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# Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the Seaway Industrial Park  
Tonawanda, New York

May 1978

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Final Report

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Prepared for

**U.S. Department of Energy**  
Assistant Secretary for Environment  
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RADIOLOGICAL SURVEY OF THE SEAWAY INDUSTRIAL PARK,  
TONAWANDA, NEW YORK

ABSTRACT

The results of a radiological survey of the Seaway Industrial Park, Tonawanda, New York, are presented in this report. The site is adjacent to the former Haist property, which was used to receive residues from uranium processing during the period 1944-46. In 1974 approximately 6000 yd<sup>3</sup> of this residue was transported to Seaway, where it was used as landfill. The survey was undertaken to determine radiation levels and the extent of radioactive materials on the Seaway property, as well as the extent of movement of radioactive residues by natural means such as surface run-off. The survey included measurement of: external gamma radiation on and near the site; beta-gamma radiation at the surface in the most contaminated areas; radium and uranium concentrations in the soil; concentrations of radium, uranium, and thorium in water samples collected from the drainage areas; and radium concentrations in mud samples taken from the drainage areas. The results indicate that the residues on the site do not pose any immediate health hazards. However, potential health hazards could result from some uses of the site. In particular, if buildings were to be built in certain areas on the site, significant concentrations of radon daughters could develop in these structures.

## INTRODUCTION

At the request of the Energy Research and Development Administration (ERDA), Oak Ridge Operations, a radiological survey was conducted in Tonawanda, New York, at the Seaway Industrial Park. Seaway is adjacent to the former Haist property, which was used to receive residue from uranium processing during the period 1944 to 1946. In 1974, approximately 6000 yd<sup>3</sup> of the residue, comprised essentially of low-grade uranium ore tailings, was excavated by Ashland Oil, Inc., the present owner of the former Haist property, and transported to the Seaway property. This residue was dumped in the areas A, B, and C indicated in Fig. 1. Area A covers approximately 10 acres, and areas B and C together cover approximately two acres. The residue was left in small, isolated mounds in areas B and C but was spread to a depth of less than 2 ft in most places in area A. Although much of the residue is not covered, it has become mixed somewhat with clean soil because of the moving and spreading it has undergone in recent years.

The Seaway Industrial Park (lot 94 of the Town of Tonawanda, Erie County, New York) covers nearly 100 acres, most of which has been used as a landfill for several years. The site is located in a large industrial area, and the areas containing the radioactive residues are more than one-half mile from the nearest dwellings. The Seaway property is bounded by Ashland Oil, Inc.; Agway Fuel, Inc.; River Road; Murphy Trucking, Inc.; Leffler Auto Parts; and property owned by Niagara Mohawk Power Corporation (see Figs. 2 and 3). There are no buildings on Seaway, and there is little vegetation. Some parts of the site (in particular, area A indicated in Fig. 1) are at a higher elevation than the surrounding terrain.

Most of the drainage from Seaway flows north or northeast into drainage ditches or a creek and is eventually carried to the nearby Niagara River. Some of the drainage from the area just south of Murphy Trucking, Inc., flows down a steep incline toward River Road, and some of this run-off accumulates near Murphy Trucking, Inc. Drainage from the Ashland property normally flows northeast across Seaway and eventually into the Niagara River. However, incomplete culvert construction near the Seaway-Ashland line has caused much of the run-off from the Ashland property to accumulate in a low area near the southern boundary of Seaway.

The radiological survey of the Seaway Industrial Park was conducted by three members of the Health Physics Division, Oak Ridge National Laboratory (ORNL), during the period August 6-13, 1976. The survey consisted of (1) measurement of external gamma radiation at one meter above the surface at intervals of approximately 400 ft (that is, on a 400-ft "grid") over the property; (2) measurement of external gamma radiation at the surface and at one meter above the surface on an approximate 100-ft grid in the region of known contamination; (3) measurement of beta-gamma contamination levels at the surface on the same grid; (4) measurement of gamma radiation at various depths in core holes dug throughout the region of known contamination; (5) collection of soil samples from some of the core holes for measurement of radium concentrations in all samples and for measurement of uranium in selected samples; and (6) collection of water and mud samples along the drainage paths between the property and the Niagara River for the determination of radionuclide concentrations.

## RADIOLOGICAL SURVEY TECHNIQUES

### Measurement of External Gamma and Beta-Gamma Radiation Levels

External gamma radiation levels were measured with scintillation survey meters which are described in Appendix I. Measurements were taken at the surface and at one meter above the surface on an approximate 100-ft grid in the region of known contamination, which is included in the areas A, B, and C shown in Figs. 1, 4, and 5. Beta-gamma surface readings were made on the 100-ft grid on area A using a Geiger-Muller survey meter (described in Appendix I).

Scintillation and Geiger-Muller survey meter measurements are indicative of the instantaneous exposure rate at the point of measurement. Errors result from the sensitivity of the instruments and from the fact that calibration of the instruments is performed under conditions which are not equivalent to all conditions encountered in the field. Hence, errors of  $\pm 30\%$  or more are possible for individual readings. Percentage-wise, largest errors for the G-M meter occur near background levels, at which the G-M meter typically shows readings in the range of 0.02 to 0.04 mrad/hr. At this level, accuracy is increased substantially by averaging several readings. Since beta-gamma measurements on this site were below 0.2 mrad/hr, readings are reported to the nearest hundredth of a mrad/hr for averaging and comparison purposes.

### Measurement of Radium in the Soil

Holes were drilled with a motorized drilling rig to depths of 6 to 12 ft at locations shown in Figs. 4 and 5. An auger with a 5-in.

inside diameter was used for the drilling. Gamma radiation was measured at various depths in the core holes by lowering a scintillation probe inside the auger. This "logging" of the core holes was done as a first step in determining the depth of contamination in the soil.

Soil samples were collected, using a split-spoon sampler, at 60 of the locations shown in Figs. 4 and 5. In addition to random samples taken throughout the site, extra samples were collected in areas which were thought to have the most-contaminated soils. The samples were packaged in plastic bags or bottles before being transported to Oak Ridge. They were then transported to the Bendix Field Engineering Corporation in Grand Junction, Colorado, where they were dried for 24 hr at 110°C and then pulverized to a particle size no greater than 500  $\mu\text{m}$ . The samples were then returned to Oak Ridge where aliquots from each sample were transferred to plastic petri dishes, weighed, and counted using a Ge(Li) detector. The spectra obtained were analyzed by computer techniques. A description of the Ge(Li) detector and the soil counting techniques is given in Appendix II. Radium concentrations were determined for all the samples; in addition, concentrations of  $^{238}\text{U}$  were determined for selected samples. Mud samples collected along the drainage area were treated as normal soil samples and were analyzed for radium content.

#### Measurement of Radioactivity in Surface Water

Water samples were collected from the drainage areas for determination of radium, uranium, and thorium content. These samples were taken at the locations shown in Fig. 6. The samples were analyzed by the Analytical Chemistry Division at ORNL, using radiochemical techniques.

## SURVEY RESULTS

In the following, unless otherwise specified, reported meter measurements represent gross readings; that is, background levels for the area have not been subtracted. Similarly, results for environmental samples have not been adjusted for natural background.

## External Gamma and Beta-Gamma Radiation Levels

The average of external gamma radiation readings taken at one meter above the surface on the area of known contamination was approximately 36  $\mu\text{R/hr}$  with readings varying between 8 and 80  $\mu\text{R/hr}$  (see Figs. 7 and 8). Areas with highest external gamma radiation levels are shown in Fig. 9. Measurements made at 200 to 400 ft intervals on the remainder of the property are given in Fig. 10. Except for some drainage areas and a small region near the boundary of the former Haist property, external gamma radiation levels on the part of the site excluding areas A, B, and C were in the range 8 to 14  $\mu\text{R/hr}$ . Background external gamma levels were measured in the Tonawanda area at locations distant enough from the residues to be uninfluenced by them. The mean background reading was 11  $\mu\text{R/hr}$ . It should be pointed out that the measurements were made over a short period of time and may not accurately reflect the annual average for that area.

Continuous exposure to the highest external gamma radiation levels measured (80  $\mu\text{R/hr}$ ) would result in an integrated dose equivalent of approximately 670 mrem/year. Exposure of 40 hr/week to an incremental exposure of 25  $\mu\text{R/hr}$  (the average external gamma radiation on areas A, B, and C minus the average background level for the area) would result in an

integrated dose equivalent of approximately 50 mrem/year. This is about half of the integrated dose equivalent which one receives over the period of a year from natural background external gamma radiation (assuming that background levels average 11  $\mu\text{R/hr}$  over the year).

Beta-gamma readings taken at the surface on area A are shown in Fig. 11. The distribution of the readings closely parallels the distribution of the external gamma radiation readings. Measurements averaged about 0.05 mrad/hr, with readings varying between 0.02 and 0.14 mrad/hr. The external gamma radiation measurements at the surface on area A (Fig. 12) averaged about 42  $\mu\text{R/hr}$ , and the average of the external gamma radiation readings taken at the surface on areas B and C (Fig. 13) was approximately 37  $\mu\text{R/hr}$ .

#### Results of Water and Mud Sample Analyses

The concentrations of radium in mud samples taken from the drainage paths leading from Ashland and Seaway to the Niagara River are given in Fig. 6. The highest concentration of radium, 26.4 pCi/g, was found on the Seaway property just north of area A. The radium concentration in a sample taken from point D (Fig. 1), about 1700 ft north of area A, was 8.3 pCi/g. Point D is the intersection of two drains, one leading from near area A on Seaway and the other leading from the former Haist Property. The low concentrations of radium found along the drain between D and the former Haist property suggest that most of the radium at point D had been carried from the residue on Seaway. At point E, about 2600 ft north of point D along a drain leading to the Niagara River, the radium concentration in the mud was found to be less than 2 pCi/g.

The concentrations of uranium, radium, and thorium in water samples from Ashland and Seaway and from drainage paths leading to the Niagara River are given in Table 1, which also shows the maximum permissible concentrations<sup>1</sup> (MPC's) in water for each isotope considered. Locations at which the samples were collected are shown in Fig. 6. In every water sample, the concentration of each isotope measured was several orders of magnitude below the MPC<sub>w</sub><sup>\*</sup>.

#### Radium Concentrations in the Soil

Concentrations of radium in soil samples collected on the site are given in Table 2; locations are shown in Figs. 4 and 5. A combination of soil sample analyses and scintillation probe "loggings" was used as shown in Figs. 14 and 15 to indicate the extent of the radium in the soil in areas A, B, and C. (The estimation of radium concentrations from scintillation probe readings is explained in Appendix III.)

In most parts of areas A, B, and C the contaminated soil extends from the surface to a depth of 0.5 to 2.0 ft. The average of the radium concentrations in soil samples taken at a depth of 0 to 1 ft was approximately 15 pCi/g, and the average for depths of 1 to 2 ft was approximately 8 pCi/g. The highest concentration of radium found was 92.6 pCi/g in a sample taken from a small residue pile in area B.

Locations 81 and 82 (Fig. 4) are in an area containing some sediment which probably has eroded from area A. Samples from these locations showed radium concentrations as high as 40 pCi/g.

Concentrations of <sup>238</sup>U found in randomly selected soil samples are listed in Table 3. The highest concentration of <sup>238</sup>U found in these

\* This is also commonly referred to as the RCG (cf. ERDAM 0524).

samples was 102 pCi/g. Background concentrations of  $^{238}\text{U}$  and  $^{226}\text{Ra}$  in the Tonawanda area are typically near 1 pCi/g.

#### Radon Emanation

The average radon emanation at the surface can be estimated using Fig. 16 for an area in which the average radium concentration in the soil is known. As an illustration, a conservative estimate for the radon emanation from area A is obtained. Over most of this area, soil samples and scintillation probe readings indicated low concentrations of radium in the soil at depths of more than 3 ft. The average radium concentration at 0 to 1 ft was about 14 pCi/g, the average at 1 to 2 ft was about 8 pCi/g, and the average at 2 to 3 ft was about 4 pCi/g. The radon emanation rate would be higher if all radium at depths of 1 to 3 ft were at depths of 1 to 2 ft. Hence, a conservative estimate for the average radon emanation from area A can be obtained by estimating the radon emanation from 2 ft of tailings with a radium concentration of about 14 pCi/g. It is estimated (using Fig. 16) that radon would emanate at a rate of about  $5 \text{ pCi/m}^2$  per sec if the conservative assumption is made that the tailings are dry for most of the year.

At location 80P the average radium concentration at a depth of 0 to 2 ft was about 80 pCi/g. Hence, radon emanations at that point might be as high as  $25 \text{ pCi/m}^2$  per sec or more, assuming dry conditions.

Figure 16 is based on a differential equation which describes the diffusion of radioactive gases through soils (see, for example, ref. 2). Hence, ideal conditions are assumed. Furthermore, errors are introduced in assumptions regarding soil type, moisture content,<sup>3</sup> uniformity of radium in the soil, and uniformity of the depth of contamination. At the Middlesex Sampling Plant in Middlesex, New Jersey, actual radon

emanation measurements were made, and results were compared with estimates based on Fig. 16. It appears from this comparison that estimates based on Fig. 16 may be in error by a factor of 5 or more for individual locations on the Seaway site; however, the average of estimates for several locations is expected to reflect the actual average radon emanation rate within a factor of 2.

