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Oak Ridge Associated
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U.S. Nuclear
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Enforcement

RADIOLOGICAL SURVEY
OF THE
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LANDFILL SITE
BAY CITY, MICHIGAN

L. L. SOWELL

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

DRAFT REPORT
(REVISED)

JULY 1985

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This draft report has not been given full review and patent clearance, and the dissemination of its information is only for official use. No release to the public shall be made without the approval of the Office of Information Services, Oak Ridge Associated Universities.

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RADIOLOGICAL SURVEY
OF THE
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LANDFILL SITE
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INTRODUCTION AND SITE HISTORY

Between approximately 1950 and 1972, Hartley and Hartley operated a hazardous waste landfill near Bay City, Michigan. During that period, slag, believed to have originated from the Wellman Dynamics Foundry in Midland, Michigan, was placed in the landfill. This slag, a waste product of the thorium-magnesium process, contains elevated levels of naturally occurring thorium. In 1972 portions of the landfill property were transferred to SCA Chemical Services, Inc. (now Waste Management, Inc.), and to the State of Michigan Department of Natural Resources (DNR). Hartley and Hartley retained property adjoining the landfill site. As part of the stabilization and final closure of the landfill, the Nuclear Regulatory Commission, Region III, requested that Oak Ridge Associated Universities (ORAU) conduct a survey to assess the radiological conditions of the DNR portion of the site.

SITE DESCRIPTION

The former Hartley and Hartley landfill site is located in Bay County, Michigan, approximately 5 km NW of Bay City (refer to Figure 1). Figure 2 is a plot plan of the DNR portion of the site. The site is approximately 100 m x 120 m and occupies 1.2 hectares. It is bounded on the north, east, and west by swampland (also owned by DNR), and on the south by property belonging to SCA and to Hartley and Hartley. A haul road parallels the southern boundary. Aerial photographs taken during active operation of the landfill indicated that numerous 55 gallon drums were placed in this area. Discussions with Mr. Hartley revealed that these drums contained various chemical wastes; these containers were subsequently burned. Mr. Hartley indicated that the slag had been placed in a strip down the center of the property for use as a road bed. There are no structures on the property.

SURVEY PROCEDURES

An initial survey of the unstabilized site was conducted by ORAU during July 1984. Shortly after this survey, stabilization and closure of the site was initiated. In June 1985 ORAU personnel returned to the site and performed further radiological measurements and sampling.

Objectives

The objectives of the surveys were to provide an assessment of the radiological conditions and associated potential health effects, if any, on the site. Radiological information collected included:

1. direct radiation levels,
2. locations of elevated surface residues, and
3. identification and determination of radionuclide concentrations in soil.

Procedures

Before Stabilization

1. A 20 m grid system was established on the site and referenced to property markers. This grid system was subdivided in certain areas into a 10 m grid to provide better definition of radiation levels and soil concentrations based on results of the walkover scan. The grid system is shown on Figure 3.
2. A walkover surface scan using portable NaI(Tl) gamma scintillation detectors was conducted at 1-2 m intervals over the accessible portions of the property and at 5-10 m intervals in the swamp areas. Locations of elevated contact radiation levels were noted.

3. Gamma exposure rate measurements were made at the surface and at 1 m above the surface at each grid line intersection, and at locations of elevated contact radiation levels as identified by the walkover surface scan. These measurements were performed using portable NaI(Tl) gamma scintillation detectors and ratemeters, cross calibrated onsite with a pressurized ionization chamber.
4. Beta-gamma dose rate measurements were made at 1 cm above the surface at each of the locations where exposure rates were measured. These measurements were conducted using thin window ($<7 \text{ mg/cm}^2$) "pancake" G-M detectors with scaler/ratemeters. Measurements were also made with the detector shielded to evaluate contributions of nonpenetrating beta and low-energy gamma radiations.
5. Soil samples were collected from the surface (0-15 cm) at grid line intersections (refer to Figure 3) and at various depths from selected locations of elevated contact radiation levels as identified by the walkover surface scan. All soil samples were collected by hand digging to avoid the possibility of damage to chemical waste containers.
6. Three sediment samples were collected from the swamp areas, and one from a stream located on the north side of the site. These locations are shown on Figure 4.
7. Surface water samples were collected from each location where a sediment sample was collected.
8. Four surface soil and water samples and two sediment samples were collected from the Bay City area (but not on or near the DNR property) to provide baseline concentrations of radionuclides for comparison purposes. Direct background radiation levels were measured at the locations where baseline samples were collected. These locations are shown on Figure 5.

After Stabilization

1. The 20 m grid used for survey reference before stabilization was re-established.
2. A walkover surface gamma scan was performed to identify elevated direct radiation levels.
3. Gamma exposure rates at the surface and 1 m above the surface and beta gamma dose rates at 1 cm above the surface were measured at 20 m grid intervals.
4. Surface soil samples were collected at randomly selected grid line intersections.
5. Water samples were obtained from 4 monitoring wells and 2 surface locations (see Figure 8).

Sample Analysis and Interpretation of Results

Soil samples and sediment samples were analyzed by gamma spectrometry. Radionuclides of primary interest included Th-232, Th-228, U-238, and Ra-226; however, spectra were reviewed for other identifiable photopeaks. Water samples were analyzed for gross alpha and beta concentrations.

Additional information concerning instrumentation and analytical procedures is contained in Appendices A and B. Results of this survey were compared to NRC guidelines for residual thorium and uranium in soil. These guidelines are summarized in Appendix C.

RESULTS

Background Levels and Baseline Concentrations

Background exposure rates and dose rates and baseline radionuclide concentrations in soil, sediment, and water for four locations in the Bay City area are presented in Tables 1A, 1B, and 1C. Exposure rates ranged from 7 to

9 μ R/h, both at contact and at 1 m above the surface. Dose rates measured at the surface ranged from 9 to 38 μ rad/h. Radionuclide concentrations in soil were: Th-232, 0.28 to 0.85 pCi/g (picocuries per gram); Th-228, 0.10 to 0.47 pCi/g; U-238, <0.74 to 1.41 pCi/g; and Ra-226, 0.37 to 0.80 pCi/g. Radionuclide concentrations in sediment were: Th-232, 0.57 and 0.96 pCi/g; Th-228, 0.26 and 0.89 pCi/g; U-238, <0.49 and 1.35 pCi/g; and Ra-226, <0.55 and 0.35 pCi/g. Gross alpha and gross beta concentrations in water ranged from 0.21 to 8.02 pCi/l (picocuries per liter) and 5.77 to 14.8 pCi/l, respectively.

Before Stabilization

Direct Measurements

Direct radiation levels measured at grid line intersections are presented in Table 2. The gamma exposure rates measured at 1 m above the surface ranged from 7 to 32 μ R/h (average 9 μ R/h). At surface contact, the exposure rates ranged from 7 to 93 μ R/h (average 10 μ R/h). Beta-gamma dose rates measured at the surface ranged from 7 to 250 μ rad/h (average 18 μ rad/h). Measurements performed with the detector shielded were not significantly different from those with the unshielded detector. This indicates only a small portion of the surface dose rate is due to nonpenetrating beta or low-energy photon radiations.

The walkover survey identified numerous areas of elevated contact radiation levels. These locations are indicated on Figure 6, and direct radiation levels at these locations are presented in Table 3. Contact gamma exposure rates ranged from 21 to 470 μ R/h. Gamma exposure rates at 1 m above the surface, and beta-gamma dose rates at contact ranged from 10 to 110 μ R/h and 21 to 470 μ rad/h, respectively.

Radionuclide Concentrations in Surface Soil

Table 4 lists the concentrations of radionuclides measured in surface soil collected at grid line intersections. These samples contained Th-232 concentrations ranging from <0.06 to 69.5 pCi/g. The highest level was in the

sample collected from grid point 70N,40E. Th-228 concentrations ranged from <0.09 to 72.8 pCi/g, with the highest levels found in the sample collected from grid point 70N,40E also. Concentrations of U-238 and Ra-226 ranged from <0.11 to 5.70 pCi/g and <0.06 to 2.53 pCi/g, respectively. Radionuclide concentrations in the majority of the samples were within the range encountered in baseline samples; the samples with higher concentrations were in the vicinity of the locations of elevated contact radiation levels identified by the walkover surface scan.

Table 5 lists the concentrations of radionuclides measured in soil, collected at selected locations of elevated contact radiation levels; these locations are shown on Figure 7. The maximum concentration of Th-232 was 561 pCi/g, measured in the sample from 25 to 35 cm deep at grid coordinate 37N,48E; the maximum concentration of Th-228 was 527 pCi/g, from the same location and depth. U-238 and Ra-226 concentrations were elevated in samples with elevated thorium levels. The material which was radioactive was gray and of a mixed rock and clay consistency. It was in a discrete 15 to 20 cm thick layer at depths varying from the surface to approximately 45 cm deep. Where it was possible to monitor below this layer, radionuclide concentrations dropped to baseline levels and direct radiation levels decreased.

Radionuclide Concentrations in Sediment Samples

Radionuclide concentrations in sediment samples are presented in Table 6. Th-232 concentrations ranged from <0.12 to 14.6 pCi/g. The maximum level was found in the sample collected at grid coordinate 42N,40E. Th-228 concentrations ranged from 0.20 to 15.4 pCi/g with the highest level in the sample collected at grid coordinate 42N,40E also. This was a location of elevated contact radiation levels identified by the walkover scan. U-238 and Ra-226 concentrations were not elevated.

