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Annual Progress Report of Burial Ground Studies at Oak Ridge National Laboratory: Period Ending September 30, 1975

J. O. Duguid

Environmental Sciences Division Publication No. 885

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ANNUAL PROGRESS REPORT OF BURIAL GROUND STUDIES AT OAK RIDGE NATIONAL LABORATORY: PERIOD ENDING SEPTEMBER 30, 1975

J. O. Duguid

Date Published: October 1976

Environmental Sciences Division

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ABSTRACT

DUGUID, J. O. 1976. Annual progress report of burial ground studies at Oak Ridge National Laboratory: Period ending September 30, 1975. ORNL-5141. Oak Ridge National Laboratory, Oak Ridge, Tenn. 54 pp.

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 have been conducted to locate sources of radioactivity release and to seek methods of reducing or eliminating them. This study, begun in April 1973, is concerned with determining the radioactivity contributions to the Clinch River from the buried waste at ORNL and with implementing corrective measures.

The ^{60}Co-organic complexes present in ground water near trench 7 have been identified to be present in two molecular weight fractions, one greater than 700 and one less than 700. Approximately 85% of the ^{60}Co is being transported with the lighter organic fraction. The chemical composition of this fraction has not been identified, but may be composed of natural organics or EDTA (ethylenediamine-tetraacetic acid).

The calculated discharge of ^{90}Sr from burial ground 4 to White Oak Creek showed a decrease in the discharge corresponding to a decrease in precipitation. The calculated discharge does not agree with stream-monitoring data, and it is believed that the stream-monitoring data are in error or that a new source of ^{90}Sr is present in the drainage. Drainage improvements for the burial ground have been installed, but as yet no data are available to show their effectiveness.

Alpha radioactivity has been found in water samples from burial ground 5. More detailed analyses of the water from one seep indicated that both ^{244}Cm and ^{238}Pu were present in the water. Because of the presence of these radionuclides, corrective measures were applied to reduce the amount of water moving through the buried waste. Four trenches were sealed with a near-surface plastic membrane; however, as yet, no data are available to show its effectiveness.

The procedures for design of a bentonite-shale mixture have been developed, and enough data have been obtained to show that an adequate sealing material can be made using approximately 10% bentonite. This material will be used for near-surface sealing of both past and current burial grounds.

Two computer codes for calculation of water movement and radionuclide transport have been completed. These models are currently being applied to seepage trench 7 to predict the future behavior of the waste.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
LIST OF TABLES	vii
LIST OF FIGURES	ix
INTRODUCTION	1
SEEPAGE TRENCH 7	4
Mechanisms of ^{60}Co Transport	4
Strontium-90 in Vegetation	7
BURIAL GROUND 4	8
Ground-water Contamination	11
Discharge of ^{90}Sr	15
Soil Contamination	21
BURIAL GROUND 5	27
Ground-water Contamination	27
Discharge of ^{90}Sr	31
Soil Contamination	34
CORRECTIVE MEASURES	37
Burial Ground 4	37
Burial Ground 5	39
Current Burial Operations	41
Design of the Bentonite-Shale Mixture	45
Chemical Methods	47
GROUND-WATER TRANSPORT MODELS	48
CONCLUSIONS	50
ACKNOWLEDGMENTS	52
REFERENCES	54

LIST OF TABLES

Table		Page
1	Radionuclide concentration in soil and vegetation from a small contaminated area near trench 7	9
2	Radionuclide concentrations (μCi/ml) in old wells near burial ground 4, September 23, 1974	12
3	Concentration (μCi/ml) of ^{3}H in wells below burial ground 4	13
4	Concentration (μCi/ml) of ^{90}Sr flowing from basin 1 . . .	16
5	Concentration (μCi/ml) of ^{90}Sr in wells in the lower portion of basin 2	17
6	Discharge of ^{90}Sr from burial ground 4 and precipitation data from water years 1963 through 1975	19
7	Concentration (μCi/g) of radionuclides in soils below burial ground 4	23
8	Analyses of water samples from the south side of burial ground 5, in μCi/ml	28
9	Discharge of ^{90}Sr from burial ground 5 and precipitation data for water years 1967 through 1975	32
10	Analyses of soil samples from burial ground 5 (μCi/g) . .	35
11	Plutonium analyses of two soil samples collected below trench 83 of burial ground 5 (μCi/g)	36

LIST OF FIGURES

Figure		Page
1	Approximate location of waste disposal areas and sampling stations at ORNL	3
2	Location of wells and a seep near intermediate-level waste trench 7	5
3	Elution profiles and associated ^{60}Co concentrations for water samples collected near trench 7	6
4	Elevation contours prior to establishment of burial ground 4	10
5	Location of ground-water monitoring wells near burial ground 4	14
6	Discharge of ^{90}Sr from burial ground 4 for water years 1963 through 1975, in millicuries per inch of precipitation (from stream-monitoring data)	22
7	Location of wells and seeps in burial ground 5	29
8	Discharge of ^{90}Sr from burial ground 5 for water years 1967 through 1975, in millicuries per inch of precipitation (from stream-monitoring data)	33
9	Surface runoff diversion system for burial ground 4 . .	38
10	Near-surface sealing of trenches in burial ground 5 . .	40
11	Cross sections of the concrete and bentonite-shale dams across trenches 105 and 83	42
12	Compaction curves for bentonite-shale mixture	46

INTRODUCTION

The offsite radioactivity releases 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," research directed toward locating sources of radioactivity releases and toward seeking methods for reducing or eliminating them has been continued. This project, 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 also indicates modifications in current burial procedures that will reduce radionuclide transport. The study encompasses all waste disposal sites at ORNL and is funded by the Division of Nuclear Fuel Cycle and Production of the Energy Research and Development Administration. The purpose of this report is to update the progress of the investigation. The progress of this study prior to this report is documented by Duguid, 1975.

Since the beginning of operations at X-10 (ORNL), land burial has been used for disposal of radioactive waste. Disposal consists of land burial of solid waste in unlined trenches excavated in Conasauga shale. The trenches are filled with waste and covered with about 2 ft of soil. This type of burial allows infiltration of precipitation with subsequent percolation of water through the waste. Contact of the waste with water causes leaching of radionuclides from the solid waste and subsequent ground-water transport from the burial site.

Past waste disposal operations have been carried out in five burial grounds, four seepage pits, and three seepage trenches (Fig. 1). Associated with most of these disposal areas are seeps which show some evidence of ground-water transport of radionuclides. Disposal of solid waste is currently carried out in disposal area 6 (burial ground 6), and as yet no ground-water contamination has been observed. However, because of the similarity of this area with other burial grounds, radionuclide transport in ground water is expected.

The ground-water table in the White Oak drainage is a shallow unconfined water table that is a subdued replica of the surface topography. The ground water 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 ground-water contamination occur locally near waste disposal sites, and the contaminated ground water discharges into surface streams within the drainage. The contamination arising from both surface water releases at X-10 and ground-water 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 (Fig. 1).

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

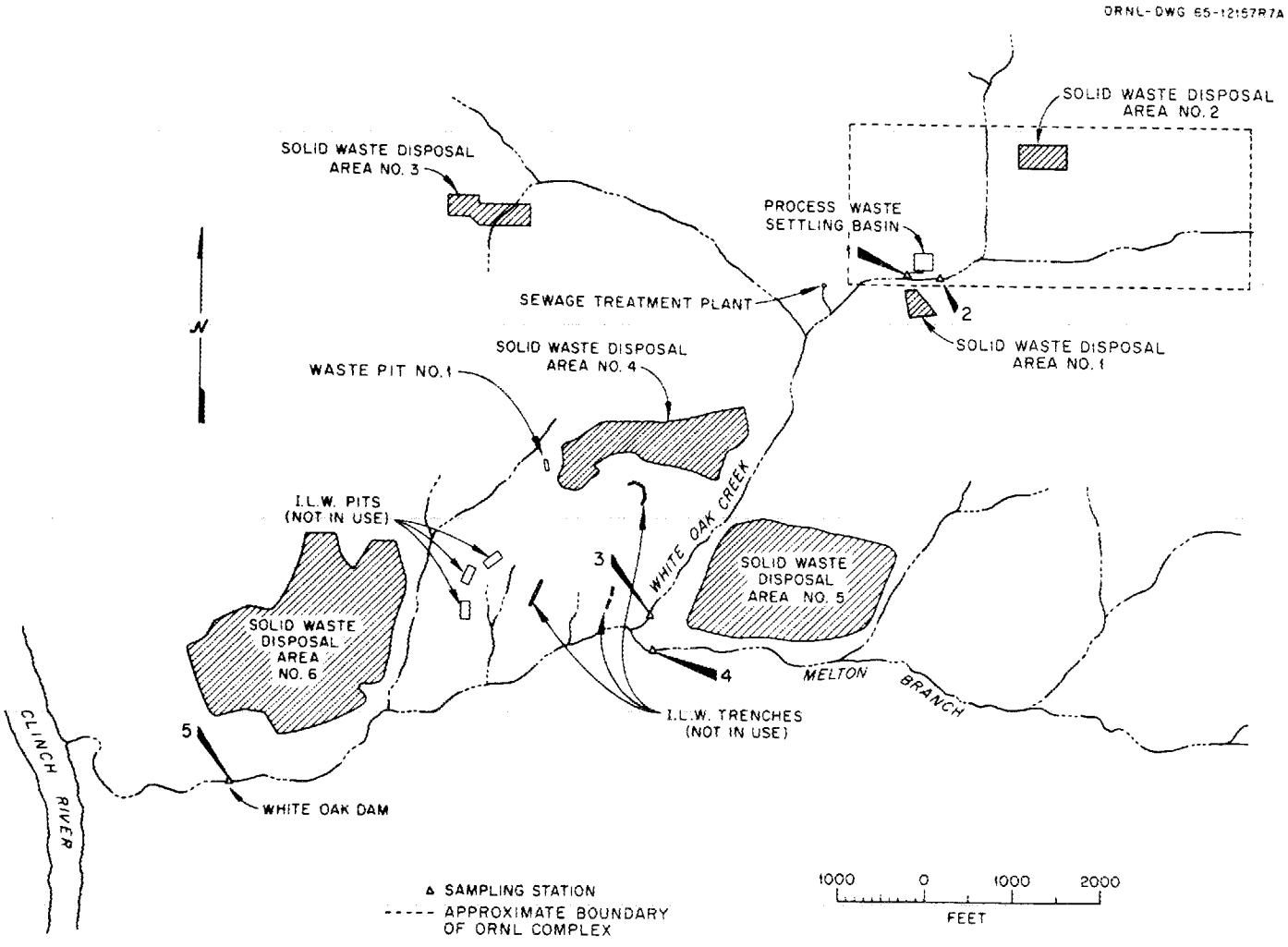

Fig. 1. Approximate location of waste disposal areas and sampling stations at ORNL.

SEEPAGE TRENCH 7

Seepage trench 7 was used for disposal of intermediate-level liquid waste for the period between 1962 and 1965. During that time, radioactive liquid waste was pumped into the covered trench and seeped into the surrounding shale. The shale acted as an ion-exchange column by sorbing much of the radioactivity. However, some radionuclides, such as tritium and ruthenium, are not readily sorbed, and others, such as ^{60}Co, combine with organics in complexes that are readily transported by ground water. These radionuclides are observed in a small surface seep (RS7) associated with the seepage trench (Fig. 2) and are also present in ground-water samples from wells near the trench.

Mechanisms of ^{60}Co Transport

The ^{60}Co-organic complexes in ground water were separated according to molecular weight using Sephedex (G-10) chromatographic gels. Columns of 50- x 2-cm dimensions were used, and the height of the gels was uniformly maintained at 40 cm. Organics were concentrated by freeze drying and then dissolved with distilled water. The sodium-resin exchange characteristics of the solution before and after concentration revealed that organic-metallic structures were preserved. A sample of the extracted concentrated solution was introduced on the surface of the gel, and eluted with 0.1 N NaCl at a constant flow rate of 25 ml/hr. Fractions were monitored for organics using an ultraviolet spectrophotometer. The fractions were also counted to obtain their ^{60}Co concentration. The results from two water samples are shown in Fig. 3.

