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HEALTH AND SAFETY RESEARCH DIVISION

**Nuclear and Chemical Waste Programs
(Activity No. AH 10 05 00 0: ONLWCO1)**

**RESULTS OF THE INDEPENDENT
RADIOLOGICAL VERIFICATION SURVEY
OF THE
LOWER SHEFFIELD BROOK FLOODPLAIN,
WAYNE, NEW JERSEY**

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Date of Issue - May 1989

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
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MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U. S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400**

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ACKNOWLEDGMENTS

Research for this project was sponsored by the Division of Facility and Site Decommissioning Projects, U. S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. The authors wish to acknowledge the support of J. E. Baublitz, Deputy Director, Office of Remedial Action and Waste Technology; J. J. Fiore, Director, Division of Facility and Site Decommissioning Projects; and members of their staff. The authors also recognize the valuable contributions of C. Leichtweis and R. Howard of Bechtel National, Inc. (BNI) for providing the data collected by BNI during the remedial action, and of A. C. Butler, B. S. Ellis, D. A. Roberts, J. A. Roberts, and W. Winton of the Measurement Applications and Development group (MAD) for participation in the collection, analyses, and reporting of data for this survey. In addition, we appreciate the graphics contributions of R. C. Phillips and T. R. Stewart of the Measurement Applications and Development Group, and R. L. Coleman of D. R. Stone & Associates, Inc. We also thank B. C. Littleton and L. J. Jeffers of the Information Research and Analysis Publications Office for their help in manuscript preparation.

ABSTRACT

Prior to 1971, the W.R. Grace Company processed and stored radioactive materials at Wayne, New Jersey, under license to the Atomic Energy Commission. Decontamination of structures and storage of waste materials on the property at the Wayne Interim Storage Site (WISS) took place in 1974. Surveys by the State of New Jersey Department of Environmental Protection and by Oak Ridge Associated Universities for the NRC in 1982 indicated that properties adjacent to the WISS contained surface contamination by radioactive residuals in amounts exceeding those acceptable under U.S. Department of Energy (DOE) remedial action guidelines. At the request of DOE, remedial actions have been conducted by Bechtel National, Inc., to remove radioactive residuals from properties adjacent to the site. It is the policy of DOE to assign an independent verification contractor to ensure the effectiveness of remedial actions performed within the Formerly Utilized Sites Remedial Action Program. This report describes the methods and results of those studies that were conducted by the Measurement Applications and Development Group of the Oak Ridge National Laboratory for the lower Sheffield Brook floodplain west of the WISS. Based upon post-remedial action and verification survey data, it was concluded that residual soil concentrations and gamma levels following excavation and backfilling of the area are within the limits prescribed by DOE radiological guidelines.

RESULTS OF THE INDEPENDENT RADIOLOGICAL VERIFICATION SURVEY OF THE LOWER SHEFFIELD BROOK FLOODPLAIN, WAYNE, NEW JERSEY*

INTRODUCTION

Rare Earths, Inc., of Wayne, New Jersey, began operations in 1948 to extract thorium and rare earths from monozite ore. In 1957, the company was merged with Davison Chemical Division of W. R. Grace and Co. Processing activities continued until July 1971. At that time, W. R. Grace ceased processing monozite ore and amended its Atomic Energy Commission (AEC) license for storage only. The decontamination of the buildings was performed in 1974. Following the decontamination, the storage license was terminated, and the property was released by the Nuclear Regulatory Commission (NRC) for unrestricted use, with the provision that the land deed indicate that radioactive material is buried on the property.

In January 1981, the NRC measured direct radiation levels and radionuclide concentrations in soil on the W. R. Grace property. The results of the survey indicated radiation levels ranging from 10 to 1000 microroentgens † per hour ($\mu\text{R}/\text{h}$) and ^{232}Th concentrations as high as 1200 picocuries ‡ per gram (pCi/g) of soil.¹ Therefore, the state of New Jersey requested an aerial radiological survey, which was conducted by EG&G in May 1981. This survey identified elevated radiation levels at 1 m above the surface with average exposure rates greater than 120 $\mu\text{R}/\text{h}$.² It was determined that a more detailed radiological survey of the plant site was needed to provide information on the extent and degree of the contamination.

A radiological survey at the processing facility was performed in July 1982 by the New Jersey Department of Environmental Protection (NJDEP).³ Because it was noted that elevated radiation levels extended along Sheffield Brook and onto the Ball Park area west of the W. R. Grace Site, a similar survey was conducted in 1982 by Oak Ridge Associated Universities (ORAU) for the NRC.⁴ The survey indicated surface radionuclide contamination greater than that acceptable under U.S. Department of Energy (DOE) remedial action guidelines.⁵

* 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 with Martin Marietta Energy Systems, Inc.