The residues deposited on areas B and C are much more unevenly distributed than residues in area A. However, since the average of radium concentrations in samples taken from B and C is less than twice the average for A and since the average depth of the residue would probably be less than 2 ft if the residue were uniformly distributed, it is reasonable to assume that the average radon emanation rate from B and C is no more than twice the average emanation rate from A. Integrating the radon emanation function (5 pCi/m<sup>2</sup>-sec for A and 10 pCi/m<sup>2</sup>-sec for B and C) over A, B, and C and dividing by the total area (4.8 x 10<sup>4</sup> m<sup>2</sup>) yields an estimated average radon emanation rate of less than 6 pCi/m<sup>2</sup> per sec for areas A, B, and C. This is roughly 14 times the average world-wide radon emanation rate which is reported to be 0.43 pCi/m<sup>2</sup> per sec.<sup>5</sup>

The radon concentration C in the first story of a building which is built on contaminated soil can be estimated from the equation<sup>6</sup>

$$C = \frac{J}{(\lambda_R + \lambda_v) h},$$

where J is the emanation rate of the radon from the soil, h is the height of the ceiling,  $\lambda_R = 2.1 \times 10^{-6} \text{ s}^{-1}$  (the radioactive decay constant for radon), and  $\lambda_v$  is the air exchange rate in the building. It is

assumed in the equation that the floor is not a barrier to radon; hence this is a "worst-case" situation. For floors which act as barriers, the value of J should be adjusted accordingly. For example, as little as 10% of the radon might diffuse through a 2-in. concrete slab<sup>7</sup>; however, radon will diffuse readily through some materials. If we assume that the emanation rate J is 6 pCi/m<sup>2</sup> per sec (the estimated average for the contaminated area), that h = 3m, and that there is one air exchange per hour in the building, then

$$C = \frac{6 \text{ pCi/m}^2 \text{ -sec}}{(2.1 \times 10^{-6} \text{ s}^{-1} + 2.8 \times 10^{-4} \text{ s}^{-1}) 3\text{m}}$$

$$\approx 7.1 \times 10^3 \text{ pCi/m}^3 \approx 7 \text{ pCi/liter.}$$

At the rate of one air exchange per hour, 1.0 pCi/liter of radon would produce a radon-daughter concentration of approximately 0.005 WL\* at steady-state conditions. Hence, a radon emanation rate of 6 pCi/m<sup>2</sup> per second might lead to a radon-daughter concentration of approximately

$$7 \text{ pCi/liter} \times 0.005 \text{ WL/pCi/liter} = 0.035 \text{ WL.}$$

The maximum emanation rates on the site were estimated to be 25 pCi/m<sup>2</sup> per sec or more, assuming that the tailings were dry. If buildings were constructed in the areas of highest radon emanation, radon-daughter concentrations of 0.15 WL could occur in these structures.

\* A working level (WL) is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of  $1.3 \times 10^5$  MeV of alpha particle energy.

## SUMMARY

Most of the radioactive residue on the Seaway property was spread over a 10-acre tract (area A) and extended from the surface to a depth of less than 2 ft in most places. In addition, there were several small, isolated residue piles contained in a separate 2-acre region (areas B and C). The average radium concentration in soil samples taken from area A was about 10 pCi/g, and the average concentration in samples taken from B and C was about 18 pCi/g.

Mud samples taken from the drainage paths between the site and the Niagara River showed radium concentrations as high as 26.4 pCi/g. One soil sample taken from a low area on Seaway about 100 ft north of area A had a radium concentration of 40 pCi/g (at a depth of 2 to 3 ft at location 82, Fig. 4). Hence, it appears that the radioactive residue is being scattered somewhat by surface run-off, particularly from area A, which is at a much higher elevation than areas B and C.

Water samples taken on the site and in drainage paths leading from Seaway and the former Haist property to the Niagara River showed only small amounts of uranium, thorium, and radium. In every sample, the concentration of each isotope tested was well below the MPC<sub>w</sub> for that isotope.

External gamma radiation levels 1 m above the surface on areas A, B, and C average about 36  $\mu$ R/hr, with readings varying between 8 and 80  $\mu$ R/hr. Except for a small drainage area near area A and a small region near the boundary of the former Haist property, external gamma radiation levels on the part of the site excluding areas A, B, and C were in the range 8 to 14  $\mu$ R/hr, which is near the background level for the Tonawanda area. Exposure of 40 hr per week to external gamma radiation of 25  $\mu$ R/hr

(the average reading in areas A, B and C minus the average background level) would lead to an integrated dose equivalent of approximately 50 mrem/year. This is roughly half of the dose equivalent which one receives over the period of a year from natural background radiation.

The average radon emanation from the contaminated area is probably less than 14 times the average world-wide background level, and the contamination covers less than 13 acres. Hence, the radon emanation from the contaminated area is probably less than the radon emanation from 180 acres of land at average background levels. Since the residue is in an industrial area and is more than one-half mile from the nearest dwellings, it appears that there are no distinct health hazards which result from atmospheric transport of radon from the site.

Potential health hazards could result from some uses of the site and the residues. Continuous exposure to the highest external gamma radiation levels measured would result in an integrated dose equivalent of approximately 670 mrem/year. The maximum allowable<sup>8</sup> whole-body dose to any individual in an unrestricted area is 500 mrem/year.\* If a building were to be constructed in certain areas on the site, radon-daughter levels of 0.15 WL or higher could develop in the building; this would exceed the Surgeon General's guidelines for dwellings constructed on or with uranium mill tailings.<sup>9</sup>

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\* EPA's present recommendation is that the whole-body radiation dose equivalent from the uranium fuel cycle should not be more than 25 mrem/year.<sup>10</sup>

ACKNOWLEDGMENT

The authors wish to thank W. F. Fox and D. L. Anderson for their excellent technical assistance.

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10. Code of Federal Regulations, Title 40, Part 190.

ORNL DWG. 77-11266

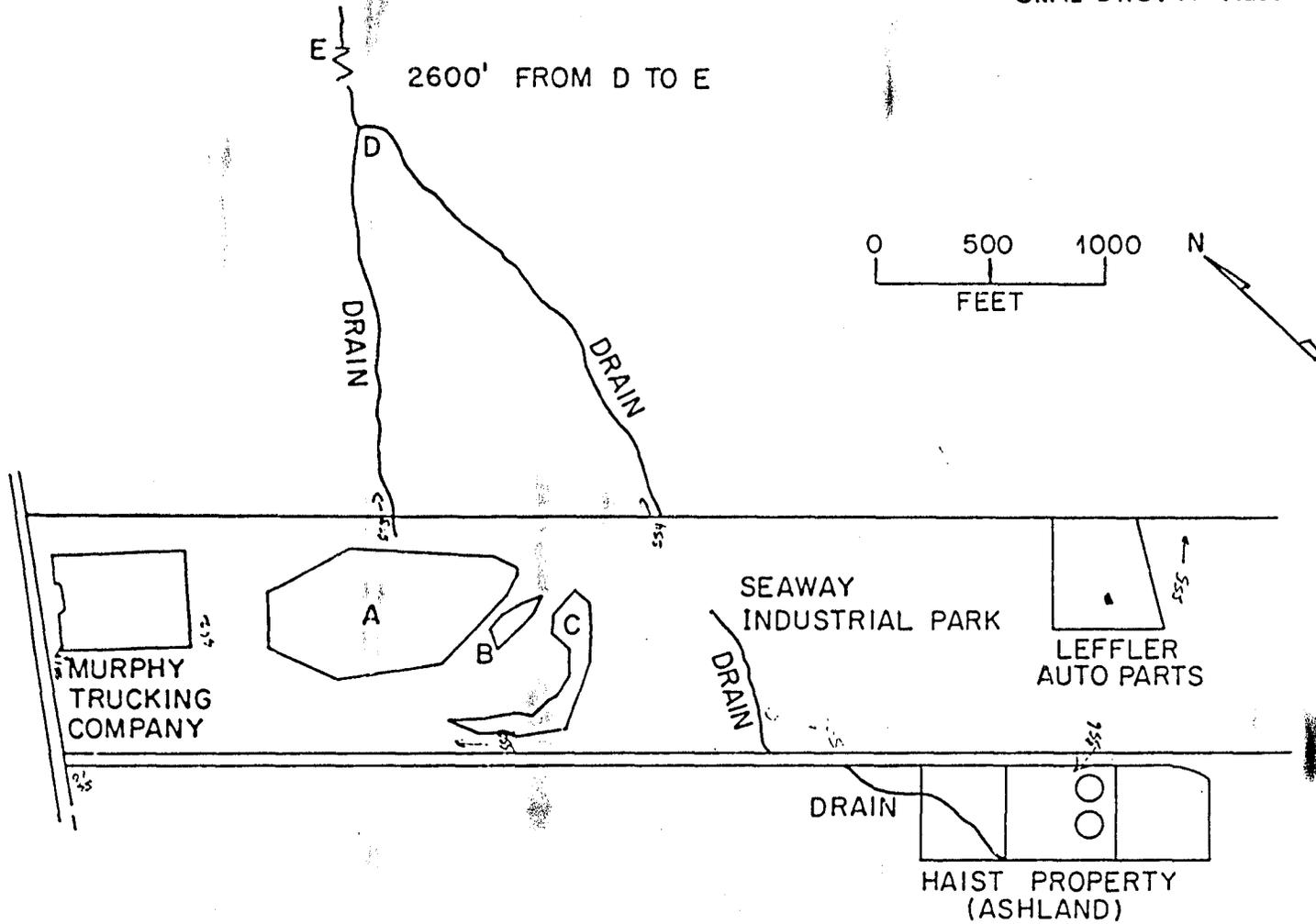


Fig. 1. Plan view of Seaway Industrial Park showing three areas (A, B, C) where radioactive residues were dumped.

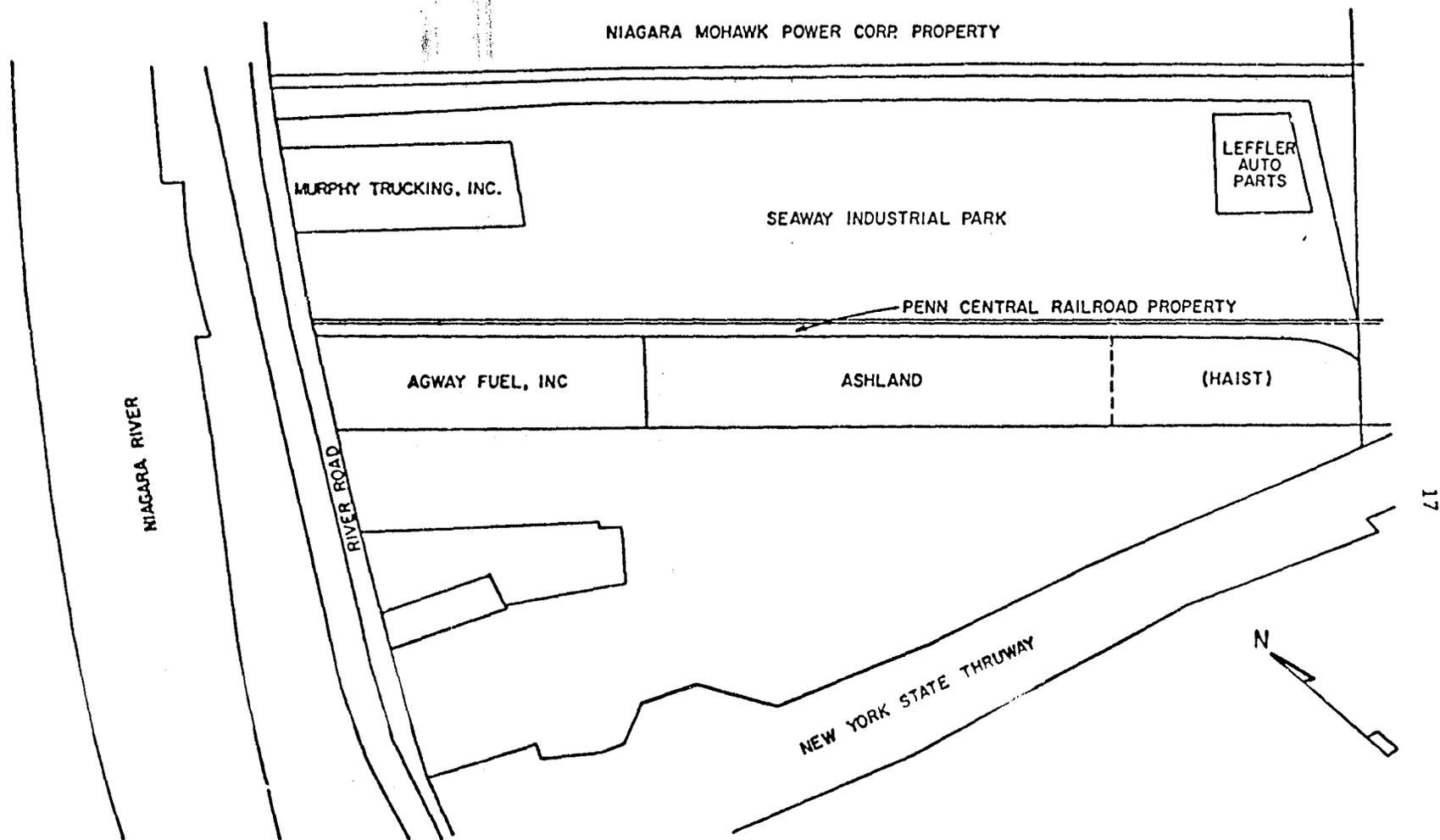


Fig. 2. Seaway Industrial Park and surrounding area.

