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ADMINISTRATIVE RECORD

for Maywood, New Jersey

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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Radiological Re-Survey Results at 146 West Central Avenue, Maywood, New Jersey (MJ034)

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Radiological Re-Survey Results at 146 West Central Avenue, Maywood, New Jersey (MJ034)

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ABSTRACT

Maywood Chemical Works (MCW) of Maywood, New Jersey, generated process wastes and residues associated with the production and refining of thorium and thorium compounds from 1916 to 1959. During the early years of operation, MCW stored wastes and residues in low-lying areas west of the processing facilities and consequently some of the residuals containing radioactive materials migrated offsite to the surrounding area. Subsequently, the U.S. Department of Energy (DOE) designated for remedial action the old MCW property and several vicinity properties. Additionally, in 1984, the property at 146 West Central Ave., Maywood, New Jersey and properties in its vicinity were included as a decontamination research and development project under the DOE Formerly Utilized Sites Remedial Action Program. In 1987 and 1988, at the request of DOE, Oak Ridge National Laboratory (ORNL) conducted a radiological survey on this property. A report describing this survey was published in 1989. Results of the survey indicated that while some radionuclide measurements were greater than typical background levels in the northern New Jersey area, no radionuclide concentrations were in excess of the DOE criteria under the Formerly Utilized Sites Remedial Action Program.

A second radiological survey by ORNL was conducted on this property in May 1993 at the request of DOE after an ad hoc radiological survey, requested by the property owner and conducted by Bechtel National, Inc. (BNI), identified some contamination not previously found by ORNL. The purpose of the second ORNL survey was to determine whether radioactive materials from the old MCW were present on the property, and if so, if radioactive materials present were above guidelines. A certified civil survey was requisitioned by ORNL to determine actual property boundaries before beginning the radiological re-survey. The re-survey included a surface gamma scan and the collection of a large number of soil samples for radionuclide analyses.

Results of this survey demonstrated that although elevated residual thorium-232 contamination was present in a few isolated spots on the southern end of the backyard, it did not exceed DOE guidelines. Additionally, much of the spotty contamination on the residential property was removed with the extensive soil sampling.

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RADIOLOGICAL RE-SURVEY RESULTS AT 146 WEST CENTRAL AVENUE, MAYWOOD, NEW JERSEY (MJ034)*

INTRODUCTION

Processing of thorium ores was performed in Maywood, New Jersey, between 1916 and 1959 by the Maywood Chemical Works (MCW).[1] The MCW ceased thorium processing in 1959 and the 30-acre property was sold that same year to Stepan Chemical Company. During the early years of operation, MCW stored wastes and residues in low-lying areas west of the processing facilities. Subsequently, residuals containing radioactive materials migrated off-site to the surrounding area, and the Stepan property and several vicinity properties were designated for remedial action by the U.S. Department of Energy (DOE).

The waste produced by the thorium extraction process was a sand-like material containing residual amounts of thorium and its decay products, with smaller quantities of uranium and its decay products. Because some of the wastes had been carried downstream by Lodi Brook, and some area residents had also used the sand-like wastes as mulch in their yards, the property at 146 West Central Ave., Maywood, New Jersey, and properties in its vicinity were included as a decontamination research and development project under the DOE Formerly Utilized Sites Remedial Action Program. Figure 1 shows the location of Central Avenue relative to the MCW plant.

At the request of the U.S. Department of Energy (DOE), ORNL conducted investigative radiological surveys of several properties surrounding the former processing plant. During 1987 and 1988 a radiological survey was conducted by ORNL on the property at 146 W. Central Ave. The interim storage facility is immediately adjacent to the far side of the tracks where the New York Susquehanna and Western Railway line abuts the south end of the property. The survey and sampling of the ground surface were carried out on August 26 and 27, 1987, and additional subsurface investigations were performed in June 1988. The principal radionuclide of interest was ^{232}Th. A report describing this survey was issued in 1989.[2] Results of this survey indicated while some measurements at this property were greater than typical background levels in the area, the property contained no significant radioactive contamination above guidelines established by the DOE for the Maywood, New Jersey area remedial action plan. Sources of the slight elevations were attributed to several factors (including fertilizers and naturally radioactive coal ashes), which are unrelated to former processing operations at the MCW. In addition, the report stated that radiation ("shine") emanating from the nearby Maywood Interim Storage Site (MISS), which distorts measurements, made it difficult to determine the degree of contamination on the south end of the property. Furthermore, radiological assessment of the property and investigation of the coal ash suggested that all soil analyses were below DOE Formerly Utilized Sites

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

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Remedial Action Program criteria. Therefore, although results showed that no remedial action was needed on the property, the report stated that "because of the proximity of the railroad property, which is to be remediated, and the DOE's ALARA (As Low As Reasonably Achievable) policy, concurrent removal of the slightly elevated soil layers may be justified."

