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Status Report on Radioactivity Movement from Burial Grounds in Melton and Bethel Valleys

J. O. Duguid

Environmental Sciences Division Publication No. 658

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ENVIRONMENTAL SCIENCES DIVISION

STATUS REPORT ON RADIOACTIVITY MOVEMENT FROM BURIAL GROUNDS IN MELTON AND BETHEL VALLEYS

J. O. Duguid

JULY 1975

(Environmental Sciences Division
Publication No. 658)

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TABLE OF CONTENTS

	Page
ABSTRACT	1
LIST OF TABLES	IV
LIST OF FIGURES	VI
INTRODUCTION	3
SEEPAGE PITS AND TRENCHES	4
Analyses of Water Samples	6
Mechanism of ^{60}Co Transport from Trench 7	10
BURIAL GROUNDS 1, 3, and 5	12
Groundwater Samples from Burial Ground 1	14
Groundwater Samples from Burial Ground 3	16
Water Samples from Burial Ground 5	20
Interpretation of Results	25
BURIAL GROUND 4	26
Geology and Hydrology	27
Groundwater Monitoring	30
Groundwater Contamination	30
Estimated Discharge of ^{90}Sr	39
Stream Monitoring Data	43
Interpretation of Results	47
INTERMEDIATE POND AREA	50
DEVELOPMENT OF GROUNDWATER TRANSPORT MODELS	57
CONCLUSIONS	58
ACKNOWLEDGMENTS	63
REFERENCES	64

LIST OF TABLES

Table		Page
1	Analyses of water samples from seeps associated with seepage pits and trenches, in dpm/ml	8
2	Analyses of soil samples from the seep near trench 7 (RS7), in dpm/g	9
3	Water quality of the seep near trench 7 (RS7)	11
4	Analyses of water samples from burial ground 1, in dpm/ml	17
5	Water samples from burial ground 3; ^{90}Sr concentration, in dpm/ml	18
6	Analyses of water samples from the west side of burial ground 5, in dpm/ml	22
7	Analyses of water samples from the south side of burial ground 5, in dpm/ml	23
8	Radionuclide concentrations in old wells in burial ground 4 and in permanent seeps below the burial ground	31
9	Concentration of ^{137}Cs in wells below burial ground 4, in dpm/ml	35
10	Locations where alpha contamination was present in water samples but was at concentrations below analytical measurement	36
11	Concentration of ^{90}Sr flowing from basin 1, in dpm/ml	37
12	Concentration of ^{90}Sr in wells in the lower portion of basin 2, in dpm/ml	38
13	Annual precipitation and evapotranspiration data from Walker Branch Watershed	41
14	Calculated and monitored annual discharge of ^{90}Sr from burial ground 4	42
15	Discharge of ^{90}Sr from burial ground 4 and precipitation data for water years 1963 through 1973	44
16	Radionuclide concentration in wells near the intermediate-pond dam, in dpm/ml	51

LIST OF TABLES (contd)

Table		Page
17	Concentration of radionuclides in soils below burial ground 4, in dpm/g.	53
18	Concentration of radionuclides in vegetation below burial ground 4, in dpm/g of 100°C oven-dryed plant.	54
19	Concentration of ^{239}Pu in soils below burial ground 4 (intermediate-pond sediment).	55

LIST OF FIGURES

Figure		Page
1	Location of small seeps associated with seepage pits 1, 2, 3, and 4 and trenches 5, 6, and 7	7
2	Approximate location of waste disposal areas and sampling stations at ORNL	13
3	Location of wells and one seep near burial ground 1	15
4	Map of burial ground 3 showing groundwater contours and well locations	19
5	Location of wells and seeps in burial ground 5	21
6	Water table contours at burial ground 4, December 24, 1959	28
7	Water table contours at burial ground 4, February 1, 1974	29
8	Location of groundwater monitoring wells for burial ground 4	32
9	Elevation contours prior to the establishment of burial ground 4	34
10	Discharge of ^{90}Sr from burial ground 4 for water years (September 1 - August 31) 1963 through 1973, in mCi/in. of precipitation (from stream monitoring data)	46
11	Section A-A' showing present land surface, original land surface, and present water table in burial ground 4	49

STATUS REPORT ON RADIOACTIVITY MOVEMENT FROM BURIAL GROUNDS IN MELTON AND BETHEL VALLEYS: I

J. O. Duguid

ABSTRACT

The offsite radioactivity releases in the Clinch River are less than 1% of the amount allowable for unrestricted use of the water by a population. However, in keeping with ERDA's objective to maintain releases to "as low as practicable," studies directed toward locating sources of radioactivity release and toward seeking methods for reducing or eliminating them have been continued. This particular study, initiated in April 1973, is concerned primarily with determining the radioactivity contributions to the Clinch River from the buried waste at ORNL and with implementing corrective measures.

Studies of the groundwater transport of radionuclides from buried waste at Oak Ridge National Laboratory show that burial ground 4 is the major contributor of ^{90}Sr to the groundwater. The concentration of ^{90}Sr in the groundwater below burial ground 4 increases the amount of ^{90}Sr in White Oak Creek, which drains the area and flows into the Clinch River. The burial ground area was used for the disposal of uncontaminated fill after burial was completed in 1959. The fill increased the surface elevation and also increased the infiltration rate, thus raising the groundwater table because of the change in topography and permeability. The resulting saturated conditions increased the transport of ^{90}Sr from the buried waste. Estimates of ^{90}Sr discharge from the burial ground made from hydrologic data and groundwater monitoring show that 1 to 2 Ci of ^{90}Sr are transported from the burial ground annually. The amount of transport is directly related to precipitation, and stream monitoring data show

that the discharge of ^{90}Sr from burial ground 4 has decreased over the past 11 years. Suggestions of engineering methods designed to decrease the ^{90}Sr discharge are made. However, more field studies and experimental field tests are required before suggestions are made in the form of proposed solutions to the problem.

Reconnaissance data collected in Melton and Bethel valleys show that burial ground 1 and 3 and the west side of burial ground 5 do not contribute significant quantities of ^{90}Sr to White Oak Creek above the confluence with Melton Branch. Burial ground 5 contributes a significant amount of ^{90}Sr to Melton Branch (an average of about 0.8 Ci/yr). As an experiment, one waste trench in burial ground 5 will be sealed in order to reduce the discharge of ^{90}Sr from the area and to determine the applicability of this type of seal for larger areas.

The seepage pits and trenches located in Melton Valley contribute little or no ^{90}Sr to the White Oak drainage. Mathematical simulation models are currently being applied to predict the future behavior of seepage trench 7. Once future problems can be predicted, preventive measures can be applied before the problem develops.

INTRODUCTION

The offsite radioactivity releases in the Clinch River are less than 1% of the amount allowable for unrestricted use of the water by a population. However, in keeping with ERDA's objective to maintain releases to "as low as practicable," studies directed toward locating sources of radioactivity releases and toward seeking methods for reducing or eliminating them have been continued. This particular study, initiated in April 1973, is concerned primarily with determining the radioactivity contributions to the Clinch River from the buried waste at ORNL and with implementing corrective measures. The research conducted for the development of corrective measures will also indicate modifications in current burial procedures that will reduce radionuclide transport from new burial sites. The study encompasses all waste disposal sites at ORNL and is funded by the Division of Waste Management and Transportation of the U.S. Energy Research and Development Administration. The purpose of this report is to document the progress of the investigation.

In the spring of 1973 reconnaissance of the waste disposal areas in Melton and Bethel valleys was begun. Small seeps and springs below seepage pits, seepage trenches, and burial grounds were sampled to determine the source, or sources, of ^{90}Sr discharge to the surface waters of the White Oak drainage. The reconnaissance data collected from seepage pits and trenches, from burial grounds 1, 3, and 5, and from burial ground 4 are discussed in this report. At this stage in the investigation an estimate of the quantity of ^{90}Sr discharge has been made for only one area, burial ground 4. Research is currently

being conducted which will aid in the selection of an engineering method to reduce the ^{90}Sr movement from burial ground 4. However, preliminary ideas for engineering solutions are presented and discussed.

The groundwater table in the White Oak drainage is a shallow unconfined water table that is a subdued replica of the surface topography. The groundwater flows from areas of high elevation to areas of low elevation where it discharges into surface streams at or near the stream surface elevation. Thus, areas of groundwater contamination occur locally near waste disposal sites, and the contaminated groundwater discharges into surface streams within the drainage. The contamination arising from both surface water releases at X-10 and groundwater discharge from waste disposal areas is monitored at White Oak Dam, which is located in the lower portion of the drainage near the confluence of White Oak Creek and the Clinch River.

The units of measurement of radionuclide concentration presented in this document are disintegrations per minute per milliliter for water analyses (dpm/ml) and disintegrations per minute per gram for soil analyses (dpm/g). These units may be converted to microcuries (μCi) by dividing the quantity by 2.2×10^6 (i.e., 1.0 μCi = 2.2×10^6 dpm).

SEEPAGE PITS AND TRENCHES

Since the beginning of operations at ORNL, soils have been used for the disposal of radioactive waste. Disposal consisted of land burial of solid waste in unlined trenches that were covered with soil or concrete. Based on this experience and with the knowledge that the

Conasauga shale is somewhat impermeable, the construction of pits for disposal of intermediate-level liquid waste was begun in 1951 (Fig. 1). The first experimental pit, pit 1, was opened in 1951 and closed almost immediately because of breakthrough of radionuclides due to the pit's poor location. A second pit, pit 2, was brought into operation in 1952, and for the first time large quantities of intermediate-level waste were discharged into terrestrial pits. Pits 3 and 4 became operational in 1955 and 1956, respectively. The first covered trench, trench 5, was brought into operation in 1960, and trench 6 and 7 in 1961 and 1962, respectively. Trench 6 was operated for only a short period in 1961 because of breakthrough of ^{90}Sr and ^{137}Cs (i.e., small amounts of ^{90}Sr and ^{137}Cs were observed in a seep below the trench which indicated rapid movement from the trench to the surface seep. This transport was attributed to groundwater flow through fractures in the Conasauga shale). In 1962 pits 2, 3, and 4 and trench 5 were taken out of routine service; however, pit 4 is still used for disposal of sludge from the Process Waste Water Treatment Plant (Lomenick, Jacobs, and Struxness, 1967). Trench 7 was taken out of service in 1965 as part of a plan to implement disposal of intermediate-level liquid waste by the process of hydrofracture in 1966 (McClain, 1967). During the operation of the seepage pits and trenches, approximately 35 million gallons of waste, containing over 1 million curies of mixed fission products, were disposed of. Approximately half of this amount was ^{90}Sr and ^{137}Cs, with most of the remainder being ^{106}Ru. The waste contained considerably lesser amounts of ^{125}Sb, ^{60}Co, and other mixed fission products (Lomenick, Jacobs, and Struxness, 1967).

Analysis of Water Samples

Because of the quantity of radioactivity contained in the seepage pits and trenches, reconnaissance sampling of small seeps located below these disposal areas was initiated (Fig. 1). All of the seeps produce small quantities of flow during the winter months and are dry during most of the summer months. The sampling was conducted over a four-month period (March-June) to determine whether measurable quantities of ^{137}Cs and ^{90}Sr were discharging from the seeps into the surface waters of the White Oak drainage. The analyses of water samples from eight seeps are given in Table 1. The samples were found to contain ^{60}Co which ranged in concentration from 10.3 to 613.0 dpm/ml. They also contain minor amounts of ^{90}Sr, ^{137}Cs, ^{125}Sb, and ^{106}Ru. From the data in Table 1, it is apparent that negligible amounts of ^{90}Sr and ^{137}Cs are being transported by groundwater to surface seeps associated with waste pits and trenches. Only one seep contains measurable amounts of ^{137}Cs, seep RS8. This seep is located below trench 6, which was closed after a short period of operation in 1961 when leakage of ^{90}Sr and ^{137}Cs was discovered (Fig. 1).

The largest quantity of ^{60}Co was found in a small seep, RS7, located below waste trench 7 (Fig. 1). The water from the seep contained 199.0 to 613.0 dpm/ml of ^{60}Co during the period of observation (Table 1). The average concentration of ^{60}Co is 383 dpm/ml, or 1.7×10^{-4} μCi/ml. Sediment in the seep and soil from the vicinity contain concentrations of ^{60}Co that range from 6.1×10^{2} to 7.2×10^{5} dpm/g (Table 2). The soil contains minor amounts of ^{90}Sr, with the exception of the sample from the depth 18 to 21 in., which has 975.0 dpm/g of ^{90}Sr.