Radionuclide Concentrations in Surface Water

Samples of surface water were collected from the same locations where sediment samples were collected; the radionuclide concentrations are

presented in Table 7. One sample had an elevated gross beta level of 30.4 pCi/l; however, all of the concentrations were within the EPA drinking water criteria of 15 pCi/l gross alpha and 50 pCi/l gross beta.¹

After Stabilization

Direct Measurements

Direct radiation levels at grid line intersections after site stabilization are presented in Table 8. At 1 m above the surface the exposure rates ranged from 6 to 9 μ R/h; at contact the exposure rates also ranged from 6 to 9 μ R/h, surface beta-gamma dose rates ranged from 7 to 31 μ rad/h.

The walkover scan did not identify any areas of elevated contact radiation.

Radionuclide Concentrations in Surface Soil

Table 9 lists the concentrations of radionuclides measured in surface soil from grid line intersections after stabilization. Thorium 232 concentrations ranged from <0.31 to 0.78 pCi/g; concentrations of Th-228 ranged from 0.18 to 0.75 pCi/g. Levels of U-238 and Ra-226 ranged from <0.60 to <1.09 pCi/g and 0.30 to 1.04 pCi/g, respectively.

Radionuclide Concentrations in Water

Radionuclide concentrations in water obtained from 4 wells and 2 surface locations after stabilization are presented in Table 10. Gross alpha and gross beta concentrations ranged from 0.46 to <5.29 pCi/l and 3.46 to 17.3 pCi/l, respectively.

COMPARISON OF SURVEY RESULTS WITH GUIDELINES

The soil guidelines applicable to this site are presented in Appendix C. The guideline for total thorium (Th-232 plus Th-228) contamination in soil is 10 pCi/g for unrestricted use (Option 1). The acceptable exposure rate at one meter above the surface is 10 μ R/h above background, or 19 μ R/h total for this

site. Before stabilization deposits of thorium slag were present on the surface. Numerous locations on the property exceeded 19 μ R/h at 1 m. Total thorium concentrations in samples collected at four locations of elevated contact radiation levels and at several of the grid intersections exceeded 10 pCi/g. It is likely, based on the direct radiation levels, that other locations identified by the surface scan, also exceeded 10 pCi/g of total thorium. Samples from several areas contained total thorium levels exceeding the Option 4 guideline of 500 pCi/g.

Addition of clean fill for stabilization and closure reduced direct radiation to background levels and covered all deposits of thorium slag. All radiation levels and radionuclide concentrations in surface soil on the site are now within the option 1 guidelines.

SUMMARY

A survey of the DNR portion of the former Hartley and Hartley landfill site was conducted during July, 1984. The survey included surface radiation scans, measurements of direct radiation levels, and analyses of radionuclide concentrations in soil, sediment, and water samples. The results of this survey indicated a 15 to 20 cm thick layer of thorium contaminated slag near to the surface. The contaminated slag appeared to be distributed in a 10 to 20 m wide strip near the center of the property, extending almost the entire north/south length of the site. These findings are consistent with the history of the site as presented by the former owner, Mr. Hartley. The site was resurveyed in June 1985, after it was covered by clean fill for stabilization and closure. Surface conditions after the addition of fill satisfy the NRC option 1 guidelines. Although subsurface thorium slag deposits remain on portions of this property, it is likely, based on the site history and use restrictions, that this material will remain covered and will therefore not pose potential hazards to the general public through direct exposure or migration.

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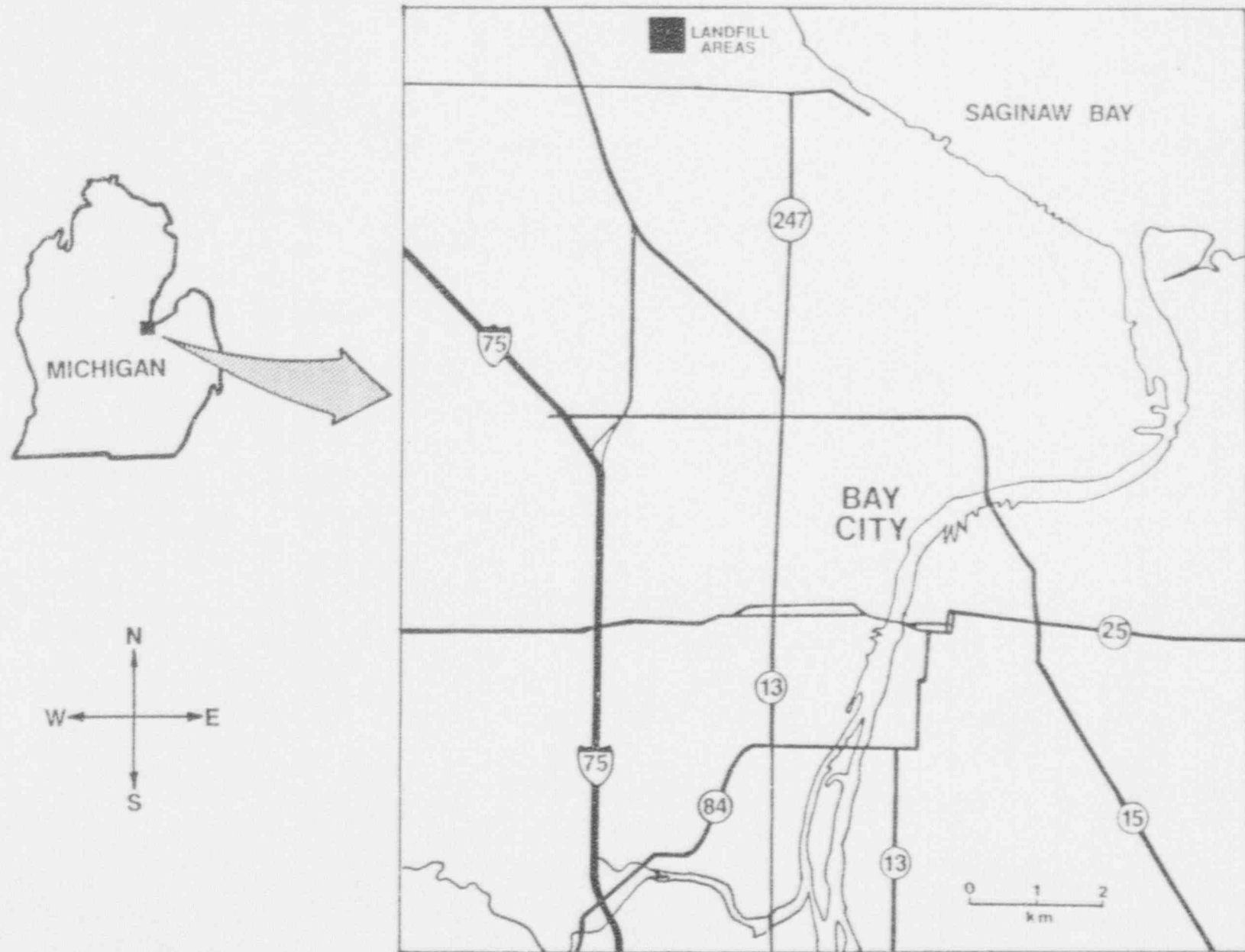


FIGURE 1: Map of Michigan and Bay City Showing the Location of the Landfill Site.