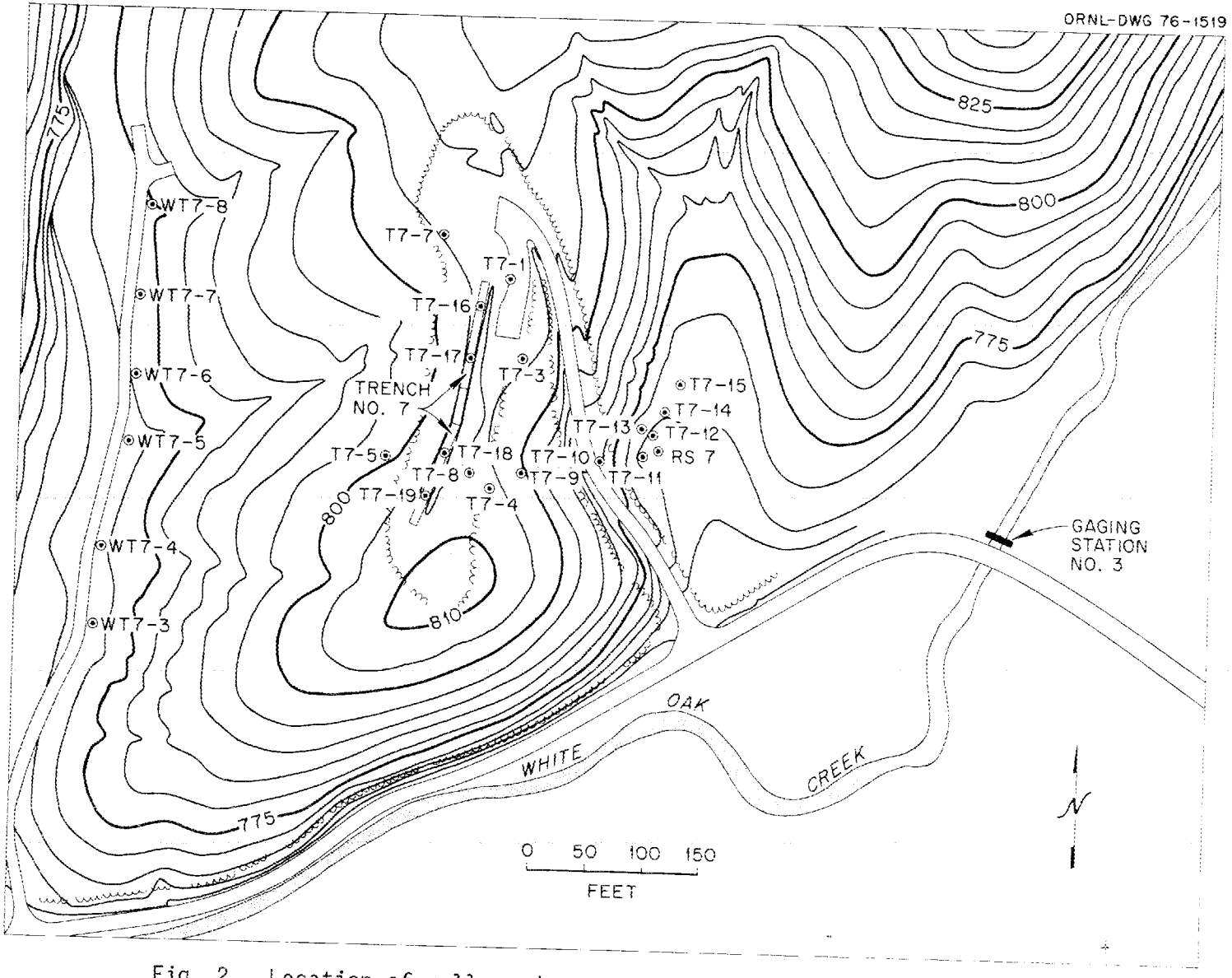

Fig. 2. Location of wells and a seep near intermediate-level waste trench

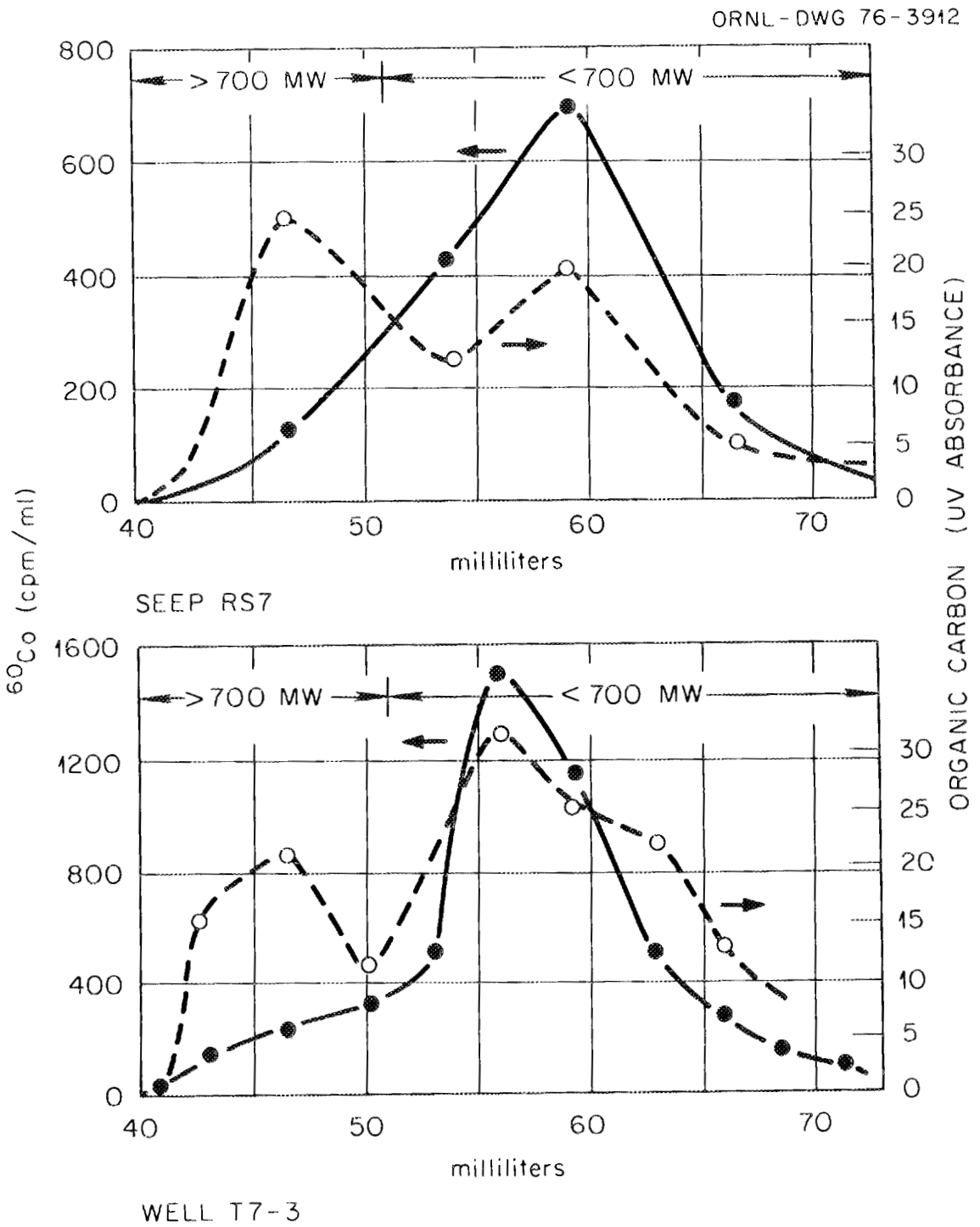

Fig. 3. Elution profiles and associated ^{60}Co concentrations for water samples collected near trench 7.

Sephedex gel G-10 is designed to retard the passage of organic solutes with molecular weights less than 700. Everything greater than 700 MW is eluted first. Lighter molecules are eluted later and fractionated so that the lightest compounds are the last to emerge from the column. Two peaks representing organic acids are apparent in both samples (Fig. 3). These data show that ^{60}Co is complexed principally with a compound of molecular weight (MW) less than 700. About 12-18% of the ^{60}Co may be associated with the greater than 700-MW fraction. This, however, may represent overlap of the lighter MW organics due to incomplete separation of the compounds.

The bulk of the ^{60}Co occurs with the less than 700-MW fraction, which implies complexation with low molecular weight natural organics, such as fulvic acids, gallic acid, etc. Nevertheless, chelation with EDTA (MW = 292) cannot be dismissed. A more detailed discussion of ^{60}Co transport mechanisms is given by Means, Crerar, and Duguid, 1976.

Strontium-90 in Vegetation

During field work near trench 7, a small area supporting contaminated vegetation was detected. Review of records shows that a small area of surface soil was contaminated during the operation of trench 7 when a small leak developed in the transfer line near the trench. Vegetation has now grown on the area (an area approximately 10 ft by 25 ft), and current data show that this area may be useful for the study of radionuclide uptake by plants. A small sweet gum tree growing in this area had a background reading of 57.7 mR/hr, which appeared to be primarily ^{90}Sr. Analysis of the leaves showed that they contained approximately 5.9×10^{-1} μCi/g of ^{90}Sr, with all other radionuclides at levels below

routine analyses (Table 1). The limits for ^{60}Co, ^{125}Sb, and ^{137}Cs in the vegetation are relatively high because of problems encountered in analyzing this sample in a low-level laboratory.

Analyses of a near-surface soil sample from the area showed the presence of ^{90}Sr, ^{60}Co, ^{137}Cs, and alpha activity in the soil. It is believed that the substantial uptake of ^{90}Sr by the vegetation may be caused by a low calcium status of the soil (because of the chemical similarity of calcium and strontium). Further studies of plant uptake from this contaminated area are being carried out under other projects in the Environmental Sciences Division.

BURIAL GROUND 4

Burial ground 4 is located approximately 1/2 mile southwest of ORNL (Fig. 1) and is situated in the lower portion of a small watershed (Fig. 4). Both the surface water and the ground water flowing from this watershed discharge into White Oak Creek. Because of the localized nature of the ground-water system in the watershed (the flow is essentially parallel to surface runoff), an effective network of ground-water monitoring wells can be established on the flood plain of White Oak Creek. The location of wells in this monitoring system is shown in Fig. 5. A more detailed discussion of the burial ground history, geology, and hydrology is given by Lomenick and Cowser, 1961, and by Duguid, 1975. The latter reference also includes a discussion of monitoring data collected from this system during 1973 and early 1974.

Table 1. Radionuclide concentrations in soil and vegetation from a small contaminated area near trench 7

Sample type	Concentration (μCi)				
	Total α	^{90}Sr	^{60}Co	^{125}Sb	^{137}Cs
Soil	2.7×10^{-5}	2.10×10^{-1}	6.6×10^{-4}	$\leq 1.3 \times 10^{-3}$	3.8×10^{-2}
Vegetation* (sweet gum)	$\leq 1.0 \times 10^{-6}$	5.9×10^{-1}	$\leq 3.1 \times 10^{-4}$	$\leq 1.9 \times 10^{-3}$	$\leq 2.6 \times 10^{-4}$

* Concentration of radionuclides per gram of 100°C oven-dried plant.

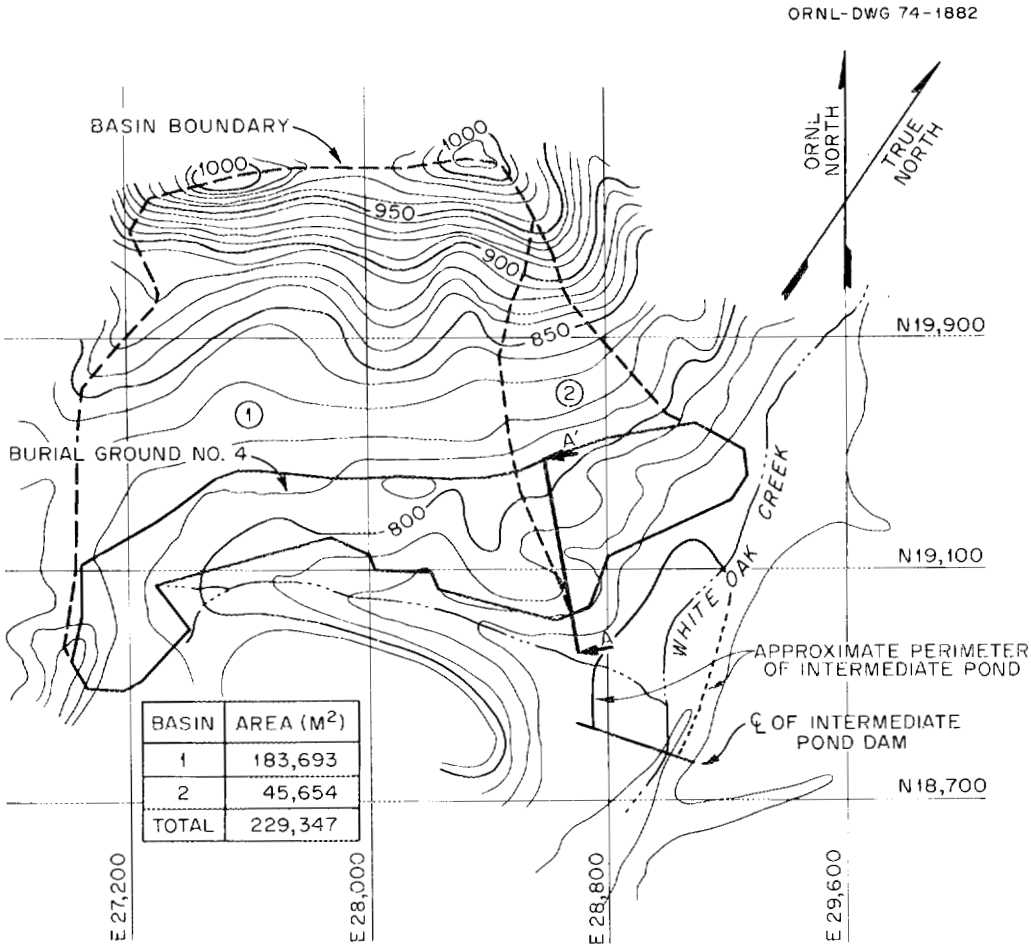

Fig. 4. Elevation contours prior to establishment of burial ground 4.

Ground-water Contamination

The principal radionuclides present in the ground water in and near burial ground 4 are tritium and ^{90}Sr. However, occasional water samples are found to contain small amounts of ^{60}Co, ^{125}Sb, and ^{137}Cs. As yet, no water sample has been found to contain alpha contamination in excess of the detection limit for routine analysis (approximately 4.5×10^{-8} μCi/ml).

During the past year the presence of tritium in the ground water near burial ground 4 was detected. This discovery does not indicate a sudden appearance of tritium in the monitoring system. Tritium analyses at this location had not been performed prior September 1974. The concentration of tritium (as well as ^{90}Sr, ^{60}Co, and ^{125}Sb) in old wells near burial ground 4 is given in Table 2, and the concentration of tritium in the monitoring wells below burial 4 is given in Table 3. These data indicate that the primary source of tritium is located within the area circumscribed by wells 190A, 195, 196, and 193 (Fig. 5).