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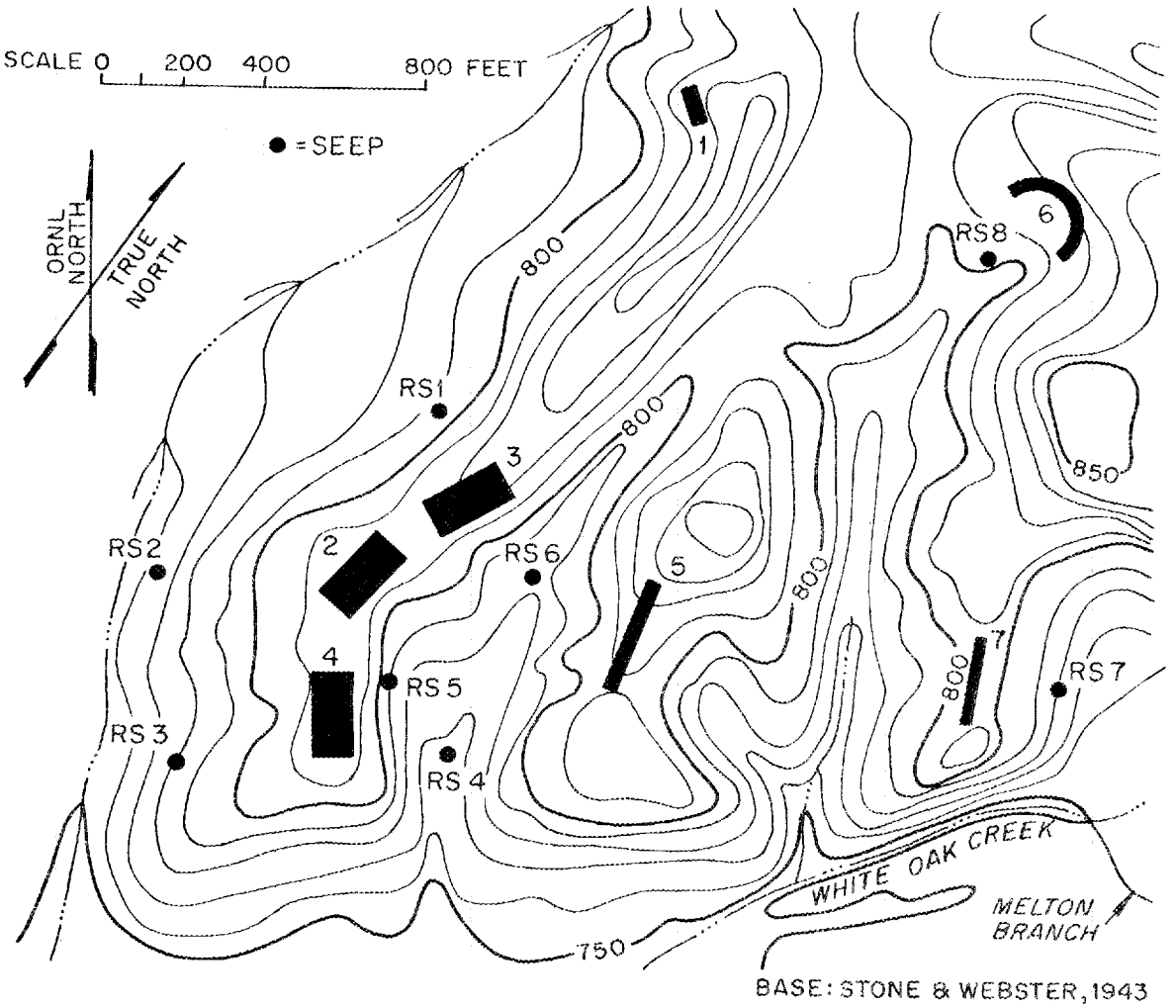

Fig. 1. Location of small seeps associated with seepage pits 1, 2, 3, and 4 and trenches 5, 6, and 7.

Table 1. Analyses of water samples from seeps associated with seepage pits and trenches, in dpm/ml

Location	Date	^{90}Sr	^{60}Co	^{137}Cs	^{125}Sb	^{106}Ru
RS 1	3- 5-73	≤ 0.3	$\leq 2.0 \times 10^{-1}$	$\leq 1.0 \times 10^{-1}$	$\leq 2.0 \times 10^{-1}$	$\leq 7.0 \times 10^{-1}$
RS 2	3- 5-73	≤ 1.1	38.5	$\leq 3.0 \times 10^{-1}$	$\leq 4.0 \times 10^{-1}$	≤ 5.0
RS 3	3- 5-73	≤ 0.3	10.3	$\leq 2.0 \times 10^{-1}$	$\leq 2.0 \times 10^{-1}$	≤ 2.0
RS 3	3-19-73	0.02	104.0	$\leq 9.0 \times 10^{-1}$	$\leq 9.0 \times 10^{-1}$	5.7
RS 4	3- 5-73	0.08	11.5	$\leq 3.0 \times 10^{-1}$	6.7×10^{-1}	≤ 2.0
RS 5	3- 5-73	≤ 0.01	23.5	$\leq 5.0 \times 10^{-1}$	8.7	4.5
RS 5	3-19-73	0.05	56.5	$\leq 9.0 \times 10^{-1}$	11.9	9.3
RS 6	3-19-73	0.07	13.4	$\leq 3.0 \times 10^{-1}$	$\leq 3.0 \times 10^{-1}$	≤ 3.0
RS 7	3- 5-73	0.07	240.0	≤ 3.0	≤ 2.0	≤ 10.0
RS 7	3-19-73	0.05	199.0	$\leq 5.0 \times 10^{-1}$	≤ 4.0	≤ 9.0
RS 7	5-11-73	≤ 0.3	479.0	≤ 4.0	6.7	≤ 20.0
RS 7	6- 4-73	≤ 0.03	613.0	—	—	—
RS 8	3-19-73	2.0	$\leq 5.0 \times 10^{-1}$	3.8	$\leq 5.0 \times 10^{-1}$	$\leq 7.0 \times 10^{-1}$

Table 2. Analyses of soil samples from the seep near trench 7 (RS7), in dpm/g

Date	Depth (in.)	^{90}Sr	^{60}Co	^{137}Cs	^{125}Sb	^{106}Ru
5-11-73	seep sediment	—	7.2×10^5	—	—	—
6- 4-73	seep sediment	5.2	1.2×10^5	—	-	—
9-25-73	0-3	≤ 49.0	8.5×10^4	$\leq 5.3 \times 10^2$	$\leq 6.9 \times 10^2$	$\leq 2.8 \times 10^3$
9-25-73	3-6	≤ 55.0	2.3×10^4	$\leq 1.6 \times 10^2$	$\leq 2.4 \times 10^2$	$\leq 7.5 \times 10^2$
9-25-73	6-9	≤ 31.0	1.1×10^4	$\leq 6.9 \times 10^2$	$\leq 1.2 \times 10^2$	$\leq 2.7 \times 10^2$
9-25-73	9-12	≤ 19.0	3.6×10^3	≤ 25.0	≤ 41.0	$\leq 1.5 \times 10^2$
9-25-73	12-15	≤ 31.0	1.3×10^3	≤ 9.9	≤ 18.0	≤ 57.0
9-25-73	15-18	≤ 59.0	6.1×10^2	≤ 5.5	≤ 13.0	≤ 36.0
9-25-73	18-21	975.0	6.5×10^2	≤ 5.9	≤ 9.7	≤ 45.0

In the analyses of these soil samples the high level of ^{60}Co radioactivity hampered routine analysis for ^{90}Sr. For this reason the concentration of ^{90}Sr given in Table 2 are less accurate than those from other locations.

Seep RS7 is characteristic of other seeps located on the Conasauga shale. The pH of the water, 7.4, is representative of a calcium carbonate spring and is dominated by the amount of carbonate in the shale. The presence of the intermediate-level waste is indicated by the amount of sodium and nitrate in the seep water (Table 3).

Mechanism of ^{60}Co Transport from Trench 7

The positive charge of ^{60}Co in its cationic form should enhance its adsorption by the Conasauga shale. The relatively high concentration of ^{60}Co in seep RS7 (below trench 7) suggests that adsorption by the shale is minimal; studies to determine the mechanism of ^{60}Co transport from the waste trench to the surface seep were initiated by E. A. Bondietti of the Environmental Sciences Division at ORNL. The initial work suggested that ^{60}Co was not present in the seep water as cationic cobalt ($^{60}Co^{2+}$) but was present as a negatively charged species. After precipitation of $SO_4^{=}$ with $Ba(NO_3)_2$ and removal of cations (Ba^{2+}, Ca^{2+}, Na^{2+}, Co^{2+}, etc.) using Dowex-50, the unconcentrated solution was studied to determine the nature and amount of the complexing agent. Standard EDTA (ethylenediamine-tetraacetic acid) and a concentrated portion of the seep water were examined using thin-layer chromatography, and the results of the analysis suggested that the complexing agent was EDTA. A base titration curve using NaOH revealed the presence of two ionizable functional groups with the same ionization constants as EDTA. From the titration

Table 3. Water quality of the seep near trench 7 (RS 7)*

T.S. (ppm)	pH	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Cr (ppm)	PO_4 (ppm)	NO_3 (ppm)	SO_4 (ppm)	CO_3 (ppm $CaCO_3$)	HCO_3 (ppm $CaCO_3$)
2050.0	7.4	61.8	8.9	525.0	3.2	< 0.02	< 0.01	0.2	880.0	487.0	0.	210.0

*Samples collected April 4, 1973.

curves, the concentration of EDTA in the seep water was estimated to be 8×10^{-4} molar. Studies using a Pb^{2+} selective ion electrode confirmed that the concentration of the complexing agent was above 10^{-4} molar and that the water contained primarily one type of complexing agent. Estimation of the stability constant for the Pb^{2+} -waste complex suggests that the organic complex is EDTA. EDTA is widely used for cleanup of equipment and decontamination at the laboratory and is, therefore, present in the intermediate-level waste. The persistence (nonbiodegradability) of EDTA in the waste and in the environment adds a new dimension to the cycling of radionuclides in terrestrial ecosystems. The substance may form numerous complexes with fission products and transuranic elements and increase their mobility.

BURIAL GROUNDS 1, 3, AND 5

Six solid burial grounds are located in Melton and Bethel valleys near ORNL (Fig. 2). These burial grounds are numbered consecutively in the order in which they were first used. The disposal method used is not unlike sanitary landfill, where waste is placed in unlined trenches and covered with approximately two feet of soil. In some areas, trenches containing alpha material were covered with concrete. Higher-level solid waste was disposed of in auger holes located within the burial grounds.

Burial grounds 1, 2, and 3 in White Oak Valley are underlain by limestone of the Chickamauga Group. Because of solution channels in this formation, later burial grounds were located in Melton Valley since it is underlain by Conasauga shale. The shale was selected for waste disposal because of its impermeability.

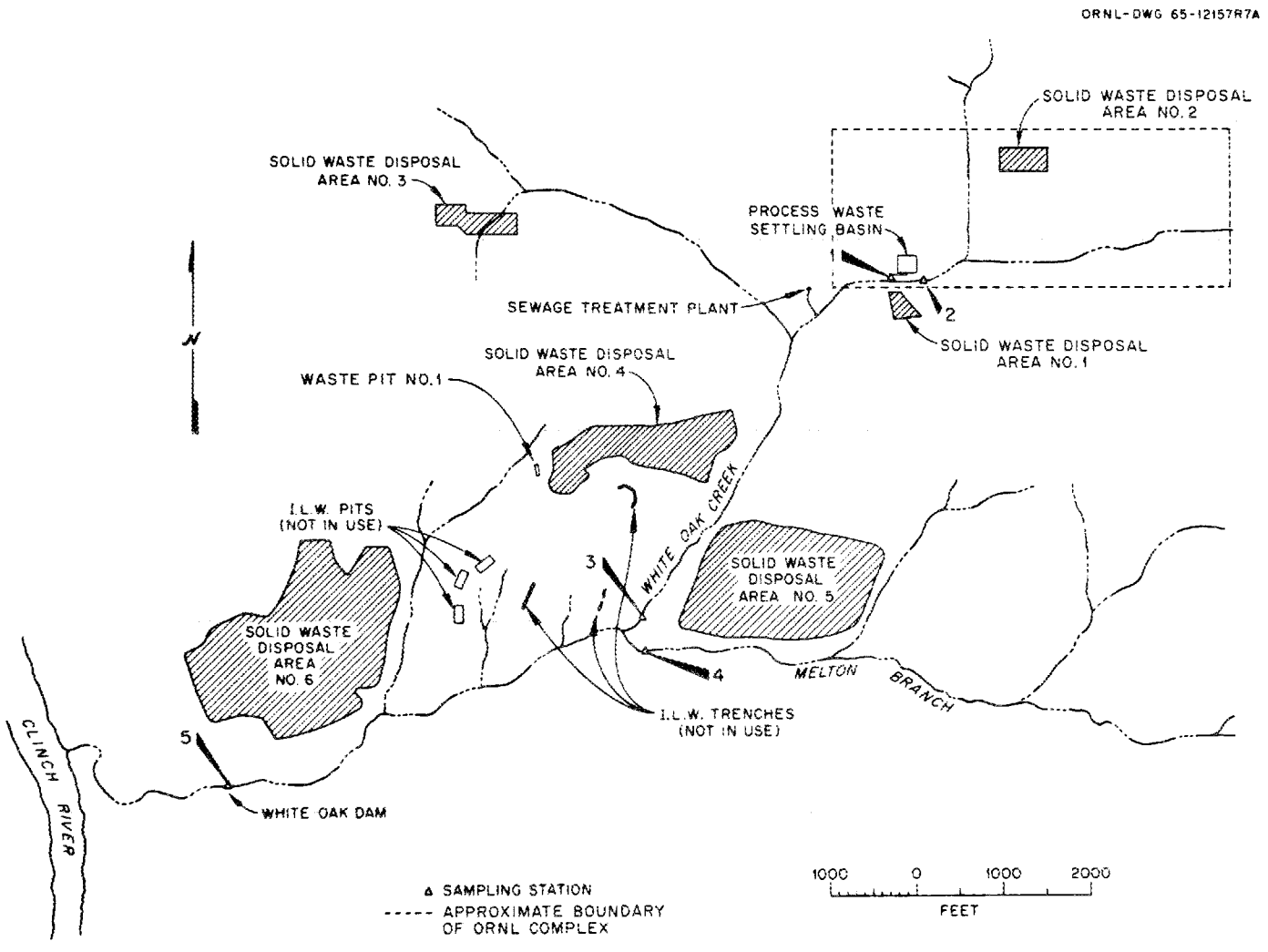

Fig. 2. Approximate location of waste disposal areas and sampling stations at ORNL.