† The roentgen (R) is a unit that was defined for radiation protection purposes for people exposed to penetrating X rays or gamma radiation. A microroentgen ($\mu\text{R}/\text{h}$) is one millionth of a roentgen. A milliroentgen (mR) is one thousandth of a roentgen or one thousand microroentgens.

‡ The curie is a unit used to define the radioactivity in a substance and equals that quantity of any radioactive isotope undergoing 2.2×10^{12} disintegrations per minute. The picocurie is one million-millionth of a curie or that amount yielding 2.2 disintegrations per minute.

In 1985 and 1987 Bechtel National, Inc. (BNI), the project management contractor designated by DOE, conducted remedial actions to remove contaminated soil along the Sheffield Brook floodplain. This area includes a public Ball Park where remedial action was completed in 1985. Completion of the Sheffield Brook remedial action from Farmingdale Road to the Pompton River was accomplished in 1987.

The remedial actions were in accordance with a January 1986 work plan,⁶ and consisted of the excavation of contaminated soil and transport of the contaminated material to the Wayne Interim Storage Site (WISS) where it was placed in interim storage. Figure 1 shows the general location of the WISS and Sheffield Brook. Following removal of all contaminated soil, the property was restored to its original condition. A combination of procedures was used to control the contamination and to prevent its spreading to other areas. A post-remedial radiological survey was conducted by BNI to ensure compliance with DOE remedial action guidelines.⁷

The DOE has adopted a policy to assign an independent verification contractor to ensure the effectiveness of remedial actions performed within the Formerly Utilized Sites Remedial Action Program (FUSRAP). The Measurement Applications and Development group of Oak Ridge National Laboratory (ORNL) has been assigned the responsibility of this task for specific portions of the former W. R. Grace Site and adjacent properties in Wayne. This report describes the methods and results of the verification studies conducted in 1986 and 1987 along the lower Sheffield Brook floodplain (i.e., generally west of Farmingdale Road between Pompton Plains Crossroads and the Pompton River). The Ball Park was verified under a type "B" survey (i.e., soil samples were collected and on-site measurements made by ORNL) in 1986. In 1987, by agreement with BNI personnel and because of inclement weather, equipment failure, and project completion deadlines, approximately 50% of the remediated area in the lower Sheffield Brook project was subjected to type "A" survey guidelines using documentation and measurement results provided by BNI. The remaining remediated area (~50%) was verified according to the "B" survey process. The data collected during the 1986 Ball Park survey and the 1987 Sheffield Brook survey are detailed separately. The grid network established for measurements over the area is shown in Fig 2.

PROCEDURES

OBJECTIVES

The objective of the verification activities was to confirm (1) that available documentation adequately and accurately describes the post-remedial action radiological conditions of the entire property that is to be certified and (2) that the remedial action reduced contamination levels to within authorized limits.

DOCUMENT REVIEWS

Review of the designation/characterization report³ indicates that surveys of the property west of the WISS including the Ball Park and area along Sheffield Brook from Farmingdale Road to the Pompton River, Wayne, New Jersey, revealed surface radionuclide concentrations that exceeded DOE remedial action guidelines. Thus, it was appropriate to designate this property for remedial action.

The post-remedial action report⁷ indicates that the area excavated at the Sheffield Brook/Ball Park property was as identified in the designation report. The post-remedial action survey was performed on this property as described for a generic site in Reference 8. This survey consists of gamma measurements at 1 m and at the surface and systematic and biased soil sampling. From the review of the post-remedial action report, it can be concluded that the BNI survey procedure used for this property is satisfactory. All reported ²³⁸U, ²²⁶Ra, and ²³²Th soil sample concentrations are below the average guideline limits set by DOE (Table 1).

VERIFICATION SURVEY AND ANALYSIS

Typical background radiation levels for the Wayne, New Jersey, area are presented in Table 2. These data are provided for comparison with survey results presented in this section. All measurements 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.

GAMMA MEASUREMENTS

Direct scanning of the surface in the excavated areas of the Sheffield Brook portion of the property yielded a range of 8 to 12 $\mu\text{R/h}$. No elevated gamma levels were found in that region. A more detailed survey was conducted over the excavated areas of the Ball Park because of repeated flooding during and after excavation, which tended to concentrate transient residuals in localized spots. A gamma scan of the 26 5-m (16.4 ft) grid blocks established over the excavated area of the Ball Park was performed by ORNL, indicating an overall range of 6 to 39 $\mu\text{R/h}$. The range of gamma exposure rate measurements for each grid block is presented in Table 3 and Fig. 3. Twenty-four gamma exposure rate measurements were made by ORNL at grid points at the ground surface and at 1 m above the surface in the excavated area of the Ball Park. The results of grid point measurements are presented in Table 4 and the locations of these readings are shown on Fig. 3. Gamma exposure rates at 1 m above the surface ranged from 7 to 32 $\mu\text{R/h}$ and averaged 12 $\mu\text{R/h}$; gamma exposure rates at the surface ranged from 7 to 34 $\mu\text{R/h}$, averaging 13 $\mu\text{R/h}$.

