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Characterization of the Near-Surface Radionuclide Contamination Associated with the Bathtub Effect at Solid Waste Storage Area 4, Oak Ridge National Laboratory, Tennessee

L. A. Melroy
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N. D. Farrow

Environmental Sciences Division
Publication No. 2716

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ENVIRONMENTAL SCIENCES DIVISION

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L. A. Melroy, D. D. Huff, and N. D. Farrow

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ABSTRACT

MELROY, L. A., D. D. HUFF, and N. D. FARROW. 1986. Characterization of the near-surface radionuclide contamination associated with the bathtub effect at Solid Waste Storage Area 4, Oak Ridge National Laboratory, Tennessee. ORNL/TM-10043. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 56 pp.

Solid Waste Storage Area 4 (SWSA-4) at the Oak Ridge National Laboratory (ORNL) was studied to determine the extent of near-surface radionuclide contamination associated with the bathtub effect in low-lying trenches. A surface survey of the low-elevation portion of the burial ground was conducted to identify areas where the bathtub effect had resulted in surface contamination. Using this initial survey as a guide, 15 soil cores, each approximately 3 m deep, were taken to determine the depth to which contamination had spread and to help identify any contamination plumes.

Results showed that two areas of surface radionuclide contamination exist, one located between the western end of the SWSA-4 tributary and the edge of the burial ground, the other located just north of the tributary below the central paved runoff channel. In addition, some downward migration of the solutes has occurred. However, the penetration depth for ^{90}Sr seems to be generally less than 2.7 m.

INTRODUCTION

Radionuclide contamination from low-level waste disposal sites is a major technological concern of the nuclear industry. With any buried waste, the possibility of contact and subsequent contamination exists between the waste and either groundwater or infiltrating surface water. If the wastes are buried in areas where the zone of saturation is close to the ground surface, such as in the humid southeastern United States, continuous contact may exist between the buried waste and the groundwater. Even in cases where the saturated zone is deeper, occasional contact may occur as the water table fluctuates seasonally. Surface water may also be a potential source of problems. During storm events, precipitation and surface runoff may collect in surface depressions and infiltrate directly into the trenches containing the buried wastes, or perched water table zones may contribute via lateral inflow. If the percolation rate for water leaving a trench is slower than the inflow rate, water will accumulate in the trench and may eventually overflow. Not considering the overflow, the water collected in the trench can result in migration of the wastes. This general pattern of trench inundation is referred to as the bathtub effect.

The purpose of the study presented here was to evaluate a shallow, low-level waste disposal site, Solid Waste Storage Area 4 (SWSA-4) located at the Oak Ridge National Laboratory (ORNL), to determine the vertical and lateral distribution of radionuclide contamination that has apparently resulted from the bathtub effect. Earlier work identified SWSA-4 as a significant source of ^{90}Sr contamination to

White Oak Creek (Steuber et al. 1981), and a recent surface water diversion has successfully reduced ^{90}Sr releases by almost 50% (Melroy and Huff 1985). Examination of remaining surface contamination patterns and soil cores taken within the suspected area of contamination are intended to serve as an information base for subsequent remedial actions to control radionuclide migration associated with the bathtub effect.

SITE HISTORY

SWSA-4 comprises an area of approximately 10 ha (25 acres) and is located along a small tributary to the west of White Oak Creek (Fig. 1).

The ORNL area is principally drained by White Oak Creek and its tributaries. In the spring of 1944, several years before the opening of SWSA-4, a small earth-fill impoundment was constructed on White Oak Creek, just south of the tributary draining SWSA-4, to act as a secondary settling basin for radionuclide-contaminated sediments. The impoundment failed during the 1944-1945 winter, but an "intermediate pond" remained until after 1951 (TVA 1951). Contaminated sediments (Fig. 1) have been found containing ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. Concentrations of 8 to 3000 pCi/g of ^{90}Sr, 4.5 to 72,000 pCi g of ^{137}Cs, and up to 168 pCi/g of $^{239,240}Pu$ were reported (Duguid 1976). Because the tributary draining SWSA-4 discharges over this area, these deposits present a potential source for contaminant migration. Because these deposits are downgradient of the disposal area, action at the site has been deferred while SWSA-4 is being stabilized.