Over a period of several years, stream monitoring data from sampling stations on White Oak Creek showed that more ^{90}Sr was passing sampling station 3 than was being discharged from ORNL (Fig. 2). In an effort to determine the source of the added amount of ^{90}Sr, reconnaissance sampling was conducted in burial grounds 1, 3, 4, and 5. In the following sections the results of sampling in burial grounds 1, 3, and 5 are discussed. Samples collected along Melton Branch are also included; however, discharge from the south side of burial ground 5 is monitored at sampling station 4 (Fig. 2) and is discussed in a further section on burial ground 5. No sampling was conducted below burial ground 2 because its groundwater discharge is monitored at sampling station 2 and does not contribute to the added amount of ^{90}Sr recorded at sampling station 3.

Groundwater Samples from Burial Ground 1

To determine whether ^{90}Sr was being transported from burial ground 1 to White Oak Creek by groundwater, two shallow wells were installed below the burial ground (Fig. 3). At this location the direction of groundwater flow is assumed to be in a northwesterly direction toward White Oak Creek; thus any ^{90}Sr that is moving in the groundwater should enter the creek below the burial ground. This assumption is made on the basis of a statement by Stockdale (1951) in which he said that, in general, the water table in the X-10 area is a subdued replica of the land surface. It rises slightly below the hills and occupies a position closer to the surface in the valleys. Thus, the directions of groundwater flow and surface runoff are roughly parallel.

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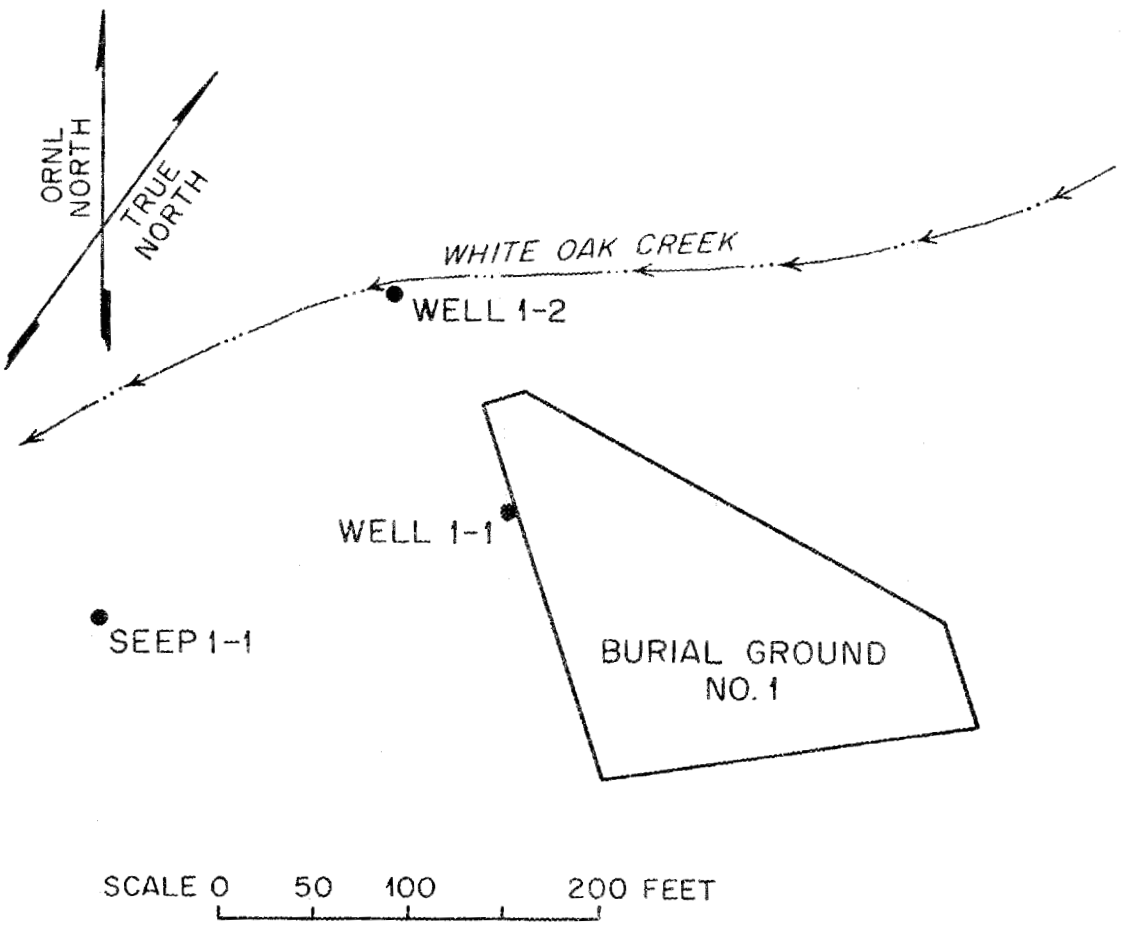

Fig. 3. Location of wells and one seep near burial ground 1.

The analyses of water samples from two wells and one surface seep are given in Table 4. The presence of ^{90}Sr was found in well 1-2, where the concentration was 0.4 dpm/ml. Because of the low concentration, burial ground 1 is not considered to be a major contributor to the added amount of ^{90}Sr recorded at sampling station 3. These analyses also indicated that little or no ^{137}Cs is transported from burial ground 1 and that no transuranic elements are present in detectable quantities in the groundwater.

Groundwater Samples from Burial Ground 3

Groundwater contours in the vicinity of burial ground 3 (Stockdale, 1951) show the presence of a groundwater divide in the west end of the burial ground (Fig. 4). The direction of groundwater flow from the burial ground is toward the north, with the exception of the western end of the burial ground where the groundwater flows in a westerly direction. Thus, if radioactivity was discharging from the disposal area, it would be detected in wells located along the north and west sides of the area.

Table 5 shows the analyses of water samples that were collected from wells in the vicinity of burial ground 3. With the exception of well 9, wells located along the north and west sides of the area yielded water with higher concentrations of ^{90}Sr. Well 9 is located near an area where there is evidence of surface contamination, which could explain the presence of ^{90}Sr in the well. Other fission products in the water either are not present or are present at a concentration below the limit of detection.

Table 4. Analyses of water samples from burial ground 1, in dpm/ml

Location	Date	^{90}Sr	^{137}Cs
Well 1-1	11-13-73	≤ 0.5	$\leq 2.1 \times 10^{-2}$
Well 1-2	11-13-73	0.4	$\leq 2.7 \times 10^{-2}$
Seep 1-1	11-13-73	$\leq 4.6 \times 10^{-2}$	$\leq 1.9 \times 10^{-2}$

Table 5. Water samples from burial ground 3; ^{90}Sr concentration, in dpm/ml*

Well	301	302	303	3	9	15	16	20	21	22	23	32
^{90}Sr	0.3	1.0	0.6	$\leq$ 0.1	3.3	$\leq$ 0.1	1.1	$\leq$ 0.1	0.6	$\leq$ 0.1	$\leq$ 0.2	$\leq$ 0.1

*Samples collected November 13, 1973.

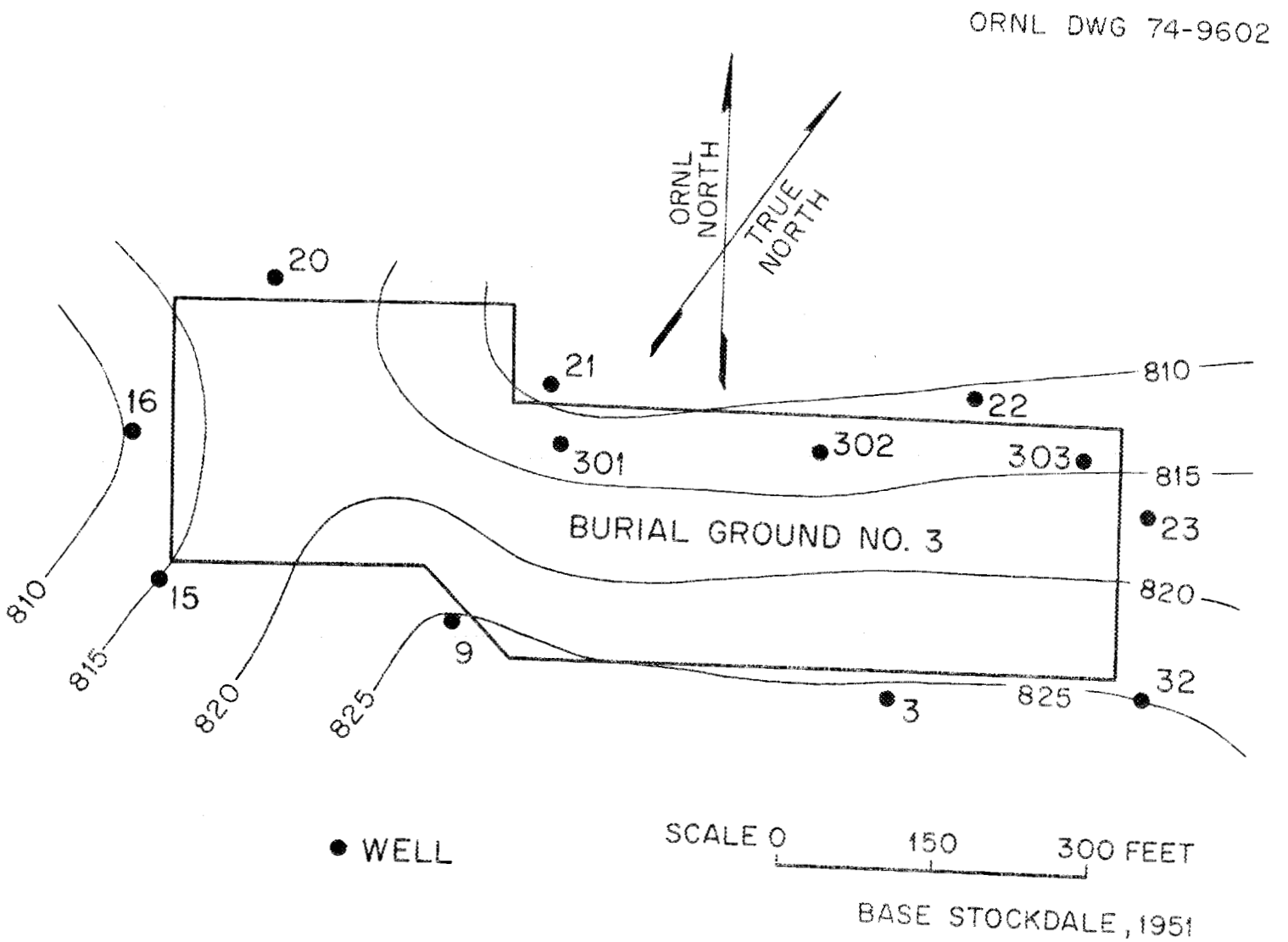

Fig. 4. Burial ground 3 showing groundwater contours and well locations.

Water Samples from Burial Ground 5

To determine whether ^{90}Sr was entering White Oak Creek along the west side of burial ground 5, samples were collected from six wells and three intermittent streams located along the west side of the burial ground (Fig. 5). The analyses of these samples for ^{90}Sr are given in Table 6. The samples indicate that no appreciable quantity of strontium is being discharged from the west side of burial ground 5. The samples collected from this area show no evidence of alpha contamination or contamination by other fission products; however, the analysis for tritium was not made on these samples.

A water table contour map of burial ground 5 suggests that the direction of groundwater flow in the area is primarily toward Melton Branch (Cowser, Lomenick, and McMaster, 1961). (The flow direction is inferred from the groundwater contours, that is, in the direction of the largest groundwater gradient.) Thus, most of the groundwater flowing from the area would reach Melton branch with only a small portion, the western end, discharging into White Oak Creek. In this area, as in Melton Valley, the groundwater contours and the topographic contours are roughly parallel.

The assumption that groundwater transport of radionuclides from burial ground 5 is primarily toward Melton Branch (southward) is substantiated by the analyses of water samples from the south side of the area. Thirteen small seeps were sampled below the south edge of the burial ground, and the analyses of these samples are given in Table 7. The samples contain measurable amounts of total α, ^{90}Sr, ^{3}H, and

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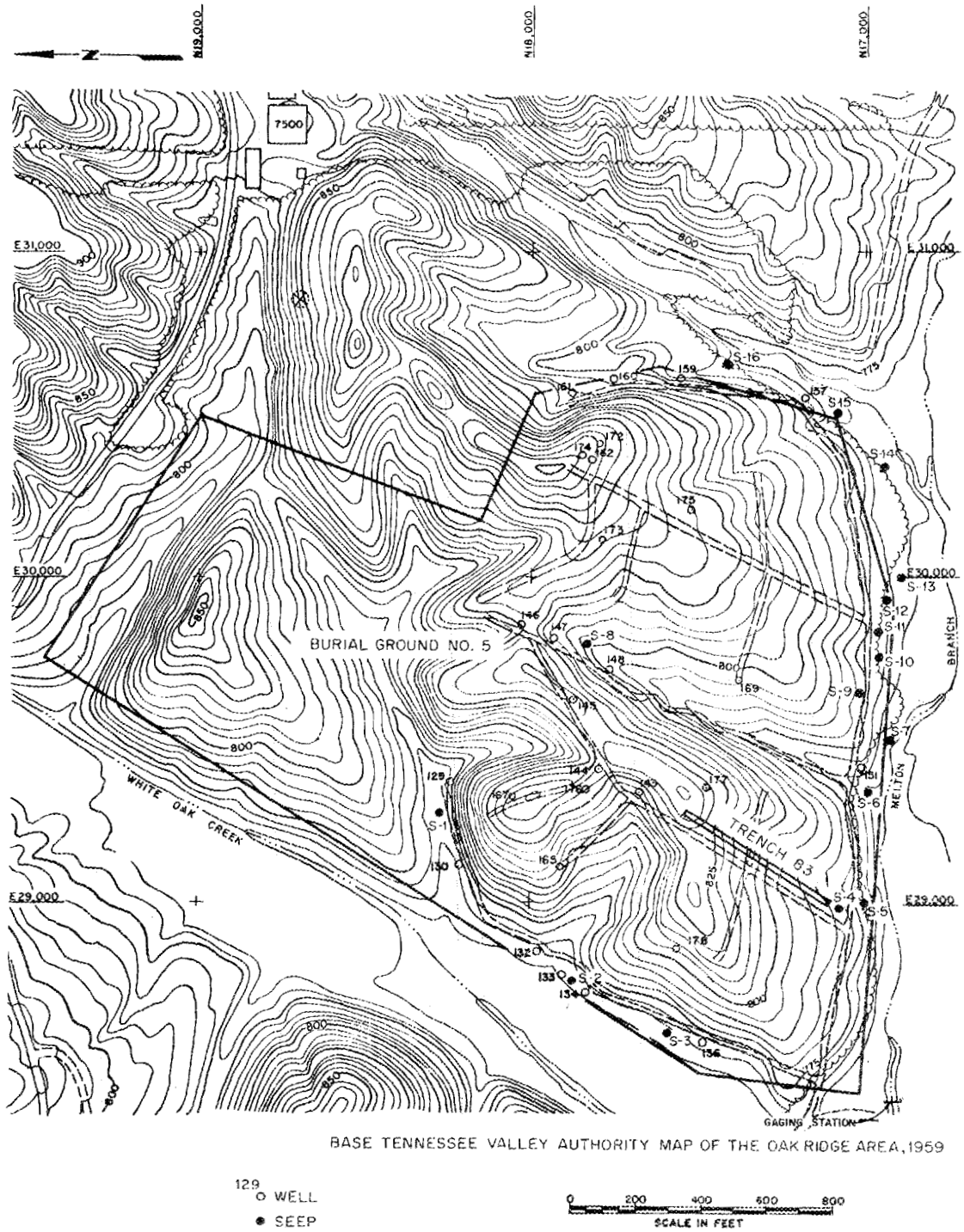


Fig. 5. Location of wells and seeps sampled in burial ground 5.

