Radiological Characterization Survey Report

for the

Cabot Performance Materials Revere Plant

Prepared for

CABOT PERFORMANCE MATERIALS INC.

REVERE, PENNSYLVANIA

April 1994

ENSERCH ENVIRONMENTAL CORPORATION

formerly the Environmental Division of Ebasco Services Incorporated

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RADIOLOGICAL CHARACTERIZATION SURVEY REPORT
FOR THE CABOT PERFORMANCE MATERIALS REVERE PLANT

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ACRONYMS AND ABBREVIATIONS

AEC	-	Atomic Energy Commission
EEC	-	Enserch Environmental Corporation
ESSAP	-	Environmental Survey and Site Assessment Program
HASP	-	Health and Safety Plan
KBI	-	Kawelcki Berylco Industries
MDA	-	Minimum Detectable Activity
NORM	-	Naturally Occurring Radioactive Materials
NRC	-	Nuclear Regulatory Commission
NUREG/CR5849	-	*NRC's Manual for Conducting Radiological Surveys in Support of License Termination*
ORISE	-	Oak Ridge Institute for Science and Education
pCi/g	-	picoCurie per gram
QA/QC	-	Quality Assurance and Quality Control
SECY 81-576	-	*NRC's Branch Technical Position for Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations*
Th	-	Thorium
U	-	Uranium
uR/h	-	microrem per hour
USGS	-	United States Geological Survey

1.0 INTRODUCTION

This Radiological Characterization Survey Report presents the results of a radiological characterization survey program performed for Cabot Performance Materials (Cabot) by Enserch Environmental Corporation (EEC) at the Revere Plant Site, Revere, Pennsylvania. The objective of the radiological characterization survey was to define the current extent and magnitude of radiological contamination in sufficient detail to develop a plan to decontaminate the site. Decontamination will be conducted as part of the "delicensing" process to remove the site from Cabot's Source Material License #SMC-1562 (Docket Number 40-9027). The Revere and Reading Sites were provided Source Material License SMC-1562 in December 1993. Previously these sites were under Source Material License #SMB-920, Docket 040-06940. A Source Material License was required to allow processing of certain types of columbium-tantalum ores which contained trace amounts of natural uranium and thorium (naturally occurring radioactive materials-NORM). The smelting process used to recover columbium and tantalum metal concentrated the NORM in a waste silicate slag, with concentrations of uranium and thorium occasionally reaching source material grade. Ores containing NORM materials are no longer used or expected to be used in the future for the production of the product.

As part of the Source Material License amendment termination process, Cabot undertook a series of decontamination activities to remove radiologically contaminated slag from the site. In January 1991, Cabot presented a Final Decontamination and Decommissioning Survey report to the Nuclear Regulatory Commission (NRC) and requested release of the plant for unrestricted use and removal from the license. The NRC contracted the Oak Ridge Institute for Science and Education (ORISE) to conduct a confirmatory radiological survey of select portions of the property. Their results indicated general agreement with regard to average surface activity soil concentrations and ambient radiation levels in the areas surveyed. They noted, however, that discrete pieces of contaminated slag with concentrations exceeding guidelines remain on and below the surface in those portions of the sited surveyed, and that similar conditions may exist at other locations on site. This Radiological Characterization Survey Program addresses these concerns.

The scope of the Radiological Characterization Survey Program was based on information supplied by Cabot concerning past plant operations, prior radiological surveys and remediation work, and the ORISE Report. The Survey Program also followed the guidance in the *Manual for Conducting Radiological Surveys in Support of License Termination*, NUREG/CR-5849 using the concentration guidelines presented in SECY 81-576 for natural uranium and thorium. The Survey Program was designed to screen "affected areas" (NRC nomenclature for areas of potential or known radiological contamination based on operating history or prior surveys) and

"unaffected areas" (all site areas not classified as affected). Note that these areas are not fixed. If contamination was detected in an "unaffected" area, it would be reclassified as "affected."

For this effort, a 5 meter triangular grid was established in the affected areas, while a 10 meter orthogonal grid was used in the unaffected areas. A portable ratemeter/scaler with a calibrated sodium iodide scintillator was used to scan for gamma exposure rate in these areas. Two types of systematic gamma surveys were conducted for each area. The first was a continuous gamma scan consisting of slowly walking along each grid line and moving the detector slowly from side to side of the grid line about one centimeter above the ground surface. The second method consisted of gamma exposure rate measurements integrated over a one minute period with the detector held first at 1 centimeter, then at 1 meter above the ground surface at each grid intersection. Integrated measurements were also performed at 1 centimeter and 1 meter above the ground surface at locations that exhibited elevated readings (≈ twice background) during the continuous gamma survey. These additional measurement locations are referred to as "biased" areas in that they are biased by elevated readings from the continuous gamma scan and are usually not at grid intersections or nodes.

In addition to the gamma scans, soil samples were taken at various locations based on the gamma exposure results. Concentrations of uranium and thorium were determined in a "real time" mode in the field using a portable gamma spectroscopy system (a 2 inch x 2 inch sodium iodide system coupled to a multichannel analyzer and 80386-based computer).

A quality assurance and quality control (QA/QC) program was initiated which included keeping field records within a bound, weatherproof field notebook. To cross-check the field determination of uranium and thorium concentrations, 12 samples were selected and sent to a radiochemical analytic laboratory for analysis (Enseco). Samples were labeled and custody sealed before being shipped to the analytical laboratory. A chain of custody form with the pertinent sample information was filled out and sent with the shipment. All sampling equipment was decontaminated before and after samples were taken. All equipment that was used in the field for radiological detection was calibrated by the supplier (CoPhysics Corporation), before coming on site. The Gamma Spectroscopy system was set up and calibrated in the field by the supplier.

A health and safety plan (HASP) was also developed to assure safe conduct of field operations, and conformance with standard practices for sites with radioactive materials. For example, field personnel were required to scan each other before leaving an affected area to prevent spread of material. Emergency plans were also identified in the HASP.

2.0 SITE CHARACTERISTICS

2.1 REGIONAL INFORMATION

Meteorology

Climatic conditions for the region are moderate with an annual average temperature of 11° Celsius. The annual rainfall for the area is approximately 115 centimeters per year, and the annual snowfall is approximately 48 centimeters per year. The climate supports forests of mixed oak, beech, sugar maple and northern hardwood varieties (Tedrow, 1986).

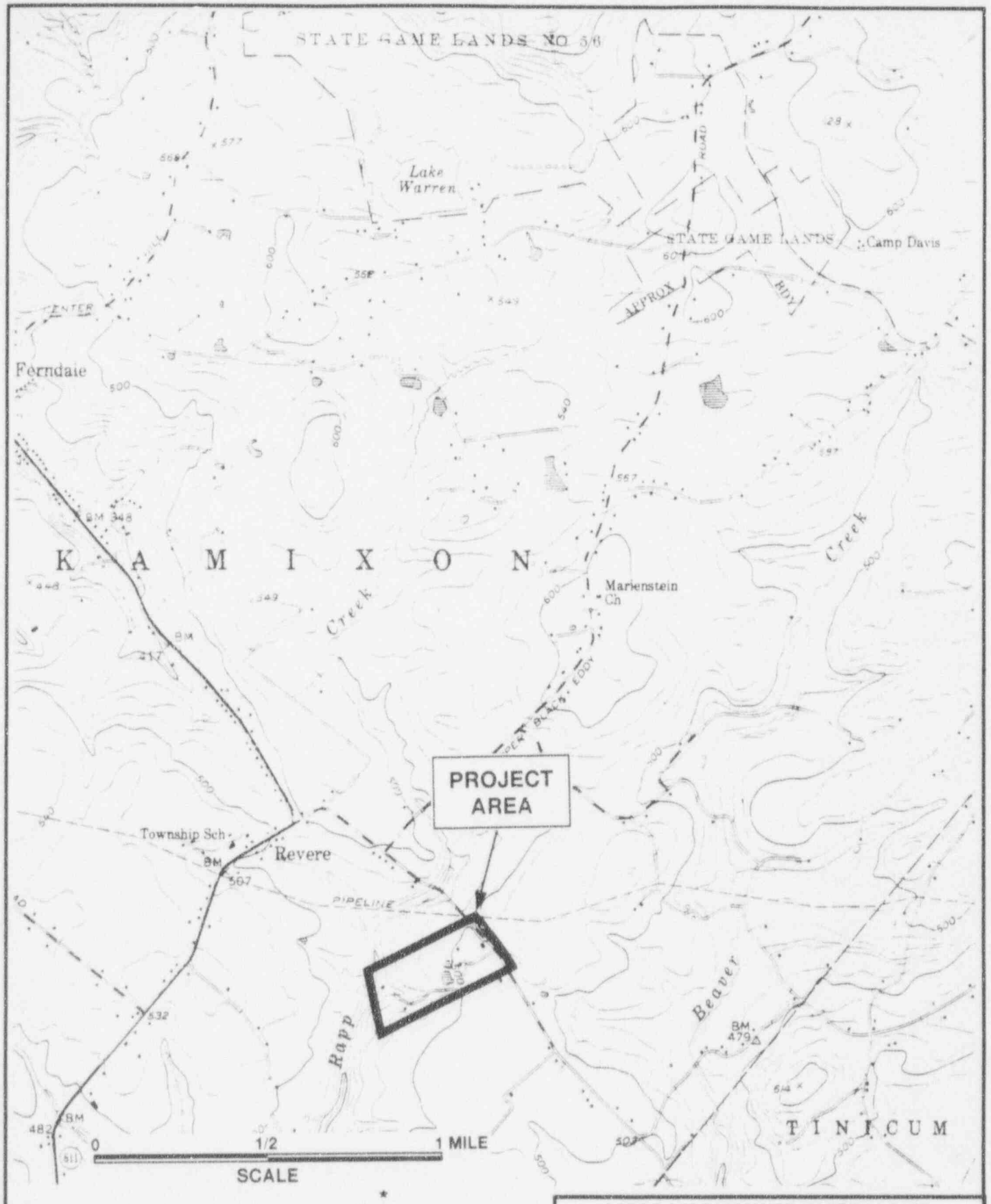
Geology

The Cabot site is located 3-1/2 miles south of the Delaware River. The site is located in the Newark Basin, several miles to the southeast of the Reading Prong (Subitzky, 1969). The Reading Prong is the southern extension of the New Jersey Highlands and the New England Berkshires, and is composed primarily of pre-Cambrian gneiss. The Newark Basin of New Jersey is a lowland extending from New Jersey southwest into Pennsylvania, with Triassic-age sedimentary rocks forming the majority of sequence (Tedrow, 1986).

The area around the site is underlain by Triassic dark gray diabase interbedded with Lockatong Formation argillite and thinly-bedded black shale. Locally, the Lockatong also contains impure limestone and calcareous shales (Commonwealth of PA Dept. of Environmental Resources Bedrock Geology Map, 1980). Pleistocene deposits overlying these Triassic formations include pre-Wisconsinan glacial outwash, as well as extensive fluvial silts and sands from the Delaware River and its tributaries.

Elevations on site range from 420-520 feet above sea level; however, elevations shown on the USGS Quadrangle of Riegelsville, PA-NJ (Figure 2-1) are as low as 100 feet above sea level adjacent to the Delaware River and as high as 850 feet above sea level in the Reading Prong. The Delaware River is the only major surficial water body near the site, although Lake Warren (approximately 0.25 mi^2) is located 2 miles due north. Rapp Creek originates from Lake Warren and flows south, through the Cabot site.

The property slopes gently to moderately in a northwesterly direction towards Rapp Creek. Rapp Creek flows in a southwesterly direction, and transects the western portion of the property. Several storm culverts and drainage ditches are diverted to this stream. Surface drains from the manufacturing and processing areas are diverted to an impoundment with a pH monitoring station with readings taken before discharge is allowed into the stream.



CABOT PERFORMANCE MATERIALS INC.

FIGURE 2-1

U.S.G.S. TOPOGRAPHIC MAP
RIEGELSVILLE, PA - N.J. (1956, PHOTOREVISED 1973, PHOTOINSPECTED 1990) 7.5 MINUTE SERIES

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2.2 SITE LOCATION AND LAYOUT

The Cabot Revere Plant is a manufacturing/processing facility for metal alloys that is located on Beaver Run Road in Revere (Bucks County), Pennsylvania. The Plant occupies approximately 41 hectares (102 acres). Figure 2-1 shows the project location. Figure 2-2 (Pocket on back cover) presents the layout of the plant site.

Affected and Unaffected Areas

The portions of the site with known or suspected radiological contamination ("the affected areas") include the Old Pit, the Drum Storage Area, Buildings 4 and 5 Storage Area, the grounds within 10 m of the Warehouse and the former Parking Area north of the sandblasting facility. The Old Pit, an area of approximately 3200 m^2, contains three standing walls of the former Blending Building and rubble from the demolition of the former Reaction Building. The Drum Storage Area, which encompasses approximately 4000 m^2, is a flat, gravel filled area surrounded by shrubbery. It is bordered by a field to the south and east, and a swampy area to the west. The Buildings 4 and 5 Storage Area is approximately 1400 m^2 and contains piping, equipment, and other debris. Excavated areas in the Drum Storage and Buildings 4 and 5 Storage Areas were backfilled by Bullinger's Mills Inc. after a partial remediation of the area. The floor space of the Warehouse is approximately 290 m^2 and the surrounding grassy area is approximately 400 m^2. The Parking Area near the sandblasting building encompasses approximately 1800 m^2. These locations are noted in Figure 2-2. The total area for these specific locations is approximately 10,400 m^2. A radiological survey outside of these areas did not indicate any area with exposure rates above twice background.

Facility areas which are unaffected areas included the Office Building area, which is 17,600 m^2, the Manufacturing Building Area, which is 13,500 m^2, the Thermite Building Area, which is 4,200 m^2, and the Sand Blasting and the Crushing Buildings Area, which is 4,200 m^2. The boundary of these areas were extended to include at least 10 meters beyond the boundary of any manufacturing or processing locations.

3.0 OPERATING HISTORY

The following is quoted from Berger and Smith's *Confirmatory Radiological Survey for Portions of the Cabot Corporation Revere Plant, Revere, Pennsylvania*, pages 1 and 2:

Beginning in July 1970, Kawecki Berylco Industries (KBI), currently Cabot Corporation, conducted processing of columbium-tantalum ores which contained traces of natural uranium (0.04%) and thorium (0.12%). This activity was conducted under Source Material License #SMB-920, Docket 40-6940, with the Atomic Energy Commission (AEC), predecessor to the Nuclear Regulatory Commission (NRC). The process used was a thermite reduction with powdered aluminum; the process produced a final product of columbium-tantalum alloy, which contained less than 0.01% of uranium and thorium, and a waste slag, which contained 0.14% of the source materials. The slag was stored on-site in the Old Pit and Drum Storage Areas and later transferred to the company's site in Boyertown, Pennsylvania, for longer-term storage. Information provided by Cabot Corporation indicates that approximately 4500 kilograms of columbium-tantalum ore were processed in two initial experimental test runs; no subsequent processing of radioactive ores occurred.

4.0 DECOMMISSIONING ACTIVITIES

On May 14, 1975, a radiological safety study was conducted at the Revere Plant by Applied Health Physics, Inc. This survey defined radiologically contaminated areas and materials as by-products from storage and the production process. Specifically, a letter submitted to KBI (Cabot) stated that one spot beneath the slag pile behind the firing house measured 0.32 mrad/hr, while the rest of the pile measured 0.02-0.03 mrad/hr. The Burial Site measured 0.02-0.14 mrad/hr (Applied Physics, 1975). A calibrated gamma survey meter, Health Physics Instruments, Model 1010, s/n 106 was used.

In late 1988 Cabot initiated actions to decontaminate the site in support of the license termination activities. Bullinger's Mills, Inc. of Fleetwood, Pennsylvania was contracted to assist with the radiological survey and decontamination of the site. From February through March of 1990, Bullinger's Mill, Inc., conducted a radiological survey to redefine affected and unaffected areas. A 20-meter grid was used which was further divided in 4-m^2 units. The information provided to Cabot indicated high readings found behind Building 5, beside the warehouse (Building 25), and several loci in the empty drum storage area and the Old Pit Area (Bullinger's Mill 1990a). Included with the information packet was a series of photographs, survey plans, and gamma scan reading results. Additionally an internal memo recommended that hand picking would be the best method to find the large chunks of slag that appeared "to be scattered here and there", which would then be placed in barrels and sent to Boyertown (Cabot 1990).

During August of 1990, Bullinger's Mill, Inc. was retained by Cabot to begin the decontamination process. Decontamination involved the excavation and removal of slag at the Old Pit, the Drum Storage Area, and Buildings 4 and 5 Storage Area. Photographs which were included in the information packet provided to EEC showed the decontamination process. They illustrated a small front end loader excavating material which was then placed on a large mesh screen with an individual scanning it for radiologically contaminated pieces. The remediation was completed in October of 1990 and a final radiological survey of the site was conducted.

The final survey report indicated that direct radiation levels were below NRC guideline values (Bullinger 1990b). An addendum to the final survey indicated that soil concentrations were also below guideline values (Cabot Corporation, W. Gannon).

Confirmatory Radiological Survey - 1991

After Cabot submitted their final report for decontamination and decommissioning, the NRC's division of Industrial and Medical Nuclear Safety requested that the Environmental Survey and Site Assessment Program of ORISE conduct a confirmatory radiological survey of the areas of

concern (affected areas) at the Cabot Revere Plant. Upon review of the subject documentation ORISE noted the following deficiencies:

- *The report indicated elevated direct radiation levels were present beside the Warehouse. However, the final report does not indicate if these areas were remediated, nor does it provide final survey data for these areas.*

- *The final report does not discuss survey techniques and methodology.*

- *Appropriate surveys were not performed to identify areas of elevated direct radiation, and measurements for alpha and beta-gamma activities were not performed on the remains of the former Blender Building.*

- *Surface scans were not performed to identify areas of elevated direct radiation.*

- *The final report does not discuss the results of the gamma spectrometry analyses performed on soil and slag samples. Additionally, it does not indicate whether the data were reviewed to confirm that the radioactivity was natural uranium and natural thorium with the daughters present and in equilibrium* (Berger and Smith, p.6).

After conducting survey scans, and sampling of soils, slag, water and sediments, some areas still had radiation levels above natural background levels. Elevated levels, for example, were found at the Old Pit, Drum Storage Area and the Buildings 4 and 5 Storage Area. According to their report, small shallow exploratory excavations in these areas exhibited elevated radiation and confirmed the presence of additional slag at "about one meter" below the ground surface. (Upon completion of the EEC scan it was concluded that descrete slag pieces are likely randomly distributed between the surface and a depth of about one meter). The ORISE report also stated that, sediment samples and water samples were within guideline values, and average exposure rates at 1 meter above the surface were within guideline values of the NRC Branch Technical Position (Berger and Smith, p. 11).

The ORISE document concluded;

> *"Although results of the ESSAP confirmatory radiological survey support the findings of the final survey performed by Cabot Corporation and indicate that average surface activity soil concentrations and ambient radiation levels satisfy the Nuclear Regulatory Commission guidelines, discrete pieces of slag, containing uranium and thorium concentrations were well above soil guideline values, remain*

on and below the surface in those portions of the site surveyed. It is also considered that similar conditions may exist at other locations on the Revere Plant Site (Berger and Smith, p. 12)."