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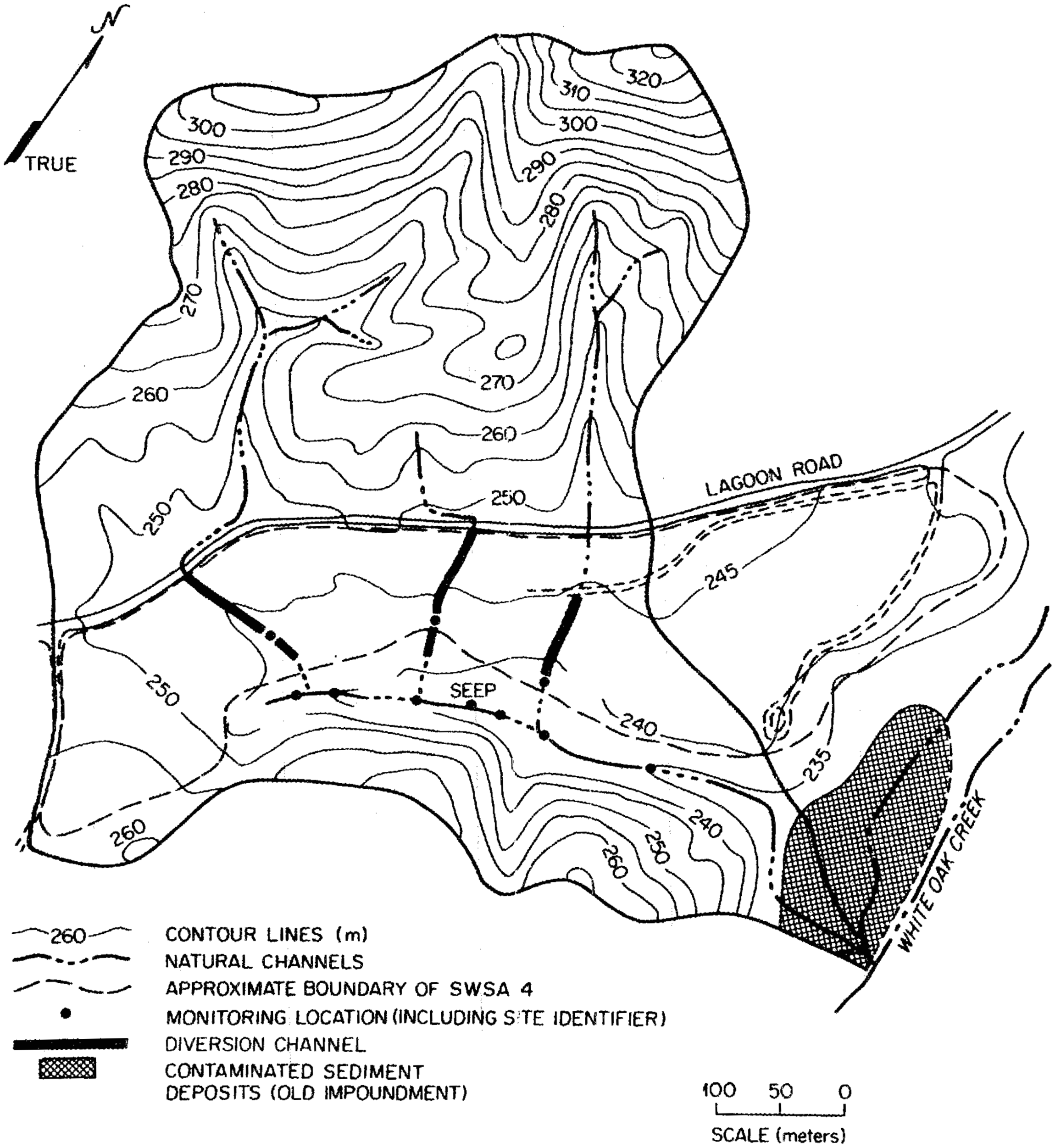

Fig. 1. Surface topography and major features of SWSA-4 before 1983.

