt would investigate the possibly affected part of the foundation below grade. A foundation may be surveyed either by direct measurement or by collecting sample(s) of concrete from the foundation surface, *e.g.*, by scabbling, scraping, or chipping. Residual source in that kind of sample would be measured, interpreted as areal contamination, and compared with the areal DCGL applicable to pavement.

A subsurface building foundation within a soil survey unit that requires remedial action adjacent the foundation and exposes it will be subject to measurement of radionuclide concentration in scabble samples from locations selected based on professional judgment. Results of those samples will be considered investigative or remedial action support survey data and will be evaluated to determine whether remedial action for the building foundation is necessary.

Soil. In revised CT 2 DP, §5.8.5 Composite Dose Factors and $DCGL_W$ and in §5.8.6 Compliance Model for Soil, $DCGL_W$ of the radionuclide groups is presented in units, pCi/g soil, and an equation for combining into a sum-of-fractions of $DCGL_W$, or composite index, is included.

Wherever the cinder-fill soil is covered by pavement, measurement of source radionuclides in the soil will begin at the pavement-soil interface. Measurement will be made by coring thorough the pavement, then soil core sampling and analysis of each soil core sample by gamma spectrometry. Alternatively, a borehole may be augered and analysis done in-situ by gamma spectrometry. In-ground analysis is described in CT 2 DP, Appendix F, Radionuclide Analysis in Soil by In-ground Gamma Spectrometry.

Soil survey design and performance is described in CT 2 DP, §14.4.3 Survey Methodology. After excavation to remove contaminated soil, an excavation cavity will be subject to measurements, whether scanning, soil sampling, and or direct measurement, to fulfill final status survey requirements applicable to that location.[24] Backfilling would be done afterward. In the event non-contaminated backfill soil were imported from off-site, its radioactivity would be subject to confirmation as natural background either by origin or confirmatory measurement, but would not be subject to final status survey. In the event backfill originates on-site, whether soil or other rubble, it would be subject to final status survey quality sampling and measurement before deposit in the excavation cavity.[25] The undisturbed remainder of the survey unit would be surveyed later, or characterization survey data of recognized quality could be used to supplement it.

Characterization survey data were used to classify Plant 5 areas according to MARSSIM categories, identified in CT 2 DP Figure 14-2. One or more soil survey units will be delineated

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[24] In the event groundwater were to prevent direct access to survey the bottom of an excavation cavity, an alternative would be to backfill as much as one meter and do final status core sampling through the backfill into the unexcavated bottom.

[25] Assuming the bottom of an excavation cavity is accessible for final status survey and backfill is either clean soil or has been characterized by MARSSIM-like survey quality, these data should be sufficient to demonstrate a backfilled excavation area to comply with radiological criteria for release. Thus, no additional survey of the excavated and backfilled area is required.

within each classified area and a final status survey will be designed for each survey unit in accordance with a final status survey design guide.
About 600 soil samples were analyzed during C-T characterization surveys. Where soil has remained undisturbed since their collection, analyses of these samples will be expected to fulfill data quality objectives to complement other final status survey measurements in the same survey unit and contribute prominently to assurance that land survey units satisfy decommissioning criteria. Where these data need to be complemented by new, systematic measurements, the final status survey design will so provide. Where subsoil contamination is reasonably suspected, final status survey design will be expected to include subsoil radioactivity measurement, either by soil core sampling and gamma spectrometry or in-ground, down-hole gamma spectrometry to measure key radionuclides.

<u>Sewerage</u>. Sediment in sewers remaining in use downstream of Building 238 extending to the Waste Water Treatment Basin area and other sewers in the Plant 5 area will be considered a separate Class 3 survey unit. For classification and evaluation purposes, this sediment is considered no different from other subsurface soil at the equivalent depth. At each location, a single vertical average radionuclide concentration (as described in Section 14.4.3.1) in the sewer sediments and in soils located between the ground surface and the sewer, all taken as combined, has been used to establish the basis for comparison to limits for classification, and will be used for FSS evaluation. [DP §14.4.3.2]
Drains and other at-grade locations that may have been exposed to C-T materials will be identified and surveyed for radioactivity. Downstream sewerage will reasonably be assumed to be uncontaminated if surveys of drains and other at-grade locations do not identify the presence of radioactivity above criteria. If these surveys identify contamination, interior surveys, *i.e.*, sediment sampling, will be performed. Drains and subsurface sewerage that served C-T yard areas will be addressed in a manner similar to that employed for drains and subsurface sewerage that served C-T support buildings. [DP §8.4.3 & 8.4.4]

Plugged Sewerage. A plugged sewer would not be usable and not be salvageable as they are clay or concrete and would break into pieces upon excavation. In the future, potential exposure as a consequence of inadvertent intrusion would be similar to that posed by other subsoil at that depth in the remainder of the survey unit. Thus, if plugged, sewers and their contents will be considered as part of the subsurface final status survey unit in which they are located.

Sewerage Remaining in Use. Characterization survey data indicate sewerage beginning about even with the west ends of Buildings 236 and 245 and extending downstream to the Wastewater Treatment Basins is expected to satisfy a final status survey and may remain in service. Applying criteria similar to other subsurface soil at the equivalent depth for classification and evaluation, sediment in this sewerage remaining in use will be considered a separate Class 3 survey unit.
Sediment in the sewerage remaining in use will necessarily be sampled through manholes and stormwater drain openings. At each sampling location, a vertical average radionuclide concentration in the sewer sediment and in soil between the ground surface and the sewer is evaluated. [DP 14.4.3.2]

Drains and Sewerage that Served C-T Support Buildings and Yard Areas. A final status survey will be designed to sample access points in drains and at-grade access locations in sewerage that served C-T support buildings and yard areas potentially exposed to C-T source material. If not contaminated, that will be accepted as confirmation that downstream sewerage is not contaminated. If contaminated, sediment in the sewer at accessible locations (manhole or surface drain opening) downstream will be sampled. [CT 2 DP §8.4.3 & §8.4.4]

Plant 7 Lift Station. Interior surfaces, including exposed joints of a concrete enclosure of wastewater valving that is below grade, the Plant 7 Lift Station, will be surveyed. This final status survey will be done in the same manner as were building surfaces during CT Phase I final status surveys. DCGL proposed for surfaces in CT 2 DP §5.8.2 are applicable to the Lift Station interior surfaces.

Wastewater Neutralization Basins. During use and afterward, the wastewater neutralization basins were lined with a rubberized liner with seams sealed to prevent wastewater from contaminating the concrete. Each of the two basins was surveyed by surface gamma walkover scan. At 26 locations, indicated in Figure 4-5, where gamma radiation was elevated the most, one-square-foot sections of the liner were removed and direct measurements for beta radiation were made. No beta measurement exceeded the proposed $DCGL_w$ for pavement or a concrete slab and were generally less than 0.1 $DCGL_W$ proposed for outdoor surfaces. [ref. DP Figure 4-5].

After the liner is removed, the entire surface of both wastewater neutralization basins will be exposed to allow a final status survey. DCGL proposed in CT 2 DP, §5.9 Industrial Work on Pavement, will be applicable to the concrete surface of the basins.

For the purpose of final status survey, the neutralization basins shall be Class 2; at least 0.1 of their area will be scanned; and judgment measurements searching for evidence of embedded residual source material will be performed. If evidence of embedment or penetration into the concrete is discovered, it will be investigated by scabbling or chipping into the concrete and or other convincing measurement. Else, if the final status survey passes without evidence of embedment into concrete, that may be interpreted as reasonable confidence that embedment has not occurred.

As with a building floor slab, joints and cracks in the basins would be subject to judgment survey if immediately adjacent surfaces were to exhibit substantial contamination. If contamination requiring decontamination were found, it would be removed either by a traditional method such as water scavenging, scabbling, or chipping; or the affected section of concrete would be broken and the rubble disposed.

14.4.3.8. Data Analysis

The evaluation of survey results is performed in four stages. The first stage will consist of a preliminary review of the data. The second stage of evaluation will consist of an evaluation of elevated measurements against investigation levels. The third stage of data evaluation will consist of statistical analysis to determine whether measurements exceed the $DCGL_W$. The last stage of data evaluation will consist of concluding whether the results of the survey meet the design objectives. Based on results from the first three stages, resurvey, reclassification, remedial action, or some combination of these measures may be required. The survey will not be complete until the conclusion that survey objectives have been met can be supported. Each of these stages is discussed in greater detail in the following subsections.

Final status surveys will be managed in the following way. In summary:

- Each final status survey design will be documented and approved for execution.
- Final status survey measurements will be recorded.

- Final status survey data of record will be examined for legibility, completeness, conformance with the survey design specifications, and apparent errors.
- Original survey design specifications and survey records will be retained.
- If the data are acceptable, tests of compliance with DP §5 release criteria will be performed. These would test each measurement for compliance with the *elevated measurements criterion* and would test the systematic measurements in the survey unit for compliance with collective data criteria.
- A final status survey report of the data, screening tests, and compliance tests is examined.
  - If either the final status survey records, checks, or a test is not accepted, contingent actions, as described in the Section 14.4.3.9, "Contingencies," will be considered.
  - Else, if the data, screening tests, and compliance tests for that survey unit are accepted, a final status survey report for that survey unit will be written.

Preliminary Data Review. The first stage of data evaluation will consist of a preliminary review of the data to check quality and reasonableness, including:

- Legibility of recorded data,
- Assessment of completeness of the data,
- Verification of instrument selection and calibration,
- Verification of survey technician training qualifications,
- An initial judgment about the overall quality of the data. This would aim to identify gross errors in data recording,
- Conversion of raw data to standard units where appropriate. (For pavement surfaces, the units are (dpm/100 cm^2). For subsurface materials, units are activity per unit mass, or an equivalent index),
- Whether the number of points taken are in accordance with the specific survey design,
- Whether the locations of systematic grid points correspond to what was prescribed in the survey design,
- Whether scan data were adequately processed, (Scan data sheets will be reviewed to determine whether any high reading requires investigation and, if so, has been adequately verified with a direct confirmatory measurement), and
- Whether biased measurements (measurements at survey unit locations where detection of licensed radioactive material would be considered to be most likely) were taken in accordance with FSS design instructions and their location accurately documented on drawings and in the database.

If, during this initial review, any measurement is considered inadequate, additional survey information may be collected. Once this review is complete and the analyst is satisfied, the survey records will be "locked," completing preliminary data review and acceptance of the survey. Permanent archive files of all survey data taken in connection with the C-T project will be maintained to provide for their security, organization, and availability to authorized reviewers, including the NRC.

The remaining stages of evaluation are performed for each survey unit, or, in the case of subsurface materials, each vertical layer (avg 0 to1 m, 0 to 2 m, 0 to 3 m, *etc.*) within a survey unit.

Evaluation of Measurements Individually. In the second stage of evaluation, scan results and individual measurements of pavement surface and vertically averaged (0 to 1 m, 0 to 2 m, 0 to 3 m, etc.) subsurface materials[26] will be compared to an appropriate investigation level for evidence of a small area of elevated radioactivity. An investigation level is a radioactivity concentration, areal density, or index that is used to indicate when additional investigation may be necessary. An investigation level depends on survey unit classification. A scan result which exceeds the corresponding investigation threshold listed in Table 14-5 shall be confirmed by stationary location measurement. Whether reclassification is needed and comparison with release criterion, $DCGL_{EMC}$, would be evaluated by the stationary measurements or by sampling. Scan measurement results will remain as paper records. The direct measurement data only will be recorded and used for further analysis and classification.

Investigation Levels. Individual measurements from pavement and indices calculated from nuclide concentration measurements in subsurface material samples will be compared to investigation levels for evidence of small areas of elevated activity. The purpose of investigation levels is to make the best use of individual sample results that may call into question validity of analyses or validity of assumptions underlying the survey. Investigation levels are not intended to be limits. Results exceeding investigation levels should not be used as the sole basis for deciding whether a survey unit has failed. Scan results for those units subject to scanning will also be compared to investigation levels. The levels established for investigation will depend upon the survey unit classification. Lower investigation thresholds will be set for those units having lower potential for elevated areas.

In the event a survey area as a whole passes final status survey tests, a partial remediation, *e.g.*, cleanup of a small area exceeding the $DCGL_{EMC}$, may be performed without an entire resurvey of the whole survey area. However, depending on the outcome of the elevated measurement test and other tests, resurvey, reclassification, partial or complete remediation, or some combination of these measures may be required. (If only partial remediation is required, resurvey of some portion of the unit after supplementary remediation will also be required. To the extent practical and appropriate, original survey data from portions of the unit outside the supplementary remediation area will be used in conjunction with new survey data from the supplementary remediation area in new tests to determine whether the unit meets release criteria.).[27,28] If subdividing a survey unit and reclassifying part of it is the logical remedy, it will be done in accordance with provisions in §14.4.3.9 *Contingencies*.

The results of all investigations will be documented in the final status survey report. Investigation levels are described in greater detail below.

In Class 3 survey units, no residual nuclides are expected above a small fraction of DCGL.. Therefore, investigation levels are set to flag measurements that are just above the range expected for background levels and a small increment (10%) of DCGL, or just above detection limits for the measurement method, whichever is greater.

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26 Although the procedures for evaluation of measurements individually applies strictly only to vertically averaged concentrations in subsurface soils, application of these procedures to individual samples (*i.e.*, not vertically averaged concentration) is more restrictive and may be used to demonstrate compliance.

27 NUREG-1727, Appendix E

28 MARSSIM, §5.5.2.6.

In Class 2 survey units, measurements of net levels above the DCGL are not expected. Therefore, investigation levels are set to flag measurements exceeding the DCGL on a net basis. If the scanning MDA exceeds the DCGL on a net basis, any scanning result exceeding the MDA will also be investigated.

For Class 1 survey units, measurements above the DCGL are not unexpected. For slab and pavement survey units, a special derived concentration guideline for elevated measurements, $DCGL_{EMC}$, is used as the basis for investigation levels. The derived concentration guideline level for the EMC (elevated measurement comparison) is determined as described in Section 5. Where topsoil is exposed in a Class 1 survey unit, the investigation level appropriate for slab and pavement is also applicable to the topsoil. For subsurface survey units, $DCGL_{EMC}$ is not applicable. For these units, the investigation level is a value indicating substantial departure from the distribution of concentrations used as the basis for determining the number of measurement locations for the central tendency analysis.

