ANL/ESH/TS-90/103

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

VOLUME ESTIMATE OF RADIUM-CONTAMINATED SOIL IN A SECTION OF
BARROWS FIELD PARK, GLEN RIDGE, NEW JERSEY

NOVEMBER - DECEMBER 1989

by

M. J. Robinet and G. D. Mosho
Environment, Safety, and Health Department

ANL Field Team

M. J. Robinet
G. D. Mosho
D. W. Reilly
J. H. Vacca

April 1990

Work sponsored by

U. S. Environmental Protection Agency
Environmental Studies and Statistical Branch
Analysis and Support Division
Office of Radiation Programs

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VOLUME ESTIMATE OF RADIUM CONTAMINATED SOIL IN A SECTION OF
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ABSTRACT

The objective of this project was to estimate the in-place volume of radium-contaminated soil in an area of Barrows Field Park, Glen Ridge, New Jersey. The information was necessary to determine whether or not there was sufficient soil with the proper radium concentration to test a new method of soil decontamination. The optimum concentration for the test was determined by the U.S. Environmental Protection Agency to be less than or equal to 200 pCi-²²⁶Ra/g of soil.

The steps used by Argonne National Laboratory personnel to obtain the required data for estimating the volume of contaminated soil was to (1) measure the contamination-depth profile at 118 locations in a 60 ft x 150 ft area in the park, (2) plot the contours of depths to the specified concentration, and (3) measure the area of the closed depth contours.

The in-place volume of contaminated soil is calculated from the product of the contamination depths and the contour areas associated with each depth.

The depth profiles were measured by taking radiation measurements inside one-in dia. metal tubes at depth increments below the surface. The 1 in dia. tubes were 5 to 10 ft long and were driven into the ground with a gasoline-powered portable hammer.

The data collected show that the tested area in Barrows Field Park has at least 1000 cubic yards of soil with radium concentrations equal to or less than 200 pCi/g of soil.

BACKGROUND AND OBJECTIVE

Barrows Field Park is in a residential area of Glen Ridge, New Jersey, which is less than 20 miles west of New York City (Fig. 1). Areas of the park are contaminated with radium because a former stream bed was filled in some time ago with radium-contaminated debris and soil. The origin of the contamination is believed to be from the former radium-processing facilities that existed in the area.

The areas of contamination in the park were previously identified by government agencies and by private firms. Two recent radiation surveys were performed by the firm of Camp, Dresser and McKee, Inc., and by the U. S. Environmental Protection Agency (EPA), Eastern Environmental Radiation Facility (CDM-89; EERF-89).

Volume estimates of contaminated soil are usually done to predict cleanup cost. However, in this case, the objective was to find sufficient contaminated soil to test a new soil decontamination process. The park was chosen as a potential source of contaminated soil because of previous data on concentration levels and because it was on public rather than private property. The soil-decontamination test required at least 1000 cubic yards of soil with radium concentrations between 5 and 200 pCi/g. The profiles of radium contamination-to-depth in a rectangular area across the park will be used to define the boundary of excavation limits and to locate local radium concentrations that exceed 200 pCi/g.

The purpose of this report is to describe the method used to make the volume estimates and to document the results. All data were collected by the Argonne National Laboratory (ANL) field team between November 28 and December 1, 1989.

Figure 1. Location of Glen Ridge, New Jersey.

METHODOLOGY AND INSTRUMENTATION

To estimate the in-place volume of radium contaminated soil, the depth profile of radium concentrations must be determined. The technique used by ANL to measure contamination profiles was to drive 1 in-dia. tubes into the ground and to take radiation measurements (count rate) in the tubes at depth increments with a collimated radiation detector. The tubes used are 1 in-dia. standard Electrical Metal Tubing (EMT) and are driven with a portable gasoline-powered hammer. One-inch EMT has a nominal inside diameter of 1.049 inches and has a wall thickness of 0.057 inch. The standard length is 10 feet. Steel points are placed on the tubes to facilitate driving and extraction in dense soil (Fig. 2). Tubes are typically driven in 5 or 10 ft sections. Couplings are used to drive tubes to 15 or 20 feet.

Figure 2.
Electrical Metal Tube
With Point.