SWSA-4 was opened in 1951 and used as a low-level radioactive waste disposal site for wastes generated both on- and off-site. Trenches and auger holes to depths of 5 to 6 m were used for disposal of the wastes. Alpha-emitting wastes were capped with concrete, and the beta- and gamma-emitting wastes were covered with a natural soil cover (Lomenick and Cowser 1961). Before closure of the burial ground in 1959, uncontaminated fill and construction debris were placed over the burial ground as cover material, resulting in an increase in land surface elevation of up to 6 m in the eastern portion. Figure 2 presents the approximate surface topography in 1943 before the construction of the burial ground. The most significant elevation increases were noted at the eastern end of the burial ground.

Cowser et al. (1961) reported that groundwater was coming in contact with the radioactive wastes, and that radionuclides were detectable in adjacent wells and streams. In 1976, Webster reported evidence that some of the trenches had been inundated by groundwater during high water-table elevations in the winter.

Originally, the runoff from the areas north of Lagoon Road (Fig. 1) drained over SWSA-4 through three natural channels, that then entered the small tributary to White Oak Creek. In the fall of 1975, in an effort to reduce ^{90}Sr migration from SWSA-4, recommendations were made to pave the three natural channels and to construct a paved interceptor ditch along the northern side of Lagoon Road. The intent of the interceptor ditch was to collect the surface runoff before it ran over the burial ground and to reduce the possibilities of contamination. A bentonite seal over the burial ground was also