5.0 CURRENT SURVEY

5.1 AREA SAMPLING

During November and December, 1993, EEC personnel conducted a radiological survey of selected areas. These areas are listed below and are shown in Figure 2-2.

1) Old Pit
2) Parking Area
3) Drum Storage Area (Area 31)
4) Buildings 4 and 5 Storage Area
5) Loading Dock Area of Warehouse
6) Office Building Area
7) Manufacturing Building Area
8) Sand Blasting and Crushing Buildings Area
9) Thermite Building Area

To support the survey, a site grid coordinate system was established. That is, a 10 meter by 10 meter reference orthogonal grid was superimposed across the entire site (Figure 2-2), using the southwest corner of the Office Building as the datum point (0,0). All points were given a designation as either being north or south of this point and east and west of it. Several base lines were then established so that each of the aforementioned areas would correspond to the grid. Areas requiring a modified grid were the Old Pit and the Drum Storage Area. Due to the topography of the Old Pit, which consisted of a steep downgrade, the modified grid was "tied into" a tree. Points on this system were later converted to the site grid coordinates. The Drum Storage Area was still being remediated when EEC personnel arrived, thus a 10 meter by 10 meter grid was paced, i.e. walked, in this area and a continuous gamma scan was conducted of the area to discern the levels of radiological activity. No soil samples were taken in the Drum Storage Area. A 5 meter by 5 meter triangular grid was established on other affected areas.

Two types of systematic surveys were conducted. The first was a continuous gamma exposure rate determination which consisted of walking each grid line and moving the detector slowly from side to side approximately 1 centimeter above the ground surface. The second method consisted of gamma exposure rate measurements integrated over a one minute period with the detector held first at 1 centimeter, then at 1 meter above the ground surface at each grid intersection. Integrated measurements were also performed at 1 centimeter and 1 meter above the ground surface at locations that exhibited elevated readings (= twice background) during the continuous gamma survey. All readings were taken using a calibrated sodium iodide scintillator

(Eberline SPA-3) which was monitored by a portable ratemeter/scaler (Eberline ESP-2) which was provided by CoPhysics Corporation.

In areas where the direct radiation was approximately twice background, a tighter grid scan was performed in order to better delineate the extent of the elevated exposure readings. This helped to define whether the source was a piece of slag present on the surface, or if subsurface contamination was present.

Soil samples for field screening were taken at ten meter intervals at grid intersections throughout the affected areas (unbiased soil samples). Other soil and/or slag samples were taken in locations that had elevated gamma exposure readings (biased soil samples). All samples were taken using a decontaminated stainless steel scoop and placed in 500ml plastic wide mouthed jars. The samples were taken to the field laboratory for analysis using the NaI Gamma-Ray Spectroscopy System. Samples were weighed and placed on a 2 inch by 2 inch sodium iodide detector in a lead shielded housing. The samples were counted using an Aptec Model 1200, 1024 channel multichannel analyzer which was connected to a portable 80386-based computer. This system was calibrated to quantify radium-226 (a daughter of U-238) and thorium-232. Appendix A provides the details on the system operation and the procedures used in the NaI Gamma-Ray Spectroscopy.

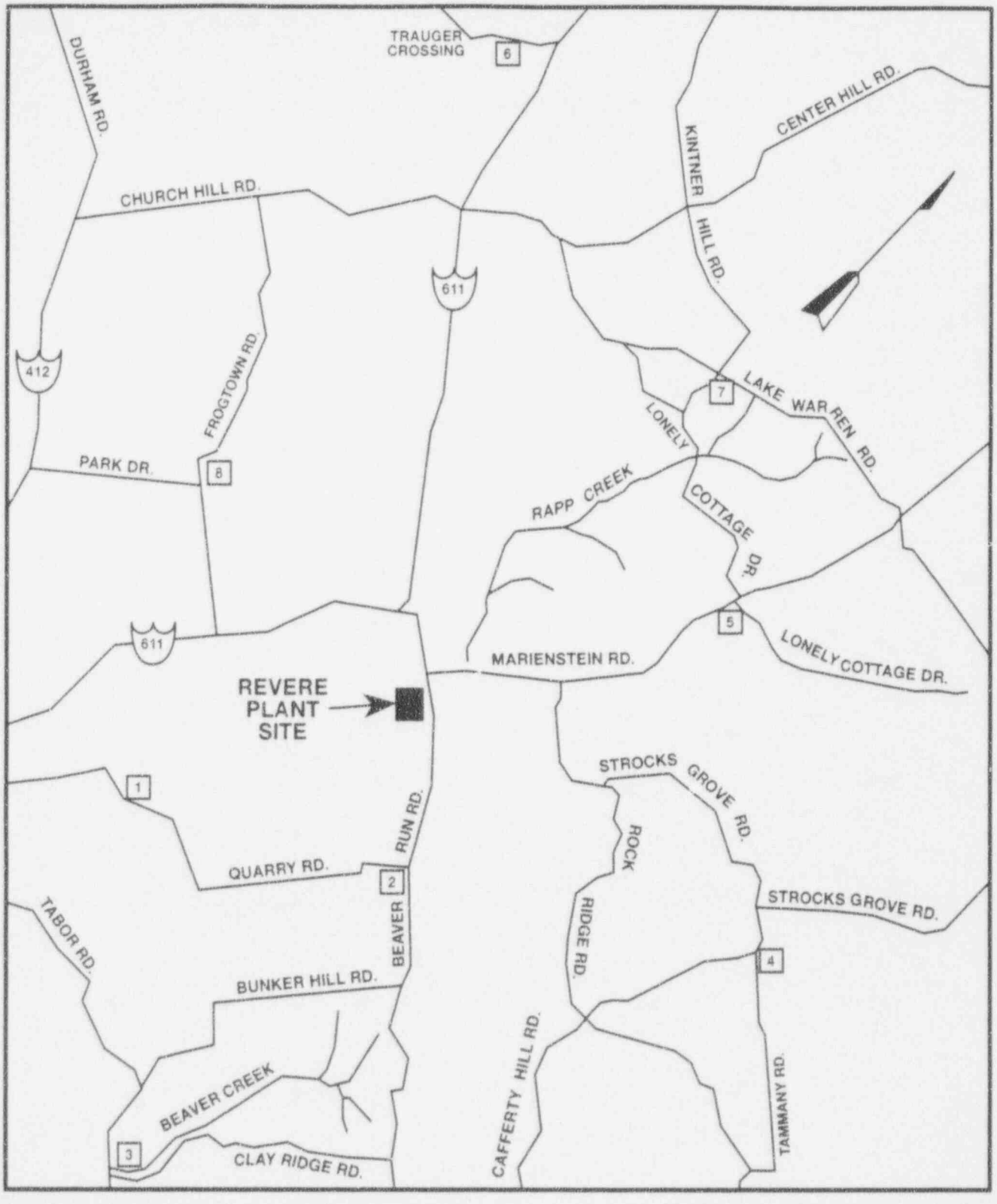
5.2 BACKGROUND/BASELINE AREA SAMPLING

In order to establish the regional background of the area, eight (8) off-site locations within 5 kilometers of the Revere Plant were selected and background determined prior to the area scans. These locations corresponded to approximately the same locations where ORISE took their background samples (Berger and Smith, 1993). Figure 5-1 shows these locations in relationship to the plant.

Each location was gamma exposure scanned at 1 centimeter and 1 meter above the ground surface. Soil samples were taken and analyzed for uranium and thorium through measurements of their daughter isotopes (see Appendix A).

5.3 PRELIMINARY GUIDELINES

Soil concentrations for residual uranium and thorium wastes are presented in the NRC's *Branch Technical Position for Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations* (Secy 81-576). The following guideline values were used for comparison with the results:



[#] BACKGROUND MEASUREMENT & SAMPLING LOCATIONS

MILE

0 1

0 1

KILOMETERS

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FIGURE 5-1

BACKGROUND MEASUREMENT AND SAMPLING LOCATIONS (FROM BERGER AND SMITH, 1991, AMENDED BY EBASCO, 1994).

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CABO 4951.003/940 (4/94)

Natural Uranium ($^{238}U + ^{234}U + ^{235}U$)< 10 pCi/g*
Natural Thorium ($^{232}Th + ^{228}Th$)< 10 pCi/g*

* with all daughter isotopes present and in equilibrium.

These guidelines are expressed in terms of concentrations above normal background levels i.e., in addition to background.

For direct radiation resulting from U and Th wastes from past operations, the NRC's Branch Technical Position establishes an exposure rate guideline for open land areas of 10 μR/hr above background measured at 1 meter above the surface.

6.0 SURVEY AND SAMPLING RESULTS

The results of the radiological survey and soil sampling program are presented in this section. They are divided into three major subsections:

- Regional background measurements, quality assurance check and guidelines
- Results of measurements in affected areas
- Results of measurements in unaffected areas

Surveys were not conducted on undeveloped and unused portions of the site (see Figure 2-2).

6.1 BACKGROUND, QUALITY ASSURANCE CHECK AND GUIDELINES

Previously, background radiation measurements were conducted in the vicinity of the Cabot plant by Berger and Smith (1993) in April, 1993 (see Figure 5-1). On the basis of eight samples, laboratory determination of the average background concentrations of total uranium and thorium in surface soils were 3.2 pCi/g and 1.7 pCi/g, respectively. Exposure rate measurements (one meter above surface) reported by Berger and Smith (1993) for the same locations averaged 8.3 uR/h.

Field gamma spectrometric analyses of background soil samples taken from approximately the same locations as those presented by Berger and Smith (1993) indicated that all samples had total uranium and thorium concentrations below the minimum detectable activity (MDA). The MDA is a function of the total counts, background, measurement efficiency and other parameters. Since the field gamma spectrometer is a field screening instrument, counts are taken for either a set period of time or a set number of counts. At low concentrations of uranium and thorium, the low count rate and statistics can result in a MDA rather than an absolute concentration. The MDA is reported as a "less than value" rather than a concentration. That is, the MDA is the activity (concentration) which is statistically significant and is greater than or equal to the actual activity (concentration). As MDA is based in part on counting statistics it can vary among individual analyses. MDA's are useful for screening; if the MDA is below a guideline concentration, the "real" concentration which is less than or equal to the MDA and is also less than the guideline limit.

Using the field spectrometry, the average total background uranium (U) concentration was <5.6 pCi/g (average MDA) and the average total background thorium (Th) concentration was <10.2 pCi/g (average MDA - see Table 6-1). These field-analyzed values are consistent with the more

Table 6-1
Survey Data for Regional Background Sample Locations

Sample #	Sample Location (Distance from Site)	uR/Hour 1cm	uR/Hour 1m	Total U (pCi/g)	Total Th (pCi/g)
1 (7)	Quarry Road (1.2 km)	14	14	<6.2	<10.5
2 (5)	Quarry Road/Beaver Run (1.1 km)	13	13	<5.7	<11.2
3 (6)	Bunker Hill Rd/Beaver Creek (3.4 km)	16	15	<5.6	<10.9
4 (4)	Tammany Rd/Cafferty Hill Rd. (2.7 km)	8	9	<5.5	<10.1
5 (3)	Marienstein Rd./Lonely Cottage Dr. (2 km)	9	9	<5.4	<9.1
6 (1)	Route 611/Traugers Crossing (4 km)	13	12	<4.9	<9.9
7 (2)	Kintner Hill Rd/Lake Warren Rd (2.1 km)	9	8	<6.5	<11.3
8 (8)	Frogtown Rd/Park Drive (1.9 km)	13	12	<5.2	<8.9
Average		11.9	11.5	<5.6	<10.2
"<" indicates that the actual activity is less than the reported minimum detectable activity (MDA) for that sample					
Sample numbers in parentheses are corresponding Berger and Smith (1993) sample designations					

precise laboratory analyses reported by Berger and Smith (1993), 3.2 pCi/g total U and 1.7 pCi/g total Th.

Direct gamma exposure rates were also measured at one meter above the surface at each of the eight background locations to ensure that instrument calibrations did not bias comparison of on-site measurements with regional background values. Additionally, exposure rates were taken at one centimeter above the surface at each location. Direct gamma exposure rates at one meter above the surface ranged from 8 to 15 μR/h, with an average value of 11.5 μR/h. Gamma exposure rates at one centimeter above the surface were approximately the same, ranging from 8 to 16 μR/h, with an average value of 11.9 μR/h. The similarity between exposure rates at the two elevations above the ground surface indicates that natural NORM is distributed homogeneously and acts as an infinite half space source. The results of the background radiation measurements are presented in Table 6-1.

Comparison of the new background radiation measurements with those reported by Berger and Smith (1993) indicates either a linear instrument calibration bias of approximately 3 μR/h or a slight increase in the long term cosmic ray or solar component of the background radiation. Figure 6-1 compares the individual background measurements from each study and shows the best-fit linear regression with a slope of 1.01 and a y-intersect of 3.15. The same exposure rate instrument was used for all background and on-site surveys in the present study, therefore an average regional background of 11.5 μR/h at one meter above the surface and 11.9 μR/h at one centimeter above the surface was used for comparison with all on-site radiation measurements.

As stated previously, as a Quality Control check, 12 soil samples were sent to an analytical laboratory (Enseco) for determination of their total uranium and thorium concentrations. Table 6-2 presents the results of the analyses. Figures 6-2 and 6-3 compare the 12 measurements over a range of concentrations. As shown, a one to one direct correspondence exists between the field and analytical determination. Importantly, the correlation "fit" is better at the lower concentrations.

With the measurement and corroboration of background values for gamma exposure, and concentrations of uranium and thorium, and assuming secular equilibrium in the uranium and thorium series (experimentally verified by Berger and Smith), guideline screening values were established. Using the previously discussed guidelines for unrestricted release of the site according to NRC's *Branch Technical Position for Disposal or Onsite Storage of Thorium and Uranium Waste from Past Operations* (SECY 81-576) and following guidance in NUREG/CR-5849, the site-specific exposure rate guidelines are 21.5 μR/h for the average over 100 m^2 at 1 meter above the surface (10 μR/h above background) and 31.5 μR/h for the maximum at any location (20 μR/h above background).

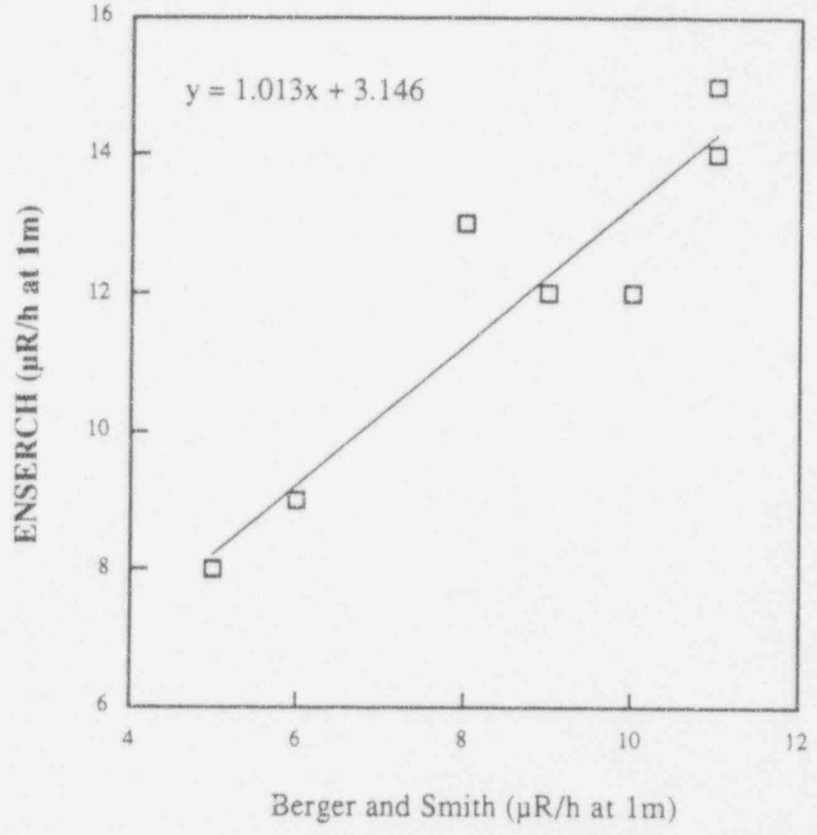

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FIGURE 6-1

COMPARISON OF BERGER AND SMITH AND ENSERCH BACKGROUND RADIATION MEASUREMENTS

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Table 6-2
Quality Assurance Laboratory Analyses

N/S Cooridnate	E/W Cooridnate	Location	Total U* pCi/g	Total Th** pCi/g
S148	W531	Old Pit Area	307.2	270.8
S187	W372.5	Parking Area	240	81.9
S1	W154	Buildings 4 & 5 Area	173.6	109.2
S195	W366.5	Parking Area	77.9	37
S195	W371	Parking Area	77.9	41.8
S204	W340	Parking Area	14.1	8.3
S203	W340	Parking Area	28.8	15.1
S195	W320	Parking Area	2.69	3.28
S5	W165	Buildings 4 & 5 Area	7.73	5.36
S120	W500	Old Pit Area	7.1	4.4
S191	W251	Thermite Building Area	34.6	31
S120	W520	Old Pit Area	1.7	1.28

* Total U assumes natural abundance of U-234, U-235 and U-238 (0.005%, 0.72%, 99.275%, respectively).

