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OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

September 25, 1996

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SUBJECT: DRAFT REPORT—VERIFICATION SURVEY OF THE PLANT 10 AREA AT THE ST. LOUIS DOWNTOWN SITE, MALLINCKRODT SPECIALTY CHEMICAL COMPANY, ST. LOUIS, MISSOURI

Dear Dr. Williams:

The Environmental Survey and Site Assessment Program (ESSAP) of the Oak Ridge Institute for Science and Education (ORISE) has completed the verification activities for the subject property. Enclosed for your review and comment is the draft report which describes the procedures and results of these activities. Comments that you may have will be incorporated into the final report.

Please contact me at (423) 576-5073 or Eric Abelquist at (423) 576-3740 should you have any questions or if we may provide additional information.

Sincerely,

Timothy J. Vitkus
Survey Projects Manager
Environmental Survey and
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TJV:dka

Enclosure

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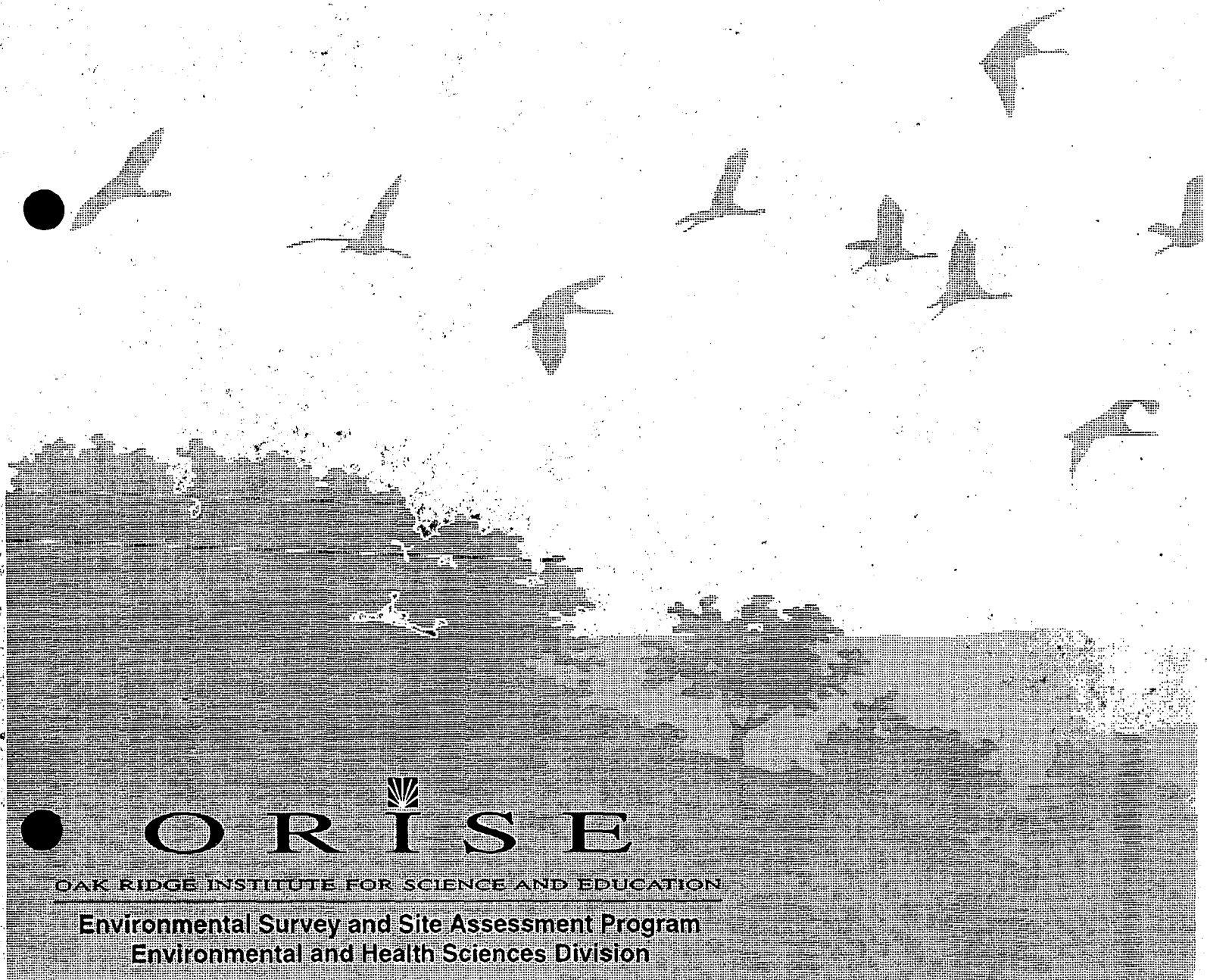
DRAFT REPORT

VERIFICATION SURVEY OF THE PLANT 10 AREA AT THE ST. LOUIS DOWNTOWN SITE MALLINCKRODT SPECIALTY CHEMICAL COMPANY ST. LOUIS, MISSOURI

T. J. VITKUS

Prepared for the Office of Environmental Restoration
U.S. Department of Energy



ORISE
OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION
Environmental Survey and Site Assessment Program
Environmental and Health Sciences Division

VERIFICATION SURVEY
OF THE
PLANT 10 AREA AT THE ST. LOUIS DOWNTOWN SITE
MALLINCKRODT SPECIALTY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Prepared by

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U.S. Department of Energy

DRAFT REPORT

SEPTEMBER 1996

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ABBREVIATIONS AND ACRONYMS

µR/h	microroentgens per hour
µrem/h	microrem per hour
AEC	Atomic Energy Commission
ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Inc.
cm	centimeter
cm^2	square centimeter
DOE	U.S. Department of Energy
dpm/100 cm^2	disintegrations per minute/100 square centimeters
EML	Environmental Measurements Laboratory
ESSAP	Environmental Survey and Site Assessment Program
FSRD	Former Sites Restoration Division
FUSRAP	Formerly Utilized Sites Remedial Action Program
GM	Geiger-Mueller
IVC	independent verification contractor
kg	kilogram
m^2	square meter
MDC	minimum detectable concentration
MED	Manhattan Engineer District
MSCC	Mallinckrodt Specialty Chemical Company
NaI	sodium iodide
NIST	National Institute of Standards and Technology
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
pCi/g	picocuries per gram
PMC	project management contractor
PRAR	post-remedial action report
SLDS	St. Louis Downtown Site
UF_4	uranium tetrafluoride
UO_2	uranium dioxide
U_3O_8	uranium oxide

VERIFICATION SURVEY
OF THE
PLANT 10 AREA AT THE ST. LOUIS DOWNTOWN SITE
MALLINCKRODT SPECIALTY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

INTRODUCTION

The St. Louis Downtown Site (SLDS) is an active chemical plant owned by Mallinckrodt Specialty Chemical Company (MSCC). From 1942 until 1957, the former Mallinckrodt Chemical Works performed work under contract to the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC), predecessor organizations to the U. S. Department of Energy (DOE). The work included development of uranium-processing techniques, production of various uranium compounds, and recovery of uranium metal from residues and scrap. The facility is comprised of a number of different plant areas. The initial uranium processing was performed in Plants 1, 2, and 4 (now known as Plant 10) from 1942 until 1945, and involved the refining of uranium oxide (U_3O_8) feed and pitchblende. Manufacturing of uranium dioxide (UO_2) from pitchblende ore began in the newly constructed Plant 6 area in 1946. Mallinckrodt decontaminated Plants 1 and 2 during the period 1948 to 1950 in order to meet the AEC criteria for release without radiological restrictions that were in effect at that time. Plant 6E, for the production of uranium metal and Plant 7, for production of green salt (UF_4), began operations at the site during the period 1950 to 1951. Plant 4 operations were discontinued at this time, and the facilities modified for use as a metallurgical pilot plant for development work with uranium, which continued until 1956. Plants 4, 6E, and 7 were decontaminated to the AEC release criteria current at the time and returned to Mallinckrodt in 1962. Since 1962, a number of other Mallinckrodt projects at the site have resulted in some buildings being demolished and others constructed within Plants 4 and 6. In addition to the uranium work, other radiological work performed at various times included extraction and concentration of Ra-226 and daughters and Th-230 from pitchblende and pitchblende raffinate.

In 1977, Oak Ridge National Laboratory (ORNL) performed a radiological survey of portions of the SLDS at the request of the DOE. This survey identified residual radiological contamination within buildings and in site soils at levels in excess of the current DOE guidelines for release of the property

without radiological restrictions (ORNL 1981). As a result, the site was designated into the Formerly Utilized Sites Remedial Action Program (FUSRAP). FUSRAP was created in 1974 to identify, investigate, and cleanup or control sites where contamination above today's guidelines remains from the early years of the Nation's atomic energy program. Bechtel National Inc. (BNI) is the project management contractor (PMC) for FUSRAP. BNI has performed site characterization of SLDS in order to identify areas of residual contamination (BNI 1990). The characterization showed that the former Plant 4, now known as Plant 10, area is radiologically contaminated, in addition to other areas of the site. Mallinckrodt plans to construct new facilities within Plant 10, and has demolished all above-grade structures. In support of this project, BNI remediated the contaminated soils from within the area in order to permit release for unrestricted use.

It is the policy of the DOE to perform independent verification of remedial actions conducted under FUSRAP. The Environmental Survey and Site Assessment Program (ESSAP) of the Oak Ridge Institute for Science and Education (ORISE) was designated as the independent verification contractor (IVC) for the St. Louis Downtown Site.

SITE DESCRIPTION

The 45 hectare (111 acre) Mallinckrodt Specialty Chemical Co. site is located within an industrial area in the eastern section of St. Louis, Missouri just west of the Mississippi River (Figure 1). The facility encompasses ten operational plants, each of which consists of various buildings and structures (Figure 2). Plant 10, which is located on the southwest corner of the facility, has an approximate area of 7.4 hectares (18 acres). Plant 10 is bordered by Destrehan Street and Plant 3 to the north, North Second Avenue to the east, Angelrodt Street to the south, and North Broadway to the west (Figure 2). Buildings 80, 81, and 82 were removed. Soils were excavated from beneath Building 81, Building 82, and the Building 82 loading dock area. Excavation depths ranged from 15 cm to several meters. Figure 3 shows excavated and surveyed areas.

PROJECT ORGANIZATION AND RESPONSIBILITY

DOE Headquarters provides overview and coordination of all FUSRAP activities. DOE's Oak Ridge Operations (DOE-ORO) is responsible for implementation of FUSRAP and the Former Sites Restoration Division (FSRD) of DOE-ORO, manages the daily activities.

Under the standard FUSRAP protocol, an initial investigation/survey of a potential site is performed by ORISE or ORNL, under contract to DOE Headquarters. If appropriate, DOE Headquarters designates the site into FUSRAP based upon the results provided by the initial investigation. DOE's project management contractor for FUSRAP is BNI. BNI is responsible for the planning and the implementation of FUSRAP activities and managing the site characterization and remedial actions. The final phase for a FUSRAP site is independent verification, which is provided by ORISE or ORNL after remedial action is complete. This verification process provides independent (third party) data to assist DOE in evaluating the accuracy of the post-remedial action status of the site, as presented by BNI, and in assuring that the documentation accurately and adequately describes the condition of the site. DOE Headquarters uses the information developed by the remediation and verification activities to certify that a site can be released for use, without radiological restrictions.