Values for $DCGL_{EMC}$ will be calculated and supplied in the final status survey design. The derived concentration guideline level for the elevated measurement comparison (EMC) is determined as described in Section 5 of this DP. For initial evaluation, the area on which $DCGL_{EMC}$ is derived *a priori* will be the systematic grid cell area derived in section 14.4.3.5. The background reference level for each data point will be the average of background measurements associated with the same reference material. Any value exceeding the EMC criterion in Table 14-5 is not sufficient to fail the survey unit, but will be flagged for investigation and evaluation.

Table 14-5 summarizes the investigation levels.

Table 14-5

Summary of Investigation Levels

Survey Unit Class	Flag Stationary Location Measurement or Sample Result When Value Exceeds:	Flag Scanning Measurement Result When Value Exceeds:
Class 1 slab and pavement	$DCGL_{EMC} + \bar{x}_{ref}{}^{a} + 2s_{ref}$	$(DCGL_{EMC} + \bar{x}_{ref}{}^{a} + 2s_{ref})$
Class 1 subsurface	$DCGL_W + \bar{x}_{ref}{}^{a} + 6s_{ref}$	NA
Class 2	$DCGL_W + \bar{x}_{ref} + 2s_{ref}$	maximum of $(DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA
Class 3	maximum of $(0.1\ DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA	maximum of $(0.1\ DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA

[a] $\bar{x}_{ref}$ and s_{ref} are the mean and sample standard deviation of the reference or background measurements. If a single-valued index, I_i, is used to represent a suite of nuclides for a particular sample, such as the sum over all nuclides of the ratio of each nuclide concentration to its DCGL value, the above expressions are modified by setting $DCGL_W$ to 1, and using for $\bar{x}_{ref}$ and s_{ref} the mean and sample standard deviation, respectively, of the I_i values for the reference or background area.

Data Set Screening Analysis. The data set for the survey unit will be processed within a database using screening software developed and verified for the project.[29] The screening software will perform the following comparison tests:

Data Screening Tests
Min/Max screen
Low Level screen
$DCGL_w$ screen
EMC limit screen

A brief description of each test applied follows.[30]

- Min/Max Screening. Recorded data points in the survey unit will first be processed to derive the difference between the largest survey value and the smallest applicable background value. If that difference is less than the $DCGL_w$, a class 1 or class 2 survey unit will be rated acceptable and no further computation will be needed.[31] A class 3 survey unit will be passed on to the low level screen. If a class 2 or 3 survey unit fails this test, it will be evaluated for additional analysis, remediation, or other appropriate action. A class 1 unit that fails this test will be passed on for the remaining tests.
- Low Level Screening. All class 3 survey units will be processed through low level screening. Each data point that fails the test will be flagged as an exception in the evaluation of measurements individually. In a class 3 survey unit, residual, regulated radioactivity at concentrations more than a small fraction of $DCGL_W$ is not expected. Therefore, the investigation level is set to flag any measurement that is just above the range expected for background and a small increment (10%) of $DCGL_W$, or just above the detection limit for the measurement method, whichever is greater (ref. Table 14-5). If the class 3 survey unit contains no flagged measurements, the unit will be rated

[29] Although the procedures for screening evaluation of data sets applies strictly only to vertically averaged concentrations in subsurface soils (0-1 m as one data set, 0-2 m as a second, etc.), application of these screening procedures to an entire survey unit data set of individual samples (*i.e.*, not vertically averaged concentration) is more restrictive and may be used to demonstrate compliance.

[30] MARSSIM, Table 8.2.

[31] If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its $DCGL_w$ value, is used to represent a suite of nuclides for a particular sample, the test is that the difference between I_{max} from the survey unit and I_{min} from the reference area is less than 1.

acceptable for this test. If the class 3 survey unit fails this test, it will be evaluated for additional analysis, remediation, or other appropriate action.

- DCGL$_W$ Limit Screening. The net radioactivity of each survey point within the survey unit will be compared with the DCGL$_W$. The reference level for each data point will be the average of background measurements associated with the same matrix. Each value exceeding DCGL$_W$ will be flagged as an exception, point by point. In addition, the mean value for the reference area and the survey unit will be compared for Classes 1, 2, and 3 survey units. If the average radioactivity observed in a survey unit exceeds background average, such that the difference between the two is greater than the DCGL$_W$, the entire survey unit will be flagged for additional analysis, remediation, or other appropriate action as to its reclassification.[32]

- Elevated Measurement Comparison (EMC) Limit Screening. In a class 1 pavement survey unit, measurements above the DCGL$_W$ might occur. In the event residual radioactivity is elevated above the DCGL$_W$ in local area(s) of a survey unit, the following expression may be employed to assess whether total radioactivity concentration in the survey unit is within the release criterion.

$$F = \left(\frac{A_{EM}}{A_T} \times \frac{\bar{C}_{EM}}{AF \times DCGL_W} \right) + \left(\frac{A_T - A_{EM}}{A_T} \times \frac{\bar{C}_{other}}{DCGL_W} \right) \qquad \text{Equation 14-7}$$

where

F = exposure-weighted fraction of DCGL$_W$ presented by residual radioactivity in survey unit

A_{EM} = area within which elevated measurements occur (m^2)

A_T = total area in survey unit (m^2)

$\bar{C}_{EM}$ = arithmetic mean radioactivity concentration in area of elevated measurements (pCi/g or dis/(min·100 cm^2))

AF = area factor for elevated measurements

$\bar{C}_{other}$ = arithmetic mean radioactivity concentration measured at unbiased locations in the survey unit area not containing radioactivity elevated > DCGL$_W$. (pCi/g or dis/(min·100 cm^2))

$DCGL_W$ = derived concentration guideline level (pCi/g or dis/(min·100 cm^2))

This expression accounts for the proportions of survey unit area represented by substantially differing measurement density and by the measurement density in each part.

These tests are performed as EMC screening of final status survey data.

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32 If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its DCGL$_w$ value, is used to represent a suite of nuclides for a particular sample, each I_i value in the survey unit is compared the average of the I_i values from the reference area, and is flagged if the difference exceeds 1. In addition, if the average of the survey unit I_i values exceeds the average of the reference area I_i values by more than 1, the entire survey unit is flagged.

If a test is failed, an analyst will decide about reclassification, remediation or release of the survey unit. Exceptions will be handled on a case-by-case basis. For example, the analyst may opt to reapply the tests after accounting for an unusually high level of K-40, if it is present. The resolution of each flagged datum will be documented to provide a clear understanding of how the survey unit was ultimately released in the final status survey report.

<u>Conduct Statistical Analysis.</u> Unless they passed the *Min-Max test*, stationary measurements at systematic grid locations in class 1 and class 2 survey units will be examined statistically to determine whether release criteria have been satisfied. This stage will also include reassessment of the power of the hypothesis test, based on survey data. If the survey unit does not pass, consideration according to §14.4.3.4 of values of Δ/σ, α, and β more suitable than those used in the survey design may be appropriate.

Statistical analysis is required only on class 1 or 2 survey units where the mean survey value is above the mean reference value by an amount less than $DCGL_W$. The analyst will perform the Wilcoxon Rank Sum Test (WRS).[35] The test result will be examined to decide whether it passes or fails the tested hypothesis. If criteria are not met, resurvey or remedial action may be required.

The logic described in Table 14-6 will be used to judge compliance with the DCGL:

Table 14-6. Summary of Statistical Tests

Survey Result	Conclusion
All survey unit measurements are less than $DCGL_W$ on a net basis	Survey unit meets release criteria
Difference between any survey unit measurement and any reference area measurement greater than $DCGL_W$ (not to be used for survey units with less than 5 measurements)	Conduct WRS test and, for pavement survey units, elevated measurement comparison

If statistical analysis is necessary for a survey unit, the two-sample Wilcoxon Rank Sum (WRS) test will be conducted. The WRS test assumes that the reference area and survey unit data distributions are similar except for a possible shift in the medians, and is applied as follows:

1. Obtain the adjusted reference area measurements, Z_i, by adding the $DCGL_W$ to each reference area measurement, X_i.[36]

$$Z_i = X_i + DCGL_W \quad \text{[Equation 14-8]}$$

[35] Also called the "Mann-Whitney Test", a *Wilcoxon Rank Sum Test* should be used when there is background radiation present and the background characteristics and radioactivity distribution are similar for the materials present in the survey unit.

[36] If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its $DCGL_w$ value, is used to represent a suite of nuclides for a particular sample, adjusted reference area measurements are computed as $Z_i = I_i + 1$. These values are then pooled with the I_i values from the survey unit for statistical analysis.

2. The *m* adjusted reference sample measurements, Z_i, from the reference area and the *n* sample measurements, Y_i, from the survey unit are pooled and ranked in order of increasing size from 1 to *N*, where $N = m+n$.
3. If several measurements are tied (have the same value), they are all assigned the average rank of that group of tied measurements.
4. Use of "less than" values in data reporting will be minimized to the extent practical. If more than 40 percent of the data from either the reference area or survey unit are "less than," the WRS test will not be used. If there are *t* "less than" values, they are all given the average of the ranks from 1 to t. Therefore, they are all assigned the rank t(t+1)/(2t) = (t+1)/2, which is the average of the first t integers.[37]
5. Sum the ranks of the adjusted measurements from the reference area, W_r.
6. Compare W_r with the critical value given in Table I.4 of the MARSSIM manual for the appropriate values of *n*, *m*, and α. If W_r is greater than the tabulated value, reject the hypothesis that the survey unit exceeds the release criterion.

Draw Conclusions and Document Survey. The last stage of data evaluation will examine whether final survey results met survey design objectives. An affirmative conclusion indicates the survey is complete. Otherwise, reclassification, resurvey, remedial action, or some other contingent action described below would be appropriate.

A final status survey will provide a record of the radiological status of the survey unit, relative to the DCGL. To the extent practicable, this report will be a stand-alone document with minimum information incorporated by reference. Each final radiation status survey shall be documented as described in Section 14.5.

14.4.3.9. Contingencies.

In the event final survey unit measurement(s) appear not to satisfy a release criterion, some alternative actions may be taken to assess whether it does and or to enable the survey unit to pass criteria. Some acceptable alternatives to remediating the entire survey unit and performing another final status survey follow. One or more may enable demonstration of compliance.

- Objectives would be reviewed with respect to how to assess whether a survey unit meets survey criteria.[38, 39]
- Ordinarily, survey data would first be reviewed to confirm its acceptability. One may also decide whether additional data are needed to determine whether the survey unit complies with release criteria.[40]
- Reassess the reference area or material to be compared with the survey unit

If DQO are inappropriate or if a survey unit is misclassified, Mallinckrodt may:

[37] NUREG-1505, p. 2-19; MARSSIM, p 8-18.
[38] MARSSIM, p. 8-25.
[39] NUREG-1505, p. 3-1.
[40] MARSSIM, p. 8-24.

- Review the DQO. If warranted, adjust values of parameters such as Type 1 and Type 2 error criteria (ref. §9.5) or the lower bound of the gray region (LBGR).

- If proposing to subdivide a survey unit and reclassify part of it to lesser status, *e.g.*, from Class 1 to 2 or Class 2 to 3, notify the NRC Project Manager of the plan and obtain concurrence before final survey.

- Reclassify part of a survey unit that contains elevated measurements (ref. §9.5, item k). Remediate if necessary. Measure at the density appropriate to the new classification. If the reclassified part were Class 1, the measurement density appropriate for Class 1, and the number of measurements in it were fewer than would be estimated for an entire Class 1 survey unit, compliance would be accepted if every measurement[41] in the reclassified part were less than the $DCGL_W$.
    - In the event a Class 1 survey unit area is less than 2000 m^2 and the number of measurements are specified and tested statistically for compliance with $DCGL_W$, the area factor shall not exceed that specified in Section 5 for the elevated measurement test.
    - Alternatively, in the event a Class 1 survey unit area is less than 500 m^2, the number measurements estimated to satisfy a WRS, Quantile, or Sign test might be unreasonably large in that survey unit. When both conditions exist, alternative measurement density may be at least one measurement per 25 square meters at locations based on judgment. In that circumstance, the criterion for release shall be that every measurement in the survey unit does not exceed the $DCGL_W$.[42] Gamma scan of 100% of the surface of land, pavement, or building slab shall be in accordance with §14.4.3.7. Before this alternative is implemented, Mallinckrodt will notify the NRC of intent to employ it.
    - In the event a Class 2 survey unit area is less than 2000 m^2, the number measurements estimated to satisfy a WRS test might be unreasonably large in that survey unit. When so, alternative measurement density may be at least one measurement per 100 m^2 at locations based on judgment. The criterion for release in that circumstance, shall be that every measurement in the survey unit does not exceed the $DCGL_W$.[43] Gamma scan of at least 10% the surface of land, pavement, or building slab shall be in accordance with §14.4.3.7. Before this alternative is implemented, Mallinckrodt will notify the NRC of intent to employ it.

- If the scanning method was not sensitive enough in a Class 2 unit, a portion containing measurements greater than $DCGL_W$ may be reclassified as Class 1, measured at the measurement density required for a Class 1 area, with the rest of the survey unit remaining Class 2.[44] Before this alternative is implemented, Mallinckrodt

[41] Interpret to be measurement net of background
[42] MARSSIM, p. 4-15.
[43] MARSSIM, p. 4-15.
[44] MARSSIM, p. 8-24.

will notify the NRC of intent to employ it. Gamma scan of the surface of land, pavement, or building slab shall be in accordance with §14.4.3.7.

If an elevated measurements test is failed, Mallinckrodt may:

- If a survey unit passes statistical test(s) but radioactivity concentration in a local area exceeds the $DCGL_{EMC}$, *i.e.*, the product of $DCGL_W$ x area factor, for its actual size, remediate the local area. If a post-remediation survey of the local area demonstrates the exposure-weighted fraction, F, of $DCGL_W$ presented by residual radioactivity in survey unit is less than unity,

$$F = \left(\frac{A_{EM}}{A_T} \times \frac{\bar{C}_{EM}}{AF \times DCGL_W} \right) + \left(\frac{A_T - A_{EM}}{A_T} \times \frac{\bar{C}_{other}}{DCGL_W} \right) \qquad \text{Equation 14-9}$$

compliance with the elevated measurements criterion is demonstrated. Else, statistical tests for the survey unit are performed again.[45]

If a non-parametric statistical test is failed, Mallinckrodt may do one or more of these:

- Construct a retrospective power curve[46] of the measurements. Evaluate whether the survey unit would have passed the release criterion using the non-parametric statistical test, *e.g.*, WRS test. If not, it would be acceptable to make more measurements at random locations in the survey unit and perform statistical test(s) on the expanded data set.[47] Mallinckrodt would review the data quality objectives, would notify the NRC Project Manager of intent to perform double or two-stage sampling, and would seek concurrence. In order to avoid delay of decommissioning activity, Mallinckrodt would expect NRC response within 4 business days.
- Make more appropriate measurements to improve determination of background.
- Reverse the tested hypothesis and apply an alternate, appropriate statistical test, *e.g.*, from Scenario A to Scenario B.[48] In the event Mallinckrodt were to want to assess compliance using Scenario B, it would notify the NRC Project Manager before implementation to seek concurrence and would expect (dis)approval or question(s) within 4 business days.
- In lieu of statistical testing, compute the radiological dose associated with the mean of measurements in the survey unit. If elevated measurements criteria are satisfied, but perhaps cause anomaly in statistical testing, potential radiological dose in the survey unit may be calculated with the same model used to derive $DCGL_W$. If so, the arithmetic average radioactivity concentration to be the source in the radiological dose calculation would be derived with the following equation.

