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SURFACE RADIOLOGICAL INVESTIGATIONS AT THE EQUALIZATION BASIN (3524) SITE

M. S. Uziel
J. K. Williams
P. F. Tiner

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M. S. Uziel, J. K. Williams, and P. F. Tiner

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ABSTRACT

A surface radiological investigation was conducted at the Equalization Basin (3524) site from November 1988 through April 1989 by the Measurement Applications and Development Group, Oak Ridge National Laboratory. The purposes of this survey were (1) to determine the presence, nature, and extent of surface radiological contamination and (2) to recommend interim corrective measures to limit human exposures to radioactivity and minimize the potential for contaminant dispersion.

Four areas of significant contamination were identified outside the Contamination Area fence:

1. At the southeast corner of the site, a contaminated region that is currently encircled by a temporary Contamination Area rope boundary had surface gamma exposure rates up to 6 mR/h and beta-gamma dose rates up to 10 mrad/h. Gamma exposure rates up to 3 mR/h were measured outside the rope. This area is situated alongside a small gravel road that is occasionally used by both pedestrians and vehicles.
2. In a region east of the basin, gamma exposure rates reached 2.3 mR/h and beta-gamma dose rates reached 5.4 mrad/h. On the ground surface beneath the steam pipe, alpha activity levels measured 1000 dpm/100 cm^2.
3. In a contaminated region north of the basin, gamma exposure rates reached 2.4 mR/h and beta-gamma dose rates reached 2.9 mrad/h.
4. South of the basin in an area that remained moist during the survey period, beta-gamma dose rates reached 5.0 mrad/h.

Recommendations for corrective actions are included.

SURFACE RADIOLOGICAL INVESTIGATIONS AT THE EQUALIZATION BASIN (3524) SITE

INTRODUCTION

A surface radiological investigation of the Equalization Basin (3524) site was conducted from November 1988 through April 1989. This survey was performed by the Measurement Applications and Development Group of the Health and Safety Research Division (HASRD) of the Oak Ridge National Laboratory (ORNL) at the request of Remedial Action Program (RAP) personnel at ORNL. The purposes of this survey were (1) to determine the presence, nature, and extent of surface radiological contamination and (2) to recommend interim corrective measures to limit human exposures to radioactivity and minimize the potential for contaminant dispersion.

The Equalization Basin has been assigned to Waste Area Group (WAG) 1 and to Solid Waste Management Unit (SWMU) 1.13 by the ORNL RAP staff.[1]

SITE HISTORY

The Equalization Basin (3524) is one of four holding ponds located in the south central part of the main ORNL complex[1] (see Figs. 1-3). The pond is on the southeast corner of the intersection of Third Street and White Oak Avenue at ORNL grid coordinates (measured in feet) North 21,695 to 21,785 and East 30,875 to 31,175 (see Fig. 4). It has functioned as an intermediate storage, collection, and mixing basin for the Process Waste Treatment System located in Building 3544.[2]

The 3524 pond formerly received process wastes from the Bethel Valley ORNL facility, but on occasion some wastes were received from the Melton Valley facilities. Process wastes consisted of steam condensate from heating coils, process cooling water, condensate from the Low-Level Waste Evaporator Facility, groundwater leakage to the pipes and tiles entering the pond, and discharges from numerous building sinks and floor drains. Several activities were responsible for the process wastes: reactor operations, radioisotope processing, hot cell operation, and general research and development. Waste streams were primarily effluents that contained traces of metals and solvents with little or no radioactivity.[2]

The Equalization Basin is an unlined natural clay basin approximately 29 × 76 m (95 × 250 ft) with a maximum depth of 2 m (6.5 ft). Elevation at the top of the berm is about 240 m (787 ft) above mean sea level. The basin is capable of storing 3.8 million L (1 million gal) of liquid.[3] The basin was constructed in two stages and has a nonuniform depth. The original pond was one-half the size of the present one and occupied only the

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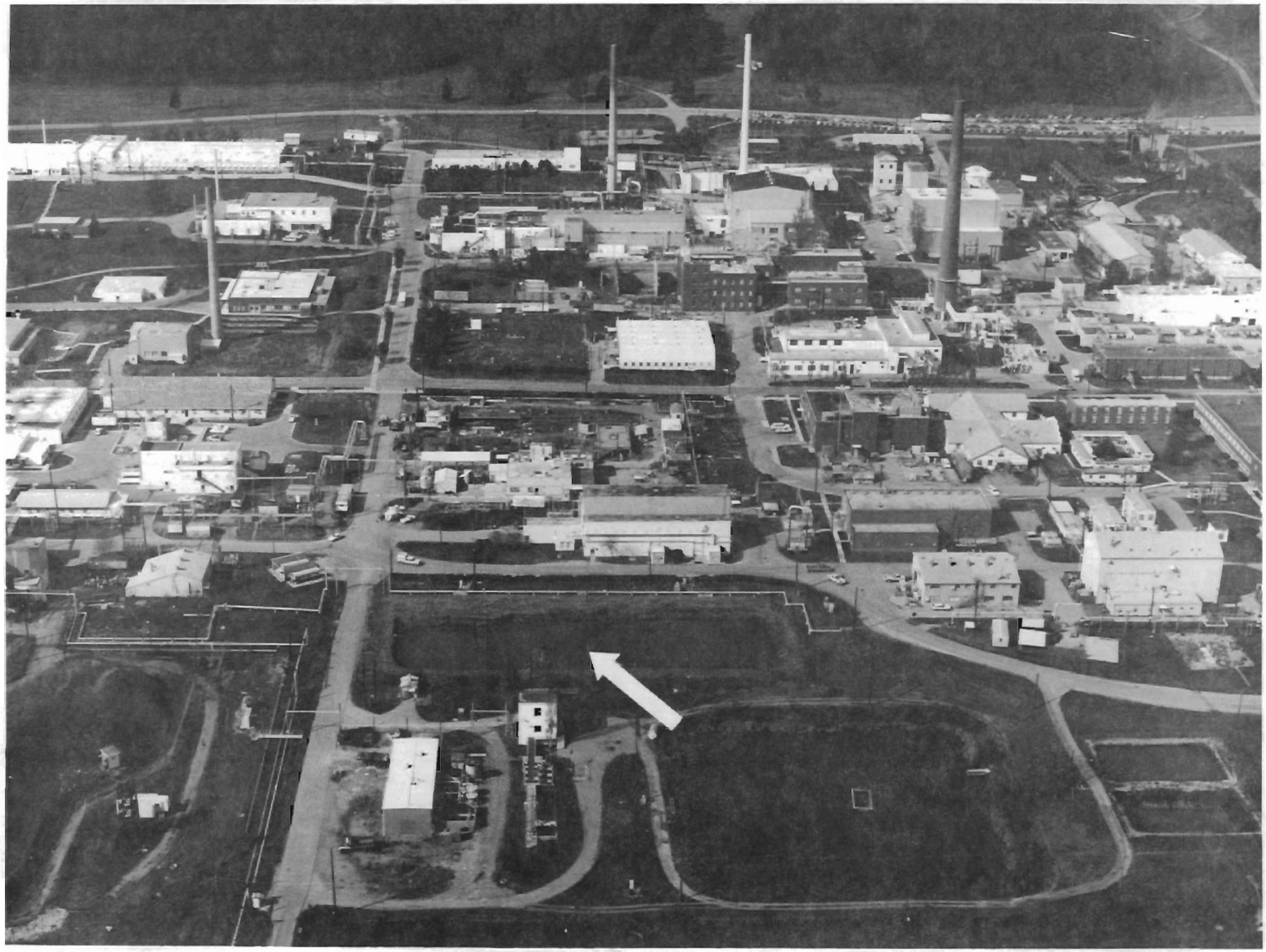

Fig. 1. Aerial view of the central part of the main ORNL complex with arrow pointing to the Equalization Basin (3524).

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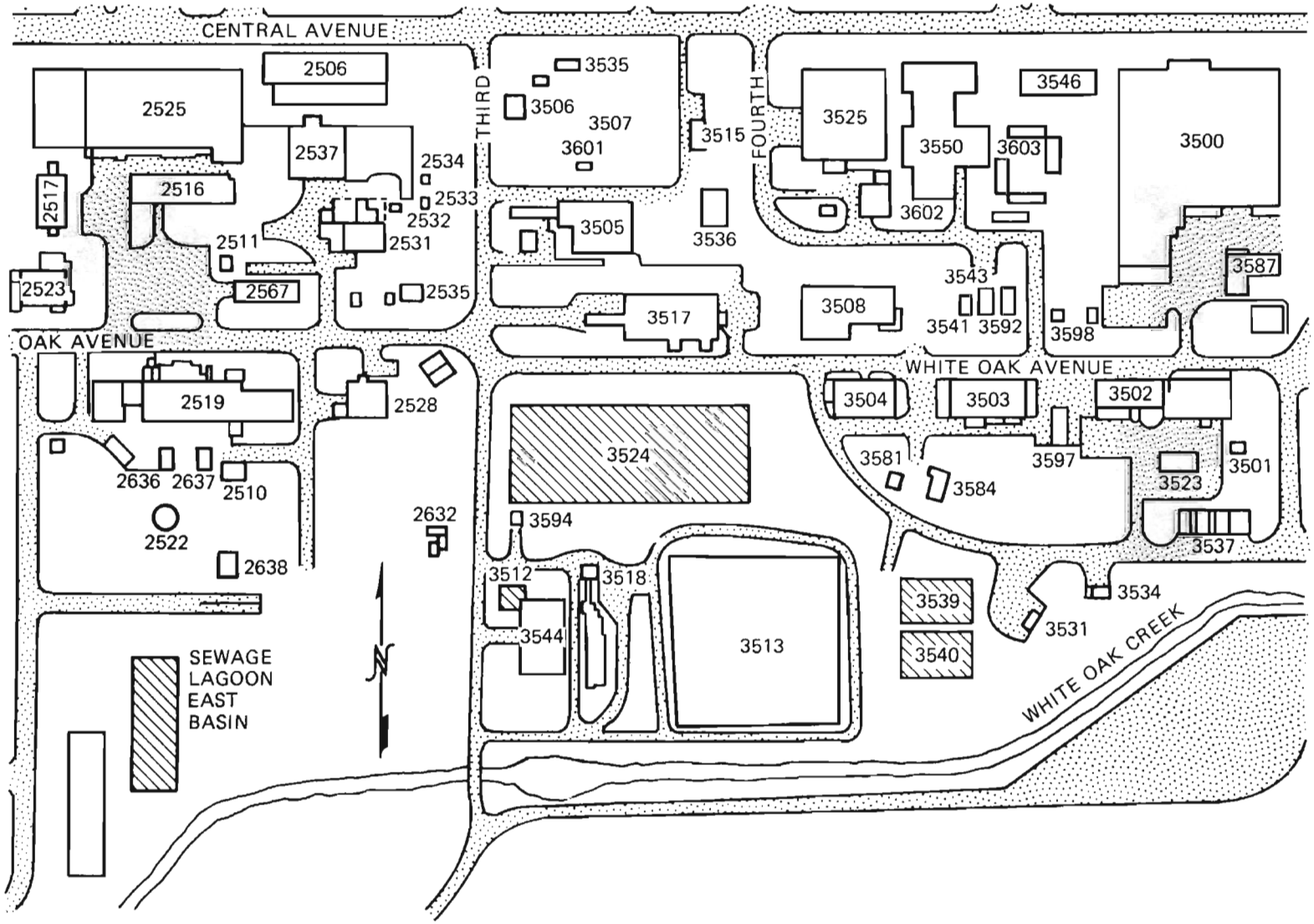

Fig. 2. Map showing the Equalization Basin (3524) and surrounding buildings and ponds.

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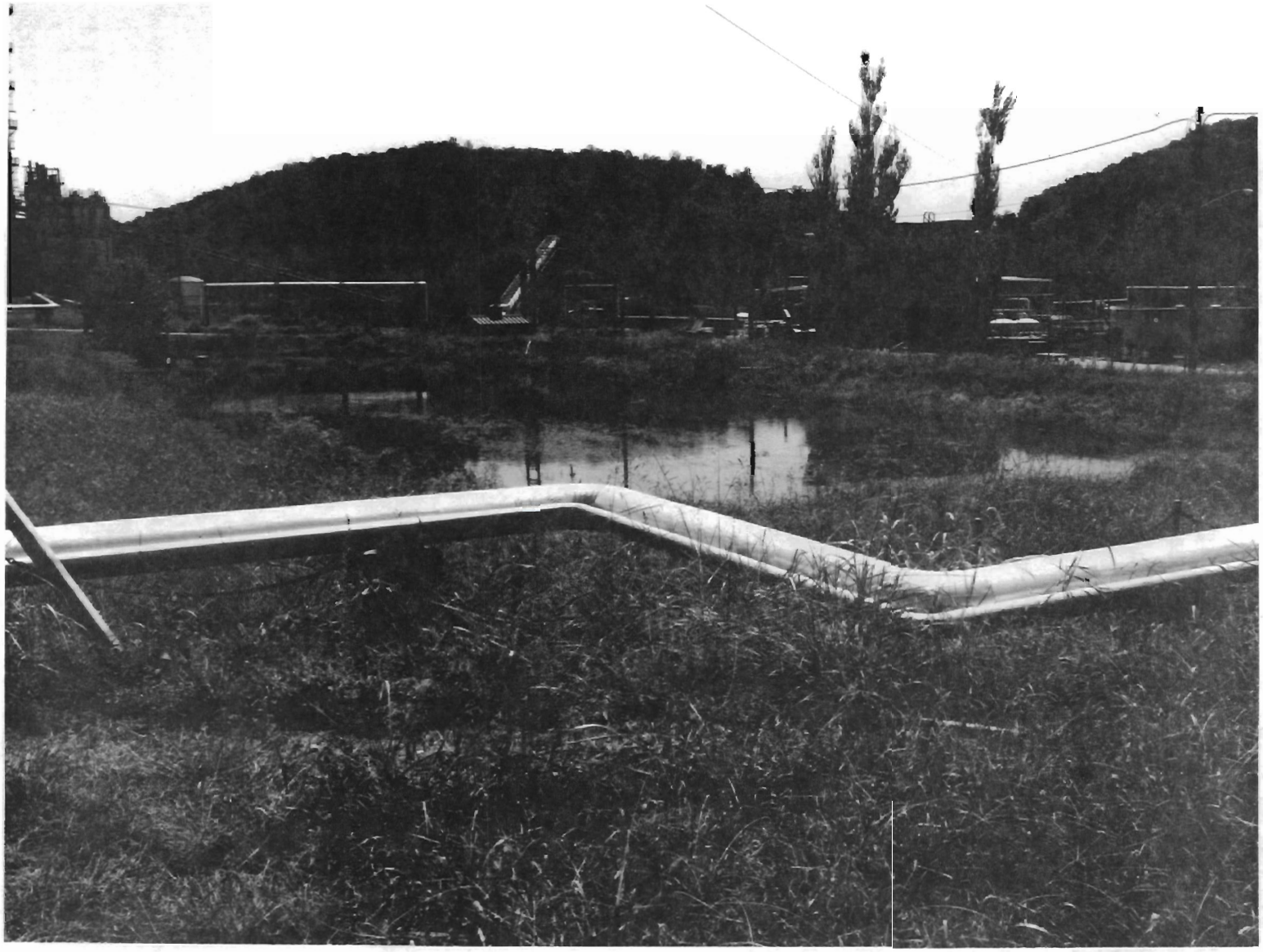

Fig. 3. View of the Equalization Basin (3524) looking southwest.