OBJECTIVES

The objectives of the verification process are to ensure that the survey, sample analyses, and supporting documentation provided by BNI give an accurate and complete description of the radiological condition, following remediation, of the SLDS Plant 10 area and that all applicable generic and site-specific DOE guidelines for release for unrestricted use have been met.

DOCUMENT REVIEW

ESSAP reviewed background documentation, BNI's post-remedial action survey plan (BNI 1995), field and laboratory data, and other pertinent information for general thoroughness and appropriateness. The data were reviewed for accuracy, completeness, and compliance with

guidelines. The post-remedial action report (PRAR), which contains the primary source of data and site information used to determine the final radiological status of a site, has not been issued at the time of the preparation of this draft report.

PROCEDURES

ESSAP performed visual inspections and independent measurements and sampling during the period from August 17 to October 12, 1995. Four separate site visits were conducted for verification survey activities during this time period. The survey dates were: August 17 and 18, 1995; September 5, 1995; September 26 and 27, 1995; and October 11 and 12, 1995. Verification activities were conducted immediately following remedial actions and post-remedial action monitoring to minimize delays or interruptions in remedial action and restoration efforts. Survey activities were conducted in accordance with current procedures in the ORISE ESSAP Survey Procedures, Quality Assurance Manuals, and with a site-specific survey plan submitted to and approved by the DOE (ORISE 1995a, b, c). Survey activities included surface scans, total and removable surface activity measurements, soil sampling, and exposure rate measurements. Additional information regarding major instrumentation and survey and analytical procedures may be found in Appendices A and B, respectively.

Reference Grid

Measurement and sampling locations were referenced to either the 10 m × 10 m grid established by BNI or to other prominent site features.

Surface Scans

Surface scans for gamma activity were conducted at 1 to 2 meter intervals over 100% of the remediated area using NaI scintillation detectors. Locations of elevated direct gamma radiation, suggesting the presence of surface or near surface contamination, were marked and identified for further investigation. In addition, two boreholes were drilled to a depth of 2 meters and the sidewalls

scanned for gamma activity in an area where the excavation was significantly more shallow than the remainder of the site. Surface scans for residual beta-gamma activity, using GM detectors, were performed on any below-grade structures that were left in place. Detectors were coupled to either ratemeters or ratemeter-scalers with audible indicators.

SURFACE ACTIVITY MEASUREMENTS

Natural uranium emits both alpha and beta radiation in approximately equal proportions. Because rough, damp, or dirty surfaces selectively attenuate alpha radiation, measurements for beta radiation typically provide a better indication of residual uranium surface activity levels. Direct measurements for total beta activity were performed on subgrade structure surfaces at 10 randomly selected locations (Figures 4 and 5). A smear sample was collected from each direct measurement location for the determination of removable gross alpha and gross beta activity.

EXPOSURE RATE MEASUREMENTS

Background exposure rates were measured using a pressurized ionization chamber at 1 m above the surface at six off-site locations during prior ESSAP surveys in the St. Louis area (ORISE 1996). Exposure rates were measured at 1 m above the surface using a microrem meter at 77 locations within the Plant 10 excavations. Grid blocks were selected either randomly, or as a result of surface scans identifying locations of elevated direct gamma radiation. Exposure rate measurement locations are shown on Figures 4 through 7.

SOIL SAMPLING

A total of 123 soil samples were collected from remediated areas of Plant 10. Grid blocks were selected for soil sampling either randomly, or based on surface scan results. For randomly selected grid blocks, samples were collected systematically from the center and four points equidistant from the center and the grid block corners. For grid blocks containing areas of elevated direct radiation, soil samples were collected at the locations of elevated radiation identified by surface scans and from

systematic locations. Subsurface soil samples (>15 cm below the base of excavations) were collected to a depth of two meters from two boreholes located within an excavation that was significantly more shallow than other excavated areas of the Plant 10 site and at other locations when field measurements indicated possible subsurface contamination. Soil sampling locations are shown on Figures 8 through 11. The data determined from background soil samples collected during previous ESSAP surveys in the St. Louis area were used for comparison (ORISE 1996). Thirteen samples that BNI had collected were also requested for confirmatory analysis.

SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and survey data were returned to the ESSAP laboratory in Oak Ridge, Tennessee for analyses and interpretation. Sample analysis was in accordance with the ORISE/ESSAP Laboratory Procedures Manual (ORISE 1995d). Soil samples were analyzed by solid state gamma spectroscopy. Spectra were reviewed for U-238, Th-230, Ra-226, and any other identifiable photopeaks. Soil samples results were reported in pCi/g. Smears were analyzed for gross alpha and gross beta activity using a low-background gas proportional counter. Smear data and direct measurement data were converted to units of disintegrations per minute per 100 cm^2 (dpm/100 cm^2). Exposure rates were either converted to, or reported directly in units of microroentgens per hour (μR/h).

FINDINGS AND RESULTS

DOCUMENT REVIEW

ESSAP reviewed the PMC's post-remedial action survey plan and at the time of each verification survey the data for each remediated area was reviewed. ESSAP provided comments on the survey plan (ORISE 1995d) and directly notified the PMC concerning deficiencies identified in the documentation and of any areas exceeding guidelines following verification survey activities. Because the post-remedial action report (PRAR) is not currently available for review, no conclusion can be made at this time as to the adequacy of the PRAR, relative to the Plant 10 area final radiological status.

SURFACE SCANS

Beta and gamma surface scans of the subgrade concrete structures did not identify any areas of elevated direct radiation. Gamma surface scans of the Plant 10 excavations identified several undocumented locations of elevated direct radiation and verified the presence of other reported areas of elevated direct gamma radiation. Direct gamma radiation levels were elevated at a number of these locations to the extent that BNI performed additional remediation. ESSAP's follow-up investigations of these areas determined that the gamma radiation activity levels were generally comparable to background following additional remediation. Surface soil locations were sampled where either BNI or ESSAP identified elevated direct gamma radiation and determined that the activity was confined to a small area and additional remediation was not necessary.

SURFACE ACTIVITY LEVELS

Beta-gamma surface activity levels on the exposed concrete surfaces ranged from less than 770 dpm/100 cm^2 to 2,700 dpm/100 cm^2. Removable activity levels were less than 12 dpm/100 cm^2 for gross alpha and less than 16 dpm/100 cm^2 for gross beta.

EXPOSURE RATES

Background exposure rates in the St. Louis area averaged 9 μR/h (ORISE 1996). Exposure rates within the remediated Plant 10 areas are shown in Table 1 and ranged from 4 to 15 μR/h.

RADIONUCLIDE CONCENTRATIONS IN SOILS

Table 1 summarizes the radionuclide concentration levels in soil samples. The radionuclide concentrations in soil samples collected from locations of elevated direct radiation identified by surface scans were as follows: 0.7 to 13.9 pCi/g for Ra-226, less than 12.9 to 25.9 pCi/g for Th-230, and 3.9 to 286.1 pCi/g for U-238. These areas were either remediated by BNI and resurveyed or additional samples were either collected by ESSAP or requested from BNI in order to bound the area of contamination. The radionuclide concentration levels in all final verification samples—excluding

the initial sample data from locations where additional remediation was performed—were: Ra-226, 0.4 to 12.6 pCi/g; Th-230, less than 12.9 to 25.9 pCi/g; and U-238, 0.8 to 169.6 pCi/g.

The average radionuclide concentrations in background samples were as follows: 0.9 pCi/g for Ra-226; 1.31 pCi/g for Th-230; 1.1 pCi/g for Th-232; and 1.1 pCi/g for U-238 (ORISE 1996).

Table 2 summarizes the results of the confirmatory soil sample analysis. Overall, the results were comparable within the expected statistical deviations of the procedure.

COMPARISON OF RESULTS WITH GUIDELINES

Results of the survey were compared to the applicable DOE generic and site-specific guidelines (DOE 1990a and b). These guidelines are summarized in Appendix C. The controlling radionuclide at SLDS is natural uranium ore and processed natural uranium. The applicable surface activity guidelines are:

Total Activity

5000 α dpm/100 cm^2, averaged over a 1 m^2 area

15,000 α dpm/100 cm^2, maximum in a 100 cm^2 area

Removable Activity

1000 α dpm/100 cm^2

Surface activity levels on all remaining subgrade structures were less than the above guidelines.

The applicable soil concentration guidelines include the generic guidelines for Ra-226 and Th-230 and the site-specific guideline for U-238. These guidelines are:

Radionuclide	Guideline
Ra-226 and Th-230	5 pCi/g averaged over the first 15 cm of soil below the surface. 15 pCi/g averaged over 15 cm thick layers of soil greater than 15 cm below the surface.
U-238	50 pCi/g

Soil samples were collected from areas excavated to depths greater than 15 cm below the surface. All excavations have since been backfilled to original site grade. Therefore, the subsurface criteria are applicable for Ra-226 and Th-230—the U-238 guideline does not specify depth. Based on these considerations, 12 samples contained concentrations of Th-230 and/or U-238 in excess of the respective guideline. The soil guidelines permit averaging residual concentration levels over 100 m^2 areas and the application of hot spot criteria. The size of the areas of elevated direct gamma radiation—determined from bounding samples and surface scan results—that were not remediated ranged from 1 m^2 to approximately 4 m^2. Application of the hot spot criteria allows multiplication factors of the authorized limits, based on $(100/A)^{½}$, where A equals the area of the hot spot. In addition, because one of the hot spots contains a mixture of radionuclides at elevated concentration levels, the sum of the ratios of the soil concentration of each radionuclide to the allowable limit for that radionuclide shall not exceed 1. In all but one case, remaining hot spots were determined to satisfy the hot spot criteria—up to 250 pCi/g of U-238 in a 4 m^2 area. The average radionuclide concentrations within each associated 100 m^2 grid block were less than the guidelines—grid block final averages ranged from 8.2 to 25.6 pCi/g for U-238 and, for the one location where Th-230 exceeded 15 pCi/g, the area average was <5.7 pCi/g. The sum of the ratios was also satisfied. The one exception was the west excavation wall bordering Broadway Avenue where all contaminated soil could not be removed without affecting the structural integrity of the road.

The exposure rate guideline is 20 µR/h above background. All exposure rates were within the guideline.

SUMMARY

The Environmental Survey and Site Assessment Program performed verification activities in support of the remediation of the Plant 10 Area at the St. Louis Downtown Site in St. Louis, Missouri. Verification activities included independent document and field data reviews, and during the period August 17 to October 12, 1995 performed independent surface scans, surface activity measurements, exposure rate measurements, and soil sampling of the remediated areas.

The verification survey identified a number of locations of elevated direct gamma radiation, several of which required BNI to perform additional remediation. After the additional remediation, radionuclide concentration levels in all final verification soil samples satisfied the guidelines. Total and removable surface activity levels on subgrade structures were also less than the guidelines as were exposure rates. Therefore, the final verification survey data supports BNI's conclusion that the excavated Plant 10 areas satisfy the DOE requirements for release without radiological restrictions.