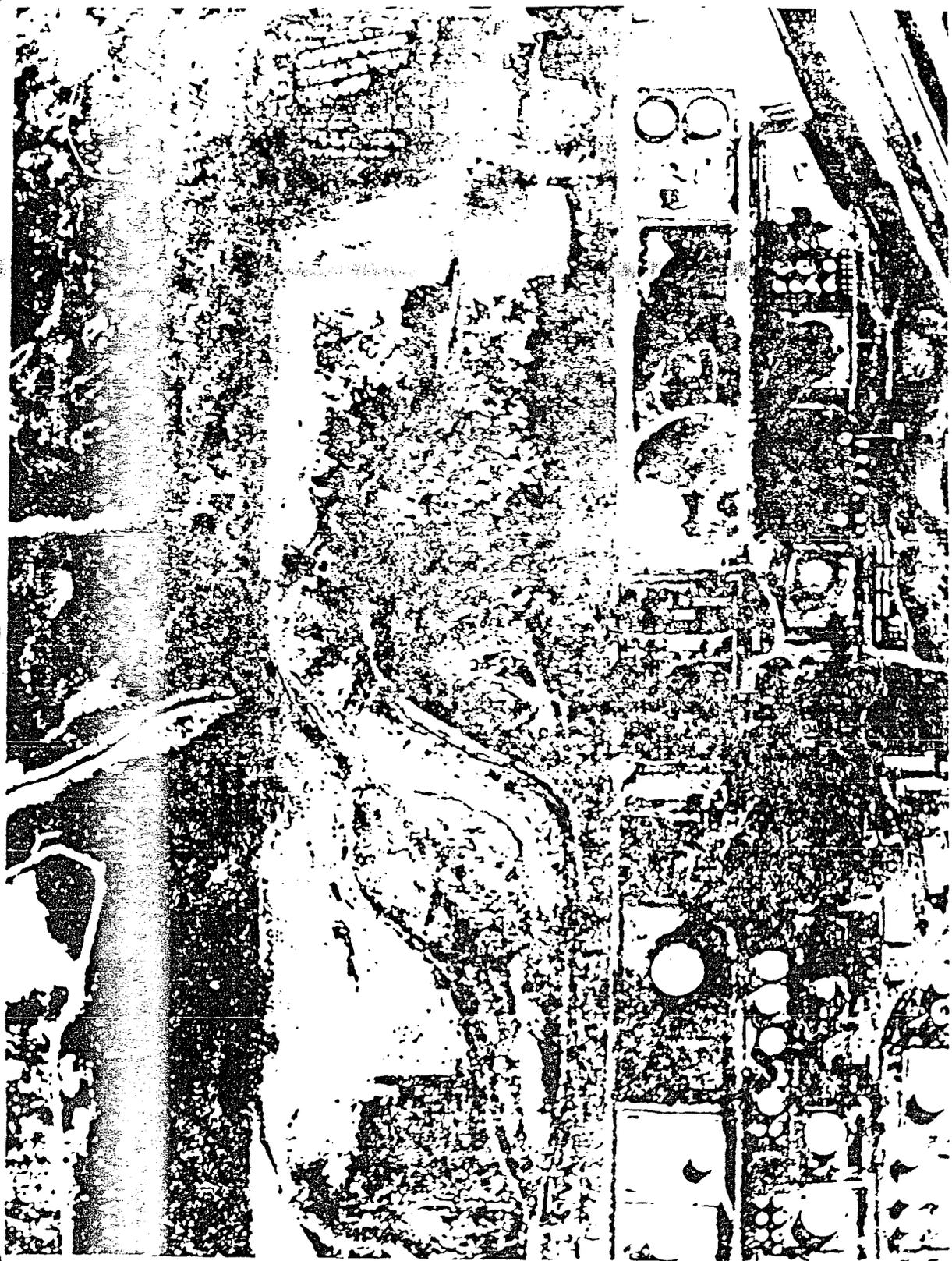


Fig. 5. Aerial photograph of Seaway and surrounding area.

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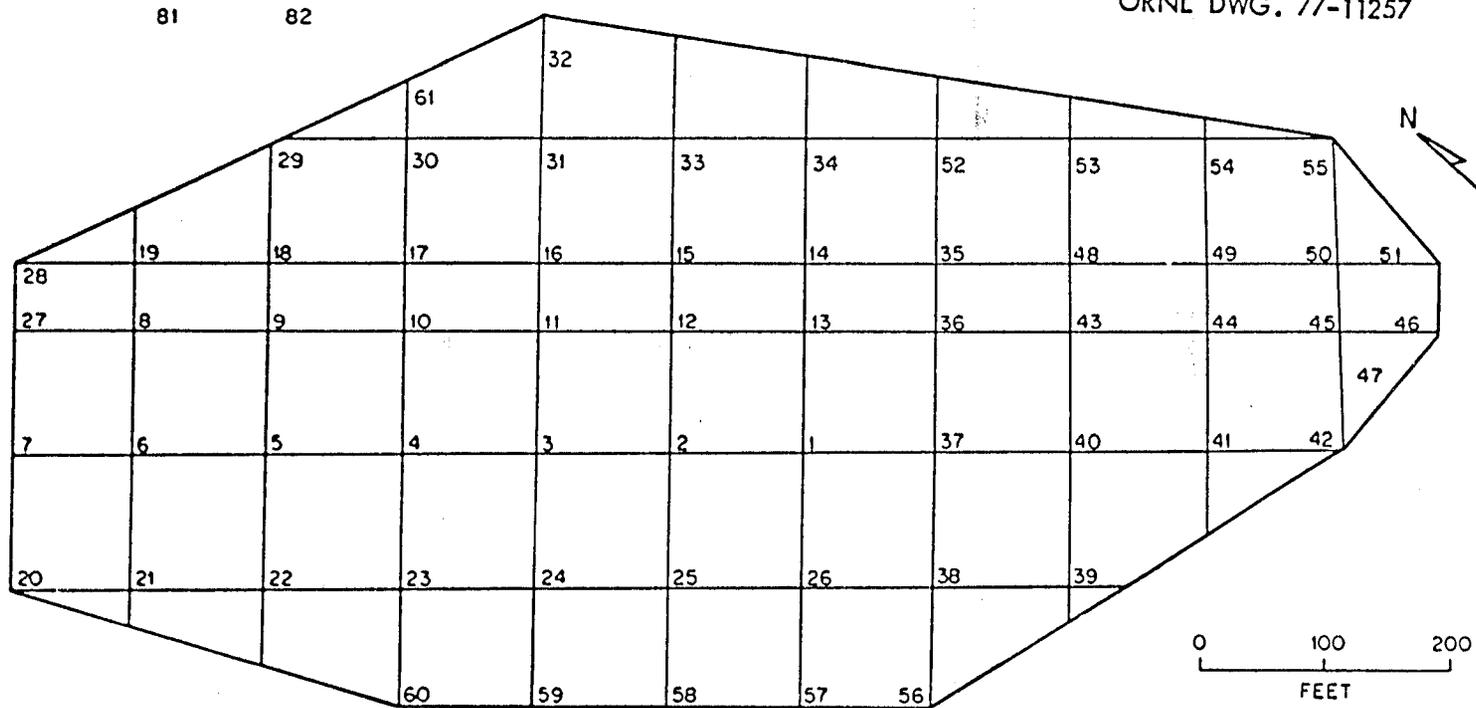


Fig. 4. Points on and near area of known contamination at which measurements were taken (Area A).

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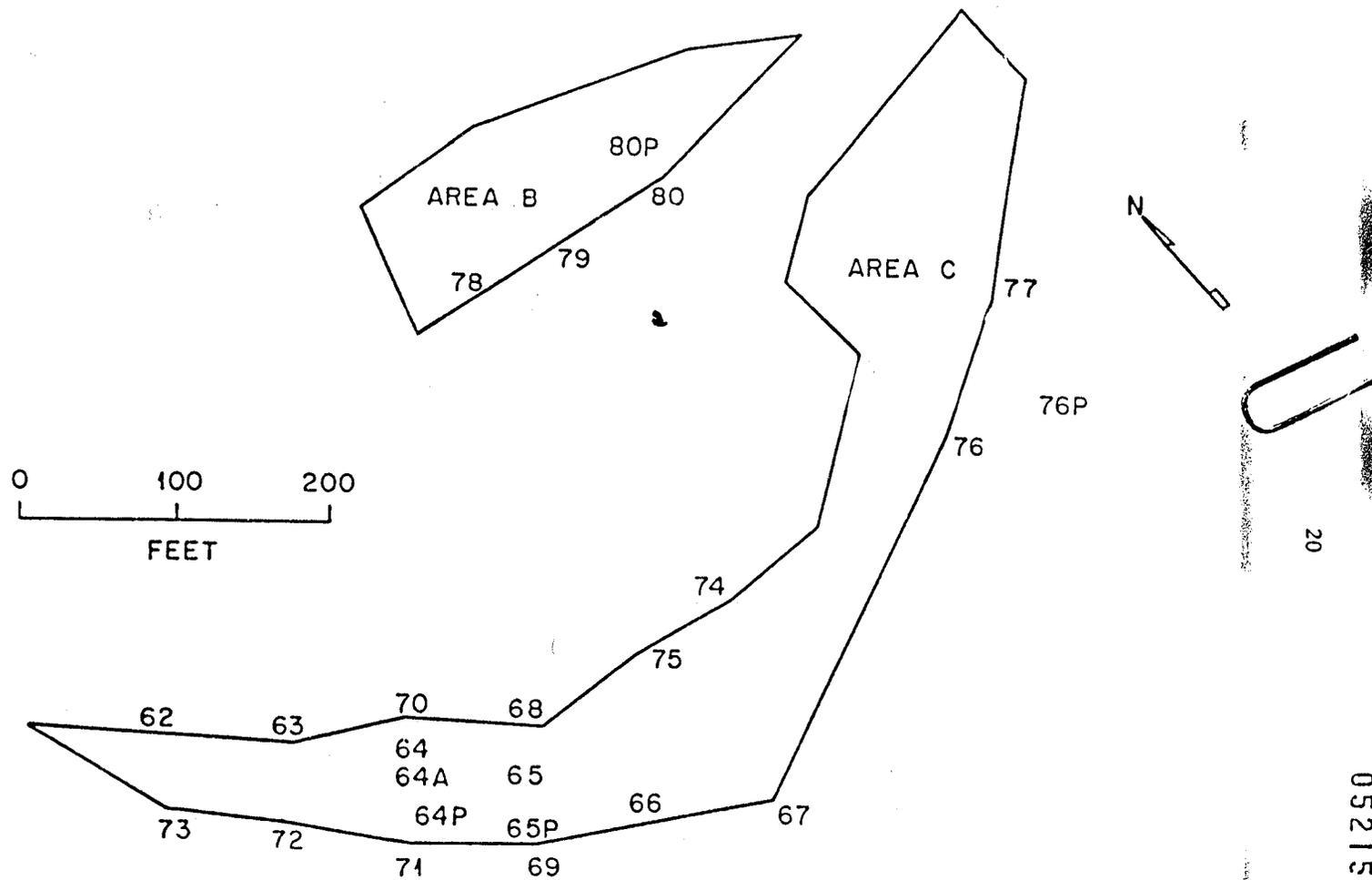


Fig. 5. Points on and near area of known contamination at which measurements were taken (Areas B and C).

