Prepared by
Oak Ridge Associated
Universities

Prepared for
Division of Fuel
Cycle and
Material Safety

U.S. Nuclear
Regulatory
Commission

RADIOLOGICAL SURVEY

OF THE

AMAX SITE

PARKERSBURG, WEST VIRGINIA

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Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT

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INTRODUCTION

Beginning in 1957, Carborundum Co., near Parkersburg, WV, produced zirconium metal for the naval reactor program. During 1961 and 1962, Nigerian zircon ore, containing up to 6% thorium and 0.2% uranium, was processed under an Atomic Energy Commission (AEC) license. The use of Nigerian ore ended in 1962. From 1965 to 1967, AMAX Inc. and Carborundum operated the plant jointly and in 1967 AMAX became sole owner of the business.

Drums of Nigerian ore and residuals from the 1961-62 process were stored onsite in steel drums until 1968, at which time considerable deterioration and loss of contents had occurred. Ore, residuals, and some contaminated soils were packaged and disposed of by burial at Morehead, KY. Laboratory-scale experiments with zirconium ores containing <0.5% uranium and thorium were conducted from 1974 to late 1975 under a license from the Nuclear Regulatory Commission (successor agency to the AEC). In 1977, following disposal of ores and residuals from these experiments, a closeout inspection of the site was conducted for the NRC. This inspection identified soil contamination above levels acceptable for release of the property. A cleanup was performed and contaminated soil was removed and disposed of at an approved burial site.

Following this cleanup, the property was sold to L.B. Foster, Co., for the construction of a pipe manufacturing plant. While the plant was being constructed, pyrophoric materials (probably zirconium metal) were uncovered and construction ceased. AMAX repurchased the site in 1978 and commissioned radiological, geological, and hydrological surveys of the area.

The radiological assessment of the site was performed by Chem-Nuclear Systems, Inc.[1] Areas where direct radiation and soil contamination still exceeded NRC decommissioning guidelines for unrestricted use were

identified. Direct radiation levels ranged from 10-900 μR/h at 1 m above the surface. Most of the contamination was in the upper 10 cm of soil; however, elevated levels were noted down to 5 m in the vicinity of some building foundations. Thorium concentrations up to 3600 pCi/g were measured in soil. Contamination was identified in major drainage ditches and in sediment from the storm drain outfall. Although not confirmed, some contamination of trenches and other drainage systems was suspected.

AMAX developed a plan to remove the contaminated soil and debris and place it on the concrete pads of the abandoned pipe manufacturing plant, where pyrophoric material and additional radionuclide contamination were already present. The material was to be stabilized by covering the area with a clay cap. Chem-Nuclear Systems provided radiological support for the cleanup and stabilization operations. Additional details concerning the site and the cleanup and stabilization are contained in the Environmental Impact Appraisal, Docket No. 40-8355, prepared by the Nuclear Regulatory Commission,[2] and the AMAX Stabilization Plan, prepared by AMAX Environmental Services, Inc.[3] The Nuclear Regulatory Commission requested that the Radiological Site Assessment Program of Oak Ridge Associated Universities verify the adequacy of the decontamination and stabilization activities.

Appendix A provides a brief summary of the site history. The thorium and uranium decay series are presented in Appendix B to aid in interpretation of the data.

SITE DESCRIPTION

AMAX, Inc., is located on the east bank of the Ohio River in an area known as Washington Bottom, approximately 12 km west southwest of Parkersburg, West Virginia (see Figures 1 and 2). The site occupies a total of 152 hectares, of which 51 hectares have been developed for commercial use. A portion of this site is presently leased to L.B. Foster, Co. (Foster), a pipe manufacturing firm. Foster occupies a small office building, a warehouse, and two pipe fabrication buildings. Other

structures or features on the property include a water storage tank, a railroad spur, numerous old building foundations (concrete pads), the two floor slabs at the original site of the L.B. Foster pipe fabrication plant (now covered by the stabilization pile), and several pump houses and other small support buildings. Portions of the storm drainage system and other underground trenches and piping still remain but are largely unused and blocked with debris. Originally, this drainage system consisted of several lines, running primarily in a north-south direction, in the vicinity of the office and old building foundations. A single line carried the combined effluents west toward an outfall at the Ohio River. A plan view of the site and adjacent property is shown in Figure 3. Figure 4 is an aerial photograph of the same area.

The AMAX site is situated on a riverbank terrace. Adjacent property is industrial and agricultural; the nearest residence is approximately 0.6 km to the south. The northern portion of the property is generally clear of underbrush and trees. Heavy brush and weeds are present on part of the southern area with larger trees along the property boundary and drainage ditches. There are also several small, isolated swampy regions on the southern portion of the property. Surface drainage is generally towards the Ohio River. A ditch along the railroad to the east and a ravine originating on the southern boundary of the site are major drainage paths. The latter extends for approximately 400 m into property owned by the Monongahela Power Company and currently leased as farmland. Surface soils are clay, sandy clay, and silt. They are well drained, being underlain by sand and gravel; bedrock is at approximately 30 m. Ground water is at about 15 m and flow is generally towards the Ohio River.

SURVEY PROCEDURES

Objectives

The objectives of this project were:

1. to evaluate the adequacy and accuracy of the soil sampling and analytical techniques used by Chem-Nuclear Systems, Inc.;

2. to evaluate the effectiveness of decontamination operations; and

3. to determine the radiological status of the site, following cleanup, backfilling, and stabilization.

Procedures

Grid Reference Systems

Before decontamination operations began, AMAX contractors established a 25 ft grid system over the area of the site in which contamination was anticipated. This grid was expanded, as required, based on findings as the survey progressed (Figure 5). During the decontamination activities, this grid system was used by both Chem-Nuclear and ORAU; however, much of it was destroyed during backfilling operations. Therefore, ORAU established two new 20 m grid systems for use during the post-remedial action survey (see Figure 6). One of these was established north of the railroad spur, over what is referred to as the pad area (Figure 7). The other was south of the spur over the stabilized pile (Figure 8). A simple survey reference system was established along the ravine by dividing its length into 20 m intervals with markers placed 5 m to either side of the centerline (Figure 9).

Walkover Surface Scans

Walkover surface scans of the site were performed during decontamination activities and following cleanup and stabilization, to identify locations of residual surface contamination. Scans were conducted by traversing the area with NaI(Tl) gamma scintillation detectors held near the ground surface and noting locations of increased radiation levels. Scanning intervals were generally 1-2 m in gridded areas and in the vicinity of ditches, roads, railroad tracks, buildings, foundations, or other locations where experience indicated a potential for contamination.

Following stabilization the pile was scanned at 5 m intervals. Other areas of the property were scanned in a more random fashion with intervals ranging from 2 to 10 m.

Soil Sampling and Analysis

Chem-Nuclear collected and analyzed soil samples from the surface of cleaned grid blocks and other decontaminated areas. These samples were composites of soil collected randomly from throughout the regions of interest. Radionuclide concentrations in these samples were determined by gamma scintillation spectrometry, using a procedure developed specifically for the AMAX project. To evaluate the adequacy of the Chem-Nuclear sampling and analysis procedures, ORAU duplicated the composite sampling procedure for eight grid blocks and analyzed these samples and aliquots from ninety-one Chem-Nuclear samples by solid state gamma spectrometry.

Seventy-two subsurface samples from beneath the concrete pads forming the old building foundations were collected by Chem ear and provided to ORAU for analyses. These samples were obtained by breaking a hole through the concrete and collecting the exposed soil with a shovel or posthole digger. Soil samples were also collected from selected locations of elevated direct radiation, identified by the walkover scans. These locations are indicated on Figures 10 and 11.

Following backfilling and stabilization, surface soil samples were collected from the pad area, ravine, and the stabilization pile. Locations of these samples are shown on Figures 12, 13, and 14.

Subsurface samples were obtained on the periphery of the decontaminated pad area and in the ravine. Shallow boreholes (to 1 m depth) were drilled to the desired depth with a motorized auger, loose debris removed from the hole, and the sample collected using a posthole digger. Subsurface sampling locations are indicated on Figures 12 and 13.

Measurement of Direct Radiation Levels

Following the completion of cleanup and stabilization, direct gamma and beta-gamma radiation levels were measured. Gamma exposure rates were measured at the surface and 1 m above the surface at each intersection of major grid lines, using gamma scintillation detectors. Along the ravine, these measurements were also performed at 20 m intervals on the centerline and 5 m either side of the centerline.

Beta-gamma dose rates were measured 1 cm above the surface at locations where exposure rates were measured. These measurements were performed using thin window ($7 mg/cm^2$) "pancake" GM detectors. To evaluate contributions from non-penetrating radiations, measurements were also made with the detector shielded.

Sediment Sampling

Sediment samples of 1 kg each were collected from the Ohio River at, and downstream of, the outfall of the storm sewer system leaving the site. Samples were also collected from accessible locations in the on-site storm sewer system. Sample locations are indicated on Figure 15.

Water Sampling

Water samples were collected from the storm sewer outfall at the Ohio River and from a well (30 m depth) situated to the northeast of the office building (refer to Figure 15).

Baseline and Background Measurements

Six soil samples were collected at least 0.5 km from the AMAX site to serve as baseline samples for comparison with the other results of this survey. Direct radiation levels were also measured at the locations of the soil samples to provide background measurements for comparison. The locations of the baseline soil samples and background measurements are indicated in Figure 16.

Analytical Procedures

Soil and sediment samples were analyzed by gamma spectrometry for Th-232, Th-228, U-238, Ra-226, and other identifiable gamma-emitting radionuclides. Water samples were analyzed for gross alpha and gross beta concentrations. Appendix C contains a list of the major equipment and instrumentation used for this survey. Analytical procedures are described in Appendix D.

RESULTS

Background Radiation Levels and Baseline Concentrations

Background exposure rates measured in the Parkersburg, West Virgina, area ranged from 10 to 15 μR/h.

Baseline radionuclide concentrations in soil are presented in Table 1. Total thorium (Th-232 + Th-228) concentrations ranged from 0.46 to 2.70 pCi/g (1.57 pCi/g average), Ra-226 concentrations ranged from 0.28 to 0.85 pCi/g (0.53 pCi/g average) and U-238 concentrations were below the minimum detectable activities. These concentrations are typical of those naturally occurring in soil.

Evaluation of Sampling and Analytical Procedures

Comparisons of thorium concentrations in composite samples, independently collected from the same grid blocks by ORAU and Chem-Nuclear, are presented in Table 2. Five of these replicate samples (from grid blocks 71, 89, 117, 146, and 151) are in close agreement. The other three pairs (from grids 4A1, 17, and 65) differ substantially. In two of the three (4A1 and 65), the ORAU-collected sample had higher thorium levels than the Chem-Nuclear sample. In the other sample set (grid 17) the ORAU-collected

sample had a lower concentration. These differences indicate the limitations inherent in attempts to obtain representative samples, where contamination is spotty, localized, or nonhomogeneous. It is important to note that, although localized areas with high levels of contamination may not be identified by the composite sampling procedure, such areas will be identified by direct surface measurements.

The results of measurements performed by ORAU and Chem-Nuclear on 30 of the 91 duplicate samples are presented in Table 3. These samples represent the initial 30 grid blocks where decontamination and soil sampling activities were performed.

The total thorium concentrations, as measured by ORAU, ranged from <1 to 132 pCi/g. Chem-Nuclear analyses of the same soil samples ranged from 1.4 to 139 pCi/g. A one way analysis of variance indicated no significant differences between the ORAU and Chem-Nuclear analyses at a 99% confidence level. Comparable agreement was also noted in the remainder of the duplicated analyses. Overall, the sampling and analytical procedures adopted by Chem-Nuclear for this site appear adequate.

Thirty soil samples were also selected for analyses to determine concentrations of Ra-226 and U-238 and their ratios to the thorium concentrations. The Ra-226, Th-232, and Th-228 analyses were by gamma spectrometry; the U-238 analyses were by neutron activation. Results are presented in Table 4. In each of these samples Th-232 and Th-228 are present in near equilibrium. The U-238 levels ranged from 0.03 to 1.34 times the total thorium concentrations (0.42 average) and the Ra-226 ranged from 0.01 to 1.37 times the total thorium levels (0.31 average). This wide range is possibly the result of the various ores processed at the facility as source material. Although it is apparent that thorium is the primary radionuclide contaminant in the soils from the AMAX site, nuclides from the uranium decay series are also present at significant concentrations, and these other contaminants may require consideration when evaluating the total radiological character of the site.

Surveys to Evaluate Decontamination Efforts

Walkover Scans

Gamma scans performed after initial decontamination efforts identified numerous locations of elevated direct radiation. It was apparent that contamination existed in isolated locations outside the main remedial action area and at greater depths than were initially anticipated. These locations were brought to the attention of AMAX and Chem-Nuclear personnel and further decontamination was performed. Soil removal down to a depth of 3-4 m was required in some areas. In several locations, decontamination efforts were terminated without complete removal of residues. One of these locations was in grid 52, where further soil removal was considered a potential threat to the stability of the nearby water tower. Another was near a section of concrete pad (grids 174 and 190). Here, decontamination efforts were continued to a point mutually agreed upon by AMAX and the NRC.

Walkover scans conducted before backfilling indicated remaining isolated areas of surface contamination. These areas are shown on Figure 11. Contact exposure rates ranged up to 350 μR/h. These areas were all below the normal grade elevation; some areas were 3-5 m below grade. It should be noted that backfilling was performed at some locations before a confirmatory walkover scan could be completed. The final contamination status of these areas is therefore unconfirmed.

Radionuclide Concentrations in Soil

Table 5 presents radionuclide concentrations in samples, collected from selected locations of elevated contact radiation levels, prior to backfilling. Thorium concentrations in these samples ranged from 0.73 to 318 pCi/g. Radionuclide concentrations in 72 samples collected from beneath two concrete pads are presented in Table 6. Samples from grid 46 contained thorium concentrations of 4246 and 5604 pCi/g. Further soil

removal was performed in that area prior to backfilling. Other samples from beneath the pads had much lower thorium concentrations; many were in the range of typical soil baseline levels.

Surveys Following Backfilling and Stabilization

Walkover Surface Scans

Surface scans conducted after completion of remedial action and stabilization identified several areas of slightly elevated surface radiation levels. These were near drains, in cracks and around the edges of concrete foundations, along the old railroad bed near the eastern boundary, and at a few additional miscellaneous locations. These areas were all small and isolated and were not indicative of significant quantities of residual thorium contamination. Exposure rates at 1 m above the surface at of these locations were in the range of normal background levels.

Direct Radiation Levels

Direct radiation levels measured at grid line intersections are presented in Tables 7, 8, and 9. On the grid established over the pad area, the gamma exposure rates at grid line intersections ranged from 8 to 26 μR/h, (14 μR/h, average) at the surface and from 7 to 20 μR/h (13 μR/h, average) at 1 m above the surface. The highest levels were on the northern and eastern edges of the grid system, i.e. the limits of the area excavated. Beta-gamma dose rates at the surface ranged from 19 to 146 μrad/h (46 μrad/h, average). Gamma exposure rates measured at the grid line intersections over the stabilization pile ranged from 9 to 20 μR/h (11 μR/h, average) at the surface and from 9 to 12 μR/h (11 μR/h, average) at 1 m above the surface. Beta-gamma dose rates ranged from 22 to 88 μrad/h (39 μrad/h, average).

In the ravine, the systematically measured surface gamma exposure rates ranged from 11 to 20 μR/h (15 μR/h, average) and the exposure rates at 1 m ranged from 11 to 19 μR/h (15 μR/h, average). Surface beta-gamma dose rate

measurements ranged from 32 to 67 μrad/h (48 μrad/h, average). The slightly higher than average direct radiation levels south of the 300 m point probably occur because the excavation activities were not extended past this point.

Radionuclide Concentrations in Soil

Radionuclide concentrations in surface and subsurface samples, collected after backfilling and stabilization, are presented in Tables 10, 11, and 12. Total thorium concentrations in samples collected in the pad area ranged from 0.94 to 12.1 pCi/g (3.80 pCi/g, average). The samples collected from the stabilization pile had thorium concentrations ranging from 0.78 to 4.54 pCi/g (1.74 pCi/g, average). Soil samples collected at the grid intervals along the ravine had total thorium concentrations ranging from 0.57 to 6.76 pCi/g (3.47 pCi/g, average). Two surface samples collected at isolated locations of elevated exposure levels along the ravine had thorium concentrations of 41.7 and 60.0 pCi/g (refer to Table 13). These areas of contamination were small and adjacent soils did not have elevated direct radiation levels. Overall, the thorium concentrations in surface soil were only slightly above baseline levels. Thorium concentrations in the subsurface samples were, on the average, slightly lower than the surface soil samples.