** Total Th assumes secular equilibrium for the Th-232 decay series: Total Th = 2 * Th-232.

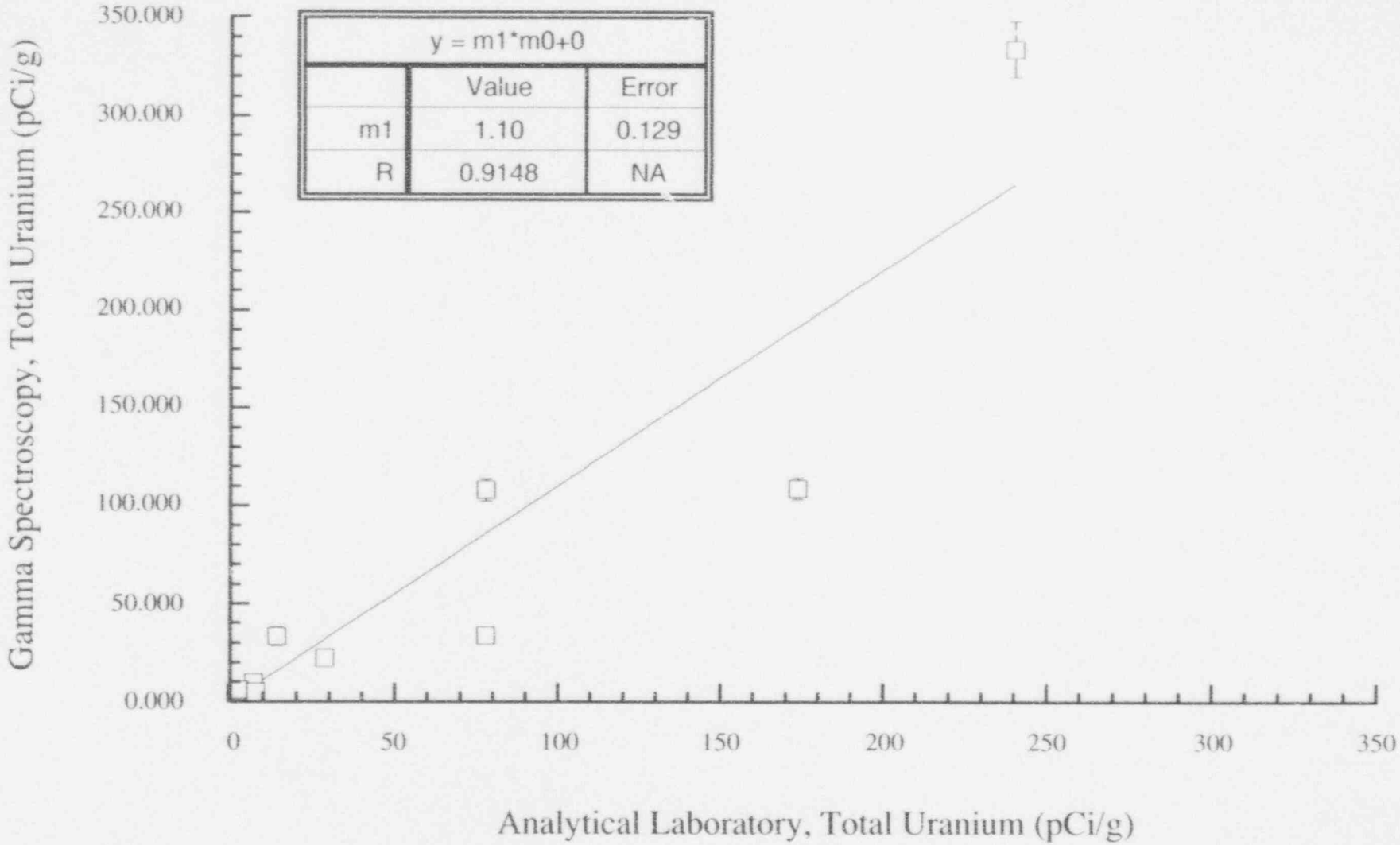

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FIGURE 6-2

COMPARISON OF FIELD SCREENING AND LABORATORY ANALYSES OF TOTAL URANIUM

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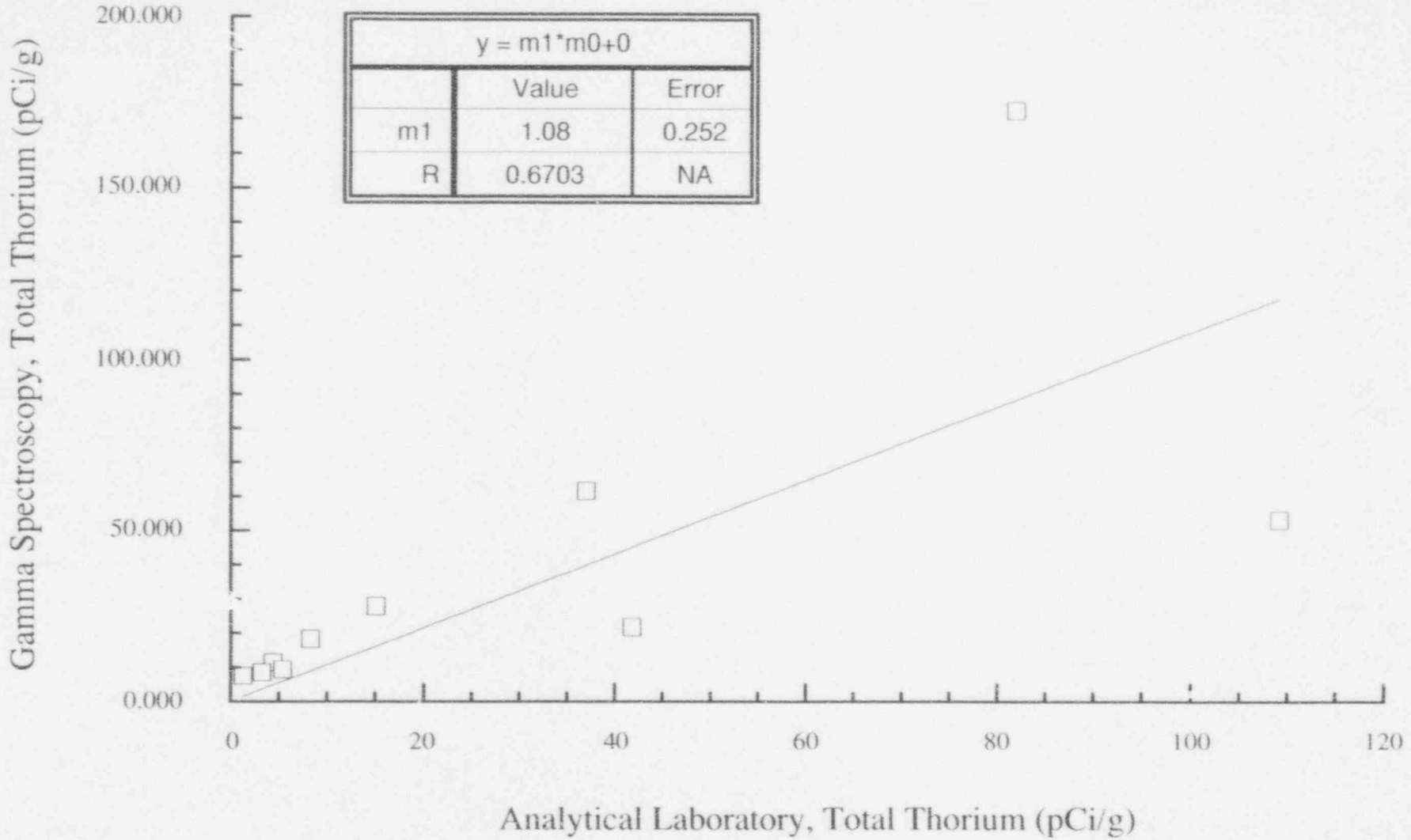

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FIGURE 6-3

COMPARISON OF FIELD SCREENING AND LABORATORY ANALYSES OF TOTAL THORIUM

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Screening guidelines for uranium and thorium concentrations were similarly determined. In this case average total uranium and thorium concentrations for soil samples from background locations reported by Berger and Smith (1993), 3.2 pCi/g and 1.7 pCi/g, were used. Following guidance in NUREG/CR-5849, site-specific soil concentration guideline values are 13.2 pCi/g total uranium and 11.7 pCi/g total thorium for the average over a 100 m^2 area (10 pCi/g above background as stated in SECY 81-576). The maximum concentration allowed at any location (30 pCi/g above background or three times the guideline values are 33.2 pCi/g total uranium and 31.7 pCi/g total thorium.

6.2 POTENTIALLY AFFECTED AREAS

Five potentially affected areas were identified prior to the present study (see Figure 2-2): (1) the "Old Pit" area near Rapp Creek, (2) the "Parking Area" north of the sand blasting facility (building 13), (3) the storage area east of buildings 4 & 5, (4) the grounds surrounding the loading dock of the warehouse (building 25), and (5) the former Drum Storage area (area 31).

With the exception of the former Drum Storage area, 5-meter by 5-meter triangular reference grids were estab' shed to guide the gamma radiation surveys. Due to ongoing remediation in the Drum Storage area, the gamma survey was conducted along a 10 meter by 10 meter orthogonal grid. Two types of systematic gamma radiation surveys were performed: "Continuous gamma scanning" consisted of moving the detector slowly (≈ 0.5 ms^{-1}) from side to side over the ground surface while walking along each grid line. The detector was kept as close as possible to the ground surface, as per guidance in NUREG/CR-5849. Locations with exposure levels greater than twice the average background exposure rate of 11.9 µR/h were designated "biased locations." Within those biased locations gamma radiation measurements were taken at 1 centimeter and at 1 meter above the ground surface. "Unbiased" gamma radiation measurements were made at one centimeter and 1 meter above the ground surface at each grid intersection. The results of all gamma exposure rate measurements made within the potentially affected areas are presented in Tables 6-3 through 6-7.

Soil/slag samples were collected in each affected area at the intersections of a 10 meter by 10 meter orthogonal grid. The exception was the Drum Storage area, where no samples were collected due to ongoing remediation efforts. Additional samples were collected at selected areas where the gamma radiation exposure rates were elevated. All soil/slag samples were analyzed using the NaI gamma-ray spectroscopy methods described in Appendix A. This analysis quantifies the activities of $^{220}_{Ra}$ and $^{232}_{Th}$ by assuming secular equilibrium with their respective daughters bismuth-214 and actinium-228. As stated previously, radiological analyses performed by Berger and Smith (1993) have confirmed that the contaminants of concern are natural U and natural Th with their daughter isotopes present in secular equilibrium. The concentration of total

U for soil/slag samples was therefore calculated assuming secular equilibrium for the uranium decay series and natural abundances of U-238 and U-235. The concentration of total Th for soil/slag samples was similarly calculated assuming secular equilibrium of Th-232 and Th-228.

These are expressed as:

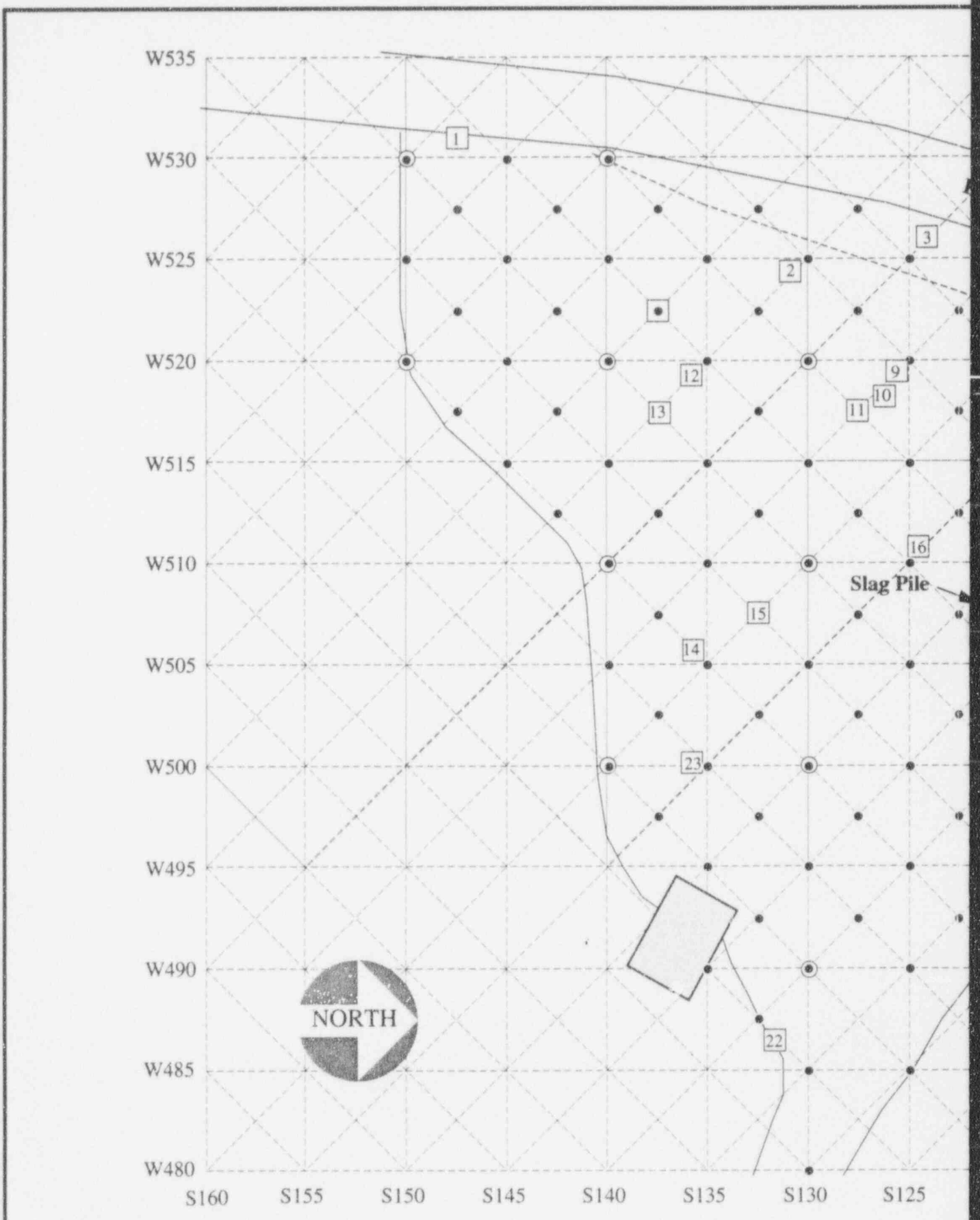
$$^{Total}U = \frac{2 \bullet ^{226}Ra,}{0.9765}$$

$$^{Total}Th = 2 \bullet ^{232}Th,$$

where 0.9765 is the fraction of the activity of natural U derived from U-238 + U-234, i.e., excluding the activity derived from U-235.

6.2.1 Old Pit Area

Survey data for the Old Pit Area are presented in Figure 6-4 and Table 6-3. Initially, a continuous gamma exposure survey was conducted along the grid lines as previously described. At the one meter elevation all the continuous readings were within the guidelines. At the 1 centimeter elevation, however, 23 "hot spots", with gamma radiation levels greater than or equal to approximately two times the average regional background of 11.9 µR/h were identified. (Note that the term "hot spot" used herein signifies a small, isolated location where the radiation at 1 cm elevation is greater than twice the background. This is different than the definition in NUREG/CR-5849 which deals with the 1 meter elevation, i.e., guideline value. The 1 centimeter measurements provided greater sensitivity in locating discrete pieces of contaminated slag). These locations are identified on Figure 6-4 by numbered boxes. The results of integrated gamma exposure rate measurements at these locations are identified at the end of Table 6-3 as biased samples 1 through 23 and range from 12 to 21 µR/h at 1 meter above the surface within the guidelines and from 19 to 225 µR/h at 1 centimeter above the surface. The results of unbiased exposure rate measurements in this area, i.e., those taken at the intersections of the 5 meter triangular grid, ranged from 8 to 16 µR/h at 1 meter above the surface (within the guidelines) and from 5 to 90 µR/h at 1 centimeter above the surface. Only two of the unbiased locations had exposure rates more than twice the average background at 1 cm above the surface, S137.5W522.5 (24 µR/h) and S140W510 (90 µR/h). These locations are identified on Figure 6-4 by open boxes similar to the numbered boxes used for hot spots found during the continuous gamma scan.


W535
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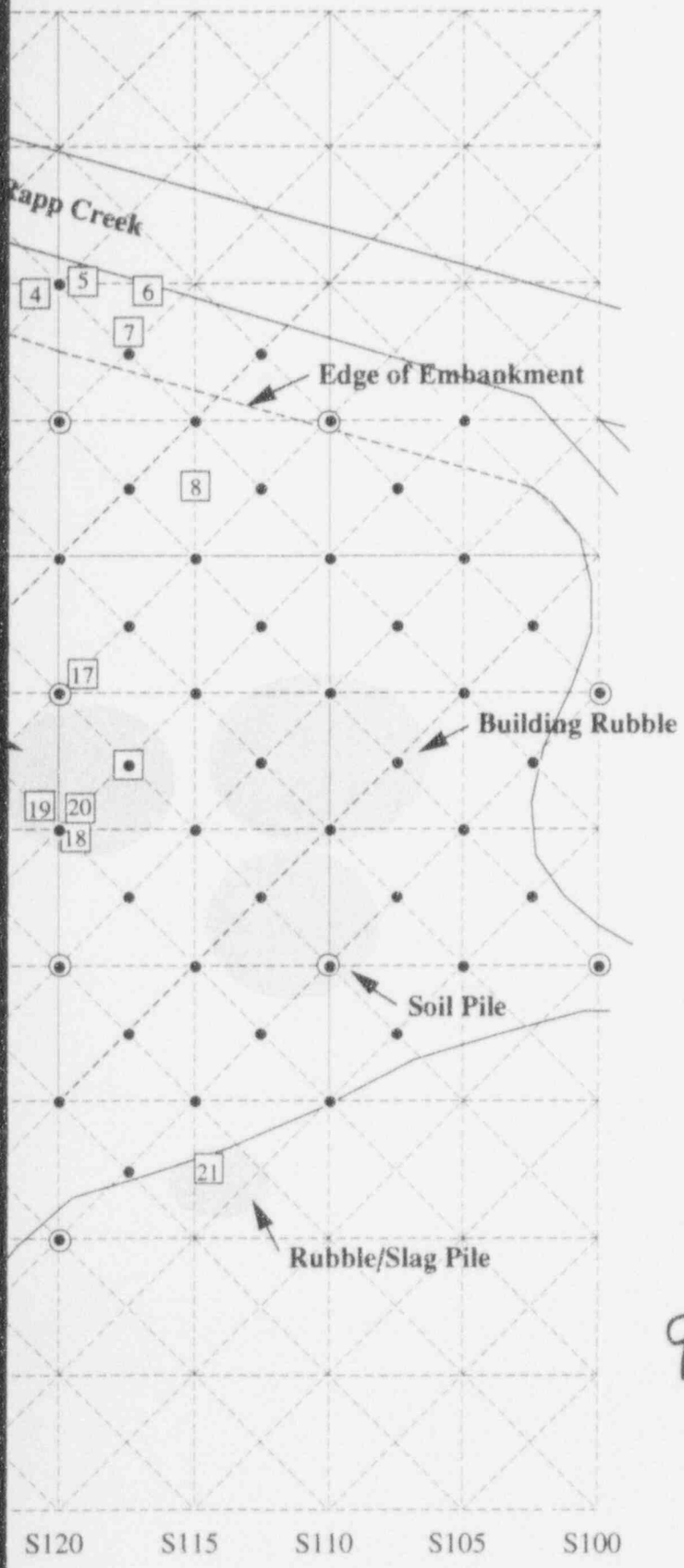
Slag Pile
NORTH



- Gamma Exposure Rate Measurement Location
- Measurement Location with Gamma Exposure Rate ≥ 10μR/h above background at 1cm above surface
- Soil/Slag Sample Location

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FIGURE 6-4

"OLD PIT" AREA

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Table 6-3
Survey Data for Old Pit Area

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations								
S150	W530		12	13	<4.2		<7.4	
S145	W530		14	12	--		--	
S140	W530		15	15	<5.0		<9.2	
S135	W530		14	13	--		--	
S147.5	W527.5		11	12	--		--	
S142.5	W527.5		10	12	--		--	
S137.5	W527.5		14	13	--		--	
S132.5	W527.5		15	14	--		--	
S150	W525		14	12	--		--	
S145	W525		11	11	--		--	
S140	W525		12	11	--		--	
S135	W525		12	11	--		--	
S130	W525		14	12	--		--	
S125	W525		13	15	--		--	
S147.5	W522.5		11	12	--		--	
S142.5	W522.5		11	11	--		--	
S137.5	W522.5		24	15	--		--	
S132.5	W522.5		14	14	--		--	
S127.5	W522.5		12	11	--		--	
S122.5	W522.5		11	11	--		--	
S117.5	W522.5		12	15	--		--	
S150	W520		16	15	<4.4		<7.7	
S145	W520		11	11	--		--	
S140	W520		16	15	<4.9		<8.9	
S135	W520		14	15	--		--	
S130	W520		15	14	<5.5		<10.1	
S125	W520		18	14	--		--	
S120	W520		10	11	<4.6		<7.5	
S115	W520		13	12	--		--	
S110	W520		16	15	<4.2		<7.7	
(Duplicate)					<4.1		<8.3	
S105	W520		15	15	--		--	
S147.5	W517.5		16	15	--		--	
S142.5	W517.5		12	12	--		--	
S137.5	W517.5		22	15	--		--	
S132.5	W517.5		13	13	--		--	
S127.5	W517.5		13	11	--		--	
S122.5	W517.5		11	11	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-3
Survey Data for Old Pit Area