[45] MARSSIM, p. 8-24 & 25.
[46] MARSSIM, appx I.
[47] MARSSIM, p. I-25 & I-27.
[48] NUREG-1505, §2.5.

$$\bar{C}_{SU} = \frac{A_{EM}}{A_T} \times \bar{C}_{EM} + \frac{A_T - A_{EM}}{A_T} \times \bar{C}_{other} \qquad \text{Equation 14-10}$$

where $\bar{C}_{SU}$ = arithmetic mean of radioactivity concentration measured at locations in survey unit. (pCi/g or dis/(min·100 cm^2))

A_{EM} = area within which elevated measurements occur (m^2)

A_T = total area in survey unit (m^2)

$\bar{C}_{EM}$ = arithmetic mean radioactivity concentration in area of elevated measurements (pCi/g or dis/(min·100 cm^2))

$\bar{C}_{other}$ = arithmetic mean radioactivity concentration measured at unbiased locations in the survey unit area not containing radioactivity elevated > $DCGL_W$. (pCi/g or dis/(min·100 cm^2))

In the event radiological dose is to be exclusive of natural background radioactivity, the average background concentration would be subtracted from the survey unit average, $\bar{C}_{SU}$, to derive the net source term to enter into the dose model.

If the mean dose does not exceed the radiological dose criterion, compliance would be demonstrated for the survey unit.[49]

If Mallinckrodt were to find substantial additional radioactive residue not accounted for in site characterization, it would provide a summary of its observations to the NRC.

14.4.4. Final Status Survey QA/QC

To assure that the Final Status Survey meets data quality objectives, all elements of the Final Status Survey will be subject to the Quality Assurance Program (QAP) described in Section 13.

14.5. FINAL STATUS SURVEY REPORT

At the conclusion of the Final Status Survey, a Final Status Survey Report will be prepared to demonstrate that the areas addressed in this Phase II Plan meet the radiological criteria for license termination. The report will include the following information:

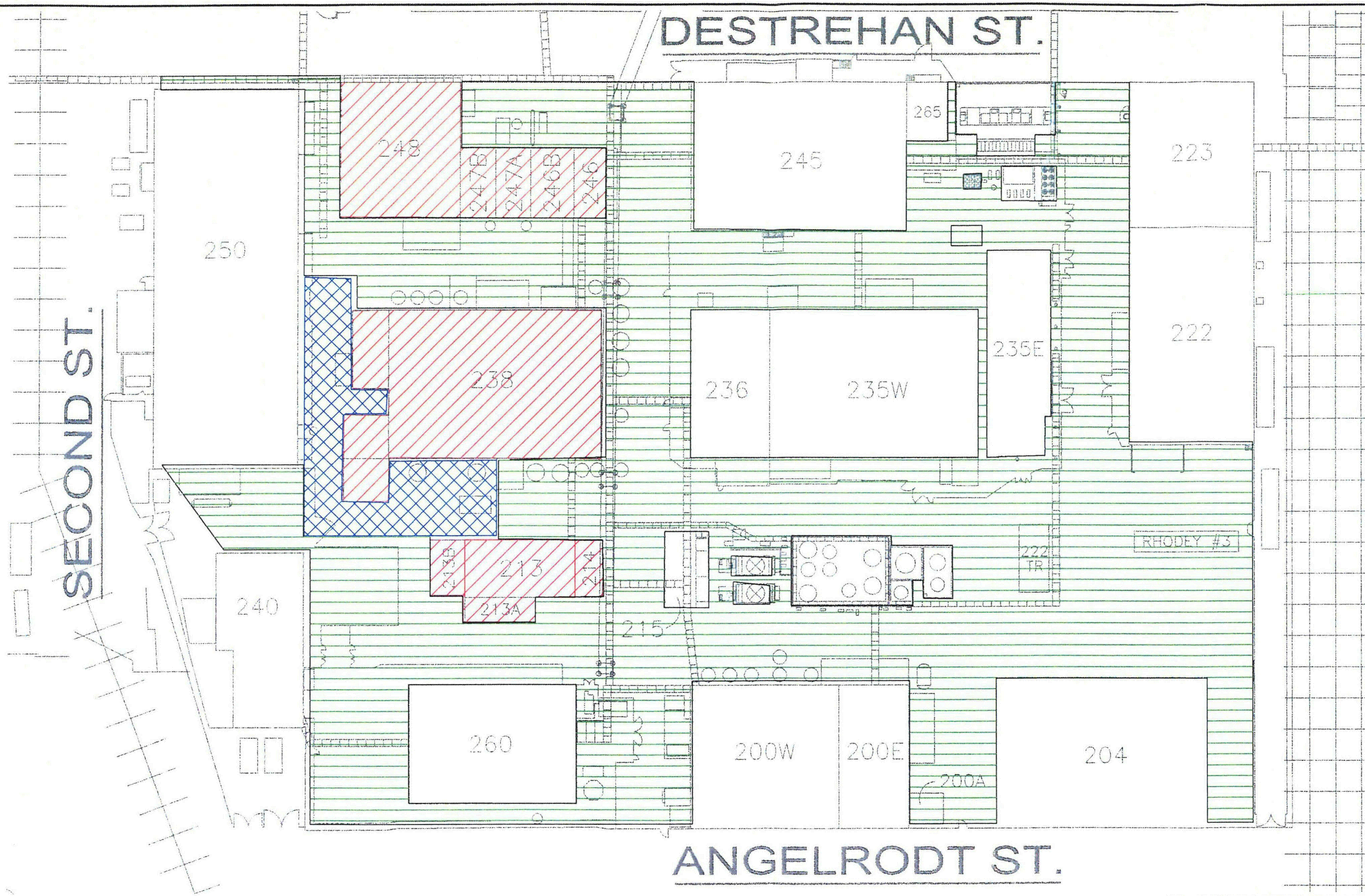
- Overview of the results of the Final Status Survey;
- Discussion of any changes made in the Final Status Survey from what was proposed in the Phase II Plan and associated submittals;
- A description of the method by which the number of samples was determined for each survey unit;
- A summary of the parameter values used to determine the number of samples and a justification for them;

[49] Testing compliance with elevated measurements criteria is specified separately herein.

- The survey results for each survey unit, including:
  - The number of samples;
  - A figure (map or drawing) depicting the survey unit, the location reference system, start locations for survey units subject to systematic sampling, randomly selected sampling locations for other survey units;
  - Sample measurement results;
  - Results of statistical evaluation of sample measurements;
  - Judgmental and miscellaneous sample data sets reported separately from those samples collected for performing the statistical evaluation;
  - Identification of each area of elevated direct radiation detected during scanning that exceeded the investigation level or measurement location(s) in excess of $DCGL_W$; and
  - A statement that the survey unit satisfied the $DCGL_W$ and, if any samples exceeded the $DCGL_W$, a statement that the survey unit satisfied the elevated measurement comparison;
- If a survey unit fails, a description of the investigation conducted to ascertain the reason for the failure and a discussion of the impact that the failure has on the conclusion that the facility if ready for final radiological surveys; and
- If a survey unit fails, a discussion of the impact of the cause of failure on other survey unit information.

The report will be reviewed and approved prior to release, publication, or external distribution.

Mallinckrodt will submit this Final Status Survey Report to the NRC.



KEY

Class 1

Class 2

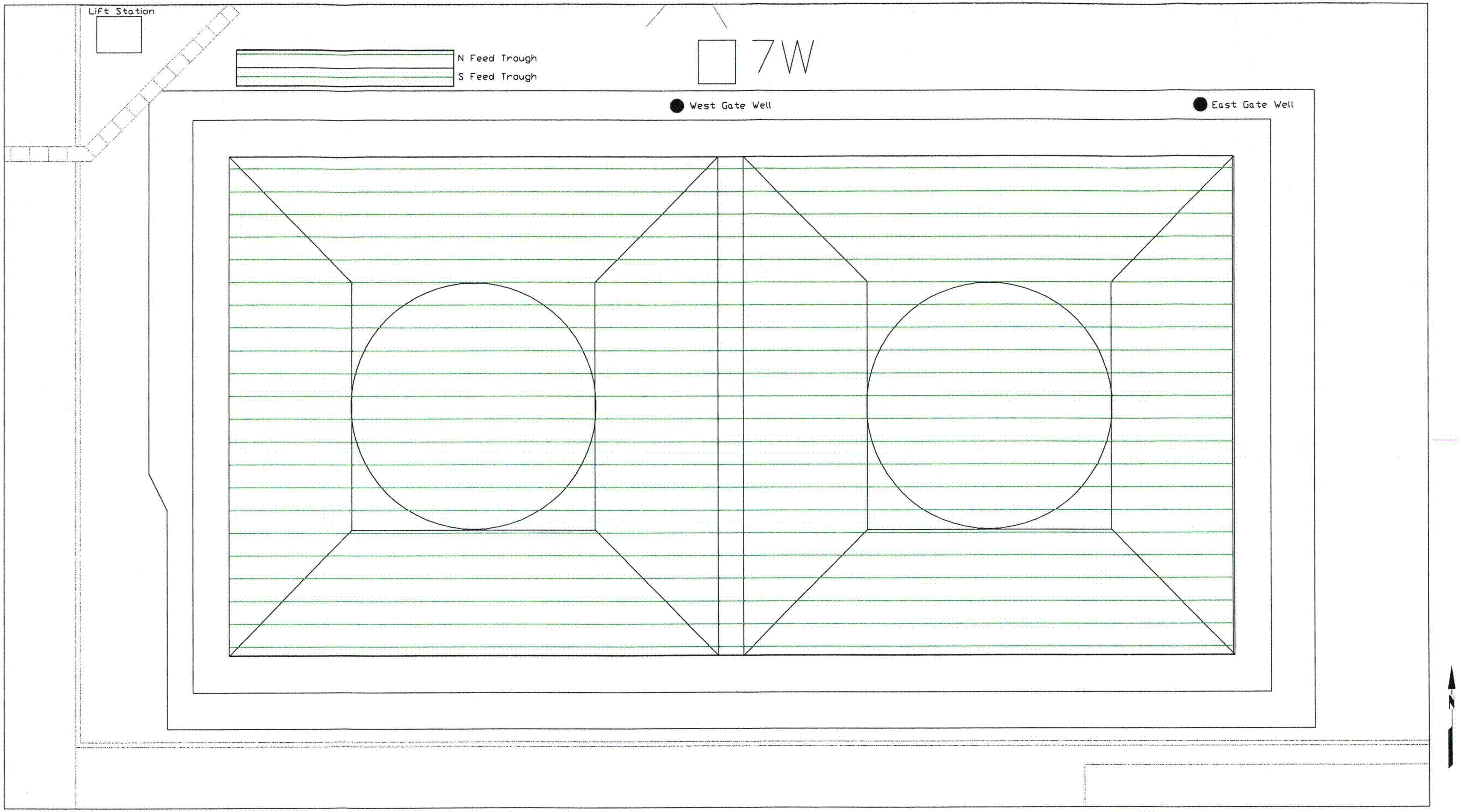
Class 3

TITLE:

Figure 14-1A
MARSSIM Classification of Pavement

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

omega PROJECT SERVICES LLC



KEY

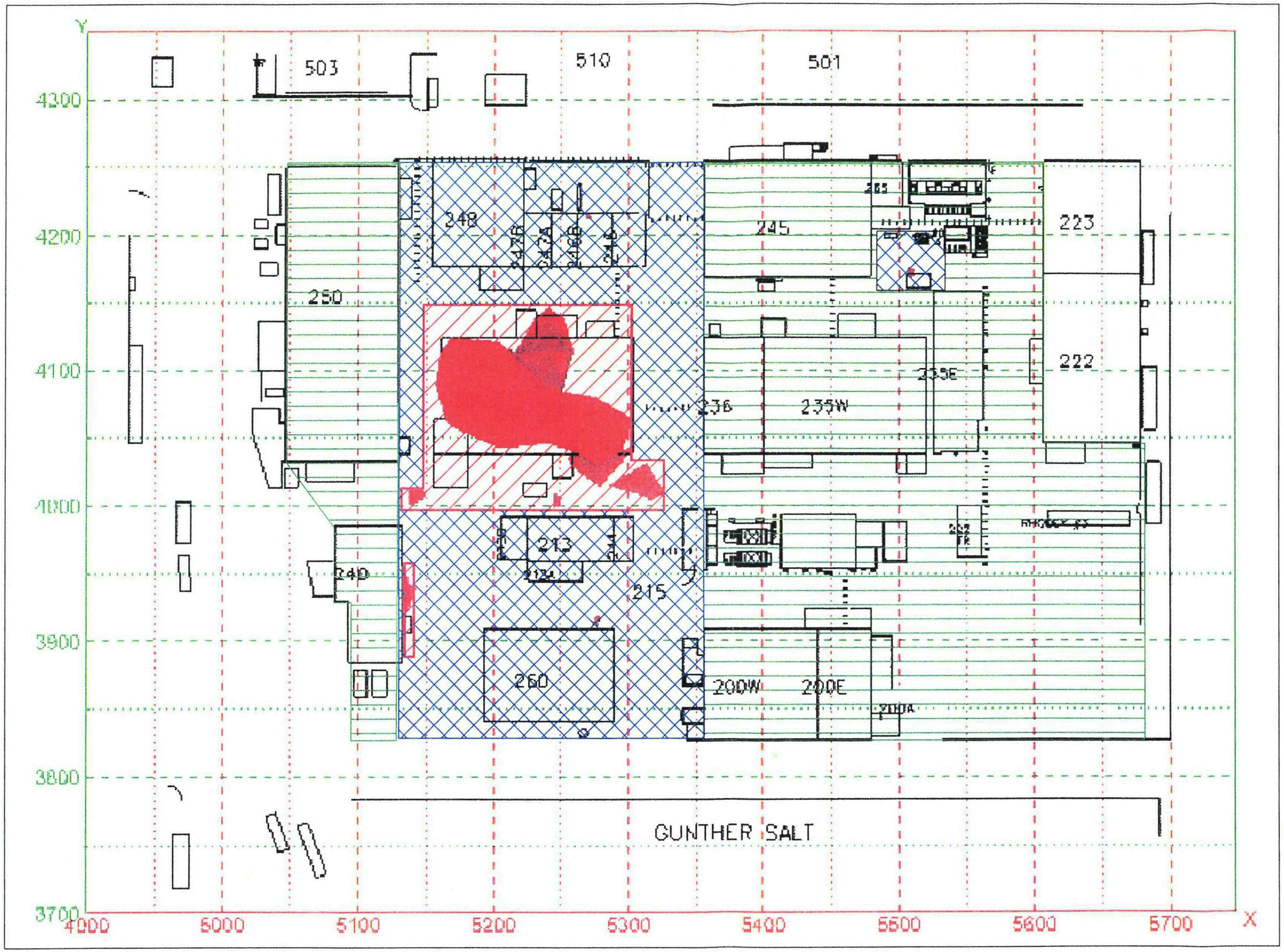
Class 3

TITLE:

Figure 14-1B
MARSSIM Classification of Pavement

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

omega PROJECT SERVICES LLC



Key

Class 1	
Class 2	
Class 3	

TITLE:

Figure 14-2
MARSSIM Classification of Subsurface Soil

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

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SECTION 15

FINANCIAL ASSURANCE

Mallinckrodt Inc.