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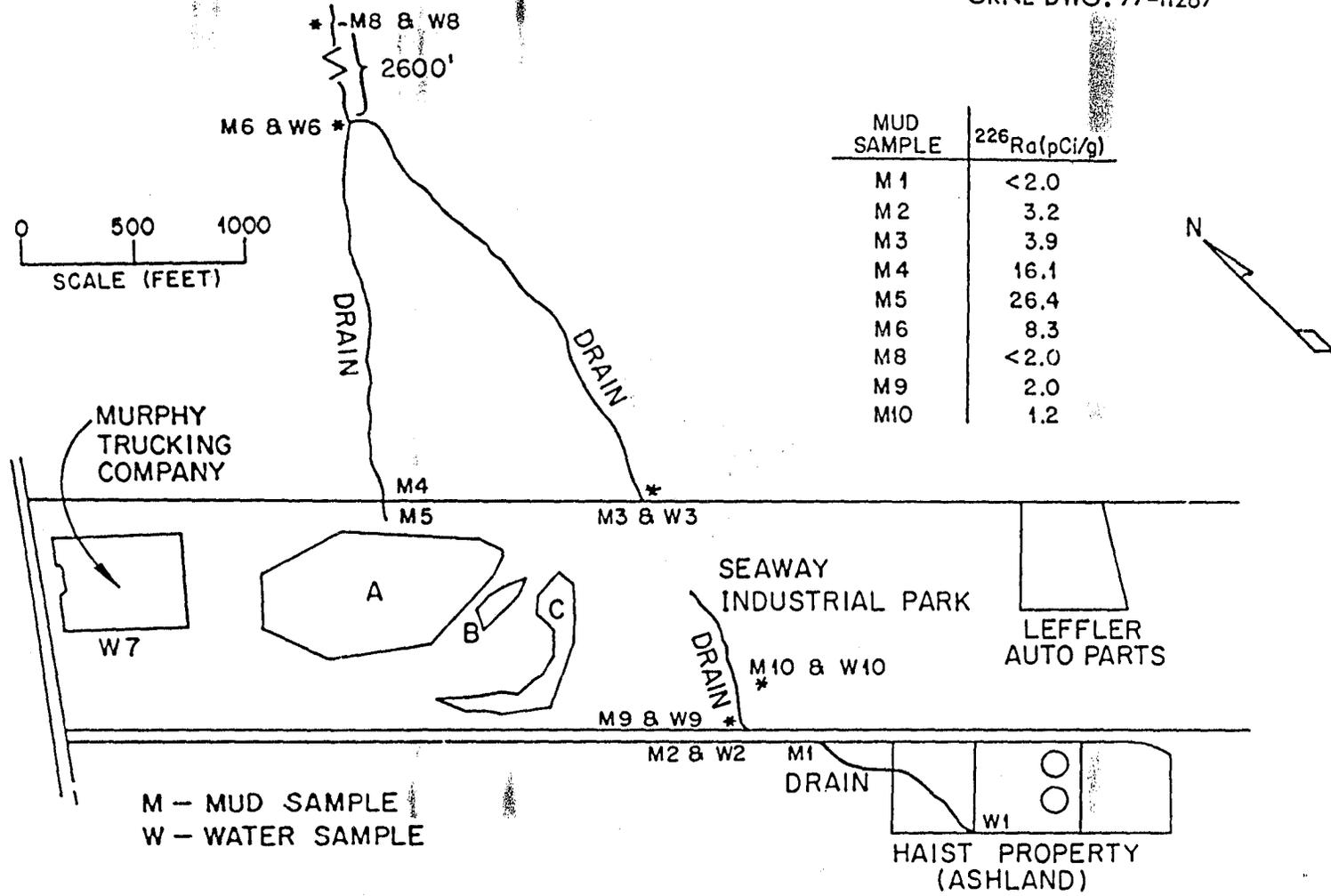
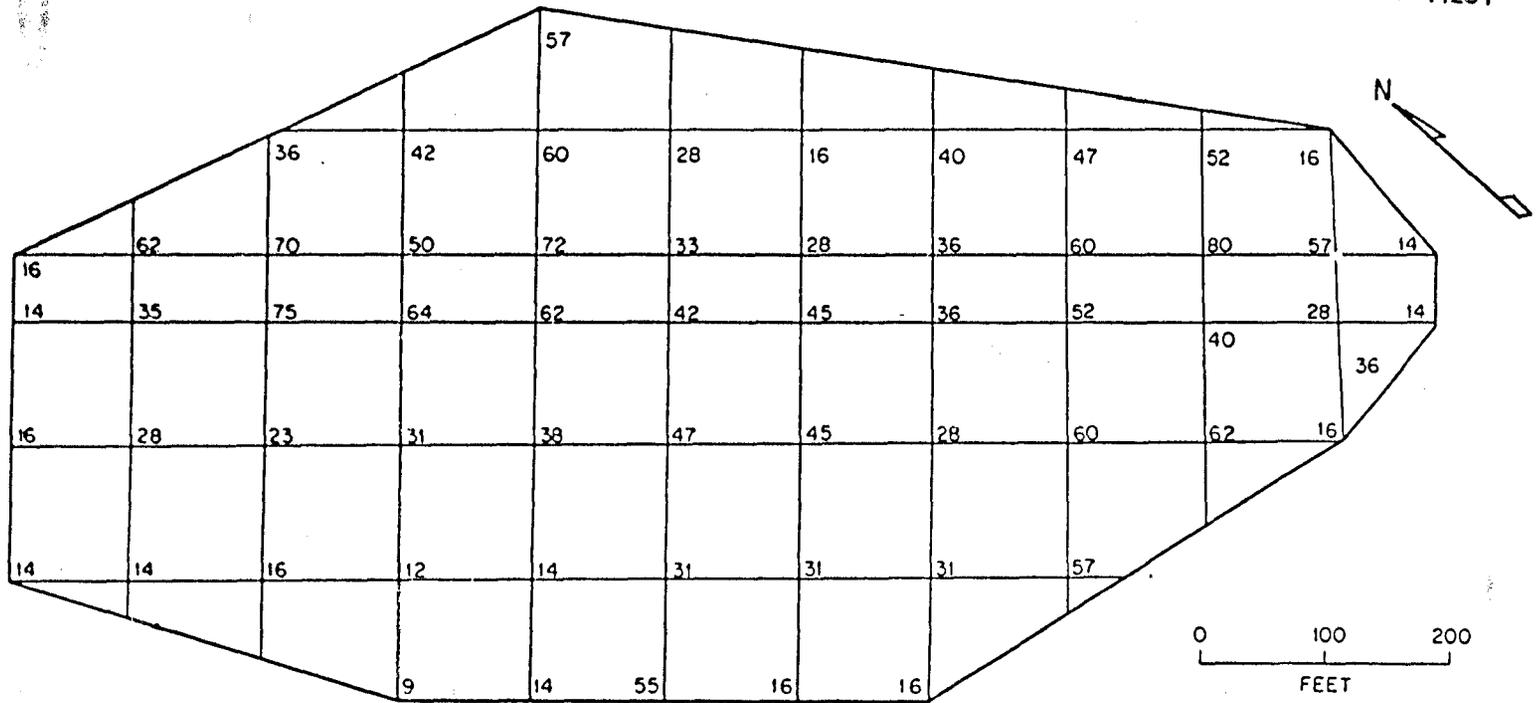


Fig. 6. Locations of water and mud samples and concentrations of <sup>226</sup>Ra in mud samples (pCi/g).

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Fig. 7. External gamma radiation levels (in  $\mu\text{R/hr}$ ) at 1 m above surface (Area A).

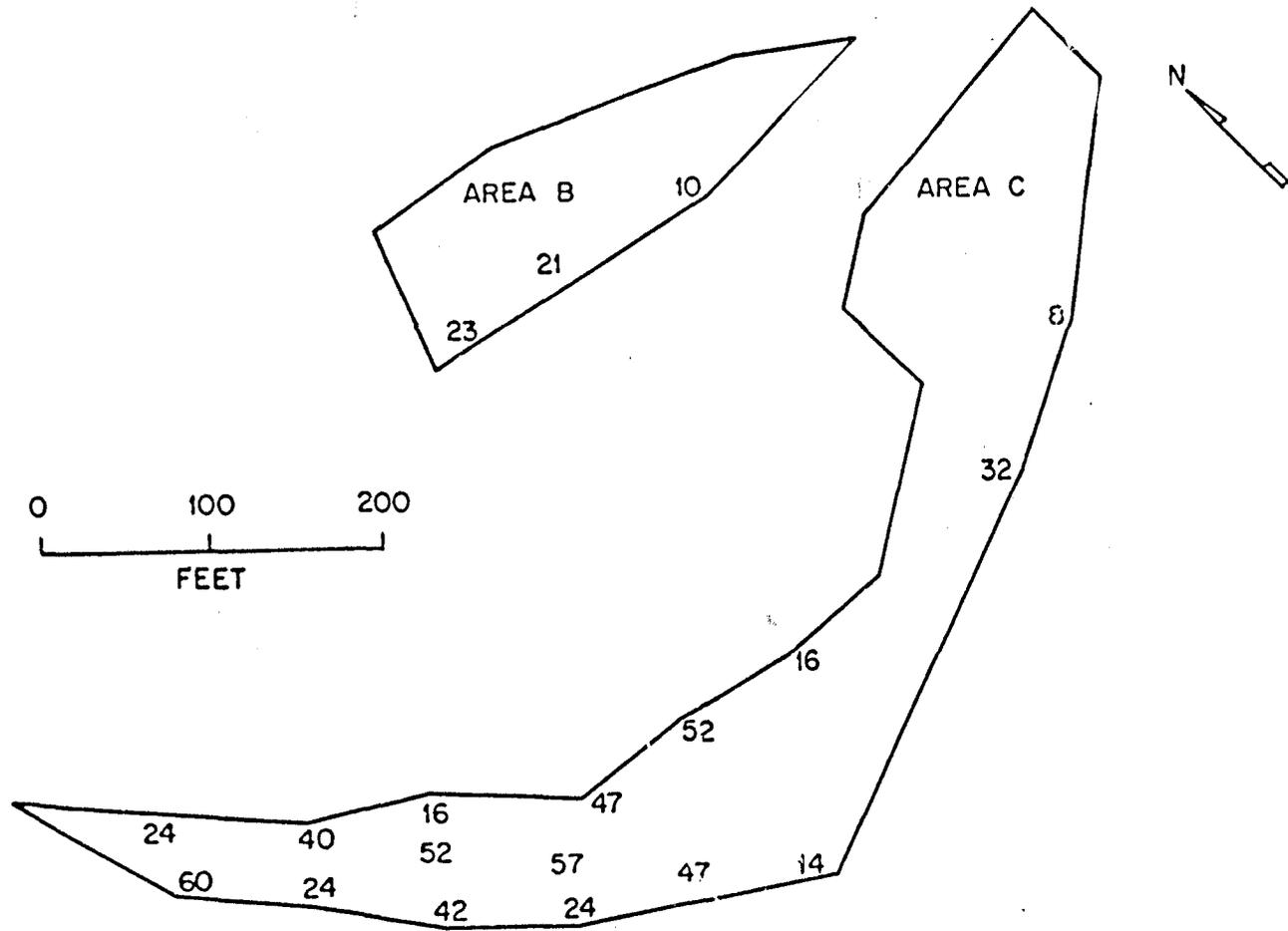
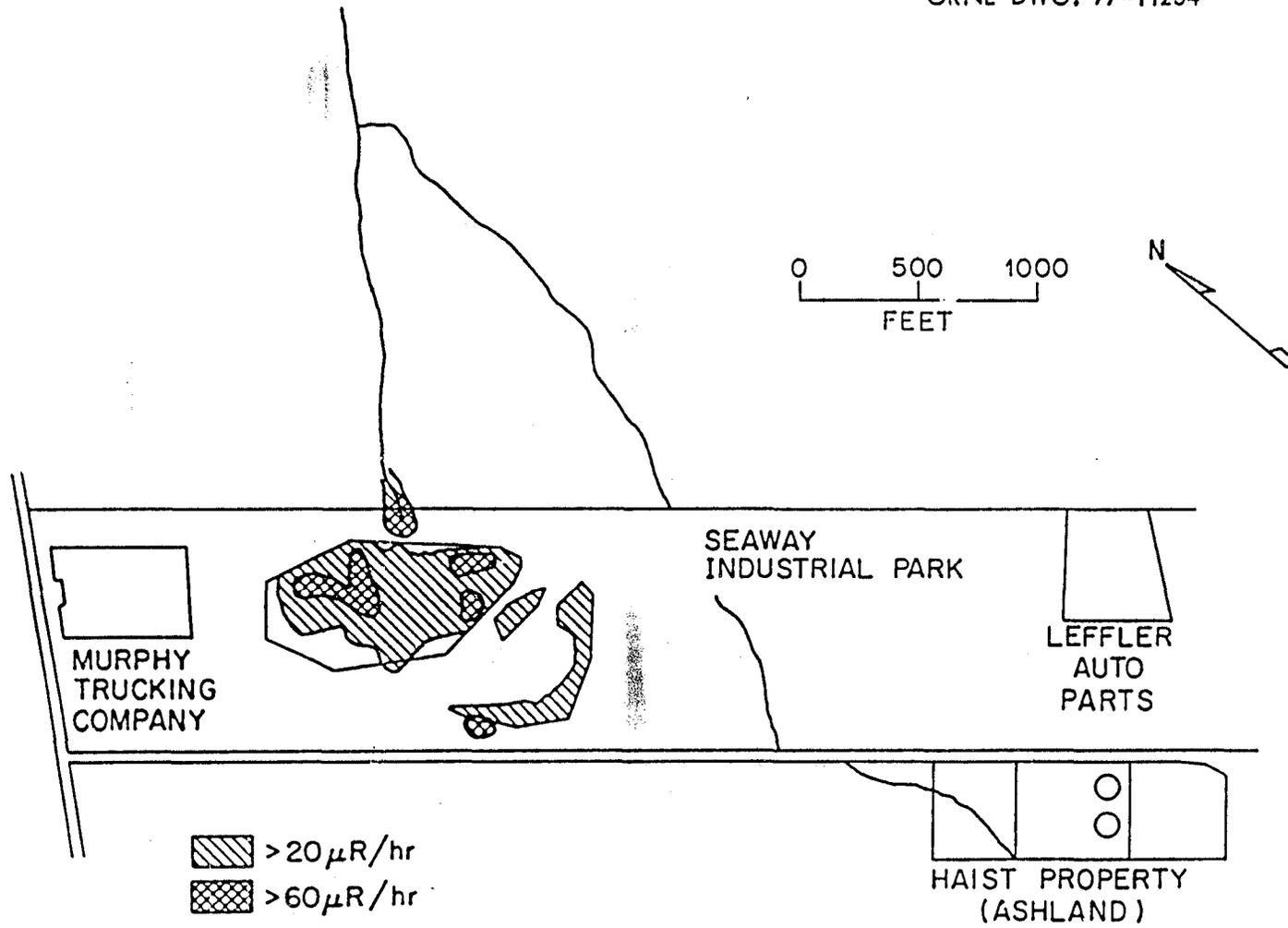