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S117.5	W517.5		10	10	--		--	
S112.5	W517.5		14	13	--		--	
S107.5	W517.5		14	13	--		--	
S145	W515		16	15	--		--	
S140	W515		14	14	--		--	
S135	W515		15	14	--		--	
S130	W515		9	10	--		--	
S125	W515		8	8	--		--	
S120	W515		10	10	--		--	
S115	W515		10	10	--		--	
S110	W515		13	12	--		--	
S105	W515		12	13	--		--	
S142.5	W512.5		13	15	--		--	
S137.5	W512.5		16	13	--		--	
S132.5	W512.5		9	10	--		--	
S127.5	W512.5		9	9	--		--	
S122.5	W512.5		9	10	--		--	
S117.5	W512.5		9	10	--		--	
S112.5	W512.5		9	9	--		--	
S107.5	W512.5		14	12	--		--	
S102.5	W512.5		19	12	--		--	
S140	W510	Soil	90	13	<4.6		<8.7	
S140	W510	Slag	90	13	427.2	16.0	150.7	25.2
(Duplicate)					517.5	47.3	<183.8	
S135	W510		10	11	--		--	
S130	W510		10	10	<4.5		<8.0	
S125	W510		14	13	--		--	
S120	W510		24	14	<4.7		<7.1	
S115	W510		10	10	--		--	
S110	W510		10	11	--		--	
S105	W510		12	12	--		--	
S100	W510		12	13	<5.4		<9.9	
S142.5	W507.5		16	14	--		--	
S137.5	W507.5		12	12	--		--	
S132.5	W507.5		30	16	--		--	
S127.5	W507.5		9	10	--		--	
S122.5	W507.5		10	12	--		--	
S117.5	W507.5		30	15	--		--	
S112.5	W507.5		12	12	--		--	
S107.5	W507.5		13	13	--		--	
S102.5	W507.5		13	12	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-3
Survey Data for Old Pit Area

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S140	W505		14	12	--		--	
S135	W505		15	13	--		--	
S130	W505		10	12	--		--	
S125	W505		9	9	--		--	
S120	W505		5	16	--		--	
S115	W505		7	11	--		--	
S110	W505		13	13	--		--	
S105	W505		13	13	--		--	
S137.5	W502.5		15	14	--		--	
S132.5	W502.5		12	12	--		--	
S127.5	W502.5		10	10	--		--	
S122.5	W502.5		12	13	--		--	
S117.5	W502.5		9	11	--		--	
S112.5	W502.5		14	14	--		--	
S107.5	W502.5		17	14	--		--	
S102.5	W502.5		14	13	--		--	
S140	W500		17	16	<4.5		<8.6	
S135	W500		14	15	--		--	
S130	W500		11	12	<5.1		<7.9	
S125	W500		10	10	--		--	
S120	W500		16	13	9.7	2.8	<11.5	
S115	W500		16	15	--		--	
S110	W500		17	14	<4.4		<8.4	
S105	W500		15	15	--		--	
S100	W500		15	15	<4.3		<7.9	
S137.5	W497.5		13	15	--		--	
S132.5	W497.5		12	11	--		--	
S127.5	W497.5		13	12	--		--	
S122.5	W497.5		12	13	--		--	
S117.5	W497.5		19	15	--		--	
S112.5	W497.5		15	15	--		--	
S107.5	W497.5		15	15	--		--	
S102.5	W497.5		15	16	--		--	
S135	W495		12	12	--		--	
S130	W495		14	14	--		--	
S125	W495		12	13	--		--	
S120	W495		12	12	--		--	
S115	W495		15	13	--		--	
S110	W495		14	16	--		--	
S132.5	W492.5		14	14	--		--	
S127.5	W492.5		15	13	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-3
Survey Data for Old Pit Area

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S122.5	W492.5		12	14	--		--	
S117.5	W492.5		14	14	--		--	
S112.5	W492.5		20	16	--		--	
S135	W490		15	13	--		--	
S130	W490		15	13	<2.4		<5.4	
S125	W490		14	14	--		--	
S120	W490		15	14	<5.3		<9.7	
(Duplicate)					<6.0		<10.7	
S132.5	W487.5		15	14	--		--	
S127.5	W487.5		15	14	--		--	
S122.5	W487.5		15	15	--		--	
S135	W485		15	15	--		--	
S130	W485		16	15	--		--	
S125	W485		14	14	--		--	
S132.5	W482.5		15	15	--		--	
S127.5	W482.5		16	15	--		--	
S136	W480		15	14	--		--	
S130	W480		15	15	--		--	
Biased Locations								
S148	W531	1	50	15	1344	46.2	554	73.9
(Duplicate)					1200	139.0	638.3	221.6
S130.5	W525	2	35	13	--		--	
S125	W525	3	35	15	<3.9		<7.5	
S120.5	W525	4	19	18	--		--	
S119.5	W525	5	40	21	--		--	
S116	W525.5	6	25	17	--		--	
S116.5	W524.5	7	225	20	--		--	
S115	W517.5	8	35	13	--		--	
S125.5	W519.5	9	23	14	--		--	
S126	W519	10	25	16	--		--	
S127	W518.5	11	45	12	--		--	
S135	W519.5	12	24	15	--		--	
S137.5	W518	13	22	15	--		--	
S135	W505	14	45	16	--		--	
S132.5	W517.5	15	25	15	--		--	
S125	W510	16	20	14	--		--	
S119.5	W510	17	24	13	--		--	
S120	W505	18	19	16	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-3
Survey Data for Old Pit Area

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S121	W506	19	40	16	--		--	
S119.5	W506	20	21	17	--		--	
S115	W492.5	21	19	17	--		--	
S131	W486	22	23	15	--		--	
S136	W500	23	40	15	5.7	1.7	<6.9	
"<" indicates that the actual activity is less than the reported minimum detectable (MDA) activity for that sample.								

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

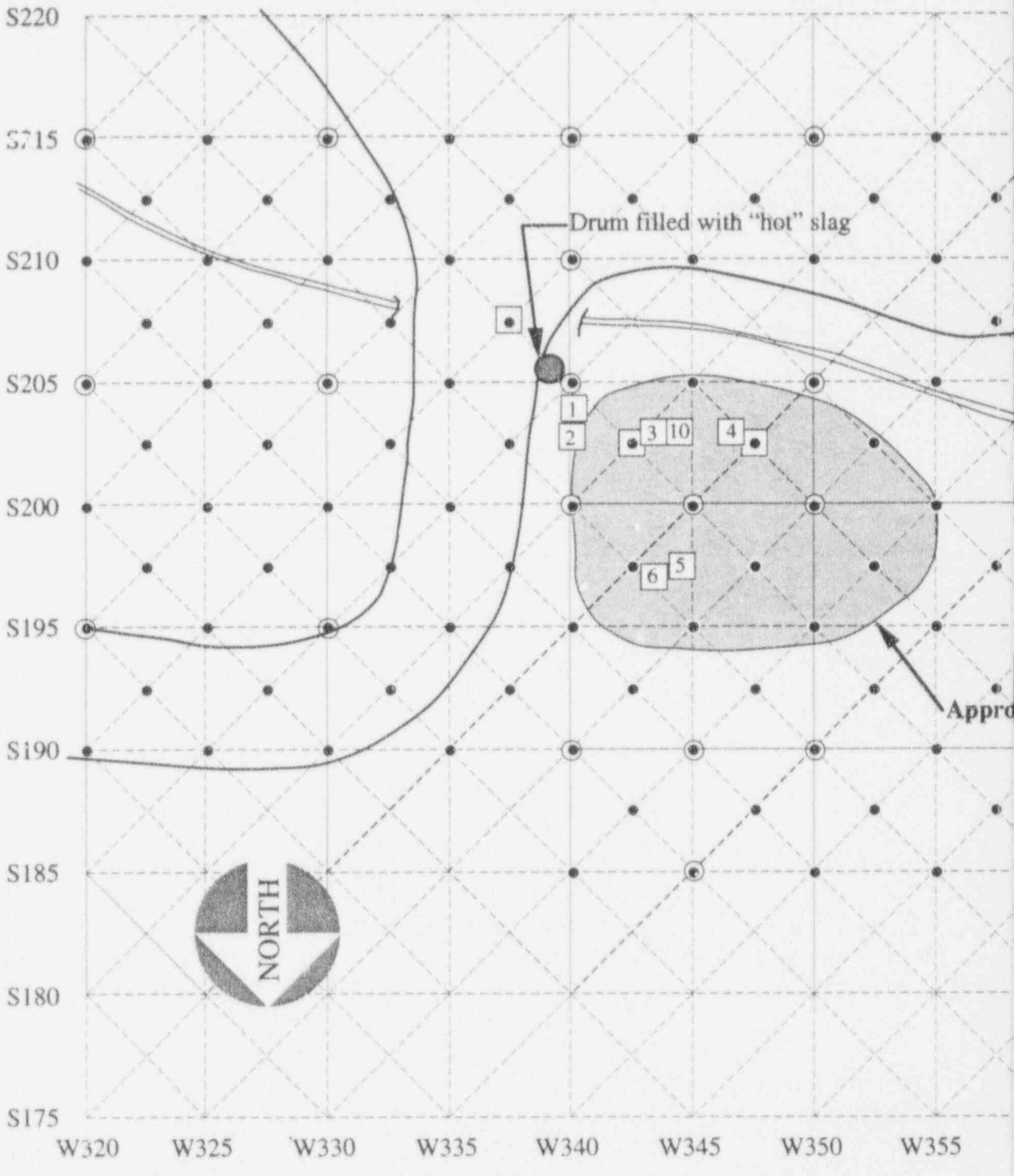
These elevated gamma exposures typically identify discrete pieces of slag with elevated concentrations of uranium and thorium. This is confirmed in Table 6-3 which indicates two point locations with slag above the concentration guideline values (S140, W510 and S148, W531).

6.2.2 Former Parking Area

Survey data for the Parking Area are presented in Figure 6-5 and Table 6-4. As in the prior area, all one-meter gamma exposure measurements were within the guidelines. Ten hot spots at the one centimeter elevation were found during the continuous gamma scan. These spots are identified on Figure 6-5 by numbered boxes, and fall both within the existing excavation and within the area where previously screened and presumably clean soil/slag has been stored. The results of integrated gamma exposure rate measurements at these locations are identified in Table 6-4 as biased samples 1 through 10 and range from 16 to 150 µR/h at 1 centimeter above the surface and from 13 to 17 µR/h at 1 meter above the surface. The results of unbiased exposure rate measurements in this area ranged from 6 to 50 µR/h at 1 centimeter and from 7 to 30 µR/h at 1 meter above the surface. Only one unbiased exposure rate measurement was near the guideline of 31.5 µR/h, an isolated area at 30 µR/h. None of the biased locations had exposure rates greater than the guidelines or greater than twice the average regional background at 1 meter above the surface. Four unbiased locations had elevated exposures at the one centimeter elevation. These locations are identified on Figure 6-5 by open boxes similar to the numbered boxes used for hot spots found during the continuous gamma scan. Five locations had uranium or thorium concentrations above the guidelines. Four of these were more than three times the maximum guideline and likely to be discrete pieces of slag. A 55-gallon metal drum filled with radioactive slag that had previously been removed from the excavation was located at S206W338 and had a direct contact gamma exposure rate of 220 µR/h. This drum was scheduled to be removed to the mausoleum at Cabot's Boyertown facility.

6.2.3 Buildings 4 & 5 Storage Area

Survey data for the storage area west of buildings 4 and 5 are presented on Figure 6-6 and in Table 6-5. Eight hot spots at the one centimeter elevation were found during the continuous gamma scan and are identified on Figure 6-6 by numbered boxes. Gamma exposure rates measured at these locations are identified in Table 6-5 as biased samples 1 through 8 and range from 30 to 110 µR/h at 1 centimeter above the surface and 12 to 15 µR/h at 1 meter above the surface. None of the biased exposure measurement exceeded guidelines (the 1 meter elevation). The results of unbiased exposure rate measurements within this area ranged from 10 to 21 µR/h at 1 centimeter and from 11 to 16 µR/h at 1 meter above the surface. None of the unbiased measurements exceeded the guideline values. Soil/slag samples were taken at the eight biased locations and sixteen unbiased locations. All of the unbiased samples had total uranium and total


S220
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W355
Drum filled with "hot" slag
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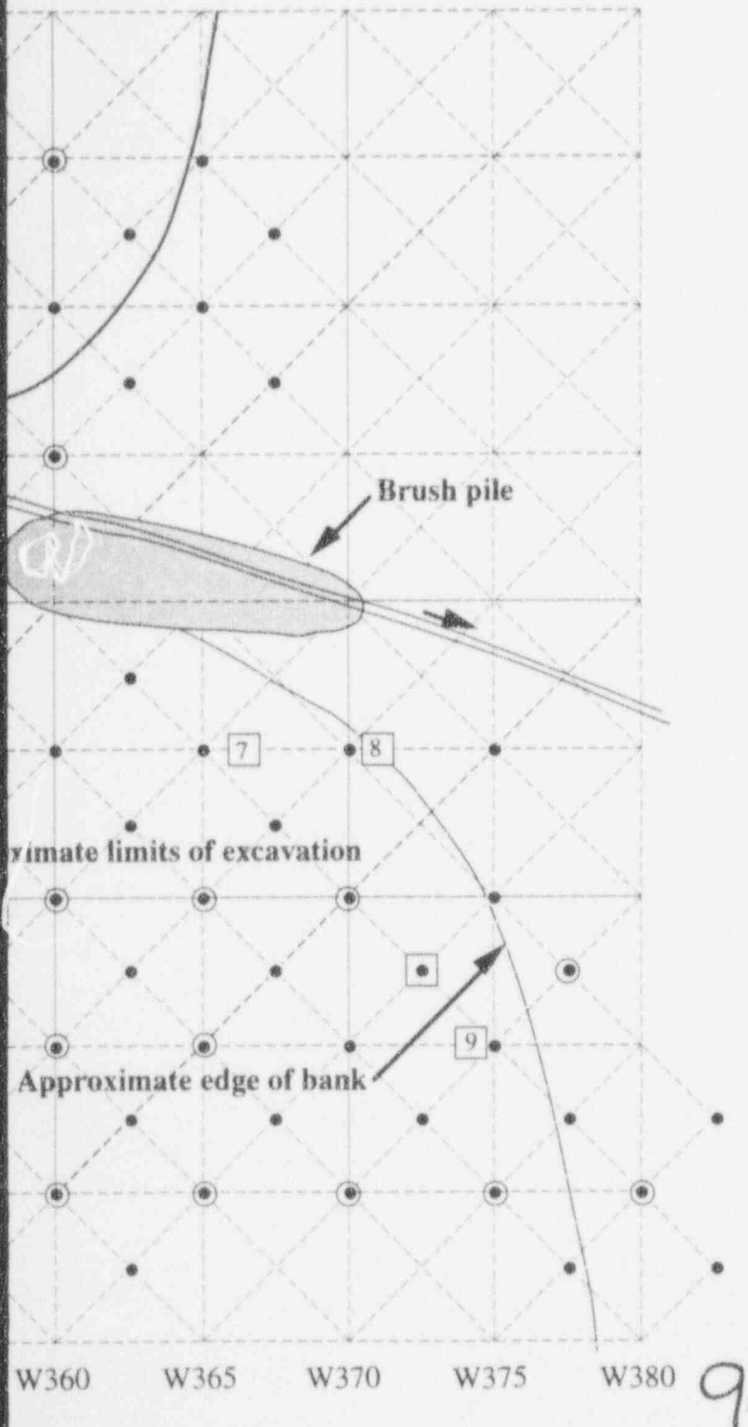
NORTH



- Gamma Exposure Rate Measurement Location
- Measurement Location with Gamma Exposure Rate ≥ 10μR/h above background at 1cm above surface
- Soil/Slag Sample Location

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FIGURE 6-5

"PARKING" AREA

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Table 6-4
Survey Data for "Parking Area"

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations								
S212.5	W327.5		-	-	--		--	
S202.5	W347.5		50	14	--		--	
S202.5	W342.5		40	13	--		--	
S207.5	W337.5		30	30	--		--	
S187.5	W372.5		30	13	334.3	14.0	172.7	21.5
S205	W340		17	18	<6.6		<12.1	
S185	W375		17	15	--		--	
S195	W325		16	16	--		--	
S202.5	W337.5		16	15	--		--	
S210	W340		16	13	<4.8		<8.5	
S177.5	W377.5		16	13	--		--	
S200	W320		15	14	--		--	
S205	W335		15	15	--		--	
S192.5	W337.5		15	13	--		--	
S187.5	W337.5		15	13	--		--	
S190	W340		15	15	<5.2		<10.3	
S200	W340		15	13	<4.3		<8.7	
					<4.9		<9.3	
S187.5	W342.5		15	13	--		--	
S200	W355		15	12	--		--	
S187.5	W367.5		15	12	--		--	
S190	W375		15	14	--		--	
S185	W385		15	13	--		--	
S205	W330		14	14	<6.1		<13.5	
S210	W335		14	13	--		--	
S200	W335		14	13	--		--	
S195	W335		14	14	--		--	
S195	W330		14	15	<4.7		<8.6	
S207.5	W322.5		14	13	--		--	
S197.5	W327.5		14	14	--		--	
S197.5	W332.5		14	11	--		--	
S202.5	W332.5		14	12	--		--	
S207.5	W332.5		14	14	--		--	
S197.5	W342.5		14	12	--		--	
S185	W345		14	13	<6.9		<11.8	
S195	W345		14	14	--		--	
S200	W345		14	13	<3.5		<5.9	
S187.5	W347.5		14	13	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-4
Survey Data for "Parking Area"

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S187.5	W352.5		14	12	--		--	
S185	W355		14	12	--		--	
S195	W370		14	14	--		--	
S187.5	W377.5		14	14	--		--	
S205	W325		13	13	--		--	
S210	W320		13	13	--		--	
S212.5	W322.5		13	12	--		--	
S212.5	W337.5		13	13	--		--	
S185	W340		13	13	--		--	
S195	W340		13	14	--		--	
S192.5	W342.5		13	13	--		--	
S190	W345		13	14	<5.2		<9.2	
S192.5	W347.5		13	14	--		--	
S190	W350		13	14	<5.8		<10.7	
S192.5	W352.5		13	11	--		--	
S197.5	W352.5		13	12	--		--	
S195	W355		13	11	--		--	
S182.5	W357.5		13	12	--		--	
S177.5	W362.5		13	12	--		--	
S182.5	W362.5		13	11	--		--	
S197.5	W362.5		13	12	--		--	
S195	W365		13	13	--		--	
S190	W365		13	13	<5.7		<9.8	
S192.5	W367.5		13	13	--		--	
S190	W370		13	13	<4.3		<7.5	
S180	W375		13	12	<6.6		<12.2	
S182.5	W377.5		13	13	--		--	
S185	W380		13	13	--		--	
S177.5	W382.5		13	13	--		--	
S182.5	W382.5		13	13	--		--	
S180	W385		13	14	--		--	
S200	W325		12	13	--		--	
S195	W320		12	13	6.1	1.9	<8.5	
S205	W320		12	12	<7.3		<13.5	
S215	W320		12	10	<5.9		<11.8	
S215	W335		12	11	--		--	
S197.5	W322.5		12	13	--		--	
S202.5	W327.5		12	13	--		--	
S197.5	W347.5		12	13	--		--	
S195	W350		12	12	--		--	
S185	W360		12	12	<5.1		<9.8	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.