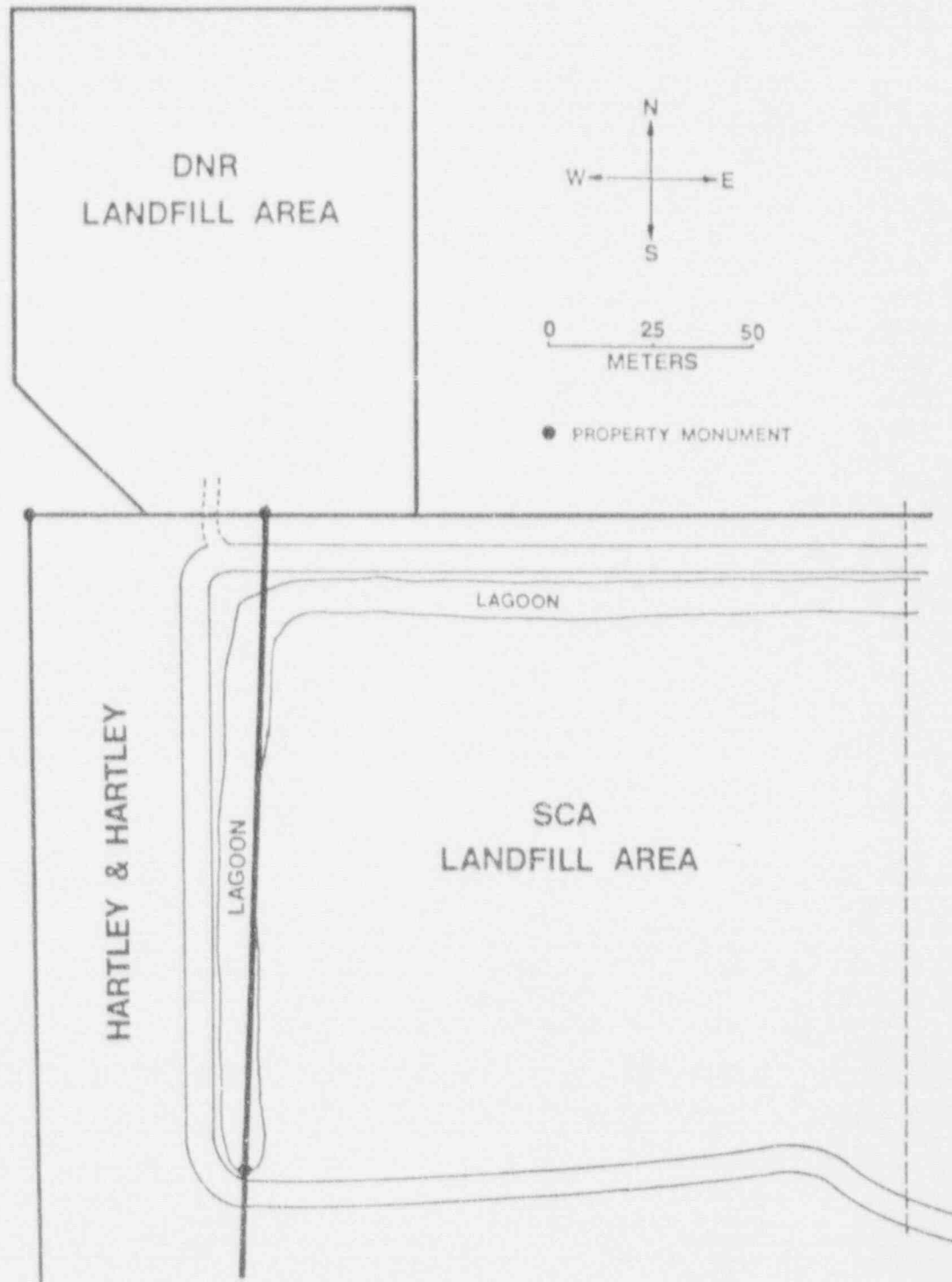


FIGURE 2: Plan View of Landfill Site.

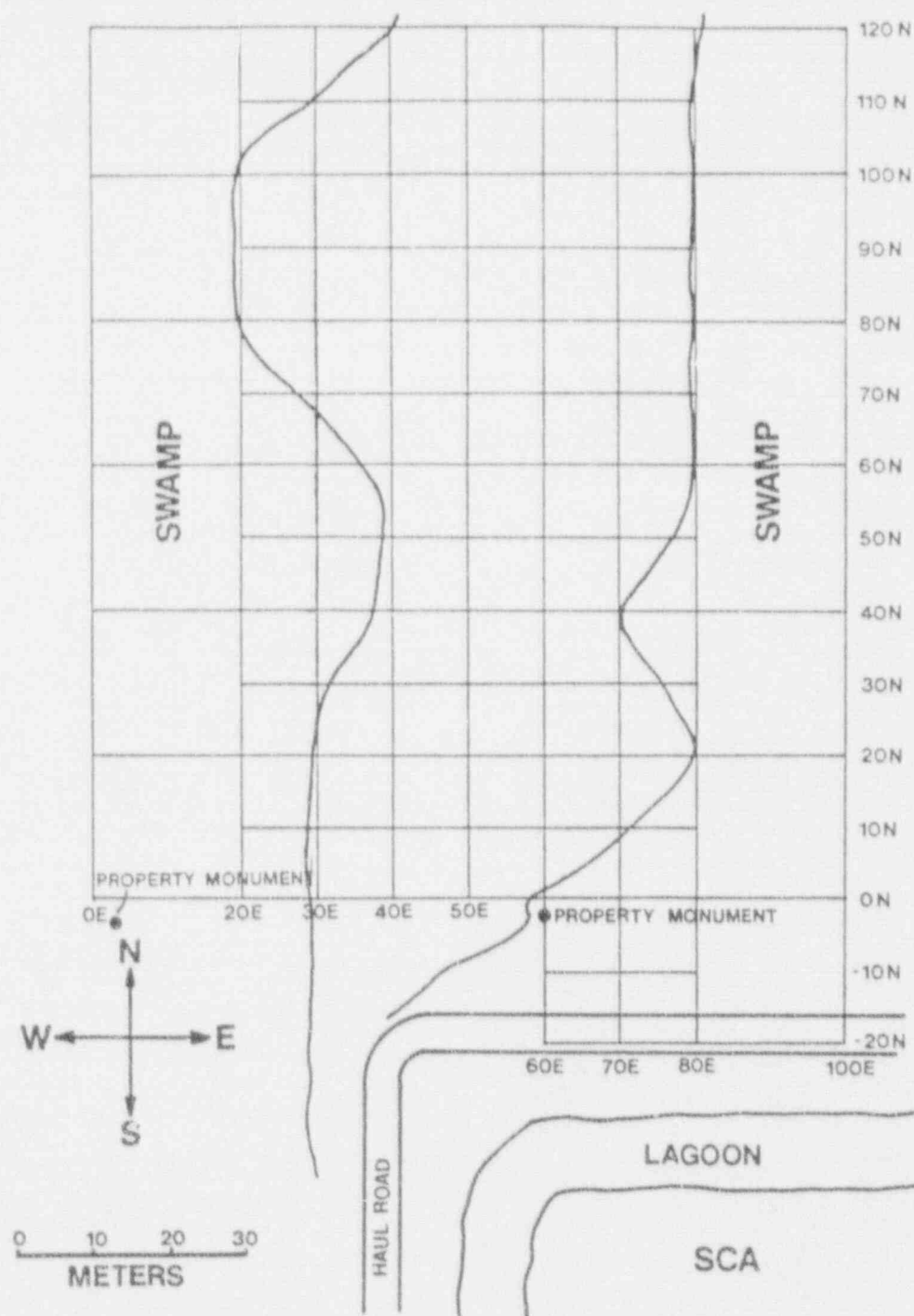


FIGURE 3: Grid of DNR Landfill Site.

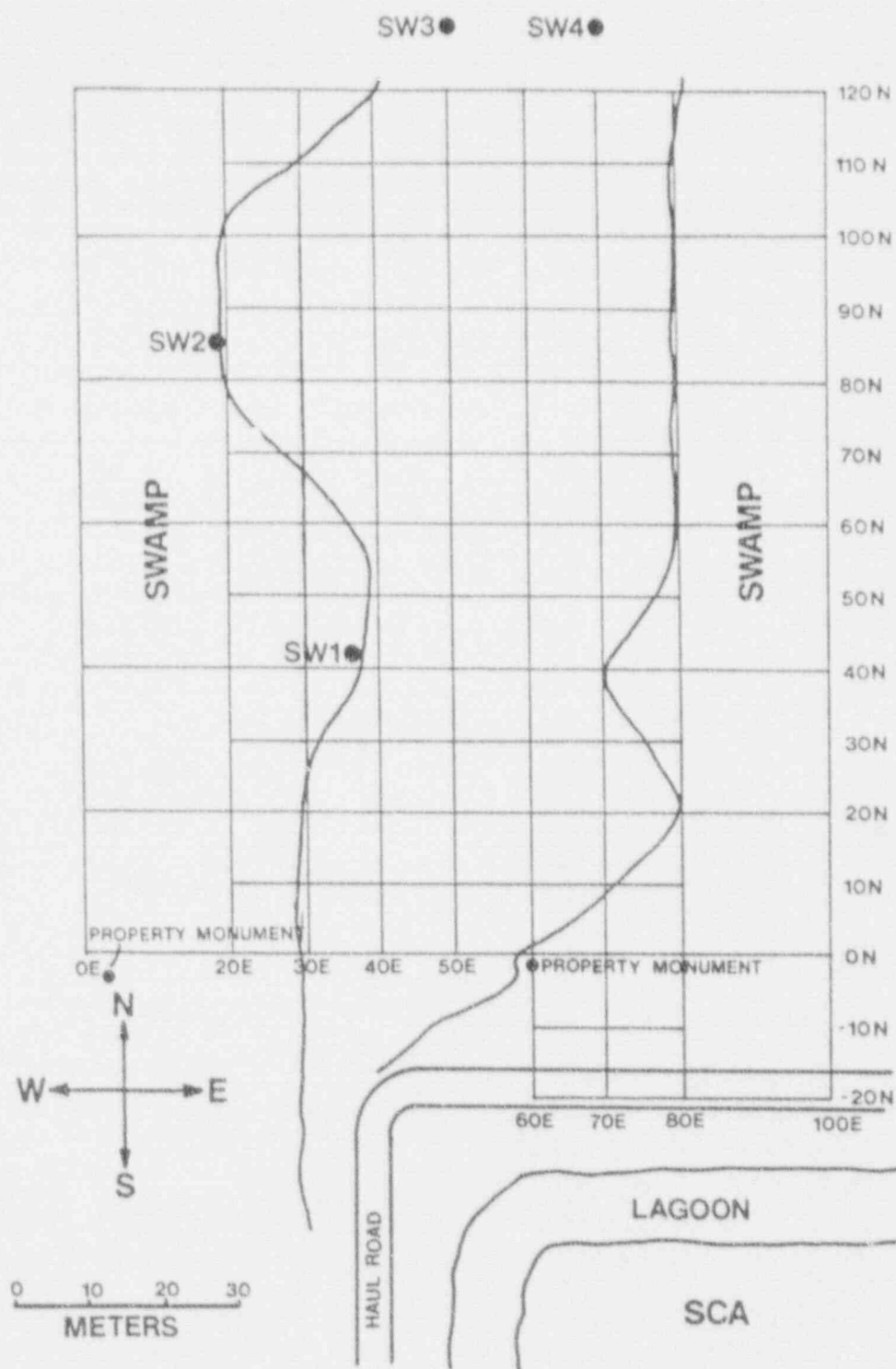


FIGURE 4: Locations of Water and Sediment Samples.