In 1992, Bechtel National, Inc. (BNI), the project management contractor designated by DOE, conducted an ad hoc radiological survey at the request of the owner of the property. One soil sample was collected and analyzed for radionuclide concentrations. Analytical results for the soil sample collected on the property indicated the presence of slightly elevated levels of uranium, thorium, and radium. The small amounts of those elements may have resulted from natural materials, such as coal ash or building materials. Additionally, although Bechtel's survey covered all areas maintained by the property owner, it may have included the adjacent railroad property, and therefore a property boundary survey was done at the request of ORNL.

Although the data from Bechtel's ad hoc survey as well as ORNL's earlier survey, when evaluated against the hot spot criteria (Table 1), indicated that the values were below criteria for remedial action, it was decided that if contamination had indeed extended onto the private property at 146 W. Central Ave. from the adjacent railroad property (which has already been designated for remediation), it could be addressed during the remediation of the railroad property, as stated in the first ORNL report.

Based on the fact that contamination could have migrated onto the property at 146 W. Central Ave. from the adjacent railroad property, it was decided to take, in addition to the confirmatory samples at the locations where elevated gamma levels were identified, a larger number of samples: (1) to define the nature and extent of the thorium, uranium, and radium present on the property, and (2) to determine whether radioactive materials present were above guidelines, and if so, whether they resulted from the operation of the Maywood Chemical Works. The Measurement Applications and Development Group of ORNL was assigned this responsibility, and in May 1993, conducted a second radiological survey of this property. This report describes the methods and results of ORNL's re-survey of the property at 146 W. Central Avenue, Maywood, New Jersey.

SCOPE OF THE SURVEY

At the request of ORNL, a certified civil survey was conducted by the Azzolina & Feury Engineering Company of Paramus, New Jersey to determine the actual property boundaries, corners, and dimensions of this property. The radiological survey included a meticulous and detailed surface gamma scan of the southern quarter of the backyard of the property within the certified property boundaries, and the collection and radionuclide analysis of 81 soil samples. Additional confirmatory samples were taken at locations in the backyard where elevated gamma levels had been identified. The area of the re-survey of the property at 146 W. Central Ave. is shown as the soil sampling area in Figs. 2 and 3.

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]

SURFACE RADIATION MEASUREMENTS

Gamma radiation levels were determined using a portable sodium iodide (NaI) gamma scintillation probe connected to a Victoreen ratemeter. Measurements were recorded and converted to microroentgens per hour (μR/h). Because NaI gamma scintillators are energy dependent, measurements of gamma radiation levels in counts per minute (cpm) are normalized to pressurized ionization chamber (PIC) measurements to estimate gamma exposure rates in μR/h.

SOIL SAMPLING AND ANALYSIS

Surface and subsurface soil samples were systematically collected over the southern part of the backyard of the property at one- and five-meter grid points. Surface and subsurface soil samples were also collected in the areas of known elevated radionuclide levels within the property lines. Such samples are referred to as biased samples and are more likely to contain elevated concentrations of radionuclides than are systematically chosen samples. At each sampling location, the gamma radiation levels are measured at each six-inch increment in the sample hole. The gamma radiation levels give an indication of possible nearby radioactive materials and their location.

SURVEY RESULTS

Current DOE guidelines for sites included within the FUSRAP are included in Table 1.[4,5] Typical background radiation levels for the northern New Jersey area are given in Table 2.[6,7] 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 in soil samples.

A photograph taken in May 1993 of the portion of the property at 146 W. Central Ave. where sampling took place is shown in Fig. 4.

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SURFACE RADIATION MEASUREMENTS

A very slow, methodical gamma scan was conducted over the backyard of the property. Gamma exposure measurements generally ranged from 18-22 μR/h at one meter above the surface in the southern quadrant (Fig. 3). In addition, surface radiation measurements were taken at the soil surface at each sampling location, both unshielded and shielded (to block out the "shine"*). At the surface, unshielded gamma exposure measurements generally ranged from 13 μR/h in the center of the backyard, increasing to 37 μR/h near the southern boundary, and measuring 48 μR/h at the location of the biased sample B3. In addition to the normal walk-over gamma scan, a special NaI detector with a cone-shield was deployed to assist in detection of hot spots. This detector/shield is mounted on a lightweight metal frame resembling a wheelbarrow.

SOIL SAMPLES

Systematic

Systematic soil samples were collected at 1- and 5-meter grid points over the southern quadrant of the backyard, beginning within one foot of the southern boundary line of the property. Samples were taken beginning at this point, continuing north towards the house, beginning at one meter apart in both directions and then in five-meter sections as gamma levels dropped nearer to the house. Some of the samples contained coca ash, which contains concentrations of natural radionuclides. Pieces of metal and glass and coca leaves were also found during sampling. In some cases no samples were taken due to mulch, gravel, or vegetation at the sampling location (Fig. 3).

