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Results of the Radiological Survey at the Town of Tonawanda Landfill, Tonawanda, New York (TNY001)

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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ACKNOWLEDGMENTS

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ABSTRACT

At the request of the U.S. Department of Energy (DOE), a team from Oak Ridge National Laboratory conducted a radiological survey at the Town of Tonawanda Landfill, Tonawanda, New York. The survey was performed in September 1991. The purpose of the survey was to determine if radioactive materials from work performed under government contract at the Linde Air Products Division of Union Carbide Corporation, Tonawanda, New York, had been deposited in the landfill. The survey included a surface gamma scan and the collection of soil samples for radionuclide analyses.

Results of the survey suggest that material originating at the Linde plant may have been deposited in the landfill. Soil samples S54 and B12 contained technologically enhanced levels of ^{238}U not unlike the product formerly produced by the Linde plant. In contrast, samples B4A, B5A, and B7B, containing elevated concentrations of ^{226}Ra and ^{230}Th with much lower concentrations of ^{238}U, were similar to the residue or byproduct of the refinery operation conducted at the Linde plant. In 24 instances, soil samples from the Town of Tonawanda Landfill exceeded DOE guideline values for ^{238}U, ^{226}Ra, and/or ^{230}Th in surface or subsurface soil. Nine of these samples contained radionuclide concentrations more than 30 times the guideline value.

Results of the Radiological Survey at the Town of Tonawanda Landfill, Tonawanda, New York (TNY001)*

INTRODUCTION

From 1942 through approximately 1948, the Linde Air Products Division of Union Carbide Corporation, Tonawanda, New York, was one of many companies performing work associated with the development of nuclear energy for defense-related projects. This work was conducted under government contract to the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC). During the first 3 years, pitchblende ore from the Belgian Congo and concentrates from the Colorado Plateau ore were converted to U_3O_8. A second process yielding UO_2 was conducted for about a year, and a third process, converting UO_2 to green salt (UF_4), operated during World War II and the following 2 years. Linde also developed and produced barrier material for the Oak Ridge Gaseous Diffusion Plant. Other contracts have been identified, but the exact nature of the work involved is unknown.[1]

As a result of these and similar activities, equipment, buildings, and land at some of the sites became radiologically contaminated resulting in low levels of contamination on the properties. At contract termination, sites used by contractors were decontaminated in accordance with the standards and survey methods in use at that time. Since the original assessments, radiological criteria and guidelines for the release of such sites for unrestricted use have become more stringent. In some instances, records documenting decontamination efforts cannot be found, and the final radiological conditions of the site cannot be adequately determined. As a result, the Formerly Utilized Sites Remedial Action Program (FUSRAP) was established in 1974 to identify these formerly used sites and to reevaluate their radiological status.[1] The radiological survey detailed in this report was performed under the FUSRAP program.

The Linde site has been previously investigated to determine the extent of on-site radiological contamination. As a follow-up to earlier investigations and as a precaution to ensure that no residual radioactive materials exceeding current U.S. Department of Energy (DOE) guidelines were transported off-site, DOE requested a radiological survey in the vicinity of the Linde site. This survey, conducted in April 1990, included suspected haul routes to the Town of Tonawanda Landfill, the landfill itself, and two other sites. Results of analysis of soil samples from the landfill showed the presence of elevated concentrations of radionuclides that might be expected to result from former processing activities at the Linde plant site. A more thorough investigation of the landfill was recommended.[2]

In September 1991, a radiological survey was conducted at the Town of Tonawanda Landfill by personnel from Oak Ridge National Laboratory at the request of DOE. Results

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*The survey was performed by members of the Measurement Applications and Development Group of the Health and Safety Research Division at Oak Ridge National Laboratory under DOE contract DE-AC05-84OR21400.

of that survey are presented in this report. The general location of the Town of Tonawanda Landfill, which is approximately 1.5 miles north of the Linde site, is shown in Fig. 1.

SCOPE OF THE SURVEY

The radiological survey included: (1) a surface gamma scan of seventy-five 100-ft^2 grid blocks and seven partial blocks; (2) measurement of gamma exposure rates at 1 m above the ground surface and at the ground surface at 102 selected grid points; (3) collection and radionuclide analysis of 132 systematic soil samples taken at 88 selected locations irrespective of gamma exposure rate; and (4) collection and radionuclide analysis of 42 biased soil samples taken at 14 locations shown to have elevated gamma exposure rates.

SURVEY METHODS

A comprehensive description of the survey methods and instrumentation used in this survey is given in *Procedures Manual for the ORNL Radiological Survey Activities (RASA) Program*, ORNL/TM-8600 (April 1987).[3]

Figure 2 shows the surveyed areas, which were divided into 100-ft grid blocks following the New York State grid system. (An individual grid block is identified by the coordinates of the southwest corner.) Two distinct sections of land were gridded and surveyed. The northern section was formerly used as a landfill while the southern section, referred to as "the flats" area, was never officially used for landfill activities. A chain-link fence running along the north boundary of the landfill (northern set of grid blocks) separates the landfill from a series of privately owned properties. Power lines belonging to Niagara Mohawk Power Corporation traverse the property at the southern edge of the landfill and separate the landfill from "the flats" area. An old incinerator is located just west of "the flats."

GAMMA RADIATION MEASUREMENTS

Gamma radiation levels were determined using portable NaI gamma scintillation meters. Because NaI gamma scintillators are energy dependent, measurements of gamma radiation levels in counts per minute are normalized to pressurized ionization chamber (PIC) measurements to estimate gamma exposure rates in μR/h.

SOIL SAMPLING AND ANALYSES

Surface and subsurface soil samples were systematically collected over the property in a pattern sufficient to obtain a characterization of the radionuclide content of the soil. Surface and subsurface soil samples were also collected in areas of elevated gamma exposure rates. Such samples are referred to as biased samples and are more likely to contain elevated concentrations of radionuclides than are systematically chosen samples. Selected biased

samples were split with the New York State Department of Environmental Conservation, Bureau of Radiation, in order to provide independent, duplicate sample analysis.

SURVEY RESULTS

DOE guidelines are summarized in Table 1. Typical background radiation levels for the Tonawanda, New York, area are presented in Table 2. These data are provided for comparison with survey results presented in this section. All direct measurement results presented in this report are gross readings; background radiation levels have not been subtracted. Similarly, background concentrations have not been subtracted from radionuclide concentrations measured in soil samples.

Photographs of the landfill taken in September 1991 are shown in Figs. 3 through 8.

GAMMA EXPOSURE RATE MEASUREMENTS

Results of the gamma scan over the property surface are shown in Figs. 9 and 10. Figure 9 displays ranges of typical surface gamma exposure rates, excluding hot spots, found in accessible grid blocks. Highest scan ranges (found in 3 grid blocks) measured 10 to 13 μR/h; the most common scan range (found in 36 grid blocks) was 8 to 11 μR/h. These values are within typical background radiation levels in the Tonawanda area (Table 2).

Figure 10 shows the locations of elevated surface gamma exposure rates identified during the survey. Elevated spots were concentrated in a moist, swampy area in grid block N1,093,100/E417,400; along a ditch running southwest from the moist, swampy area; and in two grid blocks in "the flats" area. The hottest spot, which measured 170 μR/h, was surrounded by a small contaminated area ranging from 13 to 140 μR/h. Another 18 spots ranged from 13 to 50 μR/h.

Results of measurements of surface and 1-m gamma exposure rates at 102 accessible grid points are shown in Fig. 11. Surface measurements ranged from 7 to 12 μR/h and averaged 9 μR/h, which corresponds to the average background level measured in the Tonawanda area (Table 2). One-meter measurements ranged from 7 to 11 μR/h and also averaged 9 μR/h.

SOIL SAMPLES

Systematic Soil Samples

Systematic soil sample locations are shown in Fig. 12, and results of analyses are listed in Table 3. Concentrations of ^{238}U and ^{226}Ra in surface soil (0–15 cm) ranged from 0.52 to 56 pCi/g and from 0.59 to 1.9 pCi/g, respectively. Concentrations in subsurface soil (15–46 cm) ranged from 0.33 to 9.6 pCi/g and from 0.36 to 1.4 pCi/g, respectively. Because slag, cinders, and other similar materials scattered throughout the Tonawanda–Niagara Falls

area contain naturally occurring radionuclides that may cause slight elevations in radionuclide concentrations, all samples except S54 and S62A–C are considered to be within typical background levels for ^{238}U and ^{226}Ra in the Tonawanda area (Table 2). Samples S62A, S62B, and S62C contain slightly elevated levels of ^{238}U, but these values are well below the DOE guideline value of 30 pCi/g that will be applied at the Tonawanda landfill (Table 1). Sample S54 containing 56 pCi/g ^{238}U at a depth of 0 to 15 cm is above DOE guidelines (Table 1). Naturally occurring uranium contains roughly equal amounts of ^{226}Ra and ^{238}U. Because sample S54 contains elevated concentrations of ^{238}U and low concentrations of ^{226}Ra, it is not unlike the materials that resulted from former processing activities at the Linde site.

Radionuclide concentrations were determined by gamma spectrometry analysis. In some cases, because of interference from other radionuclides, concentrations of ^{230}Th could not be determined with the precision necessary to compare ^{230}Th content with guideline values. As a result, five representative samples (S9, S14B, S41A, S55, and S69C) containing background levels of ^{238}U and ^{226}Ra and indeterminate amounts of ^{230}Th were selected for reanalysis using a chemical separation technique prior to radiochemical analysis. Results of these analyses show ^{230}Th concentrations of 0.19, 0.18, 0.21, 0.24, and 0.26 pCi/g in samples S9, S14B, S41A, S55, and S69C, respectively. From these results, it was concluded that ^{230}Th concentrations in all systematic samples were below guidelines.