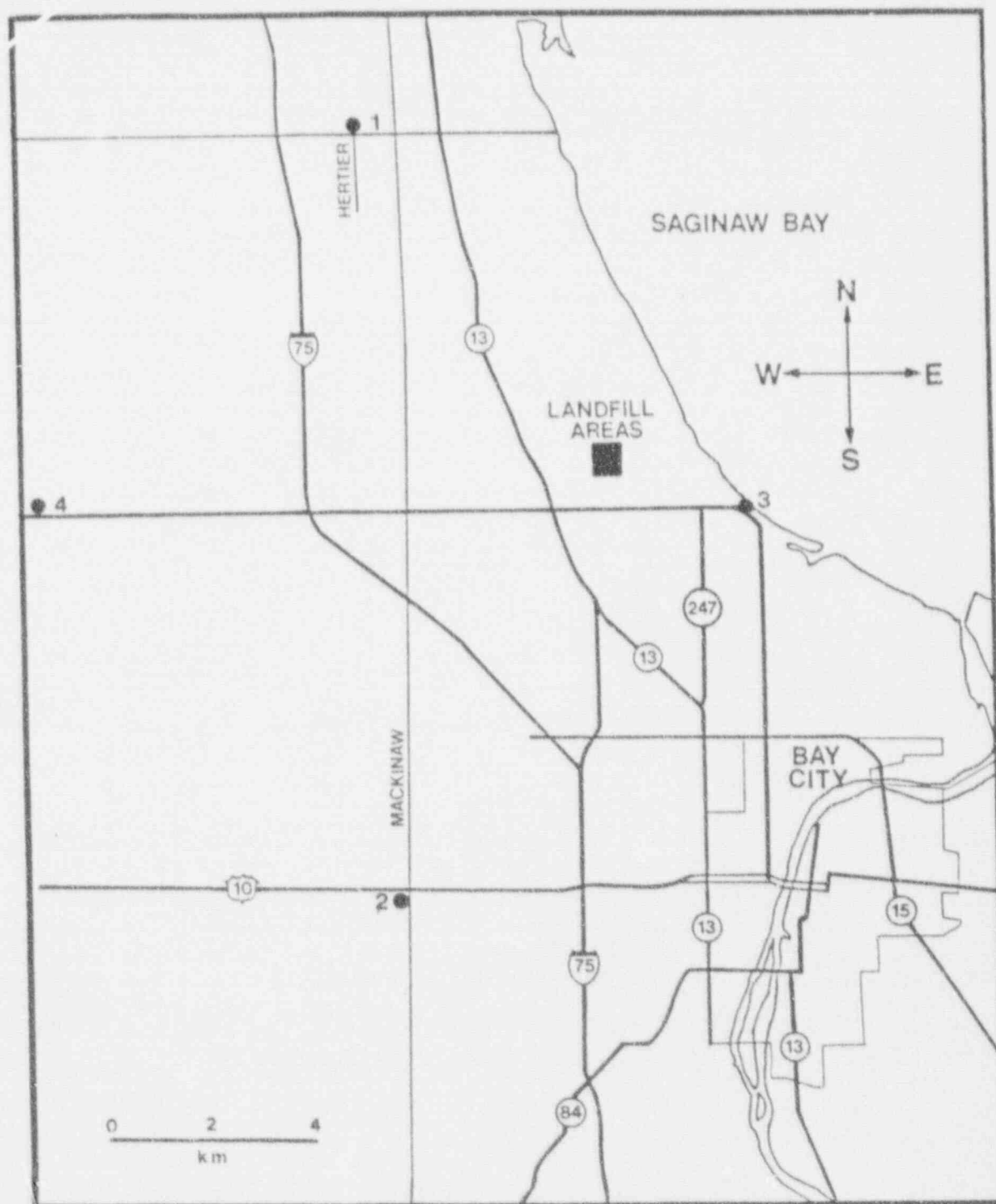


FIGURE 5: Locations of Background Measurements and Baseline Samples in the Bay City Area.

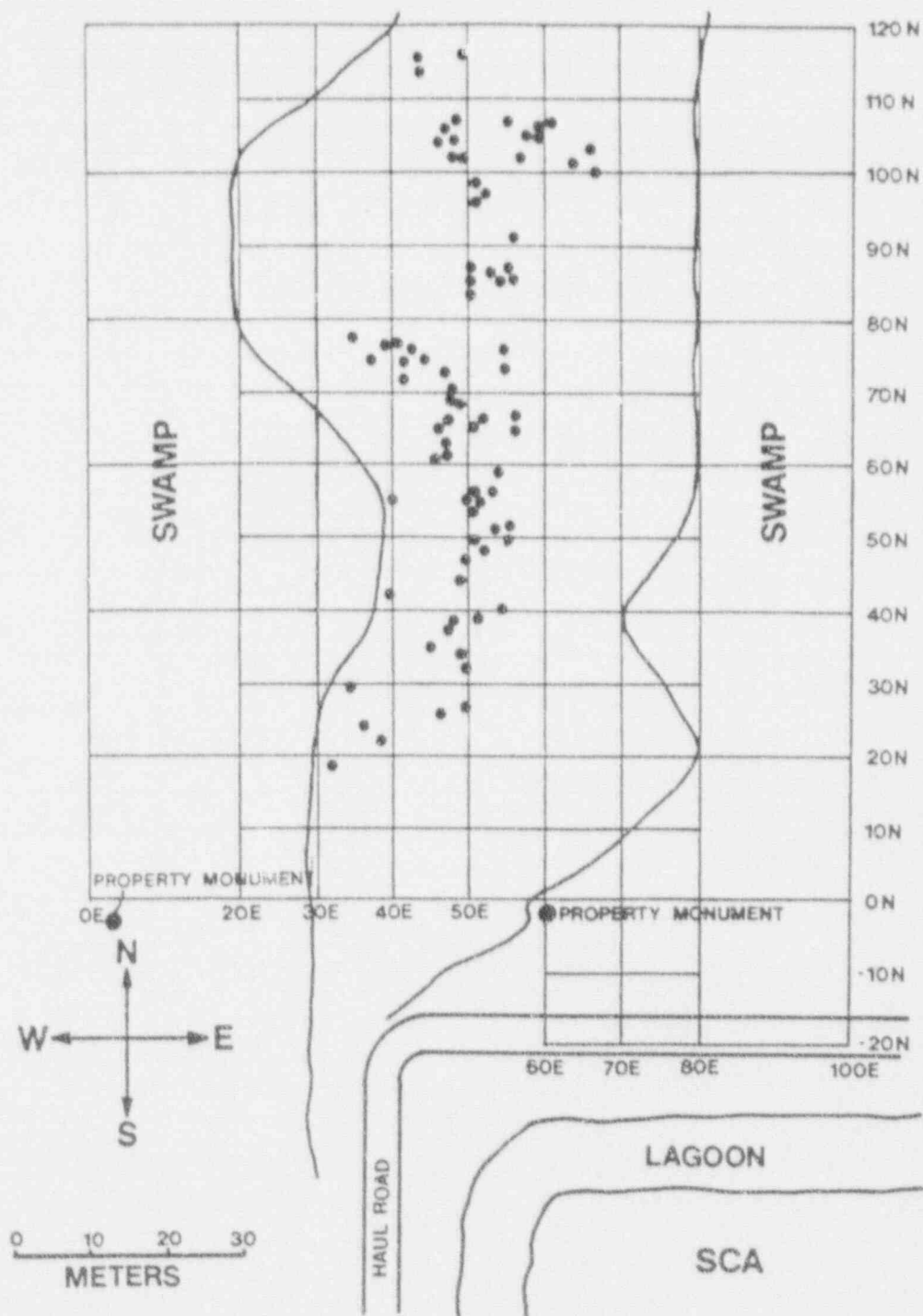


FIGURE 6: Locations of Elevated Contact Radiation Levels Identified by the Walkover Scan Before Stabilization.