SOIL SAMPLING

Before and after backfilling, 158 soil samples were taken by BNI in the excavated areas. Results of the soil sample analysis and the locations of the samples are given by BNI in the post-remedial confirmatory report.⁷ A selected number of these systematic soil

samples from different locations at various depths were chosen for confirmatory analysis by ORNL. The soil samples were analyzed by ORNL for ^{238}U , ^{226}Ra , and ^{232}Th according to the procedure described in Reference 9. Independently collected systematic and biased soil samples from various locations and depths were also analyzed by ORNL to verify the remedial action.

Ball Park Samples

Results of ORNL analyses of six systematic soil samples taken by BNI from the Ball Park area are presented in Table 5 with BNI results in parentheses for comparison. Locations of the soil samples are shown in Fig. 4. Concentrations of ^{238}U ranged from <2.0 to 4.1 pCi/g with absolute values averaging 3.7 pCi/g. Concentrations of ^{226}Ra in the soil samples ranged from 0.67 to 1.2 pCi/g and averaged 1.0 pCi/g. Concentrations of ^{232}Th in the soil samples ranged from 1.2 to 5.8 pCi/g and averaged 3.9 pCi/g. The significance of difference between average ORNL values and average BNI values was tested by a single sample *t*-test, assuming that ratios of paired values are log normally distributed. For 10 degrees of freedom and a 0.05 level of significance, the values in the critical range for a *t*-test of the null hypothesis are greater than 2.2. The observed *t* value for ^{232}Th is 0.68, which is not significant. The associated *p* value is 0.6. For 4 degrees of freedom and a 0.05 level of significance, the values in the critical range for *t*-test of the null hypothesis are greater than 2.77. The observed *t* value for ^{238}U is 1.50, which is not significant. The associated *p* value is 0.2. Hence, there is no evidence in these data to indicate that the average log ratio is different from zero.

Sheffield Brook Samples

Results of ORNL analyses of 21 systematic soil samples taken by BNI from the Sheffield Brook area are presented in Table 6 with BNI results in parentheses for comparison. Locations of the samples are shown in Fig. 4. Only one absolute value for concentration of ^{238}U was achieved by the analytical method (3.0 pCi/g). Uranium-238 was not detectable in five samples. Concentrations of ^{226}Ra in the soil samples ranged from 0.43 to 1.3 pCi/g and averaged 0.74 pCi/g. Concentrations of ^{232}Th in the soil samples ranged from 1.1 to 6.6 pCi/g, absolute values averaging 1.5 pCi/g. The significance of difference between average ORNL values and average BNI values was tested by a single sample *t*-test, assuming that ratios of paired values are log normally distributed. For 4 degrees of freedom and a 0.05 level of significance, the values in the critical range for a *t*-test of the null hypothesis are greater than 2.03. The observed *t* value for ^{226}Ra is 0.89, which is not significant. The associated *p* value is 0.40. For 18 degrees of freedom and a 0.05 level of significance, the values in the critical range for a *t*-test of the null hypothesis are greater than 2.10. The observed *t* value for ^{232}Th is 0.42, which is not significant. The associated *p* value is 0.7. Hence, there is no evidence in these data to indicate that the average log ratio is different from zero. Because BNI's results for ^{238}U were not absolute (see Table 6), no statistical test was performed for this radionuclide.

CONFIRMATORY SOIL ANALYSIS

Systematic and biased soil samples from various locations and depths were taken by ORNL for confirmatory analysis. (Samples collected from selected locations that showed elevated gamma radiation levels are designated as biased samples.) These samples were analyzed for ^{238}U , ^{226}Ra , and ^{232}Th according to the procedures described in Reference 9.

BALL PARK SOIL SAMPLES

Results and locations of the soil samples collected in the Ball Park area are shown in Table 7 and Fig. 5. Concentrations of ^{238}U in the 18 systematic soil samples ranged from 0.91 to 9.1 pCi/g and averaged 3.2 pCi/g. Concentrations of ^{226}Ra ranged from 0.71 to 1.9 pCi/g and averaged 1.1 pCi/g. Concentrations of ^{232}Th ranged from 1.0 to 14 pCi/g and averaged 5.0 pCi/g.

Concentrations of ^{238}U in the 26 biased soil samples ranged from 1.1 to 3.8 pCi/g and averaged 1.8 pCi/g. Concentrations of ^{226}Ra ranged from 0.79 to 1.2 pCi/g and averaged 0.95 pCi/g. Concentrations of ^{232}Th ranged from 1.6 to 5.9 pCi/g, averaging 3.1 pCi/g. (DOE guidelines for ^{226}Ra and ^{232}Th in surface and subsurface soil are 5 and 15 pCi/g, respectively.)