Table 6. Analyses of water samples from the west side of burial ground 5, in dpm/ml*

Location	S-1	S-2	S-3	Well 129	Well 130	Well 132	Well 133	Well 134	Well 136
^{90}Sr	0.02	≤ 0.03	$< 7.9 \times 10^{-2}$	≤ 0.02	≤ 0.01	≤ 0.03	≤ 0.02	< 0.03	< 0.03

*Samples collected November 13, 1973.

Table 7. Analyses of water samples from the south side of burial ground 5, in dpm/ml*

Location	Total α	^{90}Sr	^{3}H	^{125}Sb
S- 4	6.2	3.1×10^{4}	1.2×10^{5}	24.7
S- 5	≤ 0.6	3.5×10^{2}	5.9×10^{4}	0.2
S- 6	≤ 0.1	8.0	4.9×10^{4}	$\leq 2.6 \times 10^{-2}$
S- 7	≤ 0.4	5.3	1.7×10^{6}	$\leq 1.7 \times 10^{-2}$
S- 8	≤ 0.1	≤ 0.1	4.2×10^{3}	$\leq 2.3 \times 10^{-2}$
S- 9	0.8	136.0	4.7×10^{5}	0.2
S-10	≤ 0.2	35.9	2.3×10^{5}	7.3×10^{-2}
S-11	≤ 0.5	23.4	3.8×10^{5}	$\leq 6.8 \times 10^{-2}$
S-12	≤ 0.3	1.3	4.4×10^{4}	$\leq 2.8 \times 10^{-2}$
S-13	≤ 0.1	27.7	4.8×10^{4}	5.06×10^{-2}
S-14	≤ 0.04	0.2	1.4×10^{4}	$\leq 1.9 \times 10^{-2}$
S-15	0.6	8.7	9.6×10^{5}	$\leq 3.2 \times 10^{-2}$
S-16	≤ 0.1	0.3	2.0×10^{5}	$\leq 1.8 \times 10^{-2}$

*Samples collected March 11, 1974.

^{125}Sb. Other fission products either are not present or are present at concentrations below the level of detection. Eleven of the samples contain concentrations of ^{90}Sr that range from 0.2 to 136.0 dpm/ml, with an average concentration of 22.5 dpm/ml, which is 1.0×10^{-5} μCi/ml. The remaining two samples contain 3.1×10^{4} and 3.5×10^{2} dpm/ml of ^{90}Sr, with an average concentration of 1.6×10^{4} dpm/ml, which is 7.1×10^{-3} μCi/ml. The average concentration of tritium in the samples is 3.9×10^{5} dpm/ml, or 0.2 μCi/ml.

Of the thirteen samples collected along the south side of burial group 5, two samples were collected near the ends of trenches that were overflowing because of the "bathtub effect" (S-4 and S-9). The term "bathtub effect" refers to a trench such as trench 83 (Fig. 5), where one end of the trench is at a lower elevation than the other. Water infiltrates into the trench from precipitation, reaches the less permeable bottom, and flows to the lower end of the trench where it overflows like a tilted bathtub. Higher concentrations of ^{90}Sr were observed in seeps of this nature (S-4 and S-9) than were observed in other seeps. Seep S-5 also has a high ^{90}Sr concentration because it is influenced directly by surface runoff from seep S-4. When the bathtub effect occurs, contamination moves directly into surface runoff, where there is less adsorption to the soil.

The total alpha contamination in seep S-4 was shown to be primarily ^{244}Cm by E. A. Bondietti. Complexing of curium with EDTA or other organic compounds is suspected of providing the transport mechanism for this radionuclide.

Stream monitoring data on Melton Branch show that 0.61, 0.94, and 1.30 curies of ^{90}Sr were recorded at sampling station 4 for the years 1971, 1972, and 1973, respectively. Approximately 90% of this yearly discharge of ^{90}Sr may be attributed to burial ground 5 and the remaining 10% is from other sources in the Melton Branch drainage (personal communication with G. J. Dixon, ORNL).

Interpretation of Results

The sampling data from burial grounds 1, 3, and the west side of burial ground 5 suggest that these sources contribute only a minor portion of the added amount of ^{90}Sr which is recorded annually at sampling station 3. These data, combined with sampling data from burial ground 4 (which are discussed in greater detail in the following sections), suggest that the major portion of the added ^{90}Sr arises from burial ground 4.

The sampling data from the south side of burial ground 5, along Melton Branch, indicate that the primary discharge from the area is into Melton Branch. The movement of radioactivity is monitored at sampling station 4, which is located on Melton Branch above the confluence with White Oak Creek (Fig. 2). The sampling data suggest that the direction of groundwater flow in burial ground 5 is toward Melton Branch. The southerly groundwater flow may be inferred from a water table contour map (Cowser, Lomenick, and McMaster, 1961); however, similar movement could also be caused by the combined effects of downslope flow of contaminated water within the trenches and the bathtub effect. Within burial ground 5 most of the trenches run in a north-south direction and the bathtub effect has been observed at seeps S-4 and S-9 (Fig. 5).

BURIAL GROUND 4

Burial ground 4 is situated in Melton Valley and is located 1/2 mile southwest of ORNL (Fig. 2). The burial ground was opened in February 1951 and was closed to routine burial in July 1959. The area encompasses approximately 23 acres, which were filled from the northeast to the southwest. Much of the site, especially the northeastern section, has been covered with uncontaminated fill that was taken from building excavations at ORNL. Disposal of uncontaminated fill at this site was discontinued in July 1973 based on preliminary findings of the current burial ground study. In some places as much as 20 ft of fill material overlies the buried waste.

The burial procedures consisted of excavating trenches into the weathered shale, dumping the contaminated waste into the excavations, and covering the trenches with the original soil. Where a trench was known to contain alpha-contaminated waste, approximately 18 in. of concrete was placed over the trench. Approximately fifty auger holes, located in the northern part of the burial ground, were used for disposal of recoverable higher-level waste. These auger holes range from 1 to 2 ft in diameter, and some are lined with concrete. In addition, some special high-level waste was buried in individual stainless-steel containers.

The size and shape of the trenches are variable. They range from 50 to 400 ft in length, 8 to 30 ft in width, and 8 to 14 ft in depth. A wide variety of contaminated material was disposed of in burial ground 4. This material consisted of anything that was contaminated in normal laboratory operations, of which glassware, scrap metal, soil, lumber,

contaminated chemicals, and, in one case, a small building are a few examples. In many cases the waste was compacted using backhoes and bulldozers, causing many of the containers to rupture (Lomenick and Cowser, 1961).

Little information is available about types, concentrations, locations, and quantities of radionuclides buried at this site. All records of the location and amount of waste buried prior to 1959 were accidentally destroyed by fire.

Geology and Hydrology

Burial ground 4 is underlain by Conasauga shale, which varies from red to gray, and is interbedded with thin limestone units. The formation near burial ground 4 consists mostly of maroon-to-brown, noncalcareous shale interbedded with gray, slightly calcareous shale and silty limestone. The shale is weathered to a depth of approximately 15 ft in the upper portion of the burial ground and to a depth of about 5 ft in areas near the stream. The Conasauga shale was selected for disposal of low-level waste because of its impermeability.

All drainage from burial ground 4 is into White Oak Creek, which runs along the east edge of the burial ground. The groundwater table is essentially a subdued replica of surface topography (Fig. 6). The water table contours shown in Figs. 6 and 7 suggest that most of the groundwater discharge from the area occurs along the south edge of the burial ground. Thus, the groundwater flows from areas of high elevation to areas of lower elevation and ultimately discharges into White Oak Creek. The water table is relatively shallow and fluctuates at or near the land surface in low areas of the burial ground and attains a maximum

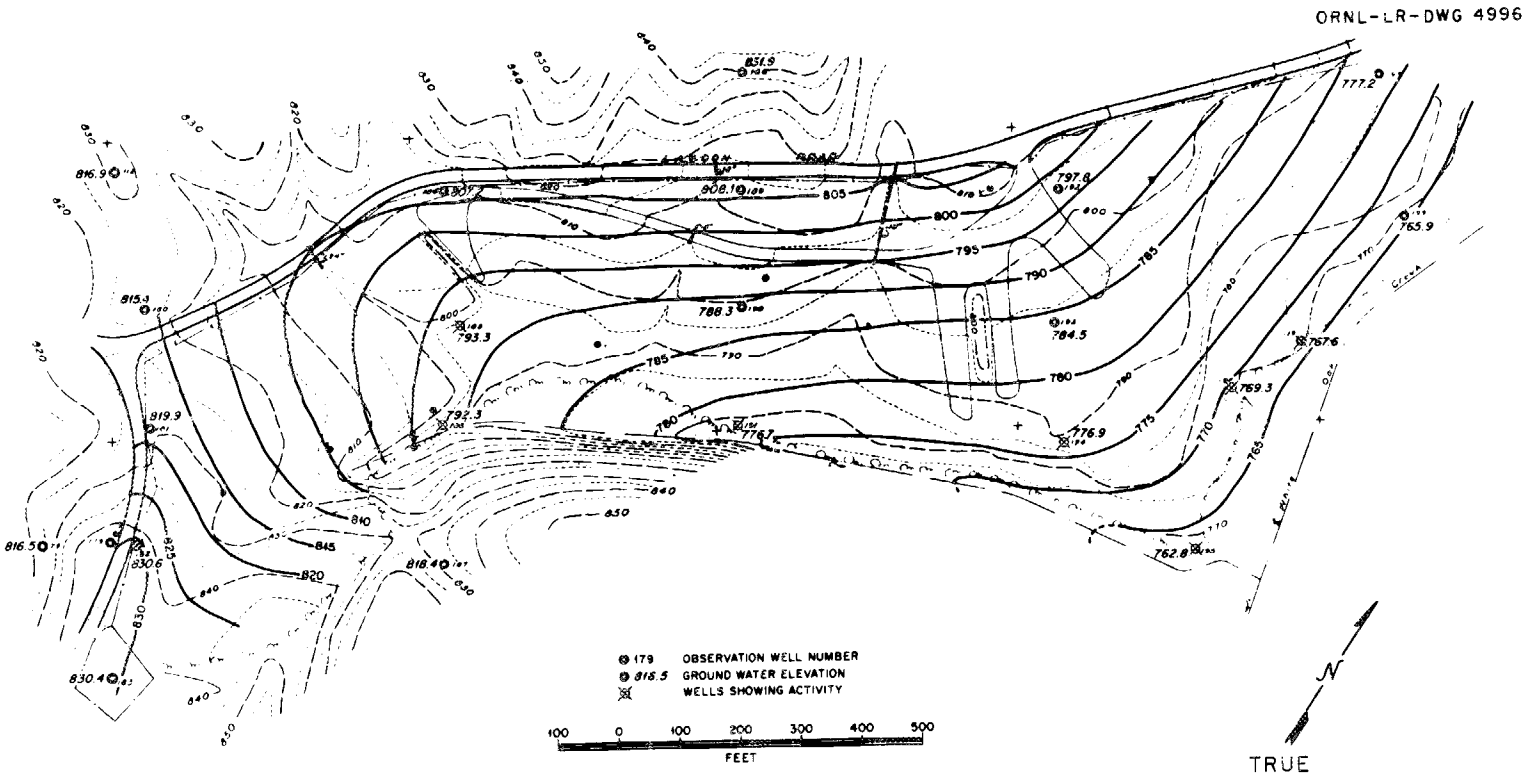
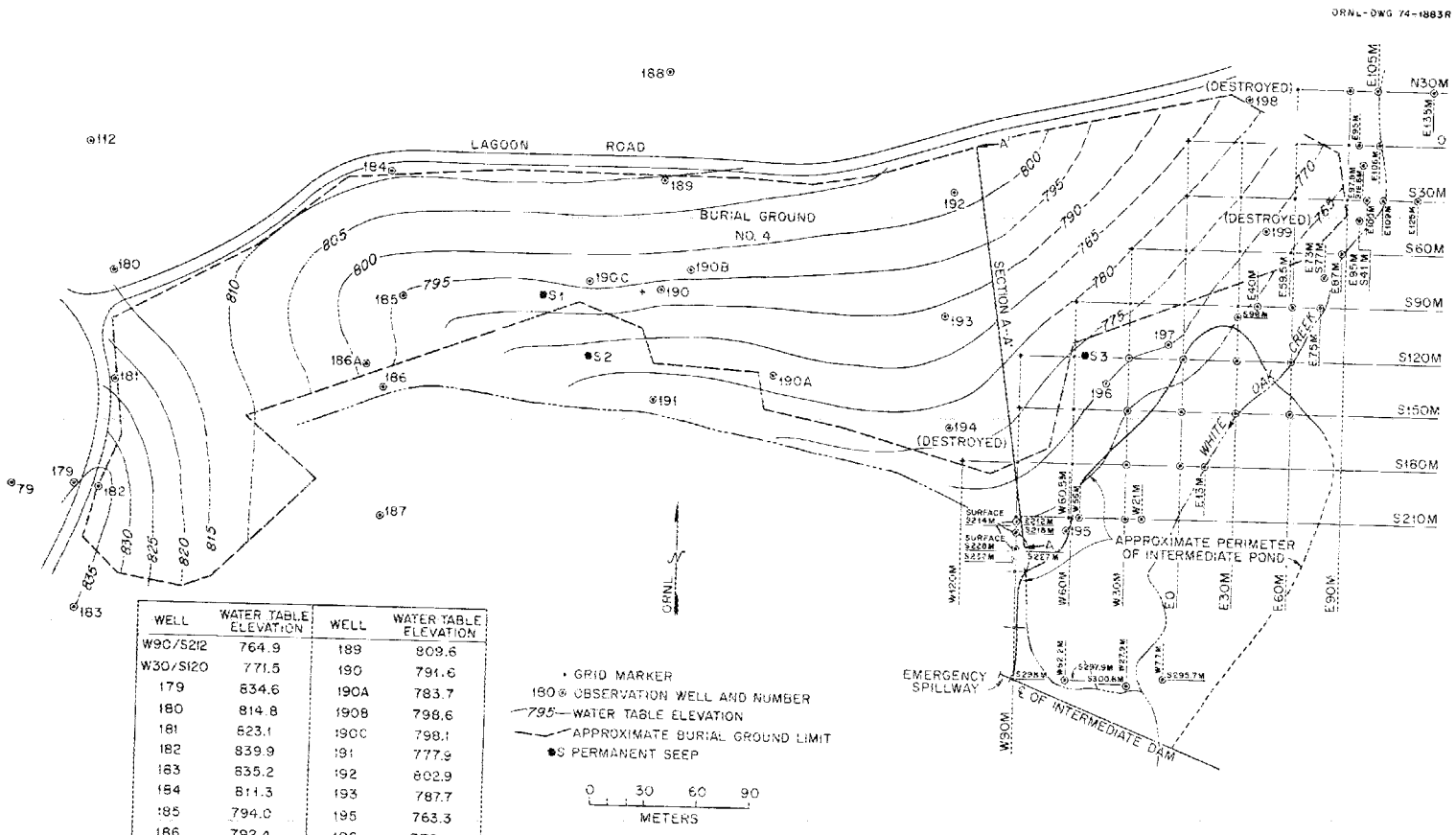