All samples were analyzed for uranium, radium and thorium concentrations. Ranges for these radionuclides (surface and subsurface) ranged from 2.7 to 36 picocuries/gram (pCi/g) for ^{238}U (with a maximum of 78 pCi/g found in the subsurface soil sample at S13), 0.50 to 3.1 pCi/g for ^{226}Ra, and 0.30 to 28 pCi/g for ^{232}Th. Averaged over 100 m^2, the concentration (above a background of 0.9 pCi/g) of ^{232}Th was <2 pCi/g in surface soil and <2 pCi/g in subsurface soil. The maximum concentrations of 78 pCi/g (^{238}U), 28 pCi/g (^{232}Th), and 3.1 pCi/g (^{226}Ra) were found in the subsurface soil sample at S13 near the southernmost boundary of the property. Radionuclide concentrations decreased generally with depth of soil and in either direction from this sample (note that the S13F sample was considerably lower in all three radionuclides than the maximums found in the S13E sample). Soil sample locations are shown in Fig. 3 and results of analyses are listed in Table 3.

*Under certain conditions, extraneous radiation emanating from a source outside the area (in this case from the Maywood Interim Storage Site (MISS) south of the property) is called "shine" or scattered radiation, which will result in elevated gamma measurements.

Biased

Biased soil samples were taken in the areas of elevated gamma readings in the backyard at the southern end of the property.

Analyses showed that radionuclide concentrations in both surface and subsurface soil ranged from: 7.3 to 55 pCi/g (^{238}U), 0.76 to 2.6 pCi/g (^{226}Ra), and 1.3 to 38 pCi/g (^{232}Th). The maximum of 38 pCi/g ^{232}Th, and 55 pCi/g ^{238}U were measured in the B1 and B3 samples, which were taken nearest the southernmost boundary as shown in Fig. 3. The area represented by the elevated concentrations of radionuclides is very small (less than 1 m^2).

SIGNIFICANCE OF FINDINGS

The measurements taken during the radiological survey at 146 W. Central Avenue, Maywood, New Jersey, indicate results that are within DOE guidelines. These guidelines ensure that unrestricted use will not result in significant exposures to anyone on the property. Isolated spots of radioactive contamination were identified in surface and subsurface soil in areas where materials from the former MCW may have been transported. These areas were located in the southern quadrant of the backyard (Fig. 2). The highest gamma exposure measurements were obtained in the backyard of the property nearest the southern boundary; this is the area adjacent to the railroad property and closest to the MISS where "shine" influences gamma readings. In addition, some of the soil samples contained coal ash, which contributes to the natural radionuclide content of some samples.

Concentrations of uranium and radium found in the majority of the soil samples taken from the backyard of the property were generally below DOE guidelines for these radionuclides. Although some of the soil samples from isolated spots near the southern boundary of the property contained elevated concentrations of ^{232}Th (Table 3), when averaged over 100 m^2 the concentration of ^{232}Th is less than 2 pCi/g above natural background for surface and subsurface soil. Guidelines set by DOE are 5 pCi/g above background, averaged over 100 m^2 in surface soil (0-15 cm), and 15 pCi/g above background in subsurface soil (15-30 cm). The guideline for nonhomogeneous concentrations of radioactive materials ("hot spots") allows concentrations of up to ten times the normal guideline for areas less than 1 m^2, i.e., 50 pCi/g surface and 150 pCi/g subsurface for ^{232}Th. Since the highest surface concentration found was 34 pCi/g, and the highest subsurface concentration was 38 pCi/g, and both spots were less than 1 meter as determined by nearby sample results or radiation measurements, then the hot spot criteria was not exceeded. Therefore, based on these findings, this property does not meet guidelines for inclusion under FUSRAP.

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REFERENCES

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2. R. D. Foley and R. F. Carrier, *Results of the Radiological Survey at 146 West Central Avenue, Maywood, New Jersey (MJ034)*, ORNL/RASA-88/37, Martin Marietta Energy Systems, Inc., Oak Ridge Natl Lab, November 1989.

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. 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.

5. U. S. Department of Energy, *Radiation Protection of the Public and the Environment,* DOE Order 5400.5, April 1990.

6. T. E. Myrick, B. A. Berven, and F. F. Haywood, *State Background Radiation Levels: Results of Measurements Taken During 1975-1979*, ORNL/TM-7343, Martin Marietta Energy Systems, Inc., Oak Ridge Natl Lab., November 1981.

7. S. G. Levin, R. K. Stoms, E. Kuerze, and W. Huskisson, "Summary of Natural Environmental Gamma Radiation Using a Calibrated Portable Scintillation Counter," *Radiological Health Data Report* 9:679-695 (1968).