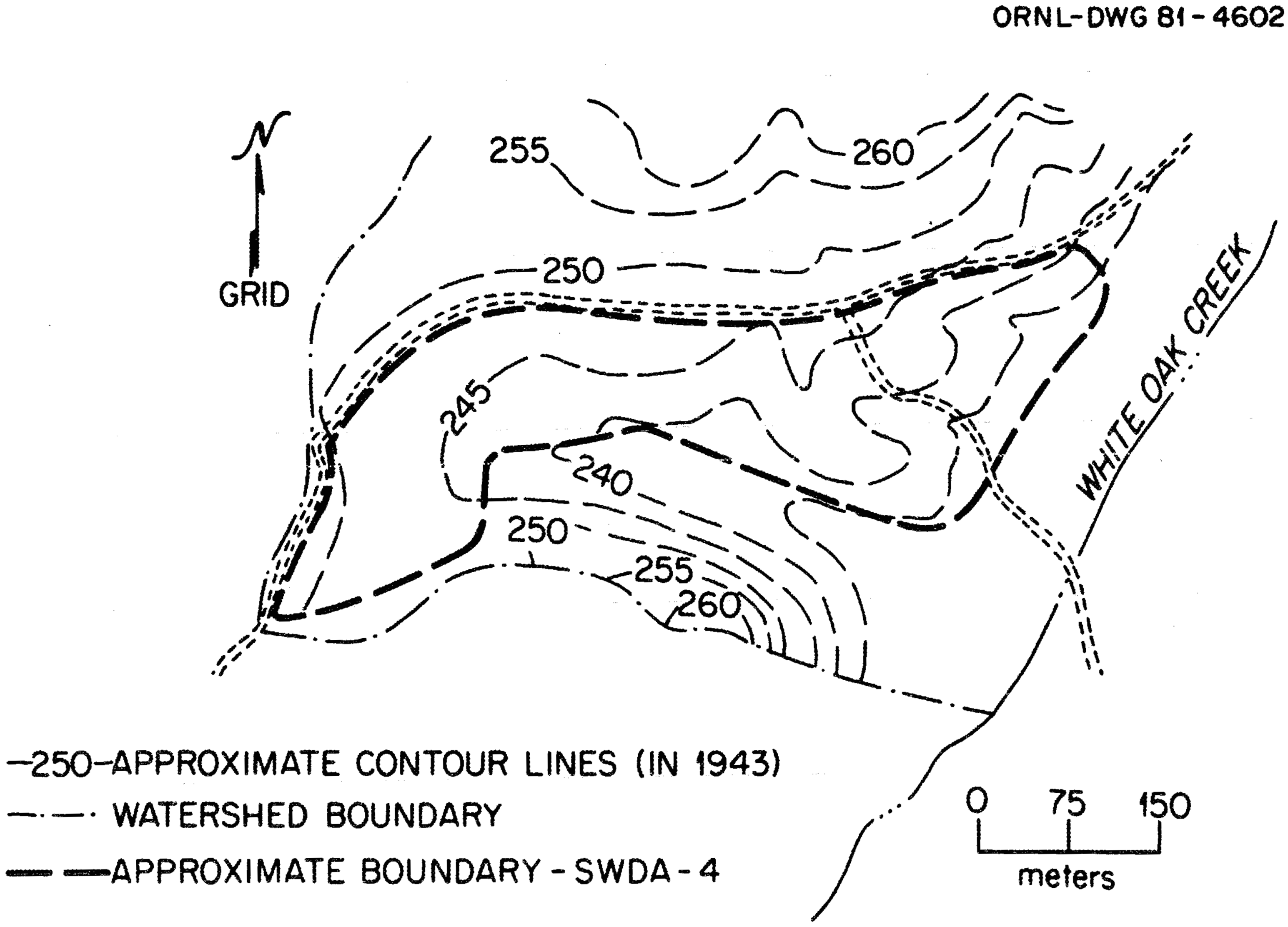

Fig. 2. Approximate topography of the SWSA-4 area before construction of the burial ground.

suggested to reduce infiltration. The three natural channels were paved in 1975 but the remaining recommendations were not acted upon partly because of budget limitations. In 1980, a study was conducted to determine the impact of the channel paving on the migration of ^{90}Sr (Tamura et al. 1980). It was discovered that no significant impact had occurred. Steuber et al. (1981) also reported that SWSA-4 was the major nonpoint source of ^{90}Sr contamination to White Oak Creek, and indicated that remedial action was necessary.

In 1982, Huff et al. evaluated SWSA-4 to determine the hydrologic factors and transport mechanisms governing ^{90}Sr migration. They found a strong relationship between surface runoff and ^{90}Sr transport, and concluded that a surface water diversion system would be an effective remedial measure for SWSA-4. The diversion system (Fig. 3) was constructed in 1983 and consisted of a paved interceptor channel that collects the runoff from north of Lagoon Road, four catch basins that collect the runoff from the inteceptor channel and upslope areas, and two storm drains that divert the runoff around the burial ground. The diversion system was evaluated (Melroy and Huff 1985) and was found to be responsible for a flow reduction of 66% in the tributary, and a ^{90}Sr flux reduction of 47%, during 1984.

METHODOLOGY

The 30-m Grid System

In 1975, Duguid established a 30-m grid on the flood plain along the southern edge of SWSA-4 (Duguid 1976). This grid, which extended