C-T Phase II Decommissioning Plan

Revision 1
August 12, 2008

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

15.0 FINANCIAL ASSURANCE

Mallinckrodt originally submitted a Phase I/Phase II financial assurance plan along with the submittal of the Phase I Plan. A revised financial assurance plan was issued on January 11, 2002. Since the Phase I decommissioning plan activities have been completed, the decommissioning financial assurance plan and cost estimate has been revised to be consistent with the planned Phase II work.

15.1 DECOMMISSIONING COST ESTIMATE

15.1.1 Facility Description

Contaminated structures are not in the scope of this Phase II decommissioning plan. A precursor document to this one, the Phase I Plan[1], describes the activities involving above-grade decommissioning of the buildings. The objective of the Phase I Plan was 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. Above-grade decommissioning has been completed. The Phase II plan addresses below-grade decommissioning. A description of the below-grade radiological status can be found in Section 4 of this plan.

15.1.2 Estimated Decommissioning Costs

Table 15.1 presents the revised decommissioning cost estimate for the Phase II work which is $17,330,728 and is based on anticipated cleanup activities using characterization data and the derived solid concentration guidelines determined in Section 5 of this plan for determining the extent of contamination. This estimate may be revised as work is implemented.

In Table 15.1, the estimated costs are broken out by the following major activities:

1. Planning and Preparation
2. Decontamination and Decommissioning
3. Packaging, Shipment and Disposal
4. Final Status Survey
5. Restoration
6. Institutional Controls

As recommended by the NRC, the contingency is 25 percent.

The key assumptions include removal and disposal of approximately 88,100 cubic feet of soil and debris and the work, once started, is anticipated to be completed in approximately one year.

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

We have not included any credit for any *salvage value* in this cost estimate.

15.2 FORM OF FINANCIAL ASSURANCE

The existing financial assurance is a Letter of Credit (LC) in the amount of $21,113,00. Additionally, in Exhibit A, Mallinckrodt has provided the following information as required by the NRC (per NUREG-1757, Vol. 3, Final Report, dated September 2003, Appendix A.10 and A.17).

(1) Copy of the Standby Trust and all supporting documentation including a certified copy of the Certificate of Amendment of the Organization Certificate of Bankers Trust Company;

(2) Copy of the LC and all supporting documentation including a copy of a letter from Intesa San Paolo IMI S.p.A, New York Branch, stating that it is regulated by the New York Banking Department the Board of Governors of the Federal Reserve System and the Federal Reserve Bank of New York; and

(3) Copy of the Notification of Merger between San Paolo IMI S.p.A and Banca Intesa S.p.A

15.3 COMPARISON OF THE COST ESTIMATE TO THE CURRENT LEVEL OF FINANCIAL ASSURANCE

The existing LC in the amount of $21,113,000 is sufficient to satisfy the cost of completion of the phase II activities. Since the current estimate to complete Phase II work is $17,330,728 the existing LC provides an adequate guarantee to cover the costs of the Phase II work. Mallinckrodt may request that NRC approve reducing the existing LC from the current $21,113,000 down to the estimated cost to implement the Phase II plan if necessary.

15.4 MEANS FOR ADJUSTING THE COST ESTIMATE AND ASSOCIATED FUNDING LEVEL

Mallinckrodt will proceed with implementation of Phase II when the NRC issues final approval of the Phase II Plan. The Phase II Plan will be managed through a Mallinckrodt project team which will work from a defined scope of work and schedule. As work proceeds, the cost estimates previously provided in this Financial Assurance Plan will be reviewed at least annually. As work is completed, Mallinckrodt will reduce the amount of financial assurance based upon money spent and work completed to date in accordance with the Phase II Plan and schedule. This will occur after discussion and review, if necessary, with the NRC. Mallinckrodt will periodically report to the NRC on the status of the project and necessary revisions to the financial assurance instruments. Mallinckrodt will not modify the content of either the LC or the STA except upon approval by NRC.

Table 15.1: Phase II Estimated Decommissioning Costs									
	Duration								
full time	65	weeks							
1/2 time	32.5	weeks							
1/4 time	16.25	weeks							
months (=12/52 X duration)	15.00	months							
Assumptions	Contractor has 6 weeks to mobilize								
Scope	**Number**	**Duration**	**Description**	**Mhrs**	**Labor Rate**	**Total Labor**	**Total Equipment**	**Total Material**	**Total Price**
1. Planning and Preparation									
Phase II Plan Prep/EIS	1		contract			$1,000,000.00		$1,000,000.00	
Phase II characterization and sampling	1		set			$70,000.00		$70,000.00	
Sub Total						$1,070,000.00			$1,070,000
2. D&D									
Total Labor Costs									
General Laborer	4	65	man-weeks	10400	$59.00	$613,600.00			
General Laborer Foreman	1	65	man-weeks	2600	$68.00	$176,800.00			
General Laborer Superintendent	1	65	man-weeks	2600	$72.00	$187,200.00			
Equipment Operators	2	65	man-weeks	5200	$70.00	$364,000.00			
Field Rad Tech	2	65	man-weeks	5200	$60.00	$312,000.00			
Lab Scientist	1	71	man-weeks	2840	$80.00	$227,200.00			
Lab Tech	1	65	man-weeks	2600	$60.00	$156,000.00			
Sub Total				31440		$2,036,800.00			$2,036,800
Project Management Support									
MI Oversight Costs	1	65	man-weeks	2600	85	$221,000.00			
Project Manager	1	71	man-weeks	2840	130	$369,200.00			
Health Physics Professional	1	71	man-weeks	2840	130	$369,200.00			
Industrial Safety Professional/QA	1	71	man-weeks	2840	130	$369,200.00			
Field Supervisor	1	71	man-weeks	2840	100	$284,000.00			
Field Clerk	1	71	man-weeks	2840	60	$170,400.00			
Temporary Living Expenses	5	15.00	man-months		2000	$150,000.00			
HP Consultant 1/4 time	1	16.25	man-weeks	650	130	$84,500.00			
Sub Total				14200		$2,017,500.00			$2,017,500
Equipment Costs						**Cost/Unit**			
Excavator (Cat 220L-1.8CY)	2	15.00	months			$6,280.00	$188,400.00		
Front End Loader (4CY)	1	15.00	months			$6,980.00	$104,700.00		
Bobcat and accessories (1/2 time)	1	7.50	months			$4,480.00	$33,600.00		
Concrete Crusher (triple roller 30x18)(1/4 time)	1	6.00	months			$6,675.00	$40,050.00		
Front-end Loader (Cat IT18B -1.5CY)(1/2 time)	1	15.00	months			$2,000.00	$30,000.00		
Compressor(1/4 time)	1	3.75	months			$725.00	$2,718.75		
Jackhammer(1/4 time)	2	3.75	months			$275.00	$2,062.50		
Dump Truck (articulating)	2	15.00	months			$2,400.00	$72,000.00		
HP Monitoring Equipment									
Area Pumps	5	15.00	months			$330.00	$24,750.00		
TLD	25		6 months				$0.00		
Ludlow Model 2221 with 43-89 detector	1	15.00	month			$325.00	$4,875.00		
Ludlow Model 2221 with 44-9 detector	3	15.00	month			$365.00	$16,425.00		
Ludlow Model 2241	1	15.00	month			$210.00	$3,150.00		

Scope	Number	Duration	Description	Mhrs	Labor Rate	Total Labor	Total Equipment	Total Material	Total Price
Model 2929 with 43-10-1 detector	1	15.00	month			$350.00	$5,250.00		
Micro R (L-19)	2	15.00	months			$125.00	$3,750.00		
Generator	5	15.00	months			$250.00	$18,750.00		
Check Sources	1	15.00	months			$150.00	$2,250.00		
LEL	1	15.00	months			$313.00	$4,695.00		
Equipment Mobilization	1	1.00	one time			$1,270.00	$1,270.00		
Trailer	1	15.00	months			$500.00	$7,500.00		
Sheet Pile driver (1/4 time)	1	3.75	months			$5,600.00	$21,000.00		
Hydraulic Hammer (1/4 time)	1	3.75	months			$8,320.00	$31,200.00		
Sub Total							$618,396.25		$618,396
						Cost/Unit			
Small Tools @$40/man day	2	65	man-weeks			$40.00		$26,000.00	
PPE @ $60/man day	6	65	man-weeks			$60.00		$117,000.00	
Decon Supplies	1	65	weeks			$300.00		$97,500.00	
Pressure Washer 1	1	15.00	months			$2,595.00		$38,925.00	
Sheet Piling (Z panels 1.6x1.6x0.25)		16.00	tons			$625.00		$10,000.00	
Waste Water Retainage (1/4 time)		3.75	months			$7,500.00		$28,125.00	
Demarcation Barrier		40,000	sq. ft			$2.00		$80,000.00	
Radiological Lab ($2,000 for mob and demob)	65		week			$2,000.00		$132,000.00	
Chemical Lab (1 sample per railcar)	39		sample			$1,000.00		$39,000.00	
Sub Total								$568,550.00	$568,550
3. Packaging, Shipment and Disposal						**Cost/Unit**			
Load out/railspur refirbishment		15.00	months			$92,800.00		$1,392,000.00	
Pavement Trans & Disposal (4,100cf x 150#/cf / 2,000 #/ton) US Ecology	308		tons			$142.00		$43,736.00	
Building Slab Trans & Disposal (13,000 x 150#/cf /2,000 #/ton) USEcology	975		tons			$142.00		$138,450.00	
Subsurface Trans & Disposal (29,000cf x 108#/cf /2,000 #/ton) USEcology	1,450		tons			$142.00		$205,900.00	
Subsurface Trans & Disposal (42,000cf x 108#/cf /2,000 #/ton) Energy Solutions	2,100		tons			$2,200.00		$4,620,000.00	
Sub Total								$6,400,086.00	$6,400,086
4. Final Status Survey									
Final Status Survey	1		set			$700,000.00		$700,000.00	
Sub Total								$700,000.00	$700,000
5. Restoration									
Backfill (71,000cfx 100#/cf /2,000 #/ton)		3,550	tons			$15.00		$53,250.00	
Asphalt									
Sub Total								$53,250.00	$53,250
6. Institutional Controls									
Institutional Controls	1		set			$100,000.00		$100,000.00	
Sub Total								$100,000.00	$100,000
Total Direct Costs									$13,564,582
NRC Oversight Costs									$300,000
Phase II Total									$13,864,582
25% Contingency									$3,466,146
Grand Total Phase II									$17,330,728

EXHIBIT A

FORM OF FINANCIAL ASSURANCE

SECTION 1

Copy of Standby Trust and all Supporting Documentation

tyco
Healthcare
Mallinckrodt

Patricia Hitt Duft
Staff Vice President, Legal

Mallinckrodt Inc.
675 McDonnell Boulevard
P.O. Box 5840
St. Louis, MO 63134

Tele: 314 654-2000
Direct: 314 654-6314
Fax: 314 654-6486

File

March 15, 2002

via UPS Overnight Express #1Z 6674640192229683 - 3/15/02

Mr. Joseph Fernandez
Banker's Trust Company
4 Albany Street
New York, New York 10006

Re: Mallinckrodt Inc.'s CT-Decommissioning Financial Assurance Plan
Amendment to Standby Trust Agreement

Dear Mr. Fernandez:

Enclosed for Bankers Trust Company's signature are three originals of the Amended Standby Trust Agreement for Mallinckrodt's CT-Decommissioning Financial Plan, which was revised to reflect the changes requested by the NRC and SanPaolo Bank after the Agreement form was sent to you on January 10, 2002. I've also included three originals of the Amendment to the Standby Trust Agreement of July 26, 2000, reflecting all of the revisions, and which will also require Bankers Trust Company's signature. As you will note, SanPaolo Bank has executed both documents, and the NRC has executed the Amendment to Standby Trust Agreement.

Upon execution by Bankers Trust Company, please return all to me. I will then gather all the originals and a complete set of originals will be returned to you for your files.

If you have any questions, please contact me.