The concentration of ^{90}Sr in ground water flowing from the east end of the burial ground is lower than the concentration in ground water along the south side of the burial ground. For computational purposes, the entire watershed was divided into two parts, basin 1 and basin 2 (Fig. 4), based on the two different concentrations. The dashed line dividing the two basins shown in Fig. 4 crosses ground-water contours at a right angle. Thus, the row of wells that transect the drainage south of the burial ground at grid line W90 is used to monitor the ^{90}Sr concentration in the ground-water discharge from basin 1 (Fig. 5). The wells near the burial ground boundary below basin 2 are used to monitor the ^{90}Sr concentration

Table 2. Radionuclide concentrations (μCi/ml) in old wells near burial ground 4, September 23, 1974

Well	^{90}Sr	^{3}H	^{60}Co	^{125}Sb
179	---	---	---	---
180	---	---	---	---
182	2.3×10^{-7}	---	---	---
183	---	---	---	---
185	7.1×10^{-6}	5.4×10^{-4}	9.0×10^{-8}	---
186	3.3×10^{-6}	2.3×10^{-4}	4.5×10^{-8}	---
186A	1.2×10^{-6}	1.8×10^{-4}	4.5×10^{-8}	---
187	---	---	---	---
188	---	---	---	---
189	---	---	---	---
190	2.0×10^{-5}	1.3×10^{-4}	---	4.5×10^{-8}
190A	1.7×10^{-5}	---	---	4.5×10^{-8}
190B	3.4×10^{-6}	2.7×10^{-4}	---	---
190C	7.1×10^{-6}	---	---	---
191	3.1×10^{-5}	1.2×10^{-4}	---	4.5×10^{-8}
192	2.3×10^{-7}	---	---	---
193	1.8×10^{-7}	---	---	---

Table 3. Concentration (μCi/ml) of ^{3}H in wells below burial ground 4

Well	Concentration (Sept. 11, 1974)	Concentration (April 7, 1975)
N0/E95	4.1×10^{-4}	3.9×10^{-4}
N0/E106	2.2×10^{-4}	3.5×10^{-4}
S30/E109	1.4×10^{-4}	$\leq 1.3 \times 10^{-4}$
S96/E30	5.2×10^{-4}	$\leq 1.8 \times 10^{-4}$
197	5.2×10^{-4}	5.5×10^{-4}
S120/W30	1.3×10^{-4}	$\leq 3.6 \times 10^{-4}$
S120/E0	8.4×10^{-4}	6.8×10^{-4}
196	7.9×10^{-4}	1.1×10^{-3}
S150/W30	1.7×10^{-3}	8.3×10^{-3}
S150/E0	7.1×10^{-3}	7.3×10^{-4}
S180/W30	5.7×10^{-4}	$\leq 3.3 \times 10^{-4}$
S180/E0	3.6×10^{-4}	$\leq 1.4 \times 10^{-4}$
S210/W56	8.0×10^{-3}	5.0×10^{-3}
S210/W30	2.5×10^{-3}	8.5×10^{-4}
S210/W21	1.6×10^{-3}	6.8×10^{-4}
195	9.5×10^{-3}	3.5×10^{-3}
S212/W90	5.3×10^{-3}	1.8×10^{-3}
S218/W90	5.4×10^{-3}	1.6×10^{-3}
S227/W90	3.5×10^{-3}	1.6×10^{-3}
S232/W90	2.3×10^{-3}	$\leq 1.1 \times 10^{-4}$
S297.9/W62.2	2.6×10^{-3}	1.4×10^{-3}
S300.6/W27.9	1.3×10^{-3}	9.0×10^{-4}

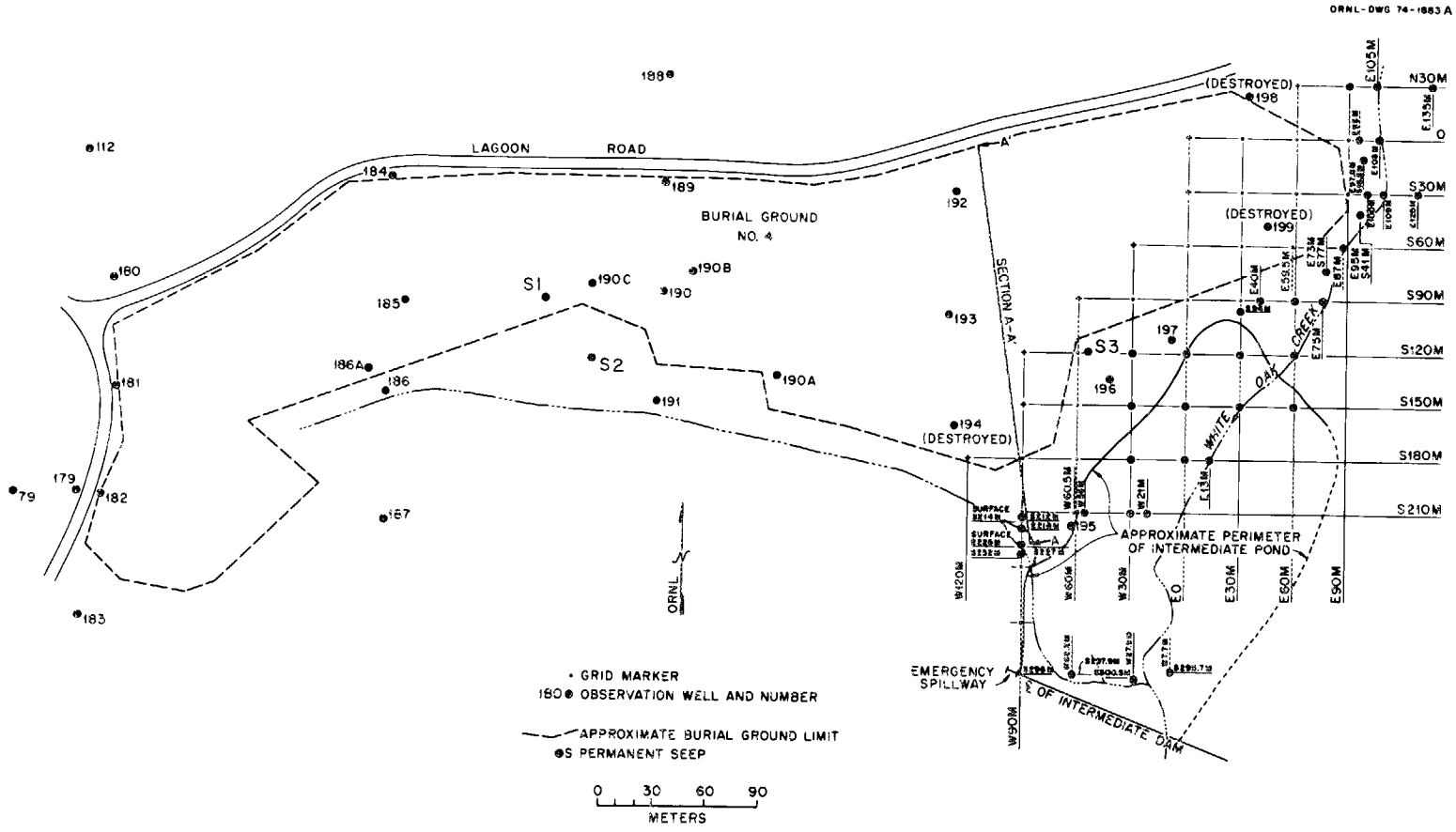

Fig. 5. Location of ground-water monitoring wells near burial ground 4.

in the ground-water flow from basin 2. The ^{90}Sr flowing in ground water from the two basins enters White Oak Creek in the reach of stream adjacent to the burial ground. The ^{90}Sr concentration in ground water flowing from basins 1 and 2 is shown in Tables 4 and 5, respectively. These data were collected in September and March because during those months the ground-water table within the burial ground is at its lowest and highest position, respectively. For the current sampling periods, the average concentration of ^{90}Sr in ground water flowing from basin 1 and 2 is 6.4×10^{-6} μCi/ml and 3.9×10^{-6}, respectively. These concentrations are lower than the 6.8×10^{-6} μCi/ml from basin 1 and the 4.7×10^{-6} μCi/ml from basin 2 reported by Duguid, 1975. However, the decrease is not assumed to indicate any significant change in the annual ^{90}Sr discharge from burial ground 4.

Discharge of ^{90}Sr

A crude estimate of the quantity of ^{90}Sr discharged from burial ground 4 during a water year can be made using precipitation, evapotranspiration, basin areas, and average ^{90}Sr concentrations in the basin discharge. This type of calculation for water years 1973, 1974, and 1975 yields approximate discharges of 1.7, 1.6, and 1.2 curies, respectively. For this calculation the precipitation values shown in Table 6 were used, evapotranspiration was assumed to be 27 in. per year, and the discharge concentrations reported by Duguid, 1975, were used. The calculated value of ^{90}Sr discharged for water year 1973 (1.7 Ci) agrees quite well with the stream-monitoring data given in Table 6 (1.58 Ci). However, for water years 1974 and 1975, stream monitoring indicates far more ^{90}Sr discharging from burial ground 4 than is predicted from these crude calculations. A

discussion of this type of calculation, as well as a comparison between calculated and stream-monitoring discharges from the burial ground for the calendar years 1971 through 1973, is given by Duguid, 1975. The reason for changing from a calendar year to a water year for reporting ^{90}Sr discharge is as follows: During a water year, September 1 to August 31, the ground-water table makes a complete cycle (from low in September to high in late February and back to low in September), and smoother yearly discharge data are obtained by breaking the cycle at the lowest point rather than near the point of highest discharge.

The ^{90}Sr discharge from burial ground 4 was obtained (from stream-monitoring data) by subtracting the ^{90}Sr discharged from plant operations (stations 1 and 2) from the ^{90}Sr discharged at monitoring station 3. This method relies on the assumption that no other source of ^{90}Sr enters White Oak Creek between the plant and station 3 (Fig. 1). 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 of ^{90}Sr (Duguid, 1975). However, more recent stream-monitoring data indicate either a new source of ^{90}Sr input to White Oak Creek between the monitoring stations or a malfunction of monitoring station 3. This monitoring station is internal to the ORNL monitoring system and its malfunction would not affect the data reported at White Oak Dam (monitoring station 5). Table 6 shows the discharge of ^{90}Sr that may be attributed to burial ground 4 from stream-monitoring data for water years 1963 through 1975 (personal communication with G. J. Dixon, ORNL). The precipitation data for calendar years 1962 through 1972 are from the X-10 site and the remaining

Table 4. Concentration (μCi/ml) of ^{90}Sr flowing from basin 1

Location	Concentration (Sept. 11, 1974)	Concentration (April 7, 1975)	Average concentration
Well, S212/W90	5.9×10^{-6}	3.3×10^{-6}	4.6×10^{-6}
Surface, S214/W90	1.2×10^{-5}		
Well, S218/W90	1.0×10^{-5}	4.7×10^{-6}	7.3×10^{-6}
Well, S227/W90	7.8×10^{-6}	6.5×10^{-6}	7.2×10^{-6}
Surface, S228/W90	5.3×10^{-6}		
Well, S232/W90	1.2×10^{-6}[a]	5.4×10^{-7}[a]	8.7×10^{-7}[a]
Average	8.2×10^{-6}	4.8×10^{-6}	6.4×10^{-6}

[a] Well excluded from the average because of dilution by uncontaminated ground water flowing from the slope south of the burial ground.

Table 5. Concentration (μCi/ml) of ^{90}Sr in wells in the lower portion of basin 2

Well	Concentration (Sept. 11, 1974)	Concentration (April 7, 1975)	Average concentration
N30/E90	0.0	9.0×10^{-8}	4.0×10^{-8}[a]
N30/E105	4.5×10^{-7}	5.8×10^{-7}	5.2×10^{-7}[a]
N30/E135	3.1×10^{-6}	1.8×10^{-6}	2.4×10^{-6}[a]
N0/E95	3.0×10^{-7}	1.8×10^{-7}	2.4×10^{-7}[a]
N0/E106	6.3×10^{-7}	3.1×10^{-7}	4.7×10^{-7}[a]
S16.6/E97.8	8.5×10^{-7}	5.4×10^{-7}	6.9×10^{-7}
S30/E100	1.2×10^{-6}	6.8×10^{-7}	9.4×10^{-7}
S30/E109	7.4×10^{-6}	1.8×10^{-6}	4.6×10^{-6}[a]
S30/E125	6.1×10^{-6}	4.3×10^{-6}	5.2×10^{-6}[a]
S41/E95	3.6×10^{-6}	2.8×10^{-6}	3.2×10^{-6}
S60/E87	1.1×10^{-6}	2.9×10^{-6}	2.0×10^{-6}[a]
S77/E73	9.6×10^{-6}	8.7×10^{-6}	9.2×10^{-6}
S90/E40	4.5×10^{-7}	1.4×10^{-7}	2.9×10^{-7}
S90/E60	4.3×10^{-6}	2.3×10^{-6}	3.3×10^{-6}
S90/E75	9.0×10^{-7}	1.7×10^{-6}	1.3×10^{-6}[a]
S96/E30	3.6×10^{-6}	2.3×10^{-6}	2.9×10^{-6}
197	7.2×10^{-7}	6.3×10^{-7}	6.7×10^{-6}
S120/W30	4.5×10^{-8}	9.0×10^{-8}	6.8×10^{-8}
S120/E0	4.6×10^{-6}	2.5×10^{-6}	3.5×10^{-6}
S120/E30	2.7×10^{-6}	8.5×10^{-7}	1.9×10^{-6}[a]
S120/E60	3.1×10^{-6}	5.4×10^{-6}	4.2×10^{-6}[a]
196	1.4×10^{-5}	9.1×10^{-6}	1.2×10^{-5}

Table 5. (Cont'd) Concentration (μCi/ml) of ^{90}Sr in wells in the lower portion of basin 2

Well	Concentration (Sept. 11, 1974)	Concentration (April 7, 1975)	Average concentration
S150/W30	7.2×10^{-6}	5.5×10^{-6}	6.3×10^{-6}
S150/E0	1.3×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
S150/E30	6.2×10^{-6}	5.6×10^{-6}	5.9×10^{-6}[a]
S150/E60	5.8×10^{-7}	5.0×10^{-6}	5.4×10^{-6}[a]
S180/W30	6.8×10^{-6}	4.6×10^{-6}	5.7×10^{-6}
S180/E0	6.3×10^{-7}	1.2×10^{-6}	9.0×10^{-7}[a]
S180/E13	7.6×10^{-7}	1.4×10^{-6}	1.1×10^{-6}[a]
S210/W56	3.8×10^{-6}	4.0×10^{-6}	3.9×10^{-6}
S210/W30	7.0×10^{-6}	4.1×10^{-6}	5.5×10^{-6}
S210/W21	5.0×10^{-6}	2.8×10^{-6}	3.9×10^{-6}[a]
195	2.5×10^{-6}	3.2×10^{-6}	2.8×10^{-6}
S295.7/W7.7	2.5×10^{-6}	6.7×10^{-7}	1.6×10^{-6}
S297.9/W62.2	4.5×10^{-6}	3.6×10^{-6}	4.0×10^{-6}[a]
S300.6/W27.9	8.1×10^{-7}	3.2×10^{-6}	2.0×10^{-6}[a]
Average			3.9×10^{-6}

[a] Wells excluded from the average because of dilution by ground water flowing down the floodplain of White Oak Creek. Thus, wells near the creek channel are excluded from the average.