The detector used for radiation measurements in the tubes has a 3/8 in-dia. x 3/8 in-long NaI(Tl) crystal coupled to a 1/2 in photo-multiplier (Fig. 3). Readout from the detector was provided by a Ludlum Model 2220 or Model 2221 rate meter/scaler. A photograph of the detector and the rate meter/scaler is shown in Fig. 4. The detector was collimated to make its view primarily sideways and to reduce the down-looking view so it "saw" a thin doughnut-shaped layer of soil. The detector and its readout system were frequently checked against a ^{137}Cs check source to assure that measurements were repeatable.

A list of other field instruments and equipment used to obtain and analyze the data is given in Appendix A.

Figure 3. Cross Section of Scintillation Detector Used in Driven Tubes.

Figure 4. Detector and Rate Meter/Scaler Used to Measure Depth Profiles of Radium Contamination.

SELECTION OF TUBE LOCATIONS

COORDINATE SYSTEM - A rectangular coordinate system with 10 ft x 10 ft grids was staked out in the designated test area of the park to identify the location of all measurements and soil samples. Locations were identified by East, North, Z coordinates, where Z is the depth below the existing grade. The location of the test area in Barrows Field Park is shown in Fig. 5.

SURFACE SCAN - The initial criterion for tube location was to place a tube at each 20 ft x 20 ft grid intersection and at radiation anomalies ("hot spots") between grid intersections. Anomalies were identified by scanning the entire test area with a collimated "down-looking" radiation detector (Eberline PG-2). A flag was placed at each hot spot.

Figure 5. Location of Test Area in Barrows Field Park.

After each hot spot was identified, aboveground radiation measurements were taken at each 10 ft x 10 ft grid intersection with the same collimated detector and also with an exposure-rate meter. These data were used to plot the contours of contamination which was detectable aboveground.

The collimated detector (Eberline PG-2) had a 2 mm x 50 mm dia. NaI(Tl) crystal with readout to a single channel analyzer and rate meter (Eberline PRM-5-3). The lead collimator on the detector was about 10 mm thick and the analyzer was operated in the gross mode with the peak set at 60 keV. When used for scanning (finding contamination), the detector is held as close to the ground as practical and is swung in a vertical arc which reaches a maximum angle of about 45-50 degrees from the verticle (while walking).

Because this instrument (Eberline PG-2 with PRM-5-3) was used only to locate anomalies and to determine the contours of aboveground detectable contamination, it is only the relative count rate that is of interest. A map of the relative count rates in the test area is shown in Fig. 6.

The exposure-rate meter used to take radiation exposure-rate measurements at each 10 ft x 10 ft-grid intersection was a scintillation detector with a 25 mm thick x 25 mm dia. NaI(Tl) crystal and a rate meter readout. This type of instrument is commonly referred to as a micro R meter and was calibrated to estimate the radiation exposure rate in micro roentgens per hour. All exposure-rate measurements were taken at approximately three feet aboveground. A plot of exposure-rate contours in the test area is shown in Fig. 7.

TUBE SPACING - Based on the results of the aboveground radiation measurements, it was decided to reduce the test area to 60 ft x 150 ft and to place tubes on 10 ft x 10 ft grids rather than 20 ft x 20 ft. Between November 27 and November 29, 1989, 118 tubes were driven in the test area. The tube locations are shown in Fig. 8.

Figure 6. Radiation Relative Count Rates Detectable Aboveground
(Few Inches from Surface).

Figure 7. Radiation Exposure Rates at 3 ft Above Surface.

Figure 8. Locations of Driven Tubes and Soil Samples in Test Area.

CONTAMINATION-DEPTH-PROFILE DATA

Contamination-depth-profile data were collected by lowering the 3/8 in x 3/8 in NaI(Tl) detector into each driven tube and taking count-rate readings at depth increments. Count-rate measurements were taken at 0.1 ft increments for the first 0.5 ft depth and at 0.5 ft increments for all other depths. An example of the raw data is shown in Table 1. The counts-per-minute (cts/min) data vs. depth were graphed for each tube location. An example graph of the data is shown in Fig. 9. Graphs of data from all of the 118 tube locations are given in Appendix B.