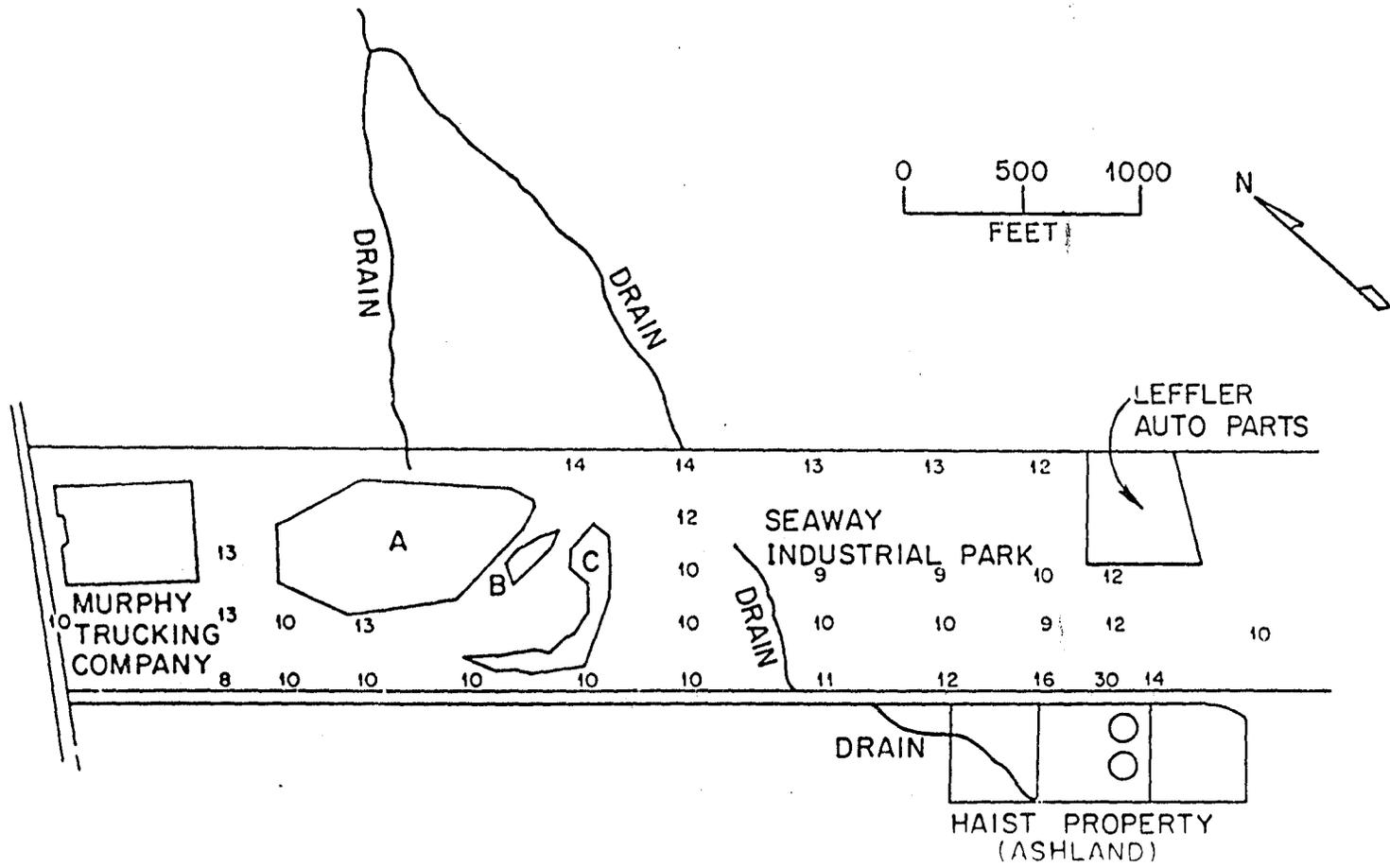
Fig. 8. External gamma radiation levels (in  $\mu\text{R/hr}$ ) at 1 m above surface (Areas B and C).



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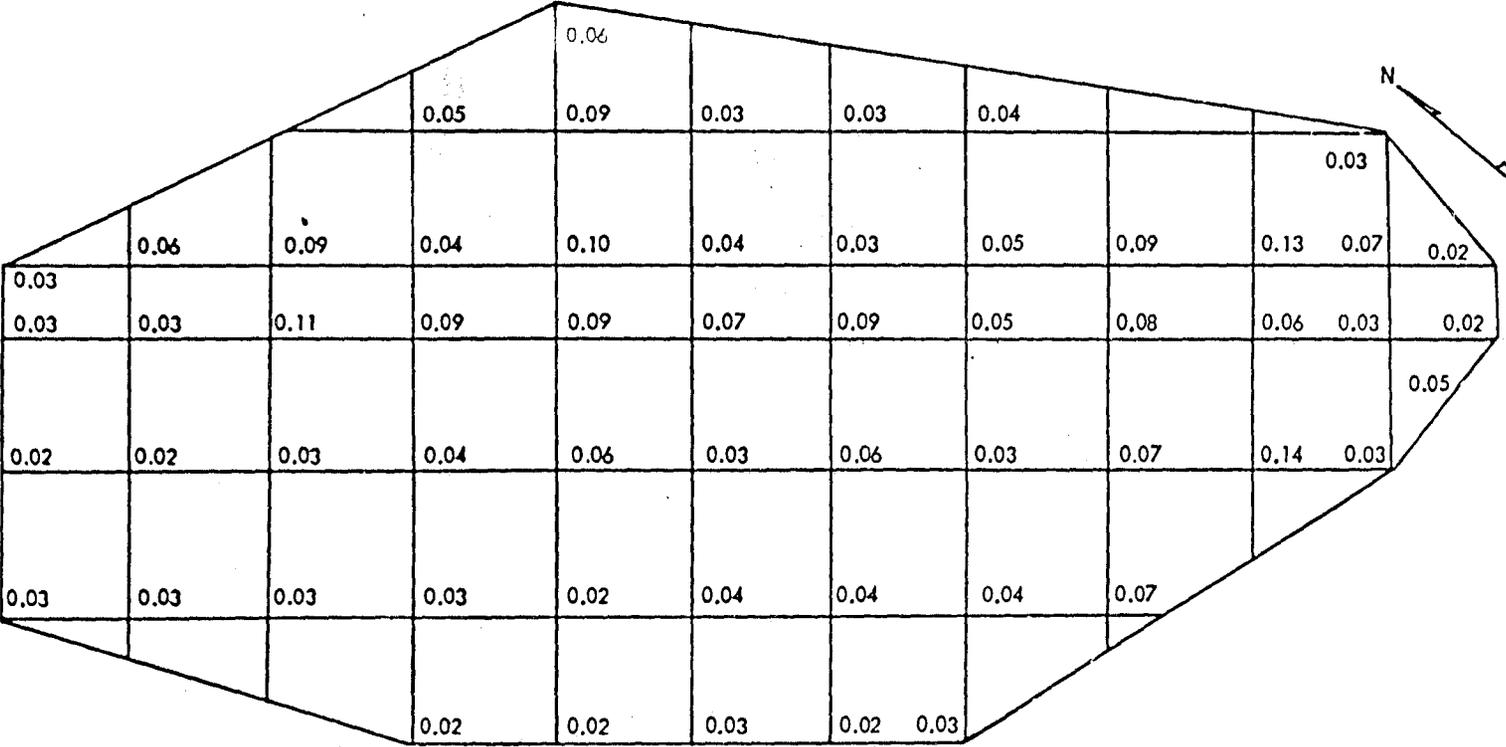
Fig. 9. Area of elevated external gamma radiation.



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Fig. 10. External gamma radiation levels (in  $\mu\text{R/hr}$ ) at 1 m above surface on 400-ft grid.



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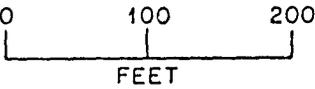


Fig. 11. Beta-gamma readings at surface (in mrad/hr).

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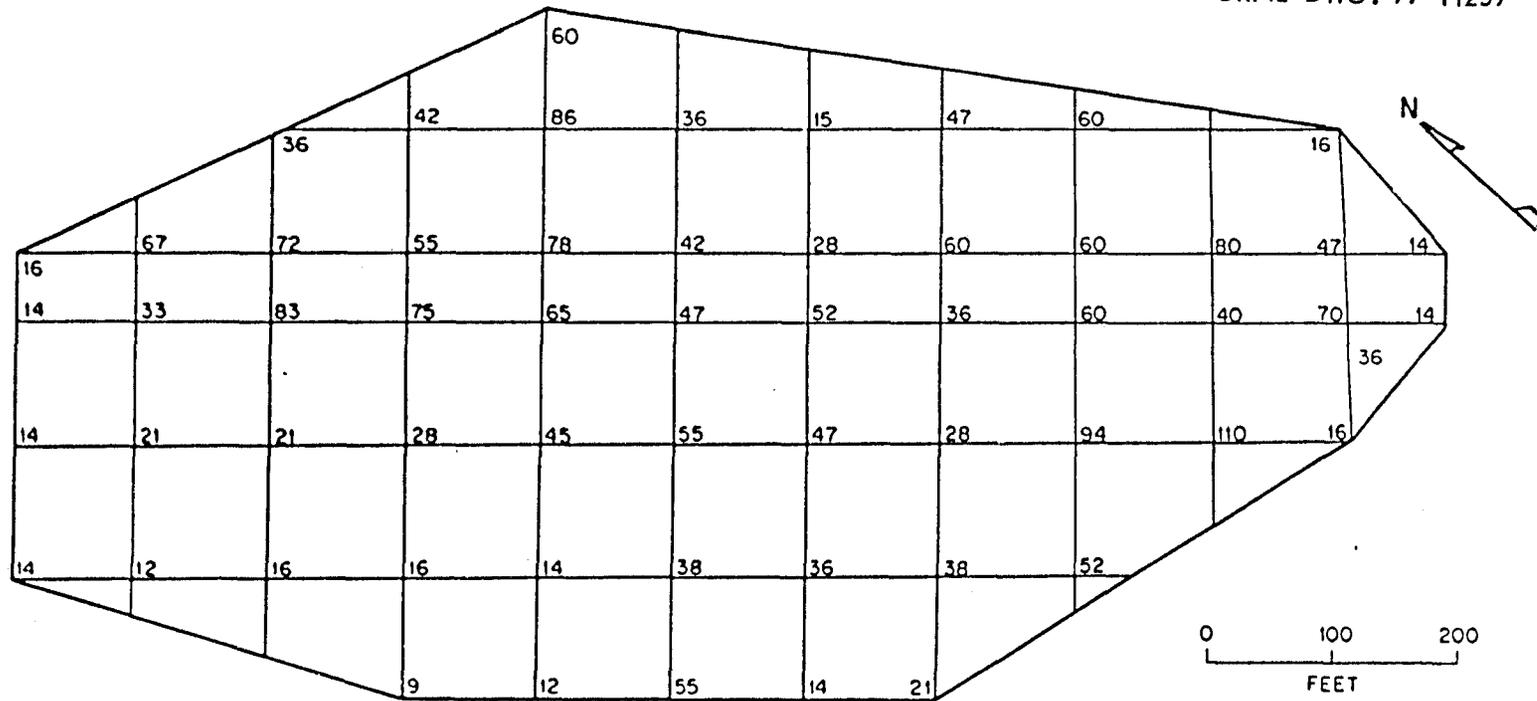


Fig. 12. External gamma radiation (in  $\mu\text{R/hr}$ ) at the surface on Area A.