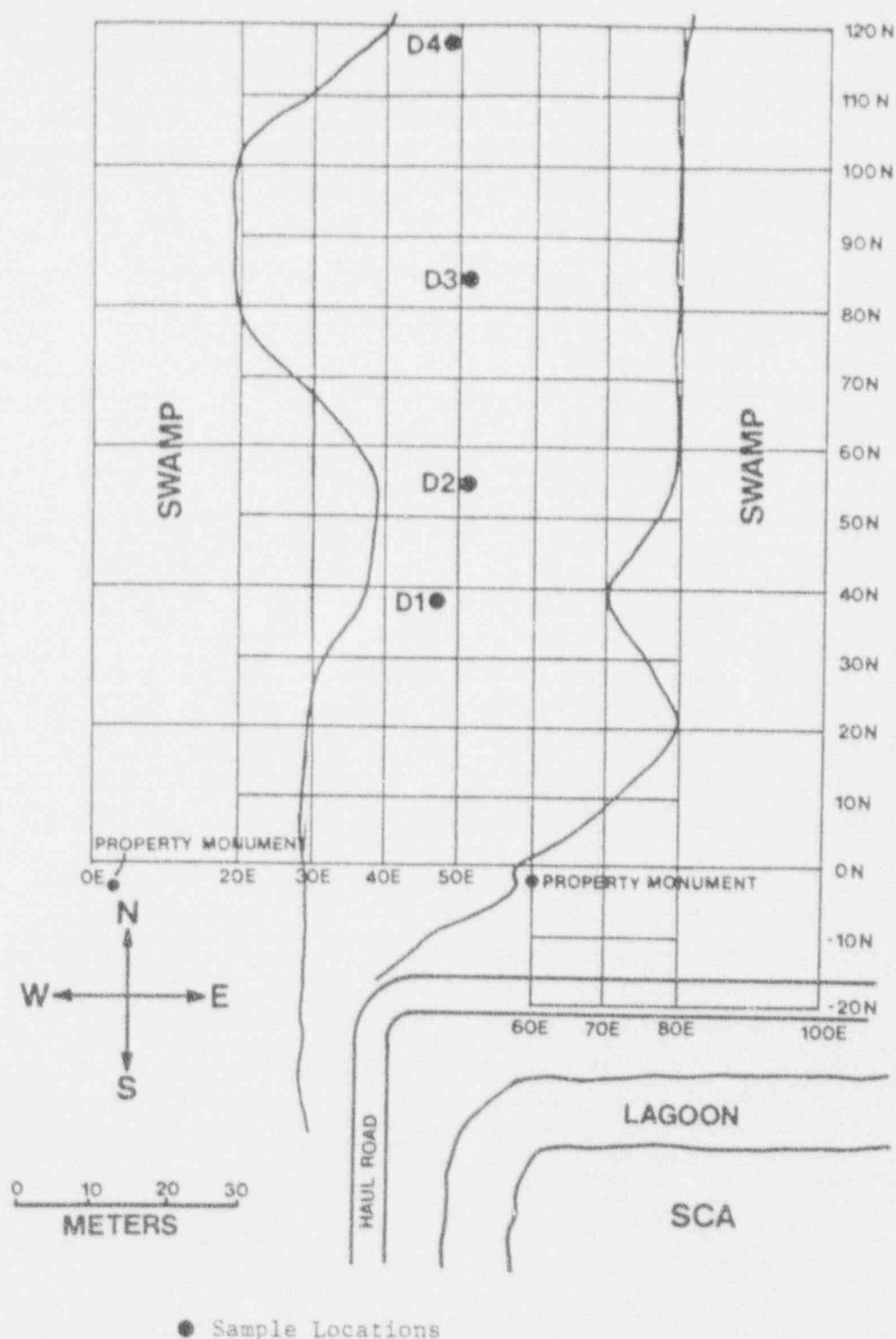


FIGURE 7: Locations of Soil Samples Collected From Areas of Elevated Contact Radiation Levels Before Stabilization.

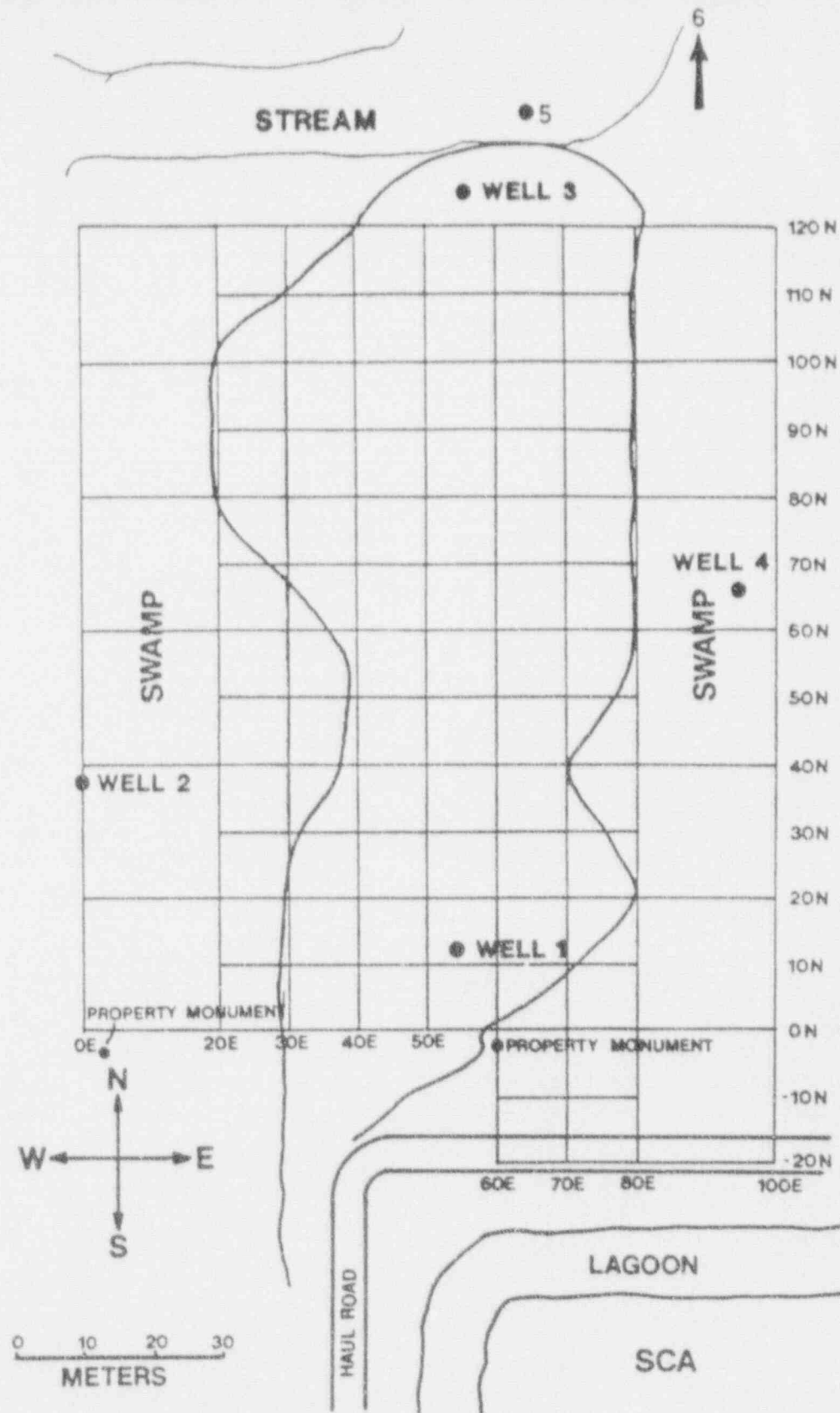


FIGURE 8: Locations of Water Samples Collected After Stabilization.

TABLE 1A
DIRECT RADIATION LEVELS MEASURED
AT BASELINE SAMPLE LOCATIONS
BAY CITY, MICHIGAN

Sample ^a Location	Exposure Rate (μ R/h)		Surface Dose Rate (μ rad/h)
	Contact	1 m Above Surface	
1	8	8	32
2	9	9	38
3	7	7	10
4	9	9	9

^a See Figure 5.

TABLE 1B

RADIONUCLIDE CONCENTRATIONS MEASURED IN BASELINE
SOIL AND SEDIMENT SAMPLES
BAY CITY, MICHIGAN

Sample ^a Location	Sample Type	Radionuclide Concentrations (pCi/g)			
		Th-232	Th-228	U-238	Ka-226
1	Soil	0.50 \pm 0.31 ^b	0.28 \pm 0.26	1.05 \pm 1.15	0.48 \pm 0.20
2	Soil	0.57 \pm 0.27	0.10 \pm 0.09	<0.74	0.80 \pm 0.19
3	Soil	0.85 \pm 0.35	0.47 \pm 0.31	1.41 \pm 1.19	0.59 \pm 0.15
3	Sediment	0.57 \pm 0.20	0.26 \pm 0.39	<0.49	<0.55
4	Soil	0.28 \pm 0.17	0.42 \pm 0.23	0.81 \pm 1.09	0.37 \pm 0.15
4	Sediment	0.96 \pm 0.34	0.89 \pm 0.29	1.35 \pm 1.79	0.35 \pm 0.33

^a See Figure 5.

^b Errors are 2 σ based on counting statistics.

TABLE 1C
RADIONUCLIDE CONCENTRATIONS MEASURED IN
BASELINE WATER SAMPLES
BAY CITY, MICHIGAN

Sample ^a Location	Radionuclide Concentrations (pCi/l or $\times 10^{-9}$ μ Ci/ml)	
	Gross Alpha	Gross Beta
1	3.19 \pm 1.27 ^b	9.81 \pm 1.55
2	8.02 \pm 1.80	14.8 \pm 1.9
3	0.21 \pm 0.61	5.77 \pm 1.12
4	2.13 \pm 0.97	6.25 \pm 1.72

^a See Figure 5.

^b Errors are 2 σ based on counting statistics.