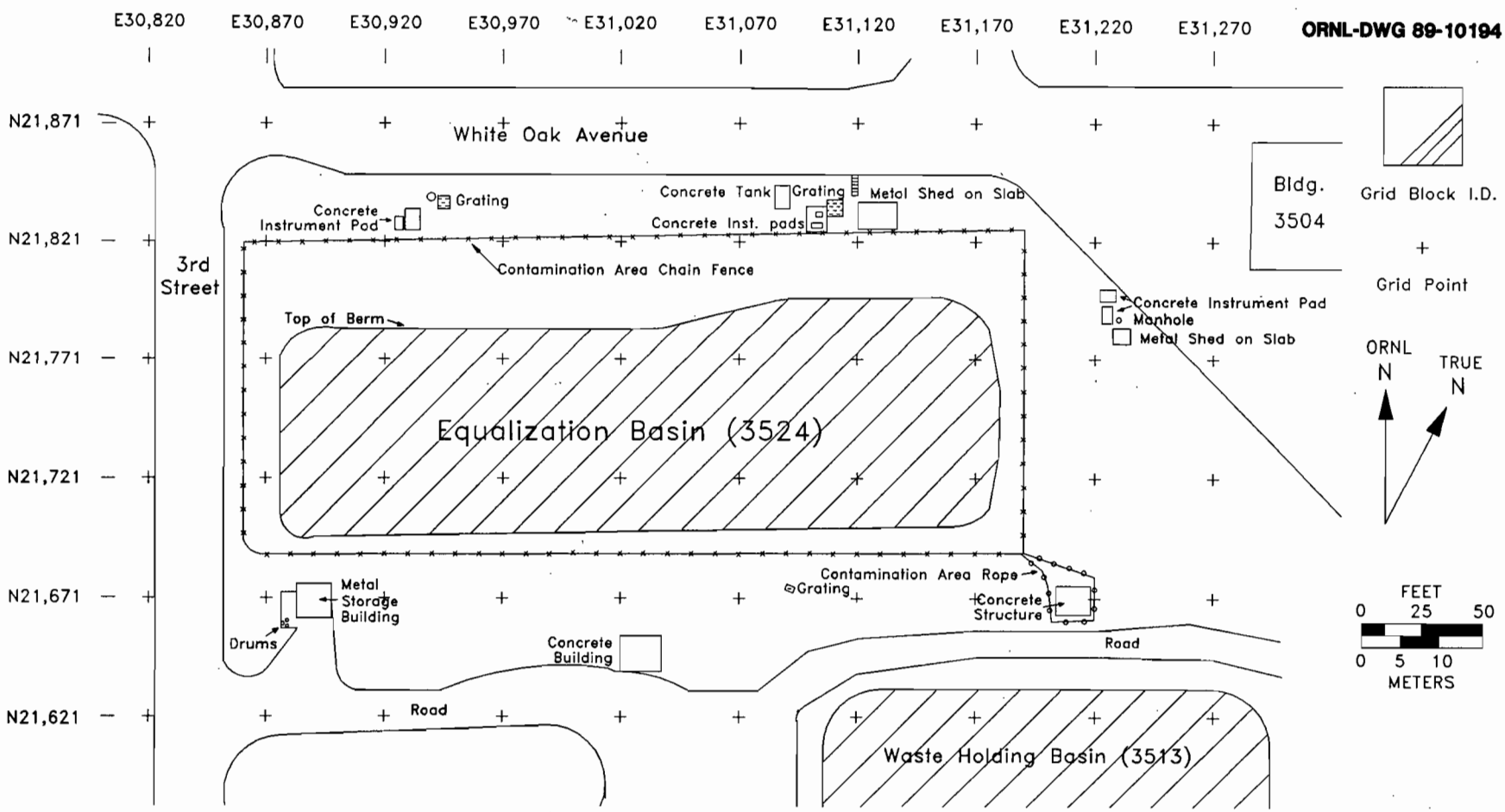

Fig. 4. Diagram of the Equalization Basin (3524) and immediate vicinity.

eastern half of the rectangular area. During the expansion of the original pond, rock prevented complete excavation of the western half. Outcroppings of rock are evident in the western end of the basin when water levels are low.[4]

The sediment in Basin 3524 has accumulated to a depth ranging from approximately 0.2 to 1.4 m (0.6 to 4.6 ft) since the site began operation in 1945.[4] In 1984 Braunstein et al. analyzed 24 sediment cores to determine the concentration, distribution, and inventory of radionuclides in preparation for future decontamination and decommissioning. The sediment was estimated to contain a total of 150 Ci of activity, 87% of which was contributed by two radionuclides, ^{137}Cs (102 Ci) and ^{90}Sr (29 Ci). Also included in this estimate were gross alpha (11 Ci), ^{241}Am (4.6 Ci), ^{60}Co (2.2 Ci), and ^{154}Eu (0.9 Ci).[4] In 1987 Francis and Sealand estimated that the sediment in the 3524 impoundment contained a total inventory of 75 Ci, including ^{137}Cs (45 Ci); ^{90}Sr (23 Ci); gross alpha (4.2 Ci); ^{239}Pu (2.6 Ci); ^{241}Am (2.2 Ci); and ^{152}Eu, ^{154}Eu, and ^{238}Pu (<1 Ci). Francis and Sealand also noted that differences in inventory by a factor of 2 should not be considered unusual.[5]

Sludge and influent water samples were collected from the Equalization Basin (3524) during January and February of 1986 and analyzed for metal, pesticide, herbicide, and volatile organic constituents. None of the data exceeded the appropriate erythrocyte protoporphyrin toxicity test limitations in either the metal or pesticide/herbicide categories, and only a few of the organic constituents were present at levels above the analytical detection limits. The ignitability, reactivity, and corrosivity tests on sludge all proved negative. All flash points were >70°C, pHs were between 7.0 and 9.0, and none of the reactivity characteristics were exhibited.[6]

A ^{82}Br tracer experiment in 1986 revealed the presence of several rapid leak paths from the Equalization Basin. Evaluation of the tracer samples and independent leak flow measurements indicated that the leakage was probably on the order of 6.3×10^{-4} m^3/s (10 gpm).[7]

In April 1989, after the survey was completed, all process waste that formerly entered the Equalization Basin was diverted to the Bethel Valley Process Waste Storage Tanks. The basin currently receives direct rainfall and seepage from the area via an abandoned north-south storm drain and another east-west storm drain. Water from the east-west drain, located south of the basin, is pumped back into the basin. The pumped water is monitored weekly for radioactivity, which averages about 45 pCi/mL.[8]

SURVEY METHODS

A comprehensive description of the survey methods and instrumentation is presented in *Procedures Manual for the ORNL Radiological Survey Activities (RASA) Program*, Oak Ridge National Laboratory, ORNL/TM-8600 (April 1987).[9] All measurements presented in this report are gross readings; background radiation levels have not been subtracted.

GAMMA RADIATION

Gamma radiation was measured with a sodium iodide (NaI) scintillation probe connected to a Victoreen Model 490 Thyac III ratemeter. Shielded surface gamma measure-

ments were obtained by inserting the NaI scintillation probe in a cylindrical lead shield with an open end facing the ground surface. The lead shield effectively blocks any radiation emanating from the basin and surrounding areas ("shine"), so that actual ground surface gamma radiation can be measured more accurately.

Because NaI gamma scintillators are energy dependent, measurements of gamma radiation levels made with these instruments must be normalized to pressurized ionization chamber (PIC) measurements to estimate gamma exposure rates. The function developed for these conversions is:

$$y = x/\mathrm{CF}$$

where

y = the exposure rate in μR/h,

x = the scintillometer measurements in counts per minute (cpm),

CF = the conversion factor determined in the field through a direct correlation between a selected number of PIC measurements and scintillometer measurements in cpm/(μR/h).

For this site, CF = 800 cpm/(μR/h).

When radiation levels exceeded the limits of the NaI gamma scintillator (800,000 cpm), measurements made with a closed-window Geiger-Mueller survey meter (GMSM) were converted to exposure rates by using the following relationship:

$$3100 \text{ cpm} = 1 \text{ mR/h} \qquad \text{or} \qquad 3.1 \text{ cpm} = 1\ \mu\text{R/h}\ .$$

This is an instrument-specific conversion factor based on ^{226}Ra.

BETA-GAMMA RADIATION

Beta-gamma and gamma energy levels were detected with a portable Technical Associates (TA) mini-scaler/ratemeter, Model PRS-3, with an HP-265 pancake detector (<2 mg/cm^2 wall thickness). The instrument was set in the open configuration to detect beta-gamma and in the closed configuration to detect gamma. After calibration of Model PRS-3 to a known strontium source at the ORNL Radiation Calibration Laboratory (RADCAL), beta radiation activity levels in cpm were converted to dose rates in mrad/h using the following relationship:

$$2800 \text{ cpm} = 1 \text{ mrad/h} \qquad \text{or} \qquad (\text{mrad/h})/\text{cpm} = 0.00036\ .$$

Gamma radiation levels measured with the portable TA ratemeter were converted to dose rates by using the following instrument-specific conversion factor based on ^{226}Ra:

$$3600 \text{ cpm} = 1 \text{ mrad/h}\ .$$

If the field measurement did not allow separation of the beta and gamma components, the more conservative beta conversion factor was used.

Beta-gamma and gamma radiation were also detected with a GMSM, Model Q-5218, equipped with a side-window probe (30 mg/cm^2 wall thickness). This instrument was set in the open configuration to detect beta-gamma radiation and in the closed configuration to detect gamma radiation. In some cases, closed configuration GMSM readings were divided by 3100 to estimate gamma levels (mR/h) based on ^{226}Ra as a calibration standard.

ALPHA RADIATION

Alpha radiation was measured with an ORNL alpha survey meter, Model Q-2789-1, connected to a zinc sulfide scintillation probe. Counts per minute were recorded for a direct, 60-s measurement and converted to disintegrations per minute (dpm) per 100 cm^2 using the instrument-specific conversion factor.

GRID

For convenience in reporting results, the entire outdoor area was divided into 15-m (50-ft) grid blocks as shown in Fig. 5. An individual grid block is identified by the coordinates of its lower right corner (see Grid Block ID legend on Fig. 5).

SCOPE OF THE SURVEY

The survey included:

- A surface gamma scan of the area between the fence delineating the Contamination Area control zone and the roads surrounding the site (see Fig. 6). A NaI scintillation probe held approximately 5 cm (2 in.) above the ground surface was used for this survey. The gamma scan range and areas of high gamma contamination were reported for each grid block. When radiation levels exceeded the detection limits of the scintillator (800,000 cpm), the GMSM was used.
- Measurement of gamma exposure rates at 1 m above the ground surface, at the ground surface, and at the surface shielded. These measurements were made at 85 selected grid points using the NaI gamma scintillator. When radiation levels exceeded the limits of the scintillator (800,000 cpm), the GMSM was used.
- A surface beta-gamma scan of the area between the fence delineating the Contamination Area control zone and the roads surrounding the site (see Fig. 6). The pancake detector of the TA mini-scaler/ratemeter was set in the open configuration and held approximately 5 cm (2 in.) above the ground surface for this survey. The beta-gamma scan range and areas of high beta-gamma contamination were reported for each grid block.
- Measurement of surface beta-gamma and gamma activity levels at 85 selected grid points using the TA mini-scaler/ratemeter with the pancake detector in the open and closed configuration.
- Measurement of surface alpha activity at 82 selected grid points using the alpha meter.

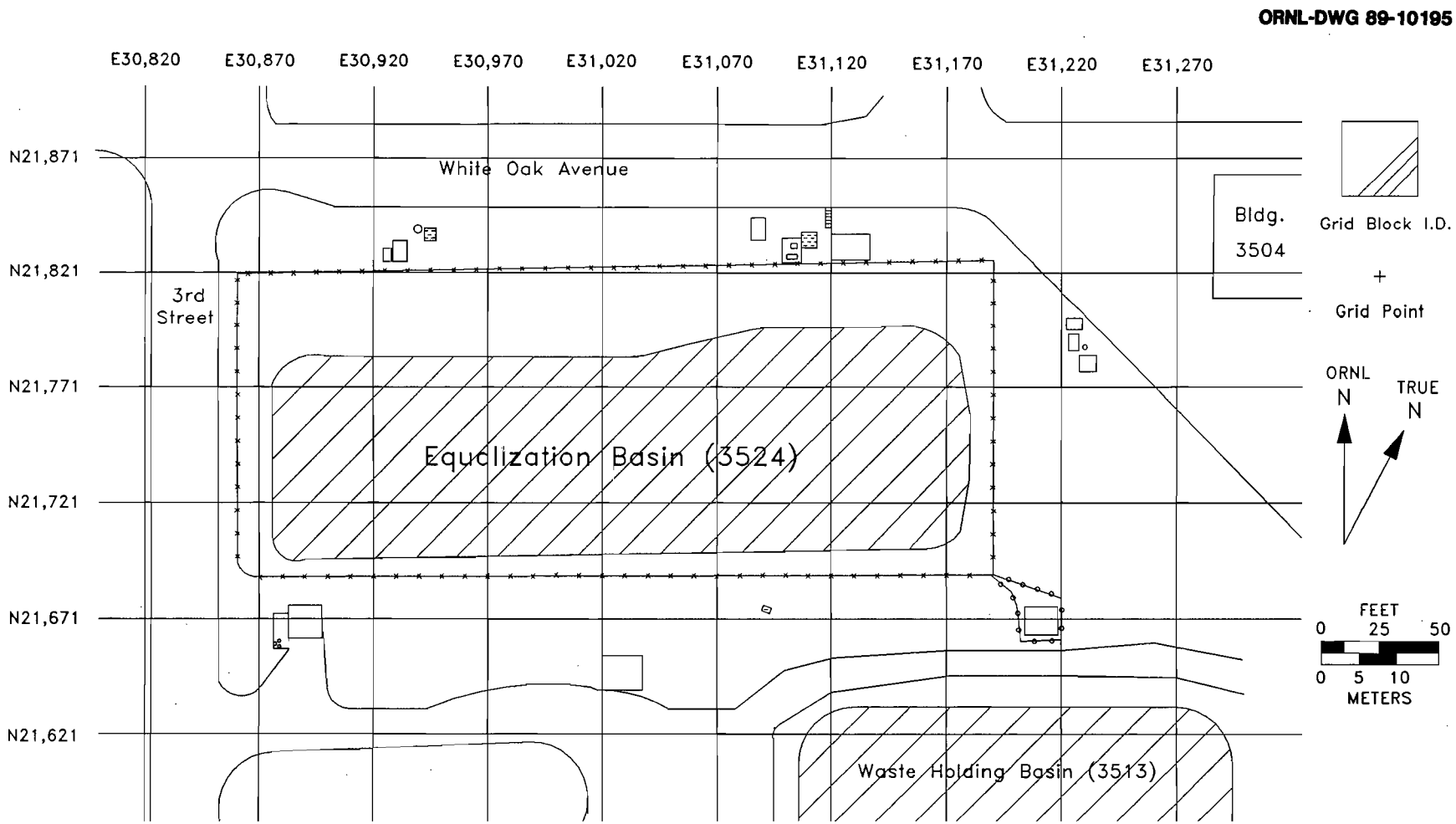

Fig. 5. Diagram showing grid block locations at the Equalization Basin (3524) site.