Sincerely,

Patricia H. Duft

Patricia H. Duft
:sar

enclosures

AMENDMENT
TO
STANDBY TRUST AGREEMENT
DATED JULY 26, 2000

WHEREAS, MALLINCKRODT INC., a Delaware corporation, located at 675 McDonnell Boulevard, P.O. Box 5840, St. Louis, Missouri (the "Grantor"), SANPAOLO IMI S.p.A., located at 245 Park Avenue, New York, New York 10167, ("SANPAOLO"), and BANKERS TRUST COMPANY, located at 4 Albany Street, New York, NY 10006 (the "Trustee"), entered into a STANDBY TRUST AGREEMENT ("Agreement") dated July 26, 2000,

WHEREAS, the U.S. Nuclear Regulatory Commission (the "NRC"), an agency of the U.S. Government, pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974, has promulgated regulations in Title 10, Chapter I of the Code of Federal Regulations, Part 40. These regulations, applicable to the Grantor, require that a holder of, or an applicant for, a Part 40 license provide assurance that funds will be available when needed for required decommissioning activities;

WHEREAS, the purpose of the Standby Trust Agreement is to meet requirements of the NRC;

WHEREAS, the Agreement did not follow the form of the NRC standard language and is unacceptable to the NRC;

WHEREAS, Mallinckrodt as Grantor, Banker's Trust as Trustee and SANPAOLO agree to amend the Agreement as requested by the NRC and in accordance with Section 15 of said Agreement;

NOW, THEREFORE, the Grantor, the Trustee and SANPAOLO agree to amend the Agreement as follows:

> The Parties agree to amend the Agreement in accordance with the attached revised Agreement, and replace the Agreement, but not the attachments to the Agreement, with the Amended Standby Trust Agreement dated as of February ___, 2002. This Amendment may be executed in counterparts by one or more of the parties on any number of separate counterparts (including by facsimile), and all of said counterparts when taken together shall be deemed to be one and the same instrument.

IN WITNESS WHEREOF, the parties have caused this Amendment to be executed by the respective officers duly authorized and the corporate seals to be hereunto affixed and attested as of this ____ day of February, 2002.

ATTEST: **MALLINCKRODT INC., a Delaware corporation**

Robert T. Budenholzer

(SEAL) By: ROBERT T. BUDENHOLZER

Title: VICE PRESIDENT

ATTEST: SANPAOLO IMI S.p.A., New York Branch

By:

Title:

By:

Title:

ATTEST: BANKERS TRUST COMPANY

By:

Title:

ATTEST: U.S. NUCLEAR REGULATORY COMMISSION

By:

Title: Chief, Decommissioning Branch

ATTEST:

SANPAOLO IMI S.p.A., New York Branch

By: LUCA SACCHI

Title: VP

By: AMARA LOWENSTEIN

Title: GENERAL COUNSEL & V.P.

ATTEST:

BANKERS TRUST COMPANY

By:

Title:

ATTEST:

U.S. NUCLEAR REGULATORY COMMISSION

By:

Title:

AMENDED STANDBY TRUST AGREEMENT

AMENDED STANDBY TRUST AGREEMENT, the Agreement entered into as of February __, 2002, by and among MALLINCKRODT INC., a Delaware corporation, located at 675 McDonnell Blvd., P.O. Box 5840, St. Louis, MO 63134, (the "Grantor"), SANPAOLO IMI S.p.A., located at 245 Park Avenue, New York, New York 10167 ("SANPAOLO"), and BANKERS TRUST COMPANY, located at 4 Albany Street, New York, NY 10006, (the "Trustee").

WHEREAS, the U.S. Nuclear Regulatory Commission (the "NRC"), an agency of the U.S. Government, pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974, has promulgated regulations in Title 10, Chapter I of the Code of Federal Regulations, Part 40. These regulations, applicable to the Grantor, require that a holder of, or an applicant for, a Part 40 license provide assurance that funds will be available when needed for required decommissioning activities.

WHEREAS, the Grantor has elected to use a letter of credit (to be issued by SANPAOLO) to provide all of such financial assurance for the facilities identified herein; and

WHEREAS, when payment is made under a letter of credit, this standby trust shall be used for the receipt of such payment; and

WHEREAS, the Grantor, acting through its duly authorized officers, has selected the Trustee to be the trustee under this Agreement, and the Trustee is willing to act as trustee,

NOW, THEREFORE, the Grantor, the Trustee and SANPAOLO agree as follows:

Section 1. Definitions. As used in this Agreement:

(a) The term "Grantor" means the NRC licensee who enters into this Agreement and any successors or assigns of the Grantor.

(b) The term "Trustee" means the trustee who enters into this Agreement and any successor Trustee.

Section 2. Costs of Decommissioning. This Agreement pertains to the costs of decommissioning the materials and activities identified in License Number STB-401 issued to Mallinckrodt Inc. under 10 CFR Part 40 as shown in Schedule A.

Section 3. Establishment of Fund. The Grantor and the Trustee hereby establish a standby trust fund with the Trustee (the "Fund") for the benefit of the NRC, in which the proceeds of any drawings under the Letter of credit shall be deposited. Access to the funds in the Trust Account shall be limited to the Grantor and the Trustee pursuant to the provisions of this Standby Trust Agreement. Under no circumstances shall any other third party have access to the Fund.

Section 4. Payments Constituting the Fund. Payments made to the Trustee for the fund shall consist of cash, securities, or other liquid assets acceptable to the Trustee. The Fund is established initially as consisting of the property, which is acceptable to the Trustee, described in Schedule B attached hereto. Such property and any other property subsequently transferred to the Trustee are referred to as the "Fund," together with all earnings and profits thereon, less any payments or distributions made by the Trustee pursuant to this Agreement. The Fund shall be held by the Trustee, IN TRUST, as hereinafter provided. The Trustee shall not be responsible nor shall it undertake any responsibility for the amount of or adequacy of the Fund, nor any duty to collect from the Grantor, any payments necessary to discharge any liabilities of the Grantor established by the NRC.

Section 5. Payment for Required Activities Specified in the Plan. The Trustee shall make payments from the Fund to the Grantor upon presentation to the Trustee of the following:

a. A certificate duly executed by the Secretary of the Grantor attesting to the occurrence of the events, and in the form set forth in the attached Specimen Certificate as Exhibit A, and

b. A certificate, attached as Exhibit B, attesting to the following conditions:

(1) that decommissioning is proceeding pursuant to an NRC-approved plan.

(2) that the funds withdrawn will be expended for activities undertaken pursuant to that Plan, and

(3) that the NRC has been given 30 days' prior notice of the Grantor's intent to withdraw funds from the Fund.

No withdrawal from the Fund by the Grantor can exceed 10 percent of the outstanding balance of the Fund unless NRC written approval is attached to the Grantor's request for such withdrawal.

In the event of the Grantor's default or inability to direct decommissioning activities, the Trustee shall make payments from the Fund as the NRC shall direct, in writing, to provide for the payment of the costs of required activities covered by this Agreement. The Trustee shall reimburse the Grantor or other persons as specified by the NRC, or State agency, from the Fund for expenditures for required activities in such amounts as the NRC, or State agency, shall direct in writing. In addition, the Trustee shall refund to the Grantor such amounts as the NRC specifies in writing. Upon refund, such funds shall no longer constitute part of the Fund as defined herein.

Section 6. Trust Management. The Trustee shall invest and reinvest the principal and income of the Fund and keep the Fund invested as a single fund, without distinction between principal and income, in accordance with general investment policies and guidelines which the Grantor may communicate in writing to the Trustee, from time to time, subject, however, to the provisions of this section. In investing, reinvesting, exchanging, selling, and managing the fund, the Trustee shall discharge its duties with respect to the Fund solely in the interest of the beneficiary and with the care, skill, prudence, and diligence under the circumstances then prevailing which persons of prudence, acting in a like capacity and familiar with such matters, would use in the conduct of an enterprise of a like character and with like aims; except that:

(a) Securities or other obligations of the Grantor, or any other owner or operator of the facilities, or any of their affiliates as defined in the Investment Company Act of 1940, as amended (15 U.S.C. 80a-2(a)), shall not be acquired or held, unless they are securities or other obligations of the Federal or a State government;

(b) The Trustee is authorized to invest the Fund in time or demand deposits of the Trustee, to the extent insured by an agency of the Federal Government, and in obligations of the Federal Government such as GNMA, FNMA, and FHLM bonds and certificates or State and Municipal bonds rated BBB or higher by Standard and Poors or Baa or higher by Moody's Investment Services; and

(c) For a reasonable time, not to exceed 60 days, the Trustee is authorized to hold uninvested cash, awaiting investment or distribution, without liability for the payment of interest thereon.

Section 7. Commingling and Investment. The Trustee is expressly authorized in its discretion:

(a) To transfer from time to time any or all of the assets of the fund to any common, commingled, or collective trust fund created by the Trustee in which the Fund is eligible to participate, subject to all of the provisions thereof, to be commingled with the assets of other trusts participating therein; and

(b) To purchase shares in any investment company registered under the Investment Company Act of 1940 (15 U.S.C. 80a-1 et seq.), including one that may be created, managed, underwritten, or to which investment advice is rendered, or the shares of which are sold by the Trustee. The Trustee may vote such shares in its discretion.

Section 8. Express Powers of Trustee. Without in any way limiting the powers and discretion conferred upon the Trustee by the other provisions of this Agreement or by law, the Trustee is expressly authorized and empowered:

(a) To sell, exchange, convey, transfer, or otherwise dispose of any property held by it, by public or private sale, as necessary to allow duly authorized withdrawals at the joint request of the Grantor and the NRC or to reinvest in securities at the direction of the Grantor;

(b) To make, execute, acknowledge, and deliver any and all documents of transfer and conveyance and any and all other instruments that may be necessary or appropriate to carry out the powers herein granted;

(c) To register any securities held in the fund in its own name, or in the name of a nominee, and to hold any security in bearer form or in book entry, or to combine certificates representing such securities with certificates of the same issue held by the Trustee in other fiduciary capacities, to reinvest interest payments and funds from matured and redeemed instruments, to file proper forms concerning securities held in the Fund in a timely fashion with appropriate government agencies, or to deposit or arrange for the deposit of such securities in a qualified central depository even though, when so deposited, such securities may be merged and held in bulk in the name of the nominee or such depository with other securities deposited therein by another person, or to deposit or arrange for the deposit of any securities issued by the U.S. Government, or any agency or instrumentality thereof, with a Federal Reserve bank, but the books and records of the Trustee shall at all times show that all such securities are part of the Fund;

(d) To deposit any cash in the Fund in interest-bearing accounts maintained or savings certificates issued by the Trustee in its separate corporate capacity, or in any other banking institution affiliated with the Trustee to the extent insured by an agency of the Federal government; and

(e) To compromise or otherwise adjust all claims in favor of or against the Fund.

Section 9. Taxes and Expenses. All taxes of any kind that may be assessed or levied against or in respect of the Fund and all brokerage commissions incurred by the Fund shall be paid from the Fund. All other expenses incurred by the Trustee in connection with the administration of the Fund, including fees for legal services rendered to the Trustee, the compensation of the Trustee, to the extent not paid directly by the Grantor, and all other proper charges and disbursements of the Trustee shall be paid from the Fund.

Section 10. Annual Valuation. After payment has been made into the Fund, the Trustee shall annually, at least 30 days before the anniversary date of receipt of the initial payment into the Fund, furnish to the Grantor and to the NRC a statement confirming the value of the Fund. Any securities in the Fund shall be valued at market value as of no more than 60 days before the anniversary date of the establishment of the Fund. The failure of the Grantor to object in writing to the Trustee, within 90 days after the statement has been furnished to the Grantor and the NRC, or State agency, shall constitute a conclusively binding assent by the Grantor, barring the Grantor from asserting any claim or liability against the Trustee, with respect to the matters disclosed in the statement.

Section 11. Advice of Counsel. The Trustee may from time to time consult with counsel with respect to any question arising as to the construction of this Agreement or any action to be taken hereunder. The Trustee shall be fully protected, to the extent permitted by law, in acting on the advice of counsel.

Section 12. Trustee Compensation. The Trustee shall be entitled to reasonable compensation for its services as agreed upon in writing with the Grantor. (See Schedule C.)

Section 13. Successor Trustee. Upon 90 days' prior notice to the NRC and SANPAOLO, the Trustee may resign; upon 90 days' prior notice to NRC, the Trustee, SANPAOLO and the Grantor may replace the Trustee, with a successor Trustee that is acceptable to the NRC; but SANPAOLO shall not unreasonably withhold or delay its acceptance of a successor Trustee, and such resignation or replacement shall not be effective until the Grantor has appointed a successor Trustee and this successor accepts the appointment. The successor Trustee shall have the same powers and duties as those conferred upon the Trustee hereunder. Upon the successor Trustee's acceptance of the appointment, the Trustee shall assign, transfer, and pay over to the successor Trustee the funds and properties then constituting the Fund. If for any reason the Grantor cannot or does not act in the event of the resignation of the Trustee, the Trustee may apply to a court of competent jurisdiction for the appointment of a successor Trustee or for instructions. The successor Trustee shall specify the date on which it assumes administration of the trust in a writing sent to the Grantor, the NRC or State agency, and the present Trustee by certified mail 10 days before such change becomes effective. Any expenses incurred by the Trustee as a result of any of the acts contemplated by this section shall be paid as provided in Section 9.

Section 14. Instructions to the Trustee. All orders, requests, and instructions required under this Agreement shall be in writing, signed by such persons as are signatories to this Agreement or such other designees as the Grantor may designate in writing. The Trustee shall be fully protected in acting without inquiry in accordance with the Grantor's orders, requests, and instructions. If the NRC or State agency issues orders, requests, or instructions to the Trustee, these shall be in writing, signed by the NRC, or State agency, or their designees, and the Trustee and SANPAOLO shall act and shall be fully protected in acting in accordance with such orders, requests, and instructions. The Trustee shall have the right to assume, in the absence of written notice to the contrary, that no event constituting a change or a termination of the authority of any person to act on behalf of the Grantor, the NRC, or State agency, hereunder has occurred. The Trustee shall have no duty to act in the absence of such orders, requests, and instruction from the Grantor and/or the NRC, or State agency, except as provided for herein.

Section 15. Amendment of Agreement. This Agreement may be amended by an instrument in writing executed by the Grantor, the Trustee, SANPAOLO and the NRC, or State agency, or by the Trustee, SANPAOLO and the NRC or State Agency, if the Grantor ceases to exist; but, SANPAOLO shall not unreasonably withhold or delay its written execution of amendments to this Agreement.

Section 16. Irrevocability and Termination. Subject to the right of the parties to amend this Agreement as provided in Section 15, this Trust shall be irrevocable and shall continue until terminated at the written agreement of the Grantor, the Trustee and the NRC or State agency, or by the Trustee and the NRC or State agency, if the Grantor ceases to exist. Upon termination of the trust, all remaining trust property, less final trust administration expenses, shall be delivered to the Grantor or its successor.