Concentrations of ^{232}Th ranged from 0.32 to 1.3 pCi/g in surface soil and from 0.39 to 1.4 pCi/g in subsurface soil. All ^{232}Th values are near or slightly above typical background levels for the Tonawanda area (Table 2) and well below DOE guideline values for surface and subsurface soil (Table 1).

Low levels of ^{241}Am ranging from 0.10 to 0.67 pCi/g were detected in 7 surface samples (S2, S24A, S36A, S43, S44, S58, and S65). The presence of ^{241}Am in five of these samples was confirmed using a chemical separation technique prior to radiochemical analysis. All other surface samples and all subsurface samples contained <0.10 pCi/g, the minimum amount of ^{241}Am that can be detected by the analytical procedure. The locations of the systematic samples containing detectable ^{241}Am are shown in Fig. 13. These sample locations are generally in close proximity to the road leading from the former incinerator to the radiological area of the landfill that received americium wastes. From this pattern it might be speculated that the americium in this area resulted from hauling fly ash from the incinerator to east areas of the landfill designated for radiological waste. (Americium wastes resulted from the manufacture of smoke detectors by a private company unrelated to DOE. These wastes were deposited in a designated area located east of the area shown in Fig. 13.)

Biased Soil Samples

Biased soil sample locations are shown in Fig. 14, and results of analyses are listed in Table 3. Uranium-238 concentrations ranged from 1.3 to 1800 pCi/g. Samples B5B, B6A, B7A–E, B12A–C, B13B–D, and B15A were above guideline values of 30 pCi/g that will be applied at the Tonawanda landfill (Table 1).

Concentrations of ^{226}Ra in surface soil (0–15 cm) ranged from 1.2 to 440 pCi/g. All samples were above typical surface background levels in the Tonawanda area (Table 2); samples B3A, B4A, B5A, B6A, B7A, B13A, B14A, and B15A were above guideline values of 5 pCi/g in the first 15 cm of soil below the surface (Table 1). Concentrations of ^{226}Ra in subsurface soil (15–76 cm) ranged from 1.4 to 2000 pCi/g. Samples B5B, B6B, B7B-E, B13C-E, B14B, and B14D were above guideline values of 15 pCi/g when averaged over 15-cm-thick soil layers more than 15 cm below the surface (Table 1).

Because of interference from other radionuclides, in some cases concentrations of ^{230}Th could not be determined with the precision necessary to compare ^{230}Th content with guideline values. Samples B3A, B8, B9, and B11A, with low levels of ^{226}Ra and ^{238}U, are similar to the representative systematic samples (S9, S14B, S41A, S55, S69C) selected to undergo a chemical separation process before radiochemical analysis. Since the systematic samples subjected to this analysis did not contain ^{230}Th, it can be assumed that these similar biased samples are most likely below guideline values for ^{230}Th. Surface samples B4A, B5A, and B15A containing 820, 1300, and 660 pCi/g of ^{230}Th, respectively, are well above guideline values of 5 pCi/g (Table 1). Subsurface samples B5B and B7B containing 660 and 4300 pCi/g of ^{230}Th, respectively, are above guideline values of 15 pCi/g (Table 1). It was not considered necessary to further investigate samples that clearly exceeded guideline values for other radionuclides (B4, B5, B6, B7, B12, B13, B14, and B15).

Thorium-232 concentrations ranged from 0.60 to 2.6 pCi/g in surface samples and from 0.76 to 2.6 pCi/g in subsurface samples. All values are well below guideline values for ^{232}Th (Table 1).

No ^{241}Am was detected in biased samples; all biased samples were below the minimum amount of ^{241}Am that can be detected by the analytical procedure (0.10 pCi/g).

Gamma exposure rate measurements taken at the ground surface and at 1 m above the surface at biased soil sample locations are shown in Table 4. Surface measurements ranged from 13 to 170 μR/h; highest surface gamma exposure rates (170 μR/h) were found at sample location B7 (Fig. 15). Gamma exposure rates at 1 m ranged from 11 to 26 μR/h with highest measurements at sample location B7. Sampling location B14 in "the flats" area is shown in Fig. 16.

Split Soil Samples

Concentrations of radionuclides in split soil samples analyzed by both Oak Ridge National Laboratory and the New York State Department of Environmental Conservation, Bureau of Radiation,[4] are given in Table 5. Discrepancies can be noted in concentrations of ^{238}U (B5B), ^{226}Ra (B4A, B5A, B5B, and B5C), and ^{241}Am (B4A and B5A). These discrepancies can be attributed to the highly heterogeneous nature of the soil. Although carefully ground and mixed, the soil still contains hot flakes of material, which are not distributed uniformly throughout the mixture. Some counting vials containing an aliquot of the soil sample are hotter at the top; other vials are hotter at the bottom. If all soil samples were shaken up and recounted, the specific results for each sample might differ significantly, but the overall conclusions drawn from the results of the recount would be similar.

SIGNIFICANCE OF FINDINGS

The results of the radiological survey at the Town of Tonawanda Landfill, Tonawanda, New York, suggest that material originating at the Linde plant may have been deposited in the landfill. Naturally occurring uranium contains roughly equal amounts of ^{226}Ra and ^{238}U. When concentrations of ^{238}U and ^{226}Ra are compared in systematic soil sample S54 and biased soil sample B12, it is clearly evident that the ^{238}U concentration has been technologically enhanced. Samples S54 and B12, containing elevated levels of ^{238}U, are not unlike the product formerly produced by the Linde plant. In contrast, samples B4A, B5A, and B7B, containing elevated concentrations of ^{226}Ra and ^{230}Th with much lower concentrations of ^{238}U, are similar to the residue or by-product of the refinery operation conducted at the Linde plant.

Twenty-four soil samples from the Town of Tonawanda Landfill exceeded DOE guideline values for radionuclides in surface and subsurface soil:

- five soil samples (B6A, B7A, B7C, B7D, and B7E) exceeded guideline values for ^{238}U and ^{226}Ra;
- three soil samples (B5B, B7B, and B15A) exceeded guideline values for ^{238}U, ^{226}Ra, and ^{230}Th;
- four soil samples (S54, B12A, B12B, and B12C) exceeded the guideline value for ^{238}U;
- ten soil samples (B3A, B13A-E, and B14A-D) exceeded the guideline value for ^{226}Ra; and
- two soil samples (B4A and B5A) exceeded guideline values for ^{226}Ra and ^{230}Th.

Nine of these samples contained radionuclide concentrations more than 30 times the guideline value.

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1. U. S. Department of Energy, *A Background Report for the Formerly Utilized Manhattan Engineer District/Atomic Energy Commission Sites Program*, DOE/EV-0097, September 1980.

2. W. D. Cottrell, D. A. Witt, R. E. Rodriguez, and R. F. Carrier, *Results of Mobile Gamma Scanning Activities in Tonawanda, New York*, ORNL/RASA-90/6, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., December 1990.

3. T. E. Myrick, B. A. Berven, W. D. Cottrell, W. A. Goldsmith, and F. F. Haywood, *Procedures Manual for the ORNL Radiological Survey Activities (RASA) Program*, ORNL/TM-8600, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., April 1987.

4. P. J. Merges, New York State Department of Environmental Conservation, Bureau of Radiation, to W. A. Williams, U. S. Department of Energy, correspondence including "Split Sample Results from Tonawanda Landfill" and "Inspection Field Report," March 12, 1992.

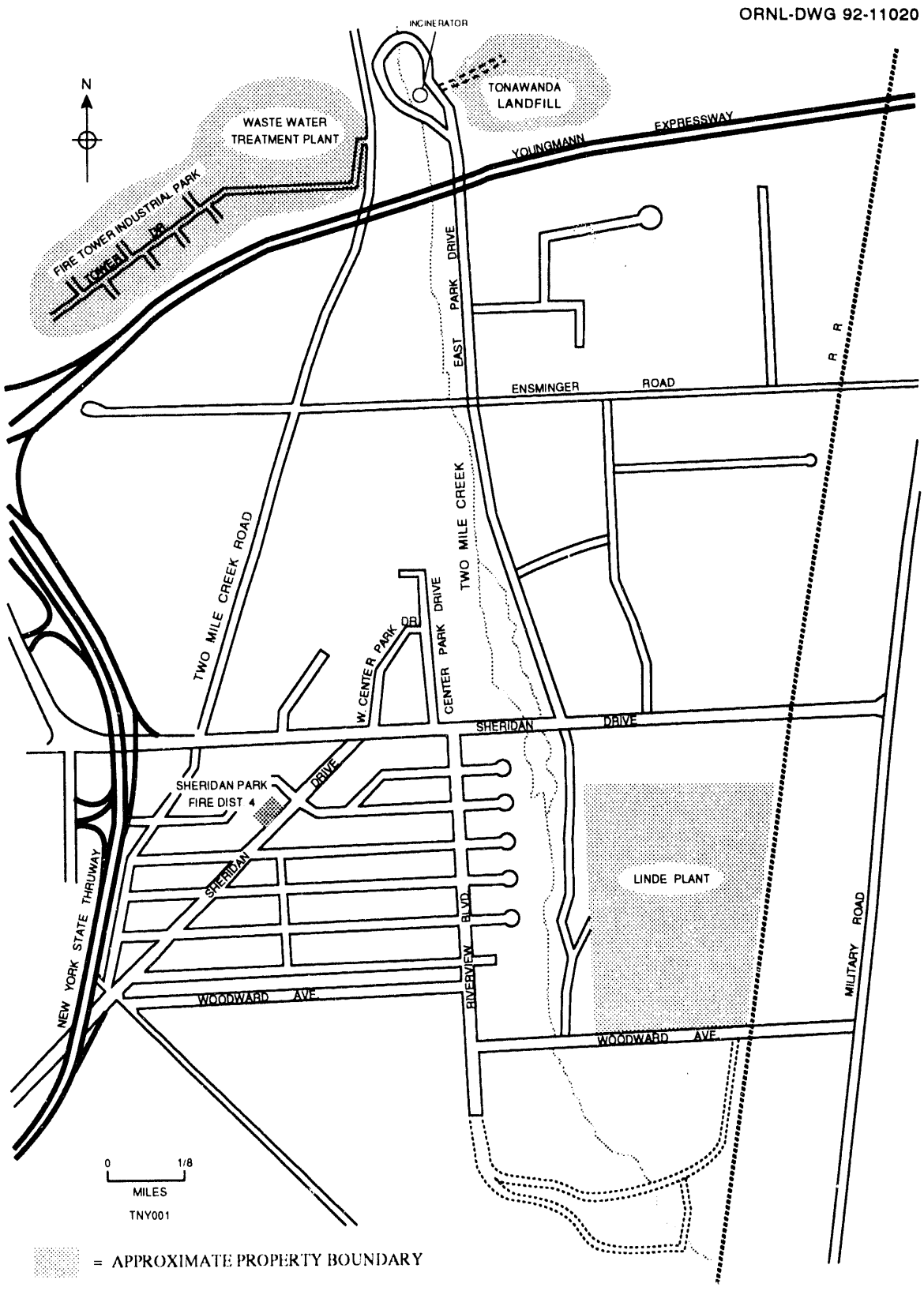

Fig. 1. Diagram showing general location of the Town of Tonawanda Landfill in relation to the Linde site in Tonawanda, New York.