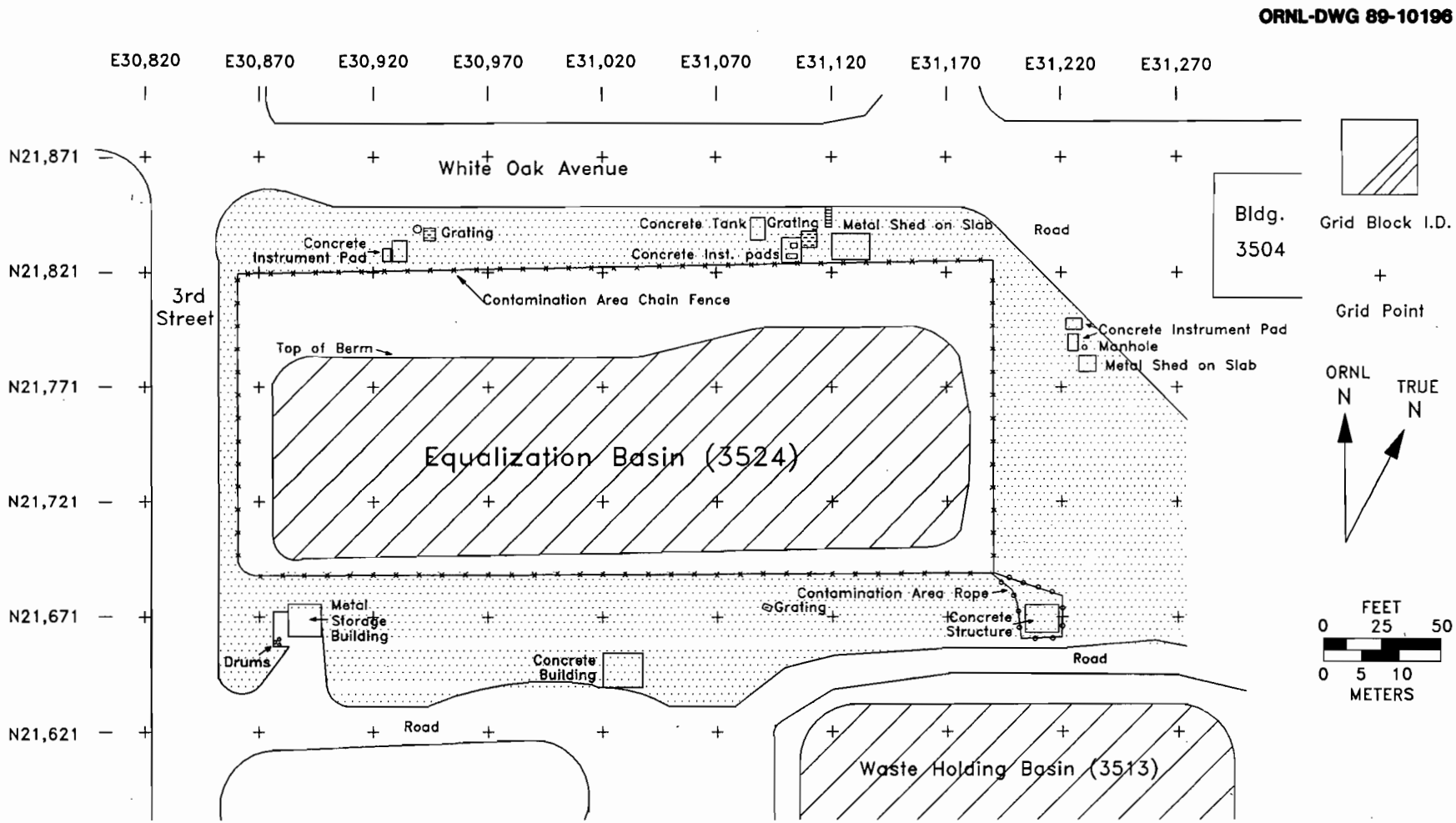

Fig. 6. Diagram showing area surveyed during the surface gamma scan and the surface beta-gamma scan (shaded area between the Contamination Area chain fence and the surrounding roads).

- Radionuclide analysis of 30 soil samples collected from 17 locations.
- Radionuclide analysis of two vegetation samples collected in contaminated areas.

SURVEY RESULTS

SURFACE GAMMA SCAN

Surface gamma exposure rate scan ranges for grid block regions outside the Contamination Area fence are shown in Table 1 and Fig. 7. Maximum surface gamma exposure rates ranged from 2300 to 6500 μR/h in 6 grid blocks, from 500 to 870 μR/h in 3 grid blocks, and from 300 to 430 μR/h in 20 grid blocks. Only three grid blocks did not exceed 250 μR/h.

Figure 8 further defines areas of contamination at the site. The shading in Fig. 8 depicts contaminated areas delineated by the surface beta-gamma scan, which will be discussed later. Light shading is used to indicate that the entire area was contaminated, and progressively darker shading defines areas of increasing beta-gamma contamination. Selected surface gamma exposure rates are shown with the shaded background of beta-gamma contamination because, in most cases, high gamma exposure rates were found in areas of high beta-gamma contamination.

Highest gamma exposure rates (6500 μR/h) were found inside a roped area extending from the southeast corner of the Contamination Area chain fence. The rope delineates a Contamination Area located outside the chain fence and surrounding an open concrete structure on the site. At the time of this study, one of the "Radiation Hazard – Keep Out" signs located on the rope had fallen off, and at one corner the weathered, inconspicuous rope was lying on the ground. (Currently the rope is raised and well marked with four highly visible "Contamination Zone" signs.) Gamma exposure rates just outside the rope to the east reached 3200 μR/h. This entire area (see Fig. 8) is situated alongside a small gravel road that is occasionally used by both pedestrians and vehicles.

Three other areas with significant surface gamma contamination were identified outside the Contamination Area fence (see Fig. 8): (1) Gamma levels up to 2300 μR/h were found east of the basin on the ground surface beneath a steam pipe in a region where significant alpha contamination was measured. (2) Gamma levels up to 2400 μR/h were found north of the basin in an area that is frequented by ORNL personnel studying the transport of liquids into the basin. This area extends southward inside the chain fence where it reaches 2900 μR/h at the top of the berm. (3) Gamma levels up to 870 μR/h were measured over surface soil surrounding a large square grating located south of the basin.

When the survey began in late November, three black metal drums with gamma exposure rates of 2000, 5000, and 13,000 μR/h were sitting on an area covered with deteriorating asphalt at the southwest corner of the site (see Fig. 4). The drums were unmarked and not roped off. They remained at this site for at least a month. After they were removed, another set of unmarked drums was placed at the same location. The second set of drums did not have elevated gamma levels.

Table 1. Range of surface gamma exposure rates and beta-gamma dose rates in grid blocks at the Equalization Basin (3524) site

Grid block I.D.[b,c]		Surface scan range[a]	
North	East	Gamma exposure rates[d] (μR/h)	Beta-gamma dose rates[e] (mrad/h)
21,621	30,870	120–310	0.018–0.36
21,621	30,920	120–250	0.036–0.72
21,621	30,970	190–250	0.054–0.11
21,621	31,020	190–310	0.072–0.12
21,621	31,070	190–430	0.072–1.0
21,621	31,120	250–380	0.11–0.72
21,621	31,170	310–380	0.11–0.50
21,621	31,220	310–370	0.072–0.18
21,621	31,270	250–3,200	0.072–6.5
21,671	30,870	120–370	0.018–0.83
21,671	30,920	120–370	0.11–0.72
21,671	30,970	250–430	0.14–0.54
21,671	31,020	250–430	0.11–0.25
21,671	31,070	250–500	0.11–1.0
21,671	31,120	310–870	0.11–5.0
21,671	31,170	350–510	0.11–0.29
21,671	31,220	250–6,500	0.036–10
21,671	31,270	250–3,200	0.072–6.5
21,721	30,870	190–430	0.018–1.2
21,721	31,220	250–2,300	0.036–5.4
21,721	31,270	190–350	0.018–0.072
21,771	30,870	190–430	0.018–0.17
21,771	31,220	190–2,300	0.036–0.54
21,771	31,270	190–310	0.018–0.18
21,821	30,870	120–250	0.018–0.036
21,821	30,920	120–310	0.036–0.72
21,821	30,970	190–430	0.036–2.9
21,821	31,020	190–370	0.036–0.090
21,821	31,070	190–370	0.036–0.090

Table 1 (continued)

Grid block I.D.[b,c]		Surface scan range[a]	
North	East	Gamma exposure rates[d] (μR/h)	Beta-gamma dose rates[e] (mrad/h)
21,821	31,120	190–2,400	0.036–2.9
21,821	31,170	190–310	0.036–0.13
21,821	31,220	190–310	0.036–0.090

[a]Grid block surface scan ranges exclude the fenced Contamination Area control zone and roads bordering the site.

[b]ORNL grid coordinates measured in feet.

[c]The lower right coordinates are used to identify the grid block (see Grid Block ID legend on Fig. 5).

[d]Gamma radiation was measured with a NaI scintillation probe connected to a Victoreen Model 490 Thyac III ratemeter. When radiation levels exceeded the limits of the NaI gamma scintillator (800,000 cpm), measurements made with a closed-window Geiger-Mueller survey meter (GMSM) were converted to exposure rates by using the following relationship: 3.1 cpm = 1 μR/h. This is an instrument-specific conversion factor based on ^{226}Ra.

[e]Beta-gamma measurements were taken with a portable Technical Associates (TA) mini-scaler/ratemeter, Model PRS-3, with a pancake detector.

GAMMA EXPOSURE RATES AT GRID POINTS

Gamma exposure rate measurements at selected grid points at the Equalization Basin are given in Table 2. Approximate grid point locations are shown in Fig. 9. (Grid point numbers on Fig. 9 correspond to the grid point numbers in the first column of Table 2.) Grid point 1 was not included in the following discussion because it was off the survey site.

Gamma exposure rates over the entire site fluctuate dramatically because they are inversely related to the water level in the basin. In early December, when water levels were low, exposure rates near the Contamination Area fence were 810 and 710 μR/h at 1 m and 460 and 500 μR/h at the surface (see grid points 51 and 62, Table 2). In contrast, mid-January levels, measured after a rainfall when water levels were within 0.3 m (1 ft) of the top of the berm at the southeast corner, were 190 and 150 μR/h at 1 m and 160 and 120 μR/h at the surface. About 9 m (30 ft) west of the Contamination Area control fence, exposure rates were 400 μR/h at 1 m and 370 μR/h at the surface during low water levels in early December (see grid point 52, Table 2). Mid-January high-water exposure rates at the same point were 160 μR/h at 1 m and 190 μR/h at the surface. This example shows a fourfold increase in exposure rates with low water levels at the Contamination Area fence and a twofold increase 9 m (30 ft) from the fence. Data presented in Table 2 were collected in early December when the water level was relatively low.