Table 6-4
Survey Data for "Parking Area"

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S180	W360		12	13	<7.4		<13	
S197.5	W367.5		12	12	--		--	
S185	W370		12	13	--		--	
S197.5	W337.5		11	14	--		--	
S215	W340		11	11	<4.2		<8.7	
S212.5	W342.5		11	12	--		--	
S207.5	W342.5		11	11	--		--	
S205	W345		11	12	--		--	
S210	W350		11	10	--		--	
S200	W350		11	11	4.9	2.4	<10.8	
S202.5	W352.5		11	11	--		--	
S190	W355		11	11	--		--	
S180	W365		11	12	<5.2		<8.6	
S180	W380		11	12	<6		<10.7	
S202.5	W322.5		10	11	--		--	
S207.5	W327.5		10	9	--		--	
S210	W345		10	10	--		--	
S215	W350		10	10	<4.5		<7.6	
S215	W355		10	9	--		--	
S210	W355		10	10	--		--	
S205	W350		10	10	<5.2		<10	
S187.5	W357.5		10	10	--		--	
S192.5	W357.5		10	10	--		--	
S197.5	W357.5		10	11	--		--	
S195	W360		10	10	--		--	
S190	W360		10	9	<6.2		<10.4	
S180	W370		10	10	<4.6		<7.9	
S210	W330		9	9	--		--	
S212.5	W332.5		9	9	--		--	
S215	W345		9	10	--		--	
S212.5	W352.5		9	9	--		--	
S212.5	W347.5		9	11	--		--	
S192.5	W362.5		9	12	--		--	
S182.5	W367.5		9	11	--		--	
S182.5	W372.5		9	11	--		--	
S212.5	W362.5		8	8	--		--	
S207.5	W352.5		8	8	--		--	
S207.5	W347.5		8	10	--		--	
S185	W365		8	10	<4.4		<7.6	
S215	W325		7	8	--		--	
S210	W325		7	8	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

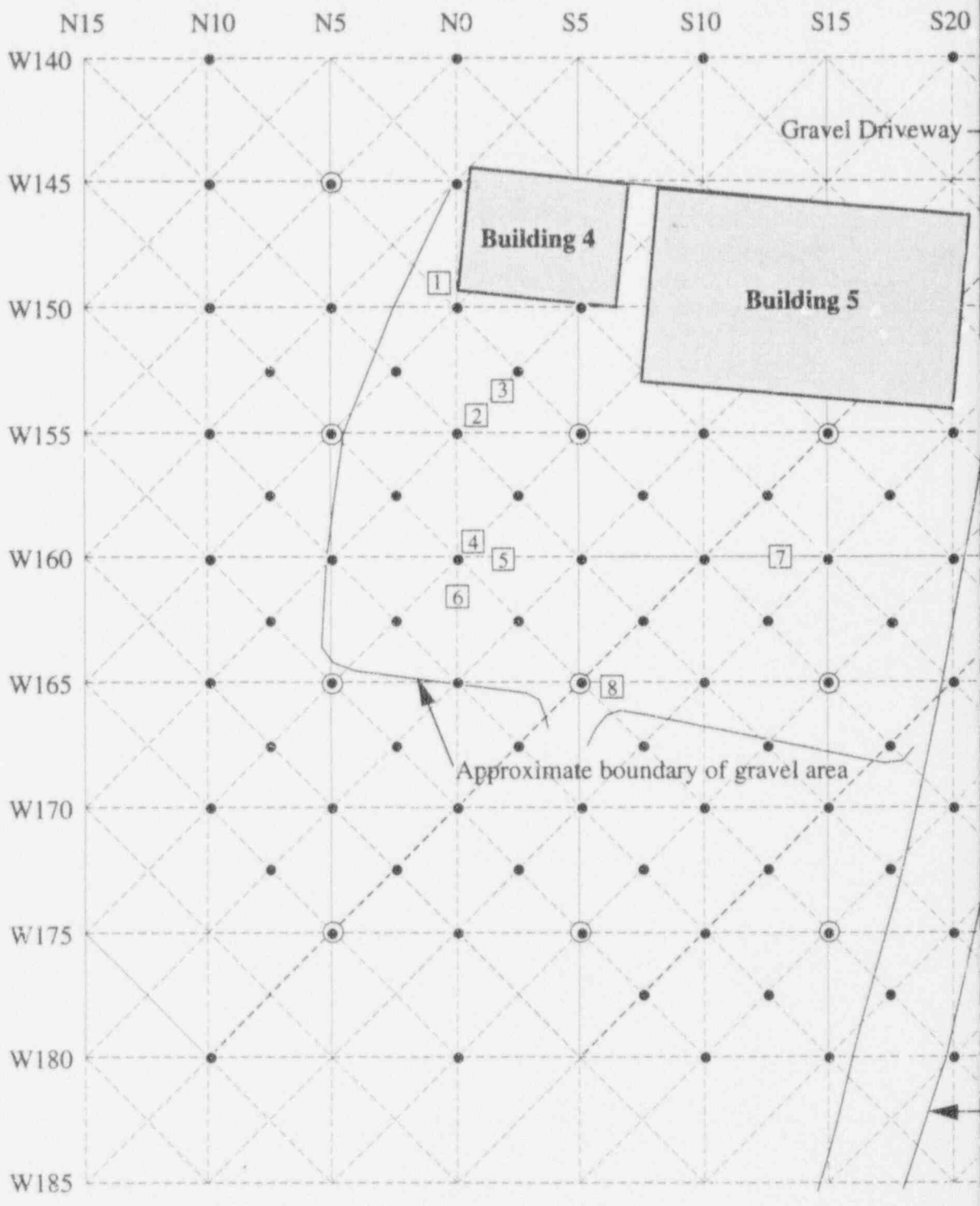
"--" indicates that no sample was collected at this location.

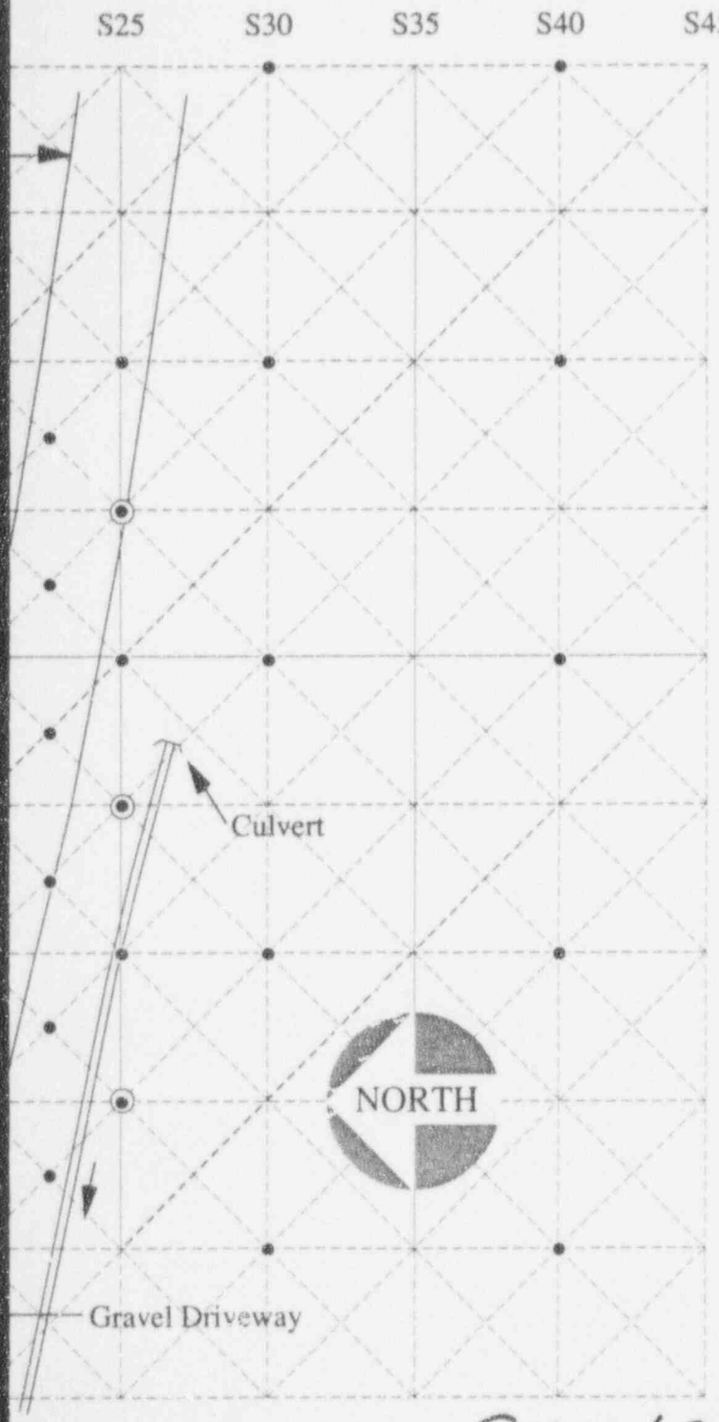
Table 6-4
Survey Data for "Parking Area"

N/S Coordinate	E/W Coordinate	Description	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S215	W360		7	8	<3.5		<6.1	
S212.5	W367.5		7	7	--		--	
S212.5	W357.5		7	7	--		--	
S210	W360		7	7	--		--	
S207.5	W367.5		7	7	--		--	
S207.5	W357.5		7	7	--		--	
S205	W360		7	8	<5.3		<7.7	
S187.5	W362.5		7	11	--		--	
S215	W330		6	8	<5.4		<10.2	
S215	W365		6	7	--		--	
S210	W365		6	7	--		--	
S207.5	W362.5		6	7	--		--	
Biased Locations								
S204	W340	1	40	16	33.2	4.6	<18.3	
					5.6	2.7	<10.5	
S203	W340	2	40	15	22.1	3.8	27.8	5.9
S202	W343	3	30	14	303.9	11.5	106.5	18.4
S203	W347	4	40	16	<7		<13.7	
S197.5	W344	5	30	13	<11.1		23.3	7.6
S197	W343	6	16	15	<4.2		<7.9	
S195	W366.5	7	40	13	108.1	5.6	61.7	9.0
S195	W371	8	30	15	33.6	4.0	21.8	6.2
S185	W374.5	9	150	17	321.4	12.6	143.8	20.1
S204	W343	10	40	15	--		--	
S206	W338	DRUM	240					
"<" indicates that the actual activity is less than the reported minimum detectable activity (MDA) for that sample.								

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th activity values.

"--" indicates that no sample was collected at this location.


N15
N10
N5
N0
S5
S10
S15
S20
W140
W145
W150
W155
W160
W165
W170
W175
W180
W185
Gravel Driveway
Building 4
Building 5
1
2
3
4
5
6
7
8
Approximate boundary of gravel area



- Gamma Exposure Rate Measurement Location
- Measurement Location with Gamma Exposure Rate ≥ 10µR/h above background at 1cm above surface
- Soil/Slag Sample Location

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FIGURE 6-6

BUILDINGS 4 & 5 STORAGE AREA

ENSERCH ENVIRONMENTAL CORPORATION

Table 6-5
Survey Data for Buildings 4 and 5 Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations								
N5	W140		15	14	--		--	
N5	W145		15	13	<5.8		<10.2	
N5	W150		13	12	--		--	
N5	W155		13	12	<5		<8.7	
N5	W160		12	13	--		--	
N5	W165		13	13	<4.9		<9.4	
N5	W170		14	15	--		--	
N5	W175		13	14	<4.7		<7.8	
N2.5	W172.5		13	13	--		--	
N2.5	W167.5		14	12	--		--	
N2.5	W162.5		12	11	--		--	
N2.5	W157.5		11	11	--		--	
N2.5	W152.5		10	11	--		--	
N2.5	W147.5		14	14	--		--	
N2.5	W142.5		15	15	--		--	
0	W140		15	15	--		--	
0	W145		16	15	--		--	
0	W150		15	14	--		--	
0	W155		11	12	--		--	
0	W160		13	13	--		--	
0	W165		12	13	--		--	
0	W170		14	14	--		--	
0	W175		14	14	--		--	
S2.5	W172.5		15	15	--		--	
S2.5	W167.5		14	14	--		--	
S2.5	W162.5		15	14	--		--	
S2.5	W157.5		12	13	--		--	
S2.5	W152.5		14	15	--		--	
S5	W150		15	15	--		--	
S5	W155		15	13	<4.6		<8.7	
S5	W160		13	13	--		--	
S5	W165		13	14	4	1.9	<8.2	
S5	W170		15	14	--		--	
S5	W175		15	15	<4.7		<8.9	
S7.5	W172.5		14	14	--		--	
S7.5	W167.5		16	15	--		--	
S7.5	W162.5		12	12	--		--	
S7.5	W157.5		12	13	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was taken at this location.

Table 6-5
Survey Data for Buildings 4 and 5 Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S7.5	W152.5		17	15	--		--	
S10	W155		13	13	--		--	
S10	W160		11	12	--		--	
S10	W165		15	14	--		--	
S10	W170		14	14	--		--	
S10	W175		15	15	--		--	
S12.5	W172.5		14	13	--		--	
S12.5	W167.5		21	13	<3.1		<5.6	
S12.5	W162.5		13	12	--		--	
S12.5	W157.5		12	13	--		--	
S15	W155		16	15	<4		<7.9	
S15	W160		12	13	--		--	
S15	W165		12	13	<4.4		<8.9	
S15	W170		15	13	--		--	
S15	W175		13	14	<4.8		<9.7	
S17.5	W157.5		12	12	--		--	
S17.5	W162.5		13	12	--		--	
S17.5	W167.5		15	15	--		--	
S17.5	W172.5		15	14	--		--	
S20	W175		15	16	--		--	
S20	W170		15	15	--		--	
S20	W165		14	15	--		--	
S20	W160		14	13	--		--	
S20	W155		13	14	--		--	
S22.5	W152.5		15	16	--		--	
S22.5	W157.5		16	15	--		--	
S22.5	W162.5		13	15	--		--	
S22.5	W167.5		14	14	--		--	
S22.5	W172.5		14	13	--		--	
S25	W175		14	14	<4.5		<9	
S25	W170		11	13	--		--	
S25	W165		13	13	<4.8		<8.9	
S25	W160		14	14	--		--	
S25	W155		14	14	<4.3		<8.7	
S25	W150		15	15	--		--	
N7.5	W147.5		14	13	--		--	
N7.5	W152.5		13	13	--		--	
N7.5	W157.5		13	13	--		--	
N7.5	W162.5		13	14	--		--	
N7.5	W167.5		14	14	--		--	
N7.5	W172.5		13	13	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was taken at this location.

Table 6-5
Survey Data for Buildings 4 and 5 Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
N10	W170		13	14	--		--	
N10	W165		14	14	--		--	
N10	W160		14	14	--		--	
N10	W155		13	13	--		--	
N10	W150		14	14	--		--	
N10	W145		14	14	--		--	
S7.5	W177.5		15	14	--		--	
S12.5	W177.5		14	14	--		--	
S17.5	W177.5		15	14	--		--	
S22.5	W177.5		15	15	--		--	
S20	W180		15	14	--		--	
S15	W180		14	14	--		--	
S10	W180		14	14	--		--	
Biased Locations								
N0.5	W149.5	1	45	15	552	24.5	319.7	38.8
S1	W154	2	50	13	109	5.6	53.1	8.5
S2	W153	3	75	13	1082.4	40.3	471.7	65.1
S0.5	W159.5	4	35	12	1267.9	77.9	819.1	123.8
S2	W160	5	30	13	147.8	11.1	315	16.9
S0	W162	6	30	13	381.9	21.1	229.2	33.4
S13	W160	7	110	12	697	28.1	386.8	44.6
S6	W165	8	40	14	<4		<7.7	
"<" indicates that the actual activity is less than the reported minimum detectable activity (MDA) for that sample.								

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was taken at this location.

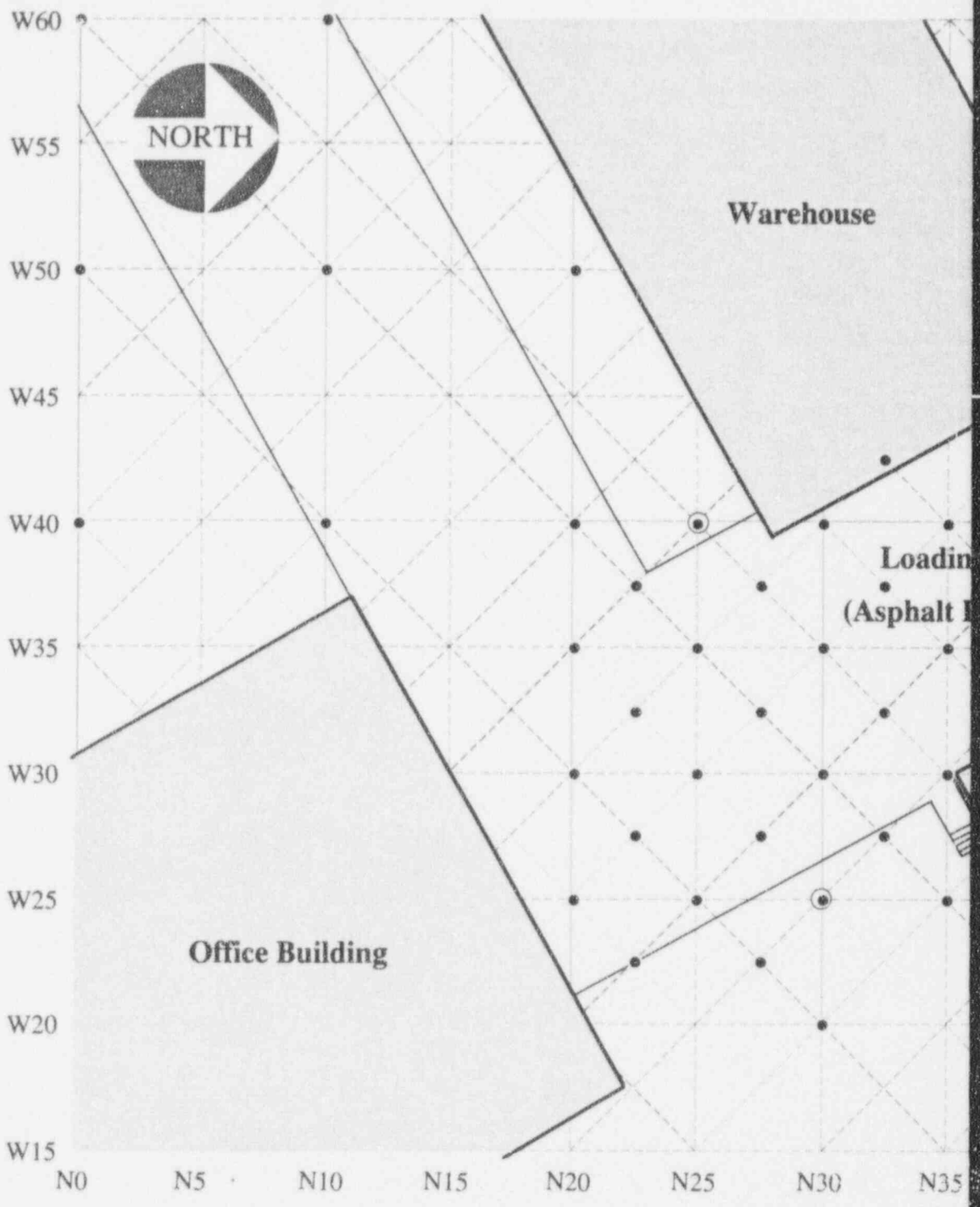
thorium concentrations within the guideline concentrations. Seven of the eight biased location samples had total uranium and total thorium concentrations above the guideline values. These concentrations ranged from 109 pCi/g, to 126 pCi/g. Interestingly, with one exception (bias location 7), all the elevated concentrations (locations 1 through 6) lie on a line east of building 4. This would signify local non-random contamination.