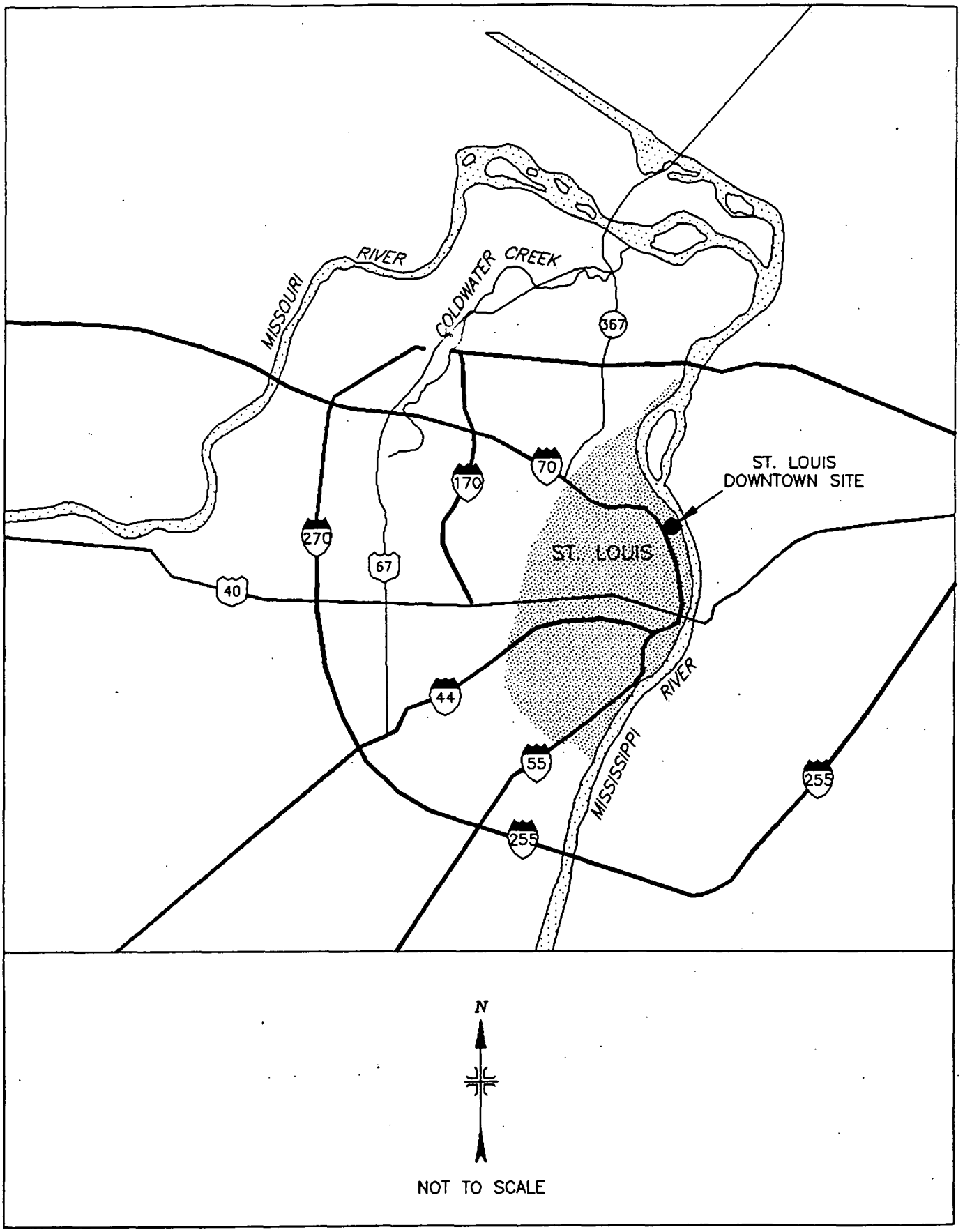


FIGURE 1: Location of the St. Louis Downtown Site (SLDS)