Table 6. Discharge of ^{90}Sr from burial ground 4 and precipitation data for water years 1963 through 1975

Water[a] 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
1974	68.76	5.22	75.9
1975	57.73	3.22	55.8

[a]Water year is September 1 through August 31.

precipitation data are from Walker Branch watershed, which is located approximately 3.5 miles northeast of burial ground 4. The fourth column of Table 6 shows the ^{90}Sr discharge attributed to burial ground 4 in millicuries per inch of precipitation. A plot of these data for water years 1965 through 1973 is shown in Fig. 6. During these years the ^{90}Sr discharge from burial ground 4 shows a steady decline. (Further discussion of Fig. 6 is presented by Duguid, 1975.) If the discharges per inch of precipitation for water years 1974 and 1975 were plotted, they would not fit the past behavior of the burial ground because they are higher. The increased ^{90}Sr for these years is not apparent in the ground-water monitoring data shown in Tables 4 and 5. In fact ground-water monitoring data indicate a slight decrease in the average ^{90}Sr concentration in ground water flowing from basins 1 and 2. (Higher average values were reported by Duguid, 1975.) Thus the higher discharges of ^{90}Sr from the area cannot be attributed to burial ground 4.

The higher discharges of ^{90}Sr (75.9 and 55.8) shown in Table 6 are not reflected in the discharge over White Oak Dam (personal communication with G. J. Dixon, ORNL). In fact, the discharge over White Oak Dam decreased slightly which would be expected during these two water years (1974 and 1975) when precipitation also decreased. Thus, the added ^{90}Sr passing monitoring station 3 (which cannot be attributed to burial ground 4) should cause a measurable increase in the amount of ^{90}Sr entering White Oak Lake, but was never detected at the monitoring station at White Oak Dam. This evidence may suggest a malfunction in monitoring station 3.

Soil Contamination

The soil in the drainage along the south side of burial ground 4

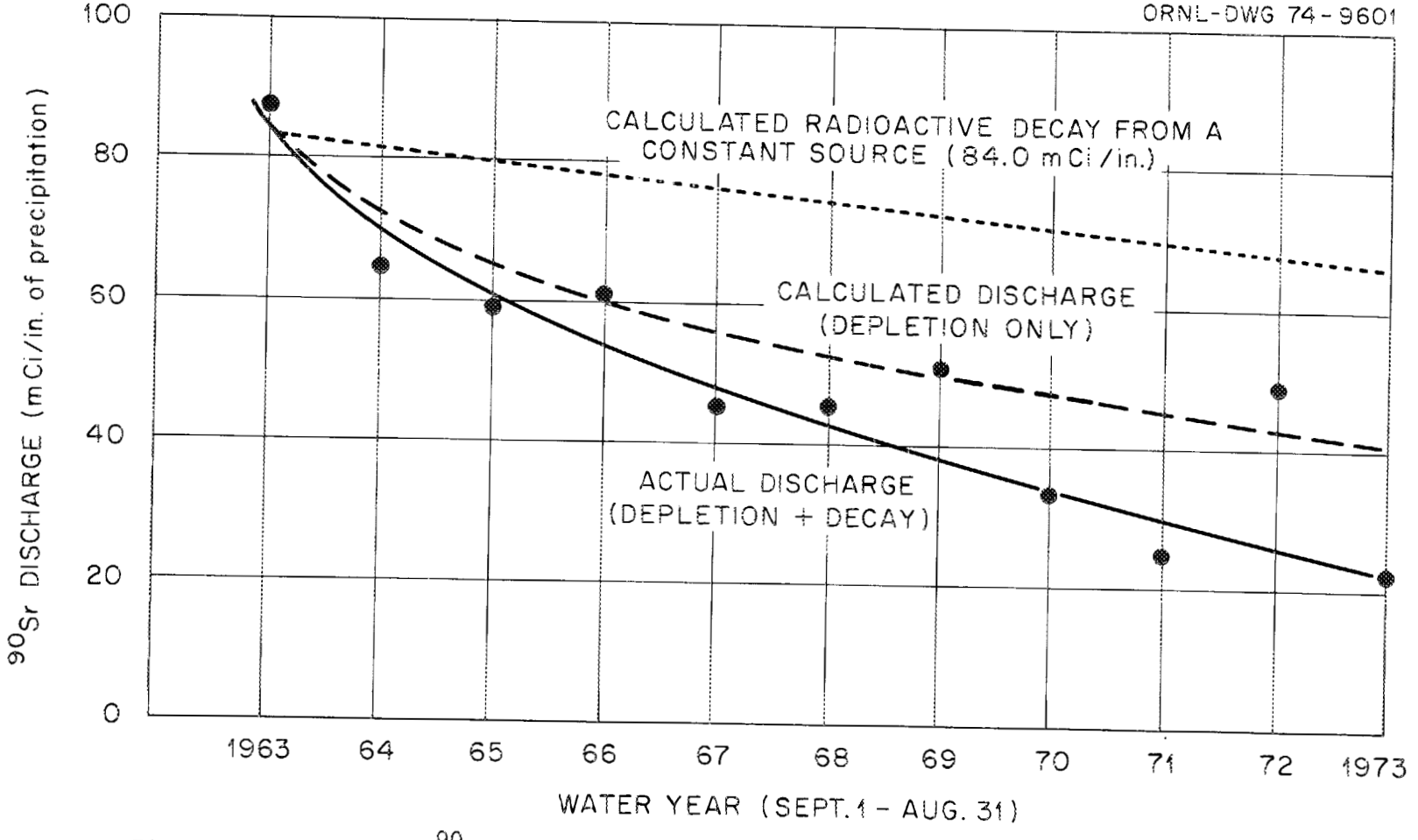

Fig. 6. Discharge of ^{90}Sr from burial ground 4 for water years 1963 through 1975, in millicuries per inch of precipitation (from stream-monitoring data).

Table 7. Concentration (μCi/g) of radionuclides in soils below burial ground 4

Location	Depth (in.)	Total α	^{90}Sr	^{60}Co	^{125}Sb	^{137}Cs
N0/E95	0-7	$\leq 3.1 \times 10^{-7}$	$\leq 8.1 \times 10^{-6}$	$\leq 2.7 \times 10^{-6}$	$\leq 8.1 \times 10^{-6}$	3.1×10^{-4}
	7-14	$\leq 5.0 \times 10^{-6}$	1.4×10^{-5}	2.5×10^{-5}	$\leq 1.5 \times 10^{-5}$	8.1×10^{-4}
	14-19.5	$\leq 5.0 \times 10^{-6}$	1.2×10^{-5}	$\leq 1.9 \times 10^{-6}$	$\leq 2.2 \times 10^{-6}$	3.5×10^{-5}
S47/E95	0-7	4.0×10^{-5}	4.5×10^{-4}	1.5×10^{-4}	$\leq 1.5 \times 10^{-4}$	6.3×10^{-3}
	7-14	5.6×10^{-5}	1.7×10^{-4}	5.0×10^{-4}	$\leq 1.4 \times 10^{-4}$	1.0×10^{-2}
	14-21	$\leq 2.3 \times 10^{-5}$	1.9×10^{-4}	$\leq 5.4 \times 10^{-5}$	$\leq 5.4 \times 10^{-4}$	2.1×10^{-2}
S77/E73	0-7	3.1×10^{-5}	3.7×10^{-4}	2.0×10^{-4}	$\leq 5.4 \times 10^{-5}$	3.5×10^{-3}
	7-14	$\leq 1.4 \times 10^{-5}$	1.7×10^{-4}	5.9×10^{-5}	$\leq 5.0 \times 10^{-5}$	3.1×10^{-3}
	14-20	$\leq 2.3 \times 10^{-5}$	2.5×10^{-4}	1.8×10^{-4}	$\leq 1.6 \times 10^{-4}$	9.5×10^{-3}
S120/W60	0-6.7	$\leq 1.3 \times 10^{-5}$	5.9×10^{-5}	$\leq 2.2 \times 10^{-6}$	$\leq 3.7 \times 10^{-6}$	4.1×10^{-5}
	6.7-12.1	$\leq 1.0 \times 10^{-5}$	3.8×10^{-5}	$\leq 2.0 \times 10^{-6}$	$\leq 4.5 \times 10^{-6}$	3.6×10^{-5}
	12.1-17.9	$\leq 7.7 \times 10^{-6}$	9.5×10^{-6}	$\leq 3.5 \times 10^{-6}$	$\leq 3.5 \times 10^{-6}$	5.0×10^{-6}
S120/E0	0-7	1.9×10^{-5}	1.5×10^{-4}	$\leq 2.2 \times 10^{-4}$	$\leq 4.0 \times 10^{-4}$	2.1×10^{-2}
	7-14	$\leq 7.2 \times 10^{-6}$	8.1×10^{-5}	$\leq 4.5 \times 10^{-5}$	$\leq 2.4 \times 10^{-4}$	1.3×10^{-2}
	14-20	$\leq 4.5 \times 10^{-6}$	8.1×10^{-4}	$\leq 2.5 \times 10^{-6}$	$\leq 5.4 \times 10^{-6}$	6.8×10^{-5}
S120/E60	0-7	$\leq 2.7 \times 10^{-6}$	1.2×10^{-4}	$\leq 2.5 \times 10^{-5}$	$\leq 3.0 \times 10^{-5}$	4.3×10^{-5}
	7-14	$\leq 8.6 \times 10^{-6}$	6.3×10^{-5}	2.2×10^{-5}	2.2×10^{-5}	$\leq 4.5 \times 10^{-6}$
	14-17.5	$\leq 8.6 \times 10^{-6}$	1.1×10^{-4}	2.2×10^{-5}	2.2×10^{-5}	$\leq 9.0 \times 10^{-6}$
S150/W30	0-7	$\leq 5.4 \times 10^{-6}$	2.4×10^{-4}	$\leq 3.1 \times 10^{-6}$	$\leq 5.9 \times 10^{-6}$	5.0×10^{-5}
	7-14	$\leq 6.8 \times 10^{-6}$	3.6×10^{-5}	$\leq 1.8 \times 10^{-5}$	9.5×10^{-5}	5.4×10^{-3}
	14-20	$\leq 7.2 \times 10^{-6}$	2.0×10^{-5}	$\leq 1.8 \times 10^{-6}$	$\leq 3.6 \times 10^{-6}$	6.8×10^{-6}
S150/E30	0-7	$\leq 1.1 \times 10^{-5}$	3.0×10^{-4}	4.5×10^{-5}	2.8×10^{-5}	6.3×10^{-4}
	7-14	$\leq 6.8 \times 10^{-6}$	1.6×10^{-4}	$\leq 5.4 \times 10^{-5}$	2.9×10^{-5}	7.2×10^{-4}
	14-19	$\leq 1.8 \times 10^{-6}$	1.0×10^{-4}	$\leq 2.7 \times 10^{-6}$	$\leq 4.5 \times 10^{-6}$	1.1×10^{-4}
Well 186	0-7	$\leq 9.5 \times 10^{-6}$	1.3×10^{-4}	$\leq 3.2 \times 10^{-6}$	$\leq 9.0 \times 10^{-6}$	3.3×10^{-4}
	7-14	$\leq 1.1 \times 10^{-5}$	8.6×10^{-5}	$\leq 2.3 \times 10^{-6}$	$\leq 5.0 \times 10^{-6}$	3.7×10^{-6}
	14-21	$\leq 6.8 \times 10^{-6}$	9.9×10^{-5}	$\leq 2.3 \times 10^{-6}$	$\leq 1.9 \times 10^{-6}$	2.7×10^{-6}
Well 191	0-7	$\leq 6.3 \times 10^{-6}$	2.0×10^{-3}	5.9×10^{-5}	$\leq 7.2 \times 10^{-6}$	2.0×10^{-5}
	7-14	$\leq 6.3 \times 10^{-6}$	1.2×10^{-3}	2.0×10^{-5}	$\leq 5.0 \times 10^{-6}$	6.8×10^{-6}
	14-21	$\leq 4.5 \times 10^{-6}$	7.2×10^{-4}	1.5×10^{-5}	$\leq 5.5 \times 10^{-6}$	4.4×10^{-6}
S180/E0	0-3	3.7×10^{-5}	2.7×10^{-4}	2.7×10^{-4}	$\leq 8.6 \times 10^{-6}$	8.1×10^{-3}
	5-8	$\leq 7.6 \times 10^{-6}$	9.0×10^{-5}	$\leq 6.8 \times 10^{-6}$	2.3×10^{-5}	2.4×10^{-5}
	10-13	$\leq 3.6 \times 10^{-6}$	2.1×10^{-5}	$\leq 1.6 \times 10^{-5}$	$\leq 2.9 \times 10^{-5}$	1.1×10^{-3}
	15-18	2.7×10^{-5}	3.0×10^{-4}	$\leq 1.3 \times 10^{-4}$	$\leq 4.5 \times 10^{-4}$	1.6×10^{-2}
	24-27	$\leq 5.9 \times 10^{-6}$	3.1×10^{-5}	$\leq 2.7 \times 10^{-4}$	$\leq 4.1 \times 10^{-4}$	5.9×10^{-4}