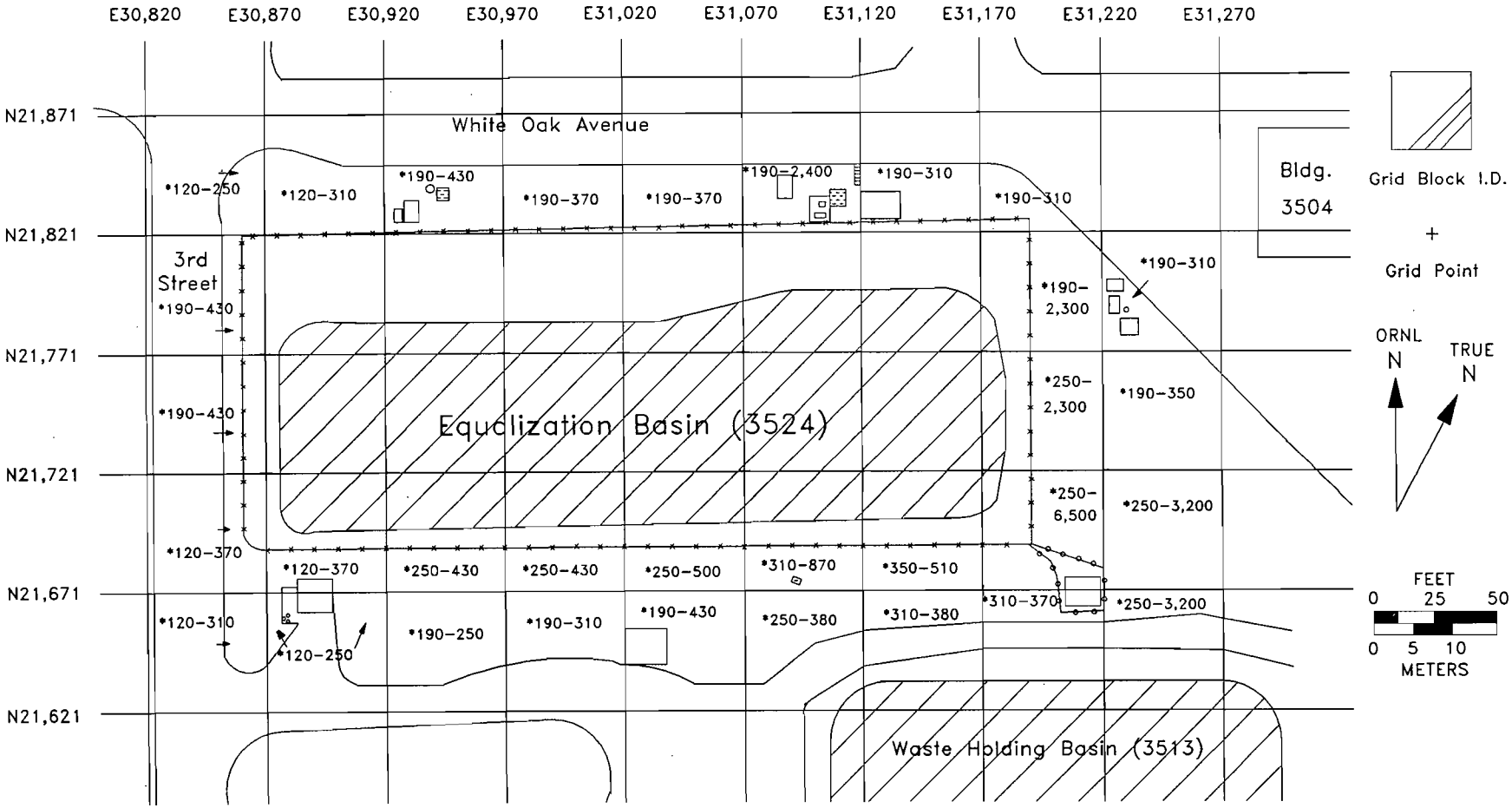

Fig. 7. Range of surface gamma exposure rates (μR/h) in grid blocks at the Equalization Basin (3524) site. Scan ranges exclude the fenced Contamination Area control zone and roads adjacent to the site.

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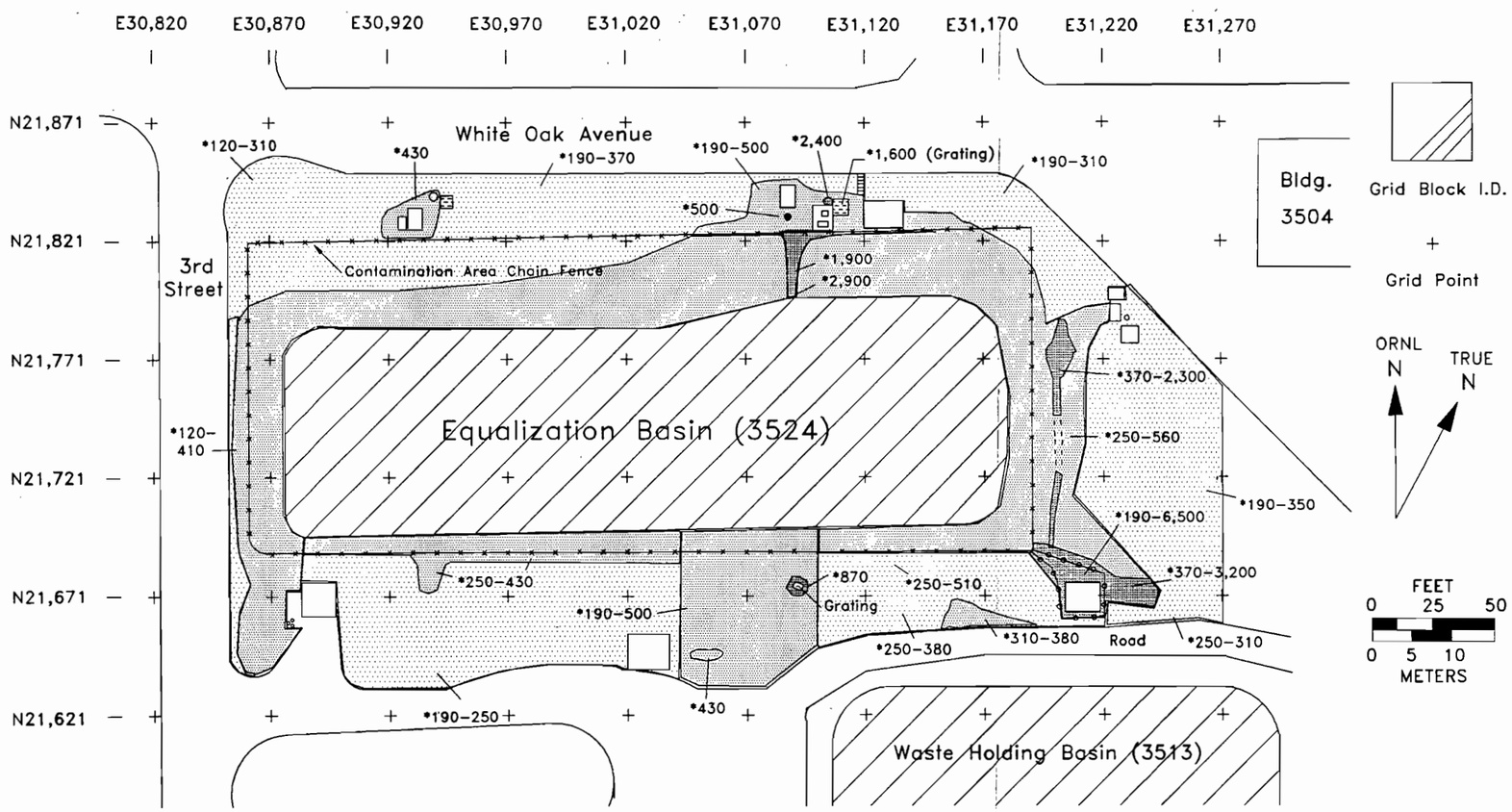

Fig. 8. Regions of surface beta-gamma contamination with selected surface gamma exposure rates (μR/h) at the Equalization Basin (3524) site. Shaded areas represent contamination based on the surface beta-gamma scan.

Table 2. Gamma exposure rates and beta-gamma dose rates measured at selected grid points at the Equalization Basin (3524) site

Grid point[c]	Grid location[b]		Gamma exposure rates (μR/h)[a]			Beta-gamma dose rates (mrad/h)[e]
	North	East	1 m above ground surface	Surface	Surface shielded[d]	
1	21,621	30,870	160	120	12	0.046
2	21,636	30,920	190	160	25	0.071
3	21,636	30,970	250	220	26	0.098
4	21,636	31,020	190	120	12	0.056
5	21,636	31,070	370	340	67	0.30
6	21,646	31,145	370	310	37	0.094
7	21,651	31,045	f	430	190	0.56
8	21,661	30,945	250	210	25	0.078
9	21,661	30,995	280	250	27	0.10
10	21,661	31,045	320	280	37	0.10
11	21,661	31,095	400	340	43	0.58
12	21,666	31,145	430	370	37	0.12
13	21,671	30,870	250	190	31	0.23
14	21,671	30,920	250	250	25	0.083
15	21,671	30,970	260	250	26	0.087
16	21,671	31,020	310	250	31	0.086
17	21,671	31,070	370	310	37	0.12
18	21,671	31,120	370	340	37	0.12
19	21,671	31,170	370	340	37	0.14
20	21,671	31,220	370	310	110	0.28
21	21,671	31,250	340	250	31	0.10
22	21,671	31,270	310	220	19	0.11
23	21,681	31,195	430	370	31	0.15
24	21,691	30,850	250	190	22	0.081
25	21,691	30,870	370	250	31	0.54
26	21,691	30,920	560	340	50	0.22
27	21,691	30,970	500	340	40	0.20
28	21,691	31,020	510	370	56	0.21

Table 2 (continued)

Grid point[c]	Grid location[b]		Gamma exposure rates (μR/h)[a]			Beta-gamma dose rates (mrad/h)[e]
	North	East	1 m above ground surface	Surface	Surface shielded[d]	
29	21,691	31,070	530	370	50	0.28
30	21,691	31,120	570	430	51	0.20
31	21,691	31,170	620	430	51	0.24
32	21,696	31,206	400	340	43	0.18
33	21,696	31,235	400	340	37	0.14
34	21,696	31,260	270	250	22	0.079
35	21,697	30,920	810	790	240	0.57
36	21,697	30,995	740	680	140	1.0
37	21,698	30,895	930	680	150	1.0
38	21,698	30,945	930	690	140	0.84
39	21,699	30,970	680	580	110	0.67
40	21,699	31,020	870	740	140	0.80
41	21,701	31,045	2,600	990	300	5.2
42	21,702	31,070	2,300	810	220	1.2
43	21,702	31,095	2,300	760	190	1.0
44	21,702	31,120	930	810	170	0.76
45	21,702	31,145	1,900	810	170	1.4
46	21,703	30,882	740	810	190	2.2
47	21,711	31,170	2,100	1,300	250	0.68
48	21,721	30,850	300	250	25	0.097
49	21,721	30,870	740	370	56	0.79
50	21,721	31,183	1,900	1,300	430	1.7
51	21,721	31,192	810	460	60	0.25
52	21,721	31,220	400	370	56	0.17
53	21,721	31,250	340	280	31	0.12
54	21,721	31,270	220	190	19	0.064
55	21,746	30,876	1,900	870	220	0.82
56	21,746	31,179	2,300	1,600	450	2.1
57	21,746	31,206	460	370	43	0.14
58	21,746	31,235	370	340	43	0.14

Table 2 (continued)

Grid point[c]	Grid location[b]		Gamma exposure rates (μR/h)[a]			Beta-gamma dose rates (mrad/h)[e]
	North	East	1 m above ground surface	Surface	Surface shielded[d]	
59	21,771	30,852	370	250	27	0.10
60	21,771	30,870	2,400	370	72	0.30
61	21,771	31,179	1,900	1,300	570	2.7
62	21,771	31,192	710	500	72	0.29
63	21,771	31,220	430	400	56	0.15
64	21,775	31,250	220	170	17	0.049
65	21,786	30,945	2,100	970	210	0.78
66	21,791	30,895	1,600	890	200	0.76
67	21,795	31,170	2,300	990	290	0.89
68	21,795	31,206	340	310	50	0.17
69	21,796	30,995	1,900	1,600	310	1.6
70	21,800	31,045	1,900	740	250	0.88
71	21,800	31,145	2,100	810	190	0.57
72	21,804	31,045	930	620	120	0.38
73	21,805	31,095	2,900	2,900	2,900	4.5
74	21,806	30,895	600	410	62	0.25
75	21,806	30,995	710	510	87	0.29
76	21,821	30,853	270	220	25	0.065
77	21,821	30,870	270	200	35	0.15
78	21,821	30,920	450	170	25	0.17
79	21,821	30,970	500	370	68	0.28
80	21,821	31,020	500	370	62	0.22

Table 2 (continued)

Grid point[c]	Grid location[b]		Gamma exposure rates (μR/h)[a]			Beta-gamma dose rates (mrad/h)[e]
	North	East	1 m above ground surface	Surface	Surface shielded[d]	
81	21,821	31,070	470	360	66	0.28
82	21,821	31,120	470	370	99	0.40
83	21,821	31,170	420	300	47	0.17
84	21,821	31,192	370	280	52	0.14
85	21,821	31,220	250	340	27	0.093

[a]Gamma radiation was measured with a NaI scintillation probe connected to a Victoreen Model 490 Thyac III ratemeter. When radiation levels exceeded the limits of the NaI gamma scintillator (800,000 cpm), measurements made with a closed-window Geiger-Mueller survey meter (GMSM) were converted to exposure rates by using the following relationship: 3.1 cpm = 1 μR/h. This is an instrument-specific conversion factor based on ^{226}Ra.

[b]ORNL grid coordinates measured in feet.

[c]Grid points are shown on Fig. 9.

[d]The NaI scintillation probe was inserted in a cylindrical lead shield with an open end facing the ground surface. The shield effectively blocks radiation emanating from surrounding areas ("shine"), so that actual ground-surface exposure rates can be measured more accurately.

[e]Beta-gamma measurements were taken with a portable Technical Associates (TA) mini-scaler/ratemeter, Model PRS-3, with a pancake detector.

[f]Not measured.

Gamma exposure rates at 1 m above the ground surface were consistently higher than surface exposure rates, and unshielded surface exposure rates were significantly higher than lead-shielded surface readings. These results clearly indicate that the 1-m and unshielded surface measurements include radiation emanating from the Equalization Basin and the Waste Holding Basin (3513) located immediately south of the survey site.

All 1-m gamma exposure rates above 930 μR/h were inside the Contamination Area fence. All 1-m exposure rates $\geqslant$470 μR/h were either inside the Contamination Area fence or at the fence line. Exposure rates outside the fence ranged from 190 to 460 μR/h at 1 m.

All unshielded surface gamma exposure rates above 430 μR/h were either inside the Contamination Area fence or at the fence line. Unshielded surface readings outside the fence ranged from 120 to 430 μR/h.

Highest shielded surface gamma exposure rates were at grid points 73 (2900 μR/h), 61 (570 μR/h), 56 (450 μR/h), and 50 (430 μR/h). These grid points are located near the top of the berm inside the Contamination Area fence. Other shielded surface gamma exposure rates inside the fence or at the fence line ranged from 25 to 310 μR/h. Shielded surface gamma exposure rates outside the fence ranged from 12 to 190 μR/h.