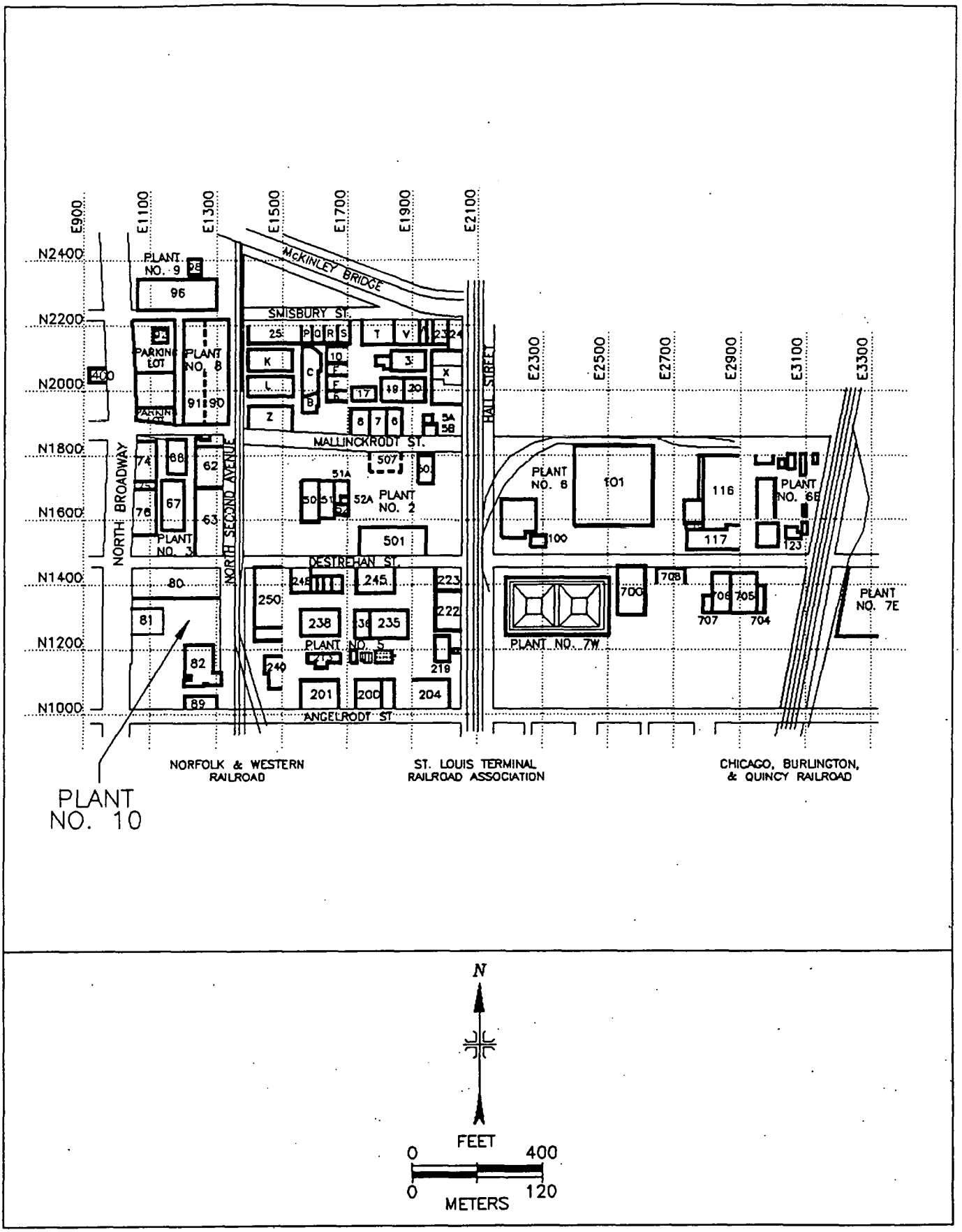


FIGURE 2: SLDS – Plant No. 10 Location

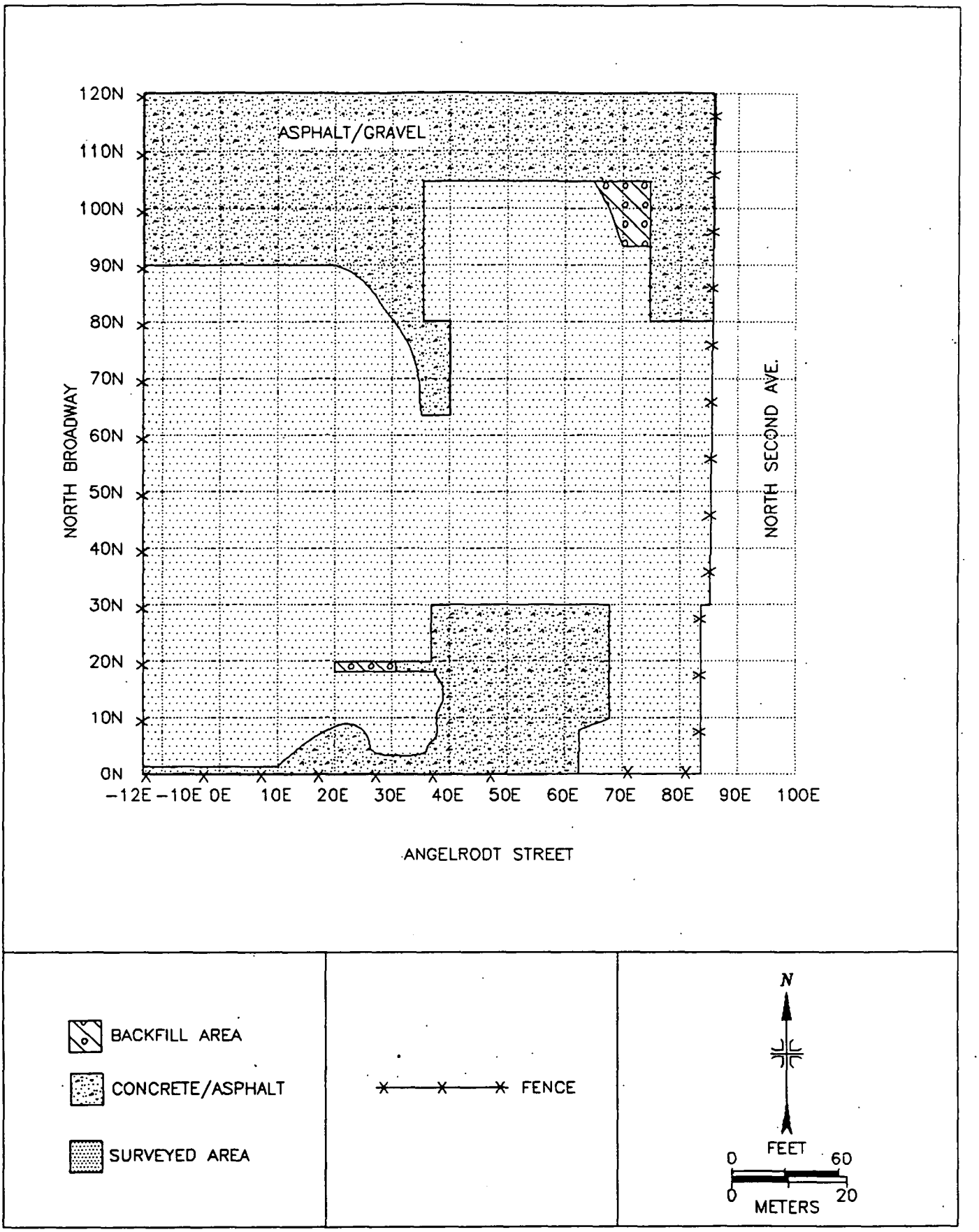
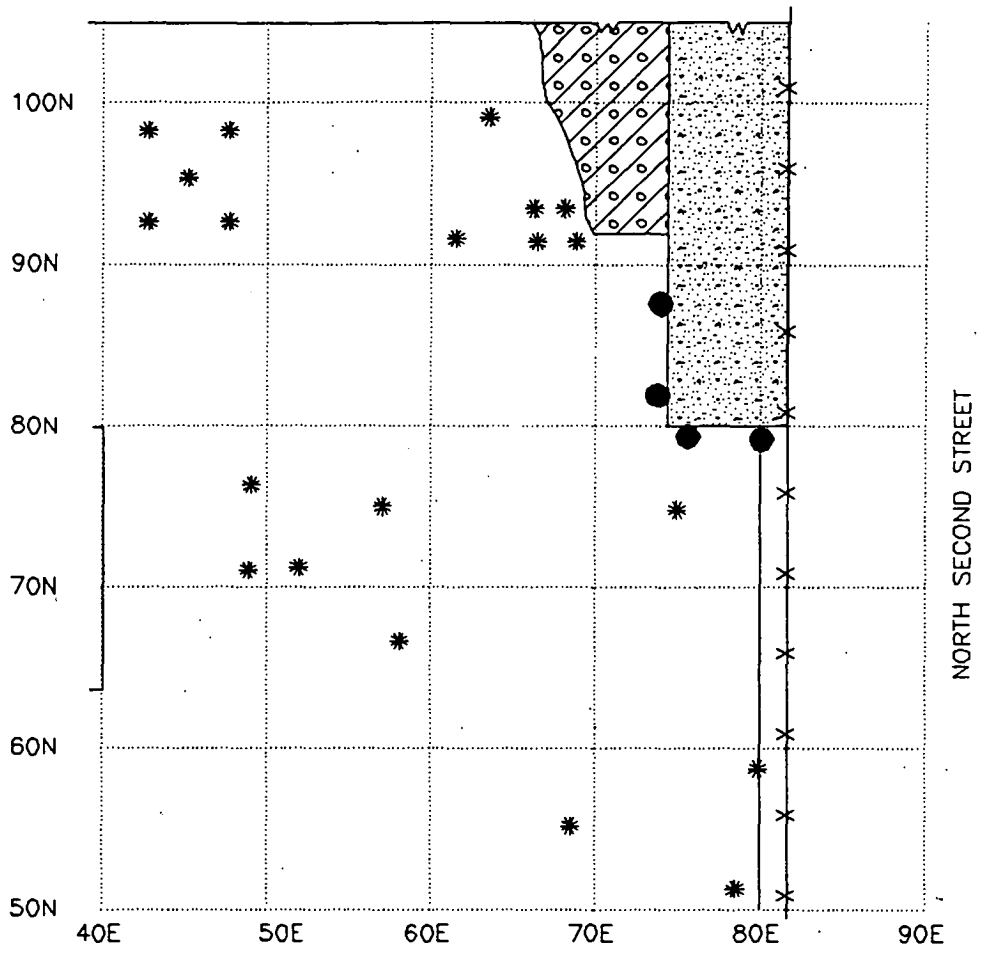