Section 17. Immunity and Indemnification. The Trustee shall not incur personal liability of any nature in connection with any act or omission, made in good faith, in the administration of this trust, or in carrying out any directions by the Grantor, the NRC, or State agency, issued in accordance with this Agreement. The Trustee shall be indemnified and held harmless by the Grantor or from the trust fund, or both, from and against any personal liability to which the Trustee may be subjected by reason of any act or conduct in their official capacity, including all expenses reasonably incurred in its defense in the event the Grantor fails to provide such defense.

Section 18. Acceptance of Trusts and Duties. The Trustee accepts the trusts hereby created and agrees to perform its duties hereunder with respect to such trusts, but only upon the terms of this Agreement. In particular:

(a) The Trustee shall not be liable with respect to any action taken or omitted to be taken in good faith by it in accordance with the instructions of the Grantor and/or the NRC;

(b) No provision of this Agreement shall require the Trustee to expend or risk funds or otherwise incur any financial liability in the performance of any of its rights or powers hereunder if the Trustee shall have reasonable grounds for believing that repayment of such funds or adequate indemnity against such risk or liability is not reasonably assured or provided to it;

(c) The Trustee shall not be responsible for or in respect of the validity or sufficiency of this Agreement or for the due execution hereof by the Grantor for the form, character, genuineness, sufficiency, value or validity of any of portion of the trust estate hereby created. The Trustee shall in no event assume or incur any liability, duty or obligation other than as expressly provided for herein; and

(d) The Trustee shall be under no obligation to institute, conduct or defend any litigation under this Agreement or otherwise or in relation to this Agreement, at the request, order or direction any of the Grantor or the NRC unless offered security or indemnity satisfactory to it against the costs, expenses and liabilities that may be incurred by the Trustee therein or thereby. The right of the Trustee to perform any discretionary act enumerated in this Agreement shall not be construed as a duty, and the Trustee shall not be answerable for other than its negligence or willful misconduct in the performance of any such act.

Section 19. Not Acting in Individual Capacity. Except as provided in this Agreement, in accepting the trusts hereby created, Trustee acts solely as Trustee hereunder and not in its individual capacity, and all Persons having any claim against the Trustee by reason of the transactions contemplated by this Agreement shall look only to the Grantor or from the trust fund or both for payment or satisfaction.

Section 20. Trustee's Fees and Expenses. The Trustee shall receive as compensation for its services hereunder such fees as have been separately agreed upon before the date hereof between the Grantor and the Trustee, and the Trustee shall be entitled to be reimbursed by the Grantor for its other reasonable expenses hereunder, including the reasonable compensation, expenses and disbursements of such agents, representatives, experts and counsel as the Trustee may employ in connection with the exercise and performance of its rights and its duties hereunder. Any amounts paid to the Trustee pursuant to this Section or Section 22 below shall be deemed not to be a part of the trust estate immediately after such payment.

Section 21. Indemnification. SANPAOLO shall be liable as primary obligor for, and shall indemnify the Trustee (in its individual and trustee capacity) and its successors, assigns, agents and servants (collectively, the "Indemnified Parties") from and against, any and all liabilities, obligations, losses, damages, taxes, claims, actions and suits, and any and all reasonable costs, expenses and disbursements (including reasonable legal fees and expenses) of any kind and nature whatsoever (collectively, "Expenses") which may at any time be imposed on, incurred by, or asserted against the Trustee or any indemnified party in any way relating to or arising out of this Agreement, the trust estate, the administration of the trust estate or the action or inaction of the Trustee hereunder, except only that SANPAOLO shall not be liable for or required to indemnify an indemnified party from and against expenses arising or resulting from the gross negligence or willful misconduct of the Trustee. The indemnities contained in this Section shall survive the resignation or termination of the Trustee or the termination of this Agreement. In any event of any claim, action or proceeding for which indemnity will be sought pursuant to this Section, the Trustee's choice of legal counsel shall be subject to the approval of SANPAOLO, which approval shall not be unreasonably withheld.

Section 22. Governing Law. This Agreement shall be administered, construed, and enforced according to the laws of the State of New York.

Section 23. Counterparts. This Agreement may be executed in counterparts by one or more of the parties on any number of separate counterparts (including by telecopy) and all of said counterparts when taken together shall be deemed to be one and the same instrument.

Section 24. Interpretation and Severability. As used in this Agreement, words in the singular include the plural and words in the plural include the singular. The descriptive headings for each section of this Agreement shall not affect the interpretation or the legal efficacy of this Agreement. If any part of this agreement is invalid, it shall not affect the remaining provisions which will remain valid and enforceable.

IN WITNESS WHEREOF, the parties have caused this Agreement to be executed by the respective officers duly authorized and the corporate seals to be hereunto affixed and attested as of the date first written above.

ATTEST:

MALLINCKRODT INC., a Delaware corporation

(SEAL)

By: ROBERT T. BUDENHOLZER

Title: VICE PRESIDENT

ATTEST:

SANPAOLO IMI S.p.A., New York Branch

By: LUCA SACCHI

Title: VP

By: DMARA LOWENSTEIN

Title: GENERAL COUNSEL & V.P.

ATTEST: Bankers Trust Company

By:

Title:

SCHEDULE A

This Agreement demonstrates financial assurance for the following cost estimates for the following licensed activities:

U.S. Nuclear Regulatory Commission License Number	Name and Address of Licensee	Address of Licensed Activity	Cost Estimates for Regulatory Assurances Demonstrated by this Agreement
STB-401/40-6563	Mallinckrodt Inc. P. O. Box 5840 675 McDonnell Blvd. St. Louis, MO 63134	2nd & Mallinckrodt Streets P. O. Box 5439 St. Louis, MO 63147	$21,113,000.

EXHIBIT A

CERTIFICATE OF RESOLUTION

I, ______________________________, do hereby certify that I am the Secretary of ____, a ________________ corporation, and that the resolution shown below was duly adopted at a meeting of this corporation's Board of Directors on ____________________.

____
Secretary

RESOLVED, that this Board of Directors hereby authorizes the President, or such other employee of the Company as he/she may designate, to commence decommissioning activities at ______________________________ [insert name of facility] in accordance with the terms and conditions described to this Board of Directors at this meeting, and with such other terms and conditions as the President shall approve with, and upon, the advice of Counsel.

EXHIBIT B

CERTIFICATE OF EVENTS

Bankers Trust Company
4 Albany Street
New York, NY 10006
Attention: Trust Division

Gentlemen:

In accordance with the terms of the Agreement with you dated ___________, 1998, I ____________________, Secretary of _________________________________ [insert name of licensee], hereby certify that the following events have occurred:

1. ______________________ [insert name of licensee] is required to commence the decommissioning of its facility located at _________________________________ [insert location of facility], hereafter called the "decommissioning").

2. The plans and procedures for the commencement and conduct of the decommissioning have been approved by the United States Nuclear Regulatory Commission (NRC), or its successor, on ________________. Copy of approval attached.

3. The Board of Directors of ____________________ [insert name of licensee] has adopted the attached resolution authorizing the commencement of the decommissioning.

____
Secretary of [insert name of licensee[

Date: ____________________

SCHEDULE B

PROPERTY USED TO ESTABLISH THE FUND

The trust fund established under the Standby Trust Agreement, to which this is attached as Schedule B, has been established to receive funds that are drawn under that certain Irrevocable Standby Letter of Credit No. 003050-793 issued by SANPAOLO IMI S.p.A., New York Branch.

SCHEDULE C

BANKERS TRUST COMPANY
FEE SCHEDULE
Mallinckrodt Inc.
Standby Trust Agreement

Acceptance Fee:	**$ WAIVED**

Includes set-up of trust and escrow accounts including internal document review, creation of ticklers and controls, and design of custom reports.

Legal Review Fee (if necessary):	**At cost**

The agreement in its current form is acceptable and will not require the review of our outside counsel. However, Bankers Trust reserves the right to charge legal fees at cost should it become necessary for legal counsel to review and comment within the provisions of the agreement.

Annual Administration Fee:	**$ 3,500.00**

Transaction Fees: *(as required)*

Per Direct Security Purchase/Sale	$ 25.00
Per Delivery/Receipt of Security	$ 25.00
Per Out-going Wire Transfer	$ 25.00

Note:
The fees set forth in this schedule are subject to review of documentation. The fees are also subject to change should duties beyond the originally intended scope of the agreement become necessary. Out-of-pocket expenses and disbursements, including counsel fees, incurred in the performance of our duties will be added to the billed fees. Fees for any services not covered in this or related schedules will be based upon an appraisal of the services rendered. We may place orders to buy/sell financial instruments with outside broker-dealers that we select, as well as BT or its affiliates. These transactions(for which normal and customary spreads or other compensation may be earned by such broker-dealers including BT or its affiliates in addition to the charges quoted above) will be executed on a riskless principal basis solely for your account(s) and without recourse to us or our affiliates. If you choose to invest in any mutual fund, BT and/or our affiliates may earn investment management fees and service fees/expenses associated with these funds as disclosed in the mutual fund prospectus provided to you, in addition to the charges quoted above. Likewise, BT has entered into agreements with certain mutual funds or their agents to provide shareholder services to those funds. For providing these shareholder services, BT is paid a fee by these mutual funds that calculated on an annual basis does not exceed 25 basis points of the amount of your investment in these mutual funds. In addition, if you choose to use other services provided by BT or its affiliates, Corporate Trust or other BT

affiliates may be allocated a portion of the fees earned. We will provide periodic account statements describing transactions executed for your account(s). Trade confirms will be available upon your request at no additional charge. If a deal should fail to close for reasons beyond our control, we reserve the right to charge our acceptance fee plus reimbursement for legal fees incurred. Shares of mutual funds are not deposits or obligations of, or guaranteed by, Bankers Trust Company or any of its affiliates and are not insured by the Federal Deposit Insurance Corporation or any other agency of the U.S. Government. Investments in the mutual funds involve the possible loss of principal.

Agreed and Accepted by: ______________________________

Title:

Date:

BANKERS TRUST COMPANY

ASSISTANT SECRETARY'S CERTIFICATE

I, Lea Lahtinen, Vice President and Assistant Secretary of Bankers Trust Company, a corporation duly organized and existing under the laws of the State of New York, the United States of America, do hereby certify that attached copy of the Certificate of Amendment of the Organization Certificate of Bankers Trust Company, dated February 27, 2002, providing for a change of name of Bankers Trust Company to Deutsche Bank Trust Company Americas and approved by the New York State Banking Department on March 14, 2002 to be effective on April 15, 2002, is a true and correct copy of the original Certificate of Amendment of the Organization Certificate of Bankers Trust Company on file in the Banking Department, State of New York.

IN WITNESS WHEREOF, I have hereunto set my hand and affixed the seal of Bankers Trust Company this 4th day of April, 2002.

[SEAL]

Lea Lahtinen

Lea Lahtinen, Vice President and Assistant Secretary
Bankers Trust Company

State of New York)
) ss.:
County of New York)

On the 4th day of April in the year 2002 before me, the undersigned, a Notary Public in and for said state, personally appeared Lea Lahtinen, personally known to me or proved to me on the basis of satisfactory evidence to be the individual whose name is subscribed to the within instrument and acknowledged to me that she executed the same in her capacity, and that by her signature on the instrument, the individual, or the person on behalf of which the individual acted, executed the instrument.

Sonja K. Olsen

Notary Public

SONJA K. OLSEN
Notary Public, State Of New York
No.01OL4974457
Qualified In New York County
Commission Expires November 13, 2002

State of New York,

Banking Department

I, P. VINCENT CONLON, Deputy Superintendent of Banks of the State of New York, **DO HEREBY APPROVE** the annexed Certificate entitled **"CERTIFICATE OF AMENDMENT OF THE ORGANIZATION CERTIFICATE OF BANKERS TRUST COMPANY under Section 8005 of the Banking Law"** dated February 27, 2002, providing for a change of name of **BANKERS TRUST COMPANY** to **DEUTSCHE BANK TRUST COMPANY AMERICAS.**

***Witness**, my hand and official seal of the Banking Department at the City of New York,*

this 14th day of March two thousand and two.

Deputy Superintendent of Banks

CERTIFICATE OF AMENDMENT

OF THE

ORGANIZATION CERTIFICATE

OF

BANKERS TRUST COMPANY

Under Section 8005 of the Banking Law

We, James T. Byrne Jr., and Lea Lahtinen, being respectively the Secretary, and Vice President and an Assistant Secretary of Bankers Trust Company, do hereby certify:

1. The name of corporation is Bankers Trust Company.

2. The organization certificate of said corporation was filed by the Superintendent of Banks on the 5th day of March, 1903.

3. Pursuant to Section 8005 of the Banking Law, attached hereto as Exhibit A is a certificate issued by the State of New York, Banking Department listing all of the amendments to the Organization Certificate of Bankers Trust Company since its organization that have been filed in the Office of the Superintendent of Banks.

4. The organization certificate as heretofore amended is hereby amended to change the name of Bankers Trust Company to Deutsche Bank Trust Company Americas to be effective on April 15, 2002.

5. The first paragraph number 1. of the organization certificate of Bankers Trust Company with the reference to the name of the Bankers Trust company, which reads as follows:

> "1. The name of the corporation is Bankers Trust Company."

is hereby amended to read as follows effective on April 15, 2002:

> "1. The name of the corporation is Deutsche Bank Trust Company Americas."

6. The foregoing amendment of the organization certificate was authorized by unanimous written consent signed by the holder of all outstanding shares entitled to vote thereon.

IN WITNESS WHEREOF, we have made and subscribed this certificate this 27th day of February, 2002.

James T. Byrne Jr.
Secretary

Lea Lahtinen
Vice President and Assistant Secretary

State of New York)
: ss.
County of New York)

Lea Lahtinen, being duly sworn, deposes and says that she is a Vice President and an Assistant Secretary of Bankers Trust Company, the corporation described in the foregoing certificate; that she has read the foregoing certificate and knows the contents thereof, and that the statements therein contained are true.

Lea Lahtinen

Sworn to before me this 27th day
of February, 2002.