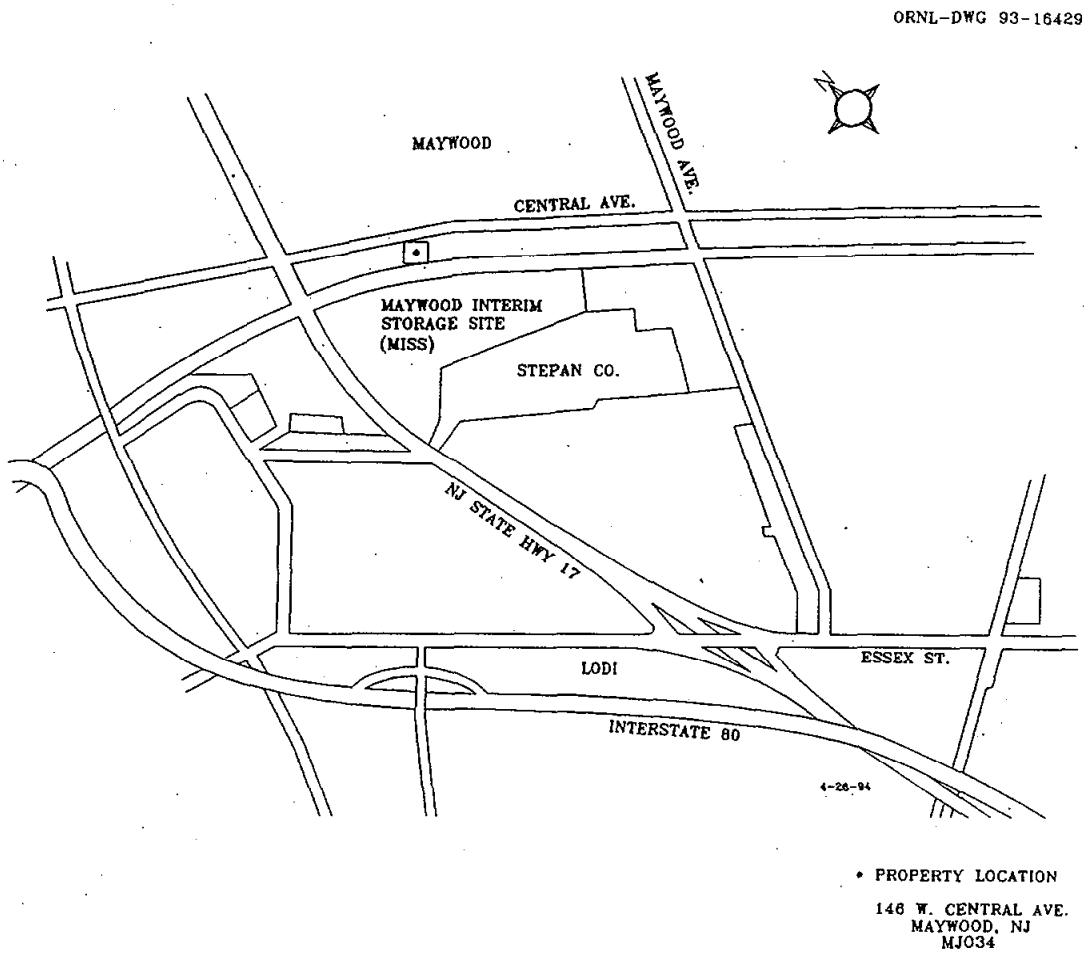

Fig. 1. Diagram showing the general location of the property at 146 W. Central Ave., Maywood, New Jersey relative to the Maywood Interim Storage Site (MISS).