Radionuclide Concentrations in Sediment

Radionuclide concentrations in the sediment samples are presented in Table 14. The thorium concentration in sediment at the storm sewer outfall to the Ohio River was 31.1 pCi/g. Levels decreased with increasing distance downstream from the outfall; at 40 m and 60 m downstream, the concentrations were in the range for baseline soil.

Radionuclide concentrations in sediment from the on-site storm sewer system varied considerably. Total thorium concentrations in two samples from the storm sewer line west of the office building were 140 pCi/g and 164 pCi/g. Other sewer samples had concentrations at, or near, baseline levels. The highest levels were in the sediment, collected from manholes,

where undissolved material in the effluents could settle and accumulate. Sediment was not present in other portions of the storm sewer system which were examined. It is unknown whether contamination is present in those sections of the sewer system that were inaccessible.

Radionuclide Concentrations in Water

Table 15 presents the radionuclide concentrations in the water samples collected from the outfall of the storm sewer and from the on-site well. Following filtration of the storm sewer sample, both the filter and filtrate were analyzed. In each of these, and in the well water sample, the radionuclide concentrations were typical of those normally encountered in groundwater.

SUMMARY

At the request of the Nuclear Regulatory Commission, the ORAU Radiological Site Assessment Program performed a survey to evaluate effectiveness of remedial action at the AMAX property near Parkersburg, West Virginia. As part of the survey, ORAU evaluated the sample collection and analytical procedures of Chem-Nuclear Systems, Inc., the health physics contractor for the cleanup; both sampling and analytical procedures appeared adequate. Additional analyses identified radionuclides of the uranium decay series. These were present in lower concentrations than the thorium but are of importance in defining the complete radiological character of the site.

Gamma surface scanning identified areas of elevated direct radiation, which had not been removed during remedial action. These were brought to the attention of Chem-Nuclear and AMAX representatives, and most of these areas received further decontamination. However, some small areas of elevated direct radiation, resulting from thorium contamination, were not thoroughly eliminated. One of these locations was immediately north of the water tower. Decontamination efforts were halted at this location because of concern that further soil removal would undermine the foundations of the

tower. Another area was beneath one of the old building foundations just north of the railroad spur. Here, decontamination proceeded to an extent deemed acceptable by both AMAX and the NRC. Some areas were backfilled before ORAU could confirm that they had been adequately decontaminated. It is therefore possible that additional small deposits of subsurface contamination remain at the site. All areas with known or possible residual thorium contamination are at least 0.5 m below grade; most are deeper than 1 m below the surface after backfilling.

Direct measurements and sampling after backfilling and stabilization indicated that surface radiation levels and thorium soil concentrations average only slightly above background and baseline values. Sediments in some of the on-site storm sewers and at the storm drain outfall to the Ohio River contained elevated concentrations of thorium. Water from the storm sewer system did not contain radionuclide levels above typical baseline concentrations.

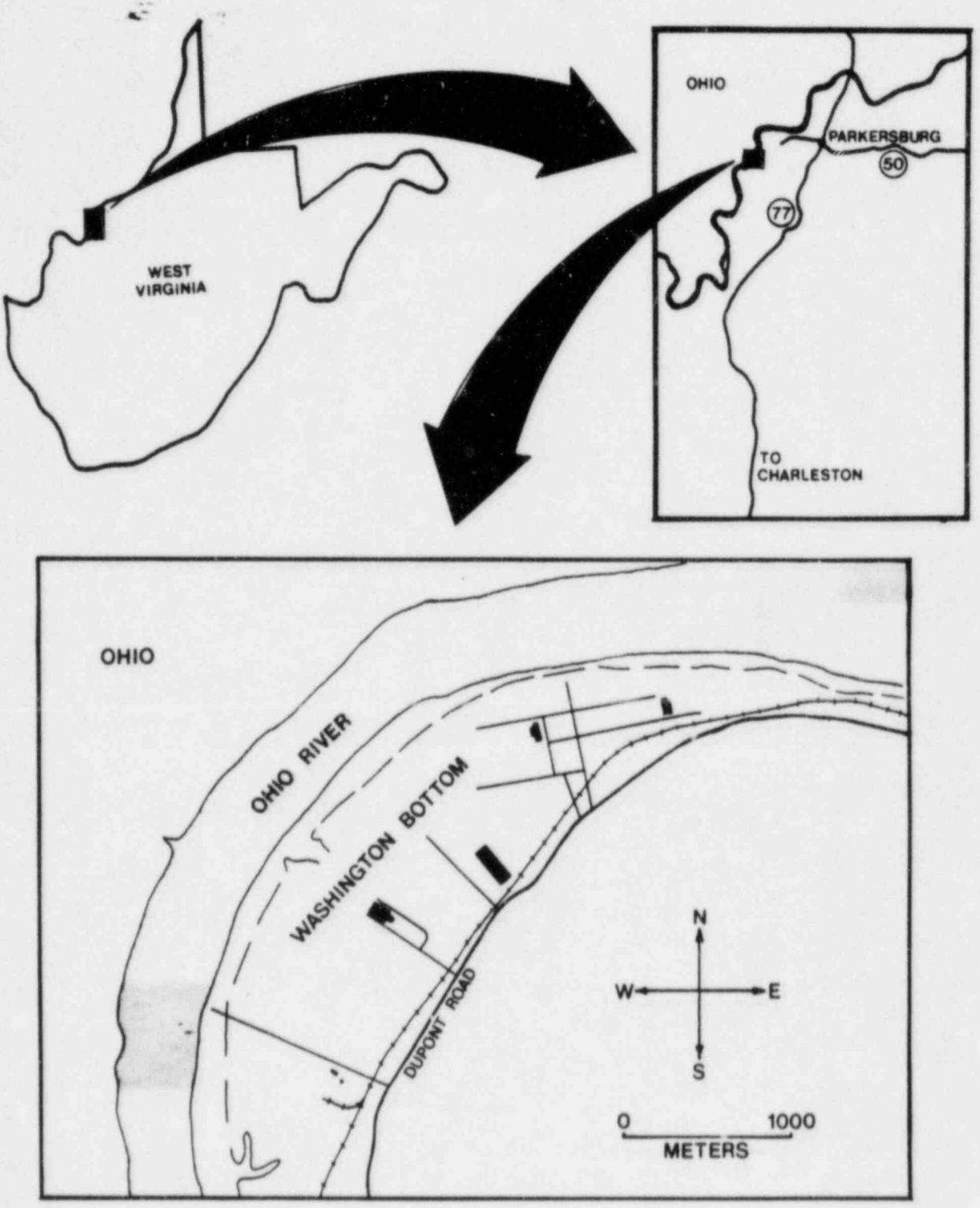

FIGURE 1. Map of Northwestern West Virginia Indicating the Location of Washington Bottom.

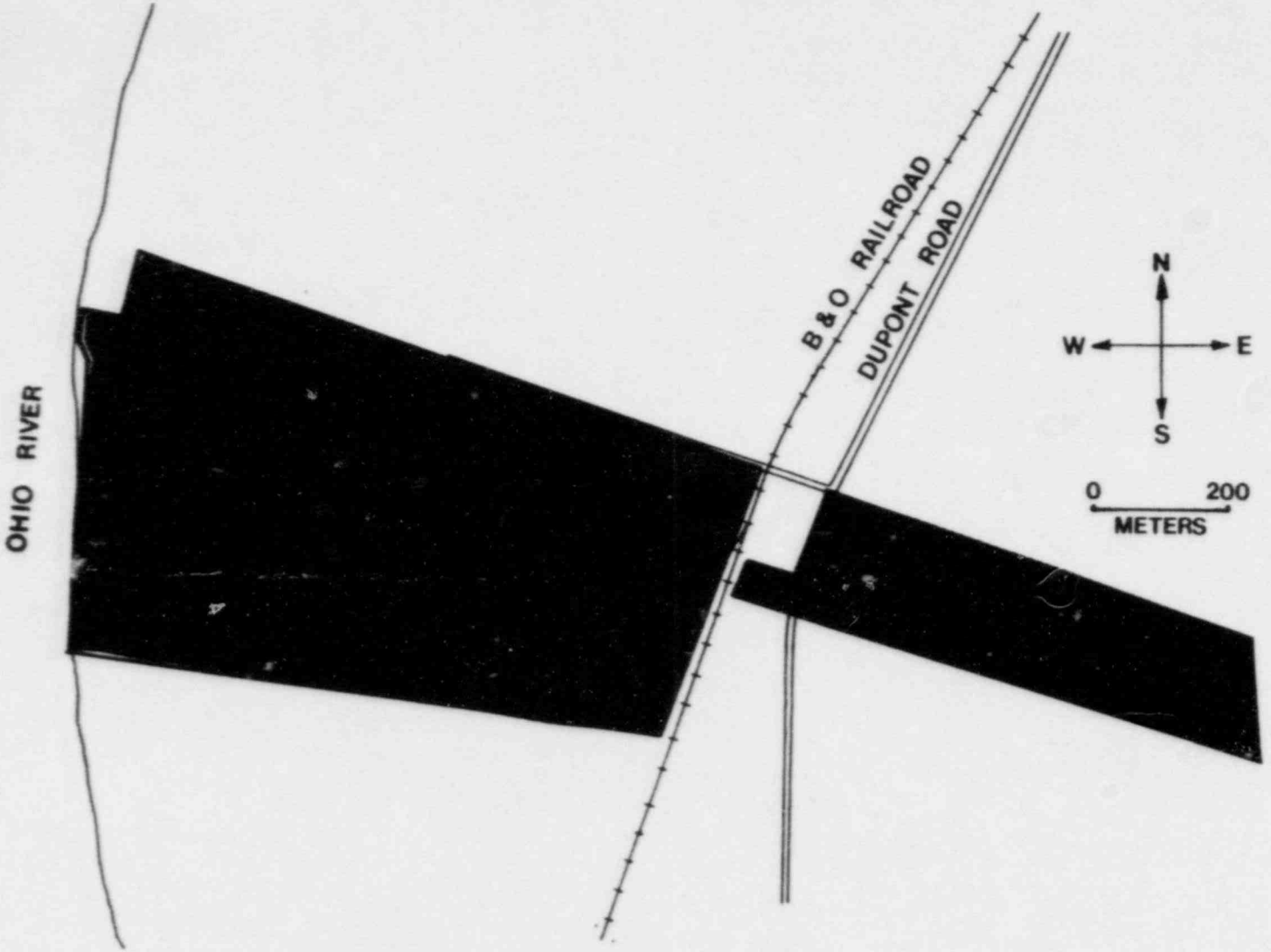

FIGURE 2. Portion of Washington Bottom Indicating the AMAX Property.

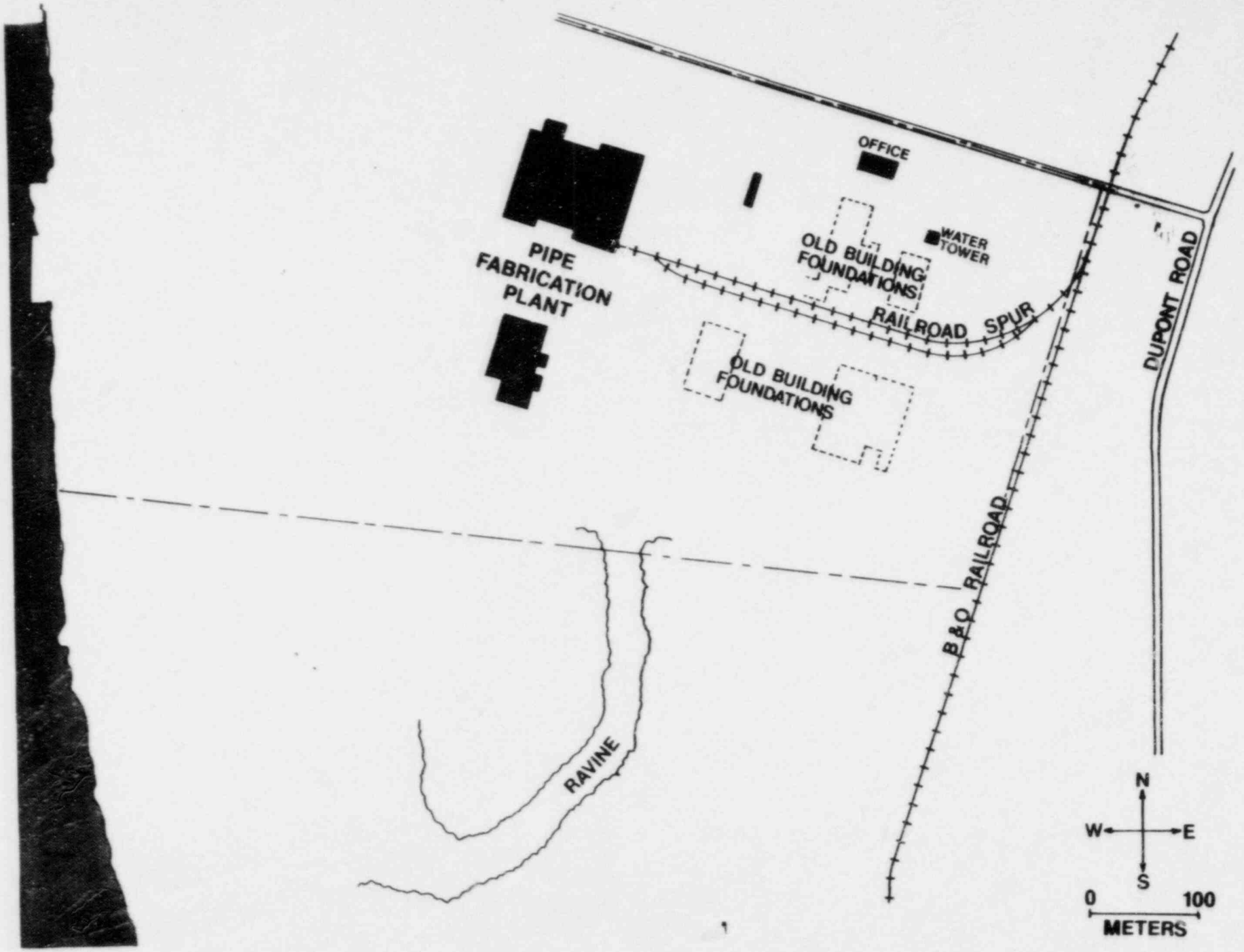

FIGURE 3. Plan View of the AMAX Property.

FIGURE 4. Aerial Photograph of the AMAX Property.

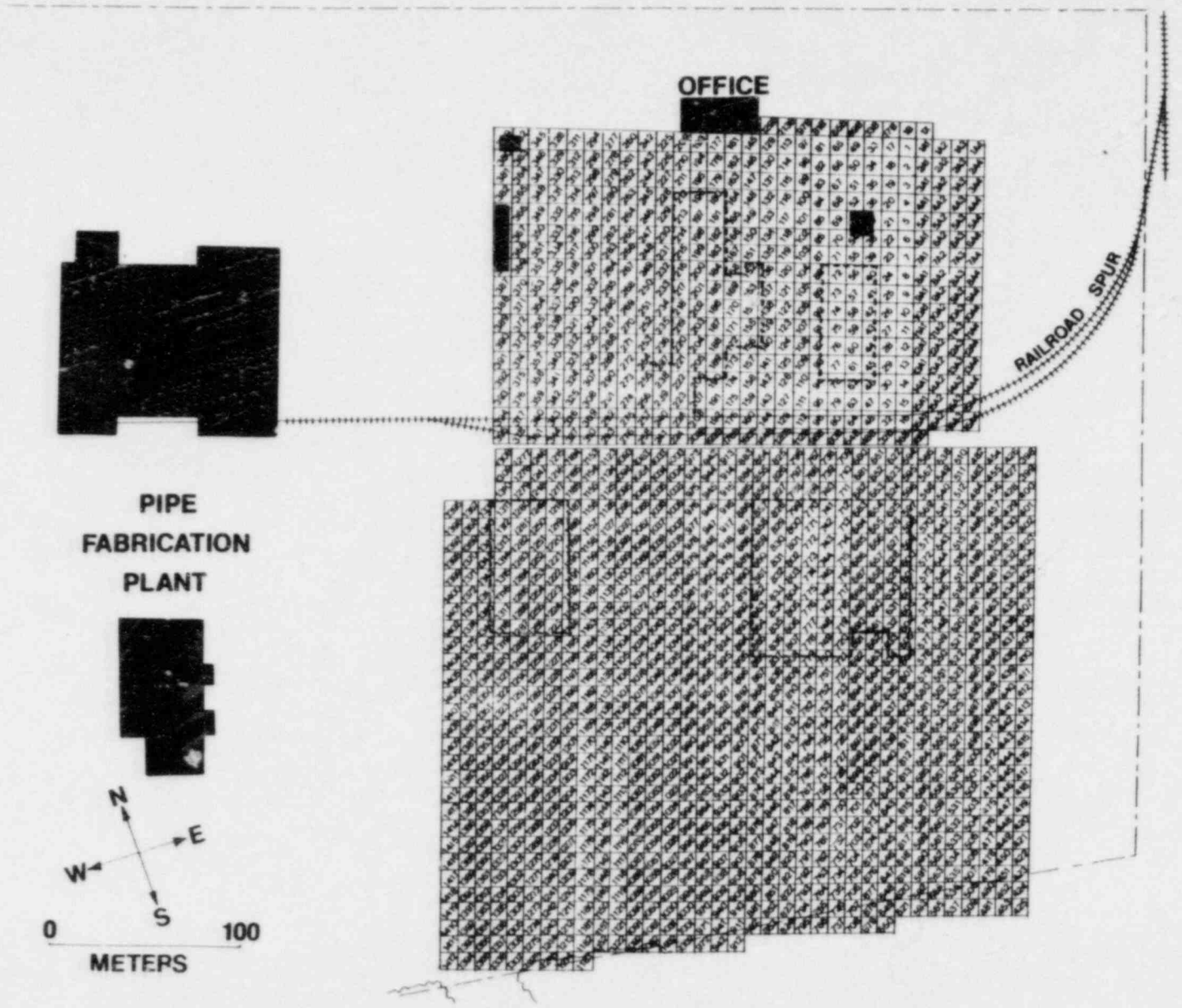

FIGURE 5. Grid System Established by AMAX for Survey Reference.