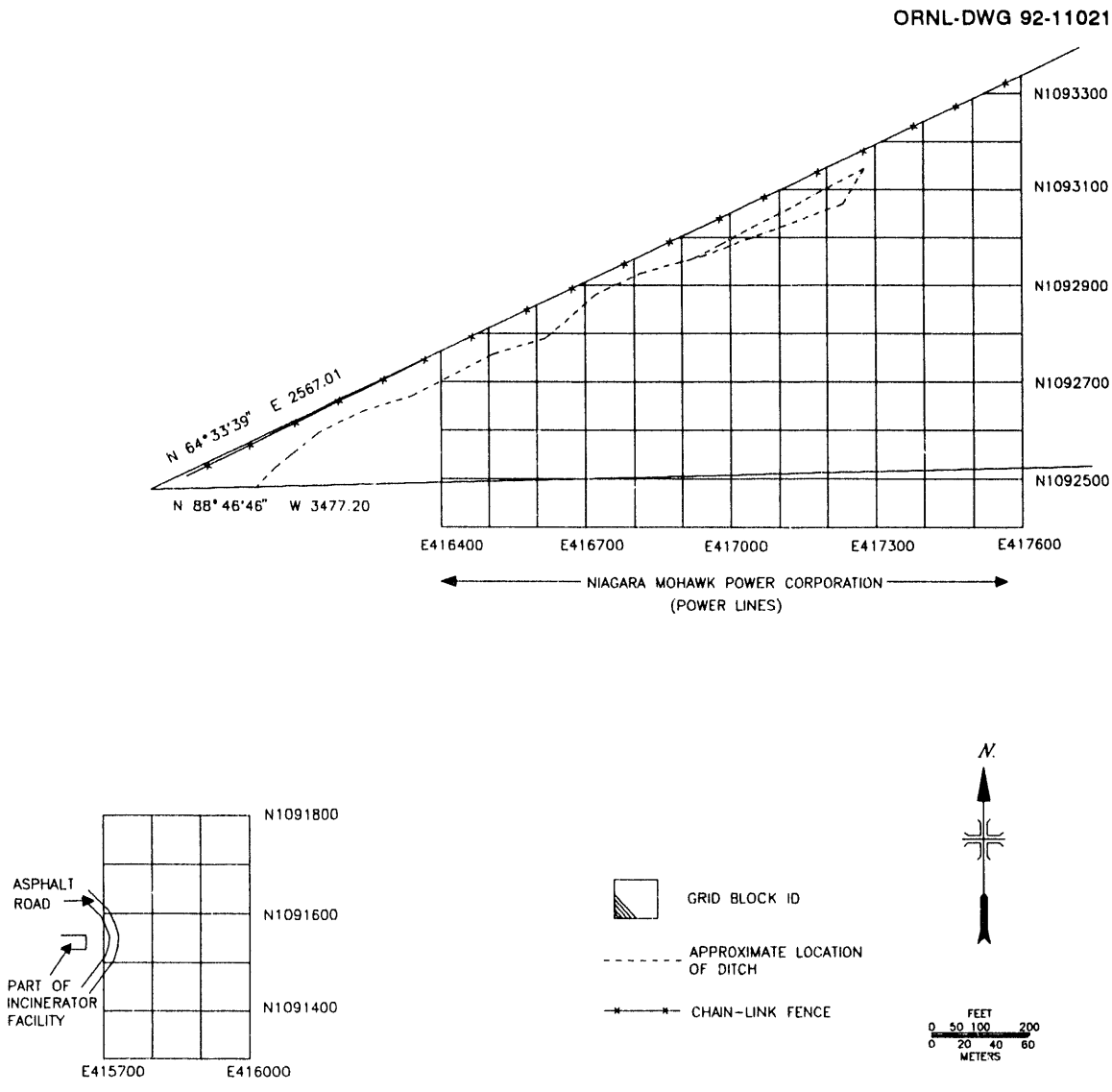

Fig. 2. Diagram showing location of the two areas surveyed at the Town of Tonawanda Landfill, Tonawanda, New York.

ORNL-PHOTO 5537-92

Fig. 3. View looking northeast at a row of small trees growing in a ditch that parallels the northern boundary of the landfill. The houses in the background are privately owned and separated from the landfill by a chain-link fence.

ORNL-PHOTO 5538-92

Fig. 4. View looking northeast from grid point N1,093,000/E417,400. Stake marking grid point is shown in foreground at left of photo. The large tree in left background marks a moist, swampy area of the landfill.

ORNL-PHOTO 5539-92

Fig. 5. View looking southeast from grid point N1,092,900/E417,300. Power lines owned by Niagara Mohawk Power Corporation are shown in background.

ORNL-PHOTO 5540-92

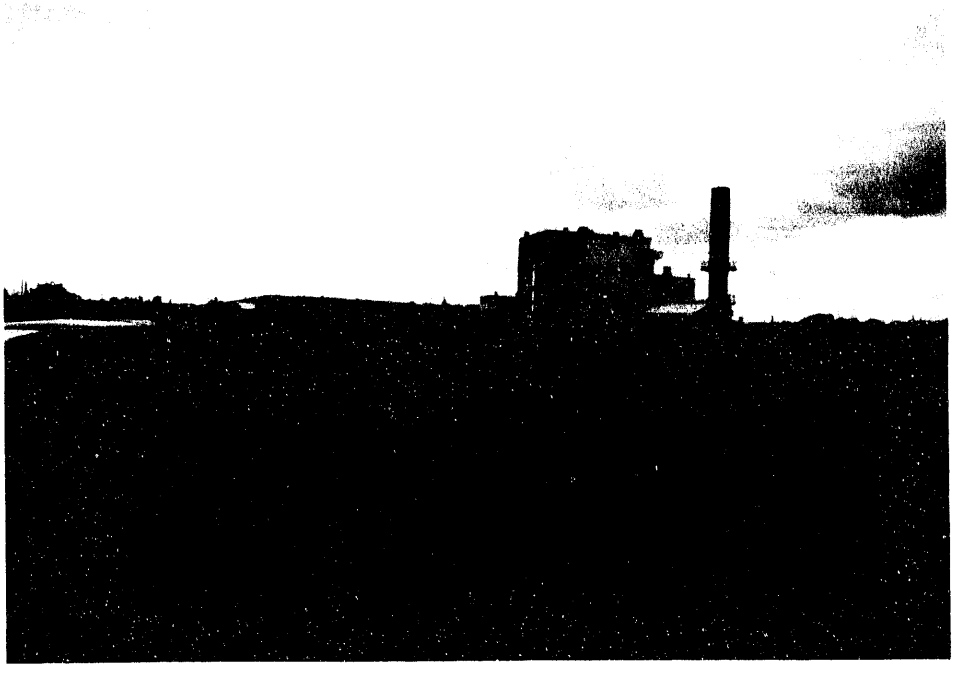

Fig. 6. View looking northwest at the incinerator from the southeastern part of "the flats" area.

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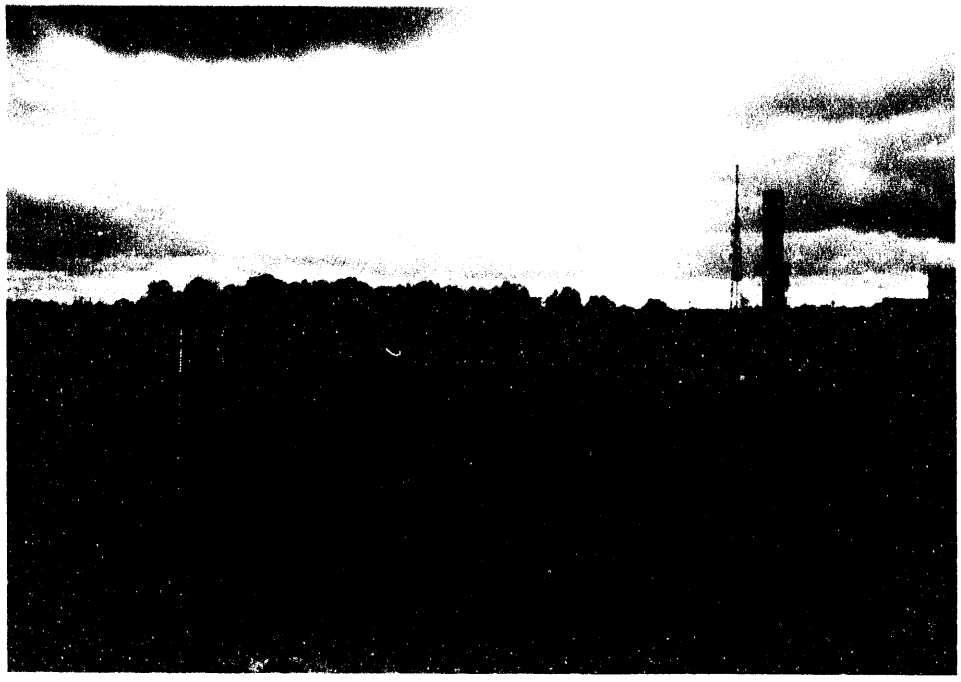

Fig. 7. View looking south at "the flats" area with the incinerator on the right.