Table 7. (Cont'd) Concentration (μCi/g) of radionuclides in soils below burial ground 4

Location	Depth (in.)	Total α	^{90}Sr	^{60}Co	^{125}Sb	^{137}Cs
S228/W90	0-7	$\leq 8.6 \times 10^{-6}$	3.4×10^{-4}	1.0×10^{-5}	$\leq 9.0 \times 10^{-6}$	3.5×10^{-4}
	7-14	$\leq 6.3 \times 10^{-6}$	2.7×10^{-4}	$\leq 2.2 \times 10^{-6}$	$\leq 4.4 \times 10^{-6}$	7.2×10^{-5}
S240/W45	0-5	$\leq 2.2 \times 10^{-5}$	7.2×10^{-4}	$\leq 4.5 \times 10^{-5}$	$\leq 3.4 \times 10^{-5}$	1.6×10^{-3}
	5-10	$\leq 6.3 \times 10^{-6}$	2.5×10^{-4}	$\leq 4.0 \times 10^{-5}$	$\leq 8.6 \times 10^{-5}$	3.7×10^{-3}
	10-15	$\leq 4.5 \times 10^{-6}$	5.6×10^{-5}	$\leq 4.0 \times 10^{-6}$	$\leq 3.6 \times 10^{-6}$	1.5×10^{-4}
S250/W45	0-5	3.7×10^{-5}	4.0×10^{-4}	8.1×10^{-5}	$\leq 9.0 \times 10^{-5}$	5.0×10^{-3}
	5-10	1.7×10^{-5}	2.7×10^{-4}	5.4×10^{-5}	$\leq 5.9 \times 10^{-5}$	4.3×10^{-3}
	10-14	$\leq 6.8 \times 10^{-6}$	1.5×10^{-4}	$\leq 3.8 \times 10^{-5}$	$\leq 3.1 \times 10^{-5}$	2.2×10^{-3}
S260/W45	0-5	2.0×10^{-5}	3.0×10^{-4}	5.9×10^{-5}	$\leq 1.4 \times 10^{-4}$	6.3×10^{-3}
	5-12.8	$\leq 1.2 \times 10^{-5}$	2.4×10^{-4}	5.9×10^{-5}	$\leq 1.5 \times 10^{-4}$	7.2×10^{-3}
S270/W45	0-4	2.6×10^{-5}	3.0×10^{-3}	1.6×10^{-4}	$\leq 6.8 \times 10^{-5}$	4.5×10^{-3}
	4-7	2.1×10^{-5}	2.7×10^{-4}	$\leq 4.5 \times 10^{-5}$	2.1×10^{-4}	7.2×10^{-2}
S275/W45	0-5	2.2×10^{-5}	3.1×10^{-4}	1.4×10^{-4}	$\leq 1.5 \times 10^{-4}$	5.9×10^{-3}
	5-8.5	1.6×10^{-5}	4.5×10^{-4}	$\leq 2.0 \times 10^{-4}$	$\leq 5.9 \times 10^{-4}$	3.3×10^{-2}
S280/W45	0-5	1.8×10^{-5}	5.0×10^{-4}	$\leq 1.2 \times 10^{-4}$	$\leq 1.5 \times 10^{-4}$	9.5×10^{-3}
	5-11.8	2.4×10^{-5}	5.9×10^{-4}	$\leq 1.4 \times 10^{-4}$	$\leq 1.4 \times 10^{-3}$	5.9×10^{-2}
S285/W45	0-5	3.7×10^{-5}	6.8×10^{-4}	7.2×10^{-5}	$\leq 6.8 \times 10^{-5}$	4.0×10^{-3}
	5-8.5	3.9×10^{-5}	5.4×10^{-4}	9.9×10^{-4}	$\leq 2.1 \times 10^{-4}$	1.1×10^{-2}
S290/W30	0-5	3.1×10^{-5}	3.2×10^{-4}	2.2×10^{-4}	$\leq 1.1 \times 10^{-4}$	5.9×10^{-3}
	5-10	3.9×10^{-5}	3.3×10^{-4}	$\leq 1.2 \times 10^{-4}$	$\leq 3.4 \times 10^{-4}$	2.6×10^{-2}
	10-13	$\leq 1.1 \times 10^{-5}$	3.7×10^{-4}	$\leq 1.1 \times 10^{-4}$	$\leq 5.9 \times 10^{-4}$	2.8×10^{-2}
S290/W45	0-5	3.2×10^{-5}	6.3×10^{-4}	1.8×10^{-4}	$\leq 2.2 \times 10^{-4}$	1.3×10^{-2}
	5-10	$\leq 1.3 \times 10^{-5}$	2.4×10^{-4}	$\leq 7.7 \times 10^{-6}$	2.2×10^{-5}	1.5×10^{-3}
	10-13.8	$\leq 2.2 \times 10^{-6}$	4.5×10^{-5}	$\leq 2.2 \times 10^{-6}$	4.5×10^{-5}	1.1×10^{-4}
S290/W60	0-5	$\leq 2.2 \times 10^{-5}$	1.0×10^{-3}	5.9×10^{-5}	$\leq 2.7 \times 10^{-5}$	1.6×10^{-3}
	5-10	$\leq 1.4 \times 10^{-5}$	5.4×10^{-4}	2.2×10^{-4}	$\leq 1.1 \times 10^{-4}$	6.3×10^{-3}
S293/W45	0-5	3.0×10^{-5}	4.3×10^{-4}	1.5×10^{-4}	$\leq 1.4 \times 10^{-4}$	7.7×10^{-3}
	5-8.5	3.9×10^{-5}	5.9×10^{-4}	$\leq 6.3 \times 10^{-3}$	$\leq 1.0 \times 10^{-3}$	4.5×10^{-2}
S296/W45	0-5	4.2×10^{-5}	4.0×10^{-4}	1.4×10^{-4}	$\leq 1.1 \times 10^{-4}$	5.9×10^{-3}
	5-8.5	3.2×10^{-5}	5.9×10^{-4}	$\leq 5.9 \times 10^{-4}$	$\leq 1.0 \times 10^{-3}$	5.9×10^{-2}
S299/W45	0-5	5.3×10^{-5}	6.3×10^{-4}	4.5×10^{-4}	$\leq 4.3 \times 10^{-4}$	3.0×10^{-2}
	5-8.8	2.2×10^{-5}	7.2×10^{-4}	$\leq 2.1 \times 10^{-4}$	$\leq 7.2 \times 10^{-4}$	4.3×10^{-2}

Table 7. (Cont'd) Concentration (μCi/g) of radionuclides in soils below burial ground 4

Location	Depth (in.)	Total α	^{90}Sr	^{60}Co	^{125}Sb	^{137}Cs
S300.6/W27.9	0-4	8.0×10^{-5}	7.7×10^{-4}	$\leq 6.8 \times 10^{-4}$	$\leq 6.8 \times 10^{-4}$	3.8×10^{-2}
	7-10	3.5×10^{-5}	3.3×10^{-4}	$\leq 1.9 \times 10^{-4}$	$\leq 4.1 \times 10^{-4}$	2.3×10^{-2}
	12-15	$\leq 6.8 \times 10^{-6}$	1.8×10^{-4}	$\leq 1.3 \times 10^{-5}$	$\leq 3.4 \times 10^{-5}$	1.6×10^{-3}
	16-19	$\leq 3.6 \times 10^{-6}$	1.5×10^{-4}	$\leq 4.1 \times 10^{-6}$	$\leq 9.9 \times 10^{-6}$	1.5×10^{-4}
	19-22	$\leq 6.8 \times 10^{-6}$	1.6×10^{-4}	$\leq 5.0 \times 10^{-6}$	$\leq 5.9 \times 10^{-6}$	4.5×10^{-4}
	24-27	$\leq 7.7 \times 10^{-6}$	1.5×10^{-4}	$\leq 1.3 \times 10^{-5}$	1.9×10^{-5}	1.2×10^{-3}
	29-31	$\leq 4.5 \times 10^{-6}$	8.6×10^{-5}	$\leq 1.9 \times 10^{-6}$	$\leq 4.0 \times 10^{-6}$	6.3×10^{-4}
S302/W45	0-5	3.6×10^{-5}	5.9×10^{-4}	3.9×10^{-4}	$\leq 5.9 \times 10^{-4}$	2.8×10^{-2}
	5-12	$\leq 9.9 \times 10^{-6}$	2.9×10^{-4}	$\leq 7.2 \times 10^{-6}$	3.3×10^{-5}	1.6×10^{-3}
S305/W45	0-5	3.2×10^{-5}	5.4×10^{-4}	$\leq 4.1 \times 10^{-4}$	$\leq 2.2 \times 10^{-4}$	1.4×10^{-2}
	5-11	2.3×10^{-5}	5.4×10^{-4}	5.9×10^{-4}	$\leq 3.8 \times 10^{-4}$	3.0×10^{-2}
S308/W45	0-5	2.6×10^{-5}	5.4×10^{-4}	4.4×10^{-4}	$\leq 1.7 \times 10^{-4}$	9.0×10^{-3}
	5-12	$\leq 2.3 \times 10^{-5}$	5.4×10^{-4}	$\leq 1.4 \times 10^{-4}$	$\leq 1.4 \times 10^{-4}$	1.1×10^{-2}
S311/W45	0-5	$\leq 1.6 \times 10^{-5}$	4.5×10^{-4}	1.3×10^{-3}	$\leq 6.3 \times 10^{-4}$	4.5×10^{-2}
	5-12.8	$\leq 3.2 \times 10^{-6}$	3.0×10^{-4}	1.2×10^{-5}	$\leq 9.9 \times 10^{-6}$	2.4×10^{-4}

contains small amounts of ^{60}Co, ^{137}Cs, and ^{90}Sr that have been sorbed from both surface and ground-water flow. The radionuclide analyses of two soil cores taken below burial ground 4 are given in Table 7. Prior analysis of one soil sample from S180/W200 indicated that ^{239}Pu levels in the soil of the drainage are near background (Duguid, 1975). This low concentration shows that little or no ^{239}Pu is being transported from basin 1.

The soil along White Oak Creek east of the burial ground has been contaminated by both the discharge of the creek and seepage from the burial ground. Much of the flood plain of White Oak Creek was once flooded by the intermediate pond (Fig. 5). The dam 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 1950's. The soils and sediments in this area are contaminated with ^{90}Sr, ^{137}Cs, and ^{239}Pu. Occasional samples also contain minor amounts of ^{60}Co and ^{125}Sb.

From previous studies it is believed that the origin of the ^{239}Pu was White Oak Creek rather than burial ground 4 (Duguid, 1975). Studies of plutonium contamination and uptake by vegetation in the intermediate pond are being conducted under the Transuranics Project in the Environmental Sciences Division. As yet, no soil concentrations have been found to exceed the 1.7×10^{-4} μCi/g reported by Duguid, 1975.

The data in Table 7 for radionuclide content of soils in the intermediate pond area reflect the original pond bottom at many locations. This feature is identified by a sudden increase in radionuclide concentration with depth. The soil samples from S300.6/W27.9 indicate that the

original pond bottom was from 19 to 22 in. below the flood plain surface. This location is near the dam where the sediment depth should be the greatest because of the existence of the residual pond. The 19 in. of sediment at this location are also substantiated by a visual character change in the sediment which was noted during sample collection. Farther upstream at S180/EO the sediment depth in the pond is from 15 to 18 in. (Table 7). Because of the increase in radionuclide content at the original pond bottom, more sediment analyses are required to obtain an accurate mass balance of radionuclides in sediment below burial ground 4.

BURIAL GROUND 5

Burial ground 5 is located in Melton Valley, along Melton Branch, east of the confluence of Melton Branch and White Oak Creek (Fig. 1). Both the surface and ground water flowing from the area discharge primarily into Melton Branch. Thus, most of the transport of radionuclides from the burial ground is monitored at station 4 on Melton Branch. Burial in this area was begun in 1958 and continued until the establishment of burial ground 6 in 1973.

Ground-water Contamination

Because of the direction of ground water flow from the burial ground, thirteen small seeps were sampled along the south edge of the area. The analyses of these samples are given in Table 8, and the sampling locations are shown in Fig. 7. The samples contain measurable amounts of total α, ^{90}Sr, ^{3}H, and ^{125}Sb. Other fission products either are not present or are present at concentrations below the level of detection for routine analyses. Eleven of the samples contain concentrations of ^{90}Sr that range

Table 8. Analyses of water samples from the south side of burial ground 5, in μCi/ml[a]

Location	Total α	^{90}Sr	^{3}H	^{125}Sb
S- 4	2.8×10^{-6}	1.4×10^{-2}	5.4×10^{-2}	1.1×10^{-5}
S- 5	$\leq 2.7 \times 10^{-7}$	1.6×10^{-4}	2.7×10^{-2}	9.0×10^{-8}
S- 6	$\leq 4.5 \times 10^{-8}$	3.6×10^{-6}	2.2×10^{-2}	$\leq 1.2 \times 10^{-8}$
S- 7	$\leq 1.8 \times 10^{-7}$	2.4×10^{-6}	7.7×10^{-1}	$\leq 7.7 \times 10^{-9}$
S- 8	$\leq 4.5 \times 10^{-8}$	$\leq 4.5 \times 10^{-8}$	1.9×10^{-3}	$\leq 1.0 \times 10^{-8}$
S- 9	3.6×10^{-7}	6.1×10^{-5}	2.1×10^{-1}	9.0×10^{-8}
S-10	$\leq 9.0 \times 10^{-8}$	1.6×10^{-5}	1.0×10^{-1}	3.3×10^{-8}
S-11	$\leq 2.2 \times 10^{-7}$	1.1×10^{-5}	1.7×10^{-1}	$\leq 3.0 \times 10^{-8}$
S-12	$\leq 1.4 \times 10^{-7}$	5.9×10^{-7}	2.0×10^{-2}	$\leq 1.3 \times 10^{-8}$
S-13	$\leq 4.5 \times 10^{-8}$	1.3×10^{-5}	2.2×10^{-2}	2.3×10^{-8}
S-14	$\leq 1.8 \times 10^{-8}$	9.0×10^{-8}	6.3×10^{-3}	$\leq 8.5 \times 10^{-9}$
S-15	2.7×10^{-7}	3.9×10^{-6}	4.3×10^{-1}	$\leq 1.4 \times 10^{-8}$
S-16	$\leq 4.5 \times 10^{-8}$	1.4×10^{-7}	9.0×10^{-2}	$\leq 8.1 \times 10^{-9}$

[a] Samples collected March 11, 1974.