Fig. 6. Water table contours at burial ground 4, December 24, 1959.



WELL	WATER TABLE ELEVATION	WELL	WATER TABLE ELEVATION
W90/S212	764.9	189	809.6
W30/S120	771.5	190	791.6
179	834.6	190A	783.7
180	814.8	190B	798.6
181	823.1	190C	798.1
182	839.9	191	777.9
183	835.2	192	802.9
184	811.3	193	787.7
185	794.0	195	763.3
186	792.4	196	770.1
186A	799.3	197	771.0

Fig. 7. Water table contours at burial ground 4, February 1, 1974.

depth of about 15 ft beneath higher elevations. Because of the high water table, waste burial was limited to higher elevations during wet periods, while the low topography was utilized during the dry summer months (Lomenick and Cowser, 1961). The rate of groundwater movement is not known, however. This rate of movement should be much greater in the trenches than in the surrounding undisturbed shale.

Groundwater Monitoring

A groundwater monitoring system designed to monitor all of the groundwater flowing from burial ground 4 was installed along the east end of the burial ground. The system consists of 37 shallow wells that were drilled during the summer of 1973 (Fig. 8). The wells are cased with 4-in.-diam aluminum casing and penetrate the floodplain of White Oak Creek to a maximum depth of 12 ft. They are on a 30-meter grid system for ease in well location. The grid system is also used for location of soil samples taken in the vicinity of the wells. Water from the monitoring system and from other wells installed during past burial ground studies is collected and analyzed periodically (Fig. 8).

Groundwater Contamination

Groundwater samples collected from surface seeps and wells in the vicinity of burial ground 4 contain primarily ^{90}Sr, with occasional small amounts of ^{60}Co, ^{137}Cs, and ^{125}Sb. In general, samples from wells located within the burial ground and seeps at the lower edge of the burial ground have higher concentrations of ^{90}Sr than wells farther from the buried waste. These wells and seeps contain ^{90}Sr in concentrations that range from 0.1 to 451.1 dpm/ml of ^{90}Sr (Table 8). The permanent

Table 8. Radionuclide concentrations in old wells in burial ground 4 and in permanent seeps below the burial ground, in dpm/ml

Location	Date	^{90}Sr	^{60}Co	^{137}Cs	^{125}Sb
Well 179	8-27-73	≤ 0.1	$\leq 1.8 \times 10^{-2}$	8.1×10^{-2}	$\leq 3.0 \times 10^{-2}$
Well 182	8-27-73	0.3	$\leq 1.8 \times 10^{-2}$	$\leq 2.0 \times 10^{-2}$	$\leq 1.9 \times 10^{-2}$
Well 185	8-27-73	16.2	$\leq 2.2 \times 10^{-2}$	$\leq 1.9 \times 10^{-2}$	$\leq 6.7 \times 10^{-2}$
Well 186	10- 5-73	8.5	$\leq 2.6 \times 10^{-2}$	$\leq 1.3 \times 10^{-2}$	$\leq 4.9 \times 10^{-2}$
Well 187	8-27-73	5.8	1.6	≤ 1.1	≤ 0.9
Well 187	10- 5-73	$\leq 6.0 \times 10^{-2}$	$\leq 1.6 \times 10^{-2}$	$\leq 1.5 \times 10^{-2}$	$\leq 1.7 \times 10^{-2}$
Well 188	10- 5-73	$\leq 4.9 \times 10^{-2}$	$\leq 2.6 \times 10^{-2}$	$\leq 2.4 \times 10^{-2}$	$\leq 2.1 \times 10^{-2}$
Well 189	8-27-73	0.1	$\leq 1.8 \times 10^{-2}$	$\leq 1.6 \times 10^{-2}$	$\leq 1.6 \times 10^{-2}$
Well 190	8-27-73	29.0	$\leq 1.9 \times 10^{-2}$	$\leq 1.7 \times 10^{-1}$	5.6×10^{-1}
Well 190A	8-27-73	35.4	$\leq 1.9 \times 10^{-2}$	1.7×10^{-1}	1.1×10^{-2}
Well 190B	8-27-73	9.0	$\leq 3.4 \times 10^{-2}$	$\leq 2.4 \times 10^{-2}$	$\leq 3.3 \times 10^{-2}$
Well 191	8-27-73	80.5	$\leq 3.9 \times 10^{-2}$	$\leq 3.4 \times 10^{-2}$	9.77×10^{-2}
Well 192	8-27-73	0.6	$\leq 1.7 \times 10^{-2}$	$\leq 3.2 \times 10^{-2}$	$\leq 2.0 \times 10^{-2}$
Well 193	8-27-73	0.2	$\leq 1.7 \times 10^{-2}$	$\leq 1.9 \times 10^{-2}$	$\leq 1.3 \times 10^{-2}$
S 1	1-23-74	1.1	$\leq 2.6 \times 10^{-1}$	$\leq 1.3 \times 10^{-2}$	$\leq 1.4 \times 10^{-2}$
S 2	8-27-73	451.1	$\leq 1.0 \times 10^{-2}$	5.42	1.0
S 2	1-23-74	174.0	9.9×10^{-2}	$\leq 2.0 \times 10^{-2}$	$\leq 2.1 \times 10^{-1}$
S 3	3-19-73	13.9	$\leq 2.0 \times 10^{-1}$	$\leq 2.0 \times 10^{-1}$	$\leq 2.0 \times 10^{-1}$

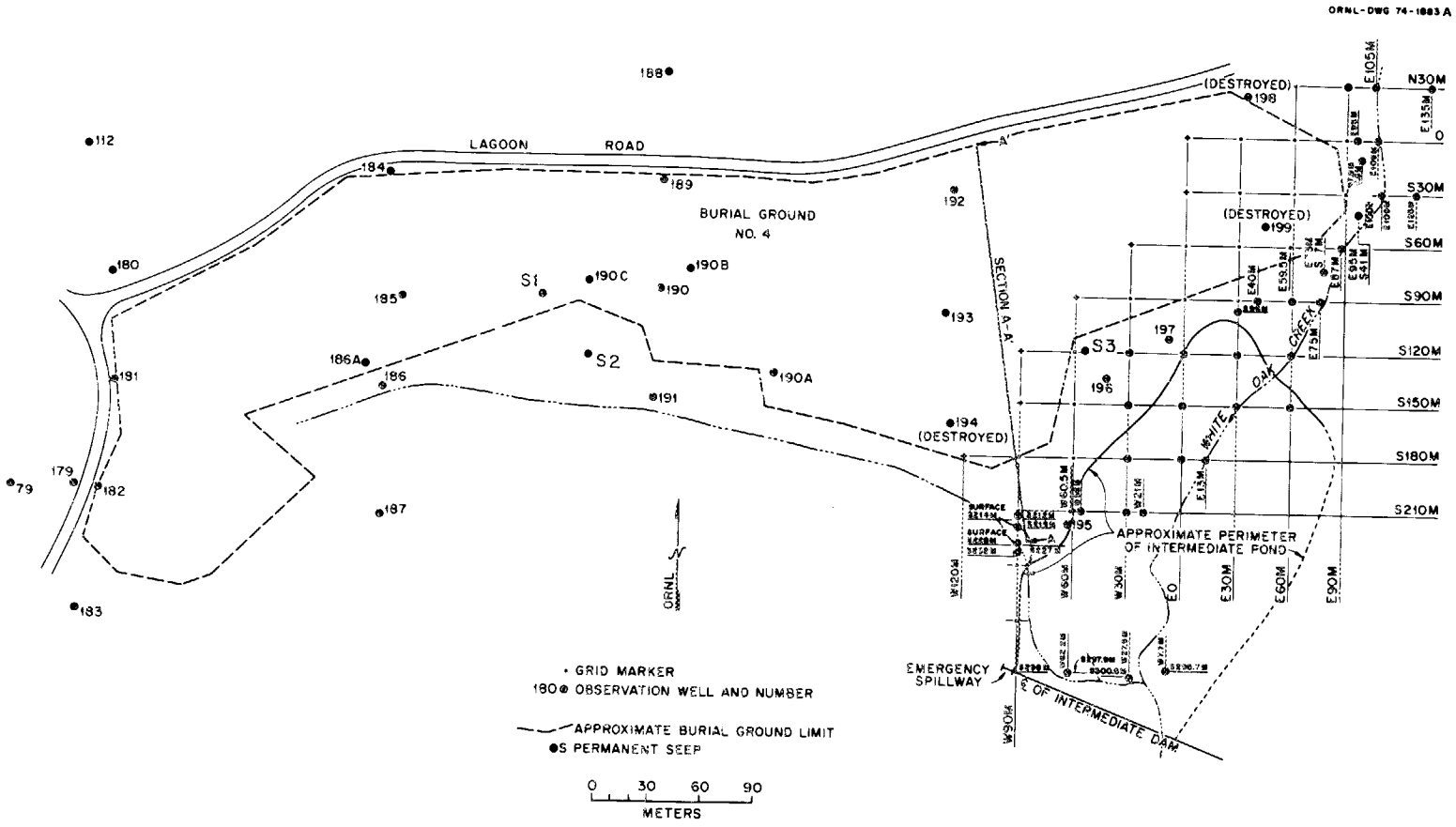
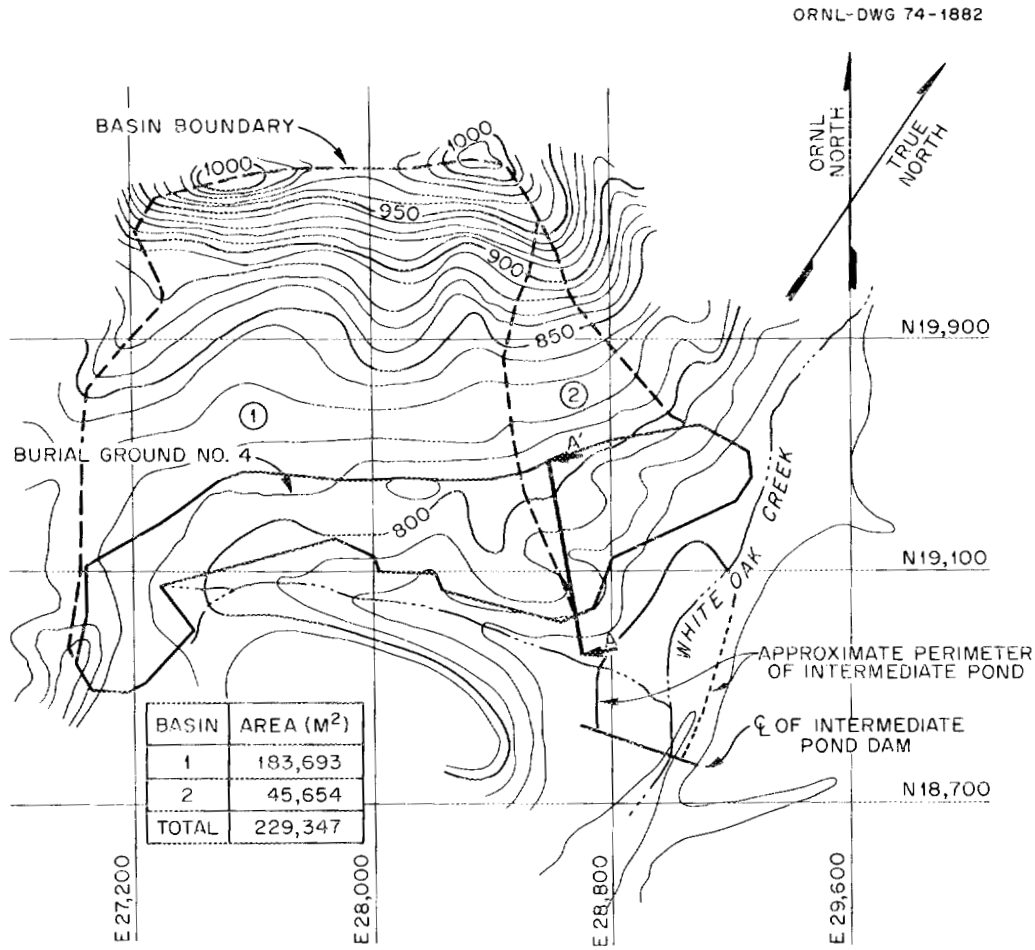