Notary Public

SANDRA L. WEST
Notary Public, State Of New York
No.01WE[illegible]
Qualified in New York County
Commission Expires September [illegible], 20 02

EXHIBIT A

State of New York
Banking Department

I, P. VINCENT CONLON, Deputy Superintendent of Banks of the State of New York, DO HEREBY CERTIFY:

THAT, the records in the Office of the Superintendent of Banks indicate that BANKERS TRUST COMPANY is a corporation duly organized and existing under the laws of the State of New York as a trust company, pursuant to Article III of the Banking Law; and

THAT, the Organization Certificate of BANKERS TRUST COMPANY was filed in the Office of the Superintendent of Banks on March 5, 1903, and such corporation was authorized to commence business on March 24, 1903; and

THAT, the following amendments to its Organization Certificate have been filed in the Office of the Superintendent of Banks as of the dates specified:

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed on January 14, 1905

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on August 4, 1909

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed on February 1, 1911

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed on June 17, 1911

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on August 8, 1911

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed on August 8, 1911

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on March 21, 1912

State of New York
Banking Department

Certificate of Amendment of Certificate of Incorporation providing for a decrease in number of directors - filed on January 15, 1915

Certificate of Amendment of Certificate of Incorporation providing for a decrease in number of directors - filed on December 18, 1916

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on April 20, 1917

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed on April 20, 1917

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on December 28, 1918

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on December 4, 1919

Certificate of Amendment of Certificate of Incorporation providing for an increase in number of directors - filed January 15, 1926

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on June 12, 1928

Certificate of Amendment of Certificate of Incorporation providing for a change in shares - filed April 4, 1929

Certificate of Amendment of Certificate of Incorporation providing for a minimum and maximum number of directors - filed on January 11, 1934

Certificate of Extension to perpetual - filed on January 13, 1941

Certificate of Amendment of Certificate of Incorporation providing for a minimum and maximum number of directors - filed on January 13, 1941

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on December 11, 1944

State of New York
Banking Department

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed January 30, 1953

Restated Certificate of Incorporation - filed November 6, 1953

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on April 8, 1955

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on February 1, 1960

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on July 14, 1960

Certificate of Amendment of Certificate of Incorporation providing for a change in shares - filed on September 30, 1960

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on January 26, 1962

Certificate of Amendment of Certificate of Incorporation providing for a change in shares - filed on September 9, 1963

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on February 7, 1964

Certificate of Amendment of Certificate of Incorporation providing for an increase in capital stock - filed on February 24, 1965

Certificate of Amendment of the Organization Certificate providing for a decrease in capital stock - filed January 24, 1967

Restated Organization Certificate - filed June 1, 1971

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed October 29, 1976

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed December 22, 1977

State of New York
Banking Department

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed August 5, 1980

Restated Organization Certificate - filed July 1, 1982

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed December 27, 1984

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed September 18, 1986

Certificate of Amendment of the Organization Certificate providing for a minimum and maximum number of directors - filed January 22, 1990

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed June 28, 1990

Restated Organization Certificate - filed August 20, 1990

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed June 26, 1992

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed March 28, 1994

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed June 23, 1995

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed December 27, 1995

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed March 21, 1996

Certificate of Amendment of the Organization Certificate providing for an increase in capital stock - filed December 27, 1996

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed June 27, 1997

State of New York
Banking Department

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed September 26, 1997

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed December 29, 1997

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed March 26, 1998

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed June 23, 1998

Restated Organization Certificate - filed August 31, 1998

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed September 25, 1998

Certificate of Amendment to the Organization Certificate providing for an increase in capital stock – filed December 18, 1998; and

Certificate of Amendment to the Organization Certificate providing for a change in the number of directors – filed September 3, 1999; and

THAT, no amendments to its Restated Organization Certificate have been filed in the Office of the Superintendent of Banks except those set forth above; and attached hereto; and

I DO FURTHER CERTIFY THAT, BANKERS TRUST COMPANY** is validly existing as a banking organization with its principal office and place of business located at **130 Liberty Street, New York, New York.

***WITNESS,** my hand and official seal of the Banking Department at the City of New York this **16th** day of **October** in the Year Two Thousand and One*

Deputy Superintendent of Banks

SECTION 2

Copy of Letter of Credit and all Supporting Documentation

SANPAOLO IMI BANK

SANPAOLO IMI S.p.A.
HEAD OFFICE: TURIN, ITALY

New York Branch
245 Park Avenue
New York, NY 10167

Tel (212) 692-3000
Fax (212) 692-3179
SWIFT Code: IBSPUS33

IRREVOCABLE LETTER OF CREDIT	L/C Number 003050-793
Place and date of issue: NEW YORK 3/19/03 — Page 1/1	Date and place of expiry: 3/31/04 NEW YORK
Applicant: MALLINCKRODT INC., A DELAWARE CORPORATION, 675 MCDONNELL BLVD., P.O. BOX 5840, ST. LOUIS, MO. 63134-0480	Beneficiary: U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC 20555

REGARDING OUR IRREVOCABLE STANDBY LETTER OF CREDIT NO. 003050-793 IN YOUR FAVOR, PLEASE BE ADVISED THAT WE HEREBY RESCIND OUR NOTICE OF NON-RENEWAL DATED DECEMBER 10, 2002 AND HEREBY CONFIRM THAT THE CURRENT EXPIRATION DATE OF THIS LETTER OF CREDIT IS MARCH 31, 2004.

IN CASE OF NEED PLEASE CONTACT K. LEISENRING AT 212-692-3070.

Yours faithfully,

L/C 5 4/00

ORIGINAL FOR BENEFICIARY

01018

SANPAOLO IMI BANK

SANPAOLO IMI S.p.A.
HEAD OFFICE: TURIN, ITALY

New York Branch
245 Park Avenue
New York, NY 10167

Tel (212) 692-3000
Fax (212) 692-3179
SWIFT Code: IBSPUS33

IRREVOCABLE LETTER OF CREDIT	L/C Number 003050-793

Place and date of issue	Page 1/1	Date and place of expiry
NEW YORK 12/10/02		3/31/03 NEW YORK

Applicant	Beneficiary
MALLINCKRODT INC., A DELAWARE CORPORATION 675 MCDONNELL BLVD. P.O. BOX 5840 ST. LOUIS, MO. 63134-0480	U.S. NUCLEAR REGULATORY COMMISSION WASHINGTON, DC 20555

REGARDING OUR IRREVOCABLE STANDBY LETTER OF CREDIT NO. 003050-793 IN YOUR FAVOR, PLEASE BE ADVISED THAT IN ACCORDANCE WITH THE TERMS AND CONDITIONS OF THE LETTER OF CREDIT WE HEREBY OFFICIALLY SERVE NOTICE THAT WE WILL NOT BE RENEWING THIS LETTER OF CREDIT FOR ANOTHER PERIOD BEYOND THE CURRENT EXPIRATION DATE OF MARCH 31, 2003

PLEASE RETURN OUR ORIGINAL LETTER OF CREDIT PLUS ANY AMENDMENTS AFTER EXPIRATION.

IN CASE OF NEED PLEASE CONTACT K. LEISENRING AT 212-692-3070.

Yours faithfully,

[signatures]

L/C 5 4/00

ORIGINAL FOR BENEFICIARY

01018

SANPAOLO IMI BANK

ISTITUTO BANCARIO SAN PAOLO DI TORINO
ISTITUTO MOBILIARE ITALIANO SPA
HEAD OFFICE: TURIN, ITALY

New York Branch
245 Park Avenue
New York, NY 10167

Tel (212) 692-3000
Fax (212) 692-3179
SWIFT Code: IBSPUS33

IRREVOCABLE LETTER OF CREDIT	L/C Number 003050-793
Place and date of issue: NEW YORK 7/26/00 — Page 1/2	Date and place of expiry: 3/31/01 NEW YORK
Applicant: MALLINCKRODT INC. A DELAWARE CORPORATION 675 MCDONNELL BLVD P.O. BOX 5840 ST. LOUIS, MO. 63134-0840	Beneficiary: U.S. NUCLEAR REGULATORY COMMISSION WASHINGTON, DC 20555

AT THE REQUEST AND FOR THE ACCOUNT OF MALLINCKRODT INC. A DELAWARE CORPORATION, 675 MCDONNELL BLVD., P.O. BOX 5840, ST. LOUIS, MO. 63134-0840 WE HEREBY ESTABLISH OUR IRREVOCABLE STANDBY LETTER OF CREDIT NO. 003050-793 IN FAVOR OF THE U.S. NUCLEAR REGULATORY COMMISSION (NRC), WASHINGTON, DC 20555 FOR UP TO THE AGGREGATE AMOUNT OF USD$21,113,000.00 (USD$ TWENTY ONE MILLION ONE HUNDRED THIRTEEN THOUSAND DOLLARS AND 00/00), AVAILABLE UPON PRESENTATION OF

(1) YOUR SIGHT DRAFT, BEARING REFERENCE TO THIS LETTER OF CREDIT NO. 003050-793, AND
(2) YOUR SIGNED STATEMENT READING AS FOLLOWS: "I CERTIFY THAT THE AMOUNT OF THE DRAFT IS PAYABLE PURSUANT TO REGULATIONS ISSUED UNDER AUTHORITY OF THE NUCLEAR REGULATORY COMMISSION 10 CFR PART 40."

THIS LETTER OF CREDIT IS ISSUED IN ACCORDANCE WITH REGULATIONS ISSUED UNDER THE AUTHORITY OF THE U.S. NUCLEAR REGULATORY COMMISSION (NRC), AN AGENCY OF THE U.S. GOVERNMENT, PURSUANT TO THE ATOMIC ENERGY ACT OF 1954, AS AMENDED, AND THE ENERGY REORGANIZATION ACT OF 1974. THE NRC HAS PROMULGATED REGULATIONS IN TITLE 10, CHAPTER I OF THE CODE OF FEDERAL REGULATIONS, PART 40, WHICH REQUIRE THAT A HOLDER OF, OR AN APPLICANT FOR, A LICENSE ISSUED UNDER 10 CFR PART 40 PROVIDE ASSURANCE THAT FUNDS WILL BE AVAILABLE WHEN NEEDED FOR DECOMMISSIONING.

THIS LETTER OF CREDIT IS EFFECTIVE AS OF JULY 26, 2000, AND SHALL EXPIRE ON MARCH 31, 2001, BUT SUCH EXPIRATION DATE SHALL BE AUTOMATICALLY EXTENDED FOR A PERIOD OF ONE YEAR ON MARCH 31, 2001 AND ON EACH SUCCESSIVE EXPIRATION DATE, UNLESS, AT LEAST 90 DAYS BEFORE THE CURRENT EXPIRATION DATE, WE NOTIFY BOTH YOU AND MALLINCKRODT INC., BY CERTIFIED MAIL, AS SHOWN ON THE SIGNED RETURN RECEIPTS. IF MALLINCKRODT INC. IS UNABLE TO SECURE ALTERNATIVE FINANCIAL ASSURANCE TO REPLACE THIS LETTER OF CREDIT WITHIN 30 DAYS OF NOTIFICATION OF CANCELLATION, THE NRC MAY

Yours faithfully,
ISTITUTO BANCARIO SAN PAOLO DI TORINO
ISTITUTO MOBILIARE ITALIANO SPA

L/C 5 1/99

DEPARTMENT COPY

01007

SANPAOLO IMI BANK

ISTITUTO BANCARIO SAN PAOLO DI TORINO
ISTITUTO MOBILIARE ITALIANO SPA
HEAD OFFICE: TURIN, ITALY

New York Branch
245 Park Avenue
New York, NY 10167

Tel (212) 692-3000
Fax (212) 692-3179
SWIFT Code: IBSPUS33

IRREVOCABLE LETTER OF CREDIT	L/C Number: 003050-793
Place and date of issue: NEW YORK 7/26/00 — Page 2 / 2	Date and place of expiry: 3/31/01 NEW YORK
Applicant: MALLINCKRODT INC., A DELAWARE CORPORATION 675 MCDONNELL BLVD. [illegible] 5840 ST. LOUIS, MO 63134 [illegible]	Beneficiary: U.S. NUCLEAR REGULATORY COMMISSION WASHINGTON DC 20555

DRAW UPON THE FULL VALUE OF THIS LETTER OF CREDIT PRIOR TO CANCELLATION. THE BANK SHALL GIVE IMMEDIATE NOTICE TO THE APPLICANT AND THE NRC OF ANY NOTICE RECEIVED OR ACTION FILED ALLEGING (1) THE INSOLVENCY OR BANKRUPTCY OF THE FINANCIAL INSTITUTION OR (2) ANY VIOLATIONS OF REGULATORY REQUIREMENTS THAT COULD RESULT IN SUSPENSION OR REVOCATION OF THE BANK'S CHARTER OR LICENSE TO DO BUSINESS. THE FINANCIAL INSTITUTION ALSO SHALL GIVE IMMEDIATE NOTICE IF THE BANK, FOR ANY REASON, BECOMES UNABLE TO FULFILL ITS OBLIGATION UNDER THE LETTER OF CREDIT.

WHENEVER THIS LETTER OF CREDIT IS DRAWN ON UNDER AND IN COMPLIANCE WITH THE TERMS OF THIS LETTER OF CREDIT, WE SHALL DULY HONOR SUCH DRAFT UPON ITS PRESENTATION TO US WITHIN 30 DAYS, AND WE SHALL DEPOSIT THE AMOUNT OF THE DRAFT DIRECTLY INTO THE STANDBY TRUST FUND OF MALLINCKRODT INC ACCOUNT NO. 030359 HELD WITH BANKERS TRUST COMPANY, NEW YORK, IN ACCORDANCE WITH YOUR INSTRUCTIONS.

EACH DRAFT MUST BEAR ON ITS FACE THE CLAUSE: "DRAWN UNDER LETTER OF CREDIT NO. 003050-793, DATED 7/26/00, AND THE TOTAL OF THIS DRAFT AND ALL OTHER DRAFTS PREVIOUSLY DRAWN UNDER THIS LETTER OF CREDIT DOES NOT EXCEED USD[illegible]"

THIS CREDIT IS SUBJECT TO THE MOST RECENT EDITION OF THE UNIFORM CUSTOMS AND PRACTICE FOR DOCUMENTARY CREDITS, PUBLISHED BY THE INTERNATIONAL CHAMBER OF COMMERCE.