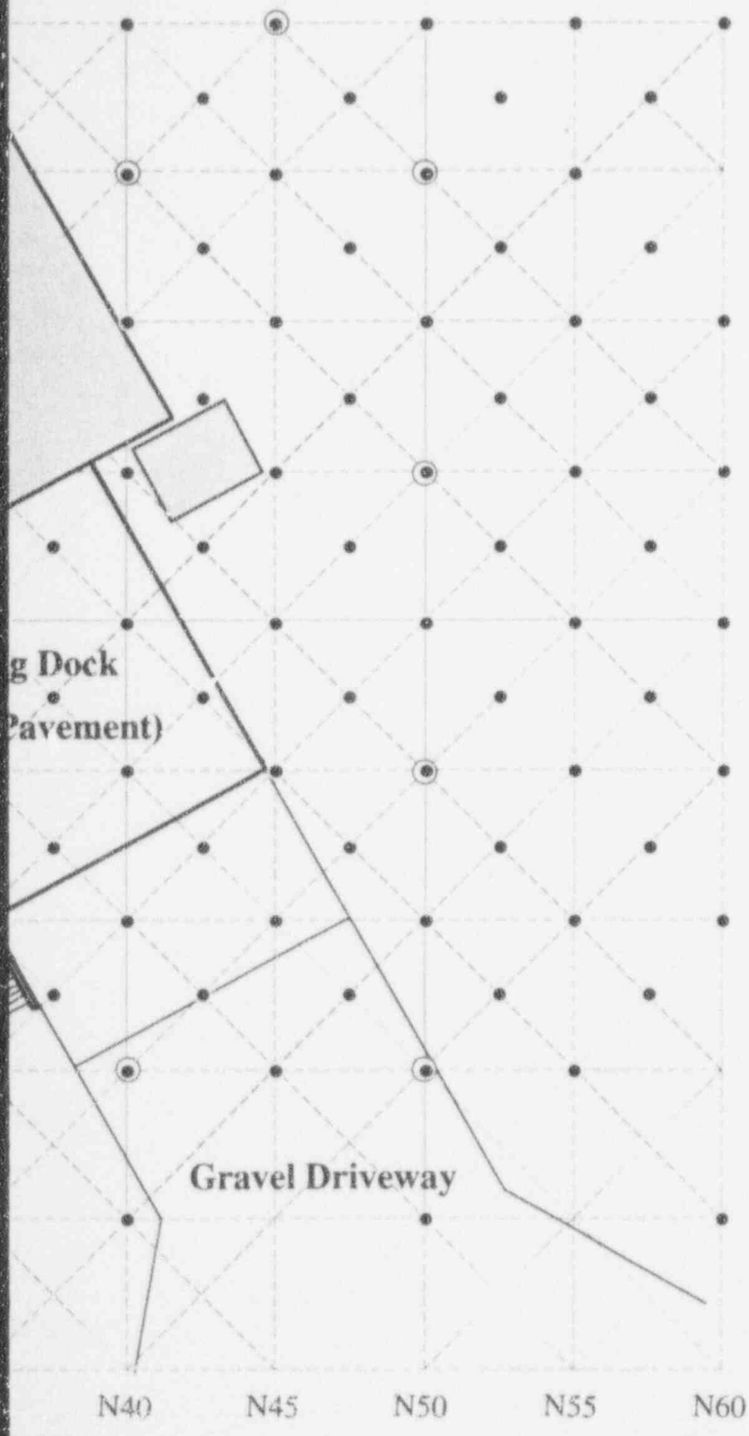
6.2.4 Warehouse/Loading Dock Area

Survey data for the Warehouse/Loading Dock Area are presented in Figure 6-6 and Table 6-6. A continuous gamma scan was conducted following a 5 meter triangular grid within this area (see Figure 6-7), but detected no locations with significantly elevated exposure rates. Integrated gamma exposure rates at the 84 grid intersections ranged from 9 to 15 µR/h at 1 centimeter above the surface and 8 to 14 µR/h at 1 meter above the surface. All gamma exposure levels were within the guideline levels. All soil samples from this area had total uranium and thorium concentrations below the guideline concentrations. No soil samples were collected from beneath the asphalt pavement of the loading dock. However, there was no indication from the exposure rate measurements that any material with activity above background levels was present in the shallow subsurface.

6.2.5 Former Drum Storage Area

Survey data for the Drum Storage Area are presented in Figure 6-8 and Table 6-7. Because remedial actions were on-going within this area, the 5 meter by 5 meter trangular grid was not used as the survey basis. A 10 meter by 10 meter grid was established within the Drum Storage Area (see Figure 6-8), but was not tied into the site-wide reference grid as were the grids within the other potentially affected areas. The locations of measurements in this area should therefore be considered approximate. A continuous gamma scan performed along the 10 meter orthogonal grid identified 14 hot spots with exposure rates greater than two times background at 1 centimeter above the surface. Integrated measurements at these locations, which are numbered 27 through 40 on Figure 6-8 and in Table 6-7, ranged from 21 to 120 µR/h at 1 centimeter above the surface and 14 to 24 µR/h at 1 meter above the surface. Additional gamma exposure rate measurements were performed at the grid intersections, numbered 1 through 26 on Figure 6-8 and in Table 6-7, and ranged from 10 to 40 µR/h at 1 centimeter and 11 to 24 µR/h at 1 meter above the surface. The majority of the exposures at 1 meter elevation are below the guidelines. Those points slightly over the guidelines lie along the approximate boundary of excavation. No soil/slag samples were collected from this area.


W60
W55
W50
W45
W40
W35
W30
W25
W20
W15
N0
N5
N10
N15
N20
N25
N30
N35
NORTH
Warehouse
Loadin
(Asphalt
Office Building



- Gamma Exposure Rate Measurement Location
- Measurement Location with Gamma Exposure Rate ≥ 10μR/h above background at 1cm above surface
- Soil/Slag Sample Location

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CABOT PERFORMANCE MATERIALS INC.

FIGURE 6-7

WAREHOUSE/LOADING DOCK AREA

ENSERCH ENVIRONMENTAL CORPORATION

Table 6-6
Survey Data for Loading Dock Area

N/S Coordinate	E/W Coordinate	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations							
N20	W40	15	13	--		--	
N25	W40	13	10	<4.3		<9.2	
N20	W35	14	14	--		--	
N20	W30	15	14	--		--	
N20	W25	11	12	--		--	
N25	W25	14	13	--		--	
N25	W30	14	13	--		--	
N25	W35	12	12	--		--	
N22.5	W37.5	13	12	--		--	
N22.5	W32.5	14	13	--		--	
N22.5	W27.5	14	13	--		--	
N22.5	W22.5	12	11	--		--	
N27.5	W37.5	14	13	--		--	
N27.5	W32.5	14	13	--		--	
N27.5	W27.5	13	14	--		--	
N27.5	W22.5	13	10	--		--	
N30	W40	14	13	--		--	
N30	W35	13	12	--		--	
N30	W30	15	13	--		--	
N30	W25	13	13	<3.4		<6.5	
N32.5	W27.5	13	12	--		--	
N32.5	W32.5	13	13	--		--	
N32.5	W37.5	13	13	--		--	
N32.5	W42.5	10	10	--		--	
N35	W25	13	13	--		--	
N35	W30	12	12	--		--	
N35	W35	13	12	--		--	
N35	W40	14	13	--		--	
N37.5	W42.5	14	12	--		--	
N37.5	W37.5	14	14	--		--	
N37.5	W32.5	14	12	--		--	
N37.5	W27.5	14	13	--		--	
N40	W25	12	13	<3.5		<7.2	
N40	W30	10	10	--		--	
N40	W35	14	12	--		--	
N40	W40	14	12	--		--	
N40	W45	12	12	--		--	
N42.5	W42.5	12	11	--		--	
N42.5	W37.5	9	10	--		--	
N42.5	W32.5	9	9	--		--	
N42.5	W27.5	14	13	--		--	
N45	W25	14	14	--		--	
N45	W30	11	11	--		--	

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

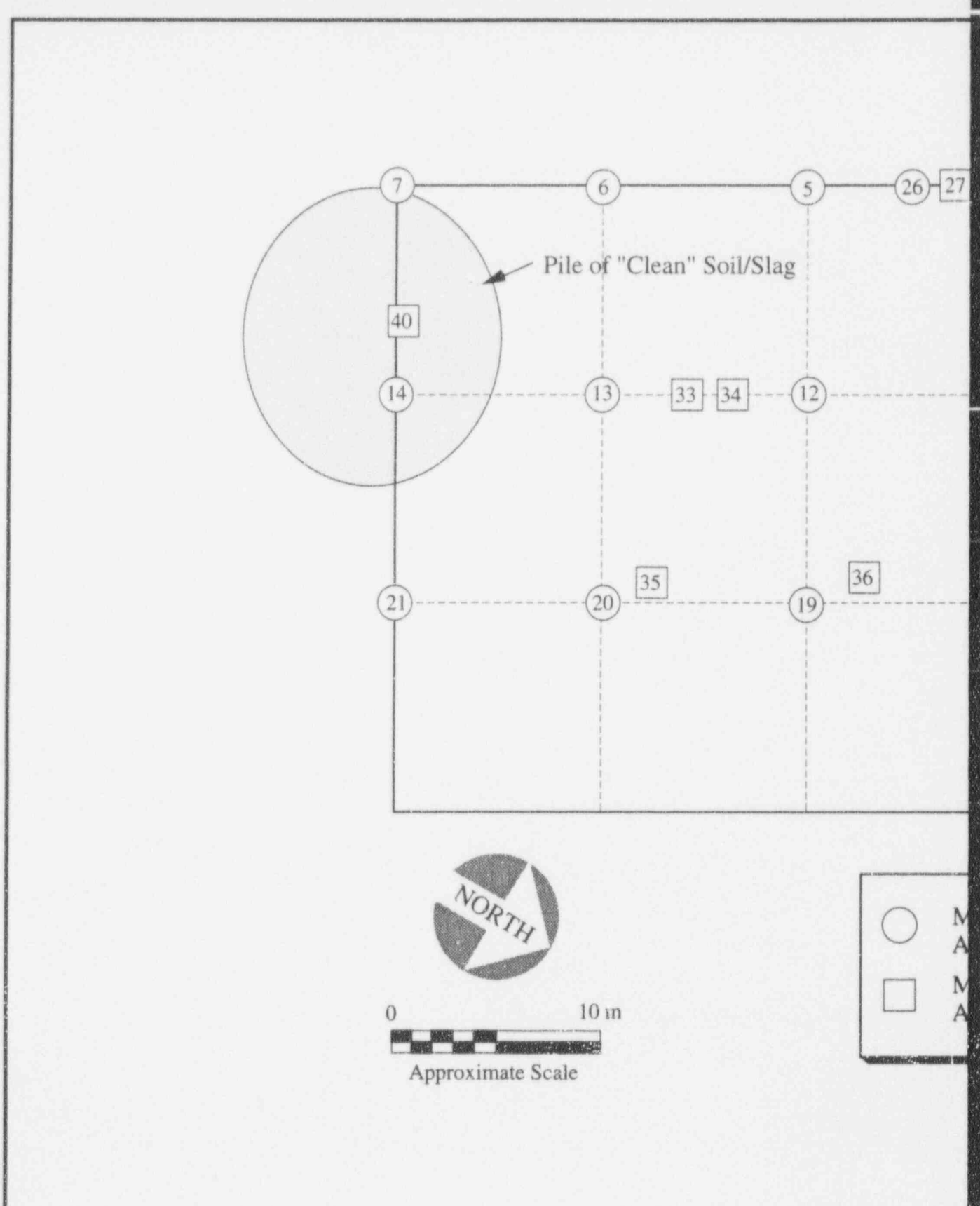
"--" indicates that no sample was taken at this location.

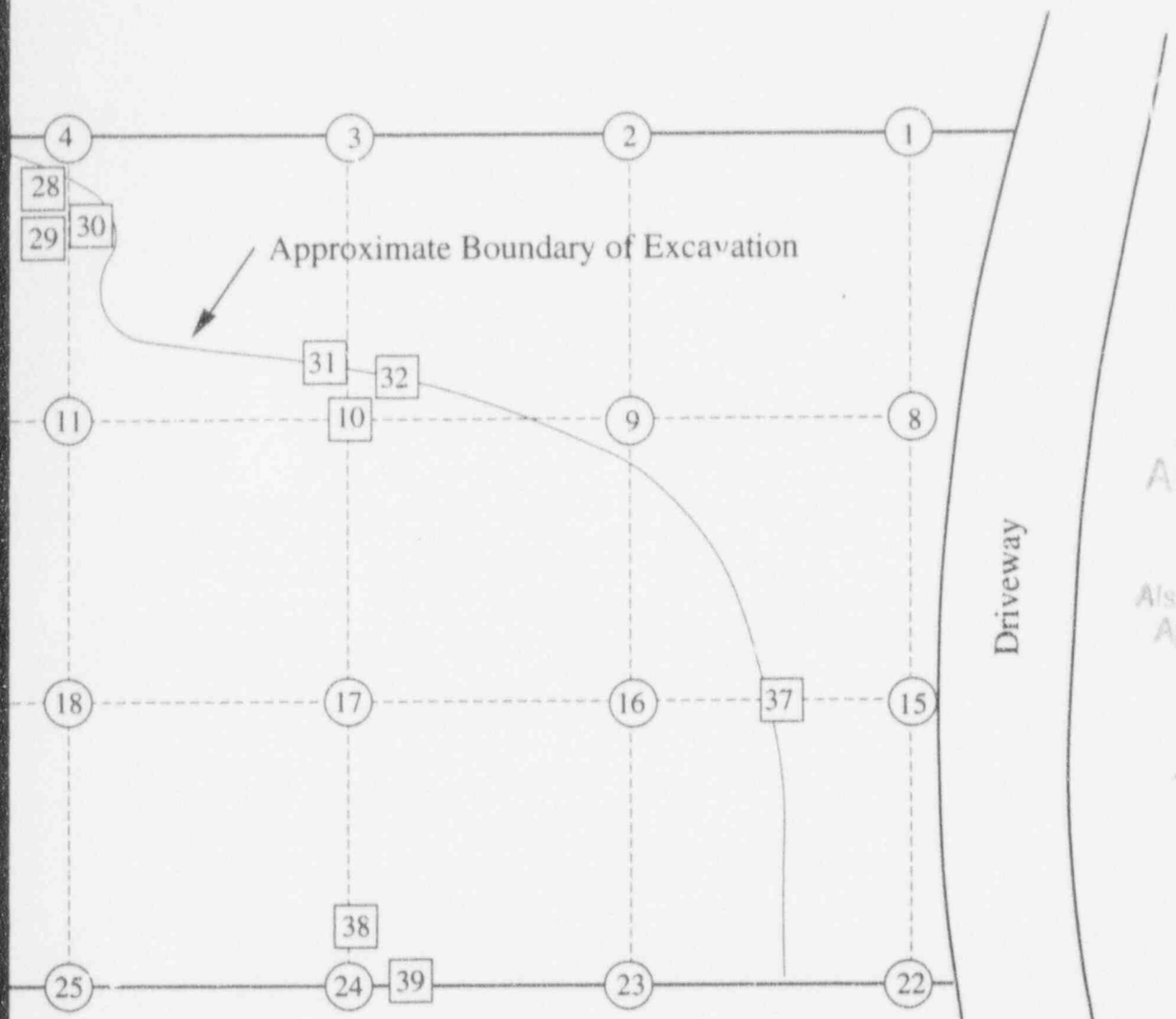
Table 6-6
Survey Data for Loading Dock Area

N/S Coordinate	E/W Coordinate	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
N45	W35	14	11	--		--	
N45	W40	12	11	--		--	
N45	W45	12	12	--		--	
N45	W50	14	13	--		--	
N45	W55	13	13	--		--	
N45	W60	13	12	<5.2		<9	
N42.5	W57.5	13	13	--		--	
N42.5	W52.5	13	14	--		--	
N42.5	W47.5	12	8	--		--	
N40	W50	12	11	--		--	
N40	W55	12	12	--		--	
N40	W60	12	12	--		--	
N47.5	W57.5	12	12	--		--	
N47.5	W52.5	13	13	--		--	
N47.5	W47.5	13	12	--		--	
N47.5	W42.5	12	12	--		--	
N47.5	W37.5	13	11	--		--	
N47.5	W32.5	13	11	--		--	
N47.5	W27.5	13	13	--		--	
N50	W25	14	14	<4.4		<7.7	
N50	W30	13	13	--		--	
N50	W35	14	14	<4.9		<7.9	
N50	W40	13	13	--		--	
N50	W45	13	13	<4.7		<9.3	
N50	W50	13	12	--		--	
N50	W55	13	13	<4.6		<8.8	
N50	W60	12	13	--		--	
N52.5	W57.5	12	13	--		--	
N52.5	W52.5	13	12	--		--	
N52.5	W47.5	13	13	--		--	
N52.5	W42.5	14	13	--		--	
N52.5	W37.5	14	14	--		--	
N52.5	W32.5	14	12	--		--	
N52.5	W27.5	14	14	--		--	
N55	W30	14	13	--		--	
N55	W35	13	12	--		--	
N55	W40	12	12	--		--	
N55	W45	12	13	--		--	
N55	W50	13	13	--		--	
N55	W55	12	12	--		--	
N55	W60	11	12	--		--	
*'<' indicates that the actual activity is less than reported minimum detectable activity (MDA) for that sample.							

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was taken at this location


7
6
5
26
27
Pile of "Clean" Soil/Slag
40
14
13
33
34
12
21
20
35
19
36
NORTH
0
10 m
Approximate Scale



easurement Location with Exposure Rate ≤ 10µR/h
bove Background at 1cm Above Surface

easurement Location with Exposure Rate ≥ 10µR/h
bove Background at 1cm Above Surface

CABOT PERFORMANCE MATERIALS INC.