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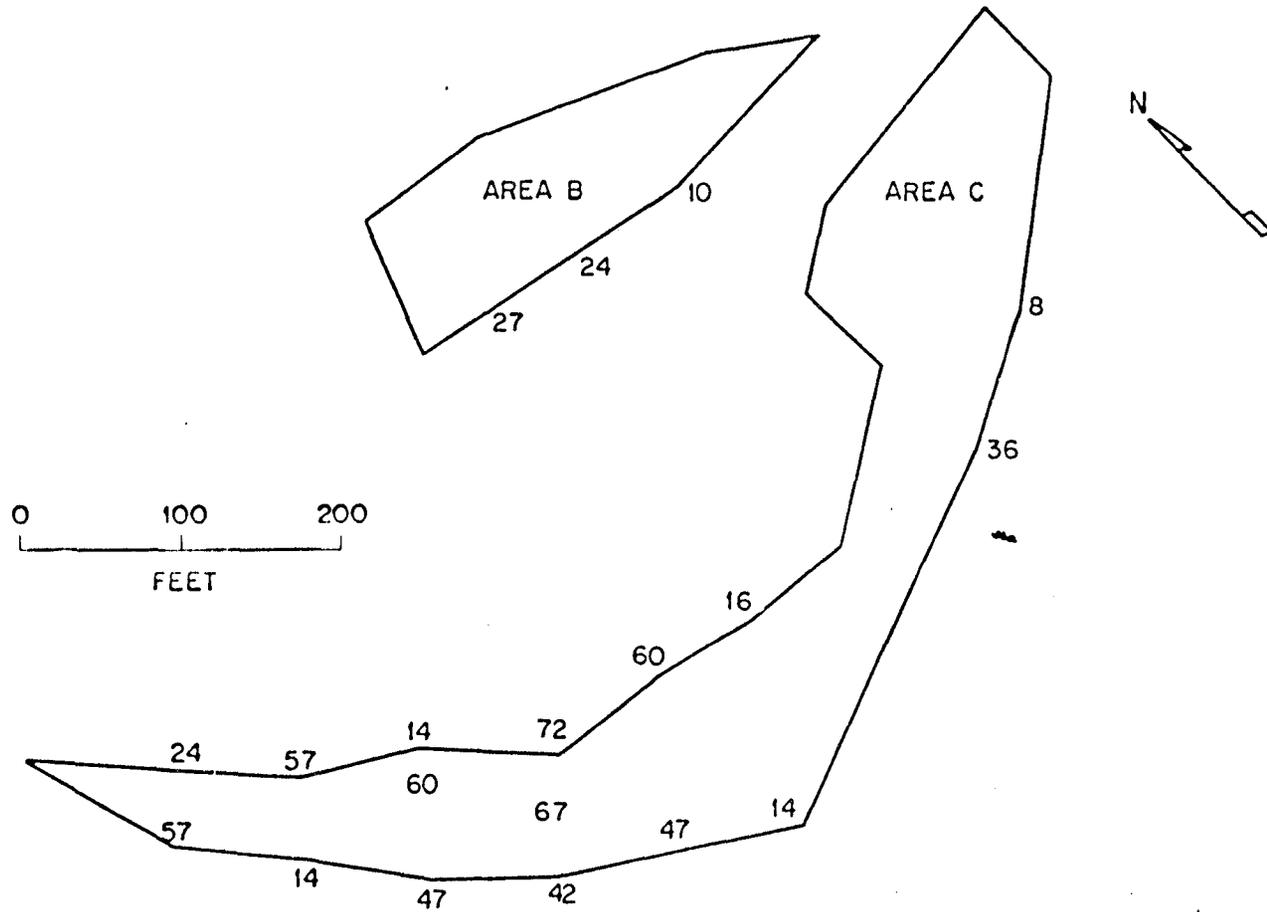


Fig. 13. External gamma radiation levels (in  $\mu\text{R/hr}$ ) at the surface on and near Areas B and C.



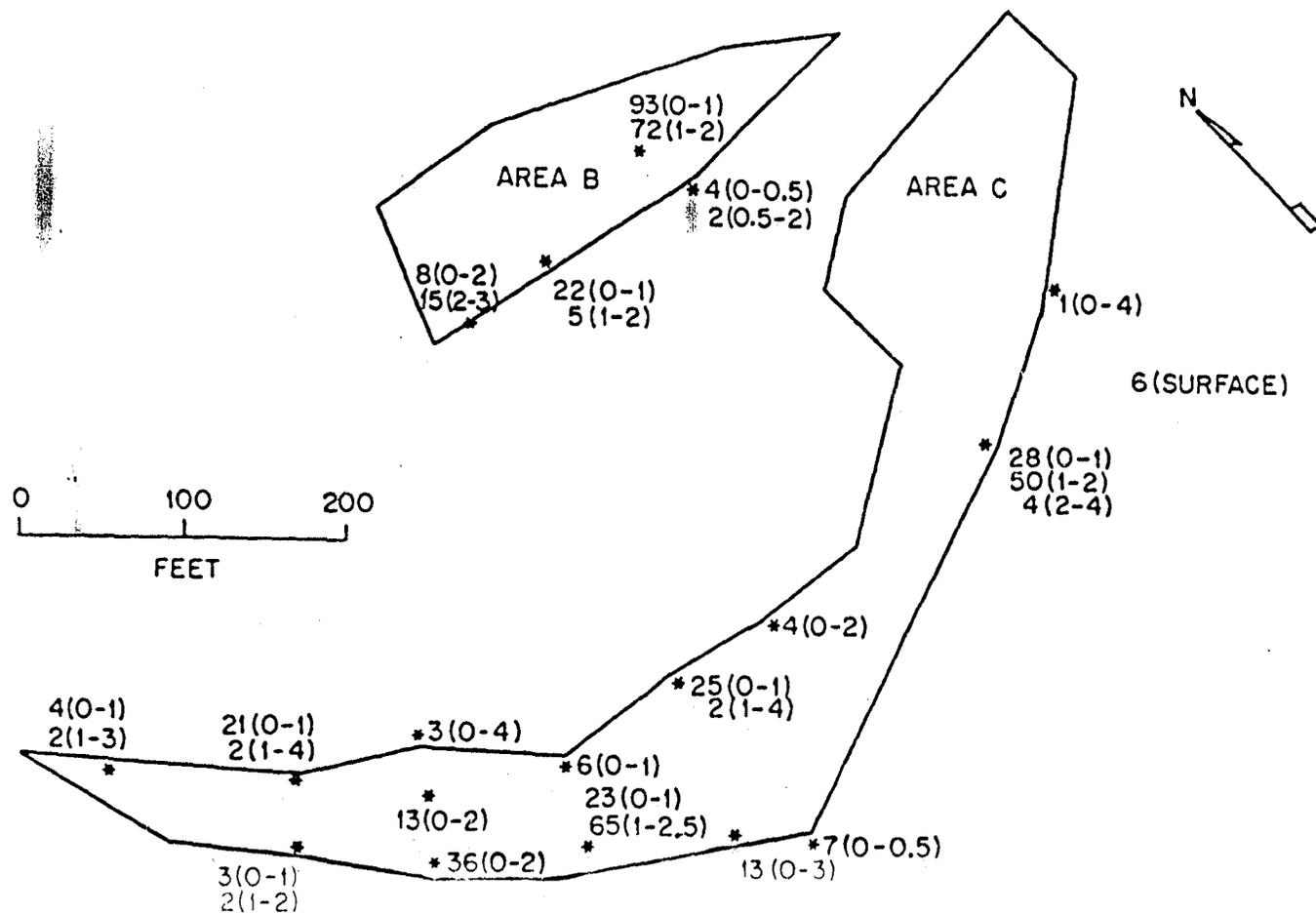


Fig. 15. Radium concentrations in Areas B and C estimated from loggings and soil sample analyses [legend u(v-w) indicates u pCi/g from a depth of v ft to a depth of w ft].

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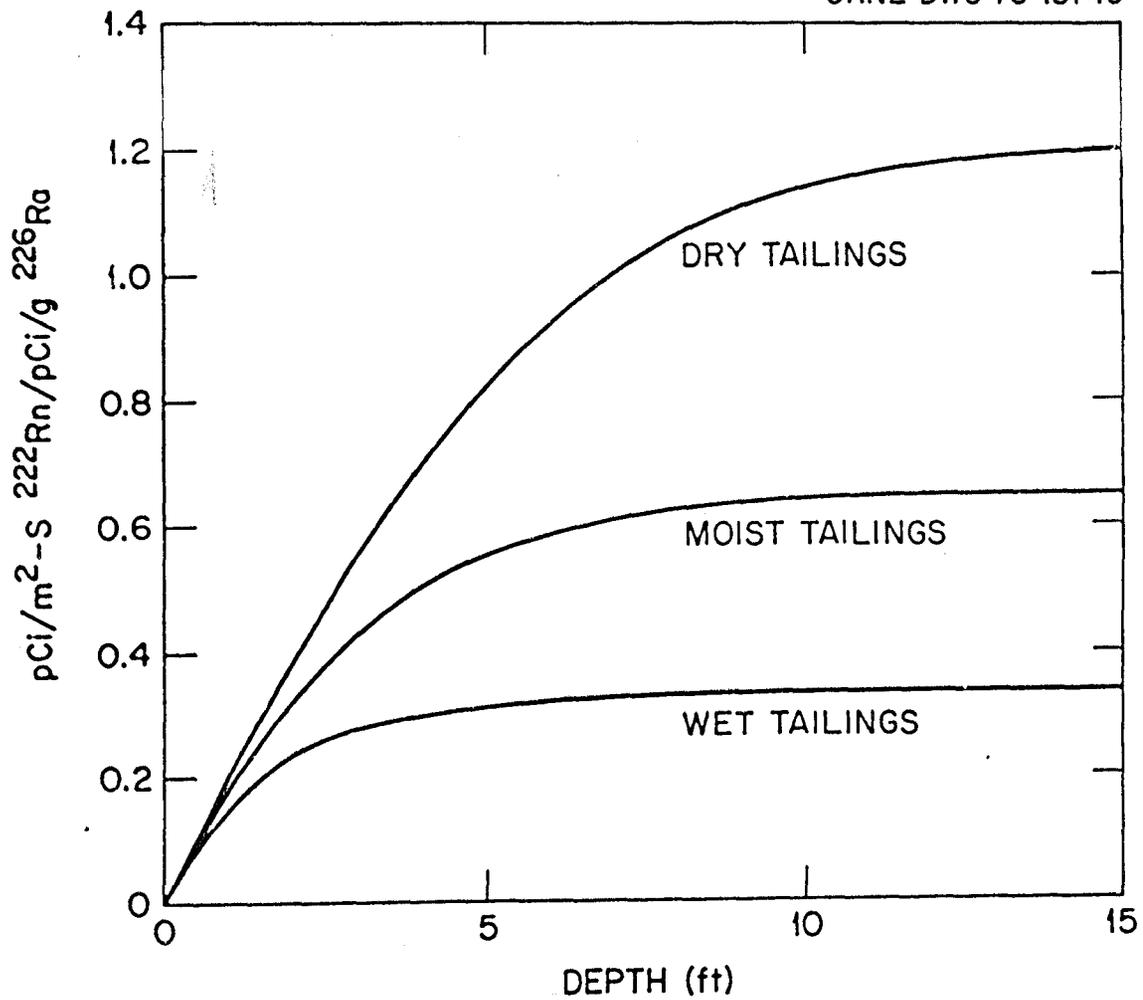


Fig. 16. Relationship of radium concentration and radon emanation.

Table 1. Results<sup>a</sup> of water sample analyses

Sample	<sup>226</sup> Ra	<sup>234</sup> U	<sup>235</sup> U	<sup>238</sup> U	<sup>228</sup> Th	<sup>230</sup> Th	<sup>232</sup> Th
W1	4.0x10 <sup>-4</sup>	2.8x10 <sup>-2</sup>	1.5x10 <sup>-3</sup>	2.8x10 <sup>-2</sup>	3.9x10 <sup>-4</sup>	1.8x10 <sup>-4</sup>	7.2x10 <sup>-5</sup>
W2	1.0x10 <sup>-3</sup>	2.0x10 <sup>-2</sup>	1.9x10 <sup>-3</sup>	2.0x10 <sup>-2</sup>	3.7x10 <sup>-4</sup>	9.0x10 <sup>-5</sup>	<4.0x10 <sup>-5</sup>
W3	6.3x10 <sup>-3</sup>	4.1x10 <sup>-3</sup>	3.4x10 <sup>-4</sup>	4.2x10 <sup>-3</sup>	3.6x10 <sup>-4</sup>	7.6x10 <sup>-5</sup>	1.1x10 <sup>-4</sup>
W6	1.6x10 <sup>-3</sup>	4.1x10 <sup>-2</sup>	1.3x10 <sup>-2</sup>	5.3x10 <sup>-2</sup>	3.2x10 <sup>-4</sup>	9.0x10 <sup>-4</sup>	6.8x10 <sup>-5</sup>
W7	9.0x10 <sup>-4</sup>	1.0x10 <sup>-2</sup>	4.4x10 <sup>-4</sup>	1.0x10 <sup>-2</sup>	3.0x10 <sup>-4</sup>	1.4x10 <sup>-4</sup>	<3.0x10 <sup>-5</sup>
W8	5.8x10 <sup>-4</sup>	4.0x10 <sup>-2</sup>	1.4x10 <sup>-3</sup>	3.9x10 <sup>-2</sup>	3.7x10 <sup>-4</sup>	1.1x10 <sup>-4</sup>	4.1x10 <sup>-5</sup>
W9	8.0x10 <sup>-4</sup>	5.0x10 <sup>-2</sup>	2.1x10 <sup>-3</sup>	5.0x10 <sup>-2</sup>	3.2x10 <sup>-4</sup>	8.6x10 <sup>-5</sup>	<3.0x10 <sup>-5</sup>
W10	1.1x10 <sup>-3</sup>	1.4x10 <sup>-2</sup>	7.6x10 <sup>-4</sup>	1.1x10 <sup>-2</sup>	3.2x10 <sup>-4</sup>	7.2x10 <sup>-5</sup>	<3.0x10 <sup>-5</sup>
MPC <sub>w</sub> (Soluble)	3x10 <sup>-2</sup>	30	30	40	7	2	2

<sup>a</sup>Concentrations given in pCi/ml.