ORNL-PHOTO 5542-92

Fig. 8. View from grid block N1,091,500/E415,700 looking southeast at "the flats."

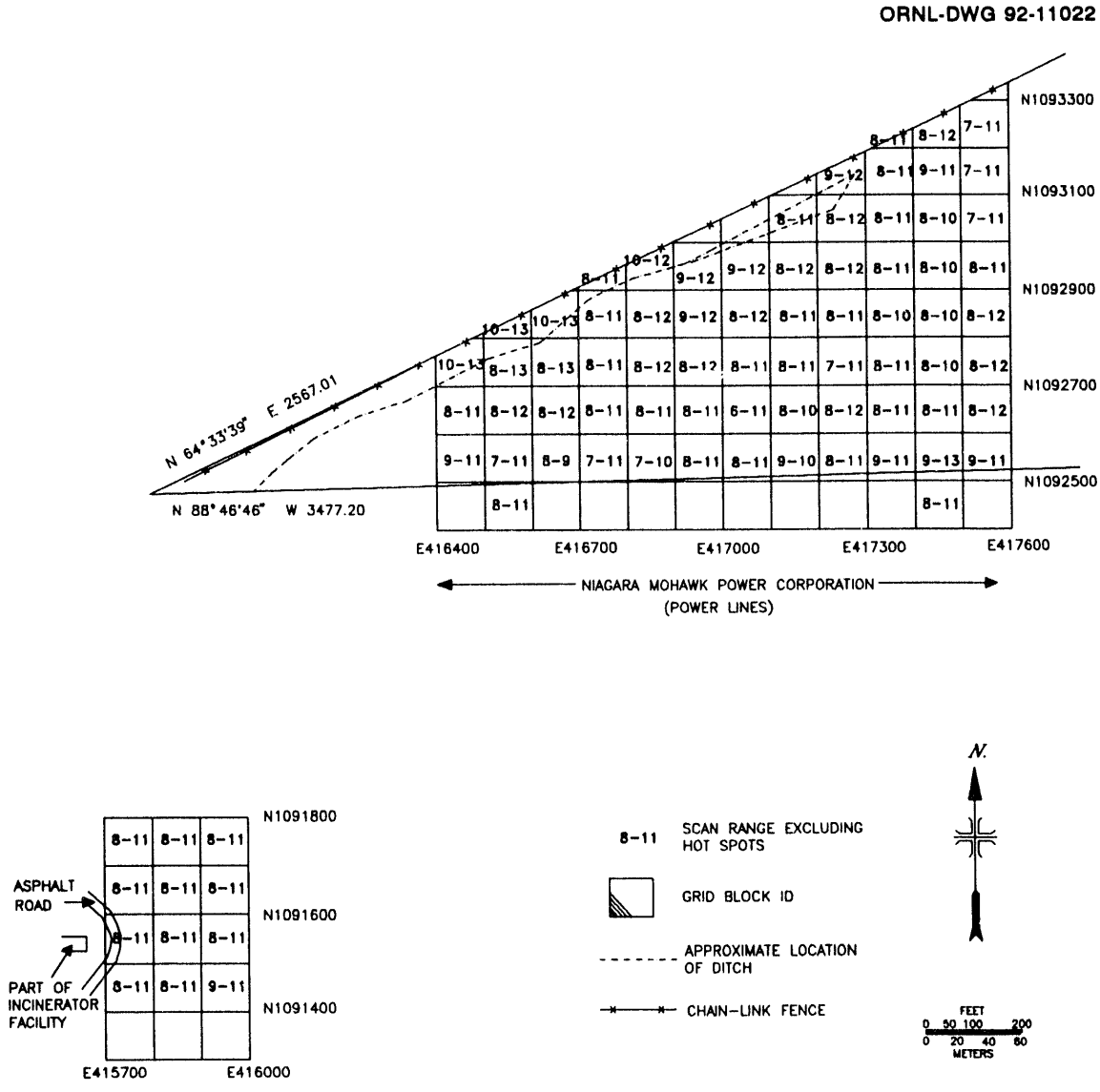

Fig. 9. Ranges of surface gamma exposure rates (μR/h) excluding hot spots in grid blocks at the Town of Tonawanda Landfill, Tonawanda, New York.

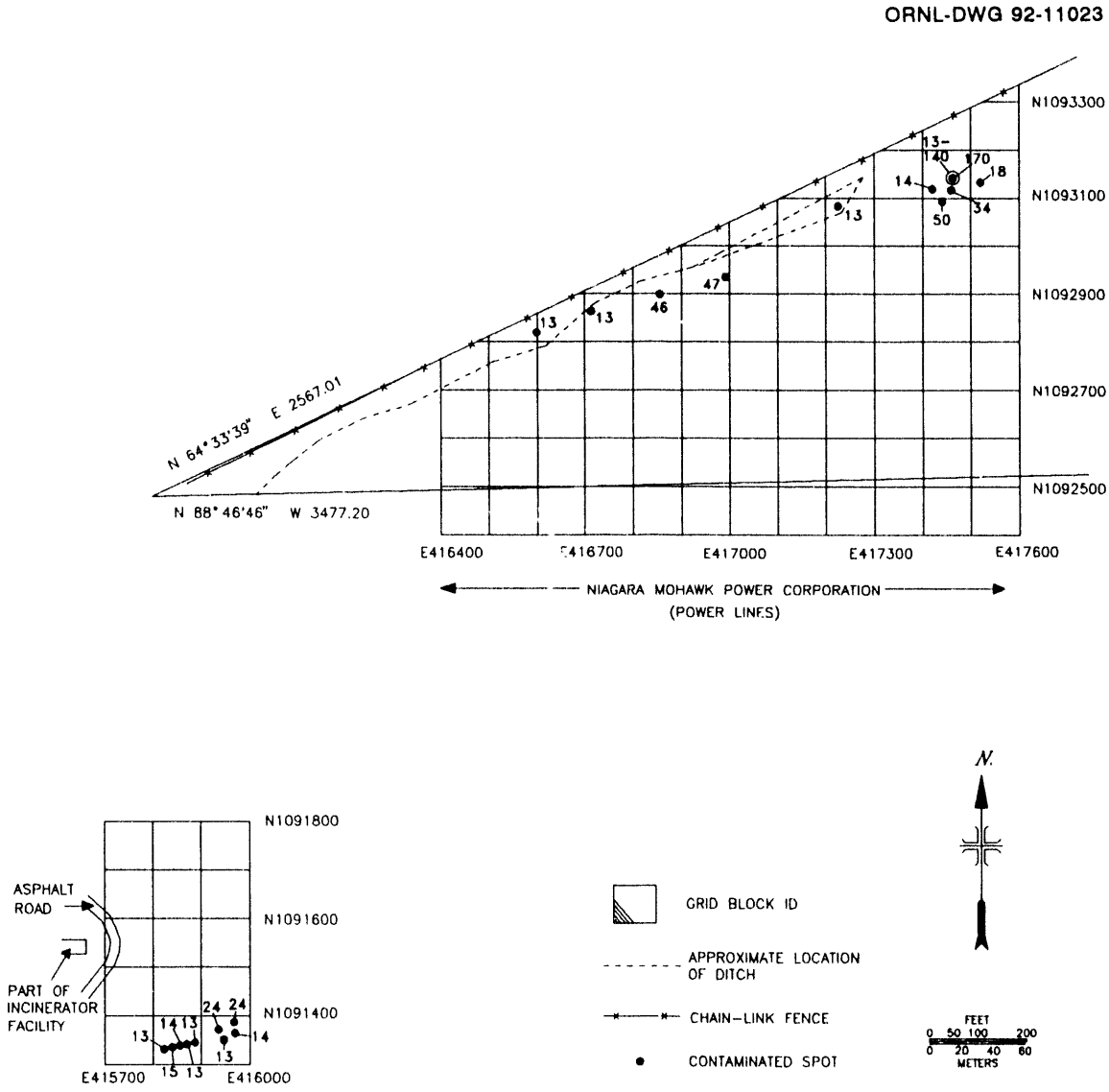

Fig. 10. Regions of elevated surface gamma exposure rates (μR/h) at the Town of Tonawanda Landfill, Tonawanda, New York.