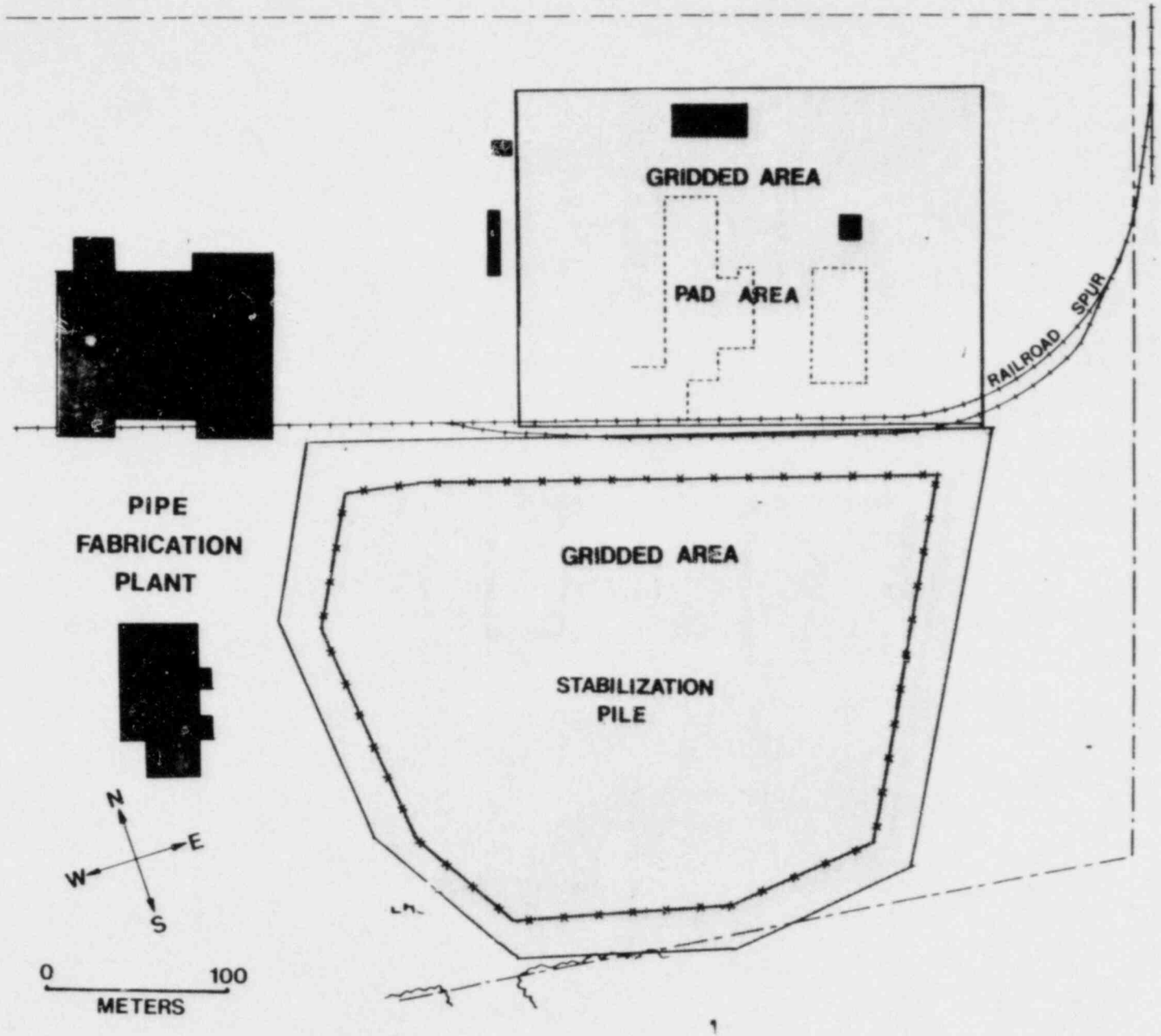

FIGURE 6. Location of Grid Systems Established by ORAU on the AMAX Property.

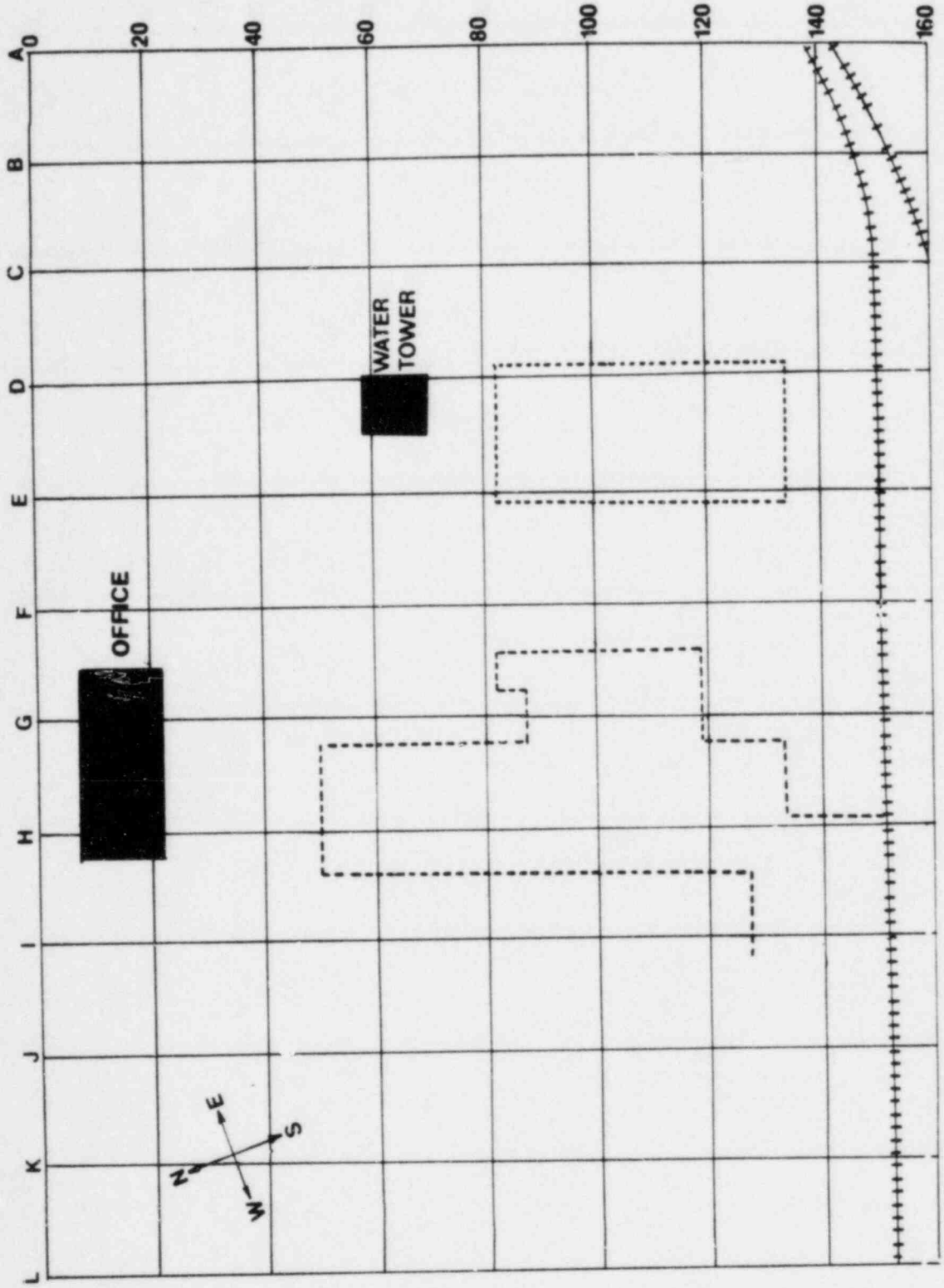

FIGURE 7. Grid System Established by ORAU for Survey Reference Over the Stabilization Pile

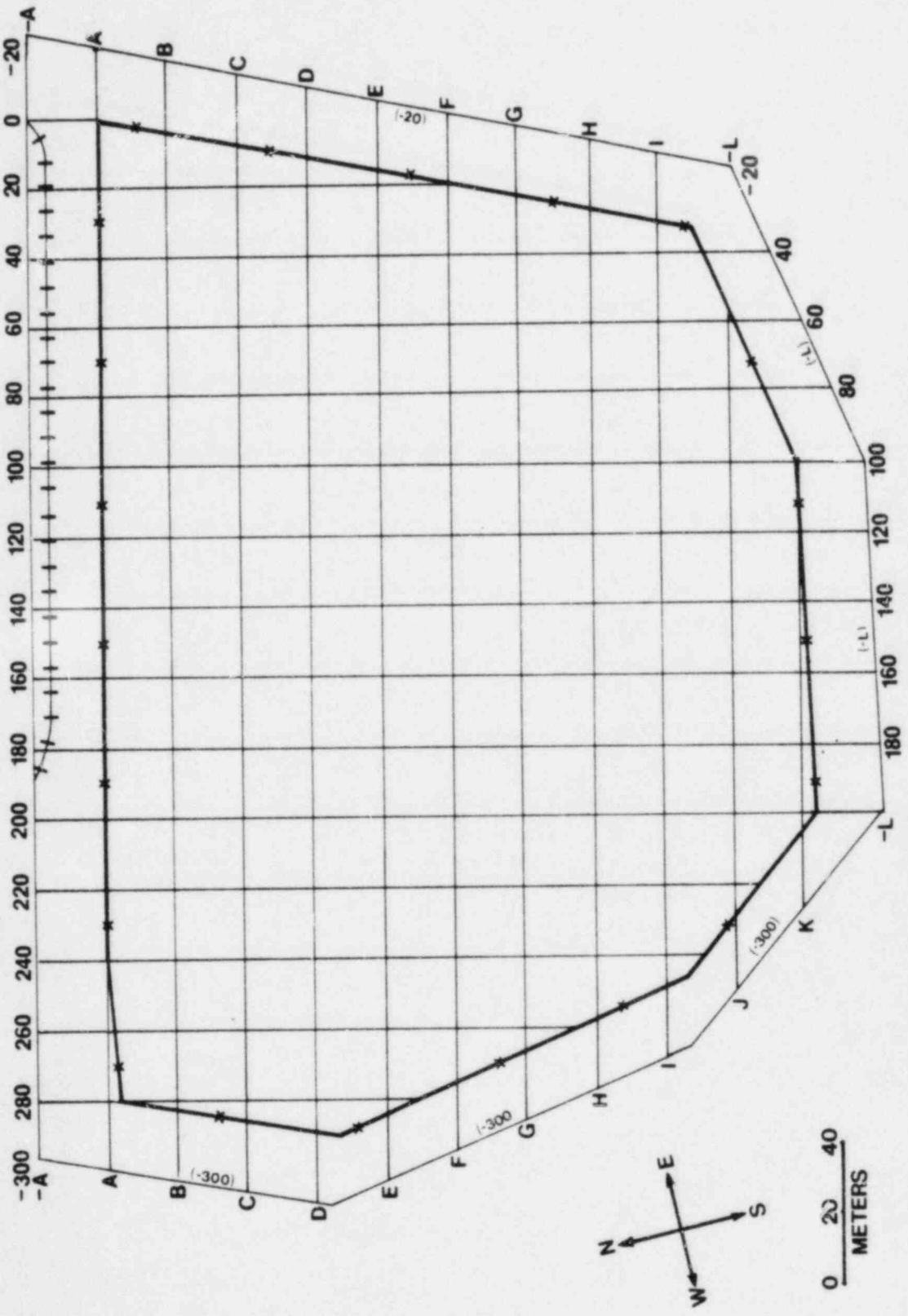

FIGURE 8. Grid System Established by ORAU for Survey Reference Along the Stabilization Pile.

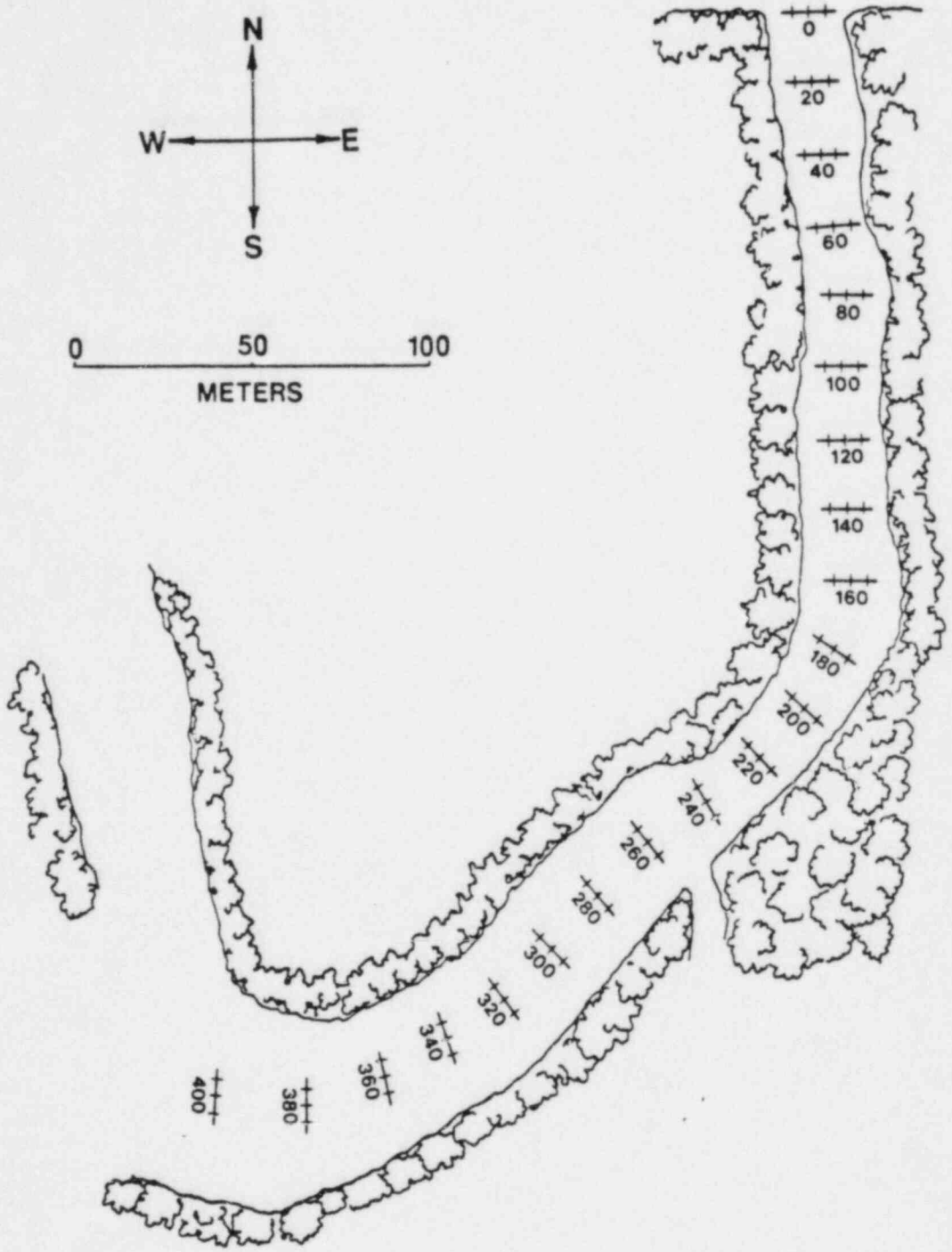

FIGURE 9. Grid System Established by ORAU for Survey Reference Along the Ravine.