FIGURE 6-8

DRUM STORAGE AREA

ENSERCH ENVIRONMENTAL CORPORATION

Table 6-7
Survey Data for Drum Storage Area

Location	µR/h 1cm	µR/h 1m
1	15	13
2	11	12
3	11	12
4	11	12
5	13	11
6	12	13
7	14	14
8	14	15
9	15	15
10	40	24
11	16	17
12	14	13
13	10	12
14	18	14
15	15	15
16	16	18
17	17	17
18	13	14
19	10	11
20	11	12
21	10	12
22	14	14
23	14	15
24	16	17
25	13	12
26	15	21
27	80	15
28	110	19
29	120	22
30	50	22
31	70	24
32	21	22
33	100	15
34	40	14
35	25	14
36	60	15
37	60	19
38	40	17
39	40	17
40	40	16

6.3 UNAFFECTED AREAS

Gamma exposure rate surveys, including both continuous scans and integrated measurements, were performed within developed portions of the site that were considered to have little or no potential for radiological contamination. The surveys followed 10 meter by 10 meter orthogonal reference grids that were established in four distinct areas of the site (see Figure 2-2): (1) the Office Building Area, (2) the Manufacturing Area, (3) the Thermite Reaction Building Area and (4) the Sandblasting and Grinding Area. The results of all gamma exposure rate measurements made within these "unaffected areas" are presented in Tables 6-8 through 6-11.

6.3.1 Office Building Area

Survey data for the Office Building Area are presented in Table 6-8. A continuous gamma scan was conducted following a 10 meter by 10 meter orthogonal grid within this area (see Figure 2-2), but detected no locations with significantly elevated exposure rates. Integrated gamma exposure rates at the 200 grid intersections ranged from 10 to 21 µR/h at 1 centimeter above the surface and 9 to 19 µR/h at 1 meter above the surface (within the guidelines). The average exposure rates at both 1 centimeter and 1 meter above the surface were 13 µR/h, well within the range of regional background exposure measurements. Furthermore, the similarity between exposure rates at 1 meter and 1 centimeter above the ground surface indicates that the soils do not contain point sources (contaminated soil/slag). These measurement systematics are similar to those found at the background locations.

6.3.2 Manufacturing Area

Survey data for the Manufacturing Area are presented in Table 6-9. A continuous gamma scan was conducted following a 10 meter by 10 meter orthogonal grid within this area (see Figure 2-2), but detected no locations with exposure rates above the guidelines. Integrated gamma exposure rates at the 98 grid intersections ranged from 9 to 17 µR/h at 1 centimeter above the surface and 8 to 16 µR/h at 1 meter above the surface. The average exposure rate at 1 centimeter above the surface was 14 µR/h and at 1 meter above the surface was 13 µR/h, both within the range of regional background exposure measurements. As previously described in Section 6.3.1, the similarity of exposure rates at different elevations indicate the soils do not contain point sources (contaminated soil/slag).

Table 6-8
Survey Data for Office Building Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
0	E10	12	12
S10	E10	13	12
S20	E10	13	13
S30	E10	14	12
S40	E10	12	12
S50	E10	12	11
S60	E10	11	12
S70	E10	13	12
S80	E10	12	12
S90	E10	13	12
S100	E10	12	12
S100	0	13	13
S90	0	12	13
S80	0	13	12
S70	0	13	13
S60	0	12	12
S50	0	12	11
S40	0	12	12
S30	0	15	13
S20	0	13	12
S10	0	13	13
0	0	15	17
S10	W10	14	13
S20	W10	16	14
S30	W10	15	14
S40	W10	15	13
S50	W10	14	13
S60	W10	13	13
S70	W10	12	12
S80	W10	13	13
S90	W10	13	12
S100	W10	13	13
S100	W20	13	13
S90	W20	13	12
S80	W20	12	12
S70	W20	13	12
S60	W20	13	11
S50	W20	12	12
S40	W20	12	12
S30	W20	14	13
S20	W20	14	14
S10	W20	15	14
N60	W30	14	14
N50	W30	13	12

Table 6-8
Survey Data for Office Building Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
N40	W30	10	10
N30	W30	15	13
N20	W30	15	14
N10	W30	18	15
0	W30	17	16
S10	W30	14	14
S20	W30	14	14
S30	W30	14	13
S40	W30	15	14
S50	W30	13	13
S60	W30	13	12
S70	W30	12	12
S80	W30	12	12
S90	W30	13	13
S100	W30	13	12
S100	W40	13	13
S90	W40	13	13
S80	W40	14	14
S70	W40	12	12
S60	W40	13	12
S50	W40	12	12
S40	W40	15	13
S30	W40	13	13
S20	W40	13	13
S10	W40	15	15
0	W40	15	13
N10	W40	14	14
N20	W40	15	14
N30	W40	13	13
N40	W40	13	13
N50	W40	13	12
N60	W40	12	13
N60	W20	14	14
N50	W20	14	15
N40	W20	14	14
N30	W20	14	13
N15	W19	21	19
N20	W10	14	13
N30	W10	12	13
N40	W10	14	14
N50	W10	14	14
N60	W10	14	14
N10	E10	12	12
N20	E10	10	11

Table 6-8
Survey Data for Office Building Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
N30	E10	13	13
N40	E10	12	11
N50	E10	12	12
N60	E10	10	11
N10	0	14	12
N20	0	14	13
N30	0	12	11
N40	0	12	12
N50	0	13	12
N60	0	15	13
S100	W50	13	13
S90	W50	12	13
S80	W50	13	12
S70	W50	12	12
S60	W50	12	11
S50	W50	14	12
S40	W50	15	14
S30	W50	13	12
S20	W50	13	13
S10	W50	14	15
0	W50	13	12
N10	W50	14	13
N20	W50	13	12
N50	W50	12	12
N60	W50	12	13
N60	W60	13	12
N50	W60	13	13
N40	W60	13	12
N20	W60	13	13
N10	W60	14	14
0	W60	13	12
S10	W60	13	14
S20	W60	13	13
S30	W60	14	14
S40	W60	12	12
S50	W60	12	12
S60	W60	12	12
S70	W60	13	10
S80	W60	12	13
S90	W60	11	11
S100	W60	13	13
S100	W70	13	12
S90	W70	11	12
S80	W70	12	12

Table 6-8
Survey Data for Office Building Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
S70	W70	11	11
S60	W70	12	12
S50	W70	12	12
S40	W70	12	12
S30	W70	15	15
S20	W70	15	15
S10	W70	14	13
0	W70	13	14
N10	W70	13	13
N20	W70	14	13
N30	W70	14	14
N40	W70	13	13
N50	W70	12	12
N60	W70	12	12
N60	W80	12	12
N50	W80	12	12
N40	W80	12	12
N30	W80	15	13
N20	W80	12	12
N10	W80	13	13
0	W80	14	12
S10	W80	11	11
S20	W80	15	15
S30	W80	13	12
S40	W80	12	12
S50	W80	12	12
S60	W80	14	14
S70	W80	13	13
S80	W80	13	13
S90	W80	10	10
S100	W80	12	11
S100	W90	12	12
S90	W90	12	12
S80	W90	10	10
S70	W90	12	12
S60	W90	14	13
S50	W90	12	12
S40	W90	10	9
S30	W90	13	12
S20	W90	13	13
S10	W90	13	14
0	W90	13	13
N10	W90	13	13
N20	W90	12	14

Table 6-8
Survey Data for Office Building Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
N30	W90	14	13
N40	W90	13	14
N50	W90	13	12
N60	W90	14	13
N60	W100	14	14
N50	W100	14	14
N40	W100	13	13
N30	W100	14	14
N20	W100	13	13
N10	W100	13	13
0	W100	12	12
S10	W100	12	13
S20	W100	14	14
S30	W100	13	14
S40	W100	11	10
S50	W100	13	13
S60	W100	13	13
S70	W100	12	12
S80	W100	13	10
S90	W100	13	13
S100	W100	15	13
S110	W100	13	13
S120	W100	13	13
S130	W100	14	13

Table 6-9
Survey Data for Manufacturing Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
N20	W110	13	13
N20	W120	13	12
N20	W130	14	14
N20	W140	13	13
N20	W150	12	13
N20	W160	13	13
N20	W170	13	13
N20	W180	13	13
N20	W190	13	12
N10	W190	14	14
N10	W180	13	14
0	W190	14	13
0	W180	14	13
S10	W190	14	14
S20	W190	14	14
N10	W140	14	14
N10	W130	13	13
N10	W120	13	13
N10	W110	12	12
0	W110	13	12
0	W120	13	13
0	W140	15	15
S10	W140	14	14
S10	W130	15	13
S10	W120	13	13
S10	W110	14	13
S20	W110	13	14
S20	W120	13	12
S20	W130	14	14
S20	W140	15	13
S20	W150	17	16
S30	W110	13	13
S30	W120	13	13
S30	W130	13	14
S30	W140	14	14
S30	W150	15	14
S30	W160	14	13
S30	W170	13	13
S30	W180	15	13
S30	W190	14	13
S40	W190	14	14
S40	W180	14	14
S40	W170	14	14
S40	W160	14	14

Table 6-9
Survey Data for Manufacturing Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
S40	W150	14	14
S40	W140	15	15
S40	W110	15	15
S50	W110	15	15
S50	W120	14	14
S60	W110	16	15
S70	W110	15	12
S80	W110	14	13
S90	W110	15	14
S100	W110	13	14
S100	W120	14	14
S100	W130	14	14
S100	W140	13	13
S90	W140	14	14
S90	W150	14	15
S90	W160	15	13
S90	W170	14	13
S90	W190	14	13
S80	W190	14	14
S80	W180	14	14
S80	W170	15	15
S80	W160	16	14
S80	W150	16	16
S70	W140	15	14
S70	W150	13	13
S70	W170	13	13
S70	W180	14	14
S70	W190	15	14
S60	W190	13	14
S60	W180	13	14
S60	W170	14	14
S60	W160	9	9
S50	W190	14	13
S50	W180	14	13
S50	W170	13	14
S50	W160	15	14
S50	W150	14	14
S50	W140	14	12
S110	W110	15	13
S110	W120	13	14
S110	W130	14	13
S110	W140	15	14
S110	W150	14	12
S110	W160	14	14

Table 6-9
Survey Data for Manufacturing Area

N/S Coordinate	E/W Coordinate	uR/Hour 1cm	uR/Hour 1m
S110	W170	14	13
S120	W160	14	15
S120	W150	14	15
S120	W140	14	13
S120	W120	13	12
S120	W110	14	14
S130	W110	14	13
S130	W120	11	8
S130	W150	14	14
S130	W160	14	14

6.3.3 Thermite Reaction Building Area

Survey data for the Manufacturing Area are presented in Table 6-10. One location, S191W251 (see Figure 2-2), was identified during the continuous gamma scan with an exposure rate at 1 centimeter above the surface that was nominally twice the average regional background. The results of integrated gamma exposure rate measurements at this location were 19 µR/h at 1 centimeter above the surface and 16 µR/h at 1 meter above the surface. This exposure rate while slightly elevated compared to the surrounding data is within the guidelines. Integrated gamma exposure rates at the 52 grid intersections ranged from 7 to 16 µR/h at 1 centimeter above the surface and 8 to 15 µR/h at 1 meter above the surface. The average exposure rates at both 1 and 1 meter above the surface were 13 µR/h. Total U and Th concentrations in a soil/slag sample taken at S191W251 (identified as biased sample 1 in Table 6-10) were <4.5 pCi/g and <8.7 pCi/g, respectively.

6.3.4 Sandblasting and Grinding Area

Survey data for the Sandblasting and Grinding Area are presented in Table 6-11. Two locations with exposure rates more than twice the average regional background at 1 centimeter above the surface were identified during the continuous gamma scan. The results of integrated gamma exposure rate measurements at these locations, S245W400 and S253.5W400, both near the grinding operation northwest of Building 12 (see Figure 2-2), were 21 µR/h and 30 µR/h, respectively, at 1 centimeter above the surface. Both locations had exposures rates of 18 µR/h at 1 meter above the surface (within the guidelines). Total U and Th concentrations in a soil/slag sample taken at S245W400 (biased sample 1 in Table 6-11) were <5.5 pCi/g and <9.0 pCi/g, respectively. Total U and Th in biased sample 2, taken at S253.5W400, were 15.7 pCi/g and <10.1 pCi/g, respectively. The results of unbiased integrated gamma exposure rate measurements at the 32 grid intersections ranged from 6 to 22 µR/h at 1 centimeter above the surface and 7 to 18 µR/h at 1 meter above the surface. The average exposure rates at both 1 centimeter and 1 meter above the surface were 13 µR/h.

The above data indicates that all the locations (except S253.5, W400) exhibited values of exposure and total uranium and thorium concentrations below the guideline values. At S253.5, W400 the gamma exposure is within the guideline. The uranium and thorium concentrations at this point are well within the guidelines for single points which are averaged over 10 square meters (the maximum concentrations for isolated points).

Table 6-10
Survey Data for Thermite Building Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations								
S200	W290		13	12	--		--	
S190	W290		14	13	--		--	
S180	W290		14	14	--		--	
S170	W290		15	13	--		--	
S160	W290		13	14	--		--	
S150	W290		14	14	--		--	
S140	W290		14	13	--		--	
S140	W280		14	15	--		--	
S150	W280		14	14	--		--	
S160	W280		14	13	--		--	
S170	W280		14	11	--		--	
S180	W280		9	9	--		--	
S190	W280		13	14	--		--	
S200	W280		12	12	--		--	
S200	W270		15	14	--		--	
S190	W270		11	12	--		--	
S180	W270		7	8	--		--	
S170	W270		9	10	--		--	
S160	W270		13	12	--		--	
S140	W270		12	11	--		--	
S140	W260		12	12	--		--	
S150	W260		15	14	--		--	
S140	W250		14	13	--		--	
S140	W240		14	14	--		--	
S150	W240		12	12	--		--	
S140	W230		15	14	--		--	
S150	W230		14	13	--		--	
S150	W220		15	13	--		--	
S140	W220		13	13	--		--	
S160	W220		14	13	--		--	
S160	W230		15	14	--		--	
S170	W230		14	14	--		--	
S170	W220		15	15	--		--	
S180	W220		16	14	--		--	
S180	W230		15	13	--		--	
S190	W220		13	14	--		--	
S200	W220		14	13	--		--	
S200	W230		14	13	--		--	

*This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was collected at this location.

Table 6-10
Survey Data for Thermite Building Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
S190	W230		15	15	--		--	
S190	W240		14	13	--		--	
S200	W240		11	12	--		--	
S200	W250		12	12	--		--	
S190	W250		16	15	--		--	
S180	W250		15	14	--		--	
S180	W240		14	15	--		--	
S170	W250		12	11	--		--	
S160	W240		13	13	--		--	
S170	W260		13	13	--		--	
S160	W260		14	13	--		--	
S180	W260		13	14	--		--	
S190	W260		15	14	--		--	
S200	W260		14	13	--		--	
Biased Location								
S191	W251	1	19	16	<4.5		<8.6	
"<" indicates that the actual activity is less than the reported minimum detectable (MDA) activity for that sample.								

*This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was collected at this location.

Table 6-11
Survey Data for Sandblasting and Grinding Area

N/S Coordinate	E/W Coordinate	Biased Sample #	µR/Hour 1cm	µR/Hour 1m	Total U* (pCi/g)	2 sigma error*	Total Th (pCi/g)	2 sigma error*
Unbiased Locations								
S225	W330		12	10	--		--	
S235	W330		12	11	--		--	
S245	W330		12	11	--		--	
S245	W340		10	10	--		--	
S235	W340		8	7	--		--	
S225	W340		8	10	--		--	
S225	W350		8	7	--		--	
S235	W350		6	8	--		--	
S245	W350		8	8	--		--	
S255	W355		14	13	--		--	
S255	W360		12	13	--		--	
S255	W370		15	15	--		--	
S265	W370		14	15	--		--	
S275	W370		14	15	--		--	
S285	W370		16	14	--		--	
S285	W380		17	15	--		--	
S285	W390		14	14	--		--	
S275	W390		22	18	--		--	
S275	W400		16	15	--		--	
S265	W390		14	14	--		--	
S265	W380		14	14	--		--	
S275	W380		7	9	--		--	
S255	W380		17	15	--		--	
S245	W380		14	14	--		--	
S245	W390		15	15	--		--	
S255	W390		16	15	--		--	
S255	W400		16	13	--		--	
S255	W410		16	15	--		--	
S245	W410		15	14	--		--	
S245	W420		8	10	--		--	
S255	W420		13	14	--		--	
S265	W410		15	13	--		--	
Biased Locations								
S245	W400	1	21	18	<5.5		<9	
S253.5	W400	2	30	18	15.7	2.7	<10.1	
"<" indicates that the actual activity is less than the reported minimum detectable activity (MDA) for that sample.								

* This column represents the 2 sigma error (based on counting statistics) associated with the reported U and Th concentration values.

"--" indicates that no sample was taken at this location.

6.3.5 Summary of Unaffected Areas

Gamma surveys of the unaffected areas in general presented no evidence for the presence of radiological contamination. With one exception (S253.5W400), adjacent to the grinding operation northwest of Building 12, gamma exposure rates measured at 1 centimeter above the surface at 385 locations were <30 µR/h. Even at location S253.5W400, the gamma exposure rate at 1 centimeter above the surface was only marginally elevated (30 µR/h), and total U and Th concentrations in a soil/slag sample were only 15.7 pCi/g and <2.7 pCi/g, respectively.

6.4 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of regional background gamma radiation measurements conducted during the present study were approximately 3 µR/h higher than those reported by Berger and Smith (1993) for the same measurement locations (Figure 5-1, Table 6-1). This slight increase may result either from a linear instrument calibration bias (see Figure 6-1) or an increase in the cosmic ray or solar component of the background radiation. The background exposure rate measurements from this study, which averaged 11.9 µR/h at 1 centimeter above the ground surface and 11.5 µR/h at 1 meter above the surface, were used for comparison of onsite measurements to the guidelines for unrestricted release of the site according to *NRC's Branch Technical Position for Disposal or Onsite Storage of Thorium and Uranium Waste from Past Operations* (SECY 81-576). Following guidance in NUREG/CR-5849, site-specific exposure rate guidelines are thus 21.5 µR/h for the average over 100 m^2 at 1 meter above the surface (10 µR/h above background) and 31.5 µR/h for the maximum at any location (20 µR/h above background).

Average total U and Th concentrations for soil samples from background locations reported by Berger and Smith (1993), 3.2 pCi/g and 1.7 pCi/g, respectively, were used for comparison to field-analyzed gamma spectrometric analyses of onsite soil/slag samples. Following guidance in NUREG/CR-5849, site-specific soil concentration guideline values are thus 13.2 pCi/g total U and 11.7 pCi/g total Th for the average over a 100 m^2 area (10 pCi/g above background), and 33.2 pCi/g total U and 31.7 pCi/g total Th for the maximum concentration allowed at any location (30 pCi/g above background).