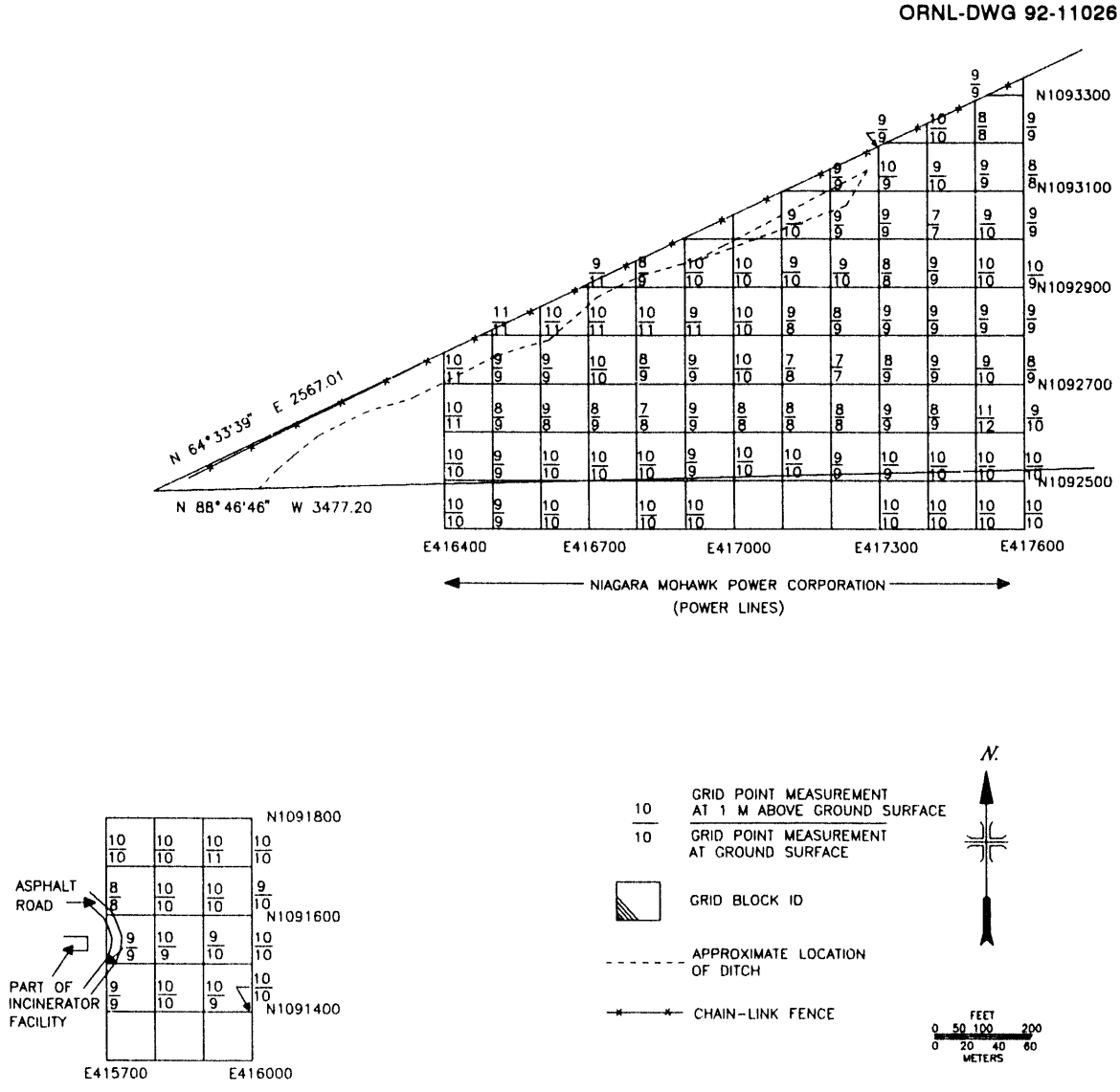

Fig. 11. Surface and 1-m gamma exposure rate measurements (μR/h) at grid points at the Town of Tonawanda Landfill, Tonawanda, New York.

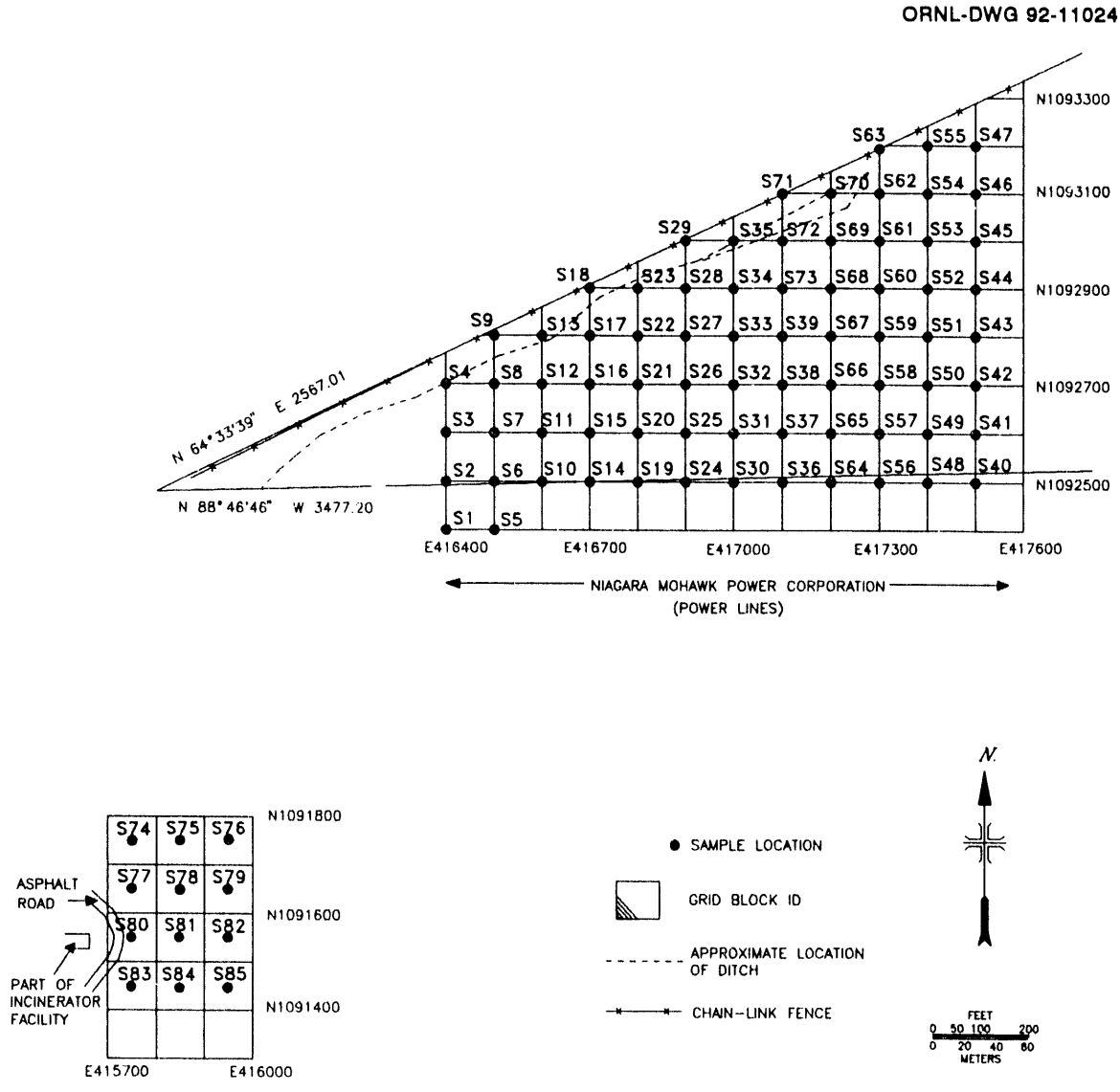

Fig. 12. Systematic soil sample locations at the Town of Tonawanda Landfill, Tonawanda, New York.

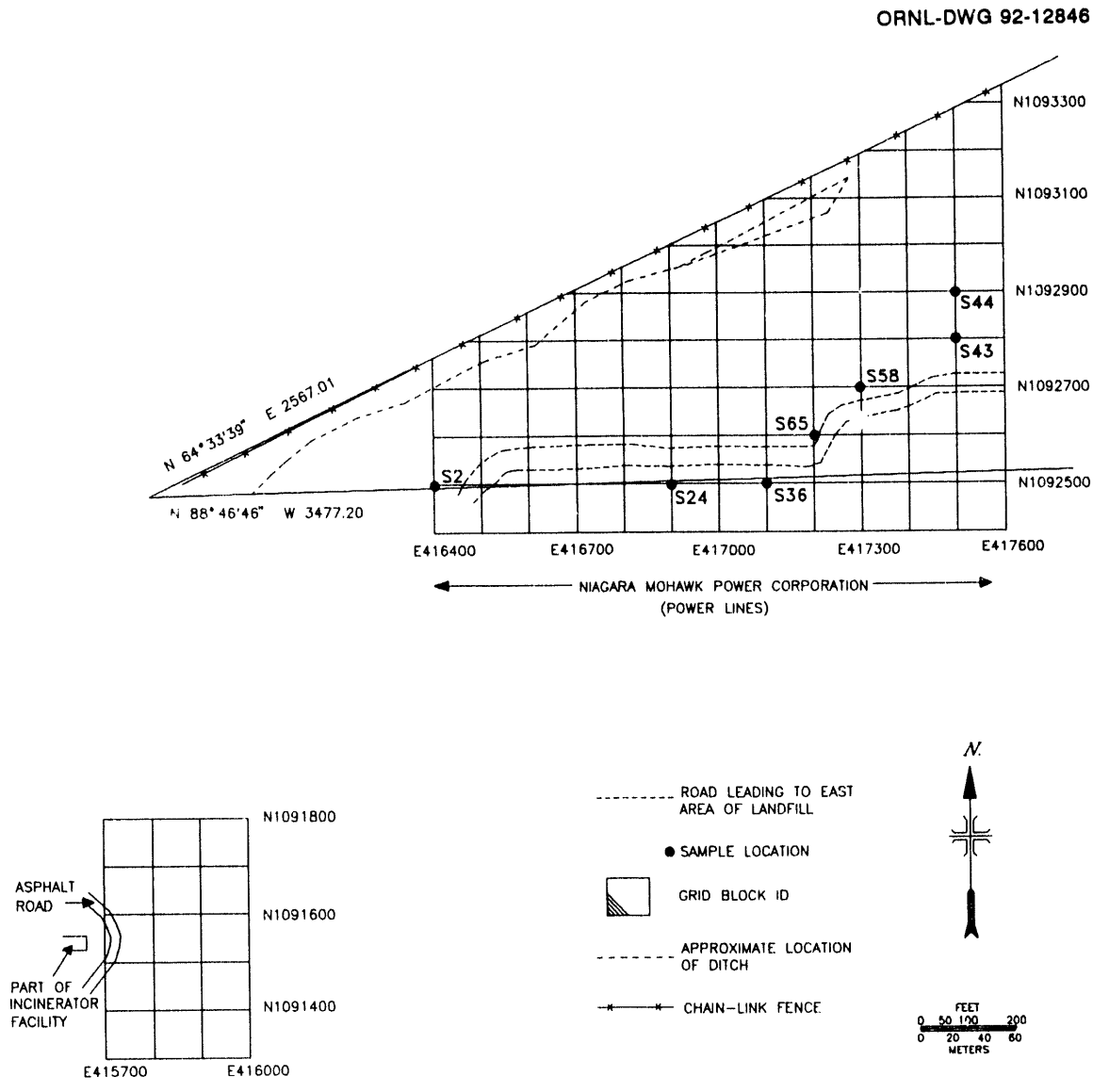

Fig. 13. Locations of systematic samples containing low levels of ^{241}Am. Note close proximity to the road.