Figure 9. Example of Contamination-Depth Profile (Count Rate Vs. Depth).

Table 1. Example of Contamination-Depth-Profile Data.

ARGONNE NATIONAL LABORATORY - BARROWS FIELD, GLEN RIDGE, N.J.

SOIL TUBE GAMMA LOG

DATE: 11 / 28 / 89PAGE: 6 OF 118SOIL TUBE NUMBER: 6COORDINATES: X (E) 56 ftY (N) 31 ftLUDLUM MODEL # 22202221SER. # 68519DETECTOR: NaI BGOBACKGROUND: 80 CTS/MINSURVEYOR(S): M.J. Robinet; J.H. VaccaNORMAL COUNTING TIME: 0.1 MIN

DEPTH (FT) Z	GROSS GAMMA CTS/MIN	COMMENTS AND CALIBRATION CHECK
0	780	- 10 ft cable on detector
0.1	750	- Cs-137 check source #132 ($\approx$ 1 μ Ci)
0.2	1160	gross mode: 20070 cpm PHA mode: 2680 cpm
0.3	1570	Battery 5.9
0.4	1710	HV 709
0.5	2430	Threshold 91
1.0	7380	Window 3951
1.5	32960	
2.0	84350	
2.5	28690	
3.0	8910	
3.5	3850	
4.0	2210	
4.5	1670	
5.0	900	
5.5	890	
6.0	920	
6.5	630	
7.0	720	

DEPTH (FT) Z	GROSS GAMMA CTS/MIN
7.5	650
8.0	500
8.5	510
9.0	770
9.5	480
9.7	450

CORRELATION OF COUNT RATE AND ACTIVITY CONCENTRATION

The depth-profile graphs, such as that in Figure 9, are interesting, but they can be used to determine depths to a specified concentration criterion only if there is a known correlation between count rates measured in the tubes and radium activity in the surrounding soil. That is, cts/min must be converted to pCi- ^{226}Ra /g. A count-rate-to-activity concentration was determined for specific detectors prior to this project by taking soil samples around the locations where count-rate measurements were taken in tubes. The concentration of radium in the soil samples was measured with a laboratory gamma-ray spectrometer. The correlation for count rates from the 3/8 in x 3/8 in detector used in Barrows Field Park is given by the following straight-line equation:

$$R = 128C + 160$$

Equation No. 1

where R = count rate in cts/min when using a 3/8 in x 3/8 in NaI(Tl) detector "system" which was calibrated to read approximately 2×10^4 cts/min- μCi of ^{137}Cs at the detector surface (1-in-dia. disk source).

C = Average (equivalent to homogeneous) ^{226}Ra concentration in pCi/g of soil.

Ten soil samples were collected at five tube locations in the test area to compare the count rates and activity concentrations to that predicted by Equation 1. The samples were collected (at about one foot away from the EMT tubes) with 2 in-dia. Shelby tubes and the radium concentrations in the samples were measured at ANL with a gamma-ray spectrometer. The radium concentration in the soil samples and the corresponding count rates measured in the EMT tubes at the sampled depths are shown in Table 2. The sample numbers indicate the tube location from which the sample was collected. The N added to the tube number indicates that the sample was taken about one foot north of the tube. Likewise, the S indicates that the sample was taken about one foot south of the tube.

Table 2. Radium Concentration in Soil Samples from Test Area in Barrows Field Park.