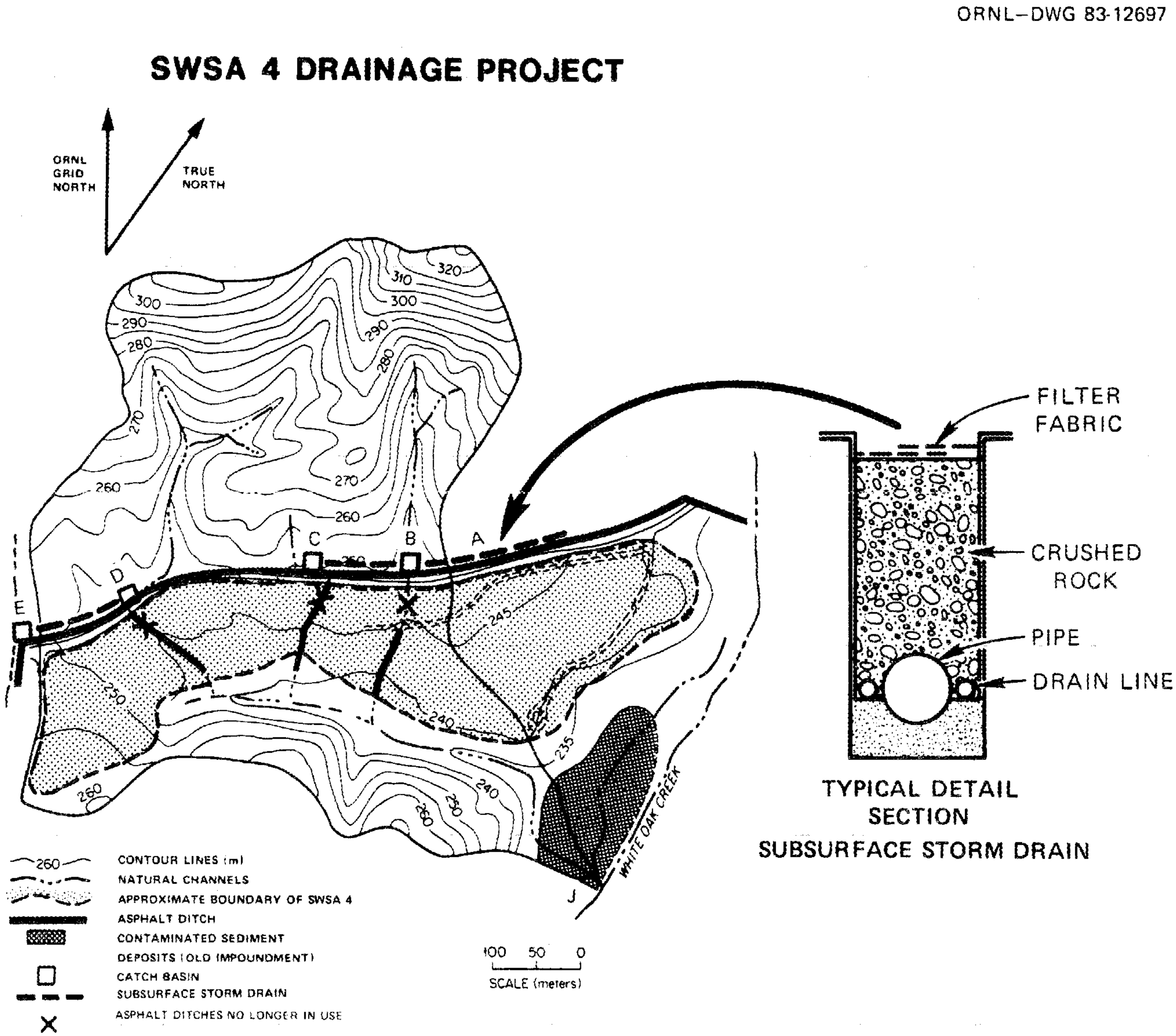

Fig. 3. Features of the SWSA-4 surface water diversion system.

over the suspected area of contamination along the small tributary south of SWSA-4, was used in this study. The grid was surveyed in December 1982 using an engineering transit and standard traverse calculations from a previously established reference point, and semipermanent markers were installed at all of the 27 new sites (Fig. 4). A second survey was completed to establish exact coordinates and elevations of each marker. The grassy areas have ground-level markers set in concrete, and the wooded areas have engraved aluminum angle posts to designate the marker point. Because the coordinates for SWSA-4 grid system are different from those of the ORNL grid, Table 1 provides a comparison of the different coordinate values, along with the marker elevation. After the 30-m grid was established, a detailed elevation survey was conducted to allow for construction of a topographic map of the study area (Fig. 5).

The Surface Radiation Survey

To develop a rational plan for taking the minimum number of soil cores, a study of surface radiation levels was conducted to establish the spatial distribution of the surface contamination. These data were then used to develop the soil-coring plan.