FIGURE 3: SLDS Plant No.10 Survey Area



MEASUREMENT LOCATIONS

EXPOSURE RATE

SINGLE-POINT CONCRETE SURFACE

BACKFILL AREA

FENCE

CONCRETE

EXCAVATED AREA

N

FEET 0 30

METERS 0 10

FIGURE 4: SLDS Plant No. 10, Northeast Quadrant – Measurement Locations

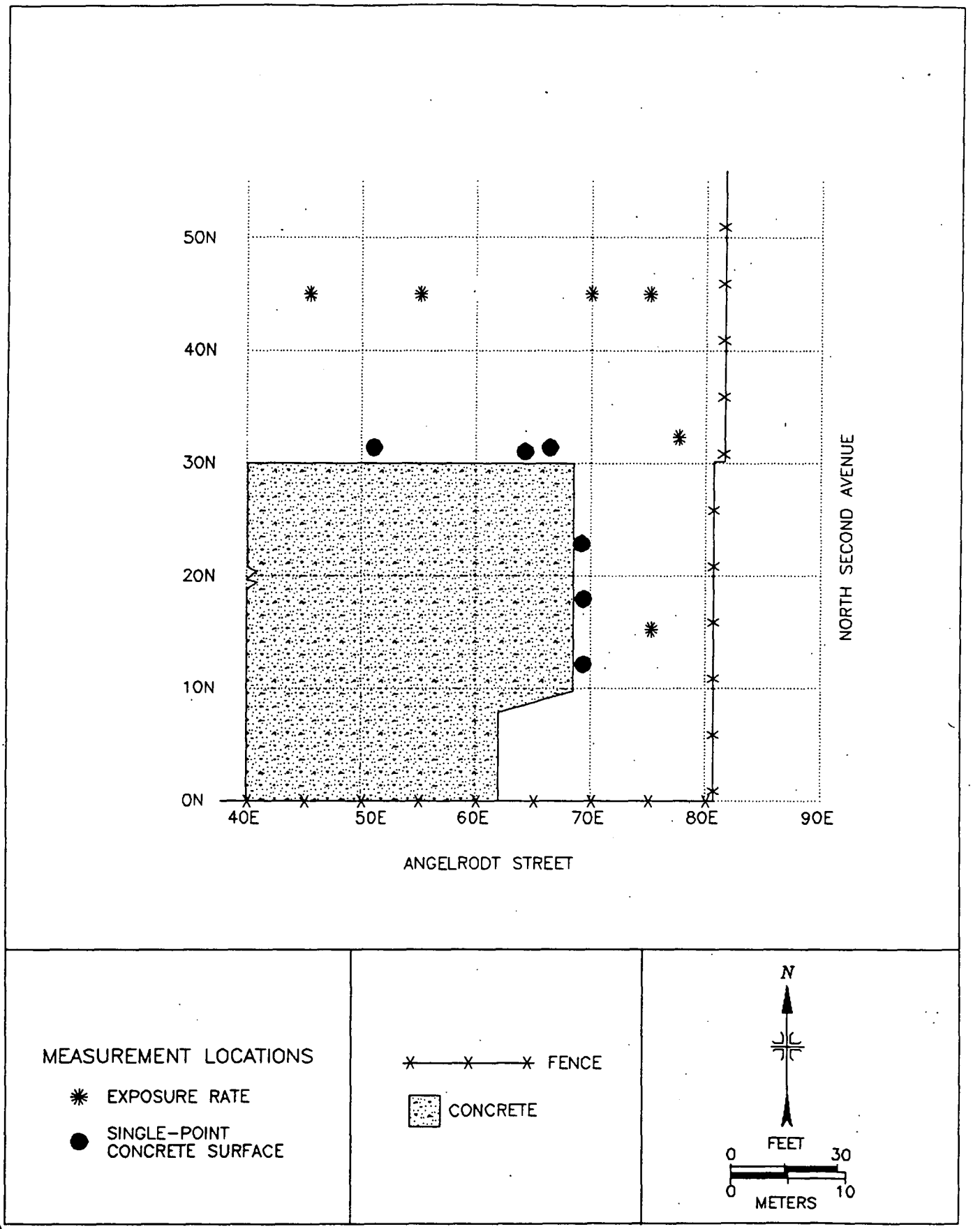


FIGURE 5: SLDS Plant No. 10, Southeast Quadrant – Measurement Locations

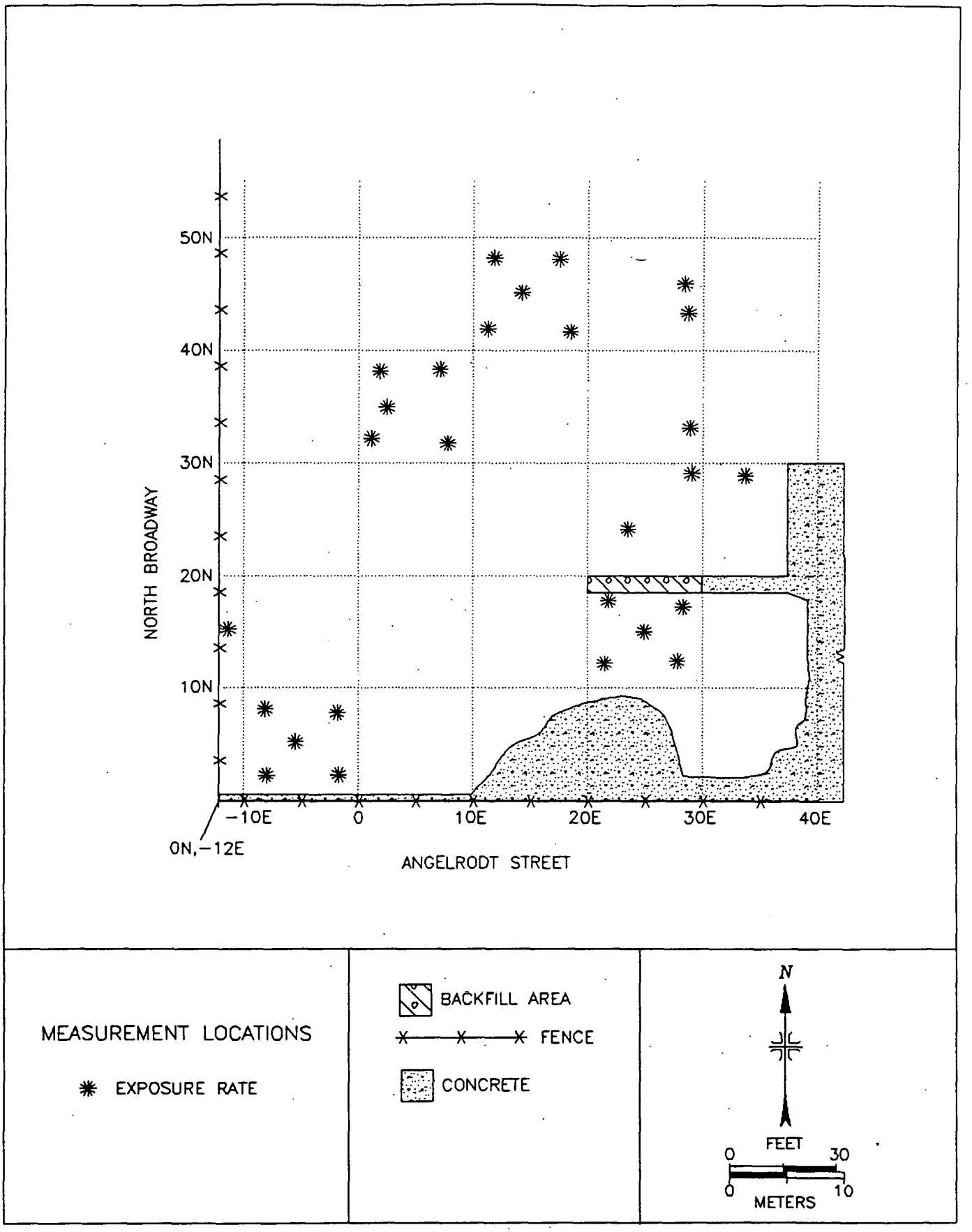
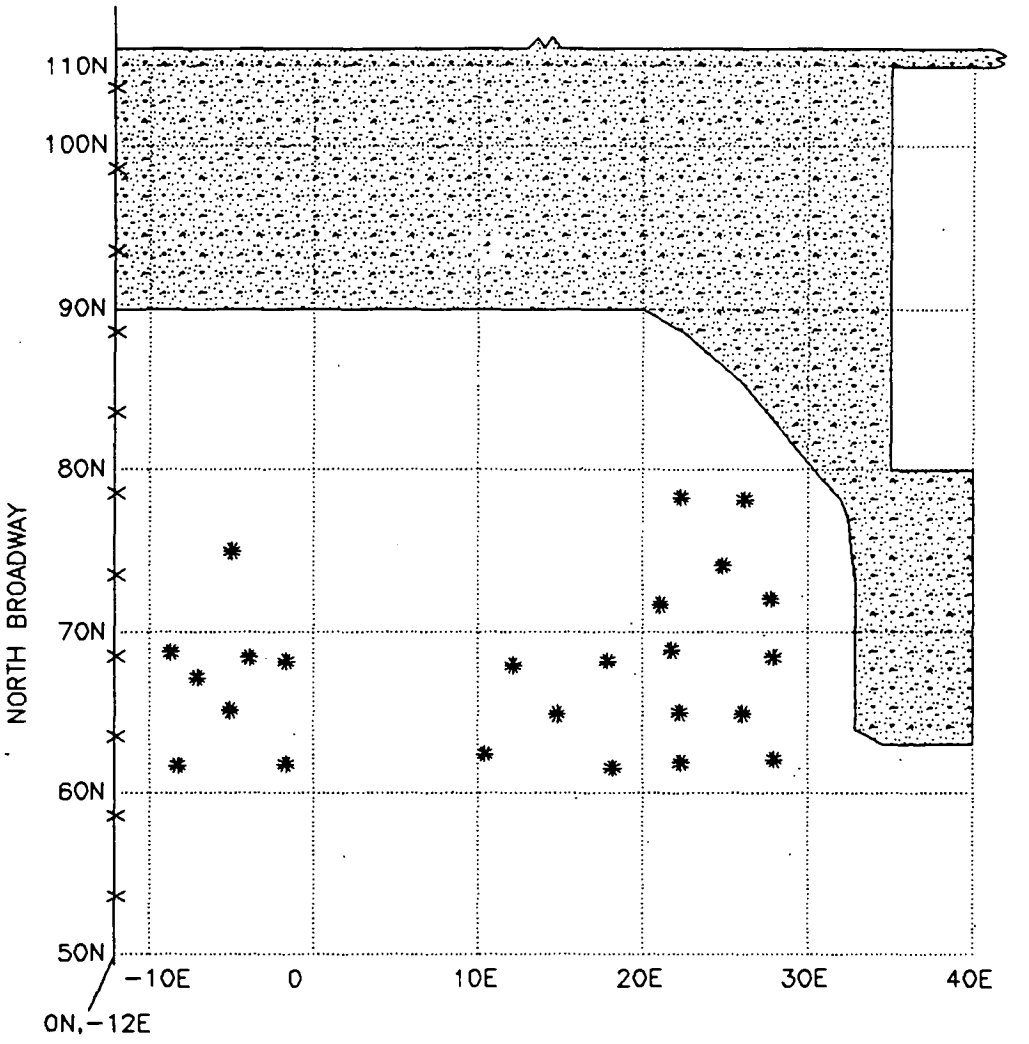


FIGURE 6: SLDS Plant 10, Southwest Quadrant – Exposure Rate Measurement Locations



MEASUREMENT LOCATIONS

EXPOSURE RATE

FENCE

CONCRETE

N

FEET

0 30

0 10

METERS

FIGURE 7: SLDS Plant No. 10, Northwest Quadrant – Exposure Rate Measurement Locations