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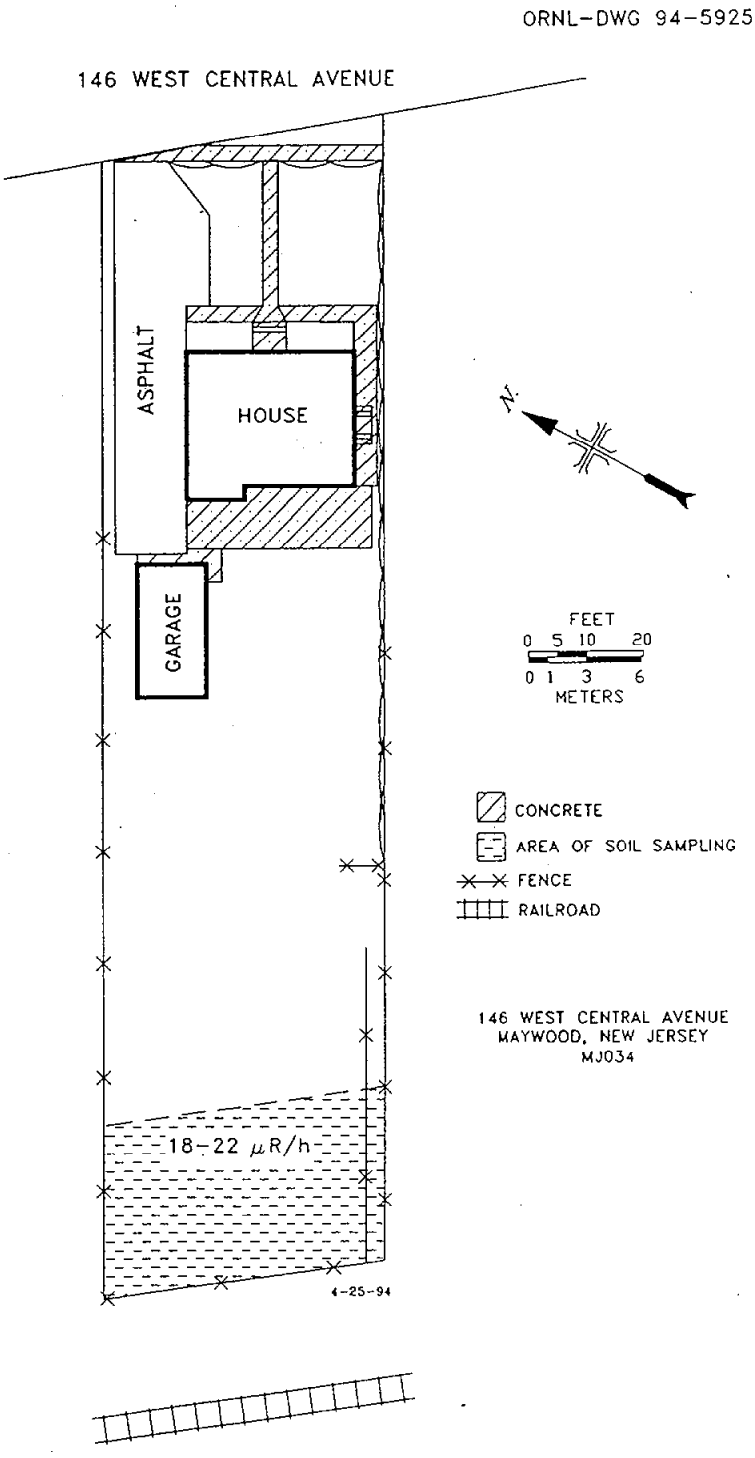

Fig. 2. Diagram of the property at 146 W. Central Ave., Maywood, New Jersey and the southern part of the backyard involved in the re-survey.

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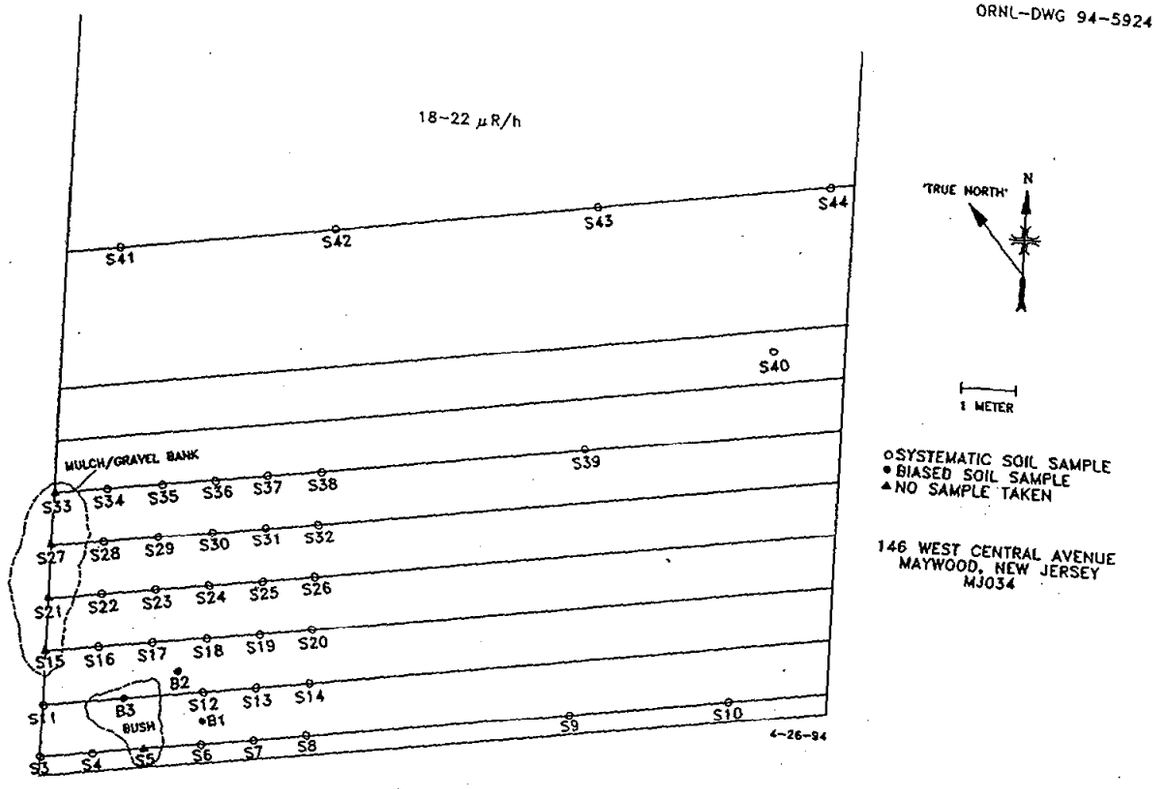