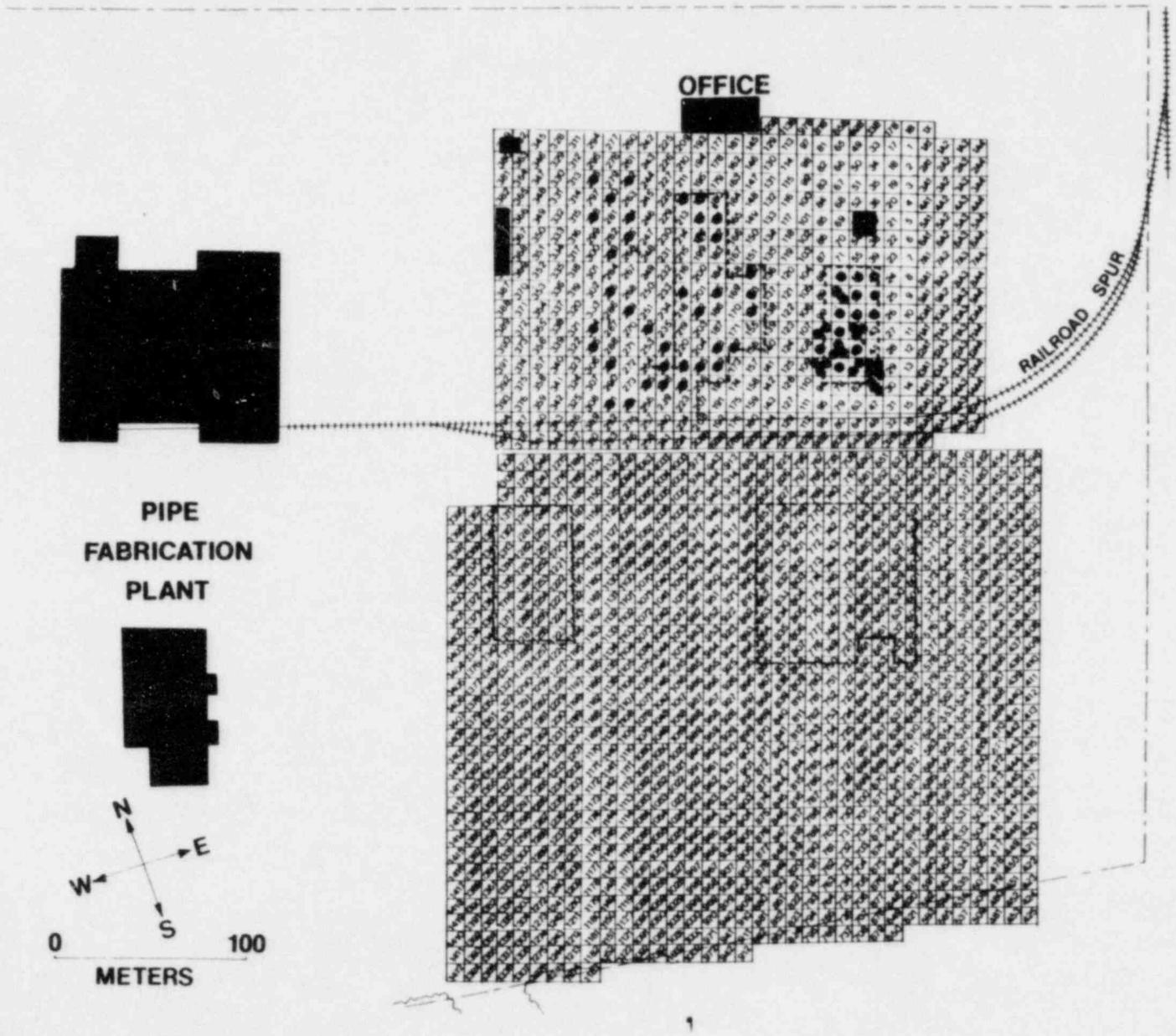

FIGURE 10. Locations of Soil Samples Collected from Beneath Concrete Pads.

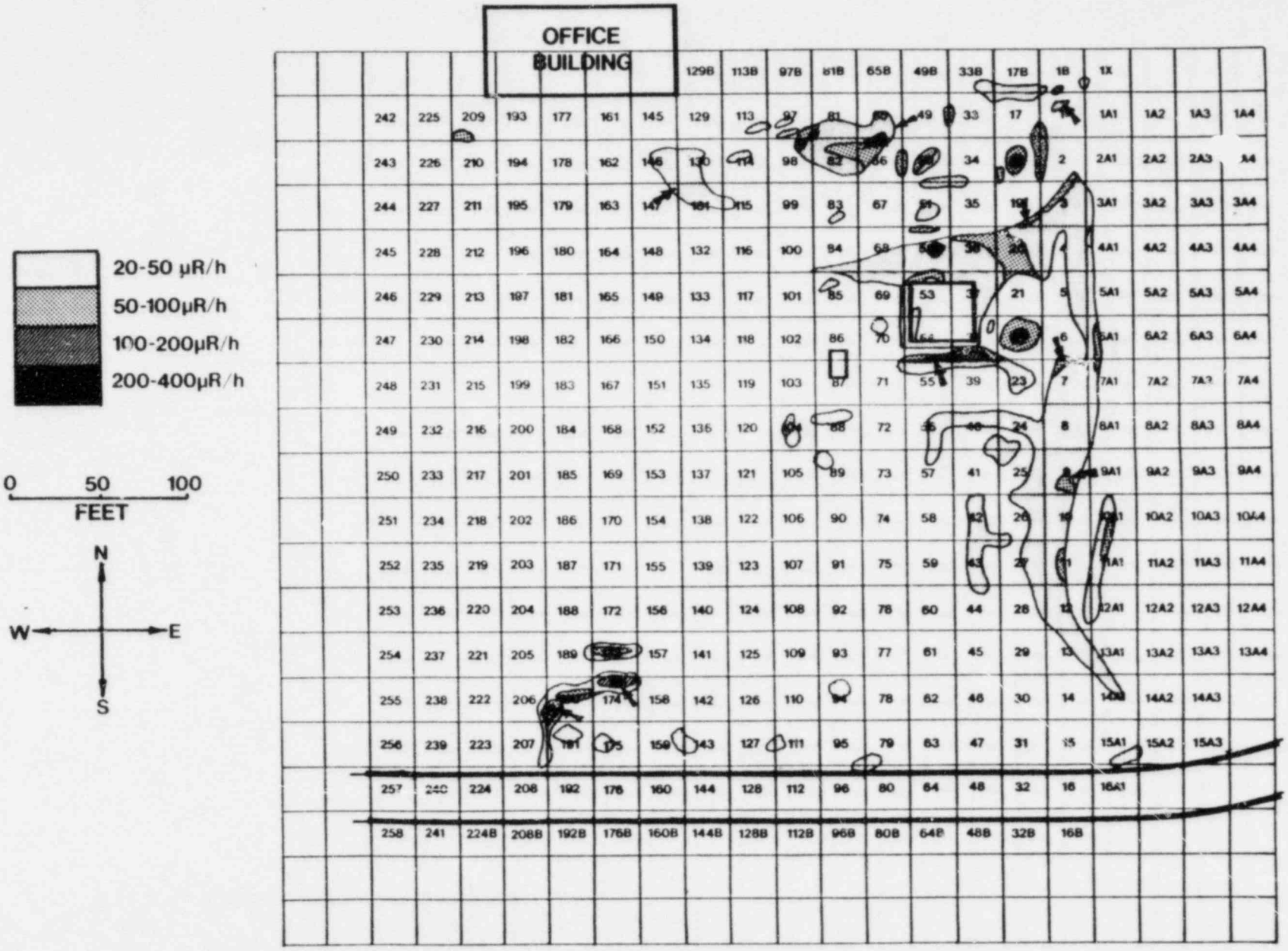

FIGURE 11. Surface Radiation Levels in the Pad Area Prior to Backfilling and Locations of Soil Samples Collected from Selected Elevated Regions. (Arrows indicate sampling sites).

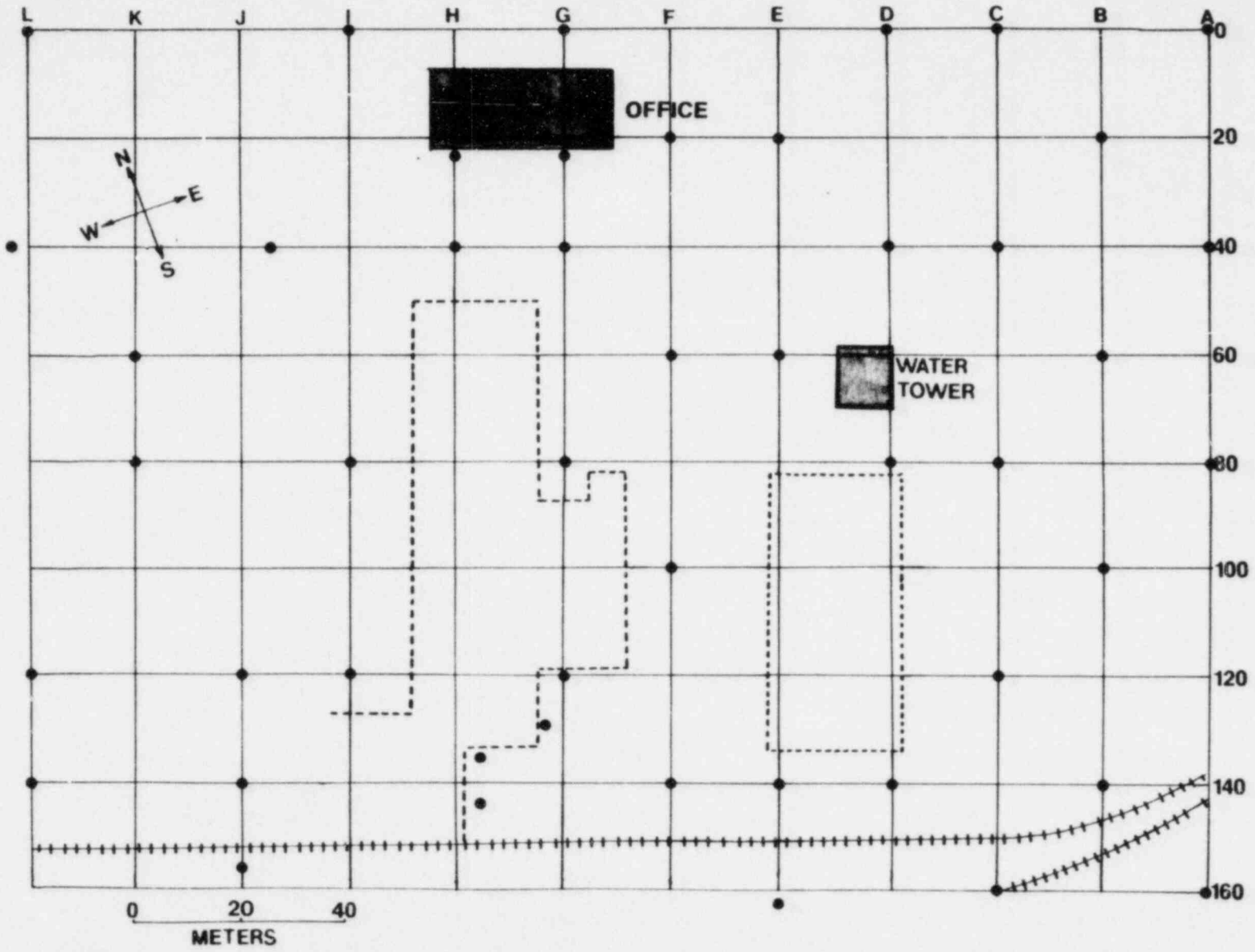

FIGURE 12. Locations of Soil Samples Collected from the Pad Area After Backfilling.

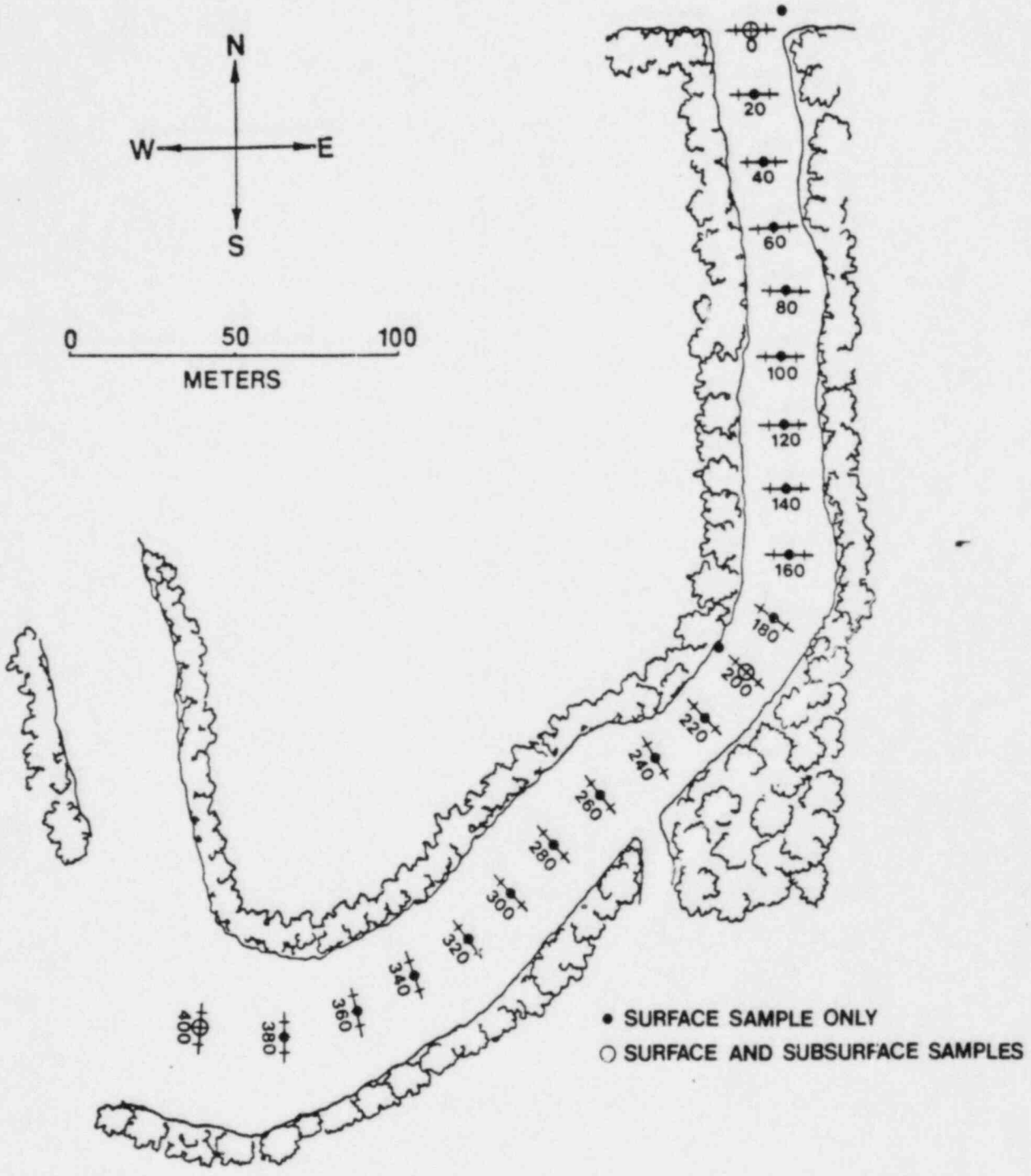

FIGURE 13. Locations of Soil Samples Collected from the Ravine After Decontamination.