SHEFFIELD BROOK SOIL SAMPLES

Concentrations of ^{238}U were not determined in the Sheffield Brook samples. Radium-226 concentrations in the 59 systematic samples ranged from 0.43 to 1.2 pCi/g and averaged 0.73 pCi/g. Concentrations of ^{232}Th ranged from 0.48 to 5.4 pCi/g and averaged 1.7 pCi/g. Results and locations of the soil samples are shown in Table 6 and Fig. 6.

Concentrations of ^{238}U in the 10 biased soil samples from the Sheffield Brook portion of the property were not determined. Radium-226 concentrations ranged from 0.69 to 2.1 pCi/g, averaging 1.0 pCi/g. Concentrations of ^{232}Th ranged from 1.6 to 5.6 pCi/g and averaged 4.0 pCi/g. (DOE guidelines for ^{226}Ra and ^{232}Th in surface and subsurface soil are 5 and 15 pCi/g, respectively, above background.)

CONCLUSION

Measurements of the gamma exposure levels taken in the excavated area of the Sheffield Brook regions before and after backfilling showed that exposure rates at the ground surface ranged from 8 to 12 $\mu\text{R/h}$. Gamma exposure rates at 1 m above the ground surface over the Ball Park area ranged from 7 to 32 $\mu\text{R/h}$ and averaged 12 $\mu\text{R/h}$. For comparison, the background for the state of New Jersey^{11,12} averages 8 $\mu\text{R/h}$ and ranges from 6 to 11 $\mu\text{R/h}$ according to 1968 measurements. Although a few transitory, localized spots of elevated gamma levels were measured in the Ball Park, soil radionuclide analyses for ^{238}U , ^{226}Ra , and ^{232}Th show that all soil concentration measurements are within the limits prescribed by DOE radiological guidelines.

Based upon the results of the post-remedial action data, which were confirmed by the verification survey data, soil concentration measurements fall well below the limits prescribed by DOE radiological guidelines established for this site. It is concluded that the site successfully meets the DOE remedial action objectives.

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Fig. 1. General location of the Wayne Interim Storage Site (WISS) and Sheffield Brook, Wayne, New Jersey.

Fig. 2. Map of the lower Sheffield Brook floodplain showing the 100-ft grid system.

ORNL-DWG 89-9934

Fig. 3. Locations of grid point measurements and gamma exposure rate ranges measured at the surface within grid blocks established in the Ball Park area (Tables 3 and 4).

Fig. 4. Locations of soil samples collected from the lower Sheffield Brook floodplain by BNT and analyzed by ORNL (Tables 5 and 6).

Fig. 6. Locations of soil samples collected by ORNL from the Sheffield Brook area (Table 8).

Table 1. Summary of residual contamination guidelines for the Wayne, New Jersey, site

Soil (Land) Guidelines (Maximum Limits for Unrestricted Use)	
Radionuclide	Soil concentration (pCi/g) above background^{a,b}
²²⁶ Ra ²²⁸ Ra ²³⁰ Th ²³² Th	5 pCi/g, averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over any 15-cm-thick soil layer below the surface layer
Other radionuclides	Soil guidelines will be calculated on a site-specific basis using the DOE manual developed for this use

Structure Guidelines (Maximum Limits for Unrestricted Use)

Indoor Radon Decay Products

For ²²²Rn and ²²⁰Rn concentrations in buildings, the average annual radon decay product concentration (including background) due to uranium or thorium by-products should not exceed 0.02 WL after remedial action. When remedial action has been performed and it would be unreasonably difficult and costly to reduce the level below 0.03 WL, the remedial action may be terminated, and the reasons for termination should be documented. Remedial action shall be undertaken for any building that exceeds an annual average radon decay product concentration (including background) of 0.03 WL.

Indoor Gamma Radiation

The indoor gamma radiation after decontamination shall not exceed 20 microroentgen per hour (20 μ R/h) above background in any occupied or habitable building.

Indoor/Outdoor Structure Surface Contamination

Radionuclide^d	Allowable Surface Residual Contamination^e (dpm/100 cm²)		
	Average^{e,f}	Maximum^e	Removable^e
Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²³⁰ Th, ²²⁸ Th, ²³¹ Pa, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	100	300	20
Natural Th, ²³² Th, ⁹⁰ Sr, ²²³ Ra, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	1,000	3,000	200
Natural U, ²³⁵ U, ²³⁸ U, and associated decay products	5,000	15,000	1,000

Table 1. (continued)

Radionuclide ^d	Indoor/Outdoor Structure Surface Contamination		
	Allowable Surface Residual Contamination ^c (dpm/100 cm ²)		
	Average ^{e,f}	Maximum ^e	Removable ^e
Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above	5,000	15,000	1,000

^aIn the event of occurrence of mixtures of radionuclides, the fraction contributed by each radionuclide to its limit shall be determined, and the sum of these fractions shall not exceed 1.