Fig. 3. Surface gamma exposure rates and soil sampling locations on the section of the backyard involved in the re-survey of the property at 146 W. Central Ave., Maywood, New Jersey. Sampling was done at 1- and 5-meter gridpoints.

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ORNL-PHOTO 859-94

Fig. 4. View of the workers in southwest corner of the backyard of the property at 146 W. Central Ave., Maywood, New Jersey, showing grid points for soil samples.

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Table 1. DOE guidelines for FUSRAP sites
(Limits for uncontrolled areas)

Mode of exposure	Exposure conditions	Guideline value
Gamma radiation	Indoor gamma radiation level (above background)	20 μR/h[a]
Total residual surface contamination[b]	^{238}U, ^{235}U, U-natural (alpha emitters)	
	or	
	Beta-gamma emitters[c]	
	Maximum	15,000 dpm/100 cm^2
	Average	5,000 dpm/100 cm^2
	Removable	1,000 dpm/100 cm^2
	^{232}Th, Th-natural *(alpha emitters)*	
	or	
	^{90}Sr *(beta-gamma emitter)*	
	Maximum	3,000 dpm/100 cm^2
	Average	1,000 dpm/100 cm^2
	Removable	200 dpm/100 cm^2
	^{226}Ra, ^{230}Th, transuranics	
	Maximum	300 dpm/100 cm^2
	Average	100 dpm/100 cm^2
	Removable	20 dpm/100 cm^2
Beta-gamma dose rates	Surface dose rate averaged over not more than 1 m^2	0.20 mrad/h
	Maximum dose rate in any 100-cm^2 area	1.0 mrad/h
Radionuclide concentrations in soil (generic)	Maximum permissible concentration of the following radionuclides in soil above background levels, averaged over a 100-m^2 area	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
	^{226}Ra	
	^{232}Th	
	^{230}Th	
Derived concentrations	^{238}U	Site specific[d]

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Table 1 (continued)
(Limits for uncontrolled areas)

Mode of exposure	Exposure conditions	Guideline value
Guideline for non-homogeneous contamination (used in addition to the 100-m^2 guideline)[e]	Applicable to locations with an area ≤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 surface contamination guidelines are consistent with *NRC Guidelines for Decontamination at Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material*, May 1987.

[c]Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr, ^{228}Ra, ^{223}Ra, ^{227}Ac, ^{133}I, ^{129}I, ^{126}I, ^{125}I.

[d]DOE guidelines for uranium are derived on a site-specific basis. Guidelines of 30 pCi/g have been applied at other FUSRAP sites. *Source:* R. E. Rodriguez et al., *Results of the Radiological Survey at the Town of Tonawanda Landfill, Tonawanda, New York (TNY001)*, ORNL/RASA-92/12, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., October 1992.

[e]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, and 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 N 5480.6 (DOE/EH-256T), June 1992.

Table 2. Average background radiation levels for the northern New Jersey area

Type of radiation measurement or sample	Radiation level or radionuclide concentration[a]
Gamma exposure at 1 m above ground surface (μR/h)	8[b]
Concentration of radionuclides in soil (pCi/g)[c]	
^{226}Ra	0.9
^{232}Th	0.9
^{238}U	0.9

[a] These values represent an average of normal radionuclide concentrations in this part of the state. Actual values may fluctuate.

[b] Source: U. S. Department of Energy, *Radiological Survey of the Middlesex Municipal Landfill, Middlesex, New Jersey*, DOE/EV-00005/20, April 1980. Values ranging from 8-11 μR/h (average 9 μR/h) were obtained from 35 locations in the Rochelle Park, New Jersey area.[7]

[c] Source: T. E. Myrick, and B. A. Berven, *State Background Radiation Levels: Results of Measurements Taken During 1975-1979*, ORNL/TM-7343, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., November 1981 (Ref. 6).