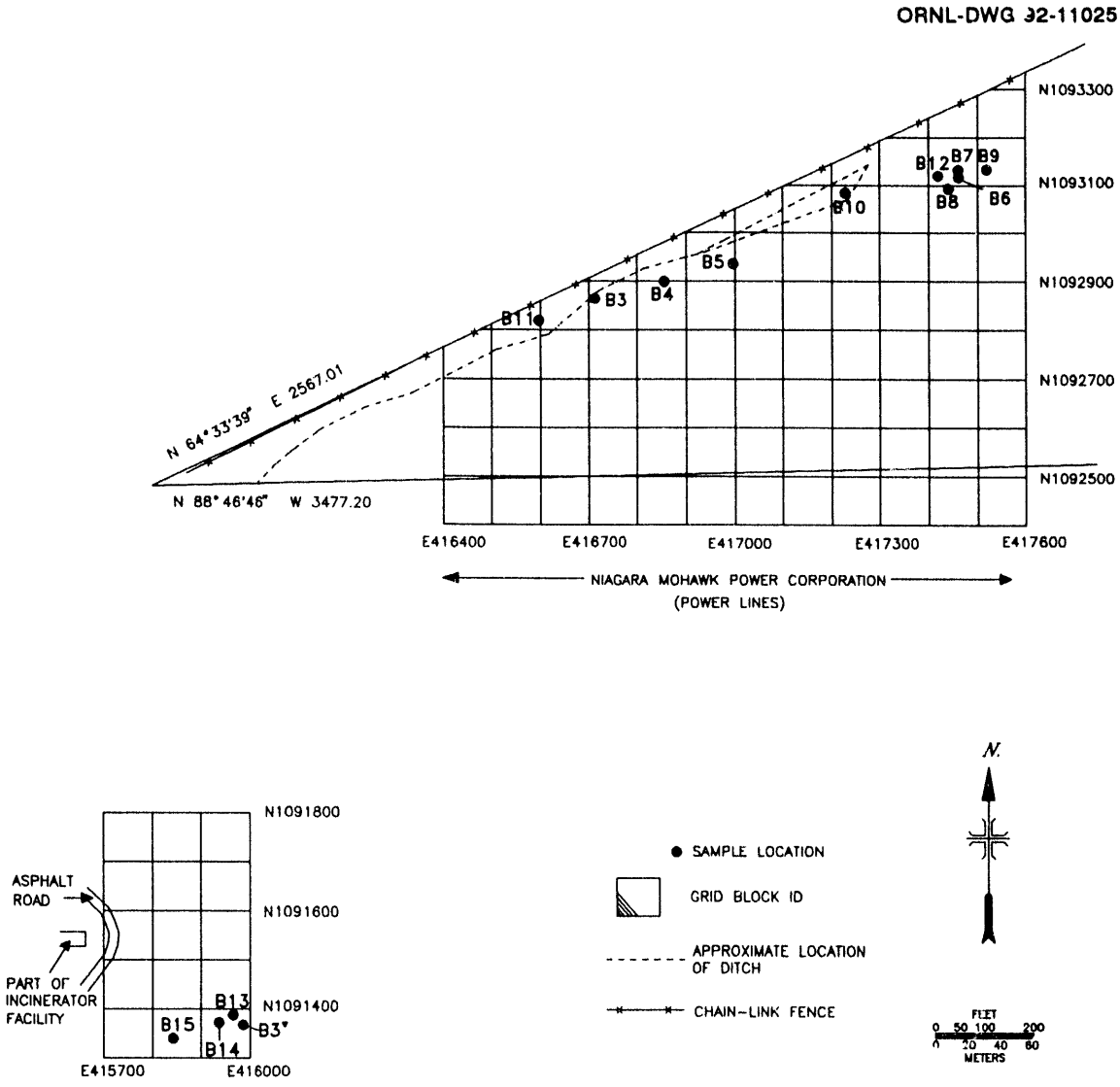

Fig. 14. Biased soil sample locations at the Town of Tonawanda Landfill, Tonawanda, New York.

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Fig. 15. View looking southwest at sampling location B7 in a moist, wooded area of the landfill.

ORNL-PHOTO 5544-92

Fig. 16. View looking southeast at small flags marking sampling location B14 in "the flats" area.

Table 1. Applicable guidelines for protection against radiation
(Limits for uncontrolled areas)

Mode of exposure	Exposure conditions	Guideline value
Gamma radiation	Indoor gamma radiation level (above background)	20 μR/h[a]
Radionuclide concentrations in soil (generic)	Maximum permissible concentration of the following radionuclides in soil above background levels, averaged over a 100-m^2 area ^{226}Ra ^{232}Th ^{230}Th	5 pCi/g averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over 15-cm-thick soil layers more than 15 cm below the surface
Derived concentrations	Total uranium	60 pCi/g[b]
Guideline for non-homogeneous contamination (used in addition to the 100-m^2 guideline)[c]	Applicable to locations with an area $\leq$25 m^2, with significantly elevated concentrations of radionuclides ("hot spots")	$G_A = G_i(100/A)^{1/2}$, where G_A = guideline for "hot spot" of area (A) G_i = guideline averaged over a 100-m^2 area

[a]The 20 μR/h shall comply with the basic dose limit (100 mrem/year) when an appropriate-use scenario is considered.

[b]DOE guidelines for uranium are derived on a site-specific basis. A total uranium guideline of 60 pCi/g will be applied at the Town of Tonawanda Landfill. This corresponds to a ^{238}U concentration of ~30 pCi/g.

[c]DOE guidelines specify that every reasonable effort shall be made to identify and to remove any source that has a concentration exceeding 30 times the guideline value, irrespective of area (adapted from *Revised Guidelines for Residual Radioactive Material at FUSRAP and Remote SFMP Sites*, April 1987).

Sources: Adapted from U.S. Department of Energy, DOE Order 5400.5, April 1990; U.S. Department of Energy, *Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites*, Rev. 2, March 1987; and U.S. Department of Energy, *Radiological Control Manual*, DOE/EH-0256T (DOE N 5480.6), June 1992.

Table 2. Background radiation levels and concentrations of selected radionuclides in soil near the Town of Tonawanda Landfill, Tonawanda, New York

Type of radiation measurement or sample	Radiation level or radionuclide concentration	
	Range	Average
Gamma exposure rate at ground surface (μR/h)[a]	8–11	9
Concentration of radionuclides in soil (pCi/g)[a]		
^{238}U	0.8–1.1	1.0
^{226}Ra	0.7–1.1	0.9
^{232}Th	0.5–0.9	0.8

[a]Values obtained from four locations in the Tonawanda area (samples X1–X4).

Table 3. Concentrations of radionuclides in soil samples from the Town of Tonawanda Landfill, Tonawanda, New York

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
		Systematic samples[c]				
S1	0–15	<2.5	0.80±0.02	<7.7	0.81±0.04	<0.10
S2	0–15	<2.0	0.92±0.02	<6.3	0.67±0.04	0.22±0.18
S3	0–15	1.5 ±0.6	0.93±0.02	<4.5	0.85±0.03	<0.10
S4	0–15	3.3 ±1	1.0 ±0.03	<8.8	0.93±0.05	<0.10
S5	0–15	1.2 ±0.5	0.90±0.02	<4.6	0.88±0.04	<0.10
S6	0–15	1.0 ±0.8	0.77±0.02	<6.1	0.48±0.03	<0.10
S7A	0–15	1.2 ±0.8	0.85±0.02	<6.1	0.64±0.04	<0.10
S7B	15–30	1.6 ±0.5	0.99±0.02	<4.0	0.73±0.03	<0.10
S7C	30–46	1.1 ±0.7	0.94±0.02	<8.3	0.70±0.03	<0.10
S8	0–15	0.92±0.8	0.92±0.02	<8.6	0.95±0.03	<0.10
S9	0–15	2.0 ±0.5	1.0 ±0.03	<12	1.0 ±0.04	<0.10
S10	0–15	1.5 ±0.5	0.96±0.02	<4.7	0.98±0.03	<0.10
S11	0–15	1.4 ±0.8	0.96±0.02	<8.4	0.72±0.03	<0.10
S12	0–15	<1.5	0.95±0.02	<7.6	0.89±0.04	<0.10
S13	0–15	2.3 ±0.8	1.7 ±0.02	<11	1.2 ±0.03	<0.10
S14A	0–15	1.1 ±0.8	0.96±0.02	<9.5	0.99±0.09	<0.10
S14B	15–30	2.1 ±0.7	0.90±0.03	<15	0.96±0.04	<0.10
S14C	30–46	1.2 ±0.9	0.79±0.03	<7.8	0.81±0.04	<0.10
S15	0–15	0.52±0.3	0.75±0.02	<3.2	0.38±0.02	<0.10
S16	0–15	1.4 ±0.4	1.1 ±0.02	<12	0.86±0.04	<0.10
S17A	0–15	<1.4	0.79±0.02	<8.4	0.77±0.03	<0.10
S17B	15–30	0.98±0.7	0.95±0.03	<7.1	0.85±0.04	<0.10
S17C	30–46	1.0 ±1	0.76±0.02	<7.4	0.80±0.05	<0.10
S18	0–15	1.4 ±0.9	0.89±0.02	<8.0	0.86±0.04	<0.10
S19	0–15	1.4 ±0.6	0.85±0.02	<4.7	0.85±0.04	<0.10
S20	0–15	0.92±0.6	0.60±0.02	<5.2	0.32±0.03	<0.10
S21	0–15	1.8 ±1	0.89±0.03	<7.1	0.69±0.03	<0.10
S22	0–15	1.4 ±0.4	0.80±0.04	<11	0.80±0.06	<0.10
S23	0–15	1.1 ±0.5	0.62±0.02	<3.8	0.53±0.02	<0.10