Table 2. Radium concentrations<sup>a</sup> in the soil

Sample <sup>b</sup>	Depth (ft)	<sup>226</sup> Ra	Sample	Depth (ft)	<sup>226</sup> Ra
2-1	0-1	16.2	13-1	0-1	12.4
2-2	1-2	8.2	13-2	1-2	17.3
2-3	2-4	12.8	13-3	2-3	30.6
2-4	4.5-5.5	1.1	13-4	3-4	20.8
2-5	5.5-6.5	0.8	14-1	0-2	9.9
3-1	0-1	27.8	14-2	2-3	1.7
3-2	1-2	9.0	15-1	0-1	1.0
3-3	2-4	1.3	15-2	1-2	0.8
4-1	0-1	3.3	16-1	0-1	17.9
4-2	1-2	3.0	16-2	1-2	1.4
4-3	2-4	8.2	17-1	0-1	40.5
5-1	0-2	1.6	17-2	1-2	1.0
6-2	1-2	1.0	18-1	0-1	15.0
6-3	2-4	7.3	18-2	1-2	1.9
9-1	0-1	32.0	19-1	0-1	11.5
9-2	1-2	1.5	19-2	1-2	1.3
10-1	0-1	40.9	22-1	0-1	1.2
10-2	1-2	1.2	24-1	0-1	1.3
11-1	0-2	20.5	24-4	4-4.5	1.8
11-2	2-3	1.3	25-1	0-1	3.3
12-1	0-2	6.3	25-3	2-3	4.4
			25-7	Surface	8.0

Table 2. (cont'd.) Radium concentrations<sup>a</sup> in the soil

Sample <sup>b</sup>	Depth (ft)	<sup>226</sup> Ra	Sample	Depth (ft)	<sup>226</sup> Ra
26-1	0-1.5	7.8	45-1	0-1	18.0
28-1	0-1	1.4	45-2	Surface	5.2
29-1	0-2	7.5	47-1	0-1	5.4
30-1	0-1	21.2	47-2	1-2	6.1
30-2	1-2	1.3	47-3	2-3	3.6
31-1	0-1	50.8	47-4	3-4	2.6
31-2	1-2	50.2	47-5	4-5	3.5
32-1	0-1	17.8	47-6	5-6	4.5
32-2	1-2	2.9	48-1	0-1.5	32.3
33-1	0-1	4.8	52-1	0-1	8.8
33-2	1-2	0.43	52-2	1-2	4.5
34-1	0-1	2.0	53-1	0-1	32.6
34-2	1-2	7.4	53-2	1-2	1.5
36-1	0-1	1.3	54-1	0-1	10.7
37-1	0-0.5	6.0	54-1	1-2	7.8
38-1	0-0.5	9.4	55-1	0-1	5.6
39-1	0-1	20.2	55-2	1-2	8.2
40-1	0-0.5	22.5	61-1	0-1	11.1
40-2	0.5-1.0	1.8	61-2	1-2	2.5
41-1	0-0.5	3.7	62-1	0-1	4.1
43-1	0-0.5	9.9	63-1	0-1	20.8
44-1	0-0.5	18.7	64A-1	0-1	11.7
			64A-2	1-2	15.1
			64P	0-2	35.6

Table 2. (cont'd.) Radium concentrations<sup>a</sup> in the soil

Sample	Depth (ft)	<sup>226</sup> Ra	Sample	Depth (ft)	<sup>226</sup> Ra
65P	0-1	23.1	77-1	0-1	1.0
66-1	0-1.5	13.0	77-2	1-2	1.0
67-1	0-1	7.2	79-1	0-1	22.2
68-1	0-1	5.8	80-1	0-0.5	3.6
70-1	0-0.5	2.6	80-P1	0-1	92.6
72-1	0-1	3.4	80-P2	1-2	71.7
72-2	1-2	1.9	81-2	1-2	1.0
75-1	0-1	24.6	82-1	0-1	6.5
76P	Surface	5.9	82-2	1-2	1.1
			82-3	2-3	40.0

<sup>a</sup>Measurements given in pCi/g.

<sup>b</sup>The first number in the sample designation refers to the sample location (see Figs. 4 and 5).

Table 3. Concentrations<sup>a</sup> of  $^{238}\text{U}$  in selected samples

Sample <sup>b</sup>	$^{238}\text{U}$ (pCi/g)
3-1	63.0
5-1	2.9
11-1	17.0
13-1	40.0
28-1	2.5
30-2	2.8
31-2	56.0
33-2	2.4
34-1	4.3
36-1	4.2
47-3	3.5
48-1	44.0
53-1	46.0
63-1	34.0
65P	21.0
66-1	12.0
68-1	12.0
77-1	2.5
79-1	N.F.
80-P2	102
82-3	59.0

<sup>a</sup>Radium concentrations and depth of these samples are given in Table 2.

<sup>b</sup>The first number in the sample name refers to the sample location (see Figs. 4 and 5).

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APPENDIX I

Description of Radiation Survey Meters

## RADIATION SURVEY METERS

## Beta-Gamma Survey Meter

A portable Geiger-Muller (G-M) survey meter is the primary instrument for measuring beta-gamma contamination. The G-M tube is a halogen-quenched stainless steel tube having a  $30 \text{ mg/cm}^2$  wall thickness and presenting a cross-sectional area of approximately  $10 \text{ cm}^2$ . Since the G-M tube is sensitive to both beta and gamma radiation, measurements are taken in both an open-window and a closed-window configuration. Beta radiation cannot penetrate the closed window and thus the beta reading can be determined by taking the difference between the open and closed window readings. This meter is shown in Fig. I-A.

The G-M survey meter was calibrated at ORNL for gamma radiation using a National Bureau of Standard (NBS) radium source and a depleted uranium source. The gamma calibration factor is typically of the order of 2600 cpm per mR/hr. The beta-gamma calibration for this site was determined by comparison with a Victoreen Model 440 ionization chamber (see Fig. I-B). Based on the measurement of a variety of uranium contaminated surfaces, the calibration factor was determined to be 1750 cpm per mrad/hr with a standard deviation of 25%.

## Gamma Scintillation Meter

A portable survey meter with a NaI scintillation probe has been used to measure low-level gamma radiation exposure (see Fig. I-C). The scintillation probe is a  $3.2 \times 3.8 \text{ cm}$  NaI crystal mounted on a photomultiplier tube. This probe is coupled with a Victoreen Model Thyac III ratemeter

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(see Fig. I-C). The unit is capable of measuring radiation levels from a few  $\mu\text{R/hr}$  to several hundred  $\mu\text{R/hr}$ . It is calibrated at ORNL with an NBS standard  $^{226}\text{Ra}$  source. Typical calibration factors are of the order of 250 to 400 cpm per  $\mu\text{R/hr}$ .

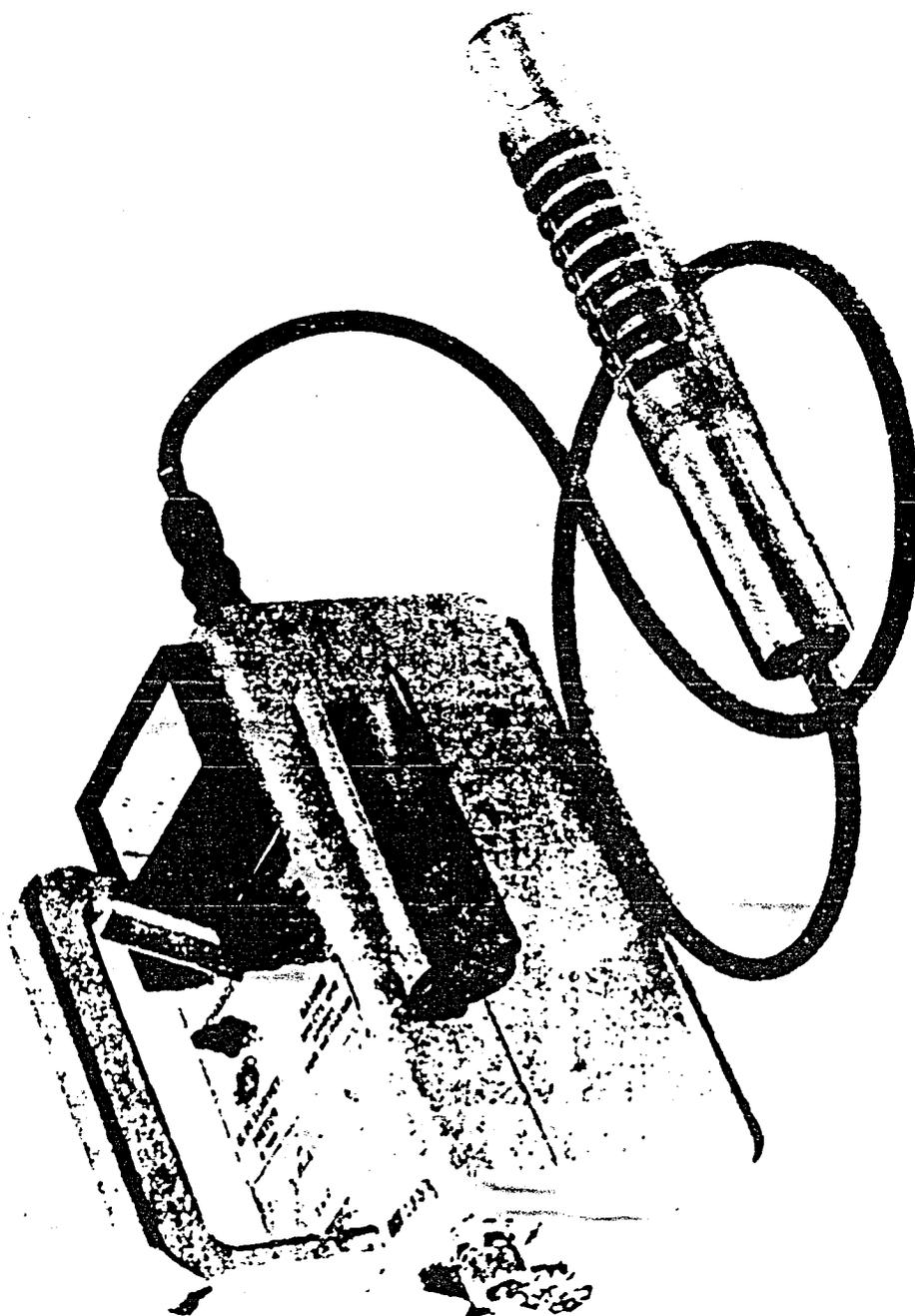


Fig. I-A. Geiger-Müller Survey Meter.

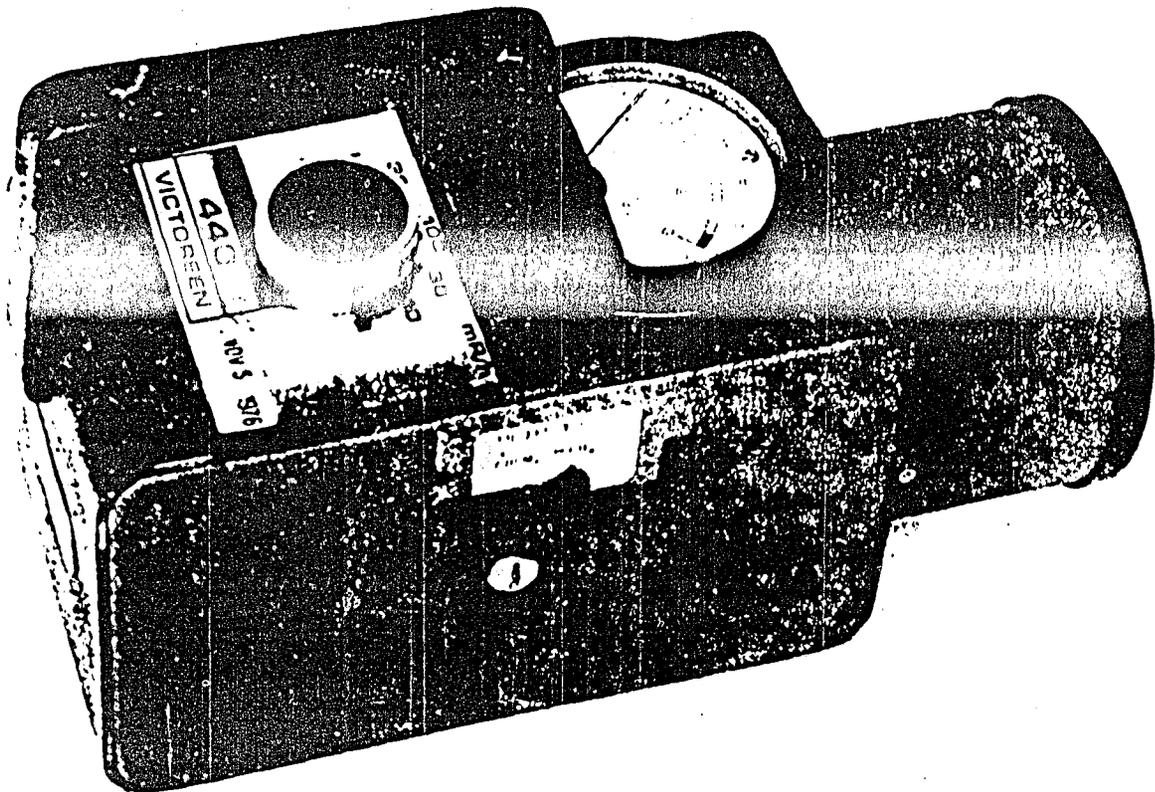


Fig. I-B. Victoreen Model 440  
Ionization Chamber.