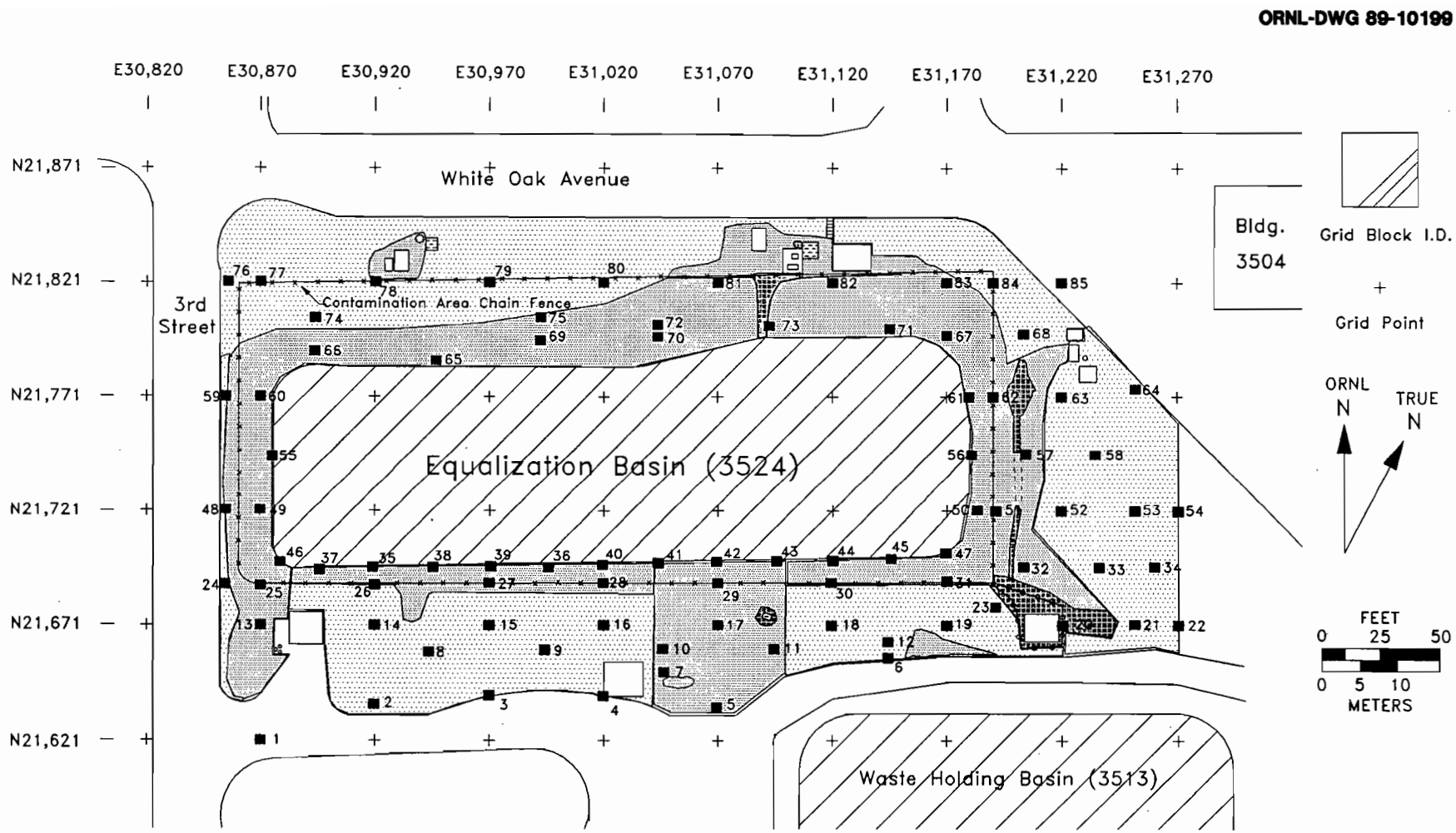

Fig. 9. Diagram showing numbers and approximate locations of grid point measurements. Grid point numbers (1-85) correspond to the first column of Tables 2 and 3.

SURFACE BETA-GAMMA SCAN

Surface beta-gamma scan ranges for portions of grid blocks outside the Contamination Area fence are shown in Table 1 and Fig. 10. Nineteen of the 32 grid blocks had surface beta-gamma dose rates that exceed the ORNL Health Physics guideline (0.25 mrad/h)[10] for establishing a Contamination Area. Eleven of the grid blocks exceeding the guideline were located adjacent to surrounding roads that are used by vehicles and pedestrians.

Figure 11 further defines areas of beta-gamma contamination at the site. Beta-gamma dose rates in grid block N21,771/E31,120, just north of the basin and inside the Contamination Area fence, reached 36 mrad/h. Another spot in grid block N21,671/E31,220, southeast of the basin in the roped Contamination Area, measured 10 mrad/h. Two areas outside the Contamination Area fence, one east and one south of the basin, measured 5.4 and 5.0 mrad/h, respectively.

BETA-GAMMA DOSE RATES AT GRID POINTS

Beta-gamma dose rates at selected grid points are shown in Table 2, beta-gamma activity levels used for dose-rate calculations are shown in Table 3, and approximate grid point locations are shown in Fig. 9. (Grid point numbers on Fig. 9 correspond to the grid point numbers in the first column of Tables 2 and 3.)

Highest beta-gamma dose rates outside the Contamination Area fence were at grid points 7 (0.56 mrad/h) and 11 (0.58 mrad/h). These points are located in a low-lying area directly south of the basin. This area was particularly unusual in that during the time of this survey, the ground surface remained moist. Other beta-gamma dose rates outside the fence ranged from 0.049 to 0.28 mrad/h. Beta-gamma levels inside the fence and at the fence line ranged from 0.15 to 5.2 mrad/h. Highest levels were found near the top of the berm at grid points 41 (5.2 mrad/h) and 73 (4.5 mrad/h).

ALPHA ACTIVITY LEVELS AT GRID POINTS

The highest grid point alpha activity was measured southeast of the basin at location 20 (180 dpm/100 cm^2) (see Table 3). Elevated alpha activities were also identified at grid locations 18 and 33 (80 and 81 dpm/100 cm^2). Other grid point alpha measurements ranged from 9 to 63 dpm/100 cm^2.

SOIL SAMPLE ANALYSES

The locations of soil sample hole numbers are shown in Fig. 12, and the results of radionuclide analyses (wet wt) are given in Tables 4 and 5. Table 4 shows the concentrations of ^{60}Co, ^{137}Cs, gross alpha, and gross beta in 30 soil samples. (Strontium-90 analyses were not considered cost effective for this investigation; however a rough estimate of ^{90}Sr can be calculated by subtracting ^{137}Cs from gross beta in Table 4.) Table 5 shows the concentrations of ^{134}Cs, ^{152}Eu, ^{154}Eu, and ^{155}Eu measured in 6 of the 30 soil samples presented in Table 4. At some locations, samples were taken at more than one depth with A (surface), B, C, and D designating progressively deeper samples.

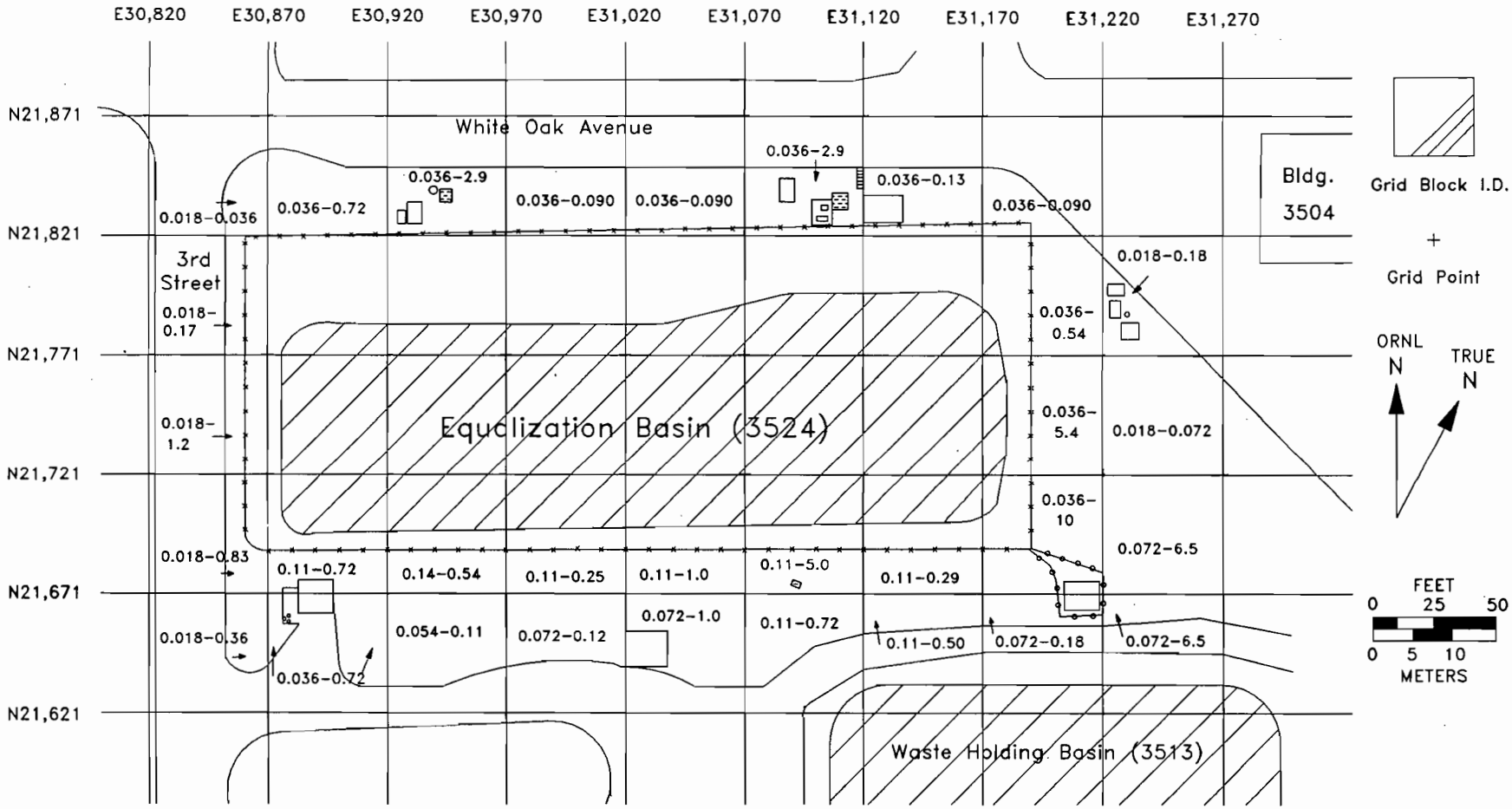

Fig. 10. Range of beta-gamma dose rates (mrad/h) in grid blocks at the Equalization Basin (3524) site. Scan ranges exclude the fenced Contamination Area control zone and roads adjacent to the site.

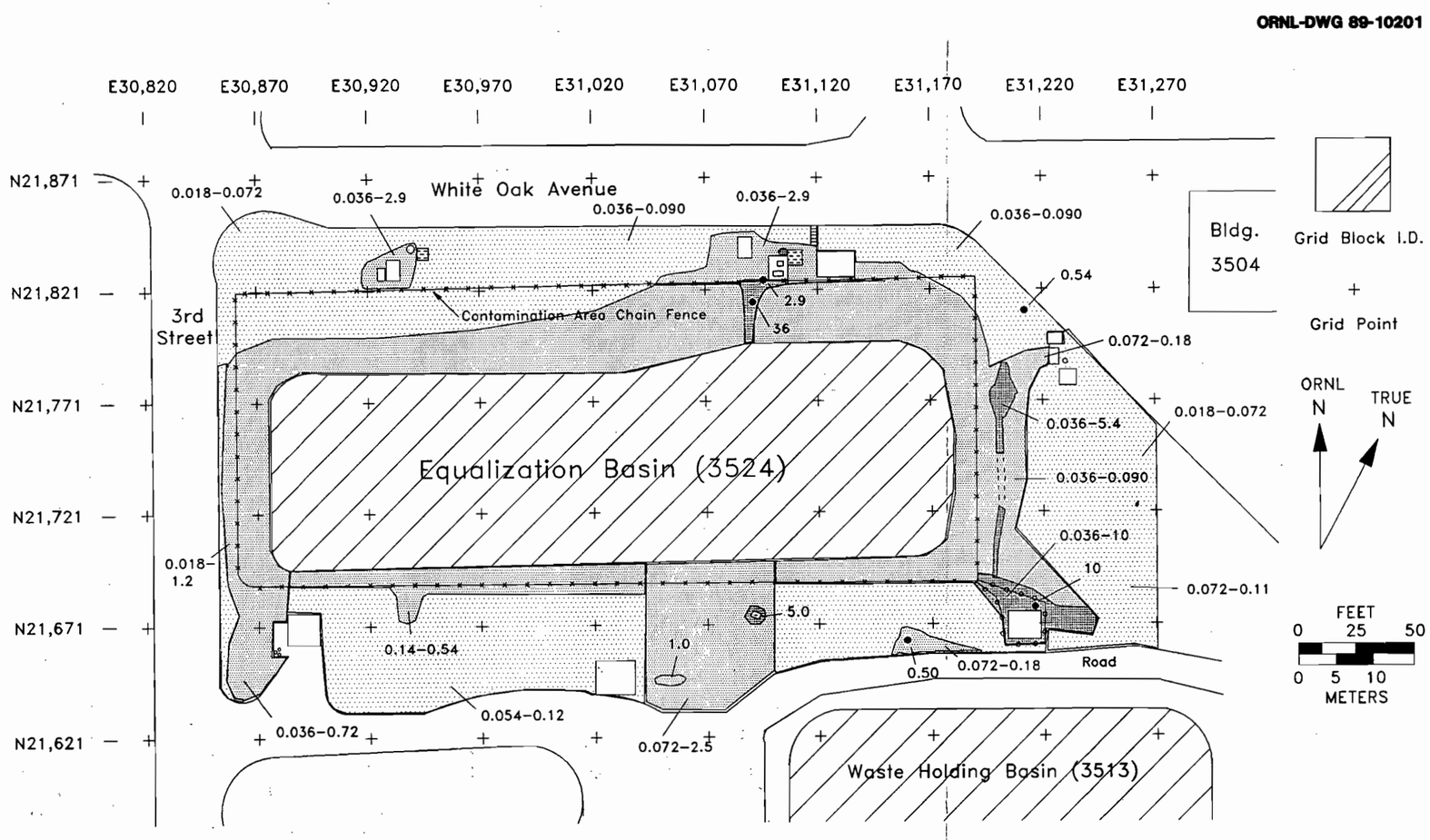

Fig. 11. Regions of surface beta-gamma contamination with selected surface beta-gamma dose rates (mrad/h) at the Equalization Basin (3524) site. Light shading is used to indicate that the entire area is contaminated. Progressively darker shading delineates areas of increasing contamination.