ORNL DWG 74-9605

BASE TENNESSEE VALLEY AUTHORITY MAP OF THE OAK RIDGE AREA, 1959

129 ○ WELL
● SEEP

0 200 400 600 800
SCALE IN FEET

Fig. 7. Location of wells and seeps in burial ground 5.

from 9.0×10^{-8} to 6.1×10^{-5} μCi/ml, with an average concentration of 1.0×10^{-5} μCi/ml. The remaining two samples contain 1.4×10^{-2} and 1.6×10^{-4} μCi/ml of ^{90}Sr, with an average concentration of 7.1×10^{-3} μCi/ml. The average concentration of tritium in the samples is 0.2 μCi/ml.

Of the thirteen samples collected along the south side of burial ground 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. 7), 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 interaction with the soil.

The total alpha contamination in seep S-4 was shown to be primarily ^{244}Cm by E. A. Bondietti. His analyses show 3.2×10^{-7} μCi/ml of ^{244}Cm and 3.2×10^{-8} μCi/ml of ^{238}Pu in the seep water. Because of these concentrations of plutonium and strontium in the water and because during wet seasons the discharge reached Melton Branch, corrective measures were applied to trench 83. (See the following section on corrective measures for burial ground 5.)

Discharge of ^{90}Sr

Stream monitoring at station 4 on Melton Branch provides data on

radionuclide discharges to Melton Branch upstream from its confluence with White Oak Creek. Approximately 90% of the radioactivity measured at this station is attributed to burial ground 5, and the remaining 10% is from other sources in the drainage (personal communication with G. J. Dixon, ORNL). The ^{90}Sr discharge from burial ground 5 and other sources, for water years 1967 through 1975, are given in Table 9. The last column of this table shows the discharge of ^{90}Sr in millicuries per inch of precipitation. A graph of these data is shown in Fig. 8.

One interesting aspect of the data in Fig. 8 is that the best fit curve through the points is a horizontal line when the point for 1968 is neglected (accidental release). The burial ground discharge per inch of precipitation is constant, and from the existing data no trend toward increasing or decreasing discharge can be observed. This is in contrast to burial ground 4 which has gone through a period of increasing discharge (no monitoring data) and is now exhibiting decreased discharge with time (Fig. 6). This type of normal distribution curve would be expected from an instantaneous release from an area source.

Sampling data collected below burial ground 5 (Table 8) show that the discharge is from many point sources caused by trench overflow during wet weather. However, as time passes, the discharge is expected to become more uniform, the total discharge will increase, and stream-monitoring data will begin to show the rising limb of the distribution curve. The discharge will increase and then decrease in a manner similar to burial ground 4. However, some differences in the shape of the discharge curve

Table 9. Discharge of ^{90}Sr from burial ground 5 and precipitation data for water years 1967 through 1975

Water[a] year	Precipitation (in.)	Total ^{90}Sr Discharge (Ci)	Discharge of ^{90}Sr (mCi/in.)
1967	60.54	0.89	14.7
1968	45.01	2.84	63.1
1969	40.07	0.88	22.0
1970	47.93	0.93	19.4
1971	48.26	0.58	12.0
1972	47.40	0.81	17.1
1973	71.27	1.43	20.1
1974	68.76	1.39	20.2
1975	57.73	2.07	35.9

[a]Water year is September 1 through August 31.

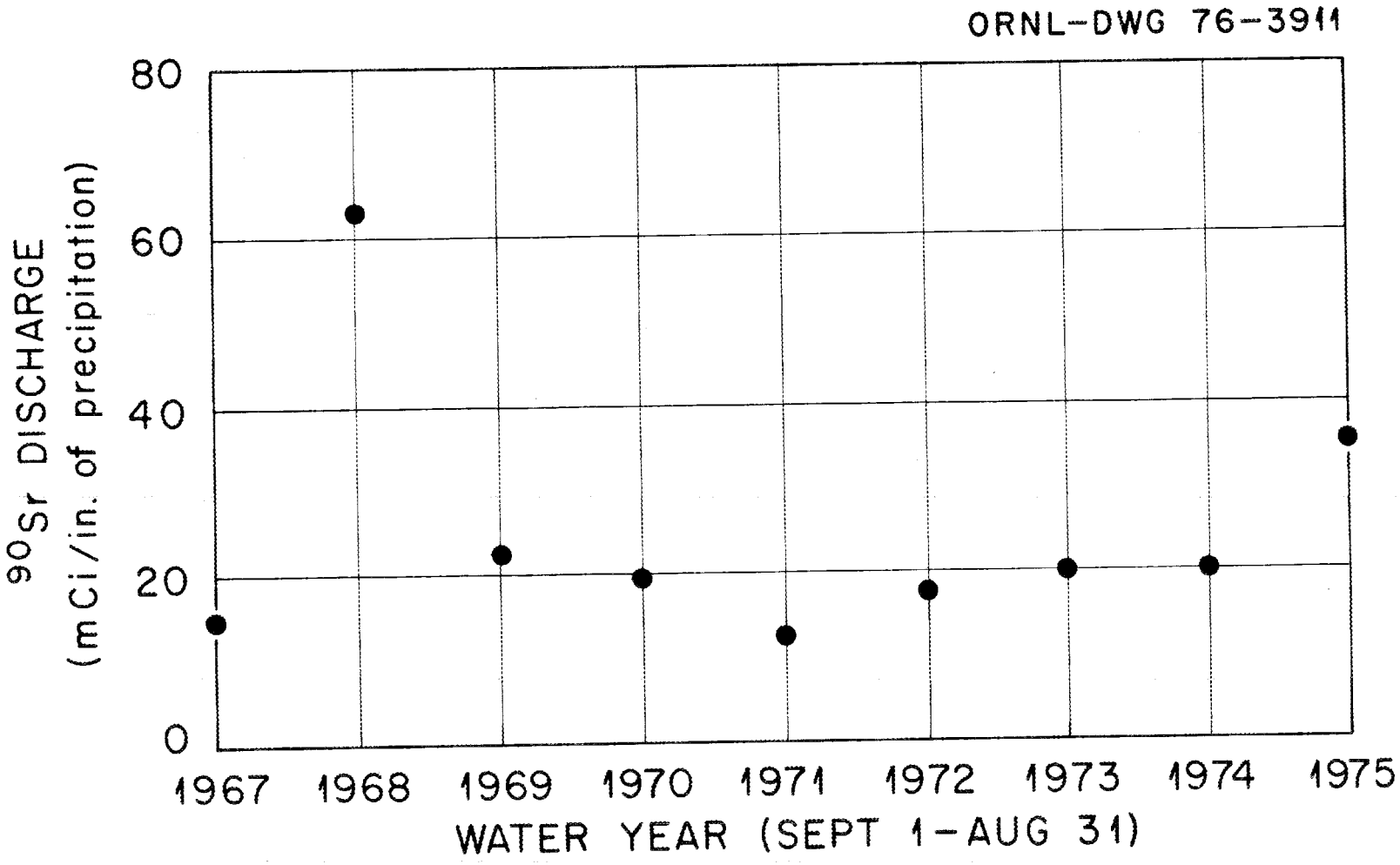

Fig. 8. Discharge of ^{90}Sr from burial ground 5 for water years 1967 through 1975, in millicuries per inch of precipitation (from stream-monitoring data).

should be expected since the ground-water conditions are different in the two burial grounds.

Soil Contamination

To further quantify the discharges of radionuclides from two seep areas in the burial ground, soil samples were collected and analyzed. The samples were collected from a seep area below trench 85 (Fig. 7), from within trench 83 during construction of corrective measures, and from a seep below trench 117 (located approximately 100 ft east of seep S-9, Fig. 7). Analyses of these samples are given in Table 10.

The total alpha radioactivity in the sample from near trench 117 is primarily ^{244}Cm, while the samples from near trench 83 contain primarily ^{238}Pu. (Very little ^{241}Am has been found in detailed analyses of water from trench 83.) All of the samples were found to contain ^{90}Sr. However, ^{137}Cs appears to be sorbed before leaving trench 83 at seep S-4. Two samples, one near S-4 and one near S-5, were taken between S-4 and the bank of Melton Branch, the latter sample taken at the point of confluence of the trench seepage with Melton Branch. These two samples were analyzed for plutonium by Dr. Tsuneo Tamura (Table 11). The sample from the bank of Melton Branch indicates that some of the plutonium-bearing effluent from trench 83 had reached Melton Branch. The plutonium in the water from seep S-4 is mobile in both surface and ground-water flow. In fact, when the effluent was passed through a cation-exchange column, very little of the alpha activity was removed from the water. As yet, the reason for this mobility of plutonium at this location has not been determined.

Table 10. Analyses of soil samples from burial ground 5 (μCi/g)

Location	Total α	^{90}Sr	^{137}Cs
Seep near trench 117	1.1×10^{-1} (mostly 5.8 MeV)	2.4×10^{-1}	9.0×10^{-2}
Bottom of trench 83	5.4×10^{-4} (83%, 5.5 MeV; 9%, 5.8 MeV)	1.4	9.0×10^{-1}
Near S-4	8.1×10^{-5}	1.5×10^{-1}	---
Near S-5	3.7×10^{-5}	1.3×10^{-2}	---

Table 11. Plutonium analyses of two soil samples collected below trench 83 of burial ground 5 (μCi/g)

Location	^{238}Pu	^{239}Pu	Total	Average[a]
Near S-4	7.8×10^{-6}	9.0×10^{-7}	8.6×10^{-6}	$9.6 \times 10^{-6} \pm 1.4 \times 10^{-6}$
	9.2×10^{-6}	1.3×10^{-6}	1.1×10^{-5}	
Near S-5	8.3×10^{-6}	1.4×10^{-6}	9.7×10^{-6}	$8.2 \times 10^{-6} \pm 2.3 \times 10^{-6}$
	6.0×10^{-6}	6.3×10^{-7}	6.6×10^{-6}	

[a] The ± quantities represent the standard deviation of analysis.

CORRECTIVE MEASURES

The transport of radionuclides from buried waste is largely a function of the amount of infiltration of precipitation, the amount of leaching of the waste by water, and the amount of leachate leaving the waste trench either as surface seepage or as ground-water flow. Therefore, many of the corrective measures discussed in the following sections are aimed at reducing the amount of water that comes into contact with the buried waste.

Burial Ground 4

Both surface runoff and ground water from the drainage basin above burial ground 4 flow southward across the burial ground (Fig. 4). Previously the suggestion had been made to construct a ground-water diversion trench along the north side of the burial ground. The proposed trench was to be approximately 20 ft deep and was to be filled with crushed rock to facilitate flow toward the low portions of the trench. The collected water was to be routed across the burial ground by means of pipe drains (Duguid, 1975). An engineering estimate placed the cost of the ground-water diversion system at approximately $500,000. In view of this cost and because of limited ground-water flow data in the area, alternative means of reducing the ^{90}Sr discharge from the burial ground were considered. A surface runoff collector and diversion system was proposed, designed, and constructed.

The surface runoff collector consists of a shallow, asphalt-lined ditch along the north side of Lagoon Road above burial ground 4 (Fig. 9). The surface runoff is diverted across the burial ground by means of three asphalt-lined conductor ditches and one unlined natural drainage at the northeast edge of the burial ground (Fig. 9).