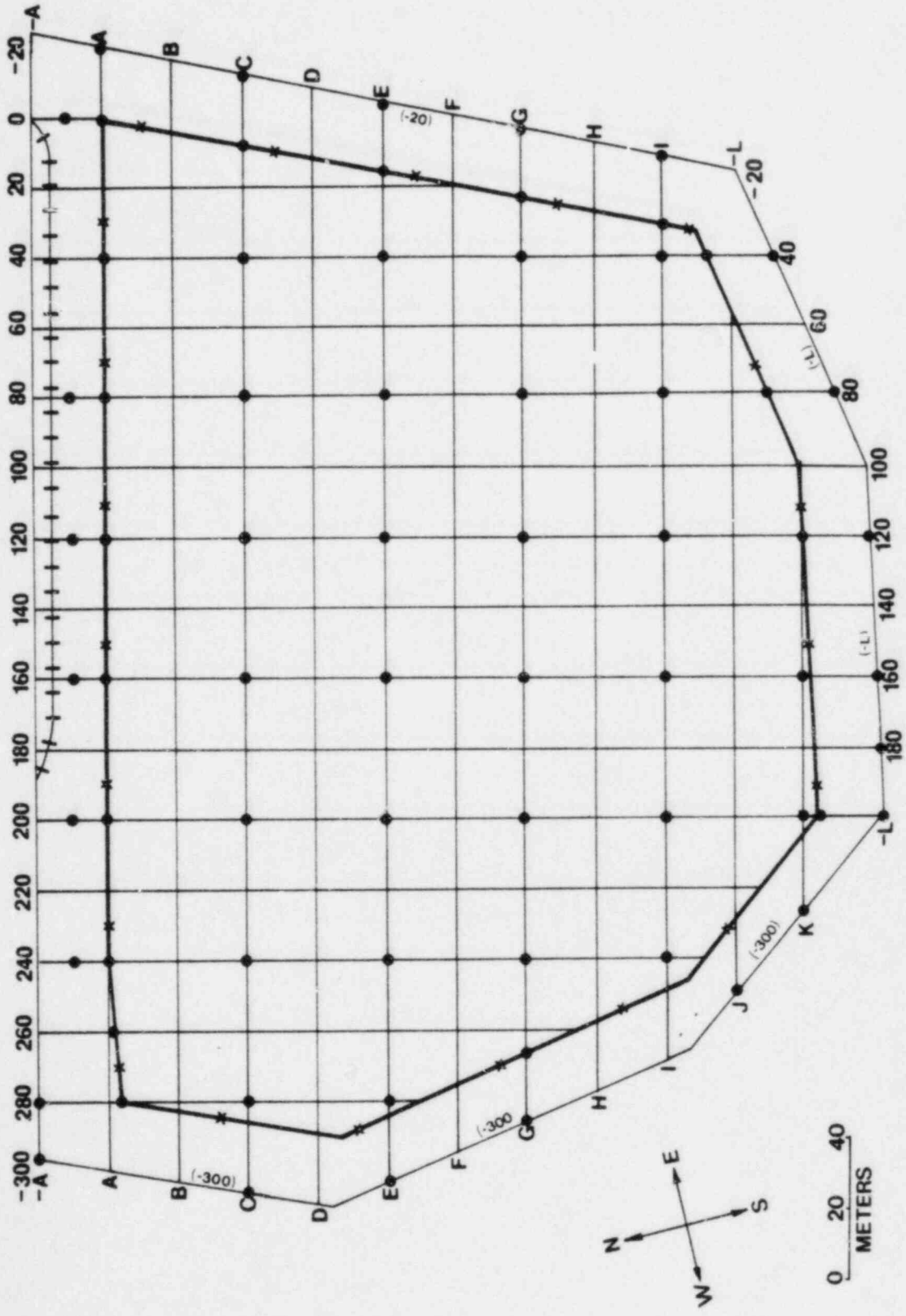

FIGURE 14. Locations of Soil Samples Collected from the Stabilization Pile.

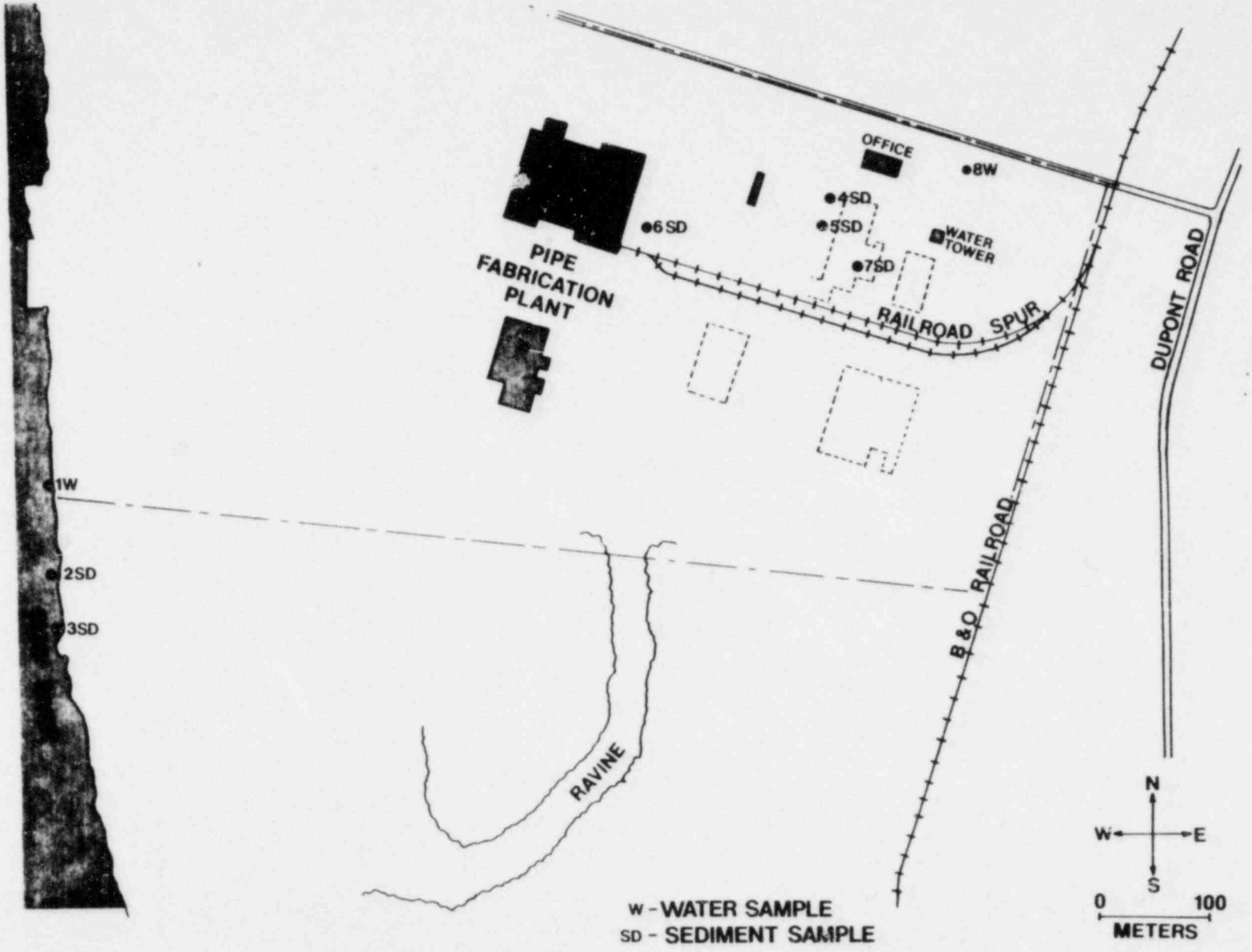

FIGURE 15. Locations of Sediment and Water Samples.

AMX

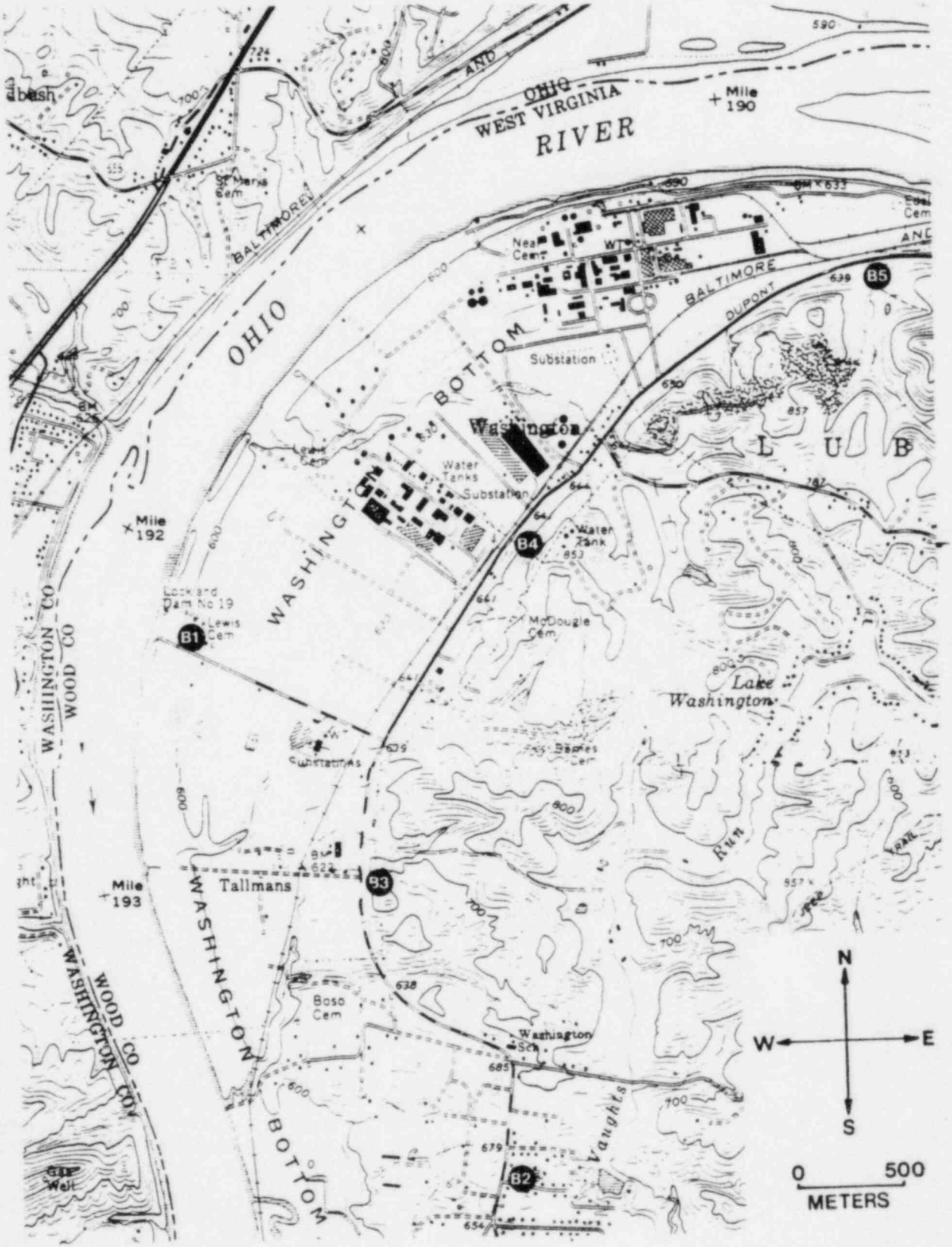

FIGURE 16. Locations of the Baseline Soil Samples and Background Measurements in Washington Botton, WV.

TABLE 1

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
1	0.19 ± 0.64[b]	0.27 ± 0.14	0.46	0.28 ± 0.08	<1.42
2	0.55 ± 0.19	0.55 ± 0.16	1.10	0.35 ± 0.11	<2.36
3	1.00 ± 0.30	1.09 ± 0.26	2.09	0.85 ± 0.18	<2.59
4	0.56 ± 0.32	0.64 ± 0.20	1.20	0.70 ± 0.13	2.96 ± 7.19
5	1.41 ± 0.31	1.29 ± 0.25	2.70	0.53 ± 0.15	<3.34
6	0.88 ± 0.29	0.95 ± 0.20	1.83	0.49 ± 0.15	<2.82
Range	0.19 - 1.41	0.27 - 1.29	0.46 - 2.70	0.28 - 0.85	---
Average	0.77	0.80	1.57	0.53	---

[a] Refer to Figure 16.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 2

COMPARISON OF TOTAL THORIUM CONCENTRATIONS
IN COMPOSITE SOIL SAMPLES COLLECTED BY
ORAU AND CHEM-NUCLEAR

Grid Location	Total Thorium Concentration (pCi/g)[a]		
	ORAU Sample	Chem-Nuclear Sample	
	ORAU Analysis	ORAU Analysis	Chem-Nuclear Analysis
4A1	8.89	<1.0	1.2
17	33.2	89.5	91.1
65	29.8	11.3	13.9
71	13.7	15.2	19.5
89	3.32	1.33	1.9
117	6.26	4.11	9.4
146	7.04	10.9	10.5
151	2.95	2.69	2.6

[a] Th-232 + Th-228

TABLE 3

COMPARISON OF ORAU AND CHEM-NUCLEAR ANALYSES
FOR TOTAL THORIUM IN SELECTED SOIL SAMPLES

Grid Location	Total Thorium Concentration (pCi/g)[a]	
	ORAU	Chem-Nuclear
1	132	139
2	53.3	46.4
3	27.6	27.9
4	33.8	34.7
5	18.5	21.2
6	20.5	26.6
7	40.8	42.2
8	46.5	48.4
9	87.4	88.5
10	35.9	39.8
11	18.3	16.1
12	4.16	3.7
13	2.65	4.4
14	4.97	6.3
15	6.37	8.0
16	<1	1.6
17	89.5	91.1
18	11.5	14.7
19	10.2	11.4
20	15.0	15.4
21	15.8	16.7
22	65.1	59.7
23	30.4	28.9
24	27.9	34.8
25	4.16	5.9
26	19.8	21.8
27	24.9	27.5
28	7.96	11.7
29	2.33	3.9
32	3.7	6.6

[a] Th-232 + Th-228

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN
SELECTED SOIL SAMPLES

Sample No.	Radionuclide Concentrations (pCi/g)						
	Th-228	Th-232	Ra-226	U-238	U-238 / Th-228 & Th-232	Ra-226 / U-238	Ra-226 / Th-228 & Th-232
1	25.8 ± 1.1[a]	25.8 ± 1.3	7.01 ± 0.55	14.7 ± 0.2	0.28	0.48	0.14
2	23.5 ± 1.3	28.3 ± 1.6	0.65 ± 0.40	27.9 ± 0.50	0.54	0.02	0.01
3	6.49 ± 0.61	6.77 ± 0.78	0.57 ± 0.22	3.78 ± 0.19	0.29	0.15	0.04
4	10.5 ± 0.9	12.1 ± 0.9	0.35 ± 0.32	6.26 ± 0.20	0.28	0.06	0.02
5	8.07 ± 0.96	8.39 ± 1.12	2.56 ± 0.43	4.41 ± 0.24	0.27	0.58	0.16
6	4.19 ± 0.58	3.45 ± 0.37	3.29 ± 0.37	5.21 ± 0.24	0.68	0.63	0.43
7	1.08 ± 0.33	0.84 ± 0.41	0.62 ± 0.27	0.34 ± 0.49	0.18	1.82	0.32
8	2030 ± 60	2220 ± 50	70.5 ± 13.8	139 ± 1	0.03	0.51	0.02
9	31.7 ± 1.4	32.9 ± 1.5	1.08 ± 0.54	34.2 ± 0.3	0.53	0.03	0.02
10	15.0 ± 1.1	16.4 ± 1.3	27.7 ± 0.9	21.1 ± 0.7	0.68	1.31	0.88
11	46.5 ± 1.8	48.0 ± 2.0	31.4 ± 1.2	27.6 ± 0.4	0.29	1.14	0.33
12	62.4 ± 2.1	66.0 ± 2.5	1.54 ± 0.75	16.2 ± .4	0.13	0.10	0.01
13	16.1 ± 1.1	15.0 ± 1.3	29.8 ± 0.9	25.1 ± 0.4	0.81	1.19	0.96
14	16.1 ± 1.1	16.7 ± 1.3	34.1 ± 0.9	25.3 ± 0.4	0.77	1.35	1.04
15	9.60 ± 4.17	14.1 ± 5.9	19.0 ± 4.6	6.68 ± 0.54	0.28	2.84	0.80
16	50.0 ± 1.6	53.5 ± 2.0	0.72 ± 0.53	34.9 ± 0.3	0.34	0.02	0.01
17	29.2 ± 1.4	29.0 ± 1.6	12.3 ± 0.8	15.0 ± 0.4	0.26	0.82	0.21
18	15.1 ± 1.26	16.2 ± 1.4	42.8 ± 1.0	23.5 ± 0.3	0.75	1.82	1.37
19	21.5 ± 1.2	21.1 ± 1.3	1.72 ± 0.45	10.4 ± 0.3	0.24	0.17	0.04
20	1.95 ± 0.45	1.94 ± 0.51	0.62 ± 0.21	1.32 ± 0.22	0.34	0.47	0.16
21	2.33 ± 0.32	2.40 ± 0.47	0.79 ± 0.16	1.59 ± 0.22	0.34	0.50	0.17
22	3.15 ± 0.57	4.06 ± 0.74	7.64 ± 0.48	11.8 ± 0.4	0.38	0.65	0.25
23	1.92 ± 0.39	2.20 ± 0.54	1.76 ± 0.28	3.34 ± 0.40	0.43	0.53	0.81
24	1.00 ± 0.26	1.22 ± 0.30	0.54 ± 0.15	1.14 ± 0.21	0.51	0.47	0.24
25	2.34 ± 0.48	2.26 ± 0.53	1.30 ± 0.26	1.37 ± 0.46	0.30	0.95	0.28
26	24.1 ± 1.2	25.2 ± 1.5	0.61 ± 0.39	19.2 ± 0.5	0.39	0.03	0.01
27	20.2 ± 1.1	22.5 ± 1.3	0.71 ± 0.41	21.3 ± 0.6	0.50	0.03	0.02
28	25.0 ± 1.1	29.9 ± 1.3	1.18 ± 0.42	8.82 ± 0.25	0.16	0.13	0.02
29	1.29 ± 0.33	2.27 ± 0.47	2.34 ± 0.31	4.77 ± 0.54	1.34	0.49	0.66
30	435 ± 6	324 ± 6	3.13 ± 1.51	101 ± 1	0.13	0.03	0.01