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Table 3. Concentrations of radionuclides in soil samples from 146 West Central Avenue, Maywood, New Jersey (MJ034)

Sample number[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]		
		^{226}Ra	^{232}Th	^{238}U
		Systematic samples[c]		
S3A[d]	0–15	0.81 ± 0.1	0.66 ± 0.1	<4.5
S3B	15–30	0.72 ± 0.1	0.92 ± 0.1	2.4 ± 0.3
S4A	0–15	1.2 ± 0.2	9.0 ± 0.5	30 ± 5
S4B	15–30	1.1 ± 0.1	5.0 ± 0.5	20 ± 5
S6A	0–15	1.1 ± 0.2	10 ± 1	19 ± 3
S6B	15–30	0.89 ± 0.1	7.0 ± 0.3	9.0 ± 2
S7A	0–15	1.1 ± 0.1	6.3 ± 0.3	11 ± 1
S7B	15–30	0.79 ± 0.1	2.6 ± 0.2	4.0 ± 0.5
S7C	30–45	0.99 ± 0.1	2.8 ± 0.2	4.6 ± 0.9
S7D	45–60	1.1 ± 0.1	3.6 ± 0.3	5.4 ± 0.9
S7E	60–75	1.7 ± 0.1	12 ± 1	22 ± 4
S8A	0–15	0.81 ± 0.1	3.2 ± 0.3	7.1 ± 0.8
S8B	15–30	0.97 ± 0.1	4.1 ± 0.2	7.0 ± 1
S9A	0–15	0.67 ± 0.1	0.91 ± 0.1	0.88 ± 0.3
S9B	15–30	0.78 ± 0.1	0.93 ± 0.1	<4.3
S10A	0–15	0.86 ± 0.1	1.1 ± 0.2	0.57 ± 0.2
S10B	15–30	0.78 ± 0.1	0.98 ± 0.1	<4.5
S11A	0–15	0.50 ± 0.1	0.32 ± 0.1	1.0 ± 0.3
S11B	15–30	0.49 ± 0.1	0.30 ± 0.1	<3.7
S12A	0–15	0.96 ± 0.1	3.8 ± 0.2	6.0 ± 1
S12B	15–30	0.80 ± 0.1	2.1 ± 0.2	2.1 ± 0.4
S13A	0–15	1.2 ± 0.1	3.4 ± 0.2	3.7 ± 0.8
S13B	15–30	1.1 ± 0.1	5.4 ± 0.2	5.0 ± 2
S13C	30–45	0.89 ± 0.1	1.8 ± 0.2	1.6 ± 0.5
S13D	45–60	1.5 ± 0.1	10 ± 1	12 ± 3
S13E	60–75	3.1 ± 0.4	28 ± 2	60 ± 10
S13F	75–90	0.75 ± 0.1	1.3 ± 0.2	3.7 ± 0.6
S14A	0–15	1.4 ± 0.1	1.9 ± 0.2	1.9 ± 0.5
S14B	15–30	1.2 ± 0.1	4.6 ± 0.2	4.8 ± 0.6
S14C	30–45	0.97 ± 0.1	2.7 ± 0.2	2.9 ± 0.5
S16A	0–15	0.69 ± 0.1	2.0 ± 0.2	<4.5
S16B	15–30	0.69 ± 0.1	1.3 ± 0.1	<4.9
S17A	0–15	0.97 ± 0.1	3.1 ± 0.2	5.0 ± 0.6
S17B	15–30	0.87 ± 0.1	1.5 ± 0.1	1.7 ± 0.4

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Table 3 (continued)