Tube No.	Coordinate E,N (Feet)	Count Rate in EMT Tube at Sampled Depth (Cts/Min)	Shelby tubes Sample No.	Sample Depth (Feet)	Ra-226(186 keV) pCi/g $\pm$ 1	Pb-214(225 keV) pCi/g $\pm$ 1	Bi-214(609 keV)* pCi/g $\pm$ 1	Ac-228 (911 keV) pCi/g $\pm$ 1	K-40(1460 keV) pCi/g $\pm$ 1
9	56, 65	90000	9N	0.5-1.0	101.0 $\pm$ 1.1	92.0 $\pm$ 0.3	76.1 $\pm$ 0.2	0.8 $\pm$ 0.2	8.0 $\pm$ 0.8
			9S	0.5-1.0	57.6 $\pm$ 1.0	53.6 $\pm$ 0.2	44.4 $\pm$ 0.2	0.8 $\pm$ 0.2	6.6 $\pm$ 0.7
12	2, 114	740-1000	12N	0.5-1.0	3.4 $\pm$ 0.3	2.8 $\pm$ 0.1	3.4 $\pm$ 0.1	0.8 $\pm$ 0.1	7.5 $\pm$ 0.4
			12S	0.5-1.0	3.6 $\pm$ 0.3	2.0 $\pm$ 0.1	1.7 $\pm$ 0.1	0.6 $\pm$ 0.1	8.0 $\pm$ 0.4
22	90, 10	550-600	22N	1.5-2.0	4.7 $\pm$ 0.3	2.1 $\pm$ 0.1	1.9 $\pm$ 0.1	2.1 $\pm$ 0.1	7.6 $\pm$ 0.4
			22S	1.5-2.0	4.8 $\pm$ 0.3	1.9 $\pm$ 0.1	1.9 $\pm$ 0.1	2.2 $\pm$ 0.1	6.0 $\pm$ 0.4
27	60, 20	1200-1300	27N	0.5-1.0	16.5 $\pm$ 0.5	12.4 $\pm$ 0.1	10.7 $\pm$ 0.1	0.6 $\pm$ 0.1	7.7 $\pm$ 0.5
			27S	0.5-1.0	9.1 $\pm$ 0.4	6.2 $\pm$ 0.1	5.2 $\pm$ 0.1	0.8 $\pm$ 0.1	9.5 $\pm$ 0.5
30	90, 20	360-460	30N	1.0-2.0	3.2 $\pm$ 0.2	1.9 $\pm$ 0.1	2.0 $\pm$ 0.1	1.8 $\pm$ 0.1	6.9 $\pm$ 0.2
			30S	1.0-2.0	3.5 $\pm$ 0.2	1.7 $\pm$ 0.1	1.6 $\pm$ 0.1	1.9 $\pm$ 0.1	6.7 $\pm$ 0.2

* The concentrations of Bi-214 were used in Figure 10 (Comparison of Equation 1 to Soil Sample Data from Test Area) as a measure of the radium concentration rather than Ra-226 itself because the 609-keV photons from Bi-214 are the predominant photons from radium and its daughter products. It is primarily the 609-keV photons from Bi-214 that are detected in the EMT tubes. The 186-keV photons emitted by Ra-226 contribute little to the measured count rate in the EMT because of self-absorption in the soil and attenuation in the wall of the EMT and in the protective cover on the detector.

A comparison of the data and the plot of Equation 1 is shown in Fig. 10. Because there is a range of values for the count rates and for the radium concentrations, the data "points" are shown as rectangles. The vertical height of a rectangle is the count-rate range measured in the EMT tube, and the horizontal length of a rectangle is the pCi/g range in the soil samples. The uncertainty (the error bars) for individual measurements are insignificant compared to the range of values at a given location. Two of the data rectangles (tube 12 and tube 22) do not intercept the predicted line from Equation 1. This is interpreted to mean that the samples did not catch the

Figure 10. Comparison of Equation 1 to Soil-Sample Data from Test Area.

full range of concentrations around those tubes. Additional samples around those tube locations would be expected to show higher radium concentrations. Overall, the limited data are considered to be consistent with the correlation provided by Equation 1. Therefore, Equation 1 was used to make all conversions from count rate to pCi/g. Fig. 11 is a graph of Fig. 9 replotted in terms of pCi/g rather than count rate.

The concentration of naturally occurring ^{40}K is included in Table 2 to determine whether or not there were large variations in ^{40}K . Very high concentrations in ^{40}K could be misinterpreted as radium contamination. However, the small NaI(Tl) detector used in the tubes is less sensitive to the 1460 keV photon from ^{40}K than to the lower energy photons from radium and its daughters. Therefore, small variations in ^{40}K do not affect the validity of the correlation between count rates measured in the tubes and radium concentration. The Barrows Field Park ^{40}K concentrations are within the lower range of values typically found in other areas of the country (NCRP-87).

Figure 11. Example of Contamination-Depth Profile (pCi/g Vs. Depth).