[a] Errors are 2σ based on counting statistics.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
FROM SELECTED AREAS OF ELEVATED DIRECT RADIATION

Grid Location[a]	Sample Depth Below Grade (m)	Surface Exposure Rate (μR/h)	Radionuclide Concentrations (pCi/g)				
			Th-232	Th-228	Total Thorium[d]	Ra-226	U-238
1	1.4	--[b]	0.38 ± 0.17[c]	0.35 ± 0.13	0.73	0.41 ± 0.08	<1.73
6	1.4	87	0.48 ± 0.33	0.33 ± 0.12	0.81	0.24 ± 0.07	<2.02
9	0.1	83	66.2 ± 1.8	62.9 ± 1.4	129	20.5 ± 0.7	28.7 ± 0.5
19	1.4	44	15.5 ± 0.9	14.9 ± 0.8	30.4	0.88 ± 0.24	<5.79
55	0.2	100	88.3 ± 2.0	86.7 ± 1.8	175	16.1 ± 0.76	30.6 ± 0.5
65	0.8	56	171 ± 2	147 ± 2	318	14.1 ± 0.66	74.6 ± 10.4
147	0.4	42	34.8 ± 1.3	31.2 ± 1.1	66.0	0.77 ± 0.33	10.2 ± 0.4
174	0.2	350	143 ± 4	135 ± 3	278	12.3 ± 1.1	24.7 ± 0.7
190	2.0	260	161 ± 4	144 ± 3	305	1.84 ± 1.03	9.7 ± 0.4

[a] Refer to Figure 11.
[b] Dash indicates measurement not performed.
[c] Errors are 2σ based on counting statistics.
[d] Th-232 + Th-228.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
FROM BENEATH CONCRETE PADS

Grid Location[a]	Radionuclide Concentrations (pCi/g)			
	Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
40	0.78 ± 0.32[b]	0.54 ± 0.21	1.32	0.56 ± 0.16	<3.00
41	0.54 ± 0.24	0.63 ± 0.15	1.17	0.50 ± 0.12	<2.47
42	0.33 ± 0.33	0.63 ± 0.27	0.96	0.75 ± 0.20	<3.29
45	0.80 ± 0.35	0.51 ± 0.21	1.31	0.44 ± 0.16	<2.91
45	0.48 ± 0.28	0.45 ± 0.27	0.93	0.59 ± 0.15	<3.83
45	0.75 ± 0.32	0.90 ± 0.30	1.65	0.66 ± 0.19	<3.58
45	0.65 ± 0.32	0.48 ± 0.24	1.13	0.55 ± 0.17	<3.53
45	48.0 ± 2.00	46.5 ± 1.80	94.5	31.4 ± 1.20	62.2 ± 30.2
46	2221 ± 46.0	2025 ± 59.4	4246	70.5 ± 13.8	746 ± 543
46	2424 ± 45.0	3180 ± 45.0	5604	16.0 ± 11.1	1363 ± 469
56	0.49 ± 0.29	0.48 ± 0.27	0.97	0.41 ± 0.17	<2.50
57	0.42 ± 0.25	0.63 ± 0.24	1.05	0.48 ± 0.16	<2.54
58	0.41 ± 0.30	0.78 ± 0.27	1.19	0.44 ± 0.15	<3.44
59	16.4 ± 1.30	15.0 ± 1.05	31.4	27.7 ± 0.90	54.3 ± 27.8
59	0.40 ± 0.30	0.54 ± 0.21	0.94	0.43 ± 0.41	<2.47
59	0.58 ± 0.21	0.60 ± 0.21	1.18	0.53 ± 0.13	<2.32
60	22.1 ± 1.50	21.0 ± 1.41	43.1	40.1 ± 1.00	73.5 ± 28.7
61	14.1 ± 5.90	9.60 ± 4.17	23.7	19.0 ± 4.60	<65.5
61	0.69 ± 0.48	1.02 ± 0.30	1.71	1.25 ± 0.22	<3.41
72	0.55 ± 0.27	0.48 ± 0.27	1.03	0.29 ± 0.15	<1.90
73	15.0 ± 1.30	16.1 ± 1.08	31.1	29.8 ± 0.90	49.3 ± 27.5
73	0.71 ± 0.25	0.78 ± 0.21	1.49	0.60 ± 0.13	<1.90
74	0.39 ± 0.25	0.81 ± 0.24	1.20	0.53 ± 0.16	<3.07
75	0.70 ± 0.51	0.45 ± 0.21	1.15	0.37 ± 0.15	<2.16
76	16.7 ± 1.30	16.1 ± 1.41	32.8	34.1 ± 0.90	57.1 ± 23.7
76	0.95 ± 0.56	1.32 ± 0.39	2.27	1.88 ± 0.30	<3.76
76	0.32 ± 0.22	0.54 ± 0.21	0.86	0.42 ± 0.14	<2.74
77	0.47 ± 0.23	0.66 ± 0.24	1.13	0.65 ± 0.19	<3.23
91	1.29 ± 0.41	1.08 ± 0.30	2.37	1.82 ± 0.26	<3.60
91	16.2 ± 1.40	15.1 ± 1.26	31.3	42.8 ± 1.00	67.1 ± 24.9
92	0.54 ± 0.44	0.57 ± 0.24	1.11	0.82 ± 0.20	<2.73
93	1.23 ± 0.39	0.90 ± 0.30	2.13	0.50 ± 0.19	<3.75
93	0.51 ± 0.32	0.63 ± 0.24	1.14	0.50 ± 0.19	4.27 ± 7.20
93	0.81 ± 0.34	0.75 ± 0.30	1.56	0.61 ± 0.20	<2.56
152	4.26 ± 0.68	3.36 ± 0.60	7.62	7.43 ± 0.51	12.5 ± 14.2
153	4.06 ± 0.74	3.15 ± 0.57	7.21	7.64 ± 0.48	17.0 ± 13.8
154	1.12 ± 0.40	1.02 ± 0.33	2.41	1.84 ± 0.26	<3.13
172	2.34 ± 0.46	2.22 ± 0.42	4.56	0.39 ± 0.21	10.4 ± 9.10
181	0.41 ± 0.40	0.93 ± 0.27	1.34	0.36 ± 0.15	<1.69
182	0.42 ± 0.35	0.72 ± 0.24	1.14	0.41 ± 0.16	<2.74
185	0.71 ± 0.26	0.48 ± 0.27	1.19	0.41 ± 0.19	<3.13

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
FROM BENEATH CONCRETE PADS

Sample Location	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium	Ra-226	U-238
188	25.2 ± 1.50	24.2 ± 1.23	49.4	0.61 ± 0.39	16.6 ± 18.6
189	11.2 ± 1.00	10.3 ± 0.81	21.5	0.81 ± 0.36	17.9 ± 13.4
196	0.57 ± 0.38	0.75 ± 0.21	1.32	0.42 ± 0.16	<3.36
197	0.38 ± 0.30	0.75 ± 0.24	1.13	0.51 ± 0.17	<3.24
198	0.36 ± 0.36	0.54 ± 0.21	0.90	0.53 ± 0.15	<2.13
202	1.00 ± 0.31	0.66 ± 0.30	1.66	0.37 ± 0.22	<2.08
205	16.2 ± 1.30	14.6 ± 1.02	30.8	0.58 ± 0.39	7.70 ± 12.3
212	0.40 ± 0.33	0.60 ± 0.30	1.00	0.43 ± 0.18	<3.03
217	0.83 ± 0.29	0.54 ± 0.24	1.37	0.54 ± 0.18	<4.24
221	1.40 ± 0.44	1.20 ± 0.3	2.60	0.43 ± 0.21	<3.58
222	0.54 ± 0.29	0.60 ± 0.21	1.14	0.33 ± 0.14	<1.59
236	0.60 ± 0.40	0.96 ± 0.33	1.56	0.68 ± 0.18	<3.43
237	0.51 ± 0.33	0.39 ± 0.24	0.90	0.35 ± 0.15	<1.86
238	0.66 ± 0.30	0.78 ± 0.30	1.44	0.47 ± 0.14	<2.24
239	1.05 ± 0.32	0.48 ± 0.30	1.50	0.55 ± 0.16	<3.64
252	0.67 ± 0.31	0.60 ± 0.27	1.27	0.68 ± 0.18	<3.00
255	0.48 ± 0.37	1.65 ± 0.39	2.13	0.41 ± 0.23	<2.64
262	0.38 ± 0.25	0.75 ± 0.24	1.13	0.69 ± 0.19	<1.81
264	1.00 ± 0.34	0.54 ± 0.24	1.54	0.72 ± 0.18	<2.68
265	0.78 ± 0.35	0.48 ± 0.21	1.26	0.54 ± 0.16	<2.84
269	0.79 ± 0.31	0.63 ± 0.27	1.42	0.55 ± 0.13	2.55 ± 7.16
274	0.63 ± 0.29	0.57 ± 0.27	1.20	0.49 ± 0.18	<4.16
280	0.54 ± 0.27	0.45 ± 0.27	0.99	0.50 ± 0.15	<1.83
283	0.20 ± 0.46	0.63 ± 0.21	0.83	0.32 ± 0.19	<2.92
285	0.70 ± 0.27	0.57 ± 0.24	1.27	0.61 ± 0.18	<2.33
289	0.44 ± 0.38	0.66 ± 0.27	1.10	0.61 ± 0.18	<3.50
291	0.41 ± 0.26	0.36 ± 0.21	0.77	0.39 ± 0.17	<3.04
296	0.68 ± 0.21	1.23 ± 0.27	1.91	0.50 ± 0.15	<3.28
298	0.75 ± 0.26	1.35 ± 0.27	2.10	0.52 ± 0.17	<2.68
304	0.66 ± 0.29	0.54 ± 0.24	1.20	0.57 ± 0.15	<2.66
305	0.80 ± 0.32	0.57 ± 0.24	1.37	0.56 ± 0.17	<2.92

[a] Refer to Figure 10.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 7

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS IN PAD AREA

Grid Location[a]	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
A, 0	17	17	39
A, 20	19	19	50
A, 40	20	20	72
A, 60	19	20	67
A, 80	19	20	70
A,100	19	20	64
A,120	15	15	38
A,140	12	12	23
A,160	13	15	39
B, 0	17	17	47
B, 20	17	19	44
B, 40	20	22	61
B, 60	13	12	35
B, 80	13	13	31
B,100	19	22	74
B,120	15	17	73
B,140	19	19	74
B,160	15	15	48
C, 0	19	19	53
C, 20	13	13	32
C, 40	13	13	26
C, 60	12	13	53
C, 80	12	13	80
C,100	12	12	47
C,120	12	13	35
C,140	13	13	42
C,160	13	12	28
D, 0	15	15	42
D, 20	13	15	32
D, 40	13	13	31
D, 60	13	13	35
D, 80	12	12	48
D,100	13	15	83
D,120	13	15	28
D,140	13	13	44
D,160	10	12	29
E, 0	19	19	51
E, 20	13	15	34
E, 40	13	13	35
E, 60	12	13	35
E, 80	13	15	45

TABLE 7 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS IN PAD AREA

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
E,100	13	26	121
E,120	12	13	29
E,140	12	13	29
E,160	10	8	19
F, 0	19	19	53
F, 20	13	13	25
F, 40	13	12	47
F, 60	12	12	54
F, 80	12	13	42
F,100	13	12	39
F,120	12	13	58
F,140	12	12	63
F,160	9	9	32
G, 0	17	19	58
G, 20	13	15	60
G, 40	13	13	35
G, 60	12	13	39
G, 80	12	13	41
G,100	12	12	45
G,120	13	13	36
G,140	12	12	53
G,160	8	8	29
H, 0	15	13	39
H, 20	15	14	60
H, 40	12	12	31
H, 60	12	10	26
H, 80	12	10	34
H,100	12	12	41
H,120	12	12	60
H,140	13	22	146
H,160	8	9	48
I, 0	14	13	38
I, 20	14	15	55
I, 40	16	19	64
I, 60	15	15	48
I, 80	15	15	61
I,100	15	15	63
,120	15	15	63
I,140	12	12	41
I,160	7	8	26

TABLE 7 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS IN PAD AREA

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
J, 20	13	13	31
J, 40	13	13	41
J, 60	12	12	38
J, 80	12	12	38
J,100	12	12	45
J,120	12	12	50
J,140	10	11	34
J,160	10	11	26
K, 20	11	12	54
K, 40	12	12	32
K, 60	12	12	42
K, 80	13	15	50
K,100	14	15	42
K,120	12	12	31
K,140	12	13	41
K,160	10	10	26
L, 0	12	13	35
L, 20	12	12	51
L, 40	12	12	41
L, 60	13	13	42
L, 80	12	13	44
L,100	12	12	34
L,120	12	12	45
L,140	13	19	48
L,160	12	12	58

[a] Refer to Figure 7.

TABLE 8

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS ON THE STABILIZATION PILE

Grid Location[a]	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
-A,-20	12	12	44
-A, 0	15	20	88
-A, 20	10	10	30
-A, 40	10	9	24
-A, 60	10	10	36
-A, 80	10	9	32
-A,100	9	9	38
-A,120	10	10	26
-A,140	9	10	34
-A,160	10	10	30
-A,180	11	10	40
-A,200	11	12	44
-A,220	10	10	40
-A,240	11	11	40
-A,260	10	10	32
-A,280	11	11	38
-A,-300	10	10	44
-A,-20	12	12	40
A, 0	11	11	42
A, 20	11	11	30
A, 40	10	10	32
A, 60	11	11	48
A, 80	10	10	26
A,100	11	11	40
A,120	10	11	38
A,140	10	10	50
A,160	11	11	36
A,180	11	11	30
A,200	11	11	34
A,220	11	10	30
A,240	10	10	38
A,260	10	10	34
A,280	10	10	36
A,-300	11	11	34
B,-20	11	11	32
B, 0	11	11	36
B, 20	11	12	36
B, 40	11	11	46
B, 60	11	11	42
B, 80	11	11	48

TABLE 8 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS ON THE STABILIZATION PILE

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
B,100	11	12	32
B,120	11	11	52
B,140	11	12	40
B,160	11	11	30
B,180	11	11	30
B,200	11	11	40
B,220	11	11	32
B,240	11	11	32
B,260	11	11	52
B,280	10	10	36
B,-300	11	10	34
C,-20	11	11	44
C, 0	10	11	44
C, 20	11	11	32
C, 40	11	11	32
C, 60	11	11	30
C, 80	11	11	38
C,100	11	11	36
C,120	11	11	40
C,140	11	11	26
C,160	11	11	46
C,180	11	11	48
C,200	11	11	32
C,220	11	11	46
C,240	11	11	34
C,260	11	11	44
C,280	11	11	38
C,-300	11	11	42
D,-20	11	11	40
D, 20	10	10	40
D, 40	11	11	30
D, 60	11	11	40
D, 80	12	11	36
D,100	11	11	44
D,120	11	11	40
D,140	11	11	34
D,160	10	11	42
D,180	11	11	36
D,200	11	11	24
D,220	11	11	44

TABLE 8 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS ON THE STABILIZATION PILE

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
D,240	11	11	58
D,260	11	11	48
D,280	11	11	42
D,-300	12	11	38
E,-20	11	11	40
E, 20	11	11	36
E, 40	11	11	40
E, 60	11	11	40
E, 80	11	11	38
E,100	11	11	36
E,120	11	10	50
E,140	11	11	40
E,160	11	11	40
E,180	10	11	46
E,200	11	11	26
E,220	10	11	32
E,240	11	11	42
E,260	10	10	46
E,280	11	11	24
E,-300	11	11	46
F,-20	11	11	36
F, 20	12	12	48
F, 40	12	12	38
F, 60	12	12	42
F, 80	12	12	40
F,100	11	11	42
F,120	12	12	34
F,140	12	12	32
F,160	12	12	36
F,180	12	12	34
F,200	11	12	30
F,220	12	11	22
F,240	11	12	30
F,260	11	11	36
F,280	10	11	40
F,-300	11	12	30
G,-20	11	11	36
G, 20	12	12	40
G, 40	11	12	48
G, 60	11	11	36

TABLE 8 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS ON THE STABILIZATION PILE

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
G, 80	12	11	38
G,100	12	12	46
G,120	12	12	38
G,140	12	12	46
G,160	12	12	42
G,180	12	12	46
G,200	12	12	48
G,220	12	12	44
G,240	12	12	40
G,260	11	11	46
G,-300	11	11	48
H,-20	11	11	44
H, 40	12	12	36
H, 60	12	12	40
H, 80	12	12	24
H,100	12	12	46
H,120	12	12	54
H,140	12	12	40
H,160	12	12	40
H,180	12	12	26
H,200	12	12	44
H,220	12	12	36
H,240	12	12	34
H,260	12	12	42
H,-300	11	11	44
I,-20	10	11	40
I, 40	11	12	46
I, 60	11	12	40
I, 80	12	12	34
I,100	12	12	36
I,120	12	12	36
I,140	11	11	40
I,160	11	11	40
I,180	11	12	38
I,200	12	12	46
I,220	12	12	52
I,240	12	12	42
I,-300	11	10	30
J, 60	11	11	38
J, 80	11	12	44

TABLE 8 (Continued)

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS ON THE STABILIZATION PILE

Grid Location	Exposure Rate at 1 m (μR/h)	Exposure Rate at Surface (μR/h)	Dose Rate at Surface (μrad/h)
J,100	12	12	28
J,120	11	11	38
J,140	12	12	48
J,160	12	12	30
J,180	12	12	36
J,200	11	12	40
J,220	12	12	42
J,-300	10	10	40
K,140	11	11	36
K,160	11	11	36
K,180	12	12	42
K,200	11	11	32
K,-300	11	12	46
-L,-20	11	12	48
-L, 40	11	12	44
-L, 60	11	11	46
-L, 80	10	11	34
-L,100	10	10	36
-L,120	10	11	44
-L,140	12	12	36
-L,160	11	11	30
-L,180	12	12	42
-L,-300	12	12	30

[a] Refer to Figure 8.