^bThese guidelines represent unrestricted-use residual concentrations above background averaged across any 15-cm-thick layer to any depth and over any contiguous 100-m² surface area.

^cAs used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

^dWhere surface contamination by both alpha- and beta-gamma-emitting radionuclides exists, the limits established for alpha- and beta-gamma-emitting radionuclides shall apply independently.

^eMeasurements of average contaminant should not be averaged over more than 1 m². For objects of less surface area, the average shall be derived for each such object.

^fThe average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h over 1 m² at 1 cm and 1.0 mrad/h over 100 cm² at 1 cm, respectively, measured through not more than 1 mg/cm² of total absorber.

**Table 2. Background radiation levels in Wayne, New Jersey
and the surrounding area**

Type of radiation measurement or sample	Radiation level or radionuclide concentration	
	Range	Average
Gamma exposure rate at 1 m above ground surface ($\mu\text{R/h}$) ^a	8-11	9
Concentration of radionuclides in soil (pCi/g dry wt) ^b		
²³⁸ U	0.13-1.4	0.86
²²⁶ Ra	0.24-1.4	0.87
²³² Th	0.31-1.5	0.9

^aValues obtained from 35 locations in the Rochelle Park, New Jersey, area (ref 10).

^bSoil samples obtained from 3 locations around the maywood, New Jersey, area (ref 12).

Table 3. Results of gamma exposure rate measurements during scan of grid blocks in the Ball Park area

Grid Block No.	Coordinates ^a		Range of gamma exposure rates during scan of grid blocks (μ R/h)
	North	East	
1	7366	6824	8-12
2	7382	6808	8-11
3	7382	6824	9-12
4	7398	6808	10-12
5	7398	6824	10-12
6	7415	6808	10-12
7	7415	6824	10-12
8	7431	6808	9-10
9	7431	6824	9-12
10	7448	6824	8-10
11	7448	6841	9-10
12	7464	6808	9-12
13	7464	6824	9-10
14	7464	6841	9-10
15	7480	6808	9-10
16	7480	6824	9-11
17	7480	6841	9-10
18	7480	6939	6-8
19	7480	6956	8-10
20	7497	6939	9-10
21	7497	6956	6-8
22	7513	6939	8-10
23	7513	6956	8-9
24	7530	6939	8-10
25	7530	6956	12-39
26	7546	6956	9-33

^aGrid block locations are shown in Fig. 3.

Table 4. Results and locations of the gamma exposure rate measurements at grid points in the Ball Park area

Grid Point No.	Coordinates ^a		Gamma exposure rate at 1 m ($\mu\text{R/h}$)	Gamma exposure rate at the ground surface ($\mu\text{R/h}$)
	North	East		
1	7398	6808	11	12
2	7415	6808	11	10
3	7431	6808	11	11
4	7448	6808	8	8
5	7464	6824	8	8
6	7464	6923	8	8
7	7464	6939	22	21
8	7480	6808	10	15
9	7480	6824	8	8
10	7480	6923	9	10
11	7480	6939	10	10
12	7497	6923	11	12
13	7497	6939	9	9
14	7513	6923	10	11
15	7513	6939	18	26
16	7530	6923	10	11
17	7530	6939	8	9
18	7530	6956	32	28
19	7546	6923	8	8
20	7546	6939	14	14
21	7546	6956	30	34
22	7562	6923	10	9
23	7562	6939	7	7
24	7562	6956	10	9

^aGrid point locations are shown in Fig. 3.

Table 5. Results of ORNL analysis of BNI soil samples from the Ball Park area

Sample	Location ^a		Depth (cm)	Radionuclide concentration(pCi/g) ^b		
	North	East		²²⁶ Ra ^c	²³² Th ^c	²³⁸ U ^d
Systematic samples ^e						
S15L	7497	6874	0-15	1.2 ±0.2 (1.0)	5.8±0.2 (5.6)	3.3 (3.5)
S16L	7530	6874	0-15	1.2 ±0.2 (1.0)	4.9±0.2 (5.2)	4.1 (3.1)
S17L	7464	6890	0-15	0.67±0.1 (0.6)	1.2±0.1 (1.2)	<2.0 (1.0)
S18L	7513	6890	0-15	1.1 ±0.2 (0.8)	3.5±0.2 (3.5)	<2.0 (3.5)
S19L	7487	6906	0-15	1.2 ±0.2 (0.9)	5.8±0.2 (5.7)	3.3 (3.3)
S20L	7546	6906	0-15	0.89±0.2 (0.8)	1.9±0.2 (2.0)	<3.0 (1.5)

^aLocations of soil samples are shown on Fig. 4.

^bBNI results are presented in parentheses.

^cIndicated counting error is at the 95% confidence level ($\pm 2\sigma$).

^dAnalytical error of measurement results is less than $\pm 5\%$ (95% confidence level).

^eSystematic samples are taken at locations irrespective of gamma exposure rates.