DEPTHS TO CRITERIA

Using Equation 1, the cleanup criterion of 5 pCi $^{226}\text{Ra}/\text{g}$ corresponds to 800 cts/min and 15 pCi $^{226}\text{Ra}/\text{g}$ corresponds to approximately 2000 cts/min (with the 3/8 in x 3/8 in NaI detector system). These count rates are used with the contamination-depth-profile plots to determine the depths where the concentration drops below the criteria of 5 and 15 pCi/g. For example, in Fig. 12 the concentration drops to 5 pCi/g at 10 ft and it drops to 15 pCi/g at a depth of about 6.8 ft.

Figure 12. Determination of Depth-to-Concentration Criteria.

The contamination-depth-profile plots in Appendix B were used to determine the depths to 5 pCi/g and to 15 pCi/g at each tube location. These depths were then plotted at their coordinates and similar depths were grouped into contours. Contours of depths to 5 pCi/g are shown in Fig. 13. Contours of depths to 15 pCi/g are shown in Fig. 14.

In addition to the depth to 5 and 15 pCi/g, the depths to the layer of soil with concentrations greater than 200 pCi/g are of special interest because the proposed soil-decontamination test has been optimized for concentrations less than 200 pCi/g. The depths to any layer of contamination and the thickness of the layer can be easily determined from the contamination-depth-profile plots. As in the previous examples, Equation 1 is used to convert cts/min to radium concentration in soil. Therefore, a concentration of 200 pCi/g corresponds to approximately 26,000 cts/min. minute. Using the depth-profile plot in Fig. 15 as an example, a horizontal line at 26,000 cts/min intercepts the rising part of the depth-profile curve at the depth Z_1 , and the falling part of the curve at the depth Z_2 . The depth Z_1 (about 2.2 ft for this example) is the depth to the top of the 200 pCi/g layer of soil. Stated more precisely, it is the depth to the top of the layer of soil where the concentration is equal to or greater than 200 pCi/g. Likewise, the depth Z_2 (about 3.8 ft) is the depth to the bottom of the ≥ 200 pCi/g layer. The difference between the depths Z_2 and Z_1 is the thickness of the ≥ 200 pCi/g layer. For this example, the layer is about 1.6 ft thick.

Figure 16 shows the same kind of analysis for the ≥ 300 pCi/g layer.

Contours of the depths to the top and bottom of the ≥ 200 pCi/g layer are shown in Figs. 17 and 18, respectively. The small icon of a depth-profile curve in the lower right hand portion of each figure is provided to further illustrate how the data were obtained. Contours of the thickness of the ≥ 200 pCi/g layer are shown in Fig. 19.

NORTH

+ GRID INTERSECTIONS
SCALE = 1:400
GRID INTERSECTION = 10 FT.

0

2.5 - 4.5 FT

5.0 - 6.5 FT

7.0 - 8.0 FT

8.5 - 11.0 FT

Figure 13. Depths to 5 pci ^{226}Ra /gram.

Figure 14. Depths to 15 pCi ^{226}Ra /gram.

Figure 15. Determination of Depths to Top and Bottom of ≥ 200 pCi/gram Layer of Soil.

Figure 16. Determination of Depths to Top and Bottom of ≥ 300 pCi/gram Layer of Soil.

Figure 17. Depths to Top of ≥ 200 pCi/gram Layer.

NORTH

+ GRID INTERSECTIONS
 GRID INTERSECTION = 10 FT
 SCALE 1:400

2.0 - 2.5 FT

2.6 - 3.0 FT

3.2 - 4.0 FT

6.2 FT

Figure 18. Depths to Bottom of ≥ 200 pCi/gram Layer.

+ GRID INTERSECTIONS
 GRID INTERSECTION = 10 FT
 SCALE 1:400

- 0.2 FT
- 0.6 - 0.8 FT
- 1.0 - 1.8 FT

Figure 19. Thickness of ≥ 200 pCi/gram Layer.

Contours of the depths to the top and bottom of the ≥ 300 pCi/g layer are shown in Figs. 20 and 21, respectively. Contours of the thickness of the ≥ 300 pCi/g layer are shown in Fig. 22.