TABLE 9

DIRECT RADIATION LEVELS
MEASURED ALONG THE RAVINE

Distance Along the Ravine[a] (m)	5 m West of Ravine Center Exposure Rate (μR/h)		Center of Ravine Exposure Rate (μR/h)		Center of Ravine Dose Rate (μrad/h)	5 m East of Ravine Center Exposure Rate (μR/h)	
	1 m	Surface	1 m	Surface	Surface	1 m	Surface
0	12	12	14	15	38	14	13
20	18	19	19	20	66	12	12
40	18	17	14	14	40	13	13
60	15	15	14	13	48	14	14
80	15	15	13	13	32	19	17
100	19	19	15	13	41	14	15
120	17	17	15	15	43	14	14
140	15	15	15	16	56	12	12
160	15	15	13	14	54	15	16
180	16	17	13	13	42	13	14
200	17	16	14	15	49	12	13
220	14	15	14	13	45	12	12
240	15	15	13	13	44	13	14
260	15	15	16	16	47	12	12
280	11	11	15	17	44	13	15
300	12	11	18	19	48	15	15
320	15	15	17	18	51	1	19
340	16	15	19	19	45	17	19
360	15	17	19	20	67	14	16
380	15	15	17	18	58	15	16
400	12	12	13	17	47	15	17

[a] Refer to Figure 9.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE PAD AREA

Grid Location[a]	Sample Description	Radionuclide Concentrations (pCi/g)				
		Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
A, 0	Surface	1.76 ± 0.45[b]	1.98 ± 0.42	3.74	1.07 ± 0.24	<3.75
A, 40	"	5.91 ± 0.78	6.23 ± 0.92	12.1	2.50 ± 0.44	<5.44
A, 80	"	4.75 ± 0.81	4.81 ± 0.68	9.56	2.14 ± 0.39	<5.51
A,160	"	0.84 ± 0.41	1.08 ± 0.33	1.92	0.62 ± 0.27	<3.85
B, 20	"	2.94 ± 0.54	3.13 ± 0.65	6.07	1.64 ± 0.36	<5.31
B, 60	"	0.54 ± 0.40	0.63 ± 0.21	1.17	0.54 ± 0.18	3.70 ± 10.3
B,100	"	1.70 ± 0.45	1.59 ± 0.33	3.29	0.82 ± 0.26	6.60 ± 1.06
B,140	"	6.39 ± 1.08	3.90 ± 0.81	10.3	2.44 ± 0.44	<6.10
C, 0	"	4.11 ± 1.17	4.20 ± 0.75	8.31	2.96 ± 0.47	<5.60
C, 40	"	0.54 ± 0.24	0.41 ± 0.33	0.95	0.41 ± 0.14	<2.39
C, 80	"	1.81 ± 0.52	2.34 ± 0.45	4.15	1.12 ± 0.23	<4.26
C,120	"	0.82 ± 0.37	0.87 ± 0.27	1.69	0.59 ± 0.24	<3.46
C,160	"	2.18 ± 0.63	2.31 ± 0.42	4.49	1.18 ± 0.25	<3.73
D, 0	"	1.66 ± 0.49	0.90 ± 0.30	2.56	0.61 ± 0.14	<3.11
D, 40	"	2.34 ± 0.45	1.81 ± 0.52	4.15	1.13 ± 0.23	<3.31
D, 80	"	0.43 ± 0.29	0.51 ± 0.18	0.94	0.43 ± 0.13	<2.89
D,140	"	1.81 ± 0.52	2.31 ± 0.45	4.12	1.12 ± 0.23	<3.90
E, 20	"	1.81 ± 0.52	2.34 ± 0.45	4.15	1.12 ± 0.23	<3.75
E, 60	"	0.95 ± 0.33	0.81 ± 0.30	1.76	0.64 ± 0.21	<2.81
E,140	"	0.79 ± 0.46	0.87 ± 0.24	1.66	0.74 ± 0.17	<3.00
E,164	"	1.49 ± 0.43	1.38 ± 0.33	2.87	0.90 ± 0.23	<3.68
F, 20	"	0.70 ± 0.50	0.72 ± 0.33	1.42	0.86 ± 0.18	<3.53
F, 60	"	0.91 ± 0.23	0.78 ± 0.18	1.69	0.63 ± 0.12	<2.54
F,100	"	0.75 ± 0.25	0.96 ± 0.21	2.52	0.60 ± 0.13	<2.44
F,140	"	0.65 ± 0.33	0.90 ± 0.27	1.55	0.58 ± 0.19	<3.87
G, 0	"	3.52 ± 0.69	3.42 ± 0.72	6.94	1.81 ± 0.35	<4.70

TABLE 10 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE PAD AREA

Grid Location	Sample Description	Radionuclide Concentrations (pCi/g)				
		Th-232	Th-228	Total Thorium	Ra-226	U-238
G, 21	"	2.26 ± 0.53	2.34 ± 0.48	4.60	1.30 ± 0.26	9.89 ± 9.41
G, 40	"	0.41 ± 0.37	0.63 ± 0.27	1.04	0.42 ± 0.14	<2.86
G, 80	"	0.73 ± 0.41	0.78 ± 0.30	1.51	0.62 ± 0.17	<2.77
G,120	Surface	0.81 ± 0.37	0.93 ± 0.27	1.74	0.61 ± 0.20	<3.61
G+5,130	90 cm	4.92 ± 0.62	4.86 ± 0.54	9.78	1.01 ± 0.29	<4.11
G+15,135	"	0.73 ± 0.29	0.69 ± 0.30	1.42	0.51 ± 0.16	<3.55
G+15,145	"	0.81 ± 0.25	0.87 ± 0.24	1.68	0.49 ± 0.17	<2.09
H, 21	Surface	2.04 ± 0.49	2.22 ± 0.42	6.26	0.80 ± 0.25	<3.94
H, 40	"	0.92 ± 0.34	0.78 ± 0.24	1.70	0.47 ± 0.17	4.64 ± 8.33
I, 0	"	1.00 ± 0.36	1.14 ± 0.30	2.14	0.71 ± 0.24	<2.47
I, 80	"	1.18 ± 0.42	1.38 ± 0.39	2.56	0.81 ± 0.29	<4.38
I,120	"	2.28 ± 0.55	2.55 ± 0.45	4.83	0.88 ± 0.27	<4.42
I+35, 40	"	0.80 ± 0.24	0.93 ± 0.21	1.73	0.66 ± 0.18	<2.63
J,120	"	1.03 ± 0.54	1.05 ± 0.27	2.08	0.64 ± 0.18	<4.02
J,140	"	0.40 ± 0.31	0.66 ± 0.27	1.06	0.56 ± 0.18	<2.75
J,155	"	1.57 ± 0.50	1.83 ± 0.36	3.40	0.89 ± 0.21	<2.87
K, 60	"	1.89 ± 0.44	1.86 ± 0.36	3.75	0.68 ± 0.22	<3.02
K, 80	"	3.00 ± 0.50	3.00 ± 0.42	6.00	1.25 ± 0.25	<3.20
L, 0	"	2.27 ± 0.47	1.29 ± 0.33	3.56	2.34 ± 0.31	<4.50
L,120	"	1.96 ± 0.39	1.83 ± 0.30	3.79	0.77 ± 0.19	<2.72
L,140	"	5.53 ± 0.75	5.13 ± 0.60	10.7	0.94 ± 0.26	<4.65
L+5, 40	"	1.48 ± 0.34	1.32 ± 0.30	2.80	0.69 ± 0.22	<2.96

[a] Refer to Figure 12.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 11

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE STABILIZATION PILE

Grid Location[a]	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
-A+10, 0	0.91 ± 0.34[b]	1.44 ± 0.30	2.35	0.99 ± 0.20	<2.98
-A+10, 80	0.89 ± 0.28	0.81 ± 0.24	1.70	0.46 ± 0.15	<2.98
-A+10,120	1.22 ± 0.33	1.14 ± 0.33	2.36	0.73 ± 0.21	<2.85
-A+10,160	0.54 ± 0.26	0.54 ± 0.21	1.08	0.43 ± 0.16	<2.46
-A+10,200	0.74 ± 0.31	0.66 ± 0.24	1.40	0.49 ± 0.13	<2.72
-A+10,240	0.89 ± 0.3	1.05 ± 0.30	1.94	0.66 ± 0.22	<2.72
-A,280	0.86 ± 0.34	0.75 ± 0.27	1.61	0.46 ± 0.17	5.07 ± 9.74
-A,-300	1.25 ± 0.30	0.63 ± 0.24	1.88	0.62 ± 0.17	<3.67
A,-18	2.11 ± 0.42	2.43 ± 0.39	4.54	1.19 ± 0.23	<3.42
A, 0	1.04 ± 0.33	0.69 ± 0.24	1.73	0.48 ± 0.18	<2.76
A, 40	0.79 ± 0.27	0.63 ± 0.21	1.42	0.34 ± 0.16	<3.15
A, 80	0.75 ± 0.27	0.60 ± 0.21	1.35	0.43 ± 0.17	<2.26
A,120	1.12 ± 0.33	0.69 ± 0.27	1.81	0.56 ± 0.16	<2.09
A,160	0.74 ± 0.43	0.75 ± 0.30	1.69	0.47 ± 0.17	<2.66
A,200	0.87 ± 0.36	1.02 ± 0.27	1.89	0.50 ± 0.19	<2.62
A,240	0.85 ± 0.28	0.78 ± 0.24	1.63	0.60 ± 0.18	<2.71
A+5,280	1.21 ± 0.51	1.18 ± 0.34	2.39	0.82 ± 0.30	<4.05
C,-20	0.79 ± 0.37	0.96 ± 0.27	1.16	0.59 ± 0.17	<3.26
C, 3.5	0.89 ± 0.38	0.92 ± 0.32	1.81	0.80 ± 0.29	<4.77
C, 40	0.82 ± 0.57	0.93 ± 0.30	1.75	0.73 ± 0.19	<4.27
C, 80	0.66 ± 0.43	0.69 ± 0.27	1.35	0.53 ± 0.19	<2.12
C,120	0.64 ± 0.28	0.84 ± 0.27	1.48	0.59 ± 0.16	4.65 ± 6.56
C,160	0.85 ± 0.38	0.87 ± 0.27	1.72	0.62 ± 0.16	4.05 ± 6.92
C,200	0.96 ± 0.37	0.90 ± 0.30	1.86	0.55 ± 0.19	<4.21
C,240	1.03 ± 0.33	0.87 ± 0.27	1.90	0.59 ± 0.17	<3.29
C,280	0.96 ± 0.32	0.78 ± 0.27	1.74	0.60 ± 0.21	<3.41

TABLE 11 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE STABILIZATION PILE

Grid Location	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium	Ra-226	U-238
C,-300	1.18 ± 0.44	0.90 ± 0.27	2.08	0.54 ± 0.17	<3.71
E,-20	0.68 ± 0.31	0.69 ± 0.27	1.37	0.51 ± 0.19	<3.43
E, 11.5	0.97 ± 0.34	1.20 ± 0.30	2.17	0.59 ± 0.18	<2.72
E, 40	0.77 ± 0.33	0.84 ± 0.24	1.61	0.59 ± 0.18	<2.74
E, 80	0.78 ± 0.48	0.78 ± 0.30	1.56	0.63 ± 0.19	<3.19
E,120	1.29 ± 0.45	0.90 ± 0.45	2.19	0.69 ± 0.29	<2.85
E,160	0.66 ± 0.31	0.81 ± 0.27	1.47	0.59 ± 0.15	<2.72
E,200	0.86 ± 0.37	1.02 ± 0.30	1.88	0.81 ± 0.21	<3.09
E,240	0.74 ± 0.31	0.57 ± 0.30	1.31	0.44 ± 0.13	<2.67
E,280	1.02 ± 0.30	0.96 ± 0.30	1.98	0.70 ± 0.20	<2.49
E,-300	0.63 ± 0.26	0.45 ± 0.27	1.08	0.53 ± 0.15	<2.53
G,-20	0.58 ± 0.43	0.66 ± 0.27	1.24	0.50 ± 0.15	<2.3
G, 20	1.40 ± 0.48	0.93 ± 0.30	2.33	0.64 ± 0.18	<4.29
G, 40	0.90 ± 0.28	0.81 ± 0.24	1.71	0.53 ± 0.18	<2.89
G, 80	0.97 ± 0.27	0.81 ± 0.27	1.78	0.49 ± 0.14	6.47 ± 7.36
G,120	0.89 ± 0.26	0.75 ± 0.21	1.55	0.53 ± 0.14	<1.92
G,160	1.03 ± 0.31	0.87 ± 0.27	1.90	0.62 ± 0.18	<3.03
G,200	1.05 ± 0.30	1.08 ± 0.27	1.13	0.62 ± 0.17	<4.43
G,240	0.78 ± 0.40	0.78 ± 0.24	1.56	0.58 ± 0.16	<3.20
G,266	1.30 ± 0.41	1.02 ± 0.98	1.32	0.66 ± 0.16	<2.44
G,-300	0.79 ± 0.38	0.69 ± 0.27	1.48	0.49 ± 0.17	<1.89
I,-20	0.74 ± 0.26	0.60 ± 0.24	1.34	0.55 ± 0.16	<1.66
I, 26	1.07 ± 0.35	0.99 ± 0.27	2.06	0.58 ± 0.20	<2.95
I, 40	1.20 ± 0.60	0.99 ± 0.39	2.19	0.08 ± 0.24	<4.34
I, 80	0.99 ± 0.65	0.75 ± 0.48	1.74	0.59 ± 0.22	<4.03
I,120	0.71 ± 0.31	0.69 ± 0.27	1.40	0.58 ± 0.15	<3.30

TABLE 11 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE STABILIZATION PILE

Grid Location	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium	Ra-226	U-238
I,160	0.82 ± 0.30	0.69 ± 0.27	1.51	0.56 ± 0.16	<3.20
I,200	1.04 ± 0.38	1.05 ± 0.27	2.09	0.67 ± 0.14	<4.16
I,240	1.10 ± 0.36	0.84 ± 0.30	1.94	0.60 ± 0.17	<2.80
I+14, 40	0.73 ± 0.30	0.78 ± 0.24	1.51	0.57 ± 0.15	<3.20
I,-300	0.63 ± 0.26	0.45 ± 0.27	1.08	0.53 ± 0.15	<2.53
J+9, 80	0.89 ± 0.29	0.57 ± 0.27	1.46	0.51 ± 0.15	<2.35
J+18,120	0.77 ± 0.29	0.90 ± 0.30	1.67	0.51 ± 0.17	<2.59
J,-300	0.33 ± 0.33	0.45 ± 0.24	0.78	0.34 ± 0.14	<2.78
K,160	1.07 ± 0.42	0.96 ± 0.30	2.03	0.53 ± 0.16	<3.01
K,200	0.63 ± 0.27	0.66 ± 0.12	1.29	0.40 ± 0.16	<2.79
K,-300	0.64 ± 0.30	0.75 ± 0.27	1.39	0.41 ± 0.15	<2.57
-L, 40	0.87 ± 0.28	0.96 ± 0.21	1.83	0.50 ± 0.15	<3.25
-L, 80	0.81 ± 0.27	0.54 ± 0.21	1.35	0.53 ± 0.17	<3.27
-L,120	1.07 ± 0.43	0.63 ± 0.30	1.70	0.46 ± 0.18	<2.91
-L,160	0.71 ± 0.42	0.51 ± 0.4	1.22	0.40 ± 0.13	<2.99
-L,180	1.19 ± 0.40	1.05 ± 0.42	2.24	0.74 ± 0.22	<3.80
-L,-300	1.12 ± 0.36	1.29 ± 0.33	2.41	0.71 ± 0.21	<4.06