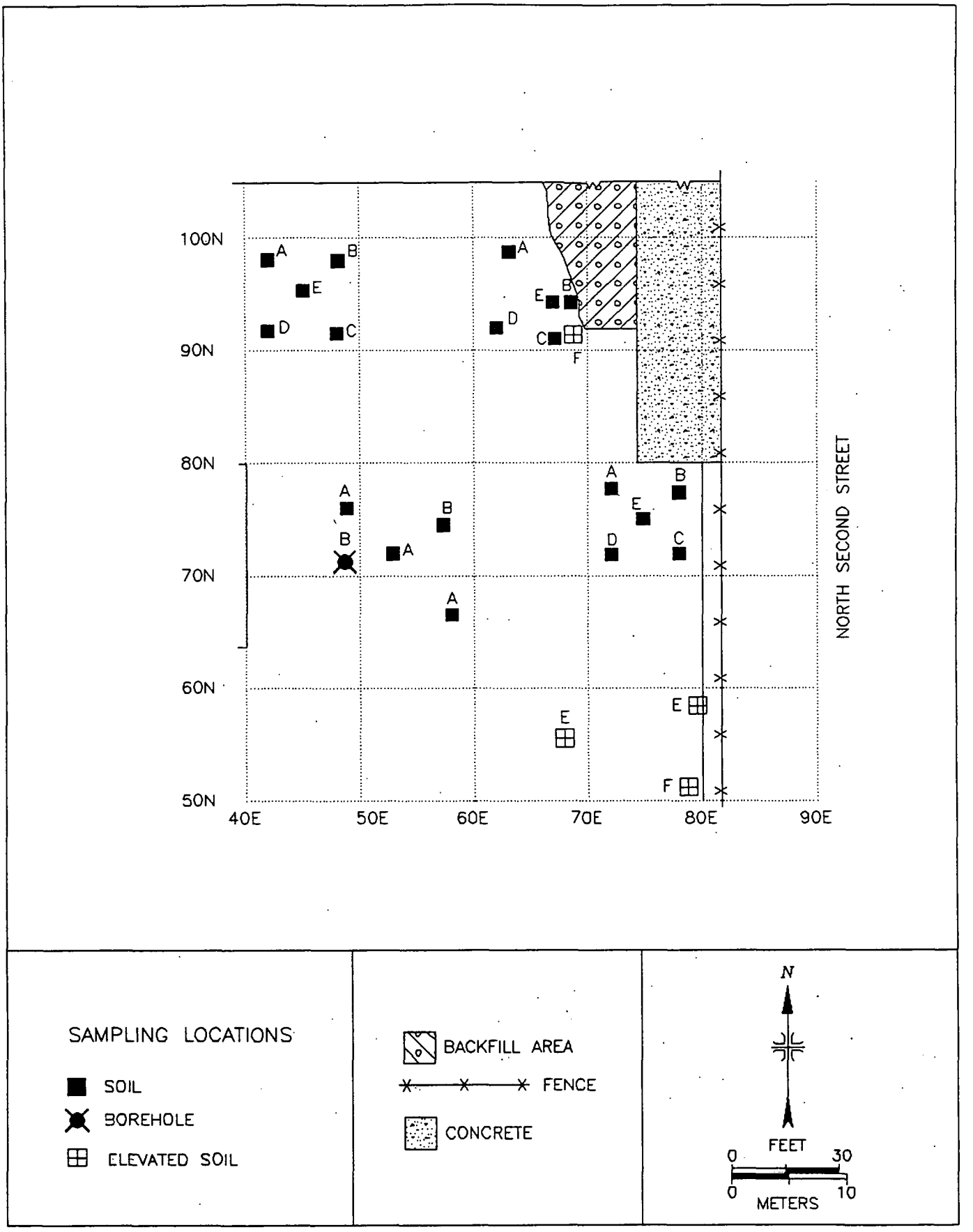


FIGURE 8: SLDS Plant 10, Northeast Quadrant – Soil Sampling Locations

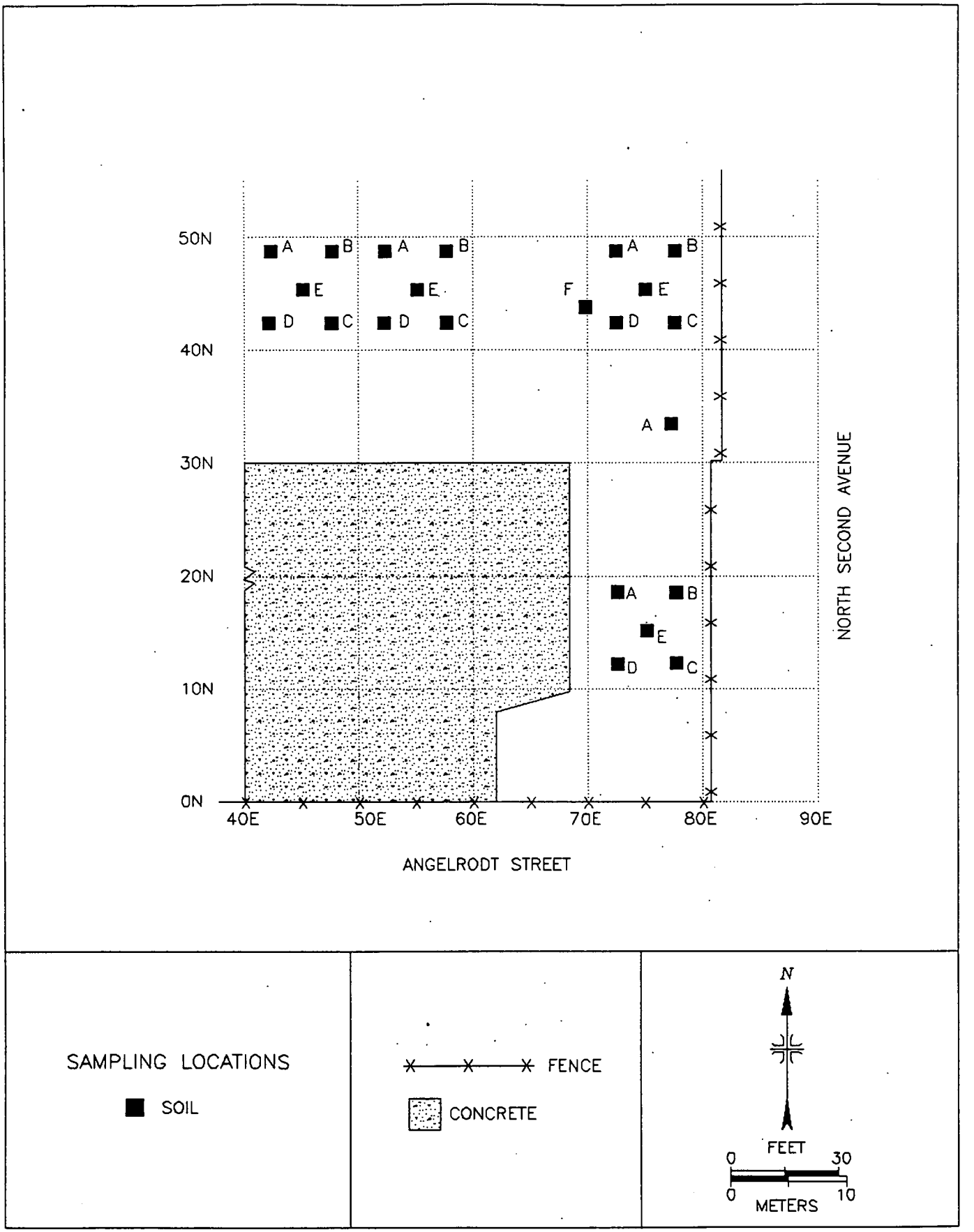
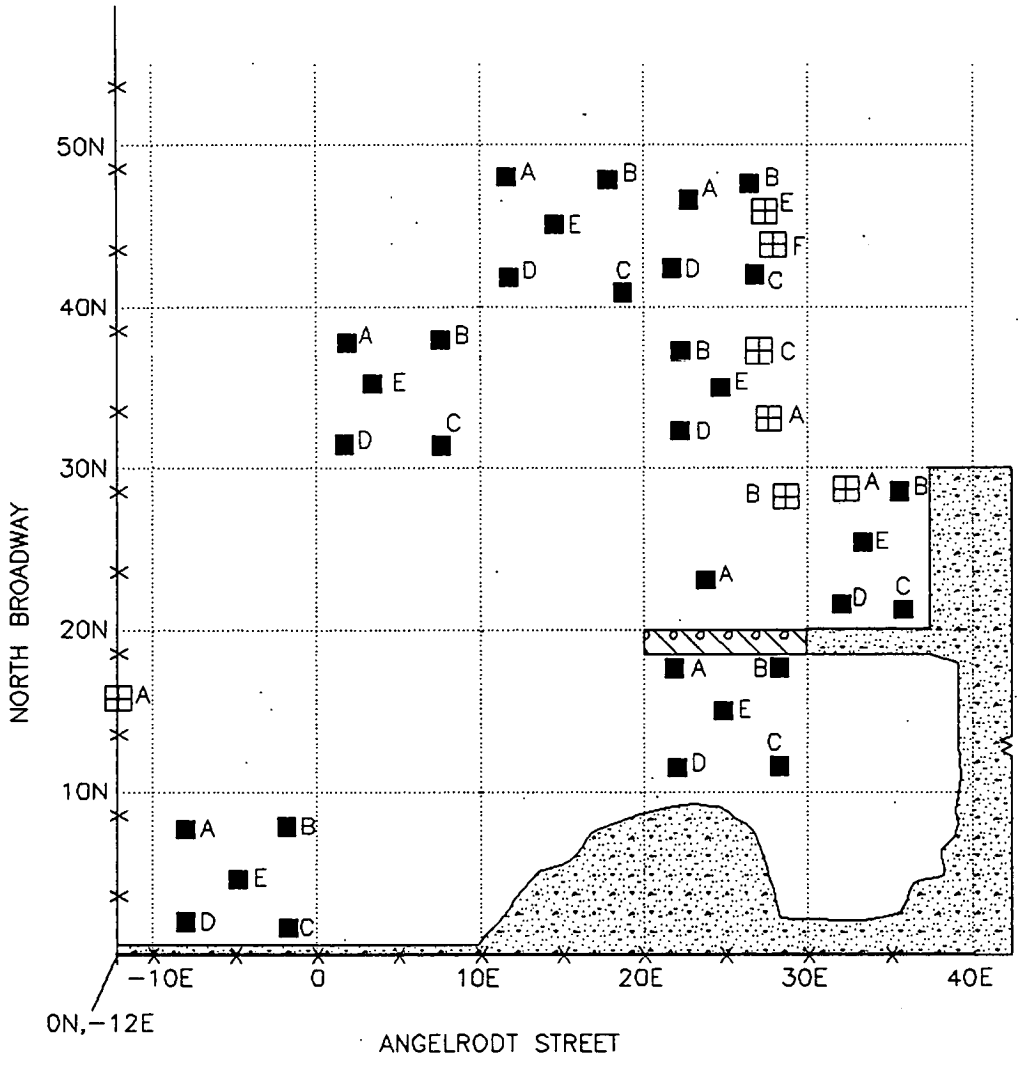


FIGURE 9: SLDS Plant 10, Southeast Quadrant – Soil Sampling Locations



SAMPLING LOCATIONS

SOIL

ELEVATED SOIL

BACKFILL AREA

FENCE

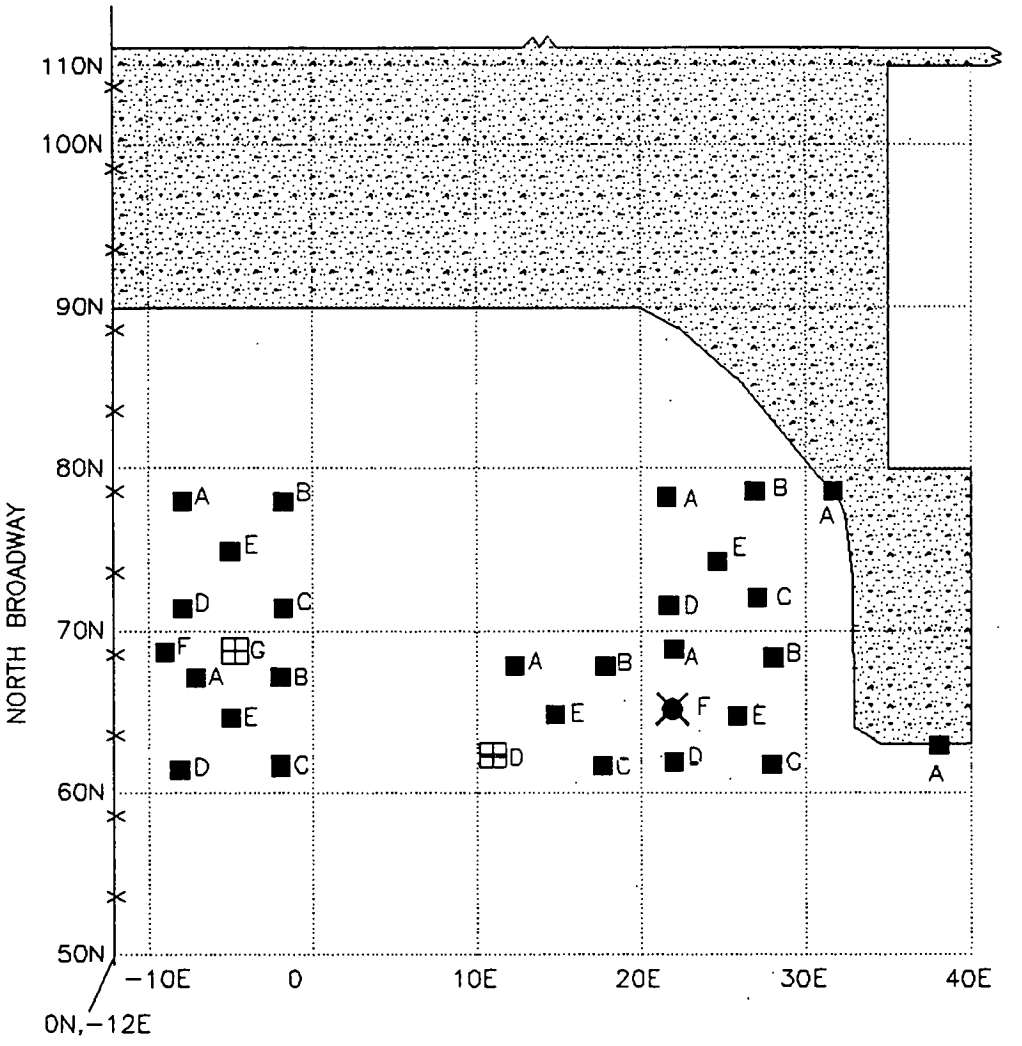
CONCRETE

N

FEET 0 30

METERS 0 10

FIGURE 10: SLDS Plant No. 10, Southwest Quadrant – Soil Sampling Locations



SAMPLING LOCATIONS

- SOIL
- BOREHOLE
- ELEVATED SOIL

FENCE

CONCRETE

N

FEET 0 30

METERS 0 10

FIGURE 11: SLDS Plant 10, Northwest Quadrant – Soil Sampling Locations

TABLE 1

EXPOSURE RATES AND RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES ST. LOUIS DOWNTOWN SITE, PLANT 10 MALLINCKRODT SPECIALITY CHEMICAL COMPANY ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (μR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
NORTHEAST QUADRANT					
50N, 60E	A[c]	10	7.1 ± 0.1[b]	<7.6	72.9 ± 0.8
	B[c]	--[d]	3.4 ± 0.1	<6.0	32.6 ± 0.6
	C[c]	--	2.5 ± 0.1	<3.9	9.5 ± 0.5
	D[c]	--	1.4 ± 0.1	2.9 ± 2.5	9.0 ± 0.5
	E	--	4.3 ± 0.1	<6.9	49.5 ± 1.0
Weighted 100 m^2 Average					25.6
50N, 70E	A[c]	--	4.2 ± 0.1	4.7 ± 4.1	22.9 ± 0.7
	B[c]	--	3.3 ± 0.1	4.2 ± 3.3	13.1 ± 0.6
	C[c]	--	2.9 ± 0.1	<4.2	10.6 ± 0.5
	D[c]	--	5.1 ± 0.1	<8.4	28.5 ± 0.8
	E	10	9.9 ± 0.1	25.9 ± 6.6	71.6 ± 1.2
	F	--	4.4 ± 0.1	13.3 ± 5.2	32.8 ± 0.8
Weighted 100 m^2 Average				<5.7	22.1
60N, 60E	A	5	1.4 ± 0.1	<2.9	1.4 ± 0.3
70N, 40E	A	6	1.4 ± 0.1	<3.5	1.5 ± 0.3
	B	6	2.8 ± 0.1	3.4 ± 2.8	3.0 ± 0.4
	B (2 meter depth)	NA[e]	1.2 ± 0.1	<3.6	1.0 ± 0.3
70N, 50E	A	5	1.6 ± 0.1	<2.8	3.0 ± 0.3
	B	6	1.1 ± 0.1	<2.7	1.6 ± 0.3