The gross radiation in counts per minute was measured at the ground surface using a standard Geiger-Müller survey meter (Table 2). The measurements were taken at 5-m centers along lines connecting the 30-m grid points. The results were plotted in the field to delineate areas requiring greater definition than the 5-m centers. The results of this survey were used to develop a surface radiation contour map

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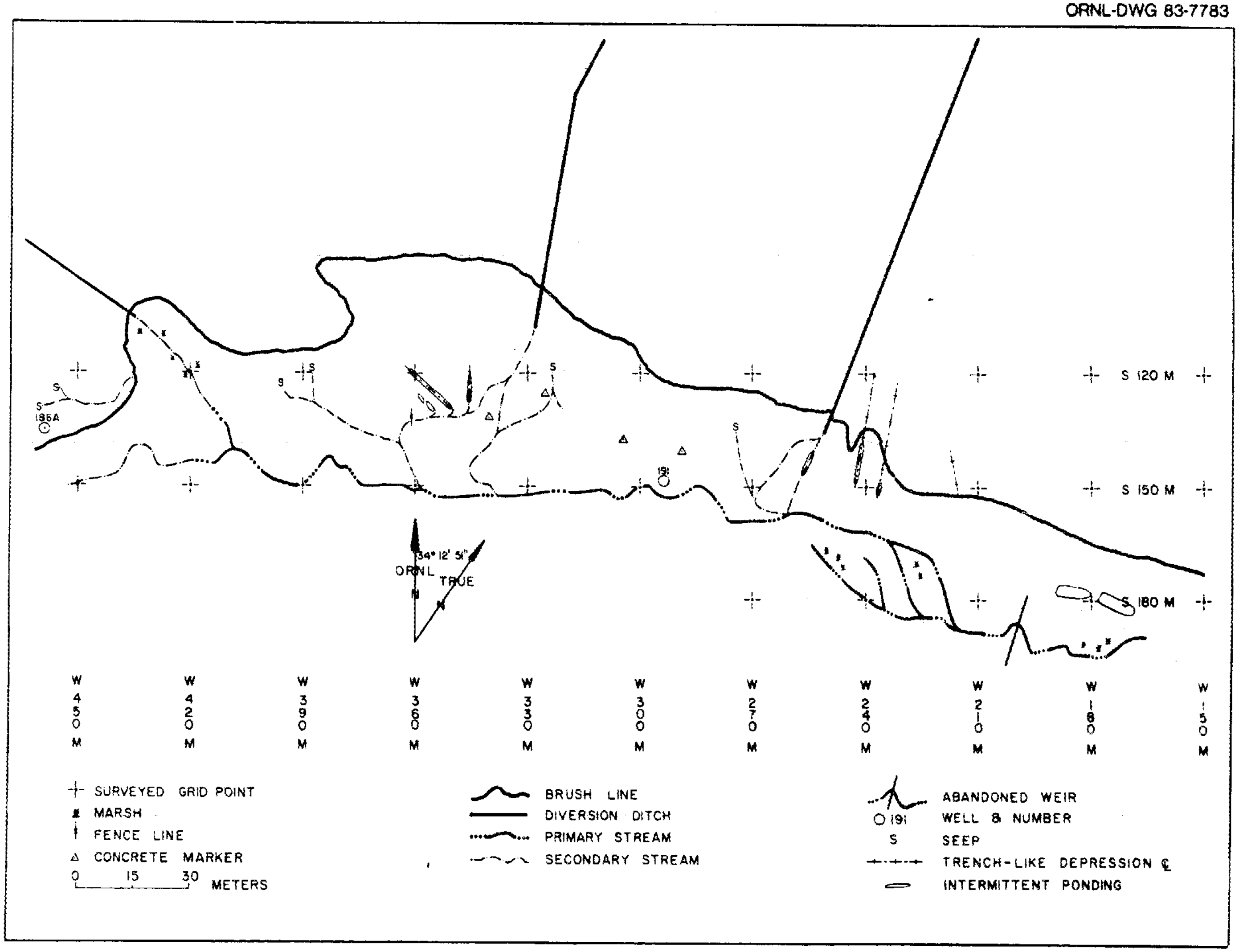

Fig. 4. Location of the 30-m grid markers.