KINDLY ACKNOWLEDGE RECEIPT BY [illegible]

COPY

Yours faithfully,
ISTITUTO BANCARIO SAN PAOLO DI TORINO
ISTITUTO MOBILIARE ITALIANO SPA

MALLINCKRODT INC., A
DELAWARE CORPORATION
675 MCDONNELL BLVD.
P.O. BOX 5840
ST. LOUIS, MO. 63134-0480

U.S. NUCLEAR REGULATORY
COMMISSION
WASHINGTON, DC 20555

AT THE REQUEST AND FOR THE ACCOUNT OF MALLINCKRODT INC., A DELAWARE CORPORATION, 675 MCDONNELL BLVD., P.O. BOX 5840, ST. LOUIS, MO. 63134-0480 WE HEREBY ESTABLISH OUR IRREVOCABLE STANDBY LETTER OF CREDIT NO. 003050-793 IN FAVOR OF THE U.S. NUCLEAR REGULATORY COMMISSION (NRC), WASHINGTON, DC 20555 FOR UP TO THE AGGREGATE AMOUNT OF USD$21,113,000.00 (USD$ TWENTY ONE MILLION ONE HUNDRED THIRTEEN THOUSAND DOLLARS AND 00/00), AVAILABLE UPON PRESENTATION OF:

(1) YOUR SIGHT DRAFT, BEARING REFERENCE TO THIS LETTER OF CREDIT NO. 003050-793, AND
(2) YOUR SIGNED STATEMENT READING AS FOLLOWS: "I CERTIFY THAT THE AMOUNT OF THE DRAFT IS PAYABLE PURSUANT TO REGULATIONS ISSUED UNDER AUTHORITY OF THE NUCLEAR REGULATORY COMMISSION 10 CFR PART 40."

THIS LETTER OF CREDIT IS ISSUED IN ACCORDANCE WITH REGULATIONS ISSUED UNDER THE AUTHORITY OF THE U.S. NUCLEAR REGULATORY COMMISSION (NRC), AN AGENCY OF THE U.S. GOVERNMENT, PURSUANT TO THE ATOMIC ENERGY ACT OF 1954, AS AMENDED, AND THE ENERGY REORGANIZATION ACT OF 1974. THE NRC HAS PROMULGATED REGULATIONS IN TITLE 10, CHAPTER I OF THE CODE OF FEDERAL REGULATIONS, PART 40, WHICH REQUIRE THAT A HOLDER OF, OR AN APPLICANT FOR, A LICENSE ISSUED UNDER 10 CFR PART 40 PROVIDE ASSURANCE THAT FUNDS WILL BE AVAILABLE WHEN NEEDED FOR DECOMMISSIONING.

THIS LETTER OF CREDIT IS EFFECTIVE AS OF JULY 26, 2000, AND SHALL EXPIRE ON MARCH 31, 2001, BUT SUCH EXPIRATION DATE SHALL BE AUTOMATICALLY EXTENDED FOR A PERIOD OF ONE YEAR ON MARCH 31, 2001, AND ON EACH SUCCESSIVE EXPIRATION DATE, UNLESS, AT LEAST 90 DAYS BEFORE THE CURRENT EXPIRATION DATE, WE NOTIFY BOTH YOU AND MALLINCKRODT INC., BY CERTIFIED MAIL, AS SHOWN ON THE SIGNED RETURN RECEIPTS. IF MALLINCKRODT INC. IS UNABLE TO SECURE ALTERNATIVE FINANCIAL ASSURANCE TO REPLACE THIS LETTER OF CREDIT WITHIN 30 DAYS OF NOTIFICATION OF CANCELLATION, THE NRC MAY DRAW UPON THE FULL VALUE OF THIS LETTER OF CREDIT PRIOR TO CANCELLATION. THE BANK SHALL GIVE IMMEDIATE NOTICE TO THE APPLICANT AND THE NRC OF ANY NOTICE RECEIVED OR ACTION FILED ALLEGING (1) THE INSOLVENCY OR BANKRUPTCY OF THE FINANCIAL INSTITUTION OR, (2) ANY VIOLATIONS OF REGULATORY REQUIREMENTS THAT COULD RESULT IN SUSPENSION OR REVOCATION OF THE BANK'S CHARTER OR LICENSE TO DO BUSINESS. THE FINANCIAL INSTITUTION ALSO SHALL GIVE IMMEDIATE NOTICE IF THE BANK, FOR ANY REASON, BECOMES UNABLE TO FULFILL ITS OBLIGATION UNDER THE LETTER OF CREDIT.

WHENEVER THIS LETTER OF CREDIT IS DRAWN ON UNDER AND IN COMPLIANCE WITH THE TERMS OF THIS LETTER OF CREDIT, WE SHALL DULY HONOR SUCH DRAFT UPON ITS PRESENTATION TO US WITHIN 30 DAYS, AND WE SHALL DEPOSIT THE AMOUNT OF THE DRAFT DIRECTLY INTO THE STANDBY TRUST FUND OF MALLINCKRODT INC. ACCOUNT NO. 030359 HELD WITH BANKERS TRUST COMPANY, NEW YORK, IN ACCORDANCE WITH YOUR INSTRUCTIONS.

EACH DRAFT MUST BEAR ON ITS FACE THE CLAUSE: "DRAWN UNDER LETTER OF CREDIT NO. 003050-793, DATED 7/26/00, AND THE TOTAL OF THIS DRAFT AND ALL OTHER DRAFTS PREVIOUSLY DRAWN UNDER THIS LETTER OF CREDIT DOES NOT EXCEED USD$21,113,000.00."

THIS CREDIT IS SUBJECT TO THE MOST RECENT EDITION OF THE UNIFORM CUSTOMS AND PRACTICE FOR DOCUMENTARY CREDITS, PUBLISHED BY THE INTERNATIONAL CHAMBER OF COMMERCE.

KINDLY ACKNOWLEDGE RECEIPT BY MAIL.

INTESA SANPAOLO

February 21st, 2008

Karen Burke
Director Environmental Remediation
Mallinckrodt, Inc.
675 McDonnell Blvd
Hazelwood, MO 63042

Dear Ms. Burke,

Please be advised that Intesa Sanpaolo S.p.A., New York Branch is a New York State licensed branch of a Milan based Italian banking institution. We are regulated by the New York State Banking Department, the Board of Governors of the Federal Reserve System and the Federal Reserve Bank of New York. We are subject to all of the same rules and regulations as any other New York licensed bank.

Attached please find:

- the License to Maintain a Branch issued to Banca Intesa Banca Commerciale Italiana S.p.A. ("BIBCI") by the NYSBD;
- name change authorizations from the NYSBD allowing:

  BIBCI to change its name to Banca Intesa S.p.A., and
  Banca Intesa S.p.A. to change its name to Intesa Sanpaolo S.p.A.

Please feel free to contact me for any further assistance.

Best Regards,

D. Mara Lowenstein, Esq.
General Counsel & Vice President
Intesa Sanpaolo S.p.A., New York Branch
(212) 607-3851 (tel)
(212) 809-9780 (fax)
dmlowenstein@intesasanpaolo.us

BANKING DEPARTMENT

STATE OF NEW YORK

LICENSE TO MAINTAIN A BRANCH

WHEREAS, Banca Commerciale Italiana S.p.A. has merged with and into Banca Intesa S.p.A. on May 1, 2001 and the surviving entity changed its name to Banca Intesa Banca Commerciale Italiana S.p.A., d/b/a IntesaBci S.p.A.; and

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A. is a banking corporation duly organized under the laws of Italy and having its principal office in the city of Milan, Italy; and

WHEREAS, Banca Commerciale Italiana S.p.A. was issued a license to operate a branch at One William Street, Borough of Manhattan, City of New York on October 18, 1984; and

WHEREAS, Banca Intesa S.p.A. was issued a license to operate a branch at 10 East 53rd Street, Borough of Manhattan, City of New York, on April 20, 2000; and

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A., pursuant to the merger, has assumed the branch of Banca Commerciale Italiana S.p.A. located at One William Street, Borough of Manhattan, City of New York; and

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A., has made application to change its principal New York office location from 10 East 53rd Street, Borough of Manhattan, City of New York to One William Street, Borough of Manhattan, City of New York; and

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A. has complied with the conditions imposed by the Banking Law and there appears to be no objection to such change of location;

NOW, THEREFORE, BE IT KNOWN THAT the said applicant is hereby authorized to carry on the business of a branch at the above location.

This license is being issued to Banca Intesa Banca Commerciale Italiana S.p.A., effective on or after August 7, 2002, to reflect the aforementioned change of location, and it is to remain in full force and effect, unless suspended, surrendered or revoked.

WITNESS, my hand and official seal of the Banking Department at the City of New York, this 7th day of August in the year two thousand and two.

Superintendent of Banks

Banking Department

State of New York

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A. is a foreign banking corporation organized under the laws of Italy and has its principal office and place of business in the city of Milan; and

WHEREAS, Banca Intesa Banca Commerciale Italiana S.p.A., as a result of a change of name, has made application to the Superintendent of Banks for approval to change the name of its New York branch located at **One William Street, Borough of Manhattan, City of New York**, to **Banca Intesa S.p.A., d/b/a Intesa**; and

WHEREAS, There appears to be no reasonable objection to such change of name of the said branch:

NOW, THEREFORE, I, MICHAEL J. LESSER, Deputy Superintendent of Banks of the State of New York, **DO HEREBY AUTHORIZE** the aforementioned change of name.

Witness, *my hand and official seal of the Banking Department at the City of New York, this 1st day of April in the year two thousand and three.*

Michael Lesser

Deputy Superintendent of Banks

State of New York

Banking Department

WHEREAS, Banca Intesa S.p.A. is a foreign banking corporation organized under the laws of Italy and has its principal office and place of business in the city of Turin, Italy; and

WHEREAS, Banca Intesa S.p.A., as a result of a change of name has made application to the Superintendent of Banks for changing the name of its New York Branch located at: 1 William Street, New York, NY 10004, to **Intesa Sanpaolo S.p.A.**; and

WHEREAS, There appears to be no reasonable objection to change the name of the said New York Branch:

NOW, THEREFORE, I, DAVID S. FREDSALL, Deputy Superintendent of Banks of the State of New York, **DO HEREBY AUTHORIZE** the aforementioned change of name on or after the 6th day of April 2007.

Witness, *my hand and official seal of the Banking Department at the City of New York, this 24th day of April in the year two thousand and seven .*

Deputy Superintendent of Banks

SECTION 3

Copy of Notification of Merger

SANPAOLO IMI SANPAOLO IMI S.p.A.
Head Office: Turin, Italy

New York Branch
245 Park Avenue 35th FL
New York, NY 10167

Tel (212) 692-3000
Fax (212) 692-3179
SWIFT IBSPUS33

Place and Date of Issue: New York, 12/15/06 Date and place of expiry: 03/31/07, New York	Irrevocable Letter of Credit L/C Number: 003050-793
Applicant: MALLINCKRODT INC., A DELAWARE CORPORATION 675 MCDONNELL BLVD., P.O. BOX 5840 ST LOUIS, MO 63134-0480	Beneficiary: U.S. NUCLEAR REGULATORY COMMISSION WASHINGTON, D.C. 20555

NOTIFICATION OF MERGER:

ON OCTOBER 12TH, 2006, THE BOARDS OF DIRECTORS OF SANPAOLO IMI S.p.A. ("SANPAOLO") AND BANCA INTESA S.p.A. ("INTESA") APPROVED A PLAN OF MERGER BY WHICH SANPAOLO WILL MERGE WITH AND INTO INTESA (THE "MERGER"), AND THE SUCCESSOR MERGED BANK WILL OPERATE UNDER THE NAME OF INTESA SANPAOLO S.p.A.

ON DECEMBER 1ST, 2006 THE SHAREHOLDERS OF BOTH SANPAOLO AND INTESA APPROVED THE PLAN OF MERGER. THE EFFECTIVE DATE OF THE MERGER WILL BE JANUARY 1ST, 2007.

CONSEQUENTLY, SUBJECT TO ANY REMAINING REGULATORY APPROVALS, BY OPERATION OF ITALIAN LAW, AS OF JANUARY 1ST, 2007, ALL OF THE RIGHTS AND OBLIGATIONS OF SANPAOLO WILL AUTOMATICALLY BE ASSUMED BY ITS SUCCESSOR, INTESA SANPAOLO S.p.A. FURTHER INFORMATION REGARDING THE MERGER MAY BE FOUND IN THE INFORMATIONAL DOCUMENT PUBLISHED TO SANPAOLO AND INTESA SHAREHOLDERS ON NOVEMBER 17TH, 2006, FILED WITH THE ITALIAN REGULATORY AUTHORITIES AND AVAILABLE ON SANPAOLO'S WEBSITE: WWW.GRUPPOSANPAOLOIMI.COM.

FOR YOUR REFERENCE MOODY'S AND STANDARD & POOR'S HAVE CURRENTLY ASSIGNED CREDIT RATINGS TO SANPAOLO AND INTESA AS NOTED BELOW:

SANPAOLO:	A-1+/P-1; AA-/Aa3	(STABLE)
INTESA:	A-1/P-1; A+/Aa3	(POSITIVE)

NOTE: STANDARD & POOR'S HAS PLACED INTESA'S RATINGS ON POSITIVE WATCH SINCE THE MERGER WAS ANNOUNCED.

UNTIL FURTHER NOTICE, THE ADDRESS, TELEPHONE NUMBERS, FAX NUMBERS, TELEX NUMBERS, SWIFT BICS AS WELL AS ALL TEST KEYS, ACCOUNT NUMBERS, PAYMENT INSTRUCTIONS AND AUTHORIZED SIGNATURES OF THE NEW YORK BRANCH OF SANPAOLO WILL REMAIN UNCHANGED.

PLEASE UPDATE YOUR RECORDS ACCORDINGLY AND NOTIFY THE APPROPRIATE OFFICES, DEPARTMENTS AND PERSONNEL WITHIN YOUR ORGANIZATION REGARDING THE MERGER.

PLEASE CONTACT K. LEISENRING, A.V.P. OF THE LETTER OF CREDIT DEPARTMENT AT 212-692-3070 SHOULD YOU REQUIRE ADDITIONAL CLARIFICATION OR INFORMATION.

AMENDMENT:

EFFECTIVE JANUARY 01, 2007 WE HEREBY AMEND OUR IRREVOCABLE STANDBY LETTER OF CREDIT NO. 003050-793 IN YOUR FAVOR AS FOLLOWS:

NO.1-NAME OF ISSUING BANK NOW TO READ AS INTESA SANPAOLO S.p.A.

NO.2-WHEREVER IT READS SANPAOLO IMI S.P.A., SANPAOLO IMI BANK OR SANPAOLO BANK REPLACE WITH INTESA SANPAOLO S.p.A.

ALL OTHER TERMS AND CONDITIONS REMAIN UNCHANGED.

KENNETH LEISENRING
ASST. VICE PRESIDENT

JOHN FERRANTE
ASST. VICE PRESIDENT