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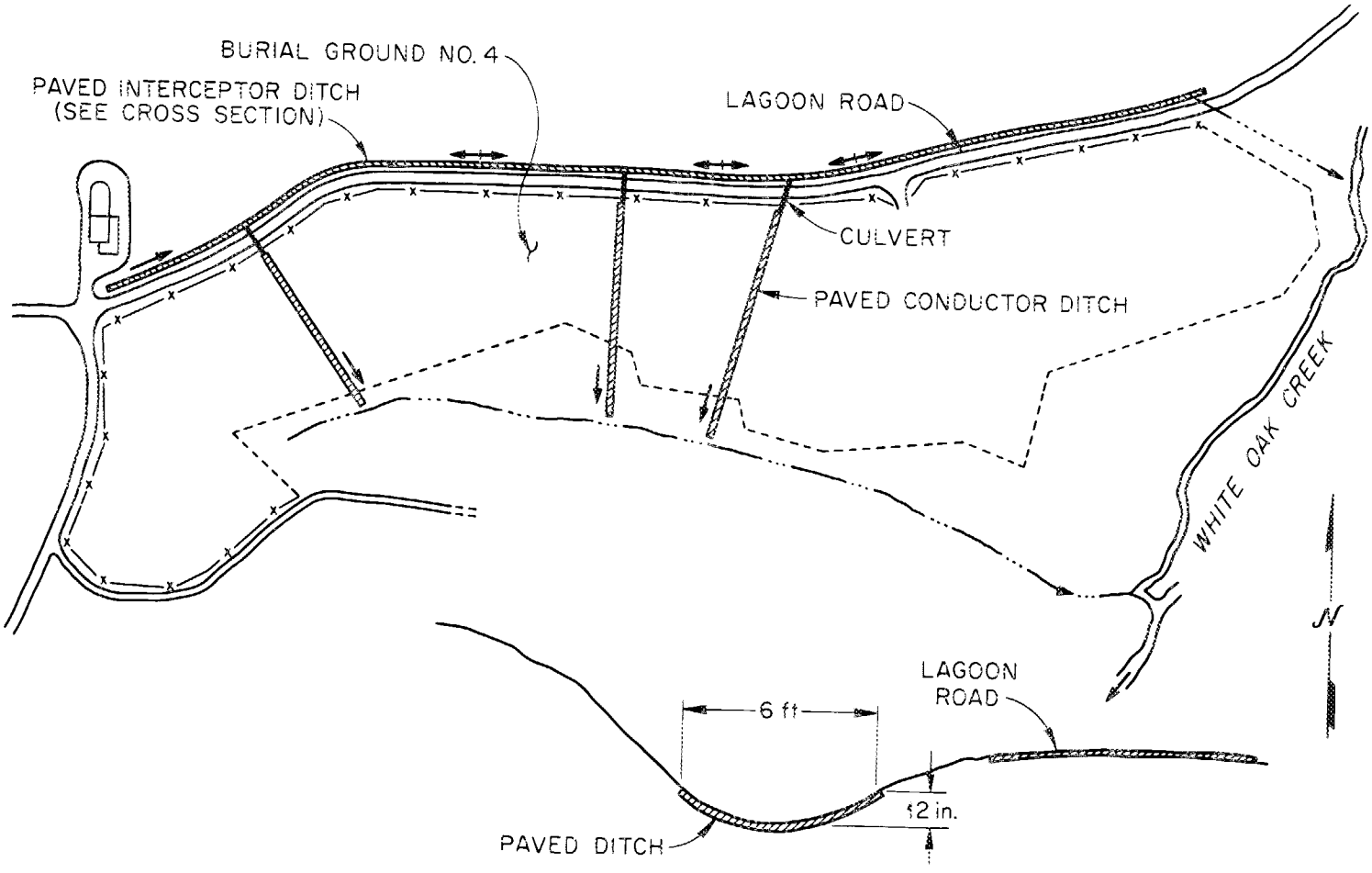

Fig. 9. Surface runoff diversion system for burial ground 4.

Before the construction of this system, surface runoff from the basin above the burial ground flowed onto the burial ground surface and infiltrated into the buried waste. Since the completion of the diversion system in September 1975, it has been observed to carry large amounts of water during heavy rains and small amounts of water for several days after a period of heavy rain. As yet, there are no monitoring data that show the effect of the diversion system on the discharge of ^{90}Sr from the burial ground.

Burial Ground 5

Because of the concentration of radionuclides (^{238}Pu, ^{244}Cm, and ^{90}Sr) in the seepage effluent from trench 83 at seep S-4 (Fig. 7), actions were taken to eliminate this discharge. The seepage usually occurred in a period from January to April after the winter rains had infiltrated the trench and caused it to overflow. Corrective measures were proposed in July 1974 that would eliminate the downward movement of water into the trench.

The original proposal called for a bentonite-shale seal over trenches 105 and 83 at a depth of 2 ft (Fig. 10) and for at least two vertical dams across the trenches. However, when it became apparent that the design of an adequate bentonite-shale mixture for surface sealing would not be completed in the very near future, the decision to use polyvinyl chloride (PVC) was made. The PVC sheet selected for this construction is 0.01 in. thick and has an estimated life of 25 years. Also because of the ease in installation, the plastic membrane was extended from trenches 105 and 83 to cover trenches 72 and 69 as well (Fig. 10).

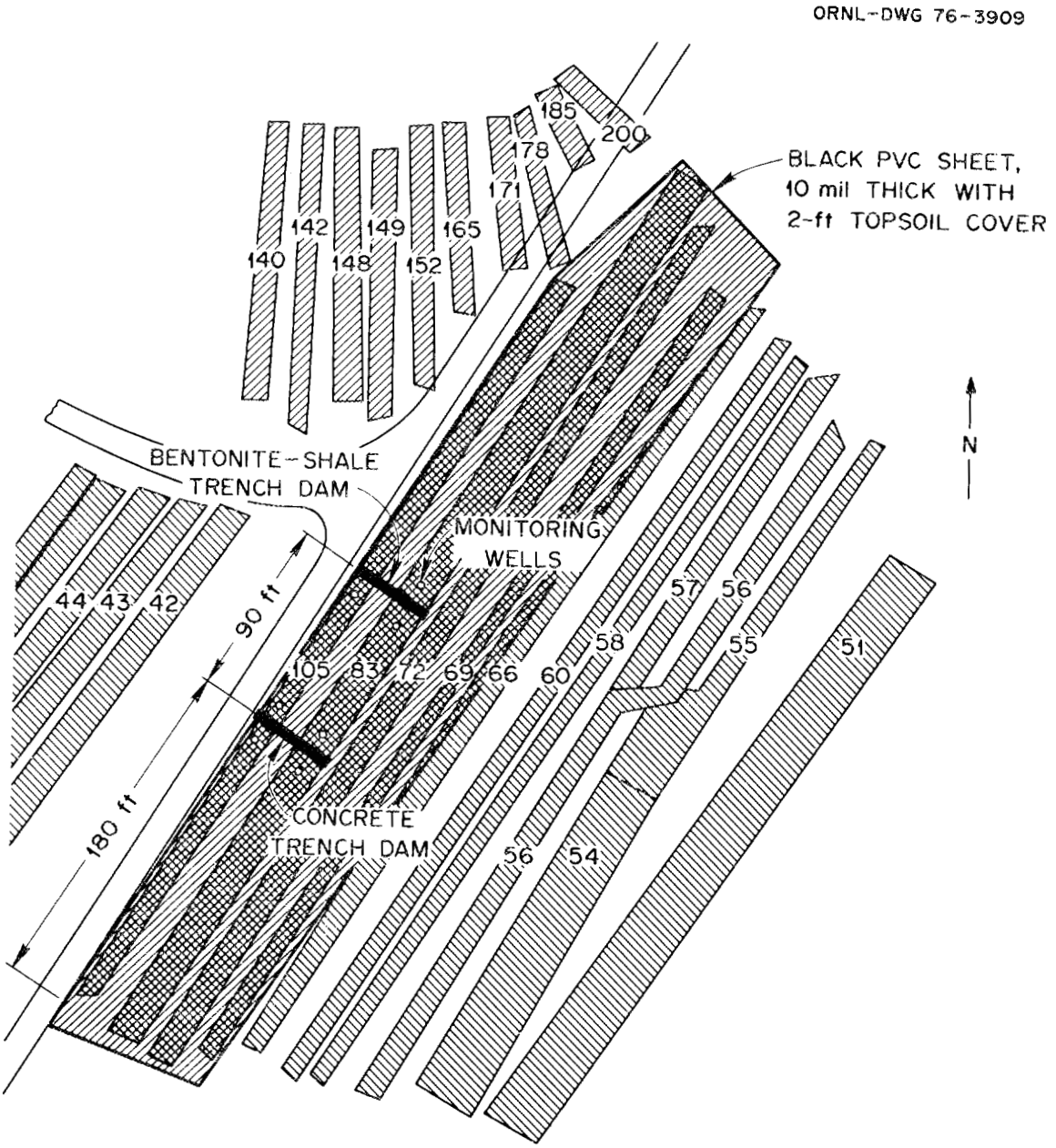

Fig. 10. Near-surface sealing of trenches in burial ground 5.

The construction began in May 1975 when 2 ft of overburden were stripped from the area. Subsequently, the trench for the lower dam was excavated. Approximately 3 ft of water was present in the excavation. The amount of water added to the problem of obtaining an effective seal under the dam. To ensure a good seal, a precast concrete slab was used with a 25% bentonite-shale mixture (Fig. 11). Thus, as water seeps around the concrete, it will carry bentonite which will eventually form a seal around the concrete slab. Also, a thin layer of bentonite was placed directly under the slab. The construction of the second day was much simpler because water was not present in the excavation and the dam could be constructed of compacted bentonite and shale (Fig. 11).

After the two dams were completed, the area was covered with the PVC membrane, and the overburden (approximately 2 ft) was placed over the area. The area was then planted in grass to prevent erosion. The sealing was completed in September 1975, and monitoring wells will be installed as shown in Fig. 10. Monitoring wells will also be installed in the lower ends of trenches 83, 105, 72, 69, and 60. Data from these wells will be used to determine the effect of the different sealing methods, no seal, near-surface seal only, and near-surface seal and trench dams.

Current Burial Operations

The corrective measures for burial ground 6 are composed of suggested modifications of current burial practices. The suggestions were made during the author's annual review of burial ground operations in September 1975 and are as follows:

1. Volume reduction. Over the next 20 to 25 years the current burial ground (solid waste disposal area 6) will be filled, and some thought should be given to waste management practices that will extend

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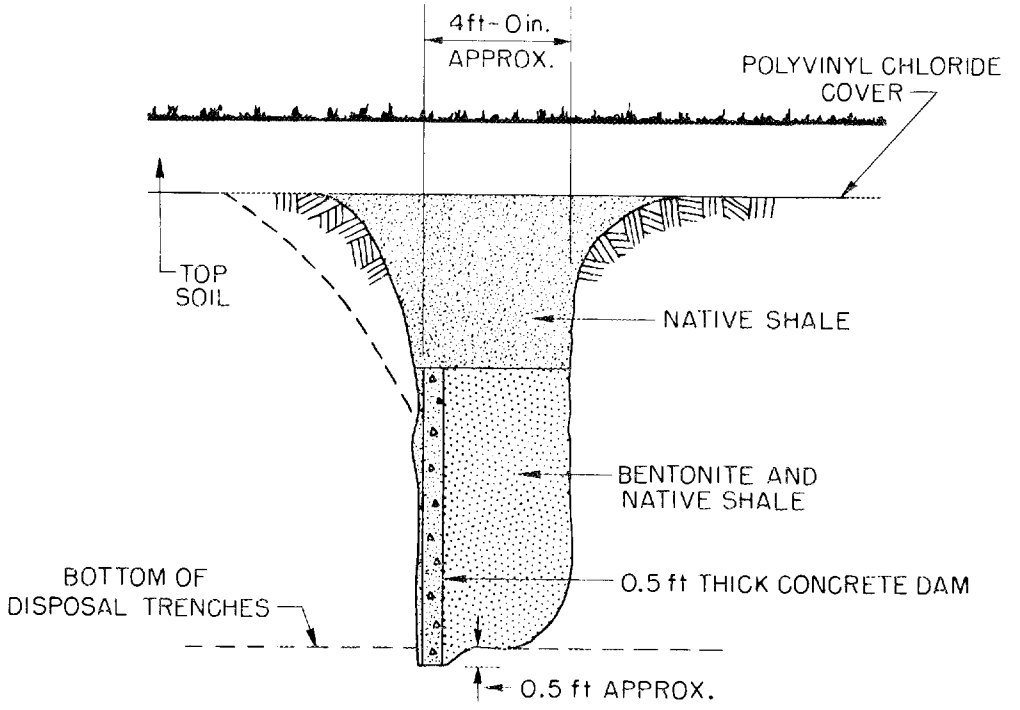
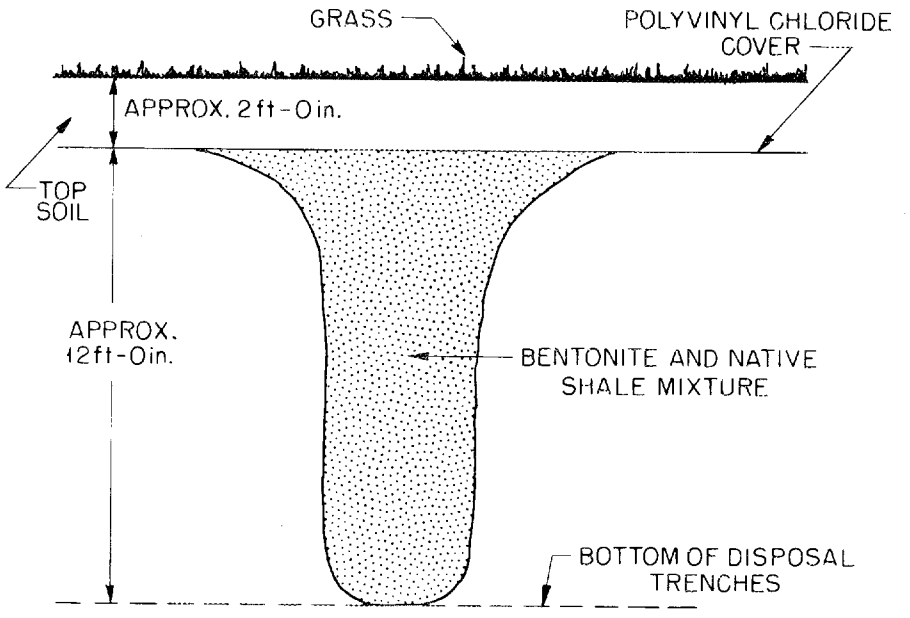


CONCRETE TRENCH DAM VIEW LOOKING WEST



BENTONITE-SHALE TRENCH DAM VIEW LOOKING WEST

Fig. 11. Cross sections of the concrete and bentonite-shale dams across trenches 105 and 83.

its projected life. One method of extending the life of the burial facility is to reduce the volume of waste. This can be effectively carried out by a program of sorting, selective burning, and compaction of the waste. Together these practices would reduce the volume of waste by more than 50%.