Fig. 8. Location of groundwater monitoring wells for burial ground 4.

seep S2 (Fig. 7) is located below an area where several trenches are undergoing the bathtub effect. This effect explains the relatively high concentrations of ^{90}Sr, ^{137}Cs, and ^{125}Sb contained in the seep water (Table 8). The concentration of ^{137}Cs in wells located below the burial ground approaches the lower limit of analytical determination. This radionuclide occurs in water samples in what appears to be a rather random fashion (Table 8). Cesium-137 is probably present in all water samples at a level of concentration that is less than 1.0×10^{-2} dpm/ml, which is well below the range of routine analytical detection.

The total alpha concentration in wells below burial ground 4 is also below the limit of analytical detection, which is approximately 1×10^{-1} dpm/ml. As the concentration of total alpha in the water approaches this limit, the presence of alpha contamination can be detected, but exact analytical measurements cannot be made. A list of wells below burial ground 4 where the presence of alpha contamination was determined is given in Table 10. In all of these wells the concentration is somewhat below routine quantitative measurement.

The concentration of ^{90}Sr found in the groundwater flowing from the east end of the burial ground is lower than the concentration found in the groundwater along the south side of the burial ground. For computational purposes, the entire drainage basin can be divided into two parts, basin 1 and basin 2 (Fig. 9), based on the two different concentrations. The dashed line dividing the two basins crosses groundwater contours at a right angle. Thus, groundwater flowing from basin 1 has ^{90}Sr concentrations shown in Table 11, and groundwater flowing from basin



BASIN	AREA (M^2)
1	183,693
2	45,654
TOTAL	229,347

Fig. 9. Elevation contours prior to the establishment of burial ground 4. The dashed line is the perimeter of the drainage basin which is divided into basins 1 and 2.

Table 9. Concentration of ^{137}Cs in wells below burial ground 4, in dpm/ml

Well	Date	Concentration
N30/E90	8- 7-73	7.1×10^{-2}
N30/E135	1-23-74	8.7×10^{-2}
N0/E106	10- 5-73	1.7×10^{-1}
S16.6/E97.8	10- 5-73	3.1×10^{-2}
	1-23-74	2.5×10^{-2}
S30/E100	1-23-74	3.9×10^{-2}
S30/E109	10- 5-73	1.1×10^{-1}
S30/E125	1-23-74	5.0×10^{-2}
S41/E95	1-23-74	5.5×10^{-2}
S60/E87	8- 7-73	4.4×10^{-2}
	10- 5-73	7.3×10^{-2}
	1-23-74	1.4×10^{-1}
S77/E75	10- 5-73	2.3×10^{-1}
	1-23-74	2.8×10^{-2}
S90/E40	10- 5-73	1.0×10^{-1}
	1-23-74	2.6×10^{-1}
S90/E60	8- 7-73	6.7×10^{-1}
	10- 5-73	2.0×10^{-1}
	1-23-74	1.7×10^{-1}
S90/E75	8- 7-73	1.3
	10- 5-73	3.3×10^{-1}
	1-23-74	3.9×10^{-1}
S120/E 0	10- 5-73	2.8×10^{-2}
S120/E30	8- 7-73	5.6×10^{-2}
	10- 5-73	1.1×10^{-1}
S120/E60	8- 7-73	1.1×10^{-1}
	10- 5-73	8.6×10^{-2}
S150/E 0	8- 7-73	7.8×10^{-1}
	10- 5-73	4.8×10^{-2}
S180/E 0	8- 7-73	5.0×10^{-1}
	10- 5-73	1.1×10^{-1}

Table 10. Locations where alpha contamination was present in water samples but was at concentrations below analytical measurement

S90/E60	S214/W90
S90/E40	S218/W90
S120/E 0	S227/W90
S210/W56	S232/W90
S212/W90	197

Table 11. Concentration of ^{90}Sr flowing from basin 1, in dpm/ml

Location	Concentration 12-12-73	Concentration 1-23-74	Average concentration
Well, S212/W90	7.9	8.0	8.0
Surface, S214/W90	17.5	20.2	18.9
Well, S218/W90	15.4	15.8	15.6
Well, S227/W90	16.2	13.5	14.9
Surface, S228/W90	16.8	19.2	18.0
Well, S232/W90	2.3	1.6	2.0 *
Average			15.1

*Well excluded from the average because of dilution by uncontaminated groundwater flowing from the slope south of the burial ground.

Table 12. Concentration of ^{90}Sr in wells in the lower portion of basin 2, in dpm/ml

Well	Concentration 8-7-73	Concentration 10-5-73	Concentration 1-23-74	Average concentration
N30/E90	0.2			0.2*
N30/E105	1.3	1.9	2.0	1.7*
N30/E135		1.3	4.6	3.0*
N0/E95		0.2	0.1	0.2*
N0/E106	1.2	1.3	0.1	0.9*
S16.6/E97.8		1.8	2.5	2.2
S30/E100		6.9	3.0	5.0
S30/E109	10.4	8.5	8.4	9.1*
S30/E125		0.3	8.7	4.5*
S41/E95			10.1	10.1
S60/E87	2.3	5.2	1.6	3.0*
S77/E73		11.5	27.0	19.3
S90/E40		14.1	1.1	7.6
S90/E60	6.8	3.9	8.4	6.4
S90/E75	3.5	4.7	2.0	3.4*
S96/E30		4.0	5.7	4.9
197	2.8	4.3	1.5	2.9
S120/W30	8.6		0.2	4.4
S120/E0	10.0	6.3	7.2	7.8
S120/E30	5.5	5.4	3.0	4.6*
S120/E60	7.6		11.6	9.6*
196		36.4	28.5	32.5
S150/W30	15.8	11.6	15.8	14.4
S150/E0	15.9	2.8	0.6	6.4
S150/E30	11.5	4.4	7.9	7.9*
S150/E60		5.1	1.5	3.3*
S180/W30	14.7	9.7	12.4	12.3
S180/E0	1.8	2.9	2.1	2.3*
S180/E13	2.0	1.6	16.3	6.6*
S210/W56		12.2	12.5	12.4
S210/W30	18.1	14.0	12.6	14.9
S210/W21	11.7	6.6	9.5	9.2*
195	13.6	10.4	12.1	12.0
Average				10.3

*Wells excluded from the average because of dilution by groundwater flowing down the floodplain of White Oak Creek. Thus, wells near the creek channel are excluded from the average.

2 has ^{90}Sr concentrations shown in Table 12. The data shown in Table 11 were collected in December and January when precipitation was extremely high; as a result the ^{90}Sr concentration in the groundwater may have been diluted by heavy rains. Thus, the average concentration of groundwater flowing from basin 1 should be higher when more data are available. Data from wells near White Oak Creek were excluded from the average because of dilution by "uncontaminated" groundwater flowing downstream in the floodplain of the creek. The average concentration of ^{90}Sr in the groundwater flowing from basin 1 is 15.1 dpm/ml (6.8×10^{-6} μCi/ml), and the ^{90}Sr concentration flowing from basin 2 is 10.3 dpm/ml (4.6×10^{-6} μCi/ml). It is expected that these averages will be more accurate when additional data are included.

Estimated Discharge of ^{90}Sr

A crude estimate of the quantity of ^{90}Sr discharged annually from burial ground 4 can be made using precipitation and evapotranspiration data from the vicinity of the burial ground. These data for the years 1971 through 1973 are shown in Table 13 (Sheppard et al., 1973, and personal communication with G. S. Henderson of ORNL). The data were collected from Walker Branch Watershed, which is located approximately 3.5 miles northeast of burial ground 4. The topography and vegetation of Walker Branch are similar to those of basins 1 and 2 with the exception that the burial ground itself is covered with grass rather than mixed hardwood forest. The surface runoff component in the Walker Branch Watershed is small and can be neglected. Surface runoff on the

grassy surface of the burial ground is somewhat higher (Rogowski and Tamura, 1970), but for the following approximation it will be neglected.

When annual evapotranspiration is subtracted from annual precipitation, the result is the component of precipitation that becomes groundwater (Table 13).* The groundwater component is then multiplied by the area of basins 1 and 2 (Fig. 9), using the appropriate conversion factor, to obtain the volumes of groundwater flowing through basins 1 and 2 each year. The results of these calculations for the years 1971 through 1973 are shown in Table 14. The volumes of groundwater flowing through basins 1 and 2 are then used with the average concentrations of ^{90}Sr at the outflow of the two basins (Tables 11 and 12) to calculate the annual discharge of ^{90}Sr from each basin. The sum of the annual discharges from the two basins yields the total discharge of ^{90}Sr from burial ground 4. This calculation shows that approximately 1.00, 1.30, and 1.78 Ci/year of ^{90}Sr were discharged from burial ground 4 for the years 1971, 1972, and 1973, respectively. It should be noted that the average concentration of ^{90}Sr flowing from basins 1 and 2 was assumed to be the average concentration measured in 1973.

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*The groundwater component was obtained for formations of the Knox Group and was then used for an area underlain by the Consauga shale. Therefore, it is only an approximation.

Table 13. Annual precipitation and evapotranspiration data from Walker Branch Watershed

Year	Precipitation (cm/year)	Evapotranspiration (cm/year)	Groundwater (cm/year)
1971	136.9	69.0	67.9
1972	157.6	67.9	89.7
1973	190.0	69.2	120.8

Table 14. Calculated and monitored annual discharge of ^{90}Sr from burial ground 4

Year	Groundwater flow (liter/year)		^{90}Sr discharge (Ci/year)		Total ^{90}Sr discharge from B.G. 4 (Ci/year)	
	Basin 1 A = 183,693 m^2	Basin 2 A = 45,654 m^2	Basin 1	Basin 2	Calculated	Stream monitoring
1971	124.7×10^6	31.0×10^6	0.85	0.15	1.00	1.19
1972	164.8×10^6	41.0×10^6	1.12	0.18	1.30	1.97
1973	221.9×10^6	55.2×10^6	1.52	0.26	1.78	2.19

Stream Monitoring Data

As mentioned previously, the sampling station at White Oak Creek below burial ground 4 (station 3) has recorded a larger annual discharge of ^{90}Sr than is recorded in the X-10 plant effluent (stations 1 and 2). This added amount of ^{90}Sr was first observed when proportional stream sampling was begun in 1962. The samplers were installed somewhat earlier than 1962, but the first reliable continuous data from the stream monitoring system began in August 1962. The amount of ^{90}Sr attributed to burial ground 4 is obtained by substracting the amount that leaves X-10 from the amount that is recorded at sampling station 3. Thus, the difference also includes any discharge from burial ground 1, burial ground 3, and the west side of burial ground 5. From reconnaissance sampling of these other sources, burial ground 4 has been shown to be the major contributor to the ^{90}Sr difference.

In the X-10 area the highest elevation of the groundwater table occurs during the wet winter months and the lowest elevation occurs during the dry late-summer months. The low water table conditions usually occur in the month of August or September; thus calculations of ^{90}Sr discharge by groundwater should be based on water years rather than calendar years. By using a water-year base, the data are divided at the point of lowest discharge and tend to smooth out a time discharge curve. The water year used in the following calculations begins on September 1 and ends on August 31 and is designated by the year in which it ends.

Table 15 shows the annual precipitation data and the discharge of ^{90}Sr from burial ground 4 for water years 1963 through 1973 (personal

Table 15. Discharge of ^{90}Sr from burial ground 4 and precipitation data for water years 1963 through 1973

Water* year	Precipitation (in.)	Total ^{90}Sr discharge (Ci)	Discharge of ^{90}Sr (mCi/in.)
1963	55.33	4.82	87.1
1964	42.09	2.71	64.4
1965	51.98	3.10	59.6
1966	40.85	2.52	61.7
1967	60.54	2.72	44.9
1968	45.01	2.04	45.3
1969	40.07	2.08	51.9
1970	47.93	1.60	33.4
1971	48.26	1.18	24.5
1972	47.40	2.36	49.8
1973	71.27	1.58	22.2

*Water year is September 1 - August 31.

communication with G. J. Dixon, ORNL). The precipitation data for calendar years 1962 through 1972 are for the X-10 site, and the remaining precipitation data are for Walker Branch Watershed (personal communication with G. S. Henderson, ORNL). The fourth column of Table 15 shows the ^{90}Sr discharge from burial ground 4 in millicuries per inch of precipitation. These values represent the actual discharge of ^{90}Sr from burial ground 4 when both depletion of the source (buried waste) by leaching and radioactive decay are considered.