A comparison of the contours of the thickness of the ≥ 200 pCi/g layer (Fig. 19) and the contours of the thickness of the ≥ 300 pCi/g layer (Fig. 22) may be initially confusing because the figures show a minimum thickness of 0.2 ft for the ≥ 200 pCi/g layer and a minimum thickness of 0.4-0.9 ft for the ≥ 300 pCi/g layer.

The depth profile curves (Figs. 15 and 16) show that it is impossible for the thickness of the ≥ 300 pCi/g layer to be greater than the thickness of the ≥ 200 pCi/g layer in the same location. In Figs. 19 and 22, the minimum thicknesses for the ≥ 200 pCi/g and the ≥ 300 pCi/g contours are in different locations. For example, there is no ≥ 300 pCi/g layer where the ≥ 200 pCi/g layer is only 0.2 ft thick.

The contamination-depth-profile plots in Appendix B show that (except in areas where there was no contamination) the count rate increased with depth, reached a maximum value (in a few cases there are more than one maxima), and then decreased. This is a very common profile, but it is not universal. There are profiles in which the contamination is a maximum at the surface. The Barrows Field Park data probably indicate that the contamination was covered with clean soil or that some of the contamination is slowly moving downward. The maximum concentration and the depth at which it occurs for each tube location is listed in Table C1 of Appendix C.

+ GRID INTERSECTIONS
 SCALE = 1:400
 GRID INTERSECTION = 10 FT.

Figure 20. Depths to Top of ≥ 300 pCi/gram Layer.

Figure 21. Depths to Bottom of ≥ 300 pci/gram Layer.

+ GRID INTERSECTIONS
 SCALE = 1:400
 GRID INTERSECTION = 10 FT.

Figure 22. Thickness of ≥ 300 pCi/gram Layer.

CALCULATION OF VOLUMES

An estimate of the in-place volume of soil for a specified radium concentration is calculated by (1) measuring the areas of the depth contours and (2) multiplying the area in each closed contour by its average corresponding depth. The product of the contour area and its average depth gives the volume within that contour outline. For example, if the area of a 6-ft contour in Fig. 13 was 1000 ft², the volume in that contour would be 6,000 ft³ (222 cubic yards). The volume for the entire test area is equal to the sum of the volumes associated with each closed depth contour. The contours were originally drawn on large maps and the areas were measured with an electronic digital planimeter. The contours were then digitized and transferred to a computer for final plotting at reduced size.

RESULTS

Using the method described in the previous paragraph, the following are estimates of the in-place volumes of contaminated soil:

- The in-place volume of radium-contaminated soil for depths to a minimum concentration of 5 pCi/g is
1520 cubic yards $\pm$ 20%
- The in-place volume of radium-contaminated soil for depths to a minimum of 15 pCi/g is
770 cubic yards $\pm$ 20%
- The in-place volume of the layer of soil which has a radium concentration equal to or greater than 200 pCi/g is
40 cubic yards $\pm$ 20%
- The in-place volume of the layer of soil which has a radium concentration equal to or greater than 300 pCi/g is
30 cubic yards $\pm$ 20%

QUALITY ASSURANCE

The ANL technique for determining the depth profile of radium contamination in soil has been field-tested at several sites (ANL-85, ANL-89; ANL-90).

The uncertainty in estimating the volume of radium-contaminated soil on a site is primarily determined by the grid spacing of measurements, and the correlation between detector-count rate and radium-activity concentration (pCi/g) in soil. For tubes placed on a 10 ft x 10 ft grid and for our current correlation between detector-count rate and pCi-Ra/g of soil, the uncertainty of our volume estimates is estimated to be about $\pm 20\%$ (based on assumptions about homogeneity of contamination within each grid and on method of extrapolation between depth profiles within grids and between adjacent grids).

The representativeness of the data is controlled solely by the grid spacing. The detector inserted into the soil "sees" a cylinder of soil with an effective radius of about two feet.

The precision of the technique was assured by frequently checking the detector/counter system against a ^{137}Cs (662-keV) check source and by remeasuring the same tubes at different times. Precision is influenced primarily by the stability of the detector/counter system.

The detector system was calibrated to have a peak response at 662 keV (^{137}Cs) and was checked at the beginning of each set of measurements.