Sample number[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]		
		^{226}Ra	^{232}Th	^{238}U
S18A	0–15	1.1 ± 0.1	1.7 ± 0.2	1.9 ± 0.6
S18B	15–30	0.85 ± 0.1	1.4 ± 0.2	1.1 ± 0.4
S19A	0–15	1.3 ± 0.1	2.0 ± 0.2	2.4 ± 0.5
S19B	15–30	1.0 ± 0.1	1.5 ± 0.2	<5.8
S20A	0–15	1.2 ± 0.1	1.7 ± 0.2	1.8 ± 0.5
S20B	15–30	1.2 ± 0.1	1.7 ± 0.2	<5.3
S22A	0–15	1.2 ± 0.1	1.8 ± 0.2	2.3 ± 0.5
S22B	15–30	0.79 ± 0.1	1.3 ± 0.2	1.3 ± 0.4
S23A	0–15	0.67 ± 0.1	1.0 ± 0.1	<5.0
S23B	15–30	0.75 ± 0.1	1.1 ± 0.1	0.75 ± 0.3
S24A	0–15	1.3 ± 0.1	1.4 ± 0.2	<5.2
S24B	15–30	1.3 ± 0.1	1.3 ± 0.1	<4.7
S25A	0–15	1.1 ± 0.1	1.5 ± 0.2	1.5 ± 0.4
S25B	15–30	1.1 ± 0.1	1.5 ± 0.2	<4.6
S26A	0–15	1.2 ± 0.1	1.5 ± 0.1	<4.5
S26B	15–30	0.90 ± 0.1	1.4 ± 0.2	1.1 ± 0.5
S28A	0–15	0.94 ± 0.1	1.2 ± 0.1	<4.5
S28B	15–30	0.82 ± 0.1	1.0 ± 0.1	<4.7
S29A	0–15	1.4 ± 0.1	2.6 ± 0.2	3.3 ± 0.6
S29B	15–30	0.94 ± 0.1	1.1 ± 0.1	<4.0
S30A	0–15	1.5 ± 0.1	1.8 ± 0.2	<5.6
S30B	15–30	1.2 ± 0.1	1.3 ± 0.1	0.98 ± 0.4
S31A	0–15	0.89 ± 0.1	1.2 ± 0.1	1.3 ± 0.3
S31B	15–30	1.1 ± 0.1	1.4 ± 0.2	0.99 ± 0.2
S32A	0–15	0.88 ± 0.1	1.2 ± 0.2	0.82 ± 0.4
S32B	15–30	1.2 ± 0.1	1.5 ± 0.2	0.93 ± 0.4
S34A	0–15	1.3 ± 0.1	2.0 ± 0.2	1.6 ± 0.4
S34B	15–30	1.2 ± 0.1	1.9 ± 0.2	2.1 ± 0.6
S35A	0–15	1.4 ± 0.1	1.9 ± 0.2	1.5 ± 0.5
S35B	15–30	1.3 ± 0.1	1.5 ± 0.2	<3.9
S36A	0–15	1.3 ± 0.1	1.5 ± 0.2	<4.4
S36B	15–30	0.96 ± 0.1	1.2 ± 0.1	<4.5
S37A	0–15	1.5 ± 0.1	1.7 ± 0.2	1.4 ± 0.4
S37B	15–30	1.2 ± 0.1	1.5 ± 0.1	<4.9
S38A	0–15	0.79 ± 0.1	0.97 ± 0.2	<4.1
S38B	15–30	0.90 ± 0.1	1.2 ± 0.1	0.86 ± 0.2

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Table 3 (continued)

Sample number[a]	Depth (cm)	Radionuclide concentration (pCi/g)[b]		
		^{226}Ra	^{232}Th	^{238}U
S39A	0–15	0.62 ± 0.1	0.71 ± 0.1	<4.6
S39B	15–30	0.69 ± 0.1	0.79 ± 0.1	0.90 ± 0.3
S40A	0–15	0.74 ± 0.1	0.82 ± 0.1	1.0 ± 0.4
S40B	15–30	0.90 ± 0.1	1.2 ± 0.2	0.99 ± 0.4
S41A	0–15	0.78 ± 0.1	1.0 ± 0.1	<4.7
S41B	15–30	0.69 ± 0.1	0.92 ± 0.2	<5.1
S42A	0–15	0.93 ± 0.1	1.4 ± 0.2	0.96 ± 0.4
S42B	15–30	0.92 ± 0.1	1.1 ± 0.2	1.0 ± 0.3
S43A	0–15	0.70 ± 0.1	0.68 ± 0.1	<5.4
S43B	15–30	0.83 ± 0.1	0.98 ± 0.1	1.2 ± 0.3
S44A	0–15	0.68 ± 0.1	1.1 ± 0.2	1.2 ± 0.6
S44B	15–30	0.83 ± 0.1	1.3 ± 0.2	<5.1
		Biased samples[c]		
B1A	0–15	0.85 ± 0.1	4.1 ± 0.3	7.9 ± 2
B1B	15–30	0.81 ± 0.1	1.8 ± 0.2	2.3 ± 0.5
B1C	30–45	0.80 ± 0.1	1.3 ± 0.2	1.2 ± 0.5
B1D	45–60	1.5 ± 0.5	38 ± 4	50 ± 10
B1E	60–75	1.2 ± 0.2	18 ± 2	20 ± 5
B2A	0–15	0.91 ± 0.2	5.8 ± 0.5	15 ± 2
B2B	15–30	0.76 ± 0.2	3.1 ± 0.3	8.0 ± 1.0
B3A	0–15	2.6 ± 0.4	34 ± 1	55 ± 10
B3B	15–30	2.0 ± 0.3	28 ± 1	37 ± 8
B3C	30–45	1.4 ± 0.2	12 ± 2	18 ± 3

[a]Samples begin at number S3; soil samples from first survey were numbered S1-S2. Sample locations are shown on Fig. 3.
[b]Indicated counting error is at the 95% confidence level (±2σ).
[c]Systematic samples are taken at locations irrespective of gamma exposure rates.
[d]No samples were taken at sites S5, S15, S21, S27, and S33 due to mulch, gravel, and vegetation at the sampling site.
[e]Biased samples are taken from areas with elevated gamma exposure rates.

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