The lowest curve on Fig. 10 shows the actual discharge of ^{90}Sr from burial ground 4 for the water years 1963 through 1973. In plotting the curve the data point for 1972 was disregarded because a small amount of ^{90}Sr entered White Oak Creek above sampling station 3 from a small leak in an intermediate-level waste transfer line (an estimated 0.4 Ci of ^{90}Sr entered White Oak Creek from this source; see following paragraph). This source of ^{90}Sr was removed through cleanup operations during the last months of water year 1972 and does not affect the data for water year 1973. The upper curve of Fig. 10 shows the decay of ^{90}Sr from a constant source, which is chosen as the discharge during the first water year, 1963. When the amount of radioactive decay is added to the actual discharge curve, a curve of calculated discharge is obtained. The center curve of Fig. 10 shows the calculated discharge of ^{90}Sr if no radioactive decay occurs; thus the curve represents the depletion of ^{90}Sr in the groundwater discharge due to reduction of the source (buried waste) by leaching. The curves in Fig. 10 indicate that the amount of ^{90}Sr discharging from burial ground 4 is declining not only from radioactive decay but also from depletion of soluble ^{90}Sr in the burial ground.

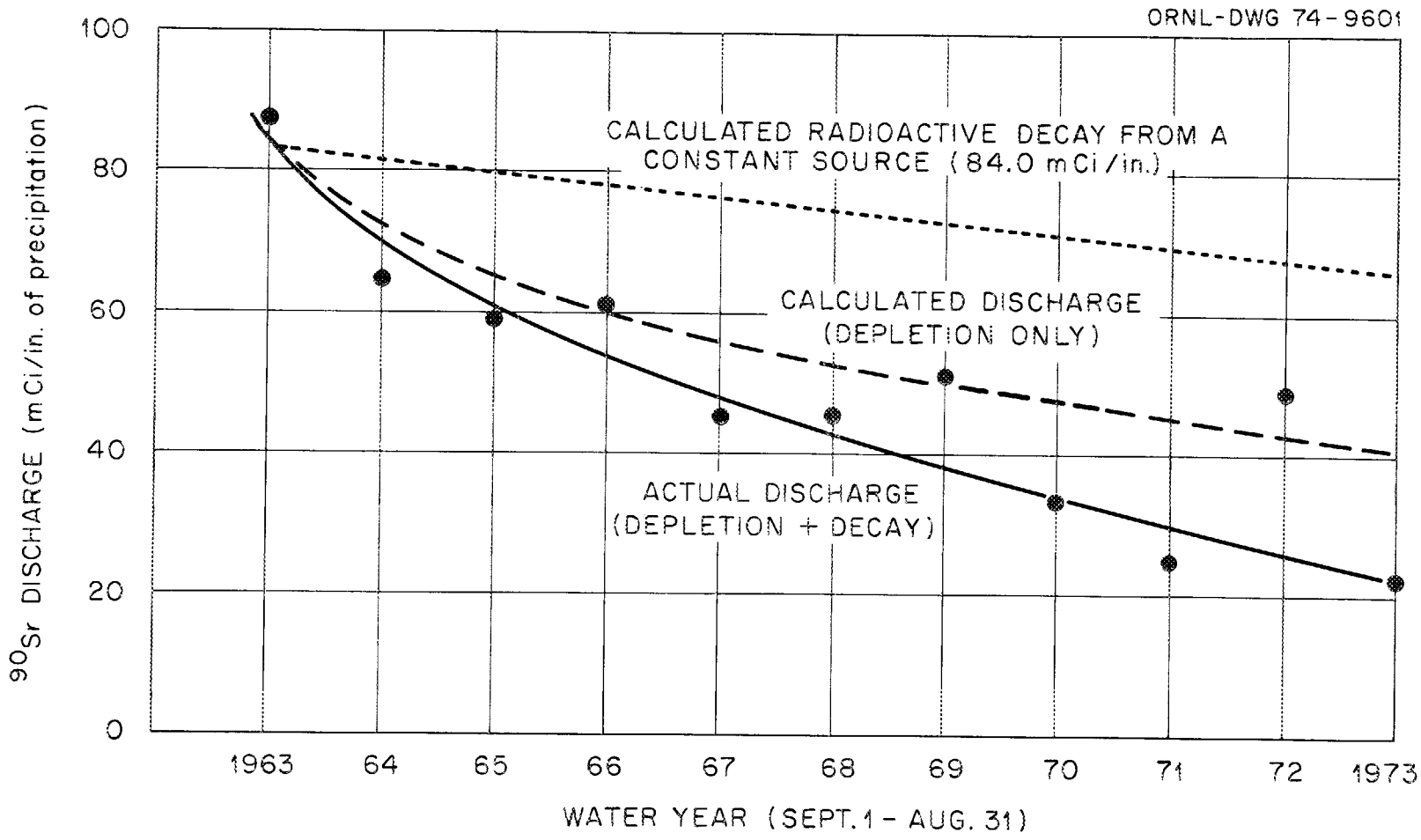

Fig. 10. Discharge of ^{90}Sr from burial ground 4 for water years (September 1 - August 31) 1963 through 1973, in mCi/in of precipitation (from stream monitoring data).

A comparison of the annual ^{90}Sr discharge from burial ground 4 determined from stream monitoring with the estimated discharge shows reasonable agreement (Table 14). The calculated values are 19 to 51% lower than the values obtained by stream monitoring, with the maximum difference occurring in calendar year 1972. Some of the 51% difference is attributed to a small leak in a waste transfer line. The maximum ^{90}Sr contribution from this leak to White Oak Creek, estimated from the data shown in Table 17, is 0.4 Ci.* A comparison of the estimated ^{90}Sr release from burial ground 4 with the measured release to the Clinch River shows that approximately one-third of the release to the river comes from burial ground 4 (personal communication with G. J. Dixon, ORNL).

Interpretations of Results

The quantity of ^{90}Sr transported from burial ground 4 is, in part, attributed to the relatively high groundwater table within the burial ground. The burial ground is located in an area where the water table initially was close to the land surface. However, the increased surface elevation due to disposal of uncontaminated fill has caused a rise in the water table. Some of the increase in water table elevation is

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*After discovery of the leak in the spring of 1972, cleanup operations began within a few days. Contaminated soil from the vicinity of the leak was removed and buried in burial ground 6 and the line was repaired. Groundwater monitoring between the leak and White Oak Creek indicated that ^{90}Sr concentrations in the groundwater returned to background concentration within three months of completion of the cleanup operation.

also brought about by an increased infiltration rate due to the permeability of unconsolidated fill material. A comparison of the water table maps of burial ground 4 which were constructed in 1959 and 1974 (Fig. 6 and 7) shows the effect of the addition of fill material. In 1959 the east end of burial ground 4 had already been filled; however, filling was still under way in the west end. In 1974 the water table in the east end of the area was approximately 3 ft higher than in 1959; this may be attributed to a wetter year in 1974. In 1974 the water table in the west end of the burial ground was approximately 10 ft higher than in 1959; thus 7 ft of this difference may be attributed to the effect of the fill that was added between 1959 and 1974. A cross section located near the east end of the burial ground (Fig. 7) is shown in Fig. 11. The cross section shows the original land surface, the depth of fill, and the current groundwater table (1974). It is interesting to note that the water table in all areas in the cross section is less than 9 ft below the original land surface (i.e., higher than the buried waste).

The high ^{90}Sr discharge from burial ground 4 is caused by the rapid leaching of the buried waste under saturated conditions and, to some extent, by the chemical nature of the buried waste. Preliminary investigations of water quality in areas where high ^{90}Sr contamination is found show abnormal water chemistry. This may indicate that chemicals buried with the contaminated waste have altered the adsorptive properties of the Conasauga shale to allow a more rapid transport of radionuclides. Detailed sampling and analyses to support this theory are currently being conducted.

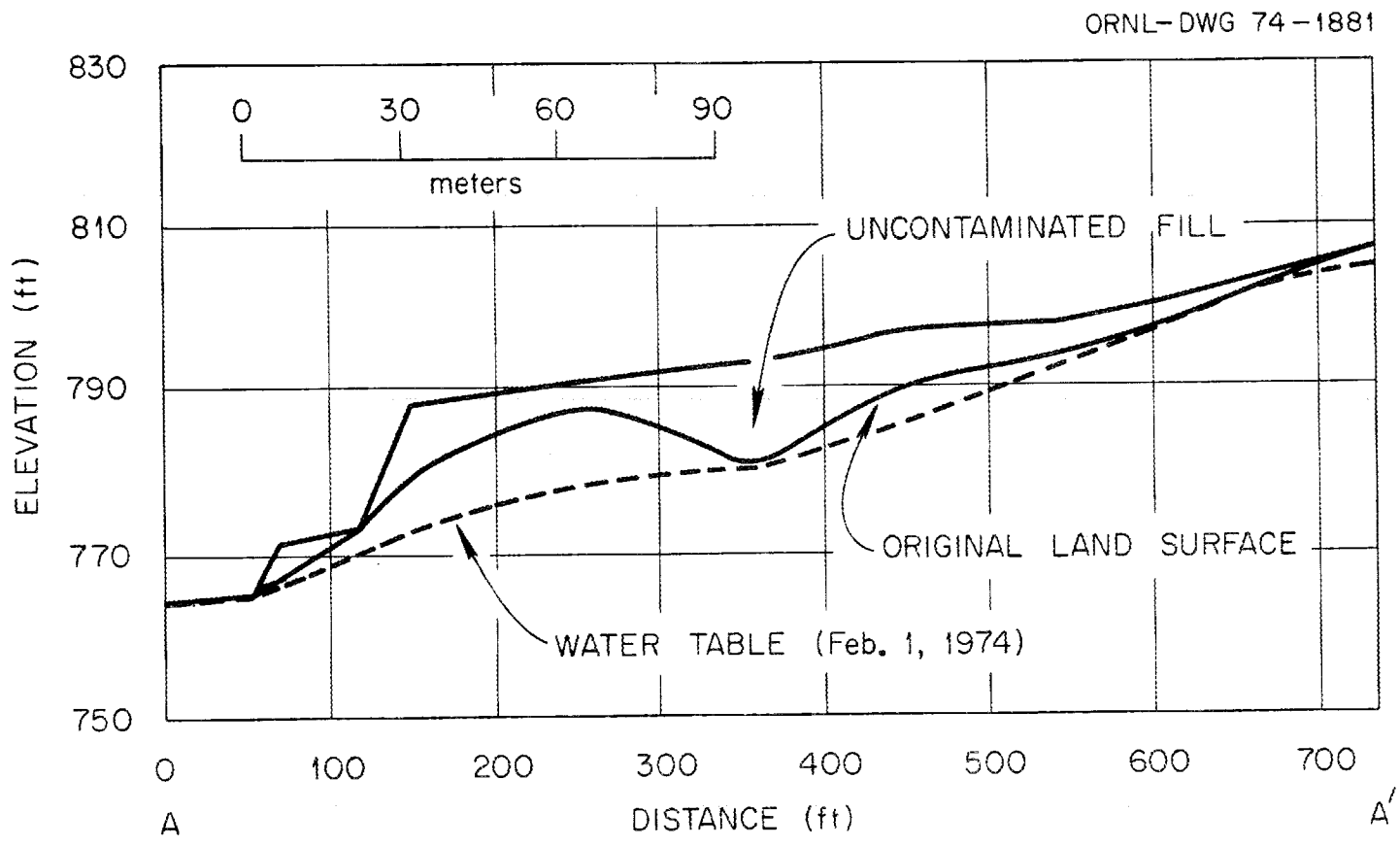

Fig. 11. Section A - A' showing present land surface, original land surface, and present water table in burial ground 4 (Fig. 8).

A comparison of estimated ^{90}Sr discharge from burial ground 4 with stream monitoring data indicates that the annual discharge from the burial ground is directly related to annual precipitation. The relation between discharge and precipitation is also supported by the plot of ^{90}Sr discharge from the burial ground per inch of precipitation (Fig. 10). Figure 10 indicates that the amount of ^{90}Sr discharge has decreased between 1963 and 1973. This decrease has been brought about not only from radioactive decay but also from depletion of soluble ^{90}Sr in the burial ground.

INTERMEDIATE POND AREA

The intermediate pond is located on White Oak Creek a short distance downstream from burial ground 4 (Fig. 8). It was constructed in the spring of 1944 to serve as an intermediate retention pond between X-10 and White Oak Lake. In September 1944 the dam was breached by high water and the pond was greatly diminished in size. A residual pond existed behind the dam until the early 1950s. During the existence of the intermediate pond approximately 1.5 ft of sediment accumulated in the residual pond. The sediment was initially contaminated by release of radioactivity from the laboratory and its chemistry was later influenced by the movement of ^{90}Sr, ^{60}Co, and ^{137}Cs from burial ground 4.

The groundwater in the lower portion of the intermediate pond contains primarily one radionuclide, ^{90}Sr (Table 16 and Fig. 8). Other radionuclides are probably present but are at concentrations below analytical determination. The concentration of ^{90}Sr in the groundwater

Table 16. Radionuclide concentrations in wells near the intermediate pond dam, in dpm/ml

Well	Date	^{90}Sr concentration
S297.9/W62.2	10- 5-73	6.6
	1-23-74	8.7
S300.6/W27.9	10- 5-73	4.1
	1-23-74	7.0
S295.7/W7.7	1-23-74	2.2

adjacent to the intermediate pond dam ranges from 2.2 to 8.7 dpm/ml (Table 16).