[a] Refer to Figure 14.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 12

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
COLLECTED FROM THE RAVINE

Distance Along the Ravine (m)[a]	Sample Description	Radionuclide Concentrations (pCi/g)				
		Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
0	Surface	1.40 ± 0.51[b]	1.48 ± 0.38	2.88	0.60 ± 0.20	7.12 ± 7.75
0	90 cm	<0.19	0.67 ± 0.24	0.67	0.36 ± 0.19	<2.99
20	Surface	2.01 ± 0.44	1.80 ± 0.39	3.81	0.62 ± 0.19	<2.71
40	"	0.21 ± 0.30	0.36 ± 0.20	0.57	0.28 ± 0.15	<1.95
60	"	0.52 ± 0.31	0.48 ± 0.21	1.0	0.44 ± 0.15	<2.81
80	"	0.60 ± 0.29	0.54 ± 0.30	1.14	0.45 ± 0.15	<2.81
100	"	1.19 ± 0.33	1.35 ± 0.27	2.54	0.61 ± 0.16	<3.36
120	"	1.59 ± 0.36	1.53 ± 0.33	3.12	0.64 ± 0.17	<3.45
140	"	3.28 ± 0.53	2.40 ± 0.57	5.68	0.73 ± 0.22	<4.34
160	"	1.68 ± 0.46	1.80 ± 0.33	3.48	0.63 ± 0.23	<2.72
180	"	0.75 ± 0.39	1.23 ± 0.30	1.98	0.85 ± 0.19	<3.75
200	"	2.80 ± 0.74	2.67 ± 0.59	5.47	1.34 ± 0.33	<5.34
200	60 cm	4.93 ± 0.83	1.05 ± 0.41	5.98	0.87 ± 0.27	<3.69
220	Surface	0.70 ± 0.34	0.69 ± 0.24	1.39	0.42 ± 0.21	<3.40
240	"	0.94 ± 0.36	1.14 ± 0.24	2.08	0.57 ± 0.14	<2.04
260	"	2.02 ± 0.40	2.07 ± 0.45	4.09	0.63 ± 0.20	<3.97
280	"	2.13 ± 0.51	2.01 ± 0.36	4.14	0.65 ± 0.19	<4.12
300	"	2.51 ± 0.48	2.49 ± 0.48	5.00	0.75 ± 0.24	<3.85
320	"	2.58 ± 0.68	2.85 ± 0.42	5.43	0.77 ± 0.26	<4.21
340	"	2.91 ± 0.66	2.76 ± 0.42	5.67	0.89 ± 0.24	<3.84
360	"	3.34 ± 0.70	3.42 ± 0.45	6.76	0.82 ± 0.24	<3.92
380	"	1.94 ± 0.45	1.71 ± 0.42	3.65	0.49 ± 0.20	4.34 ± 7.63
400	"	1.65 ± 0.71	1.44 ± 0.42	3.09	0.78 ± 0.25	<5.25
400	90 cm	1.10 ± 0.38	1.13 ± 0.35	2.26	0.79 ± 0.27	<3.95

[a] Refer to Figure 13.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 13

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
FROM AREAS OF ELEVATED DIRECT RADIATION LEVELS
ALONG THE RAVINE

Distance (m)		Radionuclide Concentrations (pCi/g)				
Along Ravine	From Ravine Ctr	Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
-5	7 East	21.1 ± 1.3[b]	20.6 ± 1.1	41.7	6.23 ± 0.58	18.3 ± 17.9
197	10 West	34.1 ± 2.3	25.9 ± 2.3	60.0	3.56 ± 0.75	<12.6

[a] Refer to Figure 13.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 14

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
COLLECTED ON THE AMAX PROPERTY AND ALONG THE OHIO RIVER

Sample Location[a]	Radionuclide Concentrations (pCi/g)				
	Th-232	Th-228	Total Thorium[c]	Ra-226	U-238
Ohio River					
1 At Outfall	16.2 ± 1.21[b]	14.9 ± 0.95	31.1	4.87 ± 0.56	16.5 ± 16.9
2 40 m Downstream	0.93 ± 0.32	0.86 ± 0.27	1.79	0.73 ± 0.17	<2.30
3 60 m Downstream	0.68 ± 0.31	0.74 ± 0.29	1.42	0.57 ± 0.15	<2.71
Storm Sewer					
4	81.0 ± 2.2	83.0 ± 1.8	164	18.7 ± 1.1	23.8 ± 23.4
5	71.9 ± 2.0	67.8 ± 1.6	140	26.0 ± 0.8	62.1 ± 25.5
6	0.53 ± 0.17	<0.45	< 0.98	<0.09	<2.15
7	2.32 ± 0.50	2.43 ± 0.47	4.75	0.73 ± 0.28	7.7 ± 12.0

[a] Refer to Figure 15.
[b] Errors are 2σ based on counting statistics.
[c] Th-232 + Th-228.

TABLE 15

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/l or x 10^{-9} μCi/ml)	
	Gross Alpha	Gross Beta
Storm Sewer:		
1 filtrate	<2.91	<4.72
1 filter	<0.02	0.33 ± 0.06[b]
Well:		
8	0.68 ± 0.71	3.03 ± 0.56

[a] Refer to Figure 15.
[b] Errors are 2σ based on counting statistics.

REFERENCES

1. Adcor, Inc., Radiological Assessment Report for AMAX, Inc., Property Located at Parkersburg, West Virginia. Vol. 1, 2, Dec. 1, 1978.

2. U.S. Nuclear Regulatory Commission, Division of Fuel Cycle and Material Safety. Environmental Impact Appraisal, AMAX, Inc., Parkersburg, West Virginia Site. Docket No. 40-8355, Proposed Site Stabilization, April 1982.

3. AMAX, Inc., Environmental Services Inc. Stabilization Plan, Construction and Final Survey, AMAX, Inc., Property Wood County, West Virginia. March 1984.

APPENDIX A

CHRONOLOGY OF EVENTS

APPENDIX A

CHRONOLOGY OF EVENTS

1957	Carborundum Company begins processing zircon ore to produce metal under contract from the Atomic Energy Commission.
1961-62	Nigerian zircon ore containing up to 6% thorium (ThO_2) and up to 0.2% uranium (UO_2) is processed.
1965-67	AMAX Inc., and Carborundum Company operate the facility as a joint venture Carborundum Metals Climax.
1967	AMAX Inc. becomes the sole owner of the facility.
1968	The remains and processing residues of the Nigerian ore are removed from the site for burial.
1969	Zirconium tetrachloride is substituted for zircon ore.
1974	The processing of zirconium ceased.
1977	An NRC inspection identified soil contaminated with residues of the Nigerian ore which is subsequently disposed of offsite. The site is sold to L.B. Foster Company for the construction of a pipe manufacturing plant.
1978	Pyrophoric material is uncovered at the site. The property is repurchased by AMAX. A radiological survey of the site is performed by Chem-Nuclear Systems Inc.
1979	L.B. Foster is leased portions of the site free of radioactive and pyrophoric material for the relocation of the pipe manufacturing plant.

1980 AMAX Inc. completes a plan for the onsite stabilization of the radioactive and pyrophoric contamination.

1982 The Nuclear Regulatory Commission completes an environmental impact appraisal of the stabilization plan and gives its approval with certain provisions.

The stabilization of the site is initiated and completed. Chem-Nuclear Systems Inc. provided the radiological data during these operations. Oak Ridge Associated Universities assessed this data and performed a post-stabilization survey of the site.

APPENDIX B

THORIUM AND URANIUM DECAY SERIES

TABLE B-1

THORIUM DECAY SERIES

Parent	Half-Life	Major Decay Products	Daughter
Thorium-232	14 billion years	alpha	Radium-228
Radium-228	5.8 years	beta	Actinium-228
Actinium-228	6.13 hours	beta, gamma	Thorium-228
Thorium-228	1.91 years	alpha	Radium-224
Radium-224	3.64 days	alpha	Radon-220
Radon-220	55 seconds	alpha	Polonium-216
Polonium-216	0.15 seconds	alpha	Lead-212
Lead-212	10.6 hours	beta, gamma	Bismuth-212
Bismuth-212	60.6 minutes	alpha (1/3)* beta (2/3)*	Thallium-208 Polonium-212
Thallium-208	3.1 minutes	beta, gamma	Lead-208
Polonium-212	0.0000003 seconds	alpha	Lead-208
Lead-208	stable	none	none

* Two decay modes are possible for Bismuth-212.

TABLE B-2

URANIUM DECAY SERIES

Parent	Half-Life	Major Decay Products	Daughter
Uranium-238	4.5 billion years	alpha	Thorium-234
Thorium-234	24 days	beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	beta, gamma	Uranium-234
Uranium-234	250,000 years	alpha	Thorium-230
Thorium-230	80,000 years	alpha	Radium-226
Radium-226	1,600 years	alpha	Radon-222
Radon-222	3.8 days	alpha	Polonium-218
Polonium-218	3 minutes	alpha	Lead-214
Lead-214	27 minutes	beta, gamma	Bismuth-214
Bismuth-214	20 minutes	beta, gamma	Polonium-214
Polonium-214	.0002 seconds	alpha	Lead-210
Lead-210	22 years	beta	Bismuth-210
Bismuth-210	5 days	beta	Polonium-210
Polonium-210	140 days	alpha	Lead-206
Lead-206	stable	none	none

APPENDIX C

MAJOR ANALYTICAL EQUIPMENT

APPENDIX C

MAJOR ANALYTICAL EQUIPMENT

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter-Scaler
Model PRS-1
Beta-Gamma "Pancake" Probe, Model HP-260
(Eberline Instrument, Sante Fe, NM)

Eberline PRM-6
Portable Ratemeter-Scaler
Scintillation Probe, Model 489-55
(Victoreen, Inc., Cleveland, OH)

Eberline "Pancake" G-M Probe
Model HP-260
(Eberline, Sante Fe, NM)

Victoreen Gamma Scintillation Probe
Model 489-55
(Victoreen, Cleveland, OH)

Pressurized Ionization Chamber (PIC)
Model RSS-111
(Reuter Stokes, Cleveland. OH)

B. Laboratory Analysis

Ge(Li) Detector
Model LGCC2220-SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

Pulse Height Analyzer, ND680
Model 88-0629
(Nuclear Data, Inc., Schaumburg, IL)

Intrinsic Germanium Detector
Model LGC2525-SD/8
(Princeton Gamma Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, Model 121212-RT
(Electronic Counter, Co., Okmulzee, OK)

Pulse Height Analyzer, ND66
Model 88-0629
(Nuclear Data, Inc., Schaumburg, IL)

Low Background Alpha-Beta Counter
Model LB5100-2080
(Tennelec, Inc., Oak Ridge, TN)

20 mg Californium-252 Source with Flexo-Rabbit
Pneumatic Transfer System
(Reactor Experiments, Inc., San Carlos, CA)

Multichannel Analyzer
Model TN-7200
(Tracor Northern, Middleton, WI)

APPENDIX D

ANALYTICAL PROCEDURES

APPENDIX D

Analytical Procedures

Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using an Eberline PRM-6 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. A graph of count rate (cpm) vs. exposure rate (μR/h) was developed by comparing the response of the scintillation detector with that of a Reuter Stokes Model RSS-111 pressurized ionization chamber at several locations on the AMAX property. This plot was used to convert the meter readings to exposure rates.

Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal" Model PRS-1 portable ratemeters with Model HP-260 G-M probes. Dose rates (μrad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a natural thorium source.

Soil and Sediment Samples Analysis

Most soil samples received from Chem-Nuclear during the confirmatory survey were prepared and analyzed at the Parkersburg site in the following manner. Samples were placed in a 0.5 liter Marinelli beaker, the quantity being chosen to reproduce the calibrated counting geometry. Net weights, typically from 500 to 800 g of soil, were determined and the samples counted using an intrinsic germanium detector (Princeton Gamma Tech) coupled to a Nuclear Data model ND66 pulse height anlayzer. The following energy peaks were used for determination of the radionuclides of concern:

Th-232 - 0.911 MeV from Ac-228 (secular equilibrium assumed)
Th-228 - 0.583 MeV from Tl-208 (secular equilibrium assumed)

Peak identifications were provided by computer analysis. Concentration calculations were performed by hand.

Some soil samples from the confirmatory survey and all the samples, soil and sediment, from the post-stabilization survey were analyzed at the laboratory in Oak Ridge. Sample preparation and analysis were similar to those performed at the site except samples were counted using a 23% Ge(Li) detector (Princeton Gamma Tech) coupled to a Nuclear Data model 680 pulse height analyzer. In addition to Th-228 and Th-232, the samples were also analyzed for Ra-226 and U-238. The following energy peaks were used:

Ra-226 - 0.609 MeV from Bi-214 (secular equilibrium assumed)
U-238 - 1.001 MeV from Pa-234 m (secular equilibrium assumed)

Both peak identification and concentration calculations were provided by computer analyses.

Selected soil samples were also analyzed for U-238 by neutron activation. Approximately 15-20 g of soil were irradiated for 15 minutes in a neutron flux of 10^8 n/cm^2/sec. After a one minute wait time, the U-239 peak (74.6 keV) was counted for 10 minutes and the U-238 concentration calculated.

Water Samples

Water samples were rough filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by filtration through 0.45 µm pore size membrane filters and the filtrate was acidified by the addition of 10 ml of concentrated nitric acid.

Gross Alpha and Gross Beta Analysis

Fifty milliliters of each sample was evaporated to dryness. The dried samples and, in the case of the storm sewer sample, the filters, were counted on a Tennelec Model LB5100 low background proportional counter.

Errors and Detection Limits

The errors, associated with the analytical data presented in the tables of this report, represent the 95% (2σ) confidence levels for that data. These errors were calculated based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 2σ statistical deviation of the background count, the sample concentration was reported as less than the minimum detectable activity (<MDA). This means that the radionuclide was not present, to the best of our ability to measure it, utilizing the analytical techniques described in this appendix. Because of variations in background levels caused by other constituents in the samples, the MDAs for specific radionuclides differ from sample to sample.

Calibration and Quality Assurance

Laboratory analytical instruments are calibrated using NBS-traceable standards. Portable survey instruments for exposure rate and dose rate measurements are calibrated by comparison of their responses to those of other instruments having NBS-traceable calibration. Field comparisons or comparisons using samples typical of the area are used to develop these calibrations.

Quality control procedures on all instruments included daily background and check-source measurements to confirm equipment operation was within acceptable statistical fluctuations. The ORAU Laboratory participates in the EPA Quality Assurance Program.

Rec'd 2/12/85

Oak Ridge Associated Universities
Post Office Box 117
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Manpower Education, Research, and Training Division

40-8820

PDR
Return to 39655

February 6, 1985

Mr. Ralph M. Wilde
Div. Fuel Cycle & Mat. Safety
MS-SS396
Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Wilde:

Enclosed you will find 20 copies of the Radiological Survey of the AMAX Site, Parkersburg, West Virginia, Final Report.

If you should have any questions regarding this report, please feel free to telephone me at FTS 626-3305.

Sincerely,

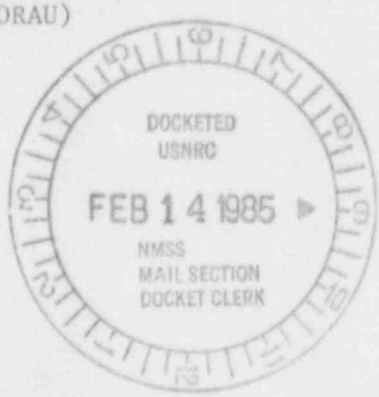
Jim Berger /ss

James D. Berger, Program Manager
Radiological Site Assessment Program

JDB:sds

Enclosures (20)

cc: Dr. William Boyle (ORAU)
Mr. Roger Cloutier (ORAU)



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Enclosed are Copies of the Radiological Survey of the AMAX Site 02/14/85 INITIAL CRC