Table 6. Results of ORNL analysis of BNI soil samples from the Sheffield Brook area

Sample	Location ^a		Depth (cm)	Radionuclide concentration(pCi/g) ^b		
	North	East		²²⁶ Ra ^c	²³² Th ^c	²³⁸ U ^d
Systematic samples ^e						
S1L	7059	6879	90-105	0.65±0.09 (0.5)	4.4 ±0.3 (2.0)	f (2.3)
S2L	6983	6900	90-105	0.89±0.2 (0.9)	6.6 ±0.5 (2.9)	f (1.0)
S3L	7010	6900	90-105	1.3 ±0.3 (0.9)	6.5 ±0.1 (1.5)	f (1.1)
S4L	7125	6969	90-105	0.50±0.04 (0.8)	1.2 ±0.09 (2.8)	f (2.4)
S5L	7080	6775	90-105	0.43±0.1 (<0.6)	0.78±0.2 (<1.4)	f (<4.4)
S6L	7070	6780	90-105	0.45±0.02 (<0.6)	1.2 ±0.03 (<1.1)	f (<3.9)
S7L	6900	6833	0-15	0.45±0.1 (0.6)	1.1 ±0.2 (3.1)	f (2.5)
S8L	7117	6966	60-75	0.80±0.1 (0.8)	2.6 ±0.8 (1.6)	<10 (2.4)
S9L	7083	6766	60-75	0.80±0.1 (0.7)	3.0 ±1 (3.4)	<7.0 (1.7)
S10L	6883	6866	60-75	0.50±0.1 (0.4)	1.2 ±0.4 (1.4)	f (1.7)
S11L	7017	6900	60-75	1.1 ±0.1 (0.9)	<2.0 (1.5)	f (1.1)
S12L	6983	6933	60-75	1.0 ±0.1 (2.0)	<4.0 (2.1)	3.0 (1.5)
S14L	7050	6866	60-75	0.60±0.1 (0.5)	<3.0 (2.0)	f (2.3)
S15L	7483	7033	455-470	0.80±0.1 (0.5)	<1.0 (0.8)	f (<1.4)
S16L	7483	7066	455-470	0.80±0.1 (0.5)	<1.0 (1.0)	<10 (2.6)
S17L	7483	7100	455-470	0.80±0.1 (0.6)	<1.0 (1.1)	g (1.7)
S18L	7517	7113	455-470	0.80±0.1 (0.6)	<1.0 (0.9)	g (1.4)
S19L	7517	7133	455-470	0.90±0.1 (0.5)	<2.0 (1.2)	g (<1.6)
S20L	7539	7148	515-534	0.64±0.03 (1.0)	1.1 ±0.04 (1.3)	g (<2.0)
S21L	7532	7134	515-535	0.64±0.2 (0.8)	1.1 ±0.2 (1.4)	g (<2.0)

^aLocations of soil samples are shown on Fig. 4.

^bBNI results are presented in parentheses.

^cIndicated counting error is at the 95% confidence level ($\pm 2\sigma$).

^dAnalytical error of measurement results is less than $\pm 5\%$ (95% confidence level).

^eSystematic samples are taken at grid locations irrespective of gamma exposure.

^fNot analyzed.

^gNone detected.

Table 7. Results of analysis of verification soil samples collected by ORNL in the Ball Park area