Table 3 (continued)

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
S24A	0–15	1.0 ±0.4	0.85±0.02	<4.3	0.79±0.03	0.10±0.07
S24B	15–30	1.0 ±0.6	0.87±0.02	<4.9	0.87±0.03	<0.10
S24C	30–46	1.8 ±0.7	0.80±0.02	<4.9	0.87±0.03	<0.10
S25	0–15	2.2 ±0.8	1.7 ±0.02	<9.3	0.67±0.02	<0.10
S26A	0–15	<2.4	1.0 ±0.02	<8.4	0.61±0.03	<0.10
S26B	15–30	<1.1	0.85±0.02	<9.0	0.55±0.03	<0.10
S26C	30–46	1.0 ±0.6	0.84±0.02	<8.5	0.60±0.03	<0.10
S27	0–15	1.1 ±0.4	0.82±0.02	<4.1	0.81±0.03	<0.10
S28A	0–15	0.74±0.5	0.81±0.02	<4.3	0.80±0.03	<0.10
S28B	15–30	1.1 ±0.5	0.81±0.02	<4.4	0.83±0.03	<0.10
S28C	30–46	1.1 ±0.9	0.86±0.03	<8.6	0.86±0.05	<0.10
S29	0–15	1.4 ±0.9	0.99±0.02	<11	0.91±0.1	<0.10
S30	0–15	<1.5	0.83±0.02	<9.0	0.88±0.03	<0.10
S31	0–15	1.2 ±0.6	0.87±0.02	<7.0	0.51±0.03	<0.10
S32	0–15	1.6 ±0.8	1.4 ±0.02	<8.8	0.70±0.02	<0.10
S33	0–15	<1.2	0.79±0.02	<8.1	0.68±0.03	<0.10
S34	0–15	0.88±0.5	0.82±0.02	<4.3	0.84±0.04	<0.10
S35	0–15	2.9 ±1	1.1 ±0.03	<8.1	1.1 ±0.06	<0.10
S36A	0–15	0.98±0.3	0.85±0.02	<4.3	0.81±0.03	0.38±0.07
S36B	15–30	1.1 ±0.7	0.84±0.02	<6.8	0.83±0.04	<0.10
S36C	30–46	0.98±0.5	0.85±0.02	<4.3	0.83±0.03	<0.10
S37	0–15	<1.2	0.77±0.02	<5.1	0.40±0.03	<0.10
S38	0–15	0.83±0.3	0.84±0.02	<3.2	0.68±0.03	<0.10
S39A	0–15	1.4 ±0.8	0.64±0.02	<6.8	0.65±0.03	<0.10
S39B	15–30	1.2 ±0.6	0.36±0.02	<6.2	0.39±0.02	<0.10
S39C	30–46	<1.5	0.44±0.02	<5.8	0.43±0.03	<0.10
S40	0–15	1.4 ±0.7	0.89±0.02	<10	0.91±0.04	<0.10
S41A	0–15	1.5 ±1	1.0 ±0.03	<15	1.0 ±0.03	<0.10
S41B	15–30	1.5 ±0.9	1.0 ±0.03	<15	0.99±0.04	<0.10
S41C	30–46	1.7 ±1	1.0 ±0.02	<11	0.96±0.06	<0.10
S42	0–15	0.58±0.3	0.70±0.01	<2.9	0.40±0.02	<0.10
S43	0–15	0.81±0.3	0.80±0.02	<4	0.58±0.03	0.63±0.06
S44	0–15	1.1 ±0.7	0.82±0.02	<10	0.72±0.03	0.67±0.2

Table 3 (continued)

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
S45A	0–15	0.90±0.6	0.78±0.02	<9.1	0.79±0.03	<0.10
S45B	15–30	1.1 ±0.8	0.82±0.02	<8.0	0.82±0.03	<0.10
S45C	30–46	1.5 ±1	0.81±0.02	<11	0.85±0.04	<0.10
S46	0–15	2.0 ±0.9	1.5 ±0.02	<9.8	0.70±0.04	<0.10
S47A	0–15	2.5 ±1.0	1.3 ±0.02	<11	1.2 ±0.1	<0.10
S47B	15–30	1.8 ±1	1.1 ±0.03	<9.1	1.1 ±0.06	<0.10
S47C	30–46	2.0 ±1	1.4 ±0.03	<17	1.4 ±0.04	<0.10
S48A	0–15	1.6 ±0.8	0.91±0.02	<9.4	0.93±0.05	<0.10
S48B	15–30	1.3 ±1	0.87±0.03	<7.6	0.90±0.04	<0.10
S48C	30–46	1.4 ±0.8	0.90±0.02	<11	0.88±0.1	<0.10
S49	0–15	1.9 ±1	0.98±0.02	<7.6	0.95±0.05	<0.10
S50	0–15	0.87±0.4	0.68±0.02	<3.6	0.50±0.02	<0.10
S51	0–15	<1.5	0.82±0.02	<6.9	0.74±0.04	<0.10
S52	0–15	0.89±0.5	0.76±0.02	<4.2	0.75±0.03	<0.10
S53	0–15	1.5 ±0.9	0.59±0.02	<6.6	0.50±0.03	<0.10
S54	0–15	56 ±4	1.5 ±0.08	<26	1.3 ±0.1	<0.10
S55	0–15	1.4 ±1	1.0 ±0.03	<19	0.99±0.05	<0.10
S56	0–15	1.5 ±1	0.84±0.02	<7.8	0.81±0.04	<0.10
S57A	0–15	<2.4	0.96±0.02	<7.7	0.87±0.04	<0.10
S57B	15–30	1.0 ±0.9	0.84±0.02	<7.4	0.81±0.03	<0.10
S57C	30–46	1.9 ±1	0.84±0.02	<8.5	0.72±0.03	<0.10
S58	0–15	0.82±0.7	0.81±0.02	<6.9	0.57±0.03	0.38±0.2
S59A	0–15	0.89±0.4	0.83±0.02	<4.6	0.69±0.03	<0.10
S59B	15–30	1.8 ±1	0.88±0.03	<7.2	0.80±0.04	<0.10
S59C	30–46	1.4 ±0.8	0.92±0.02	<13	0.80±0.04	<0.10
S60	0–15	1.5 ±1	0.66±0.02	<6.7	0.61±0.03	<0.10
S61	0–15	1.4 ±1	0.74±0.02	<7.6	0.81±0.04	<0.10
S62A	0–15	8.8 ±0.9	1.1 ±0.03	<6.4	0.89±0.04	<0.10
S62B	15–30	9.6 ±1	1.1 ±0.04	<9.5	0.91±0.07	<0.17
S62C	30–46	5.5 ±1	1.0 ±0.03	<6.8	0.93±0.04	<0.10
S63	0–15	1.3 ±0.5	0.84±0.02	<4.2	0.74±0.03	<0.10
S64	0–15	1.1 ±0.8	0.80±0.02	<7.2	0.77±0.04	<0.10
S65	0–15	1.4 ±0.9	0.72±0.03	<7.5	0.51±0.05	0.32±0.2

Table 3 (continued)

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
S66A	0–15	1.9 ±1	0.89±0.02	<9.1	0.65±0.03	<0.10
S66B	15–30	1.6 ±0.8	0.82±0.02	<8.4	0.57±0.03	<0.10
S66C	30–41	0.33±1	0.78±0.02	<6.7	0.50±0.03	<0.10
S67	0–15	2.1 ±1	0.80±0.02	<7.1	0.74±0.03	<0.10
S68	0–15	0.62±0.4	0.94±0.02	<3.8	0.89±0.03	<0.10
S69A	0–15	1.9 ±1	0.92±0.02	<15	0.94±0.04	<0.10
S69B	15–30	1.4 ±0.8	1.0 ±0.02	<10	1.0 ±0.04	<0.10
S69C	30–46	2.6 ±1	1.2 ±0.03	<16	1.1 ±0.04	<0.10
S70	0–15	2.2 ±0.9	0.63±0.02	<6.5	0.58±0.04	<0.10
S71	0–15	1.2 ±0.5	0.99±0.02	<4.7	0.87±0.04	<0.10
S72	0–15	1.2 ±1	0.95±0.03	<8.3	0.94±0.04	<0.10
S73	0–15	1.6 ±0.6	0.95±0.02	<4.9	0.97±0.03	<0.10
S74	0–15	<2.0	1.1 ±0.02	<11	1.0 ±0.04	<0.10
S75A	0–15	1.7 ±0.6	0.96±0.03	<5.5	0.96±0.04	<0.10
S75B	15–30	1.0 ±1	0.86±0.02	<8.0	0.94±0.04	<0.10
S75C	30–46	1.4 ±0.7	0.86±0.02	<5.0	0.90±0.04	<0.10
S76	0–15	0.79±0.5	0.83±0.02	<4.3	0.84±0.03	<0.10
S77A	0–15	2.0 ±0.8	1.9 ±0.03	<8.0	0.83±0.04	<0.10
S77B	15–30	1.7 ±0.9	1.3 ±0.02	<11	0.88±0.03	<0.10
S77C	30–46	1.4 ±0.6	0.97±0.02	<4.9	0.84±0.03	<0.10
S78	0–15	<2.4	0.99±0.02	<13	0.96±0.03	<0.10
S79	0–15	1.4 ±0.5	0.90±0.02	<4.3	0.88±0.03	<0.10
S80	0–15	0.81±0.4	0.81±0.02	<4.1	0.80±0.03	<0.10
S81A	0–15	<2.4	1.1 ±0.03	<7.8	0.89±0.05	<0.10
S81B	15–30	1.5 ±1	0.98±0.02	<7.9	0.91±0.04	<0.10
S81C	30–46	1.7 ±1	0.97±0.03	<7.9	0.97±0.04	<0.10
S82	0–15	1.2 ±0.9	0.97±0.02	<10	1.0 ±0.03	<0.10
S83	0–15	1.6 ±1	0.83±0.02	<7.6	0.86±0.04	<0.10
S84	0–15	1.5 ±1	1.1 ±0.03	<7.2	0.91±0.04	<0.10
S85A	0–15	1.5 ± 0.8	0.89±0.02	<9.5	0.86±0.02	<0.10
S85B	15–30	1.6 ± 1	0.94±0.02	1.4±8	0.96±0.04	<0.10
S85C	30–46	1.2 ± 0.8	0.91±0.02	<11	0.88±0.03	<0.10