Soil samples from the area contain total alpha contamination, ^{90}Sr, ^{60}Co, ^{137}Cs, and minor amounts of ^{125}Sb (Table 17). Radionuclide concentration ranges in the soil are ^{90}Sr, 1.3×10^2 to 1.5×10^3 dpm/g; ^{60}Co, 33.4 to 9.9×10^2 dpm/g; ^{137}Cs, 1.5×10^2 to 1.8×10^5 dpm/g; and ^{125}Sb, 0.0 to 18.3 dpm/g. The alpha contamination will be discussed in a following paragraph.

Because of the level of soil contamination in the intermediate pond, this area could serve as a study site for terrestrial cycling of radionuclides. To evaluate the potential of the area, reconnaissance sampling of vegetation was conducted. The concentration of radionuclides found in five types of vegetation is shown in Table 18. The concentration of ^{90}Sr in the vegetation sampled ranged from 2.3×10^2 to 2.1×10^3 dpm/g (100°C oven-dried weight), and the amount of ^{137}Cs ranged from 5.8 to 5.4×10^2 dpm/g. The vegetation samples contained minor amounts of ^{60}Co, and all other radionculides were below the limit of analytical determination (Table 18).

The amount of alpha contamination contained in the sediment of the intermediate pond (Table 17) and the alpha contamination in some wells located below burial ground 4 (Table 10) prompted a detailed investigation of the pond sediment. A soil core taken in the residual pond was analyzed by Tsuneo Tamura, ORNL, and was found to contain 374 dpm/g of ^{239}Pu in the depth interval 0.0 to 5.0 in. below the surface (Table 19). This concentration is 0.168 μCi/kg, which may be compared to the maximum allowable concentration of fissile

Table 17. Concentration of radionuclides in soils below burial ground 4, in dpm/g

Location	Depth (in.)	Total α	^{90}Sr	^{60}Co	^{137}Cs	^{125}Sb
S30/E100	0- 3		1.3×10^2	3.6×10^2	2.6×10^4	$\leq 3.0 \times 10^3$
S150/W30	0- 3		1.2×10^3	≤ 60.0	1.5×10^2	≤ 13.0
S195/W30	0- 3		4.5×10^2	5.0×10^2	1.4×10^4	$\leq 2.0 \times 10^2$
S225/W45	0- 3		1.5×10^3	33.4	4.4×10^2	18.3
S300.6/W27.9	0- 5	105.4	1.4×10^3	9.9×10^2	8.1×10^4	$\leq 1.0 \times 10^3$
S300.6/W27.9	5-10	≤ 46.0	9.8×10^2	8.5×10^2	1.8×10^5	$\leq 2.0 \times 10^3$
S300.6/W27.9	10-15	≤ 34.0	8.8×10^2	$\leq 1.6 \times 10^2$	6.4×10^3	$\leq 8.0 \times 10^2$

Table 18. Concentration of radionuclides in vegetation below burial ground 4, in dpm/g of 100°C oven-dried plant*

Plant	Approximate location	Total α	^{90}Sr	^{60}Co	^{137}Cs
Jewel weed	S180/E 0	≤ 4.1	1.5×10^3	8.3	5.4×10^2
Iron weed	S300.6/W27.7	≤ 1.7	7.0×10^2	≤ 4.1	3.8×10^2
Marsh grass	S 3	≤ 1.1	2.3×10^2	≤ 0.2	5.8
Honeysuckle	S180/E 0	≤ 0.5	5.9×10^2	2.9	1.0×10^2
Cattail	S 3	≤ 1.9	2.1×10^3	≤ 0.7	8.9

*Samples collected June 3, 1974.

Table 19. Concentration of ^{239}Pu in soils below burial ground 4 (intermediate pond sediment)

Location	Depth (in.)	Activity	
		dpm/g	μCi/kg
S300.6/W27.7	0- 5	374	0.168 ± 0.008
S300.6/W27.7	5-10	125	0.056 ± 0.004
S300.6/W27.7	10-15	45	0.020 ± 0.001
S180/E 0	0- 3	135	0.061 ± 0.005
S180/E 0	5- 8	1.2	5.3×10^{-4}
S180/W200	0-6.25	1.1	5.0×10^{-4}
S120/W60	0-6.75	1.5	6.9×10^{-4}

material in low-level buried waste of 10 μCi/kg. The concentration decreases to 45 dpm/g at a depth of 10 to 15 in. (Table 19). A second sample taken farther upstream was found to contain 135 dpm/g of ^{239}Pu at a depth of 0.0 to 3.0 in. This sample is from the portion of the pond that was flooded only during the summer of 1944. This may explain the lower concentration and the larger rate of decrease of concentration with depth.

Two other soil samples were collected from small seeps near the burial ground to determine whether the ^{239}Pu was coming from buried waste. Both samples had concentrations of ^{239}Pu, which were near the Oak Ridge area background (0.05 dpm/g, or 2.2×10^{-5} μCi/kg). This seems to indicate that the ^{239}Pu found in the intermediate pond did not originate in the burial ground. It is more likely that the ^{239}Pu was released during early plutonium production (from the graphite reactor). These data do not explain the alpha contamination in wells close to the burial ground, but they suggest that this contamination is not ^{239}Pu. It is possible that the alpha contamination in these wells is ^{244}Cm, which has been shown to occur in seeps below burial ground 5.

Seventeen additional soil cores have been collected from the intermediate pond area. The analysis of these samples will give more information on the distribution, availability, and form of the ^{239}Pu in the pond sediment. Vegetation samples were also collected and will be analyzed to determine the uptake of plutonium by plants.

DEVELOPMENT OF GROUNDWATER TRANSPORT MODELS

Computer modeling is essential for predicting future movements of radionuclides from buried waste. Modeling may also be used to evaluate proposed methods for decreasing the transport of radioactivity from buried waste.

Two computer codes have been written in collaboration with Mark Reeves, ORNL. The first program provides numerical solution to the nonlinear equation governing moisture infiltration and redistribution in unsaturated-saturated porous media; the second code gives numerical solution to the material transport equation. Both mathematical models use Galerkin finite-element methods to obtain numerical solution of the governing equations. The models are fully operational and may be applied to two-dimensional transient problems.

When the appropriate boundary conditions are applied, the first code provides fluid pressure and two components of fluid velocity at specific points within a cross section for successive time increments. For a given problem the boundary condition at the ground surface may be precipitation, flux from a seepage pond, seepage out of the surface along a seepage surface, or a combination of all three conditions. The seepage surface is allowed to increase or decrease in length to accommodate fluctuations in the water table elevation. The code has been used to simulate the moisture movement from a tilted soil slab, and the results compare favorably with experimental data obtained from an inclined soil slab at Coweeta Hydrologic Laboratory in North Carolina (Reeves and Duguid, 1975).

The velocity output of the first model is used in the second computer code, which provides numerical solution to the transport equation. In this analysis both adsorption and radioactive decay are considered (Duguid and Reeves, in preparation). The output from this model is the concentration of radioactivity in the water at specific points within the cross section at successive time increments.

The groundwater transport models have not been applied to specific problems in the burial ground studies at ORNL. However, preparations are being made to simulate the movement of radioactivity from seepage trench 7. This simulation will serve to validate the models and to predict the future behavior of movement of radioactivity from the trench.

CONCLUSIONS

The reconnaissance sampling of small seeps associated with seepage pits and trenches shows that only minor amounts of ^{106}Ru and ^{125}Sb and larger amounts of ^{60}Co are being transported from the waste to the seeps by groundwater. To predict the long-term behavior of ^{90}Sr and ^{137}Cs in the vicinity of the waste disposal areas, detailed simulation modeling is required. Work is under way to determine the mechanisms of transport and adsorption of the radionuclides, work that will aid in the simulation of radionuclide movement from seepage trench 7.

Sampling of wells and seeps in burial grounds 1 and 3 and along the west side of burial ground 5 shows that these areas contribute only a small amount of the added ^{90}Sr recorded annually at sampling station 3. This indicates that the major portion of the annual difference of ^{90}Sr between X-10 and sampling station 3 originates from

burial ground 4. Stream monitoring data from sampling station 4, on Melton Branch, combined with the absence of ^{90}Sr in groundwater along the west side of burial ground 5, show that the primary discharge of ^{90}Sr from burial ground 5 is into Melton Branch. The discharge of ^{90}Sr was 0.61, 0.94, and 1.30 Ci for calendar years 1971, 1972, and 1973, respectively. Approximately 10% of the ^{90}Sr is assumed to originate from other sources in the Melton Branch drainage. One trench within burial ground 5, trench 83, may contribute a significant portion of the ^{90}Sr recorded at sampling station 4, and methods to reduce the transport from this trench will be initiated as soon as possible.

Stream monitoring of White Oak Creek shows that 1.19, 1.97, and 2.19 Ci of ^{90}Sr have been discharged from burial ground 4 for calendar years 1971, 1972, and 1973 respectively. The groundwater monitoring system below the burial ground shows that the average concentration of ^{90}Sr flowing from burial ground 4 ranges from 10.3 to 15.1 dpm/ml, or 4.6×10^{-6} to 6.8×10^{-6} μCi/ml. Estimates of annual ^{90}Sr discharge from burial ground 4 which were based on the average discharge and hydrologic data from Walker Branch Watershed show that 1.00, 1.30, and 1.78 Ci of ^{90}Sr were discharged from the area for calendar years 1971, 1972, and 1973, respectively. The estimates agree to within 19 to 51% of the stream monitoring data. A plot of ^{90}Sr discharge from burial ground 4 for water years 1963 through 1973 shows that the discharge of this radionuclide from the burial ground has decreased over this time period. The decrease was brought about not only by radioactive decay but also by depletion of the soluble ^{90}Sr in the burial ground. Both the estimated discharge and the stream monitoring

data show that the ^{90}Sr drainage is directly related to the amount of precipitation, i.e., to the amount of groundwater flowing through the burial ground itself. A decrease in the amount of ^{90}Sr discharging from the area will require a decrease in the amount of groundwater flowing through the buried waste.

Sampling of soils and vegetation in the intermediate pond area showed that the area could be used for studies of radionuclide cycling in the terrestrial environment. Studies are currently being carried out under other projects within the Environmental Sciences Division, ORNL. In plutonium studies at ORNL, research of plant uptake of plutonium is also being investigated. The concentration of ^{239}Pu contamination in the intermediate pond sediment is low in comparison to the maximum allowable concentration of ^{239}Pu in low-level solid waste which may be disposed of by land burial. Thus, the intermediate pond sediment should not be excavated and stored with higher-level plutonium waste but should be left in place to serve as an environmental study area. In this way research on the transport mechanisms and the availability and the amount of plant uptake of ^{239}Pu can be conducted. The sampling data collected to date suggest that the plutonium was not transported from burial ground 4 but probably originated from releases during early plutonium production at ORNL (from the graphite reactor).

During the course of this investigation two recommendations concerning waste management have been made and carried out. This first recommendation was to discontinue the disposal of uncontaminated fill in the burial grounds. As discussed previously, the fill increases the surface elevation above the buried waste, which, in turn, causes a rise

in the water table elevation. This recommendation was carried out, and filling was discontinued in July 1973. The second recommendation was to cut the vegetation growing on the surface of the burial grounds. The reasons for this suggestion were twofold: (1) to eliminate trees which could facilitate uptake and subsequent transport of radionuclides to the surface and (2) to reveal (and as a result fill) any surface depressions caused by consolidation of the waste. Seasonal mowing was begun during the summer of 1973.

The amount of ^{90}Sr being transported from the burial grounds is directly related to the amount of precipitation, which is, in turn, related to the amount of groundwater passing through the buried waste. Therefore, a reduction in the volume of groundwater passing through a burial ground will reduce the quantity of ^{90}Sr discharging from the burial ground. In the case of burial ground 4, the amount of groundwater flow is controlled not only by infiltration on the surface of the burial ground but also by groundwater flowing from the drainage basin above the burial ground (Fig. 9). To reduce the effect of groundwater flow from the upper basin, a groundwater diversion trench has been proposed. The trench would be approximately 20 ft deep and would extend along the entire north and west sides of the burial ground. It would be filled with crushed rock to facilitate flow toward the low portions of the trench, where water would be routed across the burial ground by means of pipe drains. The 20-ft depth will extend through the weathered zone of the Conasauga shale, which is approximately 15 ft thick. An engineering estimate has placed the cost of this diversion trench at approximately $500,000. In view of the cost,

more hydrologic data are necessary to determine the benefits of the trench construction. The trench proposal was based on groundwater flow directions that were inferred from water table contour maps. In previous investigations groundwater was found to flow parallel to the strike of the shale, which in this area is not parallel to the direction inferred by the groundwater contours (Lomenick, et al., 1967). Before an expenditure of this magnitude is made, flow directions and groundwater velocities should be determined from tracer studies. These studies are currently being initiated in burial grounds 4 and 5 and in the basin above burial ground 4.

A second part of the engineering solution entails decreasing the amount of infiltration on the surface of the burial ground itself. The surface seal must reduce infiltration and not create a potential problem from surface runoff from the area. A seal at a depth of 1.5 to 2.0 ft would allow the growth of grass cover and thus minimize the surface runoff problem. Several materials are currently being tested to determine the composition of the seal. The materials include compacted Conasauga shale, compacted Conasauga shale to which a dispersing agent has been added, Conasauga shale mixed with bentonite, and soil cement. Natural materials were selected for consideration since they are subject to little change from weathering processes and will not require periodic resealing. The first application of surface sealing with natural material at depth is planned for trench 83 (Fig. 5) in the late fall of 1974. After sealing the trench, the results will be monitored to determine the effectiveness of the seal. The results will determine the applicability of surface sealing to larger areas; namely, burial grounds 4 and 5.

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