TABLE 2

DIRECT RADIATION LEVELS MEASURED AT GRID LINE INTERSECTIONS
BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid ^a Location		Gamma Exposure Rates at 1 m Above the Surface (μ R/h)	Gamma Exposure Rates at the Surface (μ R/h)	Beta-Gamma Dose Rates at 1 cm Above the Surface (μ rad/h)
N	E			
-20	60	8	8	8
-20	70	8	8	15
-20	80	8	8	22
-20	100	7	7	12
-10	60	8	8	25
-10	70	8	9	13
-10	80	7	8	8
-10	100	7	7	10
0	0	7	7	11
0	20	7	7	7
0	30	7	7	17
0	40	7	7	7
0	50	8	8	18
0	60	7	7	9
0	70	7	7	9
0	80	7	7	24
0	100	7	7	7
10	30	7	7	11
10	40	8	8	8
10	50	8	8	8
10	60	8	8	25
10	70	7	7	7
10	80	7	7	13
20	0	7	7	13
20	20	7	7	16
20	30	13	8	19
20	40	9	8	8
20	50	9	8	10
20	60	8	8	14
20	70	7	7	7
20	80	7	7	7
20	100	7	7	7
30	30	8	8	8
30	40	11	15	30
30	50	15	17	35
30	60	9	9	9
30	70	8	8	8
30	80	7	8	8
40	0	7	7	20
40	20	7	7	10
40	30	8	8	16

TABLE 2 (Continued)

DIRECT RADIATION LEVELS MEASURED AT GRID LINE INTERSECTIONS
BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location		Gamma Exposure Rates at 1 m Above the Surface ($\mu\text{R/h}$)	Gamma Exposure Rates at the Surface ($\mu\text{R/h}$)	Beta-Gamma Dose Rates at 1 cm Above the Surface ($\mu\text{rad/h}$)
N	E			
40	40	9	9	9
40	60	9	9	29
40	70	8	8	10
40	80	7	8	18
40	100	7	7	7
50	30	7	7	7
50	40	- b	-	-
50	50	32	40	84
50	50	32	40	84
50	60	9	9	9
50	70	8	8	16
50	80	7	7	10
60	0	7	7	7
60	20	7	7	7
60	30	7	7	7
60	40	9	8	18
60	50	15	15	15
60	60	9	9	15
60	70	8	8	18
60	80	8	8	8
60	100	7	7	7
70	30	7	8	11
70	40	30	93	250
70	50	15	13	24
70	60	9	9	12
70	70	8	8	11
70	80	8	7	9
80	0	7	7	7
80	20	7	7	13
80	30	8	8	13
80	40	9	10	28
80	50	9	9	25
80	60	9	10	18
80	70	8	8	8
80	80	7	7	7
80	100	7	7	7
90	30	8	8	13
90	40	10	11	16
90	50	13	11	16
90	60	10	10	21
90	70	8	8	8

TABLE 2 (Continued)

DIRECT RADIATION LEVELS MEASURED AT GRID LINE INTERSECTIONS
BEFORE STABILIZATION
INR LANDFILL SITE - BAY CITY, MICHIGAN

<u>Grid Location</u>		<u>Gamma Exposure Rates at 1 m Above the Surface</u> ($\mu\text{R/h}$)	<u>Gamma Exposure Rates at the Surface</u> ($\mu\text{R/h}$)	<u>Beta-Gamma Dose Rates at 1 cm Above the Surface</u> ($\mu\text{rad/h}$)
N	E			
90	80	8	8	8
100	0	7	7	15
100	20	7	7	7
100	30	8	8	15
100	40	8	8	8
100	50	15	15	46
100	60	14	14	17
100	70	9	9	9
100	80	8	8	12
100	100	7	7	17
110	30	7	7	7
110	40	8	8	32
110	50	10	10	21
110	60	22	22	57
110	70	8	9	32
110	80	8	8	17
120	0	7	7	17
120	20	7	7	7
120	30	7	7	8
120	40	7	7	7
120	50	8	8	22
120	60	8	8	14
120	70	8	9	7
120	80	8	8	8
120	100	7	7	7

^aRefer to Figure 3.

^bMeasurement not performed.

TABLE 3

DIRECT RADIATION LEVELS MEASURED AT LOCATIONS
IDENTIFIED BY THE WALKOVER SCAN BEFORE STABILIZATION
ONR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location ^a		Exposure Rate (μ R/h)		Surface Dose Rate	Sample ^b
N	E	Contact	1 m Above Surface	(μ rad/h)	Identification Number
19	33	93	24	220	
22	38	30	15	30	
24	37	47	18	66	
26	47	27	11	38	
31	35	30	10	240	
33	50	27	18	34	
34	50	110	33	110	
35	46	140	47	210	
37	48	140	93	140	D1
38	47	170	79	180	
39	52	32	18	83	
42	40	27	11	150	
45	49	55	21	68	
47	50	470	110	470	
49	53	110	44	150	
50	51	84	37	120	
50	55	47	24	100	
51	54	47	22	60	
51	55	42	18	42	
54	51	160	51	200	
55	51	200	63	250	D2
55	51	170	55	190	
56	50	140	55	160	
56	51	140	55	150	
57	53	75	30	98	
59	55	75	21	99	
61	47	88	21	120	

TABLE 3 (Continued)

DIRECT RADIATION LEVELS MEASURED AT LOCATIONS
IDENTIFIED BY THE WALKOVER SCAN BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location		Exposure Rate ($\mu\text{R/h}$)		Surface Dose Rate	Sample Identification Number
N	E	Contact	1 m Above Surface	($\mu\text{rad/h}$)	
62	48	24	17	34	
63	47	40	17	40	
65	47	38	18	44	
65	51	110	37	150	
65	57	30	17	86	
66	52	140	51	140	
66	56	33	18	50	
67	48	37	22	39	
68	50	59	30	59	
70	48	75	33	110	
70	49	79	24	97	
72	41	120	40	240	
73	47	22	15	30	
74	55	21	14	21	
75	37	24	11	24	
76	41	27	13	30	
76	43	24	13	35	
77	34	21	11	72	
84	51	110	40	220	D3
86	51	110	42	110	
86	54	27	18	33	
86	55	32	15	83	
87	53	44	21	68	
88	51	67	32	110	
92	57	24	10	38	
96	52	30	14	84	
97	53	30	13	30	

TABLE 3 (Continued)

DIRECT RADIATION LEVELS MEASURED AT LOCATIONS
IDENTIFIED BY THE WALKOVER SCAN BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location		Exposure Rate (μ R/h)		Surface Dose Rate	Sample Identification Number
N	E	Contact	1 m Above Surface	(μ rad/h)	
99	51	37	14	67	
100	68	75	21	150	
101	65	30	18	59	
102	48	71	28	110	
102	49	79	27	140	
104	47	47	24	50	
104	48	47	24	64	
104	57	110	28	270	
104	66	150	37	250	
105	59	110	47	160	
105	60	120	47	200	
106	47	75	25	75	
106	59	110	44	140	
107	55	61	21	140	
108	49	37	18	77	
108	61	93	28	200	
116	43	77	15	150	
116	44	84	17	260	
118	49	170	14	290	D4

^aRefer to Figure 6.^bRefer to Figure 7.

TABLE 4

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL SAMPLES
COLLECTED AT GRID LINE INTERSECTION BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample ^a Location		Radionuclide Concentrations (pCi/g)			
N	E	Th-232	Th-228	U-238	Ra-226
-20	60	0.57 ± 0.25 ^b	<0.24	<0.98	0.78 ± 0.21
-20	70	0.63 ± 0.35	0.63 ± 0.21	<0.71	0.46 ± 0.19
-20	80	0.47 ± 0.38	0.63 ± 0.21	3.20 ± 1.37	<0.12
-20	100	<0.16	0.21 ± 0.12	<0.35	0.21 ± 0.09
-10	60	0.50 ± 0.30	0.45 ± 0.24	<0.46	0.33 ± 0.16
-10	70	0.40 ± 0.34	0.42 ± 0.21	<0.55	0.37 ± 0.13
0	0	<0.12	<0.24	<0.56	<0.15
0	20	0.13 ± 0.07	0.15 ± 0.08	0.92 ± 0.14	0.17 ± 0.04
0	30	<0.13	<0.21	<0.69	0.25 ± 0.34
0	40	0.59 ± 0.27	0.51 ± 0.24	<0.70	<0.07
0	50	<0.17	0.27 ± 0.21	<0.44	0.17 ± 0.10
0	60	<0.11	0.21 ± 0.15	<0.41	0.15 ± 0.21
0	70	<0.11	0.12 ± 0.12	0.69 ± 0.94	<0.06
0	80	<0.17	<0.12	<0.64	0.34 ± 0.14
0	100	<0.19	<0.15	<0.52	<0.08
10	30	<0.15	0.84 ± 0.36	<0.61	<0.12
10	40	0.37 ± 0.35	0.24 ± 0.27	<0.51	0.25 ± 0.16
10	50	1.26 ± 0.31	0.75 ± 0.27	<0.72	0.39 ± 0.12
10	60	0.87 ± 0.38	0.84 ± 0.24	<0.71	0.63 ± 0.16
10	70	<0.41	0.15 ± 0.21	<0.66	<0.12
10	80	<0.15	0.18 ± 0.21	<0.33	0.10 ± 0.07
20	0	<0.12	0.27 ± 0.21	<0.65	<0.08
20	20	<0.27	<0.15	<0.58	<0.11
20	30	<0.54	<0.39	<0.11	0.62 ± 0.55
20	40	1.19 ± 0.46	1.02 ± 0.60	<0.73	0.54 ± 0.28
20	50	1.24 ± 0.34	1.35 ± 0.22	1.15 ± 0.68	0.49 ± 0.20
20	60	0.68 ± 0.30	0.60 ± 0.21	1.37 ± 1.23	0.53 ± 0.15
20	70	<0.13	0.23 ± 0.20	<0.66	0.39 ± 0.13
20	80	<0.19	<0.13	<0.76	<0.11
20	100	<0.20	<0.16	<0.54	<0.13
30	30	0.84 ± 0.78	1.19 ± 0.51	<0.93	0.37 ± 0.19
30	40	1.59 ± 0.49	1.28 ± 0.39	2.29 ± 1.84	1.35 ± 0.25
30	50	2.57 ± 0.72	2.43 ± 0.48	5.55 ± 2.18	2.53 ± 0.53
30	60	0.50 ± 0.23	0.37 ± 0.15	<0.39	0.25 ± 0.15
30	70	0.20 ± 0.13	<0.11	0.63 ± 0.75	0.19 ± 0.15
30	80	0.52 ± 0.24	0.33 ± 0.37	<0.48	0.23 ± 0.24
40	0	0.08 ± 0.06	0.10 ± 0.06	1.00 ± 0.14	0.10 ± 0.04
40	20	<0.28	<0.26	0.67 ± 2.58	<0.14
40	30	0.75 ± 0.19	0.86 ± 0.16	0.31 ± 0.59	0.16 ± 0.07
40	40	0.67 ± 0.26	0.54 ± 0.27	<0.53	0.22 ± 0.13
40	50	1.96 ± 0.81	2.46 ± 0.72	1.46 ± 3.27	2.49 ± 0.49
40	60	0.41 ± 0.12	0.36 ± 0.10	0.45 ± 0.62	0.33 ± 0.06
40	70	1.01 ± 0.36	0.66 ± 0.24	<0.74	0.33 ± 0.17