Table 3. Levels of radiation detected and/or measured with an alpha meter[a], a TA scaler/ratemeter[b], and a Geiger-Mueller survey meter[c] at selected grid points at the Equalization Basin (3524) site

Grid point[e]	Grid location[d] North	Grid location[d] East	Alpha meter, alpha, surface (dpm)[f]	TA scaler/ratemeter: Open, beta-gamma, surface (cpm)[g]	TA scaler/ratemeter: Closed, gamma, surface (cpm)	GMSM: Open, beta-gamma 1 m (cpm)	GMSM: Open, beta-gamma Surface (cpm)	GMSM: Closed, gamma 1 m (cpm)	GMSM: Closed, gamma Surface (cpm)
1	21,621	30,870	20	160	140	350	300	400	350
2	21,636	30,920	30	240	190	500	400	500	500
3	21,636	30,970	60	340	300	600	450	600	500
4	21,636	31,020	30	190	150	500	300	500	350
5	21,636	31,070	30	940	500	1,200	1,000	1,200	1,000
6	21,646	31,145	20	340	340	1,000	700	1,100	700
7	21,651	31,045	50	1,900	1,500	1,000	1,400	1,000	1,400
8	21,661	30,945	30	280	280	700	600	700	600
9	21,661	30,995	40	360	300	700	500	800	700
10	21,661	31,045	30	380	390	900	700	1,000	700
11	21,661	31,095	40	1,700	410	1,300	1,100	1,100	800
12	21,666	31,145	20	430	420	1,100	700	1,100	1,000
13	21,671	30,870	30	700	310	700	500	700	500
14	21,671	30,920	60	300	300	700	500	700	600
15	21,671	30,970	20	310	300	700	600	800	600
16	21,671	31,020	40	320	360	700	600	800	600
17	21,671	31,070	10	410	380	1,000	800	1,000	800
18	21,671	31,120	80	420	400	1,000	800	1,200	800
19	21,671	31,170	10	500	460	1,100	800	1,100	1,000
20	21,671	31,220	180	960	770	h	h	h	h
21	21,671	31,250	45	350	280	h	h	h	h
22	21,671	31,270	h	370	330	h	h	h	h
23	21,681	31,195	27	500	390	h	h	h	h
24	21,691	30,850	36	290	280	h	h	h	h
25	21,691	30,870	30	1,600	380	1,500	1,000	1,000	500
26	21,691	30,920	30	730	480	2,500	1,000	2,000	1,000
27	21,691	30,970	40	660	500	1,500	800	1,600	500
28	21,691	31,020	40	720	610	1,500	1,000	1,600	1,100
29	21,691	31,070	20	880	490	1,500	1,000	1,500	1,000
30	21,691	31,120	0	680	560	1,600	1,100	1,700	1,000
31	21,691	31,170	50	790	540	2,000	1,200	2,000	1,200
32	21,696	31,206	36	590	430	h	h	h	h
33	21,696	31,235	81	500	440	h	h	h	h
34	21,696	31,260	h	280	260	h	h	h	h
35	21,697	30,920	18	2,000	1,800	4,000	h	3,500	h
36	21,697	30,995	18	3,600	3,200	3,500	h	3,300	h
37	21,698	30,895	27	3,600	3,600	5,000	h	4,200	h
38	21,698	30,945	36	2,800	2,100	4,700	h	4,300	h
39	21,699	30,970	18	2,300	1,900	3,300	h	2,800	h
40	21,699	31,020	54	2,800	2,500	5,000	h	4,300	h
41	21,701	31,045	54	17,000	11,000	9,000	h	8,000	h
42	21,702	31,070	27	4,100	3,400	8,000	h	7,000	h
43	21,702	31,095	63	3,300	1,800	8,000	h	7,000	h
44	21,702	31,120	27	2,500	1,700	4,600	h	4,500	h
45	21,702	31,145	45	4,700	4,000	6,000	h	6,000	h
46	21,703	30,882	18	6,600	2,300	3,800	h	3,500	h
47	21,711	31,170	45	2,400	2,200	7,500	h	6,500	4,000
48	21,721	30,850	27	340	310	h	h	h	h
49	21,721	30,870	18	2,300	480	7,000	h	6,000	h

Table 3 (continued)

Grid point[e]	Grid location[d] North	Grid location[d] East	Alpha meter, alpha, surface (dpm)[f]	TA scaler/ratemeter: Open, beta-gamma, surface (cpm)[g]	TA scaler/ratemeter: Closed, gamma, surface (cpm)	GMSM: Open, beta-gamma: 1 m (cpm)	GMSM: Open, beta-gamma: Surface (cpm)	GMSM: Closed, gamma: 1 m (cpm)	GMSM: Closed, gamma: Surface (cpm)
50	21,721	31,183	45	6,000	5,500	7,000	h	6,000	4,000
51	21,721	31,192	45	840	630	h	h	h	h
52	21,721	31,220	36	600	510	h	h	h	h
53	21,721	31,250	45	400	340	h	h	h	h
54	21,721	31,270	h	230	230	h	h	h	h
55	21,746	30,876	45	2,700	1,800	6,500	h	6,000	h
56	21,746	31,179	45	7,100	5,600	8,500	h	7,000	5,000
57	21,746	31,206	18	490	400	h	h	h	h
58	21,746	31,235	27	470	370	h	h	h	h
59	21,771	30,852	9	370	400	h	h	h	h
60	21,771	30,870	18	1,000	720	7,500	h	7,500	h
61	21,771	31,179	18	9,100	6,700	6,500	h	6,000	4,000
62	21,771	31,192	9	940	620	h	h	h	h
63	21,771	31,220	36	540	560	h	h	h	h
64	21,775	31,250	18	180	190	h	h	h	h
65	21,786	30,945	45	2,700	2,300	7,000	h	6,500	h
66	21,791	30,895	36	2,600	2,200	6,000	h	5,000	h
67	21,795	31,170	54	2,600	1,500	8,000	h	7,000	h
68	21,795	31,206	18	600	560	h	h	h	h
69	21,796	30,995	36	5,000	2,900	7,000	h	6,000	5,000
70	21,800	31,045	36	3,000	2,400	6,500	h	6,000	h
71	21,800	31,145	18	1,900	1,400	7,000	h	6,500	h
72	21,804	31,045	27	1,300	1,100	h	h	h	h
73	21,805	31,095	36	15,000	11,000	10,000	h	9,000	9,000
74	21,806	30,895	45	830	640	h	h	h	h
75	21,806	30,995	18	1,000	880	h	h	h	h
76	21,821	30,853	18	240	260	h	h	h	h
77	21,821	30,870	9	490	320	h	h	h	h
78	21,821	30,920	36	540	290	h	h	h	h
79	21,821	30,970	18	950	700	h	h	h	h
80	21,821	31,020	18	770	670	h	h	h	h
81	21,821	31,070	9	920	570	h	h	h	h
82	21,821	31,120	18	1,300	810	h	h	h	h
83	21,821	31,170	18	570	420	h	h	h	h
84	21,821	31,192	54	500	450	h	h	h	h
85	21,821	31,220	18	320	270	h	h	h	h

[a]ORNL alpha survey meter, Model Q-2789-1, connected to a zinc sulfide scintillation probe.

[b]Technical Associates (TA) mini-scaler/ratemeter, Model PRS-3, with an HP-265 pancake detector (<2 mg/cm^2 window thickness). The detector was set in the open configuration to detect beta-gamma and in the closed configuration to detect gamma.

[c]Geiger-Mueller survey meter (GMSM), Model Q-5218, equipped with a side-window probe, 30 mg/cm^2 wall thickness. The GMSM was set in the open configuration to detect beta-gamma radiation and in the closed configuration to detect gamma radiation.

[d]ORNL grid coordinates measured in feet.

[e]Grid points are shown on Fig. 9.

[f]Disintegrations per minute per 100 cm^2.

[g]Counts per minute.

[h]Not measured.

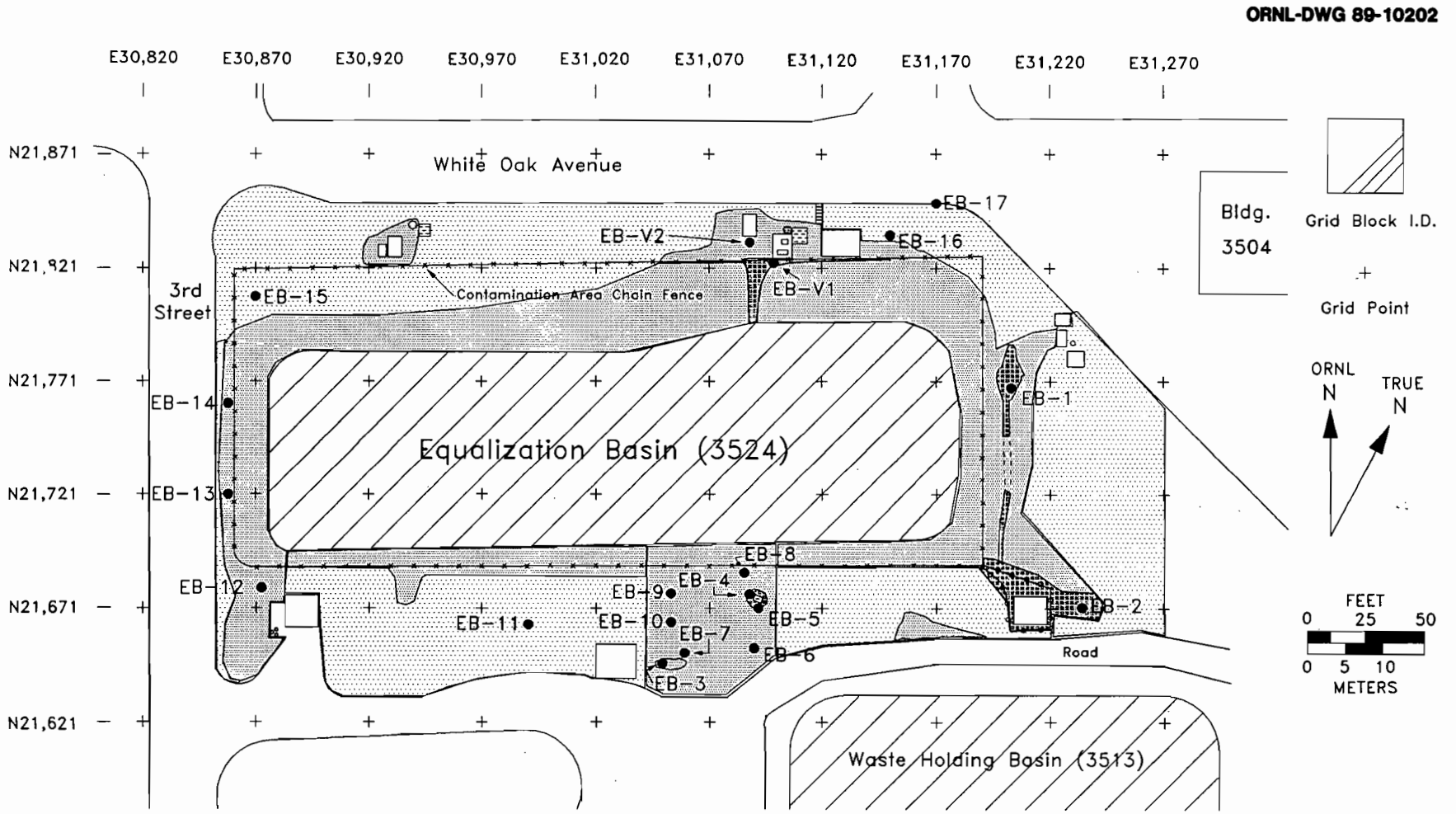

Fig. 12. Soil (EB-#) and vegetation (EB-V#) sample locations at the Equalization Basin (3524) site.

Table 4. Concentrations of ^{60}Co, ^{137}Cs, gross alpha, and gross beta in soil taken from the Equalization Basin (3524) site

Sample ID[a]	Location[b]	Soil depth (cm)	Activity/radionuclide concentration in pCi/g (Bq/kg) wet wt			
			^{60}Co	^{137}Cs	Gross alpha	Gross beta
EB-1B	N21,768 E31,203	5-15	76±3 (2,800±100)	5,700±300 (210,000±10,000)	510±80 (19,000±3,000)	9,400±300 (350,000±10,000)
EB-1C	N21,768 E31,203	15-25	20±0.3 (750±10)	1,600±30 (58,000±1,000)	240±50 (8,900±2,000)	3,500±300 (130,000±10,000)
EB-2A	N21,671 E31,232	0-15	0.94±0.2 (35±6)	13,000±300 (470,000±10,000)	160±40 (5,900±2,000)	25,000±300 (930,000±10,000)
EB-2B	N21,671 E31,232	15-25	0.32±0.05 (12±2)	4,300±300 (160,000±10,000)	62±20 (2,300±800)	7,300±300 (270,000±10,000)
EB-3	N21,641 E31,045	0-15	0.76±0.2 (28±6)	1,400±30 (51,000±1,000)	18±10 (660±400)	3,000±300 (110,000±10,000)
EB-4	N21,676 E31,089	0-15	9.7±0.3 (360±10)	190±3 (7,100±100)	38±20 (1,400±600)	4,600±300 (170,000±10,000)
EB-5	N21,670 E31,091	0-15	2.4±0.1 (89±4)	94±3 (3,500±100)	25±10 (920±500)	5,100±300 (190,000±10,000)
EB-6A	N21,652 E31,092	0-5	0.46±0.2 (17±6)	19±1 (720±40)	20±9 (750±300)	320±30 (12,000±1,000)
EB-6B	N21,652 E31,092	5-15	0.24±0.09 (8.8±3)	26±0.5 (980±20)	11±7 (410±200)	120±10 (4,400±500)
EB-6C	N21,652 E31,092	15-30	0.15±0.08 (5.7±3)	46±3 (1,700±100)	14±8 (510±300)	120±10 (4,400±500)
EB-6D	N21,652 E31,092	30-46	<0.081 (<3)	130±3 (4,900±100)	15±8 (570±300)	120±10 (4,400±500)
EB-7A	N21,651 E31,053	0-5	1.0±0.1 (38±5)	210±3 (7,600±100)	4.9±5 (180±200)	650±30 (24,000±1,000)
EB-7B	N21,651 E31,053	5-15	1.6±0.2 (59±7)	270±30 (10,000±1,000)	5.9±5 (220±200)	300±30 (11,000±1,000)
EB-7C	N21,651 E31,053	15-30	<0.081 (<3)	15±0.3 (550±10)	17±8 (620±300)	78±10 (2,900±400)
EB-7D	N21,651 E31,053	30-46	<0.081 (<3)	2.7±0.3 (100±10)	17±8 (640±300)	22±6 (830±200)
EB-8A	N21,690 E31,084	0-5	1.1±0.2 (40±8)	32±3 (1,200±100)	6.8±5 (250±200)	260±20 (9,500±800)
EB-8B	N21,690 E31,084	5-15	0.38±0.1 (14±4)	12±1 (460±40)	12±7 (430±300)	76±10 (2,800±400)