ACKNOWLEDGMENTS

All of the drawings were done by David W. Reilly. The contamination-depth-profile graphs in Appendix B were plotted by T. William Knoerzer and David R. Pepalis. Gamma-ray spectroscopy analysis of soil samples was done by Albert E. Lissy and Charlotte M. Sholeen. Thanks are given to Millie Papak and Marie D'Arpa for typing the report and to Charlotte M. Sholeen for her careful editing of the technical details of the report.

We also thank James Neiheisel, the Project Officer, and Ben Hull for their guidance, patience, and assistance. Joseph Wood, Mark Cotton, and Shawn Googan assisted with the field work.

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APPENDIX A**FIELD INSTRUMENTS AND EQUIPMENT****Personal Protective:**

- Coveralls
- Safety Glasses
- Hard Hats with Ear Protectors
- Steel Toe Footwear
- Gloves (Leather, Cotton, Plastic)
- Radiation Dosimetry
- First Aid Kit

Land Survey:

- Sledge Hammer (10 lb)
- Stakes/Hubs (Wooden)
- Survey Rope (300')
- Measuring Tapes (25'; 300')
- Flagging/Ribbon
- Lensatic Compass
- Transit with Tripod
- Field Survey Data Books

Tube Driving:

- Pionjar Model 120 Gas-Powered Hammer with Accessories for Driving 1-In-Dia. Electrical Metal Tubes and 2-In-Dia.)
- Ten-Foot-Long Tubes (1 In-Dia. EMT)
- Tube Points (ANL Design)
- Tube Couplings (ANL Design)
- Jack with Chain
- Portable Pipe-Vise Stand
- Gasoline/Two-Cycle Oil
- Tools (Saw, Hammer, Files, etc.)

Radiation Detection:

- ^{241}Am Check Source (Smoke Detector Source)
- ^{137}Cs Check Source (Button)
- Gamma Check Source (Gas Mantle-Thorium)
- Exposure-Rate (microR) Meter (Eberline PRM-7)
- Surface Gamma Detector (Eberline PRM 5-3 with Shielded PG-2 Detector)
- Sub-Surface Gamma Detector (Ludlum Model 2220 or 2221 with an ANL-fabricated NaI(Tl) 3/8 In x 3/8 In or BGO 1/2 In x 1/2 In Detector)
- Geiger-Mueller Detector (Eberline E-530 with End-Window G-M Detector)

Soil Sampling:

- Shelby Tube Kit
- Hand Trowels
- Shovel
- Zip-Lock Plastic Bags
- Auger (3-In-Dia.) Kit

Data Analysis:

- Laptop Computer (Zenith Z-183)
- Portable Printer (Diconix/Kodak)
- Portable Electronic Planimeter and Digitizer (Ushikata Model X-PLAN 360i)
- Computer-Aided Drafting Program (Drafix CAD Ultra)
- Drafting Board
- Data-Base Program (DBASE III+)
- Semi-Log Graph Paper

Transportation:

- ANL/Government Vehicle (ME-58), Chevrolet Suburban 4X4 with Heavy Duty Suspension

APPENDIX B**GRAPHS OF CONTAMINATION DEPTH PROFILES**

Figure B1 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B2 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B3 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B4 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B5 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 6 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B7 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B8 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B9 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B10 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B11 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 12 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 13 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 14 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 15 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B16 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B17 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B18 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B19 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B20 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B21 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure 22 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N. J.

Figure B23 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B24 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B25 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B26 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B27 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B28 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

Figure B29 Contamination Depth Profile at Barrows Field Park, Glen Ridge, N.J.

8/20/19

Figure B30 Contamination Depth Profiles at Barrows Field Park, Glen Ridge, N.J.