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (μR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
NORTHEAST QUADRANT (Continued)					
70N, 70E	A	--	2.5 ± 0.1	3.4 ± 2.7	9.8 ± 0.4
	B	--	3.5 ± 0.1	4.1 ± 3.5	4.9 ± 0.5
	C	--	2.9 ± 0.1	<4.4	8.0 ± 0.4
	D	--	3.3 ± 0.1	4.9 ± 2.8	17.9 ± 0.6
	E	13	3.4 ± 0.1	<6.5	18.4 ± 0.6
90N, 40E	A	5	1.2 ± 0.1	<2.5	1.4 ± 0.3
	B	6	1.0 ± 0.1	<3.6	1.2 ± 0.3
	C	4	1.0 ± 0.1	<2.6	1.6 ± 0.3
	D	5	0.7 ± 0.1	<3.1	1.1 ± 0.2
	E	6	1.2 ± 0.1	<3.1	1.6 ± 0.3
90N, 60E	A	8	1.2 ± 0.1	<2.8	1.4 ± 0.3
	B	6	1.3 ± 0.1	<4.2	4.4 ± 0.4
	C	6	2.1 ± 0.1	<4.9	2.8 ± 0.4
	D	6	0.9 ± 0.1	<2.6	1.6 ± 0.3
	E	5	1.3 ± 0.1	2.4 ± 2.2	9.0 ± 0.4
	F	7	3.4 ± 0.1	5.1 ± 3.0	3.9 ± 0.4
SOUTHEAST QUADRANT					
10N, 70E	A	--	2.3 ± 0.1	3.6 ± 2.7	11.2 ± 0.5
	B	--	2.8 ± 0.1	3.6 ± 2.2	5.3 ± 0.4
	C	--	2.1 ± 0.1	<4.9	5.1 ± 0.4
	D	--	2.1 ± 0.1	<4.1	8.9 ± 0.5
	E	10	1.3 ± 0.1	<4.0	4.5 ± 0.3

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (µR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
SOUTHEAST QUADRANT (Continued)					
30N, 70E	A	12	3.5 ± 0.1	<4.5	6.4 ± 0.4
40N, 40E	A	--	1.6 ± 0.1	<5.5	13.8 ± 0.6
	B	--	1.8 ± 0.1	<4.2	11.6 ± 0.6
	C	--	1.7 ± 0.1	<3.6	8.6 ± 0.5
	D	--	1.5 ± 0.1	<5.3	11.4 ± 0.5
	E	8	1.8 ± 0.1	<4.5	17.6 ± 0.6
40N, 50E	A	--	1.8 ± 0.1	<4.1	10.0 ± 0.5
	B	--	1.4 ± 0.1	<3.4	2.4 ± 0.4
	C	--	1.7 ± 0.1	<5.1	7.0 ± 0.4
	D	--	1.4 ± 0.1	<3.6	3.2 ± 0.4
	E	10	1.4 ± 0.1	<3.4	1.5 ± 0.3
40N, 70E	A	--	2.0 ± 0.1	<3.7	10.0 ± 0.5
	B	--	3.2 ± 0.1	<7.0	21.1 ± 0.8
	C	--	3.2 ± 0.1	4.8 ± 3.0	11.9 ± 0.6
	D	--	4.4 ± 0.1	<5.1	12.1 ± 0.6
	E	10	4.4 ± 0.1	<6.9	13.3 ± 0.7
	F	13	13.9 ± 0.2	10.0 ± 7.0	45.4 ± 1.1
SOUTHWEST QUADRANT					
0N, -10E	A	10	2.1 ± 0.1	<4.9	4.3 ± 0.4
	B	11	1.0 ± 0.1	<2.9	3.6 ± 0.3
	C	12	0.7 ± 0.1	<2.5	2.5 ± 0.2
	D	11	0.7 ± 0.1	<3.5	1.5 ± 0.3
	E	6	0.9 ± 0.1	<3.1	1.9 ± 0.3

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (μR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
SOUTHWEST QUADRANT (Continued)					
10N, 20E	A	11	1.3 ± 0.1	<4.6	20.5 ± 0.6
	B	9	1.1 ± 0.1	<4.6	1.3 ± 0.3
	C	10	1.1 ± 0.1	<4.0	6.4 ± 0.4
	D	10	1.1 ± 0.1	<3.6	5.6 ± 0.4
	E	9	1.1 ± 0.1	<5.5	9.2 ± 0.5
N15, E-12	A Excavation Wall (0-15 cm)	15	1.6 ± 0.1	<4.7	29.3 ± 0.5
	A Excavation Wall (15-30 cm)	--	1.2 ± 0.1	<9.8	92.4 ± 0.9
	A Excavation Wall (30-45 cm)	--	0.9 ± 0.1	<5.2	43.4 ± 0.6
20N, 30E	A	10	1.3 ± 0.1	<5.7	52.0 ± 0.7
	B	--	0.9 ± 0.1	<3.3	9.1 ± 0.4
	C	--	1.1 ± 0.1	<6.7	32.5 ± 0.8
	D	--	1.8 ± 0.1	<4.8	21.8 ± 0.7
	E	--	1.2 ± 0.1	<3.3	13.6 ± 0.3
Weighted 100 m^2 Average					19.7
24N, 23.5E	A PRA[f]	--	1.3 ± 0.1	<5.2	7.0 ± 0.5
N29, E29	B Hotspot	9	4.3 ± 0.1	<12.9	286.1 ± 1.5
	B PRA	--	1.4 ± 0.1	<5.6	36.7 ± 0.6

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (µR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
SOUTHWEST QUADRANT (Continued)					
30N, 0E	A	9	0.8 ± 0.1	<3.6	9.5 ± 0.5
	B	9	1.1 ± 0.1	<3.1	2.2 ± 0.3
	C	9	0.9 ± 0.1	2.6 ± 2.0	4.4 ± 0.3
	D	11	0.9 ± 0.1	<3.4	2.7 ± 0.4
	E	10	0.9 ± 0.1	<5.3	45.8 ± 0.6
30N, 20E	A	8	1.2 ± 0.1	<9.4	83.9 ± 0.9
	A (PRA)	--	1.3 ± 0.1	<6.0	17.4 ± 0.6
	B	--	1.4 ± 0.1	<3.4	9.4 ± 0.4
	C	--	1.4 ± 0.1	<5.3	43.8 ± 0.6
	D	--	1.3 ± 0.1	<5.1	13.9 ± 0.5
	E	--	1.3 ± 0.1	<3.6	2.2 ± 0.4
Weighted 100 m^2 Average					18.0
40N, 10E	A	7	0.9 ± 0.1	<3.4	2.1 ± 0.3
	B	7	1.0 ± 0.1	<3.2	3.9 ± 0.3
	C	6	1.1 ± 0.1	<5.6	14.0 ± 0.6
	D	6	1.1 ± 0.1	<3.4	1.2 ± 0.3
	E	7	1.1 ± 0.1	<3.0	6.9 ± 0.3
40N, 20E	A	--	1.4 ± 0.1	<3.9	16.3 ± 0.6
	B	--	1.2 ± 0.1	<5.2	9.3 ± 0.5
	C	--	1.3 ± 0.1	<4.9	4.8 ± 0.5
	D	--	1.6 ± 0.1	<4.4	21.3 ± 0.6
	E	8	1.3 ± 0.1	<6.1	62.5 ± 0.9
	F	9	1.3 ± 0.1	<9.5	79.9 ± 1.1
Weighted 100 m^2 Average					14.1

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (μR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
NORTHWEST QUADRANT					
60N, -10E	A	7	0.9 ± 0.1	<4.7	29.6 ± 0.6
	B	7	0.8 ± 0.1	<3.8	0.8 ± 0.3
	C	6	0.9 ± 0.1	<3.1	1.9 ± 0.3
	D	6	0.9 ± 0.1	<3.2	3.3 ± 0.3
	E	6	0.7 ± 0.1	<3.8	2.6 ± 0.3
	F	7	0.8 ± 0.1	<3.8	15.0 ± 0.5
	G	6	0.7 ± 0.1	<8.7	169.6 ± 1.1
Weighted 100 m^2 Average					10.5
60N, 10E	A	6	1.0 ± 0.1	<4.2	1.5 ± 0.3
	B	7	1.0 ± 0.1	<3.6	1.2 ± 0.3
	C	7	0.9 ± 0.1	<3.3	8.3 ± 0.4
	D	7	0.9 ± 0.1	<12.0	120.5 ± 1.4
	E	5	0.9 ± 0.1	<4.2	15.1 ± 0.5
Weighted 100 m^2 Average					8.2
60N, 20E	A	4	1.1 ± 0.1	<4.9	12.1 ± 0.4
	B	7	1.5 ± 0.1	<3.6	5.8 ± 0.4
	C	6	0.9 ± 0.1	<3.1	11.6 ± 0.4
	D	6	1.1 ± 0.1	<4.9	11.1 ± 0.5
	E	7	1.3 ± 0.1	<3.4	5.7 ± 0.4
	F	6	1.7 ± 0.1	<6.4	75.0 ± 0.9
	F (15-30 cm)	--	0.9 ± 0.1	<4.8	5.5 ± 0.4
Weighted 100 m^2 Average					12.2

TABLE 1 (Continued)

EXPOSURE RATES AND
RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
ST. LOUIS DOWNTOWN SITE, PLANT 10
MALLINCKRODT SPECIALITY CHEMICAL COMPANY
ST. LOUIS, MISSOURI

Grid Location[a]	Sample Designation	Exposure Rate (μR/h)	Radionuclide Concentration (pCi/g)		
			Ra-226	Th-230	U-238
NORTHWEST QUADRANT (Continued)					
63N, 37E	A	--	3.4 ± 0.1	13.1 ± 4.2	13.7 ± 0.6
	A 15-30 cm[c]	--	12.6 ± 0.1	12.9 ± 5.2	10.0 ± 0.6
70N, -10E	A	--	0.4 ± 0.1	<2.4	8.1 ± 0.4
	B	--	1.3 ± 0.1	<7.1	34.5 ± 0.6
	C	--	1.1 ± 0.1	<3.1	6.0 ± 0.4
	D	--	0.7 ± 0.1	<3.0	7.1 ± 0.4
	E	10	1.1 ± 0.1	<6.3	65.4 ± 0.7
Weighted 100 m^2 Average					13.2
70N, 20E	A	5	0.9 ± 0.1	<5.1	10.9 ± 0.5
	B	7	1.2 ± 0.1	<3.3	5.8 ± 0.4
	C	6	1.8 ± 0.1	<3.2	5.6 ± 0.4
	D	7	0.8 ± 0.1	<4.3	1.0 ± 0.3
	E	7	1.0 ± 0.1	<3.5	7.4 ± 0.4
77N, 32.5E	A Excavation Wall	NA	2.6 ± 0.1	<3.6	2.3 ± 0.4

[a]Refer to Figures 4 through 11.
[b]Uncertainties represent the 95% confidence level, based on counting statistics.
[c]Bounding samples collected by BNI (not shown on figures).
[d]-- = measurement not performed.
[e]NA = Not applicable.
[f]PRA = Post-remedial action.