Table 4 (continued)

Sample ID[b]	Location[a]	Soil depth (cm)	Activity/radionuclide concentration in pCi/g (Bq/kg) wet wt			
			^{60}Co	^{137}Cs	Gross alpha	Gross beta
EB-9A	N21,676 E31,057	0-15	0.14±0.08 (5.3±3)	4.9±0.3 (180±10)	18±10 (660±400)	300±30 (11,000±1,000)
EB-9B	N21,676 E31,057	15-30	<0.054 (<2)	1.3±0.1 (49±4)	14±10 (510±400)	62±10 (2,300±500)
EB-10	N21,665 E31,051	0-15	0.12±0.05 (4.6±2)	11±0.3 (420±10)	19±10 (690±500)	130±20 (4,900±900)
EB-11A	N21,665 E30,988	0-15	<0.081 (<3)	2.0±0.1 (73±4)	11±8 (420±300)	40±10 (1,500±400)
EB-11B	N21,665 E30,988	15-30	<0.054 (<2)	0.25±0.07 (9.1±3)	14±10 (530±400)	46±10 (1,700±400)
EB-12	N21,684 E30,874	0-15	0.18±0.08 (6.5±3)	5.7±0.3 (210±10)	11±9 (390±300)	76±50 (2,800±2,000)
EB-13A	N21,721 E30,862	0-5	1.6±0.2 (58±7)	15±0.3 (570±10)	18±10 (680±400)	2,000±80 (75,000±3,000)
EB-13B	N21,721 E30,862	5-15	0.46±0.1 (17±4)	1.9±0.1 (69±4)	30±10 (1,100±500)	460±30 (17,000±1,000)
EB-14A	N21,760 E30,859	0-5	0.097±0.07 (3.6±3)	2.4±0.03 (88±1)	22±20 (810±600)	810±80 (30,000±3,000)
EB-14B	N21,760 E30,859	5-15	<0.054 (<2)	1.2±0.08 (45±3)	9.4±10 (350±400)	320±30 (12,000±1,000)
EB-15	N21,814 E30,870	0-15	2.1±0.1 (76±5)	21±0.3 (760±10)	8.9±8 (330±300)	130±20 (4,700±800)
EB-16	N21,833 E31,145	0-5	0.16±0.08 (6.1±3)	32±3 (1,200±100)	c (c)	200±30 (7,400±1,000)
EB-17	N21,851 E31,170	0-5	0.12±0.06 (4.3±2)	11±0.3 (390±10)	c (c)	150±30 (5,600±1,000)

[a]Soil sample hole numbers are shown on Fig. 12.
[b]ORNL grid coordinates measured in feet.
[c]Not measured.

Table 5. Concentrations of ^{134}Cs, ^{152}Eu, ^{154}Eu, and ^{155}Eu in soil taken from the Equalization Basin (3524) site

Sample ID[b]	Location[a]		Soil depth (cm)	Activity/radionuclide concentration in pCi/g (Bq/kg) wet wt			
	North	East		^{134}Cs	^{152}Eu	^{154}Eu	^{155}Eu
EB-1B	21,768	31,203	5-15	1.1 ± 0.4 (40 ± 20)	23 ± 0.8 (870 ± 30)	7.3 ± 0.5 (270 ± 20)	2.5 ± 1 (93 ± 50)
EB-1C	21,768	31,203	15-25	0.38 ± 0.2 (14 ± 7)	5.9 ± 0.5 (220 ± 20)	2.1 ± 0.3 (76 ± 10)	0.68 ± 0.5 (25 ± 20)
EB-4	21,676	31,089	0-15	c c	14 ± 0.8 (520 ± 30)	4.9 ± 0.3 (180 ± 10)	1.9 ± 0.5 (69 ± 20)
EB-5	21,670	31,091	0-15	c c	5.4 ± 0.3 (200 ± 10)	1.8 ± 0.2 (65 ± 7)	0.46 ± 0.3 (17 ± 10)
EB-13A	21,721	30,862	0-5	c c	1.4 ± 0.4 (50 ± 10)	c c	c c
EB-15	21,814	30,870	0-15	c c	1.4 ± 0.4 (50 ± 10)	c c	c c

[a]ORNL grid coordinates measured in feet.
[b]Soil sample hole numbers are shown on Fig. 12.
[c]Not measured.

Cobalt-60

Highest concentrations of ^{60}Co were found at soil sample locations EB-1 (76 and 20 pCi/g) and EB-4 (9.7 pCi/g). Concentrations ranging from 0.32 to 2.4 pCi/g were found in 12 samples from locations EB-2, EB-3, EB-5, EB-6, EB-7, EB-8, EB-13, and EB-15. The remaining 15 samples contained concentrations below or only slightly above the lower detection limits of the analytical procedure (0.1 pCi/g). Cobalt-60 is not present in uncontaminated soil.[11]

Cesium-137

All 30 soil samples contained ^{137}Cs contamination, with concentrations ranging from 0.25 to 13,000 pCi/g. Highest levels were found at locations EB-2 (13,000 and 4300 pCi/g), EB-1 (5700 and 1600 pCi/g), and EB-3 (1400 pCi/g). Concentrations ranging from 11 to 270 pCi/g were found in 16 samples from locations EB-4, EB-5, EB-6, EB-7, EB-8, EB-10, EB-13, EB-15, EB-16, and EB-17. The remaining nine samples ranged from 0.25 to 5.7 pCi/g, which is well above the lower detection limit of the analytical procedure (0.1 pCi/g).

Samples from location EB-6 are of particular interest because they showed ^{137}Cs concentrations increasing with soil depth: 19 pCi/g at 0-5 cm (0-2 in.), 26 pCi/g at 5-15 cm (2-6 in.), 46 pCi/g at 15-30 cm (6-10 in.), and 130 pCi/g at 30-46 cm

(12-18 in.). EB-6 samples were taken from the low-lying area directly south of the basin that remained moist during the course of the survey. The other soil samples generally showed radionuclide concentrations decreasing with increasing soil depth.

Gross Alpha

Gross alpha measurements were highest at locations EB-1 (510 and 240 pCi/g) and EB-2 (160 and 62 pCi/g). Uncontaminated soil on the Oak Ridge Reservation (ORR) normally contains 5 to 20 pCi/g (dry wt) gross alpha.[11]

Gross Beta

Highest gross beta levels were found at sample locations EB-2 (25,000 and 7300 pCi/g) and EB-1 (9400 and 3500 pCi/g). Four samples ranged from 2000 to 5100 pCi/g (EB-3, EB-4, EB-5, and EB-13A); 19 samples ranged from 62 to 460 pCi/g. Gross beta in uncontaminated soil on the ORR normally ranges from 15 to 40 pCi/g (dry wt).[11]

Cesium-134

Cesium-134 was measured at location EB-1, where 1.1 and 0.38 pCi/g were found at 5-15 cm (2-6 in.) and 15-25 cm (6-10 in.), respectively. Uncontaminated soil does not contain ^{137}Cs in amounts greater than the lower analytical detection limits of 0.1 pCi/g.[11]

Europium

Levels of ^{152}Eu, measured in six samples, ranged from 1.4 to 23 pCi/g. Europium-154 and ^{155}Eu, measured in four samples, ranged from 1.8 to 7.3 pCi/g and from 0.46 to 2.5 pCi/g, respectively. Highest concentrations of ^{152}Eu, ^{154}Eu, and ^{155}Eu were found at location EB-1. Uncontaminated soil does not contain ^{152}Eu, ^{154}Eu, or ^{155}Eu in amounts greater than the lower analytical detection limits of 0.1 pCi/g.[11]

Plutonium

High alpha counts at location EB-1 (1000 dpm/100 cm^2, see Table 6) instigated a plutonium analysis of the surface soil sample collected at this site. Sample EB-1A (not shown), collected at a soil depth of 0-5 cm (0-2 in.), contained 4.0 pCi/g ^{238}Pu and 140 pCi/g ^{239}Pu. Plutonium would not ordinarily be present in uncontaminated soil in amounts greater than 10 times the lower analytical detection limits of 0.004 pCi/g.[11]

Uranium

Uranium analysis of sample EB-1A, collected at a soil depth of 0-5 cm (0-2 in.), showed 20 pCi/g of ^{234}U, 0.5 pCi/g of ^{235}U, and 11 pCi/g of ^{238}U. Uranium-234, 235, and 238 occur naturally in soil and concentrations can vary depending on where the sample was collected. Background levels of ^{234}U and ^{238}U in the main ORNL complex are usually around 0.027 to 0.54 pCi/g (dry wt).[11] Background levels of ^{235}U range from 0.008 to 0.05 pCi/g (dry wt).[11]

Table 6. Gamma exposure rates, radiation activity levels, and beta-gamma dose rates in soil sample holes at the Equalization Basin (3524) site

Hole number[g]	Location[a]		Depth (cm)	Gamma exposure rates[b] (μR/h)	Radiation activity levels			Beta-gamma dose rates[f] (mrad/h)
	North	East			Alpha[c,d] (dpm)[h]	Beta-gamma[e] (cpm)[i]	Gamma[e] (cpm)[i]	
EB-1	21,768	31,203	0	2,300	1,000	j	j	j
EB-1	21,768	31,203	5	>990	580	15,000	8,800	4.7
EB-1	21,768	31,203	15	>990	570	14,000	8,700	4.3
EB-1	21,768	31,203	25	>990	240	6,900	5,600	2.0
EB-2	21,671	31,232	0	3,200	9	18,000	14,000	5.3
EB-2	21,671	31,232	15	>990	45	17,000	15,000	4.9
EB-2	21,671	31,232	25	>990	18	8,500	7,600	2.4
EB-3	21,641	31,045	0	430	18	2,900	1,700	0.90
EB-3	21,641	31,045	15	430	j	3,100	1,900	0.96
EB-3	21,641	31,045	25	330	j	j	j	j
EB-4	21,676	31,089	0	330	63	14,000	1,300	4.9
EB-4	21,676	31,089	15	270	72	6,000	960	2.1
EB-5	21,670	31,091	0	310	72	11,000	1,200	3.9
EB-5	21,670	31,091	15	150	9	3,900	560	1.4
EB-6	21,652	31,092	0	330	j	2,000	550	0.68
EB-6	21,652	31,092	5	310	j	870	480	0.27
EB-6	21,652	31,092	15	160	j	700	340	0.22
EB-6	21,652	31,092	30	120	j	800	470	0.25
EB-6	21,652	31,092	46	56	j	290	250	0.084
EB-7	21,651	31,053	0	310	j	2,500	880	0.83
EB-7	21,651	31,053	5	300	j	1,600	780	0.51
EB-7	21,651	31,053	15	200	j	j	j	j
EB-7	21,651	31,053	30	91	j	320	280	0.092
EB-7	21,651	31,053	46	31	j	160	140	0.046
EB-8	21,690	31,084	0	320	j	7,400	540	2.6
EB-8	21,690	31,084	5	320	j	780	470	0.24
EB-8	21,690	31,084	15	120	j	350	220	0.11
EB-9	21,676	31,057	0	250	j	2,800	320	0.98
EB-9	21,676	31,057	15	87	j	270	120	0.087
EB-9	21,676	31,057	30	31	j	200	120	0.062

Table 6 (continued)

Hole number[g]	Location[a] North	Location[a] East	Depth (cm)	Gamma exposure rates[b] (μR/h)	Radiation activity levels: Alpha[c,d] (dpm)[h]	Radiation activity levels: Beta-gamma[e] (cpm)[i]	Radiation activity levels: Gamma[e] (cpm)[i]	Beta-gamma dose rates[f] (mrad/h)
EB-10	21,665	31,051	0	250	j	1,000	400	0.33
EB-10	21,665	31,051	15	87	j	170	110	0.052
EB-11	21,665	30,988	0	190	j	320	310	0.090
EB-11	21,665	30,988	15	56	j	160	80	0.051
EB-11	21,665	30,988	30	25	j	190	90	0.061
EB-12	21,684	30,874	0	160	j	2,000	320	0.69
EB-12	21,684	30,874	15	56	j	560	120	0.19
EB-13	21,721	30,862	0	220	j	2,300	260	0.81
EB-13	21,721	30,862	5	140	j	1,100	290	0.37
EB-13	21,721	30,862	15	68	j	440	120	0.15
EB-14	21,760	30,859	0	220	j	3,300	280	1.2
EB-14	21,760	30,859	5	120	j	790	230	0.26
EB-14	21,760	30,859	15	68	j	270	130	0.087
EB-15	21,814	30,870	0	190	j	470	300	0.14
EB-15	21,814	30,870	15	93	j	290	180	0.090
EB-16	21,833	31,145	0	j	j	350	j	0.13
EB-17	21,851	31,170	0	j	j	160	j	0.058

[a]ORNL grid coordinates measured in feet.

[b]Gamma radiation was measured with a NaI scintillation probe connected to a Victoreen Model 490 Thyac III ratemeter. When surface radiation levels at EB-1 and EB-2 exceeded the limits of the NaI gamma scintillator (800,000 cpm), measurements made with a closed-window Geiger-Mueller survey meter (GMSM) were converted to exposure rates by using the following relationship: 3.1 cpm = 1 μR/h. This is an instrument-specific conversion factor based on ^{226}Ra.

[c]Alpha radiation measured with an ORNL alpha survey meter, Model Q-2789-1, connected to a zinc sulfide scintillation probe.

[d]Alpha measurements below surface made on soil removed from hole.

[e]Beta-gamma and gamma radiation measured with a Technical Associates (TA) mini-scaler/ratemeter, Model PRS-3, with an HP-265 pancake detector (<2 mg/cm^2 window thickness). The pancake detector was set in the open configuration to detect beta-gamma and in the closed configuration to detect gamma.

[f]Beta-gamma and gamma activity levels in the previous two columns were converted to dose rates by combining two conversions using 2800 cpm = 1 mrad/h for the beta component and 3600 cpm = 1 mrad/h for the gamma component.

[g]Soil sample hole numbers are shown on Fig. 12.

[h]Disintegrations per minute per 100 cm^2.