TABLE 4 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL SAMPLES
COLLECTED AT GRID LINE INTERSECTIONS BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample Location		Radionuclide Concentrations (pCi/g)			
		Th-232	Th-228	U-238	Ra-226
N	E				
40	80	<0.16	<0.13	<0.66	0.27 ± 0.15
40	100	0.11 ± 0.09	0.11 ± 0.09	0.36 ± 0.45	0.11 ± 0.07
50	30	0.37 ± 0.18	<0.09	<0.58	0.28 ± 0.14
50	50	3.21 ± 0.70	2.97 ± 0.50	<1.21	2.12 ± 0.37
50	60	1.77 ± 0.40	1.89 ± 0.41	<0.71	0.29 ± 0.21
50	70	0.20 ± 0.25	0.24 ± 0.20	<0.43	0.21 ± 0.13
50	80	<0.15	<0.11	<0.43	<0.08
60	0	0.19 ± 0.07	0.18 ± 0.07	1.02 ± 0.14	0.12 ± 0.04
60	20	<0.21	0.39 ± 0.48	<0.52	0.44 ± 0.20
60	30	0.42 ± 0.32	0.16 ± 0.13	<0.40	0.11 ± 0.05
60	40	0.16 ± 0.15	0.11 ± 0.14	<0.76	0.26 ± 0.11
60	50	2.91 ± 0.63	2.79 ± 0.63	4.64 ± 2.23	1.77 ± 0.39
60	60	0.47 ± 0.27	1.23 ± 0.29	<0.65	0.40 ± 0.14
60	70	0.39 ± 0.20	0.42 ± 0.27	<0.69	<0.10
60	80	0.82 ± 0.32	0.48 ± 0.22	<0.81	0.18 ± 0.11
60	100	<0.20	0.35 ± 0.23	<0.61	<0.10
70	30	0.32 ± 0.18	0.23 ± 0.11	<0.53	0.24 ± 0.08
70	40	69.5 ± 3.4	72.8 ± 2.9	5.65 ± 5.27	<0.45
70	50	3.29 ± 0.80	3.18 ± 0.72	5.11 ± 3.03	2.34 ± 0.51
70	60	0.65 ± 0.39	0.54 ± 0.27	0.96 ± 0.93	0.17 ± 0.15
70	70	0.28 ± 0.21	<0.17	<0.43	0.20 ± 0.13
70	80	<0.09	0.15 ± 0.10	<0.35	0.13 ± 0.09
80	0	<0.32	0.44 ± 0.39	<0.70	<0.16
80	20	0.80 ± 1.19	0.59 ± 0.50	<0.71	<0.12
80	30	0.94 ± 0.66	1.61 ± 0.41	2.11 ± 1.29	1.17 ± 0.31
80	40	1.21 ± 0.43	1.18 ± 0.40	3.02 ± 1.56	1.08 ± 0.25
80	50	1.46 ± 0.40	1.67 ± 0.42	3.57 ± 1.40	1.15 ± 0.22
80	60	1.16 ± 0.21	1.33 ± 0.20	0.88 ± 0.00	0.31 ± 0.09
80	70	0.54 ± 0.24	0.30 ± 0.17	<0.62	0.33 ± 0.13
80	80	0.74 ± 0.37	0.42 ± 0.20	<0.67	<0.96
80	100	<0.18	0.18 ± 0.11	<0.41	0.14 ± 0.11
90	30	0.43 ± 0.41	0.36 ± 0.29	<0.60	0.31 ± 0.10
90	40	0.92 ± 0.81	1.71 ± 0.50	1.66 ± 3.16	1.59 ± 0.36
90	50	1.27 ± 0.37	1.17 ± 0.31	1.37 ± 0.95	0.31 ± 0.24
90	60	1.16 ± 0.36	1.00 ± 0.26	<0.60	0.49 ± 0.16
90	70	<0.13	0.42 ± 0.22	<0.44	0.18 ± 0.18
90	80	<0.19	0.42 ± 0.19	<0.51	0.20 ± 0.16
100	0	<0.38	<0.20	<0.68	<0.19
100	20	<0.14	<0.19	<0.54	0.21 ± 0.21
100	30	0.31 ± 0.30	0.57 ± 0.22	<0.47	0.26 ± 0.16
100	40	0.35 ± 0.18	0.36 ± 0.17	<0.60	<0.07
100	50	5.01 ± 0.72	4.50 ± 0.51	<1.47	0.43 ± 0.25

TABLE 4 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL SAMPLES
COLLECTED AT GRID LINE INTERSECTIONS BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample Location		Radionuclide Concentrations (pCi/g)			
N	E	Th-232	Th-228	U-238	Ra-226
100	60	2.46 ± 0.48	3.00 ± 0.41	0.99 ± 1.85	0.60 ± 0.20
100	70	1.79 ± 0.61	1.49 ± 0.35	1.78 ± 2.12	0.25 ± 0.30
100	80	0.72 ± 0.24	0.47 ± 0.19	1.85 ± 1.31	0.21 ± 0.13
100	100	0.58 ± 0.25	0.38 ± 0.34	1.20 ± 1.65	0.18 ± 0.11
110	30	<0.14	0.33 ± 0.20	<0.51	<0.06
110	40	0.41 ± 0.21	0.50 ± 0.15	<0.60	<0.08
110	50	1.10 ± 0.37	1.05 ± 0.35	<0.53	0.28 ± 0.14
110	60	7.84 ± 0.96	8.13 ± 0.86	5.70 ± 1.63	0.43 ± 0.31
110	70	1.88 ± 0.46	1.65 ± 0.38	1.68 ± 2.02	0.31 ± 0.34
110	80	0.17 ± 0.14	0.21 ± 0.14	<0.23	0.16 ± 0.06
120	0	<0.24	<0.24	<0.54	<0.13
120	20	<0.24	0.37 ± 0.26	<0.47	<0.12
120	30	0.13 ± 0.28	0.17 ± 0.10	<0.28	0.16 ± 0.26
120	40	<0.06	0.25 ± 0.13	1.04 ± 0.55	0.12 ± 0.08
120	50	0.20 ± 0.12	0.21 ± 0.11	<0.44	0.13 ± 0.09
120	60	0.43 ± 0.29	0.22 ± 0.16	<0.60	0.27 ± 0.12
120	70	<0.38	<0.26	0.87 ± 1.53	0.27 ± 0.27
120	80	0.32 ± 0.23	0.25 ± 0.10	0.43 ± 0.56	0.20 ± 0.05
120	100	<0.11	<0.15	<0.30	0.35 ± 0.13

^a Refer to Figure 3.

^b Errors are 2σ based on counting statistics.

TABLE 5

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL SAMPLES COLLECTED
AT LOCATIONS OF ELEVATED CONTACT RADIATION LEVELS BEFORE STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample ^a Location	Grid Coordinate		Depth (cm)	Radionuclide Concentrations (pCi/g)			
	N	E		Th-232	Th-228 U-238*	Ra-226	
D1	37	48	0 - 15	2.13 + 1.97 ^b	2.50 + 1.09	1.85 + 0.66	
			25 - 35	561 + 11	527 + 10	4.58 + 2.61	
			35 - 45	0.60 + 0.90	0.87 + 0.45	0.48 + 0.25	
D2	55	51	0 - 6	70.9 + 4.2	71.4 + 4.1	1.30 + 1.09	
			6 - 15	355 + 9	352 + 9	2.28 + 2.16	
D3	84	51	0 - 7	47.5 + 4.0	44.1 + 3.3	1.15 + 0.93	
			15 - 25	0.74 + 0.43	0.87 + 0.54	0.45 + 0.31	
D4	118	49	0 - 15	2.67 + 1.44	173 + 6	12.4 + 2.1	
			15 - 30	199 + 7	192 + 6	14.1 + 2.2	
			45 - 55	1.32 + 0.61	1.44 + 0.57	0.12 + 0.12	
						<17.8	
						<54.7	
						<0.64	
						<21.2	
						<42.9	
						<19.2	
						1.06 + 1.69	
						<3.40	
						<35.7	
						<0.77	

^a See Figure 7.

^b Errors are 2σ based on counting statistics.

* Large minimum detectable values are due to interference from high thorium concentrations.

TABLE 6
RADIONUCLIDE CONCENTRATIONS MEASURED IN
SEDIMENT SAMPLES
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample ^a Location	Grid Coordinate		Radionuclide Concentrations (pCi/g)			
	N	E	Th-232	Th-228	U-238	Ka-226
1	42	40	14.6	15.4	<7.36	0.61 ± 0.40
2	86	20	0.66 ± 1.3 ^b	0.36 ± 0.18	<0.59	0.26 ± 0.12
3	130	50	<0.12	0.20 ± 0.15	<0.38	0.18 ± 0.12
4	170	70	<0.13	0.23 ± 0.23	<0.57	0.23 ± 0.12

^a See Figure 4.