Table 1. Comparison of the SWSA-4 30-m grid coordinates and the ORNL grid system

SWSA-4 grid coordinates[a] (m)		Actual grid locations[b] (m)		SWSA-4 marker elevations (m NGVD)[c]	ORNL grid system coordinates[d] (ft)	
NS	EW	NS	EW		NS	EW
120	150	120.00	150.00	242.12	19106	28508
120	180	120.02	179.97	242.26	19106	28409
120	210	119.98	209.95	241.09	19106	28311
120	240	119.97	239.89	239.77	19106	28213
120	270	119.95	269.86	239.27	19106	28114
120	300	119.95	299.86	240.03	19106	28016
120	330	119.99	329.85	239.79	19106	27917
120	360	119.94	359.80	239.36	19106	27819
120	390	119.91	389.79	241.17	19106	27720
120	420	119.93	419.81	241.10	19106	27622
120	450	119.95	449.75	244.53	19106	27524
150	150	149.78	149.91	241.35	19008	19008
150	180	149.80	179.89	241.02	19008	18909
150	210	149.82	209.93	239.59	19008	28311
150	240	149.86	239.86	237.91	19008	28213
150	270	149.89	269.85	236.88	19008	28114
150	300	149.92	299.87	236.57	19008	28016
150	330	149.96	329.85	237.86	19008	27917
150	360	149.96	359.97	238.72	19008	27819
150	390	149.97	389.92	238.93	19008	27720
150	420	149.80	419.77	241.98	19008	27622
150	450	150.02	449.76	241.88	19008	27524
180	150	179.82	149.91	238.78	18909	19008
180	180	179.82	179.92	234.85	18909	18909
180	210	179.85	209.89	235.32	18909	28311
180	240	179.85	239.87	235.53	18909	28213
180	270	179.90	269.87	240.46	18909	28114
180	300				18909	28016
180	330				18909	27917
180	360				18909	27819
180	390				18909	27720
180	420				18909	27622
180	450				18909	27524

[a]These values are the theoretical grid locations.

[b]These values are the surveyed marker locations.

[c]NGVD = National Geodetic Vertical Datum.

[d]To convert from SWSA-4 grid to ORNL grid:

ORNL EW = 29,000 - (SWSA-4 EW/0.3048),

ORNL NS = 19,500 - (SWSA-4 NS/0.3048).