TABLE 2

CONFIRMATORY ANALYSIS AND COMPARISON OF RADIONUCLIDE CONCENTRATION RESULTS FOR POST-REMEDIAL ACTION SAMPLES MALLINCKRODT SPECIALTY CHEMICAL COMPANY ST. LOUIS DOWNTOWN SITE, PLANT 10 ST. LOUIS, MISSOURI

Sample Identification[a]	Location[b]	Radionuclide Concentrations (pCi/g)			
		Ra-226		U-238	
		ORISE	BNI	ORISE	BNI
116955198	30-40N,20-30E	1.3 ± 0.1[d]	1.0 ± 0.1[c]	14.5 ± 0.8	18.5 ± 3.1
116955199	34N, 29E	1.0 ± 0.1	0.9 ± 0.1	34.3 ± 1.1	42.7 ± 7.2
11695200	30-40N, 30-40E	1.4 ± 0.1	1.4 ± 0.1	13.5 ± 1.1	17.2 ± 2.9
11695201	30N, 36E	1.0 ± 0.1	1.0 ± 0.1	59.9 ± 2.0	78.9 ± 12.4
11695203	40-50N, 20-30E	1.2 ± 0.1	1.2 ± 0.1	24.4 ± 1.0	23.4 ± 3.8
11695215	33N, 28.5E	1.1 ± 0.1	0.8 ± 0.1	20.4 ± 1.0	29.4 ± 5.1
11695216	24N, 23.5E	0.9 ± 0.1	0.8 ± 0.1	4.4 ± 0.8	4.7 ± 1.6
11695218	29N, 33E	1.1 ± 0.1	1.1 ± 0.1	42.4 ± 1.4	54.0 ± 8.7
11695223	45N, 28.5E	1.1 ± 0.1	0.8 ± 0.1	45.4 ± 1.3	60.6 ± 9.7
11695234	20-30N, 30-37E	1.0 ± 0.1	0.9 ± 0.1	7.4 ± 0.9	8.8 ± 1.8
11695235	22N, 37E	1.2 ± 0.1	0.9 ± 0.1	2.3 ± 0.7	<5.8
11695236	20-30N, 20-30E	1.2 ± 0.1	1.0 ± 0.1	7.0 ± 0.7	8.0 ± 1.6
11695237	24N, 27E	1.2 ± 0.2	1.0 ± 0.1	1.6 ± 1.0	<5.6

[a,b]Sample identification and location provided by BNI.
[c]BNI errors quoted @ 1.0 sigma.
[d]ORISE uncertainties represent the 95% confidence level, based only on counting statistics.

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APPENDIX A

MAJOR INSTRUMENTATION

APPENDIX A

MAJOR INSTRUMENTATION

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or their employers.

DIRECT RADIATION MEASUREMENT

Instruments

Bicron Micro-Rem Meter
(Bicron Corporation, Newburg, OH)

Eberline Pulse Ratemeter
Model PRM-6
(Eberline, Santa Fe, NM)

Ludlum Ratemeter-Scaler
Model 2221
(Ludlum Measurements, Inc.,
Sweetwater, TX)

Detectors

Eberline GM Detector
Model HP-260
Effective Area, 20 cm^2
(Eberline, Santa Fe, NM)

Victoreen NaI Scintillation Detector
Model 489-55
3.2 cm x 3.8 cm Crystal
(Victoreen, Cleveland, OH)

LABORATORY ANALYTICAL INSTRUMENTATION

High Purity Extended Range Intrinsic Detectors
Model No: ERVDS30-25195
(Tennelec, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, TN) and
Multichannel Analyzer
3100 Vax Workstation
(Canberra, Meriden, CT)

High-Purity Germanium Detector
Model GMX-23195-S, 23% Eff.
(EG&G ORTEC, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-16
(Gamma Products, Palos Hills, IL) and
Multichannel Analyzer
3100 Vax Workstation
(Canberra, Meriden, CT)

Low Background Gas Proportional Counter
Model LB-5110-W
(Oxford, Oak Ridge, TN)

APPENDIX B

SURVEY AND ANALYTICAL PROCEDURES

APPENDIX B

SURVEY AND ANALYTICAL PROCEDURES

SURVEY PROCEDURES

Surface Scans

Surface scans were performed by passing the probes slowly over the surface; the distance between the probe and the surface was maintained at a minimum—nominally about 1 cm. Surfaces were scanned using hand-held detectors. Identification of elevated levels was based on increases in the audible signal from the recording and/or indicating instrument. Combinations of detectors and instruments used for the scans were:

Beta — GM detector with ratemeter-scaler

Gamma — NaI scintillation detector with ratemeter

Surface Activity Measurements

Measurements for total beta activity levels were performed using GM detectors with ratemeter-scalers. Count rates (cpm), which were integrated over 1 minute in a static position, were converted to activity levels (dpm/100 cm^2) by dividing the net rate by the 4 π efficiency and correcting for the active area of the detector. The beta activity background count rates for the GM detector was 50 cpm. The beta efficiency factor was 0.23 for the GM detector calibrated to Tl-204. The effective probe area for the GM detector is 20 cm^2.

Removable Activity Measurements

Removable activity levels were determined using numbered filter paper disks, 47 mm in diameter. Moderate pressure was applied to the smear, and approximately 100 cm^2 of the surface was wiped. Smears were placed in labeled envelopes with the location and other pertinent information recorded.

Exposure Rate Measurements

Measurements of dose equivalent rates (μrem/h) were performed at 1 meter above the surface using a microrem meter. Although the instrument displays data in μrem/h, the μrem/h to μR/h conversion is essentially unity.

Soil Sampling

Approximately 1 kg of soil was collected at each sample location. Collected samples were placed in a plastic bag, sealed, and labeled in accordance with ESSAP survey procedures.

ANALYTICAL PROCEDURES

Removable Activity

Smears were counted on a low background gas proportional system for gross alpha and gross beta activity.

Gamma Spectrometry

Soil samples were dried, mixed, crushed, and/or homogenized as necessary, and a portion sealed in a 0.5-liter Marinelli beaker or other appropriate container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined and the samples counted using intrinsic germanium detectors coupled to a pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. Energy peaks used for determination of radionuclides of concern were:

Ra-226	0.352 MeV from Pb-214*
Th-230	0.067 MeV
U-238	0.063 MeV or 0.093 MeV from Th-234*

*Secular equilibrium assumed.

Spectra were also reviewed for other identifiable photopeaks.

UNCERTAINTIES AND DETECTION LIMITS

The uncertainties associated with the analytical data presented in the tables of this report represent the 95% confidence level for that data. These uncertainties were calculated based on both the gross sample count levels and the associated background count levels. Additional uncertainties, associated with sampling and measurement procedures, have not been propagated into the data presented in this report.

Detection limits, referred to as minimum detectable concentration (MDC), were based on 2.71 plus 4.65 times the standard deviation of the background count [$2.71 + (4.65\sqrt{BKG})$]. When the activity was determined to be less than the MDC of the measurement procedure, the result was reported as less than MDC. Because of variations in background levels, measurement efficiencies, the detection limits differ from sample to sample and instrument to instrument.

CALIBRATION AND QUALITY ASSURANCE

Calibration of all field and laboratory instrumentation was based on standards/sources, traceable to NIST, when such standards/sources were available. In cases where they were not available, standards of an industry recognized organization were used. Calibration of pressurized ionization chambers was performed by the manufacturer.

Analytical and field survey activities were conducted in accordance with procedures from the following documents of the Environmental Survey and Site Assessment Program:

- Survey Procedures Manual, Revision 9 (April 1995)
- Laboratory Procedures Manual, Revision 9 (January 1995)
- Quality Assurance Manual, Revision 7 (January 1995)

The procedures contained in these manuals were developed to meet the requirements of DOE Order 5700.6C and ASME NQA-1 for Quality Assurance and contain measures to assess processes during their performance.

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.
- Participation in EPA and EML laboratory Quality Assurance Programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

APPENDIX C

SUMMARY OF DEPARTMENT OF ENERGY RESIDUAL RADIOACTIVE MATERIAL GUIDELINES

APPENDIX C

SUMMARY OF DEPARTMENT OF ENERGY RESIDUAL RADIOACTIVE MATERIAL GUIDELINES[1]

BASIC DOSE LIMITS

The basic dose limit for the annual radiation dose (excluding radon) received by an individual member of the general public is 100 mrem/yr.[2] In implementing this limit, DOE applies as low as reasonably achievable principles to set site-specific guidelines.

EXTERNAL GAMMA RADIATION

The average level of gamma radiation inside a building or habitable structure on a site that has no radiological restriction on its use shall not exceed the background level by more than 20 μR/h and will comply with the basic dose limits when an appropriate-use scenario is considered.

SURFACE CONTAMINATION GUIDELINES

	Allowable Total Residual Surface Contamination (dpm/100 cm²)[a]		
Radionuclides[b]	Average[c,d]	Maximum[d,e]	Removable[d,f]
Transuranics, Ra-226, Ra-228, Th-230 Th-228, Pa-231, Ac-227, I-125, I-129	100	300	20
Th-Natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000	3,000	200
U-Natural, U-235, U-238, and associated decay products	5,000α	15,000α	1,000α
Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	5,000β-γ	15,000β-γ	1,000β-γ

[a] As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute measured by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[b] Where surface contamination by both alpha- and beta-gamma-emitting radionuclides exists, the limits established for alpha- and beta-gamma-emitting radionuclides should apply independently.

[c] Measurements of average contamination should not be averaged over an area of more than 1 m^2. For objects of less surface area, the average should be derived for each such object.

[d] The average and maximum dose rates associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h and 1.0 mrad/h, respectively, at 1 cm.

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

[f] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping an area of that size with dry filter or soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area should be based on the actual area and the entire surface should be wiped. The numbers in this column are maximum amounts.

SOIL GUIDELINES

Radionuclides	**Soil Concentration (pCi/g) Above Background[a,b,c]**
Radium-226, Radium-228, Thorium-230, Thorium-232	5 pCi/g, averaged over the first 15 cm of soil below the surface; 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface.
Uranium-238	50 pCi/g[3]

[a] These guidelines take into account ingrowth of radium-226 from thorium-230 or thorium-232 and radium-228 and assume secular equilibrium. If either Th-230 and Ra-226 or Th-232 and Ra-228 are both present, not in secular equilibrium, the guidelines apply to the higher concentration. If other mixtures of radionuclides occur, the concentrations of individual radionuclides shall be reduced so that (1) the dose for the mixtures will not exceed the basic dose limit, or (2) the sum of ratios of the soil concentration of each radionuclide to the allowable limit for that radionuclide will not exceed 1 ("unity").

[b] These guidelines represent allowable residual concentrations above background averaged across any 15-cm-thick layer to any depth and over any contiguous 100 m^2 surface area.

[c] If the average concentration in any surface or below-surface area, less than or equal to 25 m^2, exceeds the authorized limit of guideline by a factor of $(100/A)^{½}$, where A is the area or the elevated region in square meters, limits for "hot spots" shall also be applicable. Procedures for calculating these hot spot limits, which depend on the extent of the elevated local concentrations, are given in the DOE Manual for Implementing Residual Radioactive Materials Guidelines.[4] In addition, every reasonable effort shall be made to remove any source of radionuclide that exceeds 30 times the appropriate limit for soil, irrespective of the average concentration in the soil.

REFERENCES

"Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites," U.S. Department of Energy, Revision 2, March 1987.

"Radiation Protection of the Public and the Environment," DOE Order 5400.5, U.S. Department of Energy, February 8, 1990.

DOE Memorandum from J. Fiore to L. Price, "Uranium Cleanup Guidelines for St. Louis, MO, FUSRAP Sites." November 6, 1990.

Argonne National Laboratory "A Manual for Implementing Residual Radioactive Material Guidelines," DOE/CH/8901, June 1989.