APPENDIX C**DEPTHS TO MAXIMUM CONCENTRATIONS**

Table C1. Depths to Maximum Concentrations

Tube No.	Location East, North (ft)		Max. Conc. pCi- ²²⁶ Ra/g	Depth at Max. Conc. (ft)
1	49,	11	124	2.0
2	45,	18	1014	1.7
3	42,	25	1405	2.0
4	35,	22	780	1.5
5	55,	37	1952	2.0
6	56,	31	639	2.0
7	60,	5	155	1.3
8	59,	25	858	2.1
9	56,	65	53	2.7
10	76,	96	468	1.7
11	50,	116	1718	2.5
12	2,	114	194	2.5
13	0,	10	1	3.5
14	10,	10	2	2.0
15	20,	10	5	2.7
16	30,	10	4	3.0
17	40,	10	17	1.5
18	50,	10	116	2.0
19	60,	10	108	1.5
20	70,	10	7	1.5
21	80,	10	3	3.0
22	90,	10	5	1.0
23	100,	10	3	0.5
24	30,	20	9	5.5
25	40,	20	116	1.5
26	50,	20	366	2.0
27	60,	20	108	2.0
28	70,	20	18	1.5
29	80,	20	3	1.0
30	90,	20	2	2.0

Table C1. Depths to Maximum Concentrations
(Cont'd.)

Tube No.	Location East, North (ft)		Max. Conc. pCi- ²²⁶ Ra/g	Depth at Max. Conc. (ft)
31	20,	30	4	5.0
32	30,	30	5	5.0
33	40,	30	116	2.0
34	50,	30	311	2.3
35	60,	30	405	2.0
36	70,	30	14	1.5
37	80,	30	3	3.5
38	90,	30	3	2.5
39	30,	40	6	4.0
40	36,	40	108	2.5
41	40,	40	139	2.5
42	50,	40	311	2.5
43	60,	40	147	2.5
44	70,	40	30	3.4
45	80,	40	2	0.5
46	90,	40	?	?
47	30,	50	7	6.0
48	40,	50	30	2.5
49	50,	50	85	2.0
50	60,	50	25	3.0
51	70,	50	85	2.5
52	80,	50	14	2.0
53	90,	50	4	3.5
54	30,	60	6	3.0
55	40,	60	1983	3.0
56	50,	60	77	2.6
57	60,	60	22	2.5
58	70,	60	123	2.5
59	80,	60	202	2.0
60	90,	60	15	2.5

Table C1. Depths to Maximum Concentrations
(Cont'd.)

Tube No.	Location East, North (ft)		Max. Conc. pCi- ²²⁶ Ra/g	Depth at Max. Conc. (ft)
61	30,	70	4	4.5
62	40,	70	11	3.0
63	50,	70	77	3.0
64	60,	70	28	3.0
65	70,	70	18	2.5
66	80,	70	8	1.5
67	90,	70	13	2.0
68	30,	80	3	3.5
69	40,	80	7	4.0
70	50,	80	19	3.0
71	60,	80	18	3.0
72	70,	80	7	3.0
73	80,	80	5	3.0
74	90,	80	3	3.0
75	30,	90	30	4.5
76	40,	90	42	3.5
77	50,	90	26	3.5
78	60,	90	93	3.0
79	70,	90	4	4.0
80	80,	90	6	1.5
81	90,	90	3	2.0
82	30,	100	38	3.5
83	40,	100	26	3.5
84	50,	100	194	2.5
85	60,	100	139	2.3
86	70,	100	?	?
87	80,	100	124	2.0
88	90,	100	14	2.0
89	30,	110	15	3.0
90	40,	110	21	2.9

Table C1. Depths to Maximum Concentrations
(Cont'd.)

Tube No.	Location East, North (ft)		Max. Conc. pCi- ²²⁶ Ra/g	Depth at Max. Conc. (ft)
91	50,	110	27	2.0
92	60,	110	39	3.0
93	70,	110	3	3.5
94	80,	110	2	2.0
95	90,	110	4	2.5
96	30,	120	22	4.0
97	40,	120	147	3.0
98	50,	120	1014	2.5
99	60,	130	155	4.0
100	70,	120,	311	3.0
101	80,	120,	22	2.0
102	90,	120	14	3.0
103	30,	120	233	6.0
104	40,	120	4	4.0
105	50,	130	?	?
106	60,	130	3	7.5
107	70,	130	93	5.0
108	80,	130	14	3.0
109	90,	130	11	4.0
110	30,	140	14	4.3
111	40,	140	5	4.0
112	50,	140	3	5.0
113	60,	140	77	5.0
114	70,	140	202	5.0
115	80,	140	4	4.5
116	90,	140	4	4.0
117	60,	150	3	3.0
118	70,	150	3	3.5

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