^b Errors are 2σ based on counting statistics.

TABLE 7

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SURFACE WATER SAMPLES
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample ^a Location	Grid Coordinate		Radionuclide Concentrations (pCi/l or $\times 10^{-9}$ μ Ci/ml)	
	N	E	Gross Alpha	Gross Beta
1	42	40	<1.72	30.4 \pm 3.9 ^b
2	86	20	1.26 \pm 1.19	14.5 \pm 1.9
3	130	50	3.46 \pm 1.09	9.23 \pm 1.27
4	170	70	2.48 \pm 0.98	8.00 \pm 1.22

^a See Figure 4.

^b Errors are 2σ based on counting statistics.

TABLE 8

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS AFTER STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location ^a		Exposure Rate (μ R/h)		Surface Dose Rate
N	E	Contact	1 m Above Surface	(μ rad/h)
0	0	8	8	12
20	0	8	8	15
40	0	8	8	19
60	0	8	7	12
80	0	8	8	9
100	0	8	8	13
120	0	8	8	15
0	20	9	8	9
20	20	8	8	19
40	20	8	9	14
60	20	9	8	21
80	20	8	8	11
100	20	8	8	8
120	20	8	8	14
0	40	8	8	8
20	40	9	8	11
40	40	8	8	14
60	40	9	8	19
80	40	9	8	13
100	40	8	8	19
120	40	8	7	8
0	60	9	8	25
20	60	9	8	12
40	60	9	8	31
60	60	8	8	17
80	60	8	8	17
100	60	8	8	14
120	60	8	7	15
0	80	8	8	12
20	80	9	8	12
40	80	9	8	14
60	80	8	8	14
80	80	8	8	9
100	80	8	8	18
120	80	8	7	14

TABLE 8 Continued

DIRECT RADIATION LEVELS MEASURED
AT GRID LINE INTERSECTIONS AFTER STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Grid Location ^a		Exposure Rate (μ R/h)		Surface Dose Rate (μ rad/h)
N	E	Contact	1 m Above Surface	
0	100	7	7	8
20	100	8	7	16
40	100	7	7	10
60	100	7	7	7
80	100	7	7	7
100	100	7	7	7
120	100	6	6	11

^a Refer to Figure 3.

TABLE 9

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL SAMPLES
COLLECTED AT GRID LINE INTERSECTION AFTER STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample Location ^a		Radionuclide Concentrations (pCi/g)			
N	E	Th-232	Th-232	U-238	Ra-226
0	0	0.71 ± 0.46 ^b	0.18 ± 0.16	1.05 ± 1.21	0.62 ± 0.22
0	100	0.42 ± 0.29	0.48 ± 0.27	<0.60	1.04 ± 1.02
20	20	0.45 ± 0.35	0.28 ± 0.26	0.85 ± 1.20	0.38 ± 0.24
20	80	0.50 ± 0.22	0.54 ± 0.20	0.97 ± 1.61	0.32 ± 0.21
40	40	0.55 ± 0.33	0.53 ± 0.25	<0.64	0.52 ± 0.15
40	60	0.34 ± 0.37	0.64 ± 0.30	<0.67	0.31 ± 0.20
60	40	0.68 ± 0.29	0.44 ± 0.32	<0.73	0.52 ± 0.23
60	60	0.78 ± 0.47	0.75 ± 0.30	<0.66	0.33 ± 0.20
80	80	0.51 ± 0.30	0.69 ± 0.37	<0.63	0.54 ± 0.18
100	100	<0.31	0.68 ± 0.53	<1.09	0.30 ± 0.18
120	0	0.32 ± 0.34	0.48 ± 0.26	0.85 ± 1.34	0.35 ± 0.27

^a Refer to Figure 3.

^b Errors are 2σ based on counting statistics.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN WELL AND SURFACE
WATER SAMPLES OBTAINED AFTER STABILIZATION
DNR LANDFILL SITE - BAY CITY, MICHIGAN

Sample ^a Number	Sample Location		Radionuclide Concentrations (pCi/l or $\times 10^{-9}$ μ Ci/ml)	
	N	E	Gross Alpha	Gross Beta
Well 1	11N	54E	<1.45	17.3 \pm 3.2 ^b
Well 2	36N	0E	<3.06	16.4 \pm 5.8
Well 3	124N	56E	<1.99	5.94 \pm 4.01
Well 4	65N	94E	<5.29	7.22 \pm 9.44
Surface 5	Stream - 25M North of Site		0.87 \pm 0.73	8.42 \pm 3.18
Surface 6	Stream - North of Slurry Wall		0.46 \pm 0.67	3.46 \pm 1.04

^a Refer to Figure 8.

^b Errors are 2σ based on counting statistics.

REFERENCES

1. Title 40, Code of Federal Regulations, Part 141, Interim Primary Drinking Water Standards. Federal Register, July, 1976.

APPENDIX A

MAJOR ANALYTICAL EQUIPMENT

APPENDIX A

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
(Eberline, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
(Eberline, Santa Fe, NM)

Eberline Beta-Gamma "Pancake" Probe
Model HP-260
(Eberline, Santa Fe, NM)

Victoreen Beta-Gamma "Pancake" Probe
Model 489-110
(Victoreen, Inc., Cleveland, OH)

Victoreen Gamma Scintillator (NaI) Probe
Model 489-55
(Victoreen, Inc., Cleveland, OH)

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

B. Laboratory Analyses

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)

High-Purity Germanium Detector
Model GMX-23195-S, 23% efficiency
(EG&G ORTEC, Oak Ridge, TN)

Used in conjunction with:
Lead Shield, G-16
(Gamma Products Inc., Palos Hills, IL)

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

APPENDIX B
ANALYTICAL PROCEDURES

APPENDIX B

Analytical Procedures

Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using Eberline Model PRM-6 portable ratemeters with Victoreen Model 489-55 gamma scintillation probes containing 3.2 cm x 3.8 cm NaI(Tl) crystals. Count rates were converted to exposure rates (μ R/h) using factors determined by comparing the response of the scintillation detectors with that of a Reuter Stokes model RSS-111 pressurized ionization chamber at several locations on the surveyed property.

Beta-Gamma Dose Rate Measurement:

Measurements were performed using Eberline "Rascal" PRS-1 portable ratemeters with Model HP-260 G-M probes. Dose rates (μ rad/h) were determined using a factor of 1.4 cpm/ μ rad/h.

Soil and Sediment Sample Analysis

Soil and sediment samples were dried, mixed, and a portion sealed in a 0.5-liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and ranged from 400 to 800 g of soil. Net soil weights were determined and the samples counted using Ge(Li) and intrinsic germanium detectors coupled to a Nuclear Data model ND-680 pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. Energy peaks used for determination of radionuclides of concern were:

Th-232 - 0.911 MeV from Ac-228*
Th-228 - 0.583 MeV from Tl-208*
U-238 - 0.094 MeV from Th-234* or 1.001 MeV from Pa-234m*
Ra-226 - 0.609 MeV from Bi-214*

*Secular equilibrium was assumed

Water Sample Analysis

Water samples were rough-filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by subsequent filtration through 0.45 μ m membrane filters. The filtrate was acidified by addition of 10 ml of concentrated nitric acid. Aliquots were then evaporated to dryness and counted for gross alpha and gross beta using a Tennelec Model LB 5100 low-background proportional counter.

Calibration and Quality Assurance

All survey and laboratory instruments were calibrated with NBS-traceable standards. Quality control procedures on all instruments included daily background and check-source measurements to confirm equipment operations are within acceptable statistical fluctuations. The ORAU laboratory participates in the EPA Quality Assurance Program.

APPENDIX C

NUCLEAR REGULATORY COMMISSION
GUIDELINES FOR RESIDUAL CONCENTRATIONS
OF THORIUM AND URANIUM WASTES IN SOIL

Guidelines for Residual Concentrations of Thorium and Uranium Wastes in Soil

On October 23, 1981, the Nuclear Regulatory Commission published in the Federal Register a notice of Branch Technical Position on "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations." This document establishes guidelines for concentrations of uranium and thorium in soil, that will limit maximum radiation received by the public under various conditions of future land usage. These concentrations are as follows:

Material	Maximum Concentrations (pCi/g) for various options			
	1a	2b	3c	4d
Natural Thorium (Th-232 + Th-228) with daughters present and in equilibrium	10	50	--	500
Natural Uranium (U-238 + U-234) with daughters present and in equilibrium	10	--	40	200
Depleted Uranium:				
Soluble	35	100	--	1,000
Insoluble	35	300	--	3,000
Enriched Uranium:				
Soluble	30	100	--	1,000
Insoluble	30	250	--	2,500

^aBased on EPA cleanup standards which limit radiation to 1 mrad/yr to lung and 3 mrad/yr to bone from ingestion and inhalation and 10 μ R/h above background from direct external exposure.

^bBased on limiting individual doses to 170 mrem/yr.

^cBased on limiting equivalent exposure to 0.02 working level or less.

^dBased on limiting individual doses to 500 mrem/yr and in case of natural uranium, limiting exposure to 0.02 working level or less.

Option 1 concentrations permit unrestricted use of the property and is the guideline applicable to surface soils. Options 2, 3, and 4 apply to buried wastes and assume that intrusions into the burial sites may occur. Regardless of the concentrations in the buried materials, surface soil must meet the Option 1 concentration guidelines.