Sample	Coordinates ^a		Depth (cm)	Radionuclide concentration(pCi/g)		
	North	East		²²⁶ Ra ^b	²³² Th ^b	²³⁸ U ^c
Systematic samples ^d						
S7AV	7484	6821	0-5	1.3 ±0.1	4.5±2	2.6
S10AV	7433	6819	0-5	1.3 ±0.1	5.3±2	3.7
S12AV	7385	6818	0-5	1.2 ±0.06	5.1±1	2.9
S14AV	7497	6920	0-30	1.6 ±0.1	9.1±2	6.3
S15AV	7464	6745	0-15	0.73±0.2	2.5±0.2	1.6
S15BV	7464	6745	15-30	1.9 ±0.1	14 ±2	9.1
S16AV	7444	6778	0-5	1.0 ±1	4.7±0.4	2.8
S17AV	7536	6792	0-5	1.1 ±0.1	4.9±0.4	3.0
S17BV	7536	6792	5-15	1.1 ±0.2	4.6±0.6	2.8
S18AV	7516	6775	0-5	1.1 ±0.2	5.2±0.3	3.5
S19AV	7444	6811	0-5	0.71±0.09	1.1±0.2	0.91
S19BV	7444	6811	5-15	0.72±0.08	1.0±0.2	0.96
S19CV	7444	6811	15-25	1.6 ±0.09	11 ±2	6.3
S20AV	7478	6785	0-5	0.87±0.1	2.8±0.2	1.7
S20BV	7478	6785	5-15	1.1 ±0.1	4.7±0.3	2.5
S21AV	7480	6792	0-5	0.77±0.08	1.9±0.4	1.4
S21BV	7480	6792	5-15	0.80±0.07	3.0±0.5	1.3
S22AV	7497	6808	0-5	1.2 ±0.1	5.3±0.3	3.3
Biased samples ^e						
B23AV	7464	6795	0-5	0.92±0.09	5.8±0.7	3.3
B24AV	7464	6782	0-5	1.0 ±0.08	5.9±0.3	3.4
B25BV	7592	6883	5-15	1.2 ±0.1	5.6±0.3	2.7
B26AV	7589	6857	0-5	1.1 ±0.2	5.0±0.5	2.1
B26BV	7589	6857	5-15	1.0 ±0.09	2.4±0.4	1.3
B27AV	7612	6775	0-5	0.80±0.3	2.1±0.3	1.3
B27BV	7612	6775	5-15	0.79±0.07	2.0±0.2	1.3
B28AV	7638	6759	0-5	1.1 ±0.07	4.0±1	1.9
B28BV	7638	6759	5-15	1.2 ±0.09	5.7±0.7	2.5
B29AV	7687	6775	0-5	0.81±0.07	2.3±0.9	1.4
B29BV	7687	6775	5-15	0.83±0.05	2.6±0.4	1.5
B30AV	7595	6788	0-5	0.85±0.05	2.2±0.5	1.3
B30BV	7595	6788	5-15	0.84±0.1	3.0±0.3	1.4
B31AV	7854	6815	0-5	0.87±0.07	2.0±0.2	1.5
B31BV	7854	6815	5-15	0.82±0.05	1.9±0.1	1.3
B32AV	7907	6778	0-5	0.86±0.2	1.8±0.8	1.2
B32BV	7907	6778	5-15	0.98±0.06	1.6±0.1	1.1
B33AV	7632	6769	0-5	0.89±0.1	2.3±0.2	1.5
B33BV	7632	6768	5-15	0.88±0.1	2.2±0.2	1.4

Table 7. (Continued)

Sample	Coordinates ^a		Depth (cm)	Radionuclide concentration(pCi/g)		
	North	East		²²⁶ Ra ^b	²³² Th ^b	²³⁸ U ^c
B34AV	7894	6867	0-5	0.85±0.1	3.0±0.2	1.9
B34BV	7894	6867	5-15	0.92±0.1	2.6±0.5	1.6
B35AV	7798	6854	0-5	0.80±0.06	2.6±0.3	1.6
B35BV	7798	6854	5-15	1.1 ±0.08	3.5±0.9	1.8
B36AV	7677	6877	0-5	0.93±0.07	2.1±0.5	1.3
B36BV	7677	6877	5-15	1.2 ±0.05	1.6±0.7	1.2
B37AV	7766	6903	0-5	1.2 ±0.08	5.7±0.9	2.8

^aLocations of soil samples are shown on Fig. 5.

^bIndicated counting error is at the 95% confidence level ($\pm 2\sigma$).

^cAnalytical error of measurement results is less than $\pm 5\%$ (95% confidence level).

^dSystematic samples are taken at locations irrespective of gamma exposure rates.

^eBiased samples are taken from areas shown to have elevated gamma exposure rates.

Table 8. Results of analysis of verification soil samples collected by ORNL in the Sheffield Brook area

Sample	Location ^a		Depth (cm)	Radionuclide concentration(pCi/g)	
	North	East		²²⁶ Ra ^b	²³² Th ^b
Systematic samples ^c					
S2V	8099	6905	0-15	0.86±0.08	1.7 ±0.09
S3V	8070	6925	0-15	0.65±0.07	1.7 ±0.1
S5V	8010	6935	0-15	0.55±0.06	1.0 ±0.3
S6V	7978	6940	0-15	0.68±0.1	0.93±0.2
S7V	7850	6968	0-15	1.1 ±0.3	4.5 ±0.2
S8V	7820	6962	0-15	0.66±0.08	0.79±0.3
S9V	7790	6976	0-15	0.57±0.04	0.87±0.2
S10V	7780	6992	0-15	0.83±0.1	1.1 ±0.3
S11V	7750	6974	0-15	0.65±0.03	1.4 ±0.07
S12V	7688	7117	0-15	0.85±0.1	1.4 ±0.1
S13V	7647	7010	0-15	1.1 ±0.05	1.1 ±0.3
S14V	7717	6990	0-15	0.80±0.08	1.3 ±0.03
S15V	7712	7048	0-15	0.81±0.04	1.6 ±0.08
S16V	7414	6958	0-15	1.1 ±0.2	5.4 ±0.2
S17V	7300	6951	0-15	0.43±0.06	0.61±0.2
S18V	7242	6966	0-15	0.34±0.04	0.48±0.1
S19V	7320	6951	0-15	0.52±0.02	1.4 ±0.06
S20V	7120	6715	0-15	0.56±0.09	1.1 ±0.3
S21V	7120	6980	0-15	1.2 ±0.1	5.4 ±0.2
S22V	7050	6733	0-15	0.74±0.07	4.3 ±0.1
S23V	7017	6800	0-15	0.50±0.2	1.9 ±0.5
S24V	7012	6860	0-15	0.5±0.06	2.9 ±0.09
S26V	7983	6833	0-15	0.51±0.05	1.4 ±0.3
S28V	6920	6873	0-15	0.67±0.04	2.2 ±0.5
S29V	6920	6750	0-15	0.39±0.05	0.49±0.1
S31V	7050	6933	0-15	0.49±0.08	1.1 ±0.3
S32V	7713	6776	0-15	1.2 ±0.05	5.4 ±0.3
S33V	7768	6773	0-15	0.94±0.1	2.9 ±0.2
S34V	7790	6950	0-15	0.72±0.06	1.8 ±0.1
S35V	7783	6930	0-15	0.71±0.02	0.96±0.1
S36V	7683	6923	0-15	0.76±0.06	0.93±0.1
S37V	7670	7235	0-15	0.72±0.07	1.0 ±0.3
S38V	7670	7214	0-15	0.81±0.05	1.1 ±0.06
S39V	7648	7216	0-15	0.57±0.04	0.89±0.1