Gamma radiation exposure rates are within guideline values in all areas of the site, including the potentially affected areas. Additionally most exposure rates are well within the guidelines (in or about background) with only isolated locations exceeding 21.5 µR/h at 1 meter above the surface and none exceeding the maximum exposure rate guideline of 31.5 µR/h. Measured or inferred (Section 6.2.6) U and Th concentrations in soil/slag samples, however, exceed the

maximum site-specific guideline values of 33.2 pCi/g total U and 31.7 pCi/g total Th in localized areas in four of the five potentially affected areas: (1) the Old Pit Area (2 hot spots), (2) the Parking Area (5 hot spots), (3) the Buildings 4 & 5 Storage Area (7 hot spots) and (5) the former Drum Storage Area being remediated. These exceedances are not wide spread and are indicative of discrete point sources (pieces of slag/soil). Removal of these discrete pieces of slag should reduce the areas to below guidelines for unrestricted use. Further remediation will therefore be required in these areas to comply with the guidelines for unrestricted release of the site (NUREG/CR-5849; SECY 81-576).

There is no evidence for residual contamination (localized or general) within the area surrounding the Warehouse and Loading Dock (Figure 6-5). Integrated gamma exposure rates measured at both 1 centimeter and 1 meter above the surface were all well within the range of regional background exposure rates. All soil/slag samples taken from the area had total U and Th concentrations below the minimum detectable activity for the field gamma spectroscopic analyses, with maximum values of <5.2 pCi/g total U and <9.3 pCi/g total Th. Furthermore, a continuous gamma scan of the area, conducted following a 5 meter by 5 meter triangular grid (see Figure 6-7) with the probe held as close as possible to the ground or pavement surface, revealed no areas with exposure rates exceeding the range of background measurements at 1 centimeter above the surface. The Warehouse/Loading Dock Area should, therefore, be considered free of radiological contamination.

Gamma surveys of the unaffected areas in general presented no evidence for the presence of radiological contamination. The single anomaly S253.5, W400 (Figure 2-2, Table 6-10), had marginally elevated gamma exposure rates (30 µR/h at 1 centimeter above the surface, 18 µR/h at 1 meter above the surface) and total U concentrations (15.7 pCi/g). This isolated occurrence does not exceed the maximum guideline values. Thus all developed areas of the of the site previously identified as "unaffected" (Section 6.3) should be considered free of radiological contamination.

Recommendations

The results of the characterization indicate that any residual contamination on the affected areas is localized and the result of discrete pieces of slag material. The slag pieces have concentrations ranging up to a maximum of about 1300 pCi/g for total U and 800 pCi/g for total Th. It is also noted that the exposures resulting from these discrete pieces of slag are within the release criteria guideline at the one meter elevation. Detection of these pieces was the result of checking exposure rates at the 1 cm elevation.

This is consistent with the inverse square low reduction in exposures from point/descrete sources. Additionally, it was noted in the field that the size of the discrete pieces of slag giving rise to measurable exposures was about 5 cm on a side. A theoretical calculation confirms that it would require a 7 cm (2.8 in) cubic "point source" with 1000 pCi/g total U to provide a 30 uR/hr exposure at a 10 cm distance from the cube.

It is suggested therefore that in addition to locating and removing the discrete pieces of slag which gave rise to the elevated exposures at 1 cm elevation in the specific local biased areas, that a coarse screening of material be initiated in these areas. Bulk material screening could be rapidly accomplished using a 2 inch vibratory screen. This could screen bulk material and segregate the 2 inch or greater pieces which could quickly be checked for radiological contaminants. This would provide further assurance that contaminated slag has been removed.

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APPENDIX A

10/93

Procedure for the
Analysis of Radium and Thorium in Soil
By NaI Gamma-Ray Spectroscopy

Cabot Site Project

Theodore E. Rahon, CHP
CoPhysics Corporation

1.0 Introduction

This procedure outlines a method to quantitate radium-226 and thorium-232 concentrations in soil samples using a sodium iodide (NaI)-based gamma spectroscopy system.

2.0 Equipment

- Portable, 80386-based computer
- Aptec Model 1200, 1024 channel MCA card
- Aptec Model 1HV-PC high voltage supply card
- 2" x 2" NaI gamma radiation detector with < 7% peak resolution at 662 keV
- Aptec spectrum acquisition and analysis software
- weighing scale (0 - 1200g, min. 1 g precision)
- Ra-226 standard source (0.036 uCi)
- Ra-226 check source (1 uCi)

3.0 Methodology

3.1 General:

Soil samples in nominal 500 ml jars are to be placed in a fixed geometry with a gamma radiation detector consisting of a NaI crystal and photomultiplier tube, surrounded by a lead shield. The detector is coupled to a computer-based multichannel analyzer (MCA) which has the ability to quantitate the emission rate of characteristic gamma radiation from the radionuclides of interest. The MCA and detector high voltage supply are situated on two circuit boards (AT-bus compatible) in the portable computer.

Generally, this analysis is based on counting the 609 keV gamma-ray emission of Bi-214 for Ra-226 quantification and the 911 keV gamma-ray emission of Ac-228 for Th-232 quantification.
The following sections describe the steps performed during the analysis. All spectrum analysis and mathematics are performed by the software.

3.2 Standardization:

A 0.036 uCi liquid radium-226 standard from the National Institute of Standards and Technology was solidified in a plaster/styrofoam matrix. The matrix contained <1 pCi/g natural radium and was formulated to a density of 1.0 g/cc which is approximately equivalent to that of typical soil. The container used for the standard was identical to those used for samples. The radium-226 counting efficiency (in counts per disintegration) was determined by counting the NIST-traceable source and then dividing the net count rate (cpm) in the 609 photopeak by the activity in the standard (dpm).

The thorium-232 efficiency was obtained by a similar procedure using the 911 keV gamma-ray line. The Th-232 standard was obtained from a mass-determined quantity of thorium oxide (ThO_2) aged to greater than 30 years to allow Ac-228 equilibrium with Th-232.

The efficiency values were placed into the software equation files used for spectrum analysis.

Recalibration should be performed on a semiannual basis, whenever the geometry is changed, or if system components have been changed or repaired. Checks of the efficiency and energy calibrations of the system must be performed on a daily basis using a check source.

3.3 Background Subtraction:

There are two types of background to be subtracted from the photopeak of interest: peak and Compton.

Compton background is due to scatter or escape of photons from higher energy gamma-rays originating mostly from the sample itself. It is calculated by performing a least squares or straight-line fit of the Compton continuum under the photopeak (see Figure 1). The calculated Compton background is then subtracted from the gross photopeak count to obtain the net photopeak count.

Peak background is due to naturally occurring radium and thorium in the surroundings of the counting system. It is determined by performing a count of a deionized water sample and analyzing the resultant spectrum. The net count rate for each background photopeak is subtracted from the corresponding sample photopeaks after Compton background is subtracted.

The radium-226 measurement uncertainty is most effected by the Compton background. Thus, the greater the quantity of K-40 and Th-232 in a sample, the greater the Ra-226 measurement uncertainty.

Another factor to be considered when Th-232 is present in a sample being analyzed for Ra-226 is the contribution of the 583 keV Th-232 line to the 609 keV Ra-226 photopeak. During concentration calculations, the 911 keV Th-232 count rate is used to calculate the 583 keV contribution to the 609 keV photopeak by utilizing the 583 to 911 count rate ratio. This ratio was determined to be 0.72 during calibration with the Th-232 standard. The sample analysis program utilizes this ratio to correct the 609 keV count rate for the presence of Th-232 in the sample.

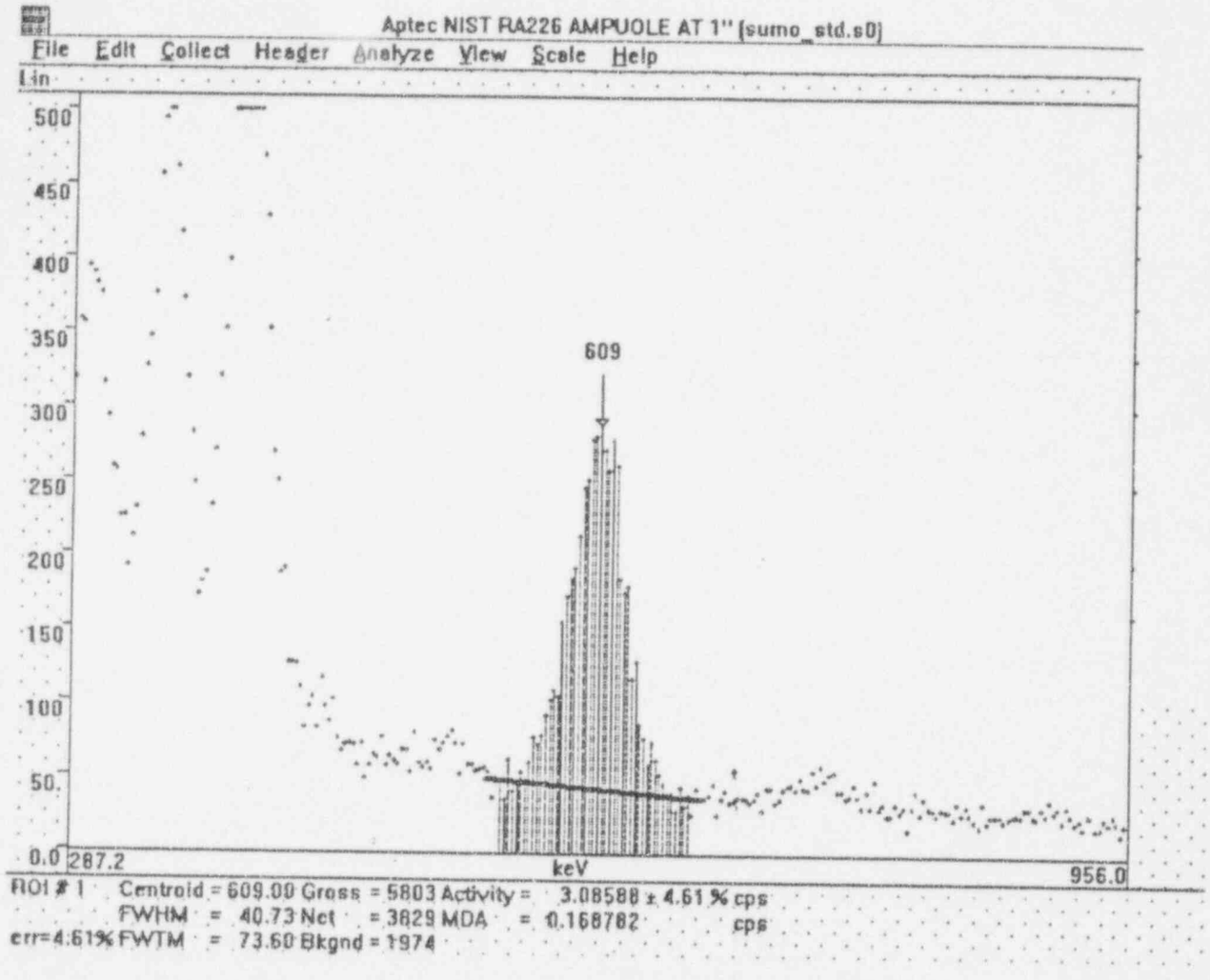

Figure 1 - 609 keV Photopeak showing calculated background line

3.4 Radionuclide Equilibrium:

The radium-226 analysis is based on counting the 609 keV gamma-ray from the progeny radionuclide Bi-214. The method assumes near-equilibrium of the parent with the progeny.

The degree of Bi-214 to Ra-226 equilibrium is based on the Rn-222 half-life (3.8 days) and the fraction of Rn-222 lost to degassing during sample preparation. Radon degassing is normally not a problem and can be kept to an acceptable level (i.e., less than 10-20%) if the sample is containerized soon after collection and no mechanical pulverization or heating is performed. Simple mixing usually does not affect the equilibrium because most of the radon is trapped within the soil particle matrix.

The degree of Ac-228 equilibrium with Th-232 is based on the Ra-228 half-life (6.7 years). For ores aged 30-40 years after processing, the degree of equilibrium is greater than 90 % and no loss occurs during sample mixing.

4.0 Sample Analysis Procedure

All samples are to be treated carefully to avoid spillage which may result in the loss of sample and possible contamination of the lab. No liquids are to be brought into the lab area unless in closed containers. No highly radioactive samples are to be brought into the lab.

The steps for sample analysis are:

a.) Place the sample into the type of container specified by the counting geometry (i.e., 500 mL plastic sample jar).

b.) Determine the net weight of the sample.

c.) Place the sample on the NaI detector in its shielded housing. Close the shield carefully and completely.

d.) Click the computer mouse on the "Count Sample" icon. Enter the sample ID, net weight, date of collection, and any additional information into the data entry window.

e.) Start the count by using the computer mouse to close the data entry window.

The computer is programmed to acquire and analyze the spectrum and to print out the results in pCi/g of Ra-226 and Th-232 and their uncertainties. The spectrum will be saved on the computer's hard disk. The saved spectra should be periodically backed-up to tape or floppy disks for permanent filing.

All analysis parameters such as counting time are preset to provide a specified lower limit of detection. To change the presets or run a different analysis, see the Aptec PC/MCA reference manual for instructions.

The equations used to calculate the radionuclide concentrations and uncertainties are listed in the equation template file (see appendix).

5.0 Quality Assurance:

5.1 Background Count:

Count a sample of deionized water as specified in 4.0 above, however, use the "Background Count" icon. The software will analyze the spectrum, determine the peak background values and print out a background analysis report which should be reviewed and filed. The report will warn the user if the background values have changed significantly from the preprogrammed values. The user must investigate the source of the problem upon such a warning. The background procedure shall be conducted once per day and the result entered into the appropriate Quality control record (see 5.4).

5.2 Standardization Check:

The efficiency and energy calibrations are performed on a semiannual basis, whenever the geometry is changed, or if system components have been changed or repaired. However, to ensure proper operation on a routine basis, a check source is counted daily.

Count the source as specified in 4.0 above, however, use the "Count Check Source" icon. The software will analyze the spectrum, determine the count rates and energy calibration values and print out a check source analysis report which should be reviewed and filed. The report will warn the user if the energy or efficiency calibration values have changed significantly from the preprogrammed values. The user must investigate the source of the problem upon such a warning. The source check procedure shall be conducted once per day and the result entered into the appropriate Quality control record (see 5.4).

5.3. Other Quality Assurance Tests:

a.) Duplicate or repeat sample analysis: Duplicate, or "split", samples of soil or other media provide an estimate of the precision of the laboratory's gamma spectroscopy analysis results. Because soil is not a matrix conducive for homogenous splitting, repeat counting of samples is more appropriate for such comparisons. The laboratory should recount 1 out of every 20 samples to meet the duplicate analysis requirement. The results of the duplicate analysis along with the uncertainties must be entered into a cumulative table.

b.) Blanks: Blanks are essentially background samples (e.g., water) that contain non-detectable levels of radioactivity. Analysis of these samples provides a means to calculate the lower limit of detection (LLD) for specified nuclides. The counting of daily background samples meets the requirement for analyzing blanks. The results of the blank analysis along with their uncertainties must be entered into a cumulative table.

c.) Spiked samples: Spikes are essentially radioactivity standard samples that contain a calibrated quantity of radioactivity. Analysis of these samples provides a means to check the detector efficiency and energy calibration. The performance of daily source checks meets the requirement for analyzing spikes. The results of the check source analyses along with their uncertainties must be entered into a cumulative table.

5.4 QA Reports:

The QA reports (duplicate, standard, and background) provide a record of system quality assurance. The QA reports shall be kept in a labeled binder. In addition, the results of background and source check tests shall be kept in an on-going table or graph.

5.5. QA Criteria - The laboratory must comply with the following criteria for each type of quality control check:

a.) duplicates: 90% of the results must fall within 2 standard deviations of each other; all results must fall within 3 standard deviations of each other.

b.) blanks: all results must be within +/-3-sigma of the mean (the mean is calculated from the previous twenty results).

c.) Standardization checks: all results must be less than +/-3-sigma of the initial reference calibration value

The person responsible for the system shall review and analyze the data with comparisons to the above guides at least on a quarterly basis and so note the review in the gamma spectroscopy logbook, on the last QA report of the quarter. If the laboratory fails to meet any one of these guides, then the project manager shall be notified in writing. The notification shall include the test results in question and an explanation of the criteria used to initiate this action. Actions necessary to correct the problem must be taken before additional samples are analyzed.

Appendix A
Equations Used in Gamma Spectroscopy Calculation Programs

EV1
911 EFF TH232
CPM/DPM (ROI1)
9.81E-4

Note: EV1 denotes "Equation Value #1"

RN1 = net count rate for peak 1 (911 keV)
RN2 = net count rate for peak 2 (609 keV)

EV2
609 EFF RA226
CPM/DPM (ROI2)
1.75E-3

EV3
911 BKG TH232
CPS (ROI1)
0.004

EV4
609 BKG RA226
CPS (ROI2)
0.053

EV5
TH # OF CHN
62

EV6
RA # OF CHN
47

EV7
TH CNT RATE
cps
RN1/LT

EV8
RA CNT RATE
cps
RN2/LT

EV9
TH CONC
pCi/g
(RN1/LT-EV3)/EV1 * 60.0 / 2.22 / SQ

EV10
RA CONC
pCi/g
IF RN1<0 (if no thorium detected)
(RN2/LT-EV4)/EV2* 60.0 / 2.22 / SQ
ELSE (if thorium detected, subtract contribution of 583 keV peak, i.e. 72% of 911 count rate)
(((RN2/LT)-(0.72*RN1/LT)-EV4)/EV2)*60.0/2.22/SQ

EV11
TH BKG VAR (variance)
CPS^2
RB1/LT/LT*EV5/8 <- EV5/8 is the # of ROI channels/ # of endpt channels[1]

EV12
PRINT
RA BKG VAR (variance)
CPS^2
RB2/LT/LT*EV6/8 <- EV6/8 is the # of ROI channels/ # of endpt channels[1]

EV13
TH ST'D ERROR
PCI/G
SQRT((EV3/LT)+EV11+(RG1/LT^2))*60.0/EV1/2.22/SQ

EV14
RA ST'D ERROR
PCI/G
IF RN1 <= 0 (if no thorium detected)
SQRT((EV4/LT)+EV12+(RG2/LT^2))*60.0/EV2/2.22/SQ
ELSE (if thorium detected, add uncertainty due to contribution of 583 keV peak)
SQRT(0.72*(RG1/LT^2) +(EV4/LT)+EV12+(RG2/LT^2))*60/EV2/2.22/SQ

EV15
TH CRIT LEVEL (LC = Critical Level, or "Less Then Level)
PCI/G
2.33*SQRT((EV3/LT)+EV11)*60.0/EV1/2.22/SQ

EV16
RA CRIT LEVEL
PCI/G
IF RN1 <= 0 (if no thorium detected)
2.33*SQRT((EV4/LT)+EV12)*60.0/EV2/2.22/SQ
ELSE (if thorium detected, add uncertainty due to contribution of 583 keV peak)
2.33*SQRT(0.72*(RG1/LT^2)+(EV4/LT)+EV12)*60/EV2/2.22/SQ

EV17
TH LC CHECK
IF EV9 < EV15
EV15
ELSE
LESS THAN LEVEL

EV18
RA LC CHECK
IF EV10<EV16
EV16
THEN
LESS THAN LEVEL

[1] Normally the variance of a single count rate = the count rate/time. However, in a multichannel analysis, the line separating the background counts from the net counts under a photopeak varies with the uncertainty in the line's endpoints, not the entire background continuum. In this analysis, 4 low end points and 4 high end points are used to draw the background line. Thus, the background variance in equations 11 and 12 are corrected by a factor of: the number of ROI channels/8.

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