One advantage of volume reduction is that the amount of leaching from the buried waste is reduced. This decrease in leaching is explained as follows: For a given decreased volume, the ratio of land surface area to amount of radionuclides is reduced; in turn the volume of precipitation passing through the waste is reduced; the transport of radionuclides from the waste (which has been shown to be a function of precipitation) should decrease because the surface area underlain by the buried waste has been reduced. However, there are larger quantities of radionuclides buried in fewer trenches that have less void space. If the trenches are allowed to develop perched ground water, water levels in the trenches will be higher than if no compaction had been performed. This would lead to more waste undergoing saturated leaching and ultimately more radionuclide transport from the trenches. Thus, the volume reduction should be considered in conjunction with near-surface sealing of the burial area.

Another advantage of volume reduction is that the waste density in a given trench is increased and there will be less surface subsidence than now occurs under natural consolidation of the waste (i.e., the burial ground would require less surface maintenance).

While the methods suggested here may not prove to be the best approach to extending the burial ground life and reducing radionuclide discharges to the ground water, they indicate an area that should be investigated in order to establish better waste management practices.

2. Wells. Wells within the burial grounds (for monitoring waste trenches, measuring ground-water levels, or monitoring radionuclide discharges to the ground water) have in the past been destroyed by burial ground operations, such as periodic mowing and surface maintenance. To avoid this accidental attrition of the well system, wells should be terminated about 1 in. above the ground level, surrounded by a concrete apron that extends from a few inches below the ground level to the top of the casing, and covered by a removable cap. The apron should be about 1 ft wide around the well and should contain a metal plate suitable for stamping the well number.

3. Spoil removal. The uncontaminated shale that remains (from trench excavation) after burial should be removed from the burial ground surface. In the past this material has been spread evenly over the burial ground surface, which caused an increase in the water table elevation by increased infiltration into the fill as compared to the original surface material and by the increased land surface elevation itself.

4. Sealing of trenches. Areas that have been filled with waste in burial ground 6 should be sealed to reduce the infiltration of precipitation. The seal should be a bentonite-shale misture, approximately 3 in. thick, placed at a depth of 2 ft, and should extend over the entire burial area. The impermeable membrane formed by the bentonite-shale mixture will reduce the downward percolation of precipitation, while the 2 ft of overburden will allow vegetation growth, which will reduce erosion. The percentage of bentonite used should be the same as that recommended for sealing previous burial ground areas. As yet, the recommended percentage has not

been determined, but will be made available as soon as testing of bentonite-shale mistures has been completed. After the utilized areas in burial ground 6 have been sealed, newly utilized areas should be sealed at least on an annual basis.

5. Surface maintenance. The surface depressions on burial ground 4, formed from natural compaction of the waste, will not be utilized in the burial ground studies. Therefore, these depressions can be filled in, using a program of surface maintenance similar to that carried out on burial ground 5.

These suggested changes in operations are intended to complement rather than replace the recommendations made by D. A. Webster of the U. S. Geological Survey.

Design of the Bentonite-Shale Mixture

The bentonite Conasauga shale mixture, which will be used for near-surface sealing of burial grounds, must contain enough bentonite to fill the voids in the compacted shale under saturated conditions. Thus, as water enters the compacted shale, the bentonite will swell, filling the voids and reducing the permeability. As the material dries out, shrinkage of the shale matrix will not occur because the original swelling will not change the matrix configuration.

To begin the disign, compaction curves similar to those shown in Fig. 12 will be generated for various percentages of bentonite. From the curves the bentonite and water contents for maximum density can be selected. This mixture can then be compacted into a mold for permeability tests. Subsequent swell tests will be used to determine if the selected percentage of bentonite causes undue swelling of the compacted material.

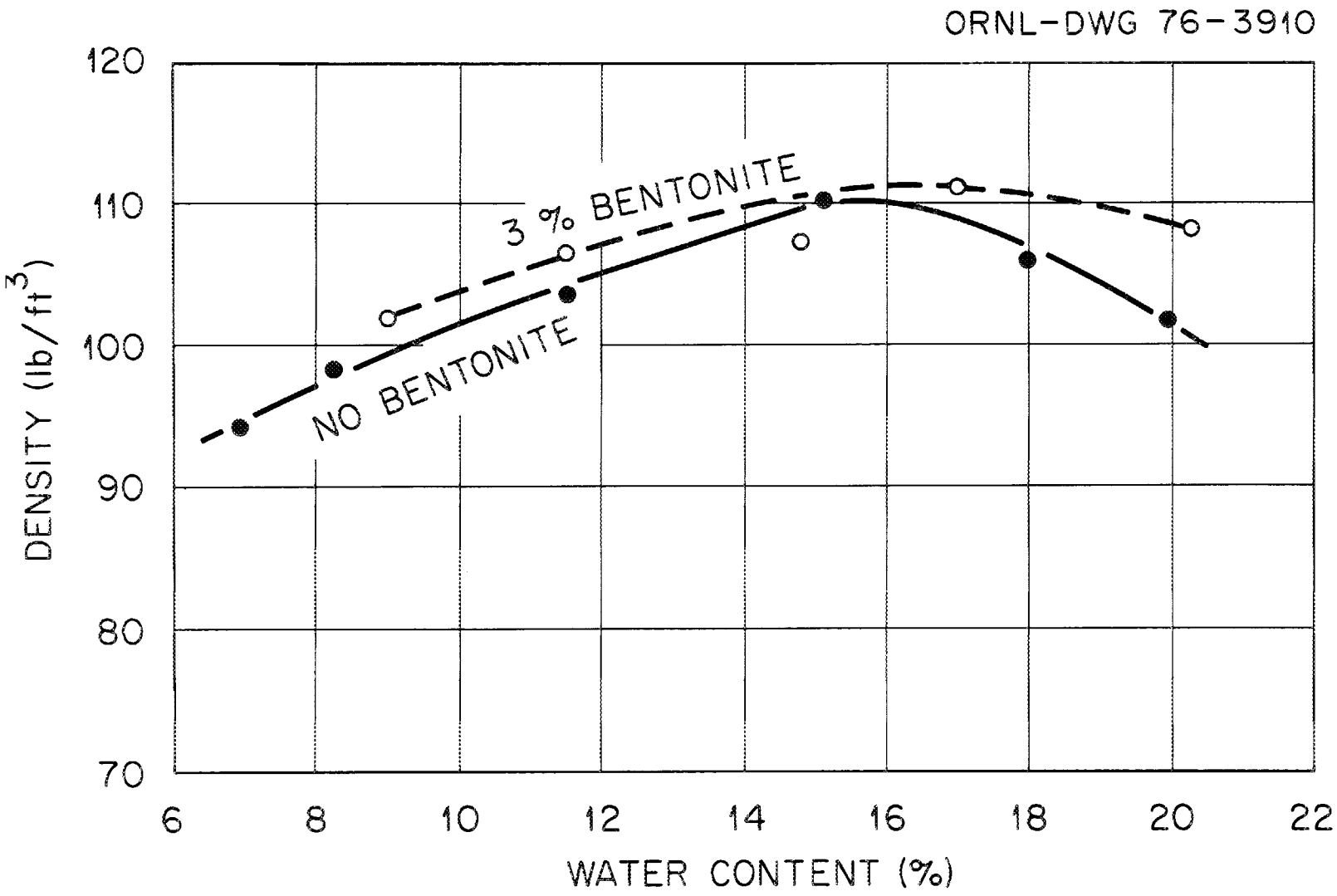


Fig. 12. Compaction curves for bentonite-shale mixture.

The curves shown in Fig. 12 were generated using a standard Proctor Test as described by Lambe, 1960. Following this procedure, curves will be generated up to approximately 10% bentonite.

Initially it was assumed that permeabilities would be tested using a constant water head of 2 ft. However, the time required for this test was long, and pressures of 100 psi were then used to speed up data acquisition. These tests were conducted using compacted samples in standard 1.5-in.-diam steel pipe. From preliminary testing it is believed that the steel pipe is too elastic, and because of this an effective seal between the compacted material and the pipe is not achieved. This problem can be overcome in future testing by using a thick-walled cyclinder in place of the steel pipe.

As yet, most of the work expended on design of the bentonite-shale mixture has produced very little data. However, from this work experimental procedures have been established and the equipment necessary for final design has been selected. The original procedures for measuring permeability (steel pipe mold) were used to test the permeability of two samples which contained 5% bentonite; the first sample, compacted to a density of 95 lb/cu ft with no moisture, had a permeability of 1.9×10^{-3} cm/day; and the second sample, compacted to a density of 116 lb/cu ft with 6% moisture, had a permeability of 7.4×10^{-4} cm/day. From the data obtained thus far, it is estimated that the final design will contain approximately 10% bentonite.

Chemical Methods

In conjunction with the drainage improvements for burial ground 4, research was also conducted to test the ion-exchange capacity of several

materials with the intention of constructing an ion-exchange trench in the drainage south of burial ground 4. The materials tested were limestone, phosphate, activated alumina, activated carbon, and bone charcoal. Of these materials, activated alumina and bone charcoal produced the best ^{85}Sr removal data in 24-hr batch tests. These materials were then tested in column tests using ^{85}Sr in water that contained 50 ppm clacium. For the activated alumina, approximately 37 column volumes had passed through the column before breakthrough of strontium occurred. Even fewer column volumes were required to cause breakthrough of the strontium in the bone charcoal column. Because of the short life expectancy of the inexpensive ion-exchange mediums and because of the cost and anticipated short life of more sophisticated exchange mediums, the research was discontinued.

GROUND-WATER TRANSPORT MODELS

Computer modeling is an essential part of the burial ground studies. The models developed thus far can be used in evaluation of radionuclide transport from proposed burial sites, evaluation of accidental release at power reactor sites, and approximate evaluation of proposed methods for decreasing the radionuclide transport from buried waste. These models are limited in their application because they can only be applied to two-dimensional problems. However, their use and development have provided the necessary insight for development of quasi-three-dimensional models.

Two computer codes have been written in collaboration with Mark Reeves, Computer Sciences Division. The first program provides numerical solution to the nonlinear equation describing 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 equations.

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, 1976). 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 two models have been used for calculation of radionuclide transport from a hypothetical seepage pond (Duguid and Reeves, 1976) and from a seepage trench (Reeves and Duguid, in press). These two hypothetical cases have been studied to provide the necessary understanding for simulation of ^{60}Co transport from ILW-trench 7* (for a validation of the two

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*Work supported by the Division of Biomedical and Environmental Research, Energy Research and Development Administration.

codes). After validation the models will then be used to simulate future transport of ^{90}Sr from the trench.

To obtain the necessary coefficients for the simulation of ^{60}Co transport from trench 7, field studies have begun. These studies consist of measurement of the relationship between moisture content and pressure, the effective porosity, the dispersivities, and the hydraulic conductivity. These coefficients will also be applicable to other localities in the Conasauga shale and should aid in the burial ground studies.

CONCLUSIONS

The ^{60}Co-organic complexes in ground water near trench 7 were separated according to molecular weight (MW), and the amount of ^{60}Co was determined. The data indicate that approximately 82 to 88% of the ^{60}Co is associated with the less than 700-MW fraction, while the remainder of the ^{60}Co may be carried with the greater than 700-MW fraction. However, the ^{60}Co in the larger organics may represent overlap of the lighter MW organics. These data indicate that complexation of ^{60}Co may occur with low molecular weight natural organic acids such as fulvic or gallic acids. However, chelation of ^{60}Co with EDTA (MW = 292) cannot be dismissed.

Calculation of ^{90}Sr discharge from burial ground 4 using ground-water monitoring data for water years 1973, 1974, and 1975 yields 1.7, 1.6, and 1.2 curies, respectively. These calculated discharges do not agree with the amount attributed to burial ground 4 from stream-monitoring data--1.58, 5.22, and 3.22 curies for the years 1973, 1974, and 1975, respectively. The difference between the ^{90}Sr discharges (calculated versus

stream monitoring) for water years 1974 and 1975 can be attributed to either a new source of ^{90}Sr between X-10 and monitoring station 3 or a malfunction in monitoring station 3. The higher discharges were not reflected in the amount of ^{90}Sr discharged over White Oak Dam (monitoring Station 5) during water years 1974 and 1975. This fact would tend to support the attribution of the difference to a malfunction of monitoring station 3.

Analyses of soil samples from the flood plain of White Oak Creek below burial ground 4 (the intermediate pond area) showed evidence of a buried contaminated soil profile. The increased contamination with soil depth is believed to reflect the original bottom of the intermediate pond. Because of this increase in radioactivity at depth, more soil analyses are required to obtain an accurate mass balance of ^{90}Sr in the flood plain below burial ground 4.

Water samples collected below burial ground 5 show the alpha radioactivity is transported by ground water from buried waste. Further analyses show that ^{244}Cm and ^{238}Pu are the primary components of the alpha activity in one seep area. Analyses of soil samples collected between this seep and Melton Branch indicate that a small amount of ^{238}Pu has reached the stream. Because of the movement of transuranics and ^{90}Sr from this seep, corrective measures have been implemented. These corrective measures consist of installation of a near-surface plastic membrane over trenches 105, 83, 72, and 69, an area approximately 550 by 80 ft. Also, two vertical dams have been placed across trenches 105 and 83 to restrict the downslope movement of water in the trenches. This work was completed in September, and no monitoring results on its effectiveness are available.

A practice of reviewing current burial practices on an annual basis was begun in September 1975. Suggestions made in this review were to consider methods of volume reduction of the waste, terminate wells at the ground surface with a cap, remove spoils from trench excavation from the burial ground surface, place a near-surface seal over trenches, and begin surface maintenance on burial ground 4.

Work was initiated on the design of a bentonite-shale mixture of near-surface sealing of burial grounds. A procedure for design has been established, and work thus far indicates that an adequate seal can be made using approximately 10% bentonite.

Two computer codes have been completed for simulation of unsaturated-saturated water movement and radionuclide transport in porous media. They can be used for evaluation of potential burial sites, accidental releases, and approximate evaluation of proposed methods for decreasing radionuclide transport from buried waste. The models are limited in application because they are two-dimensional. However, their use and development have provided the necessary understanding for development of quasi-three-dimensional models.

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