Table 8. (Continued)

Sample	Location ^a		Depth (cm)	Radionuclide concentration(pCi/g)	
	North	East		²²⁶ Ra ^b	²³² Th ^b
S40V	7648	7204	0-15	0.64±0.04	0.85±0.07
S41V	7626	7182	0-15	0.80±0.08	1.9 ±0.1
S42V	7618	7176	0-15	0.72±0.08	1.1 ±0.06
S44V	7638	7200	0-15	0.71±0.05	1.0 ±0.07
S46V	7445	6961	0-5	0.90±0.05	0.98±0.05
S47V	7931	6945	0-5	0.92±0.1	4.6 ±0.6
S48V	7883	6955	0-5	0.84±0.1	1.1 ±0.2
S49V	7885	6962	0-5	1.2 ±0.1	5.4 ±0.2
S50V	7880	6966	0-5	0.63±0.4	1.7 ±0.1
S51V	7517	7040	0-10	0.69±0.03	0.85±0.08
S52V	7537	7045	0-10	0.77±0.2	1.2 ±0.1
S53V	7517	7070	0-10	0.76±0.1	1.1 ±0.3
S54V	7446	7044	0-10	0.71±0.2	4.9 ±0.2
S55V	7478	7033	0-13	0.69±0.07	1.0 ±0.1
S56V	7527	7145	0-5	0.98±0.1	1.1 ±0.3
S57V	7532	7127	0-10	1.0 ±0.03	1.0 ±0.1
S58V	7537	7134	0-8	0.79±0.2	1.1 ±0.4
S59V	7484	7061	0-10	0.47±0.1	0.61±0.3
S60V	7478	7050	0-10	0.65±0.02	0.84±1.0
S61V	7490	7045	0-10	0.66±0.07	0.80±0.04
S62V	7490	7084	0-10	0.57±0.1	0.59±0.2
S63V	7490	7102	0-10	0.58±0.03	0.90±0.2
S64V	7523	7112	0-13	0.74±0.03	0.98±0.1
S65V	7507	7106	0-13	0.50±0.03	0.72±0.08
S66V	7507	7106	0-13	0.68±0.05	0.91±0.1
<i>Biased samples^d</i>					
B1BV	8169	6874	0-15	0.94±0.3	3.0 ±0.1
B2BV	8187	6880	0-15	1.3 ±0.1	4.3 ±0.2
B3AV	8158	6892	0-15	0.82±0.4	4.5 ±0.3
B5V	7360	6903	0-15	0.97±0.1	3.5 ±0.3
B6V	7396	6946	0-15	1.3 ±0.2	4.1 ±0.3
B7V	7355	6971	0-15	0.69±0.1	1.6 ±0.3
B13V	7032	6872	0-15	0.71±0.06	4.7 ±0.1
B14V	7020	6825	0-15	0.73±0.1	5.6 ±0.6

Table 8. (Continued)

Sample	Location ^a		Depth (cm)	Radionuclide concentration(pCi/g)	
	North East			²²⁶ Ra ^b	²³² Th ^b
<i>Biased samples^d</i>					
B21V	7758	6843	0-15	1.1 ±0.2	4.2±0.3
B22V	7605	6960	0-15	2.1 ±0.2	12 ±0.5
B24V	7450	6981	0-5	0.97±0.2	4.8±0.2

^aLocations of soil samples are shown on Fig. 6.

^bIndicated counting error is at the 95% confidence level ($\pm 2\sigma$).

^cSystematic samples are taken at grid locations irrespective of gamma exposure.

^dBiased samples are taken from areas shown to have elevated gamma exposure rates.

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