[i]Counts per minute.

[j]Not measured.

SOIL SAMPLE EXPOSURE RATES, RADIATION ACTIVITY LEVELS, AND DOSE RATES

Gamma Exposure Rates

Gamma exposure rates, radiation activity levels, and beta-gamma dose rates measured in the soil sample holes are shown in Table 6. The soil depth in Table 6 corresponds to the soil sample depths in Tables 4 and 5. All soil sample locations were outside the Contamination Area fence.

Gamma exposure rates were highest at soil sample locations EB-1 and EB-2, with surface levels of 2300 and 3200 μR/h and subsurface levels >990 μR/h down to soil depths of 25 cm (10 in.). Surface gamma exposure rates ranged from 310 to 430 μR/h at EB-3, EB-4, EB-5, EB-6, EB-7, and EB-8. At the remaining soil sample locations, surface levels ranged from 160 to 250 μR/h. In all cases, exposure rates decreased with increasing depth.

Alpha Measurements

Alpha activity levels at soil sample location EB-1 reached 1000 dpm/100 cm^2. This is approximately three times the ORNL Health Physics guideline (300 dpm/100 cm^2)[10] for establishing a Contamination Area. Alpha measurements at EB-2, EB-3, EB-4, and EB-5 ranged from 9 to 72 dpm/100 cm^2. Alpha activity was not measured at the other soil sample holes.

Beta-Gamma Dose Rates

Highest surface beta-gamma dose rates were found at soil sample locations EB-2, EB-4, EB-5, EB-8, and EB-1 (inferred from subsurface measurements) with measurements ranging from 2.6 to 5.3 mrad/h. Eight additional locations also exceeded the recommended ORNL Health Physics guideline (0.25 mrad/h)[10] for establishing a Contamination Area: EB-3, EB-6, EB-7, EB-9, EB-10, EB-12, EB-13, and EB-14 had dose rates ranging from 0.33 to 1.2 mrad/h. Dose rates generally decreased with increasing depth.

VEGETATION ANALYSES

Concentrations of radionuclides (wet wt) in vegetation taken from the Equalization Basin (3524) site are given in Table 7. The two vegetation sampling locations (EB-V1 and EB-V2) are indicated on Fig. 12.

Vines (EB-V1) collected over a 2-m^2 area in grid block N21,821/E31,120 showed elevated levels of ^{60}Co, ^{137}Cs, ^{152}Eu, ^{154}Eu, gross beta, and total Sr. Concentrations ranged from 0.89 pCi/g ^{154}Eu, 1.9 pCi/g ^{60}Co, 2.0 pCi/g ^{152}Eu, and 27 pCi/g ^{137}Cs to 400 pCi/g total Sr and 1100 pCi/g gross beta. Uncontaminated vegetation would be expected to contain less than the lower analytical detection limits (<0.1 pCi/g) for ^{60}Co, ^{137}Cs, ^{152}Eu, ^{154}Eu, and ^{155}Eu. Gamma exposure rates on contact with this vine sample were approximately 500 μR/h.

Grass (EB-V2) collected in grid block N21,821/E31,120 showed elevated levels of ^{137}Cs, gross beta, and total Sr. Concentrations (in pCi/g) were 0.89 for ^{137}Cs, 680 for gross beta, and 260 for total Sr. Gamma exposure rates on contact were 100 μR/h.

Table 7. Concentrations of radionuclides in vegetation taken from the Equalization Basin (3524) site

Sample ID[a]	Location[b]	Gamma exposure rates (μR/h)	Activity/radionuclide concentration in pCi/g (Bq/kg) wet wt							
			^{7}Be	^{60}Co	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	Gross beta	Total Sr
EB-V1	N21,824	500	3.8 ± 0.5	1.9 ± 0.08	27 ± 0.3	2.0 ± 0.2	0.89 ± 0.2	0.22 ± 0.2	1,100 ± 30	400 ± 30
(vine)[c]	E31,100		(140 ± 20)	(71 ± 3)	(990 ± 10)	(75 ± 7)	(33 ± 7)	(8.1 ± 6)	(39,000 ± 1,000)	(15,000 ± 1,000)
EB-V2	N21,835	100	2.4 ± 0.6	<0.11	0.89 ± 0.1	d	d	d	680 ± 30	260 ± 3
(grass)	E31,090		(90 ± 20)	(<4)	(33 ± 5)	(d)	(d)	(d)	(25,000 ± 1,000)	(9,700 ± 100)

[a]Sample locations are shown on Fig. 12.
[b]ORNL grid coordinates measured in feet.
[c]Collected from a 2-m^2 area.
[d]Not measured.

SIGNIFICANCE OF FINDINGS

Measurements of gamma exposure levels taken at the 3524 Equalization Basin site determined that exposure rates at 1 m above the ground surface at 84 grid point locations ranged from 190 to 2900 μR/h and averaged 790 μR/h. Additionally, gamma exposure rates at the ground surface at 85 grid locations ranged from 120 to 2900 μR/h and averaged 510 μR/h. For comparison, background gamma exposure rates (determined from measurements taken from uncontaminated locations on ORR) at 1 m above the ground surface ranged from 8 to 13 μR/h and averaged 10 μR/h; background levels at the ground surface ranged from 10 to 17 μR/h and averaged 13 μR/h.[12] Gamma exposure rates at the Equalization Basin consistently exceed background with μR/h values ranging from 10 to 500 times ORR background levels.

Significantly elevated gamma exposure rates are due to radioactive wastes in the basin, residual radionuclides in soil circumjacent to the basin, and radiation emanating from nearby waste operations. The most significant and immediate radiological concern is contamination identified outside the radiation control zone. Figure 8 clearly depicts these areas of surface contamination with levels of gamma exposure rates at specified locations. Regions of particular concern outside the Contamination Area fence include:

1. The contaminated region at the southeast corner of the site, which is currently encircled by a temporary rope boundary (see dark-shaded region at the described location in Fig. 8). This region showed surface gamma exposure rates of up to 6500 μR/h, beta-gamma dose rates of up to 10 mrad/h, and an alpha activity measurement of up to 180 dpm/100 cm^2. Surface soil samples from this region contained 25,000 pCi/g gross beta, 13,000 pCi/g ^{137}Cs, and 160 pCi/g gross alpha. A narrow, gravel road along the southeastern boundary of the site is close to this contaminated region. During the course of the survey, it was observed that the road was traveled by pedestrians and vehicles.

2. At the contaminated surface region east of the basin, gamma exposure rates reached 2300 μR/h and beta-gamma dose rates reached 5.4 mrad/h (see dark-shaded region at the described location in Fig. 8 and Fig. 11). On the ground surface beneath the steam pipe, alpha activity levels measured 1000 dpm/100 cm^2. Surface soil samples from this region contained the following concentrations of radionuclides: 9400 pCi/g gross beta activity, 5700 pCi/g ^{137}Cs, 510 pCi/g gross alpha activity, 140 pCi/g ^{239}Pu, 76 pCi/g ^{60}Co, 23 pCi/g ^{152}Eu, and 4 pCi/g ^{238}Pu.

3. The contaminated region north of the basin is an area frequented by ORNL personnel studying water movement into the basin (see dark-shaded region at the described location in Fig. 8). In this area, gamma exposure rates reached 2400 μR/h and beta-gamma dose rates reached 2.9 mrad/h. Vegetation samples from this region had significant concentrations of gross beta activity (1100 pCi/g), total Sr (400 pCi/g), and ^{137}Cs (27 pCi/g).

4. The contaminated region immediately south of the basin remained moist during the survey period (see medium-shaded region at the described location in Fig. 8). Surface gamma exposure rates reached 870 μR/h and beta-gamma dose rates reached 5.0 mrad/h. Analysis of soil samples from this region showed radionuclide concentrations of 5100 pCi/g gross beta, 1400 pCi/g ^{137}Cs, and 9.7 pCi/g ^{60}Co. Concentrations of ^{137}Cs increased with soil depth at one sampling location.

Results of analysis of 30 soil samples show gross beta and ^{137}Cs as the major radiological contaminants. In surface soil sample EB-2A, gross beta and ^{137}Cs concentrations were 25,000 and 13,000 pCi/g, respectively. If surface soil remedial action guidelines* were applicable for this site, the maximum surface ^{137}Cs concentration (13,000 pCi/g) would exceed (by a factor of 162) the criterion of 80 pCi/g above background.[13] It should be noted that these guidelines are based on evaluation of pathways of inhalation, ingestion, and external radiation exposure to humans from a 100-m^2 area of contamination.[13] For comparative purposes, the average background concentration of ^{137}Cs, as determined by gamma spectrometry analysis of soil samples taken from uncontaminated areas on ORR, is 0.77 pCi/g (dry wt).[12]

RECOMMENDATIONS FOR CORRECTIVE ACTIONS

Because the 3524 Equalization Basin was in operation during the survey period, the radiological data presented in this report should be considered only a "snapshot" representation of the site (i.e., basin and circumjacent land areas). Subsequent to the time of the survey, the radiological status of the site significantly changed with regard to external gamma exposures as a result of water level fluctuation in the basin. The proposed corrective actions are based exclusively on the results of this survey and should be considered only as interim evaluations pending final site closure and detailed radiological and hazardous waste characterizations of the site.

Highly elevated levels of ground-surface gamma and beta-gamma radiation and concentrations of radionuclides in soil and vegetation warrant immediate corrective actions. It is important to note that this site is located in the main plant area; hence the primary concern in considering corrective actions is the minimization of exposures of personnel to radiation. These recommendations are in accordance with the radiation safety policy of ORNL to conduct all operations in such a manner that personnel exposures to radiation or contamination are maintained at a level as low as is reasonably achievable (ALARA).

Two basic approaches to interim corrective actions are (1) isolation of contaminated areas (e.g., fencing), including measures to prevent further dispersion of radioactivity, and (2) removal, treatment (if needed), and disposal of contaminated soil, ground cover, and vegetation, followed by stabilization of the treated areas. Because of significantly elevated gross beta activity levels and high concentrations of radionuclides (e.g., ^{90}Sr, ^{137}Cs) in soil sampled from the site, removal, treatment, and disposal of contaminated soil may pose a greater human health risk than leaving in situ. In this scenario, a "no action" approach coupled with the application of proven, demonstrable technologies for long-term stabilization and/or reduction of radiation exposures should be considered.

Corrective action options listed below involve ground-surface measures to limit human exposures, minimize surficial dispersion of contamination, and monitor any such dispersion. These actions would not necessarily involve the implementation of all recommendations listed below; rather, the recommendations are to be considered individually, although

*Remedial action guidelines have been derived for specific application to the DOE's Formerly Utilized Site Remedial Action Program (FUSRAP). These guidelines are applicable to FUSRAP sites prior to their release for unrestricted use.

a combination of measures might be selected. A more detailed investigation (with core hole borings and soil analysis) would be required to fully characterize the radiological status of the 3524 Equalization Basin site and address the most appropriate methods for effective long-term remediation.

Isolation of contaminated areas

- Existing radiation control measures at the 3524 Equalization Basin site include a metal chain and posts placarded with several "Contamination Area" and "Radiation Hazard – Keep Out" signs. In addition, a rope extends from the southeast corner of the chained zone and encircles a concrete structure. Based on guidelines outlined in the ORNL Health Physics Procedure Manual,[10,14] radiation control measures currently in place at the site are applicable. However, it is recommended that the perimeter of the control zone be extended to include the immediate boundaries of all roads that encompass the perimeter of the site. Dilapidated warning signs, chain fencing, and metal posts should be removed, replaced with upgraded materials, and relocated beyond the areal boundaries of regions of surficial contamination. Special emphasis should be given to the placement of signs along White Oak Avenue and Third Street. Access should be restricted into this site and the number of zone portals (point of entrance and exit) limited to one. A map of the site showing radiation levels and regions of surface contamination and including instructions to contact the Radiation Protection Department should be posted at the zone portal.
- The gravel road along the southeastern boundary of the site should be closed to pedestrians and vehicles and stringent entrance requirements should be mandated by ORNL Health Physics. Highly elevated surface gamma exposure rates of up to 6 mR/h were measured at the contaminated region located near the gravel road (see Fig. 7). Furthermore, radionuclide analysis of a surface soil sample (EB-2A) taken from this contaminated region verifies significant concentrations of gross beta (25,000 pCi/g) and ^{137}Cs (13,000 pCi/g).
- Radiation protection measures (e.g., monitoring devices) should be considered for ORNL service personnel involved with maintenance activities at the 3524 Equalization Basin site. At the identified regions of surface soil and vegetation contamination, all activities that may potentially disturb and/or disperse radioactivity should cease if personnel involved with these operations (e.g., grass mowing, research interests) do not wear some type of radiation protection gear. Personal respirators would minimize the potential for inhalation of radioactively contaminated soil and vegetation dust.
- Additional radiation control measures should be considered for the more highly contaminated "hot" areas inside the fenced area. Warning signs could be posted in these regions with instructions to contact the Radiation Protection Department before entering the area.
- If remedial or cleanup actions are not implemented at this site, institutional control should be maintained for a specified period of time to allow for radioactive decay. Long-term institutional control (~300 years) would result in a 99% reduction of ^{90}Sr and ^{137}Cs activities (~10 half-lives). Periodic monitoring of radioactivity in soil, surface water, and groundwater should be performed.

- Land stabilization procedures (e.g., earthen caps, hydrologic isolation, and limited in situ grouting or vitrification) should be considered at the identified contaminated areas.
- Exposure rates could be reduced at contaminated areas by covering contaminated ground-surface areas with clean, uncontaminated soil. However, if eventual remedial action requires removal of contaminated soil, the added cover would increase the volume of waste to be disposed of.

Removal, treatment, and disposal of contaminated soil

- In the highly contaminated areas, soil, ground cover, and vegetation could be removed and disposed of in a designated radioactive waste disposal site. Excavation and removal of the contaminated soil must be carried out in full compliance with guidelines stated in the *Health, Safety, and Environmental Protection Procedures for Excavating Operations* manual [ORNL/M-116/R1 (March 1988)].[15] It is essential that ORNL Health Physics personnel be present to monitor all activities associated with any disturbance of soil at the 3524 Equalization Basin site.

Recently, additional radiation control measures have been implemented on the site. The roped area at the southeast corner of the site has been placarded with several "Radiation Hazard – Keep Out" and "Contamination Area" signs. Furthermore, physical barriers (i.e., galvanized chicken wire and monofilament streamers) have been installed to prevent waterfowl intrusion into the basin area.

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