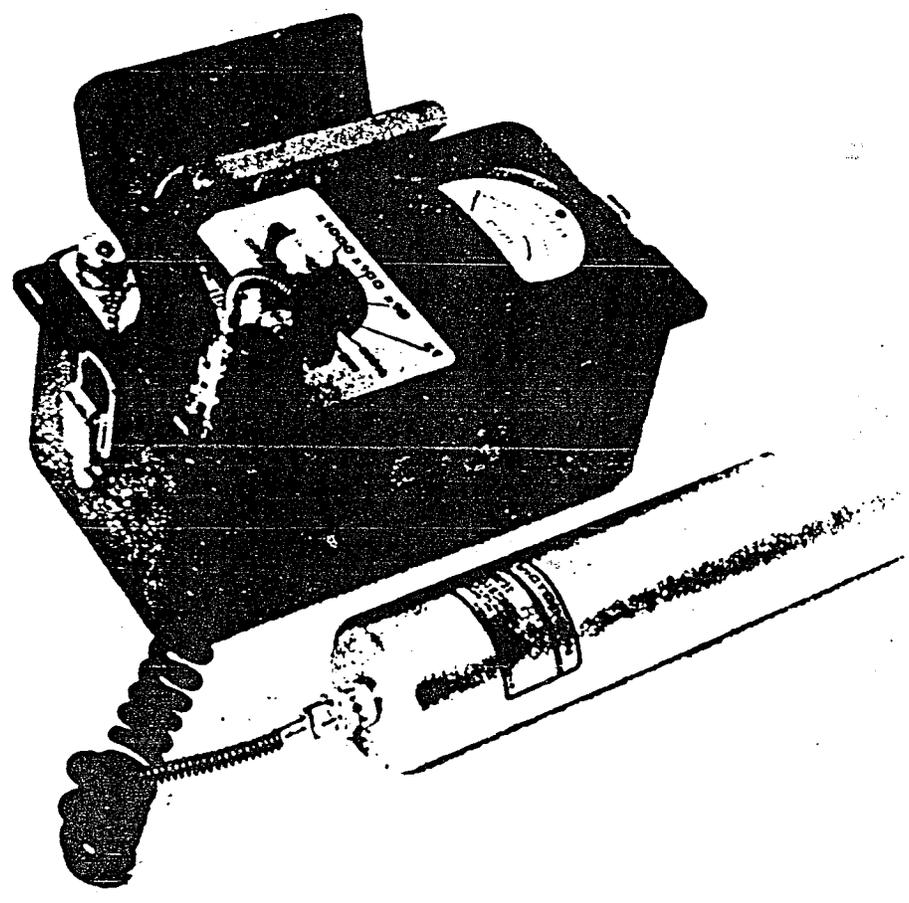


Fig. I-C. Gamma scintillation survey meter.

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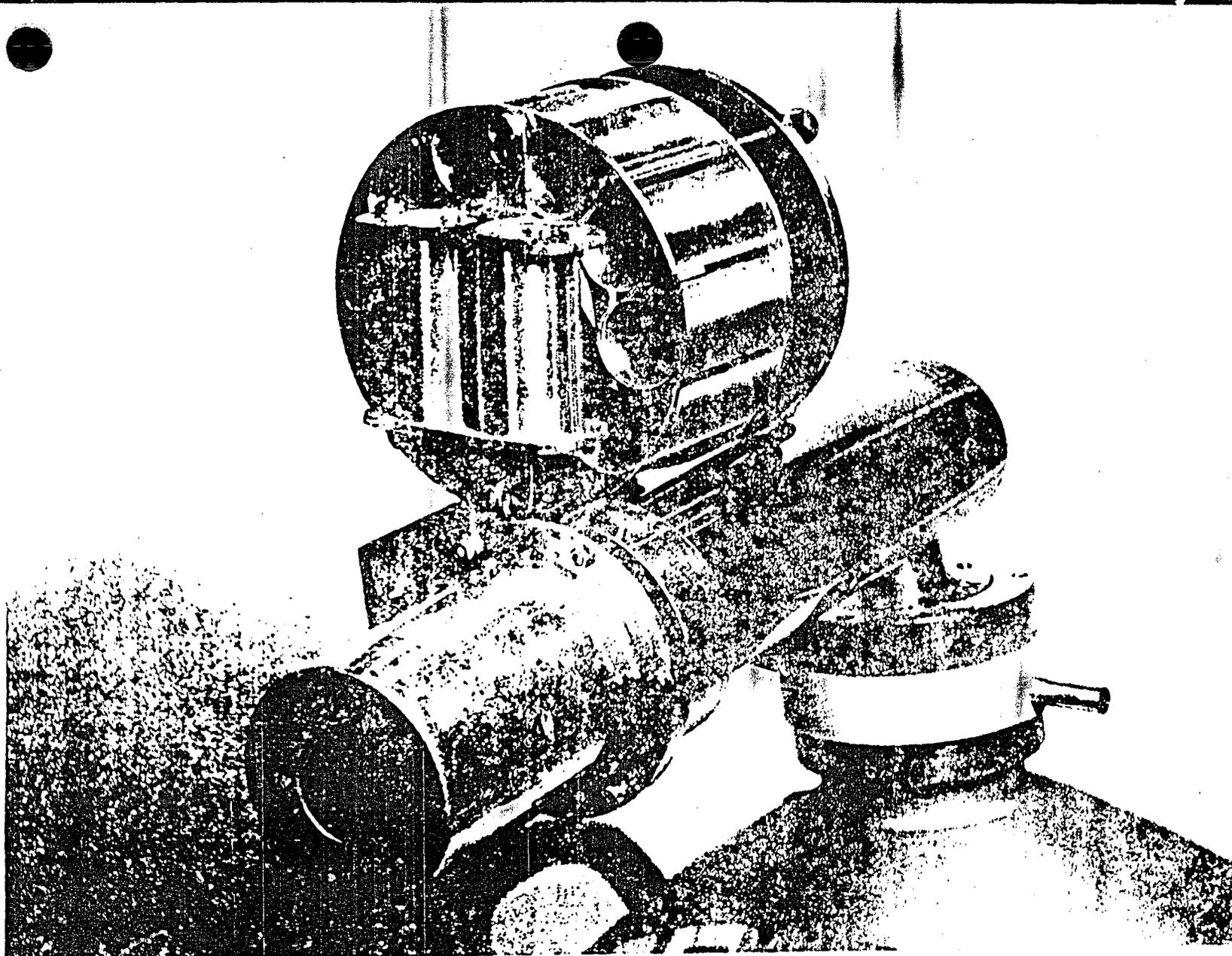
APPENDIX II

Description of Ge(Li) Detector and  
Soil Counting Procedures

## DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

A holder for twelve 30-cc polyethylene (standard liquid scintillation sample) bottles and a background shield have been designed for use with a 50-cc Ge(Li) detector system in laboratory counting of radioactivity in environmental samples (see Figs. II-A, II-B). During counting of the samples, the holder is used to position ten of the sample bottles around the cylindrical surface of the detector, parallel to and symmetric about its axis, and two additional bottles across the end surface of the detector, perpendicular to and symmetric with its axis. With a 300-cc sample and a graded shield developed for use with the system, it is possible to measure 1 pCi/g of  $^{232}\text{Th}$  or  $^{226}\text{Ra}$  with an error of  $\pm 10\%$ .

Data is gathered by a 4096-channel analyzer, stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to identify radionuclides corresponding to those gamma-ray lines found in the sample. The program relies on a look-up table of radioisotopes which contains approximately 700 isotopes and 2500 gamma-rays and runs continuously on the IBM-360 system at ORNL. In identifying and quantifying  $^{226}\text{Ra}$ , six principal gamma-ray lines are analyzed. Most of these are from  $^{214}\text{Bi}$  and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estimate of the concentration of  $^{238}\text{U}$  is obtained from an analysis of the 93 KeV line from its daughter  $^{234}\text{Th}$ .



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Fig. II-A. Holder for Ge(Li) detector system sample.

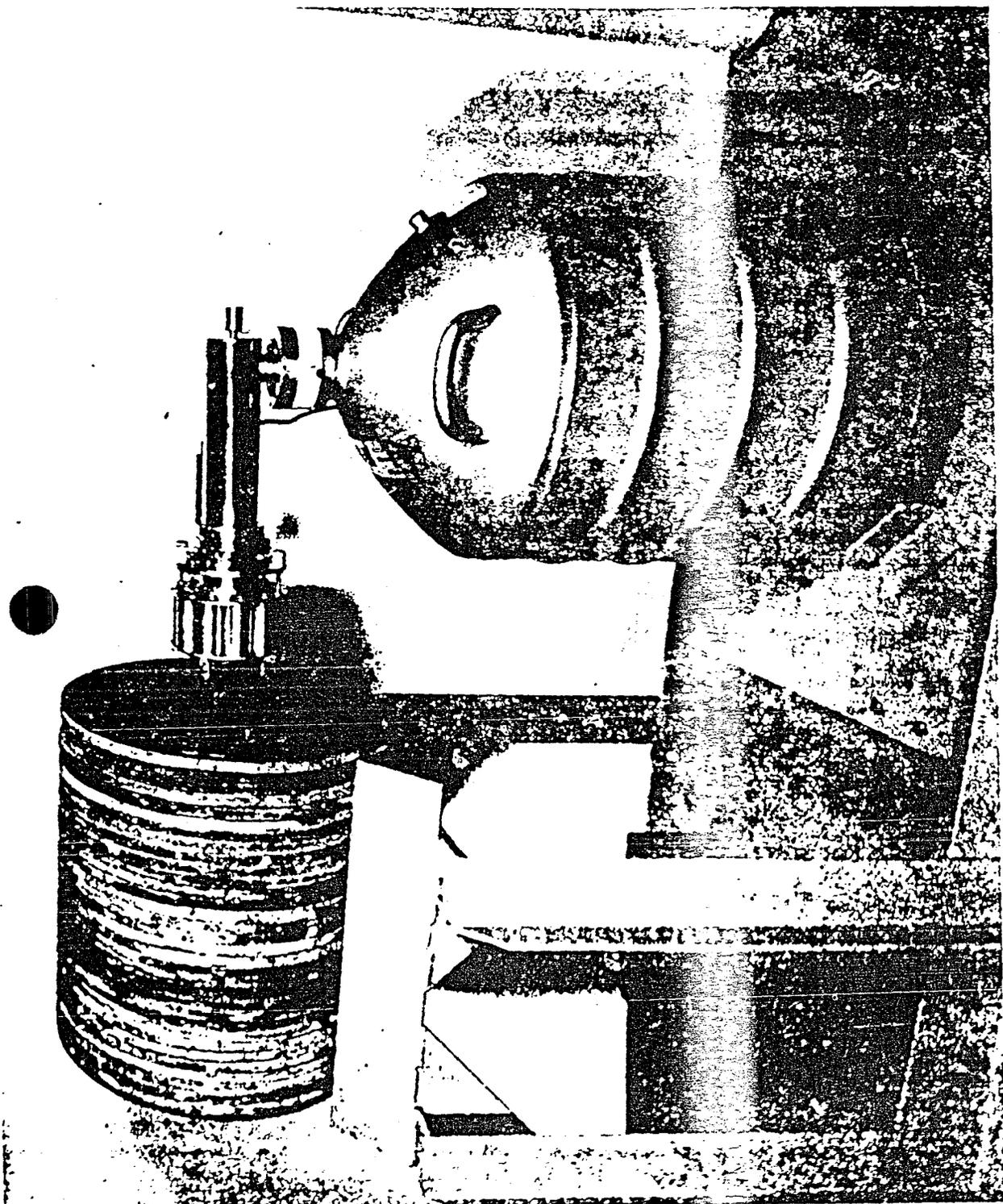


Fig. II-B. Ge(Li) detector system.

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APPENDIX III

Estimates of Radium Concentrations  
from Scintillation Probe Readings

ESTIMATES OF RADIUM CONCENTRATIONS FROM  
SCINTILLATION PROBE READINGS

Scintillation probe readings were used to make conservative estimates of radium concentrations at points where no soil samples were taken. For example, at location 19, no samples were taken below 2 ft. However, scintillation probe readings decreased by a factor of 2 from 1 ft to 4 ft; and since the measured radium concentration at 1 to 2 ft was 1.3 pCi/g, an estimate of 1 pCi/g was made for the average radium concentration from 1 to 4 ft. At location 33 no soil samples were taken below 2 ft. The measured concentration at 1 to 2 ft was near 0.5 pCi/g, and the scintillation probe readings decreased slightly from 1 to 4 ft. Hence, a conservative estimate of 1 pCi/g was made for the average radium concentration at 1 to 4 ft. As a final example, we consider location 34 where no soil samples were taken below 2 ft. The measured concentration at 1 to 2 ft was about 7 pCi/g, and the average scintillation probe reading at 2 to 4 ft was slightly more than half the scintillation probe reading at 1.5 ft. Hence, a conservative estimate of 5 pCi/g was made for the average radium concentration at 2 to 4 ft.

For core holes at which no soil samples were taken at any depth, estimates were based on the formula  $y = 1.33x$ , where

$x$  = scintillation probe cpm/1000,

$y$  = pCi  $^{226}\text{Ra/g}$ .

The line  $y = 1.33x$  is a "best-fitting" curve for about 90 pairs  $(x,y)$  for which both the scintillation probe reading  $x$  and the radium concentration  $y$  were known. (These scintillation probe readings and soil samples were taken

at points on Seaway.) Estimates obtained from this formula were correct within a factor of 1.5 for 60% of the samples which were taken at points on Seaway and which contained at least 5 pCi  $^{226}\text{Ra/g}$ ; estimates were correct within a factor of 2 for 84% of these samples. For Seaway samples which contained less than 5 pCi  $^{226}\text{Ra/g}$ , the formula usually yielded very conservative estimates for the radium concentration.