Table 3 (continued)

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
S86A	0–15	1.2 ± 0.5	0.89±0.02	<4.3	0.80±0.03	<0.10
S86B	15–30	<2.5	1.0 ±0.02	<11	1.0 ±0.03	<0.10
S86C	30–46	1.2 ± 0.8	1.0 ±0.02	<9.8	1.1 ±0.04	<0.10
S87	0–15	1.1 ± 0.5	0.93±0.02	<4.3	0.82±0.03	<0.10
S88	0–15	1.3 ± 0.5	0.97±0.02	<4.4	0.95±0.03	<0.10
		Biased samples[d]				
B3'A[e]	0–15	18 ± 3	11 ±0.1	*f*	0.84±0.07	*f*
B3'B[e]	15–30	16 ± 1	5.4 ±0.06	*f*	0.98±0.07	*f*
B3A	0–15	1.8 ± 1	2.2 ±0.04	<22	2.2 ±0.06	<0.10
B3B	15–30	4.0 ± 2	2.2 ±0.04	<11	1.4 ±0.06	<0.10
B3C	30–46	1.4 ± 0.7	1.4 ±0.03	<7.4	1.2 ±0.04	<0.10
B4A	0–15	<15	240 ±0.9	820±200	<0.42	<0.10
B4B	15–30	1.3 ± 1	5.2 ±0.05	<9.3	0.76±0.05	<0.10
B5A	0–15	<32	440 ±2	1300±300	<0.96	<0.10
B5B	15–30	78 ± 20	120 ±0.7	660±100	0.90±0.2	<0.10
B5C	30–46	<2.2	2.4 ±0.03	<13	0.92±0.04	<0.10
B6A	0–15	57 ± 20	300 ±1	<300	<0.88	<0.10
B6B	15–30	18 ± 4	75 ±0.3	<47	1.1 ±0.2	<0.10
B6C	30–46	4.9 ± 0.8	11 ±0.06	<9.6	1.0 ±0.04	<0.10
B7A	0–15	120 ± 7	170 ±0.5	<58	0.84±0.2	<0.10
B7B	15–30	150 ± 60	2000 ±6	4300±400	<3.3	<0.10
B7C	30–46	310 ± 50	1000 ±9	<820	<5.3	<0.10
B7D	46–61	290 ± 20	46 ±0.7	<150	0.92±0.4	<0.10
B7E	61–76	1800 ±200	21 ±0.5	<72	0.79±0.1	<0.10
B8	0–15	1.3 ± 0.8	1.2 ±0.02	<9.9	0.78±0.03	<0.10
B9	0–15	1.6 ± 1	3.7 ±0.04	<9.7	0.60±0.04	<0.10
B10A	0–15	7.2 ± 1	2.6 ±0.04	<15	2.6 ±0.07	<0.10
B10B	15–30	5.2 ± 2	2.6 ±0.04	<12	2.6 ±0.07	<0.10
B11A	0–15	4.2 ± 1	2.6 ±0.04	<8.4	1.8 ±0.06	<0.10
B11B	15–20	2.4 ± 0.9	2.1 ±0.02	<11	1.5 ±0.04	<0.10
B12A	0–15	220 ± 7	1.6 ±0.08	<82	1.3 ±0.1	<0.10
B12B	15–30	170 ± 7	1.5 ±0.1	<46	1.4 ±0.1	<0.10
B12C	30–46	89 ± 7	2.8 ±0.1	<89	2.1 ±0.2	<0.10

Table 3 (continued)

Sample ID[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]				
		^{238}U	^{226}Ra	^{230}Th	^{232}Th	^{241}Am
B13A	0–15	30 ± 4	16 ±0.2	27±40	0.94±0.1	<0.10
B13B	15–30	35 ± 2	14 ±0.1	<21	0.86±0.08	<0.10
B13C	30–46	35 ± 4	19 ±0.2	31±40	0.87±0.1	<0.10
B13D	46–61	34 ± 4	33 ±0.2	<67	0.97±0.1	<0.10
B13E	61–76	20 ± 2	22 ±0.1	<20	0.87±0.08	<0.10
B14A	0–15	12 ± 3	13 ±0.1	<26	0.82±0.08	<0.10
B14B	15–30	18 ± 2	22 ±0.1	<22	1.1 ±0.1	<0.10
B14C	30–46	16 ± 1	12 ±0.1	<15	0.92±0.07	<0.10
B14D	46–61	13 ± 3	20 ±0.2	<28	1.0 ±0.1	<0.10
B15A	0–15	78 ±20	120 ±0.7	660±100	0.90±0.2	<0.10
B15B	15–30	2.6 ± 1	3.5 ±0.04	<9.9	1.1 ±0.04	<0.10
B15C	30–46	3.4 ± 1	3.4 ±0.04	<17	1.2 ±0.04	<0.10
B15D	46–58	3.0 ± 1	2.8 ±0.04	<17	1.3 ±0.04	<0.10

[a]Sample locations are shown on Figs. 12, 13, and 14.

[b]Indicated counting error is at the 95% confidence level (±2σ).

[c]Systematic samples are taken at selected locations irrespective of gamma exposure rate.

[d]Biased samples are taken from areas shown to have elevated gamma exposure rates.

[e]Landfill biased soil sample collected during April 1990 survey (W. D. Cottrell, D. A. Witt, R. E. Rodriguez, and R. F. Carrier, *Results of Mobile Gamma Scanning Activities in Tonawanda, New York*, ORNL/RASA-90/6, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., December 1990).

[f]Not measured.

Table 4. Gamma exposure rates at biased[a] soil sample locations, Town of Tonawanda Landfill, Tonawanda, New York

Sample ID[b]	Gamma exposure rate (μR/h)	
	1 m above ground surface	Ground surface
B3	11	13
B4	11	46
B5	11	47
B6	12	34
B7	26	170
B8	9	49
B9	10	18
B10	11	13
B11	10	13
B12	12	14
B13	14	22
B14	13	20
B15	13	15

[a]Biased samples are taken from areas shown to have elevated gamma exposure rates.

[b]Sample locations are shown on Fig. 14.

Table 5. Concentrations of radionuclides in split soil samples analyzed by both Oak Ridge National Laboratory and the New York State Department of Environmental Conservation, Bureau of Radiation

Sample ID[a]	Depth (cm)	Laboratory	Radionuclide concentration (pCi/g)[b]			
			^{238}U	^{226}Ra	^{232}Th	^{241}Am
B3A	0–15	ORNL[c]	1.8± 1	2.2 ±0.04	2.2 ±0.06	<0.10
		NY DEC[d]	2.5± 1	1.5 ±0.2	2.0 ±0.5	0 ±0.1
B3B	15–30	ORNL[c]	4.0± 2	2.2 ±0.04	1.4 ±0.06	<0.10
		NY DEC[d]	0 ± 1	1.7 ±0.2	1.8 ±0.4	0 ±0.1
B3C	30–46	ORNL[c]	1.4± 0.7	1.4 ±0.03	1.2 ±0.04	<0.10
		NY DEC[d]	2.2± 1	1.2 ±0.1	1.5 ±0.3	0 ±0.1
B4A	0–15	ORNL[c]	<15	240 ±0.9	<0.42	<0.10
		NY DEC[d]	0 ±10	750 ±2	0 ±2	2.3 ±1
B4B	15–30	ORNL[c]	1.3± 1	5.2 ±0.05	0.76±0.05	<0.10
		NY DEC[d]	0 ± 0.9	1.2 ±0.1	0.7 ±0.4	0 ±0.1
B5A	0–15	ORNL[c]	<32	440 ±2	<0.96	<0.10
		NY DEC[d]	0 ± 2	2200 ±4	0 ±3	5.0 ±2
B5B	15–30	ORNL[c]	78 ±20	120 ±0.7	0.90±0.2	<0.10
		NY DEC[d]	0 ± 8	280 ±1	0 ±1	1.0 ±0.8
B5C	30–46	ORNL[c]	<2.2	2.4 ±0.03	0.92±0.04	<0.10
		NY DEC[d]	0 ± 3	57 ±0.7	0 ±0.6	0 ±0.3

[a]Sample locations are shown on Fig. 14.

[b]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).

[c]Sample analyzed by Measurement Applications and Development Group at Oak Ridge National Laboratory.

[d]Sample analyzed by New York State Department of Environmental Conservation, Bureau of Radiation (*Source:* P. J. Merges, New York State Department of Environmental Conservation, Bureau of Radiation, to W. A. Williams, U. S. Department of Energy, correspondence including "Split Sample Results from Tonawanda Landfill" and "Inspection Field Report," March 12, 1992.)

END

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