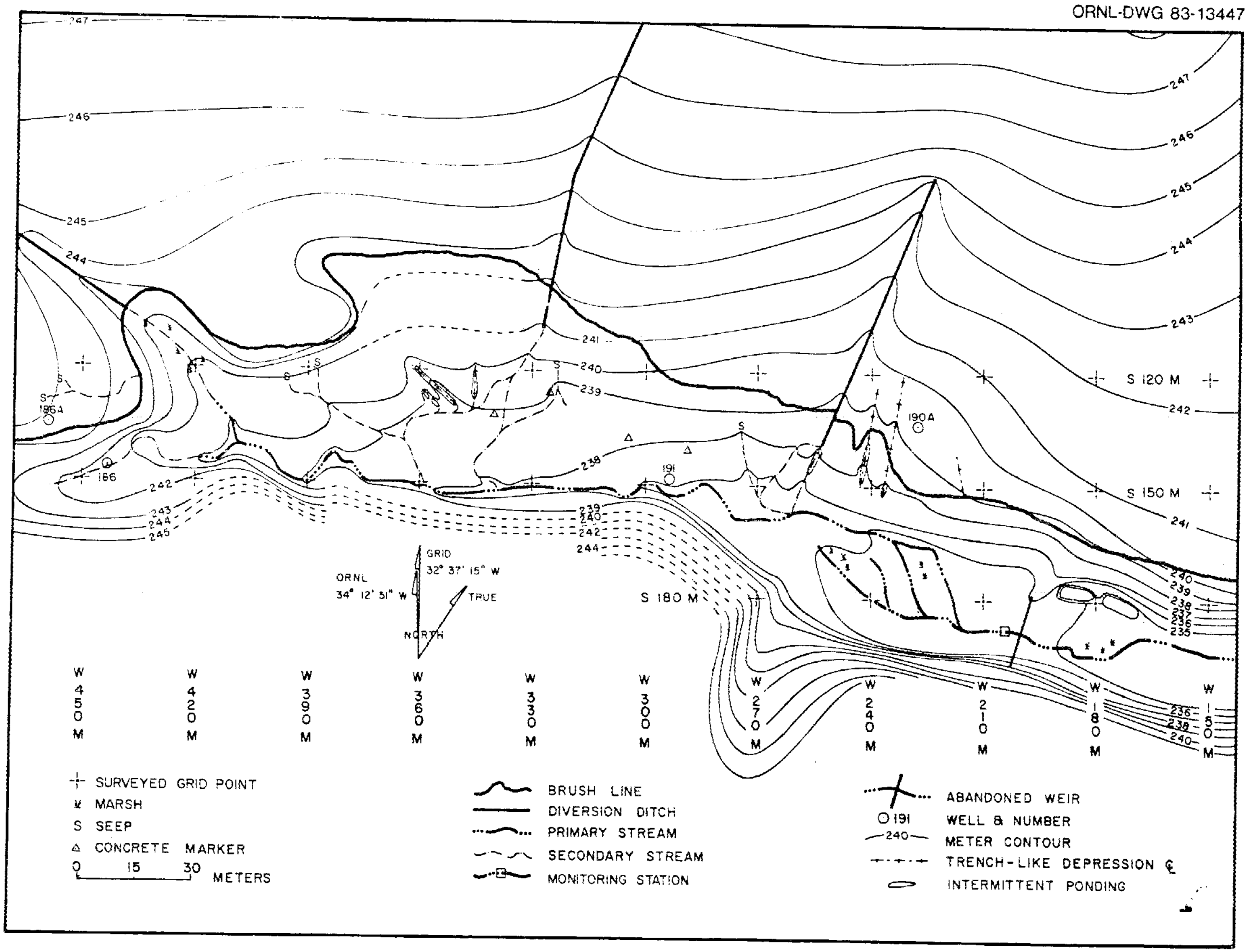

Fig. 5. Detailed topographic map of the SWSA-4 study area.

Table 2. Measured gross surface radiation at the SWSA-4 study area

30-m grid location NS (m)	30-m grid location EW (m)	Gross radiation (cpm)[a]
130	460	10,000
144	450	1,000
126	450	5,000
135	423	7,000
120	382.5	2,000
120	370	2,000
135	375	2,000
138	364.5	2,000
130	360	2,000
124.5	354	5,000
127	343.5	5,000
136	348	5,000
144	345	2,000
132	342	1,500
126	324.5	3,500
126	318	7,500
135	312	10,000
146	318	3,500
141	288	3,500
147	294	3,500
144	279	7,500
135.5	280	10,000
150	268	2,000
150	256	40,000
150	245	2,000
141	240	2,000
163.5	213	10,000
169	213	2,000

[a]To convert from counts per minute to becquerels, multiply by 3.7×10^{10}.

(Fig. 6) and to develop the locations for surface soil samples and coring (Fig. 7).

Surface soil samples (Fig. 7) were taken using a 7.6 cm (3-in.) cutter. The samples were transferred to preweighed aluminum cans, labeled as to location, and sealed. The samples were then weighed and subjected to a gamma scan using a scintillation counter. Corrections were made for background radiation and sample geometry. Gamma-emitting radionuclide concentrations were also determined. Several radionuclides were identified, including ^{137}Cs, ^{60}Co, and $^{154,155}Eu$. The results of the gamma scan analyses for ^{60}Co and ^{137}Cs are presented in Table 3. After the gamma scan analysis, the samples were measured for ^{90}Sr concentration and the results are presented in Table 4. Figures 8, 9, and 10 show the surface distribution patterns for ^{137}Cs, ^{60}Co, and ^{90}Sr, respectively.

Soil Coring

From the results of the surface radiation survey, 17 sites were selected for soil coring. During July 1982, two initial cores were taken in the area south of Lagoon Road (Fig. 11). These cores were also driven to test field operating procedures and to determine local soil conditions. The first samples were taken to a depth of 150 cm, and the second core samples were taken at 250 cm. Both cores were saved and stored in 3-cm, polyvinyl chloride (PVC), sewer pipe liners. Experimentation showed that for best field operation the optimal maximum length of the individual soil cores was 50 cm. Greater length resulted in compaction of the core and difficulty in determining the

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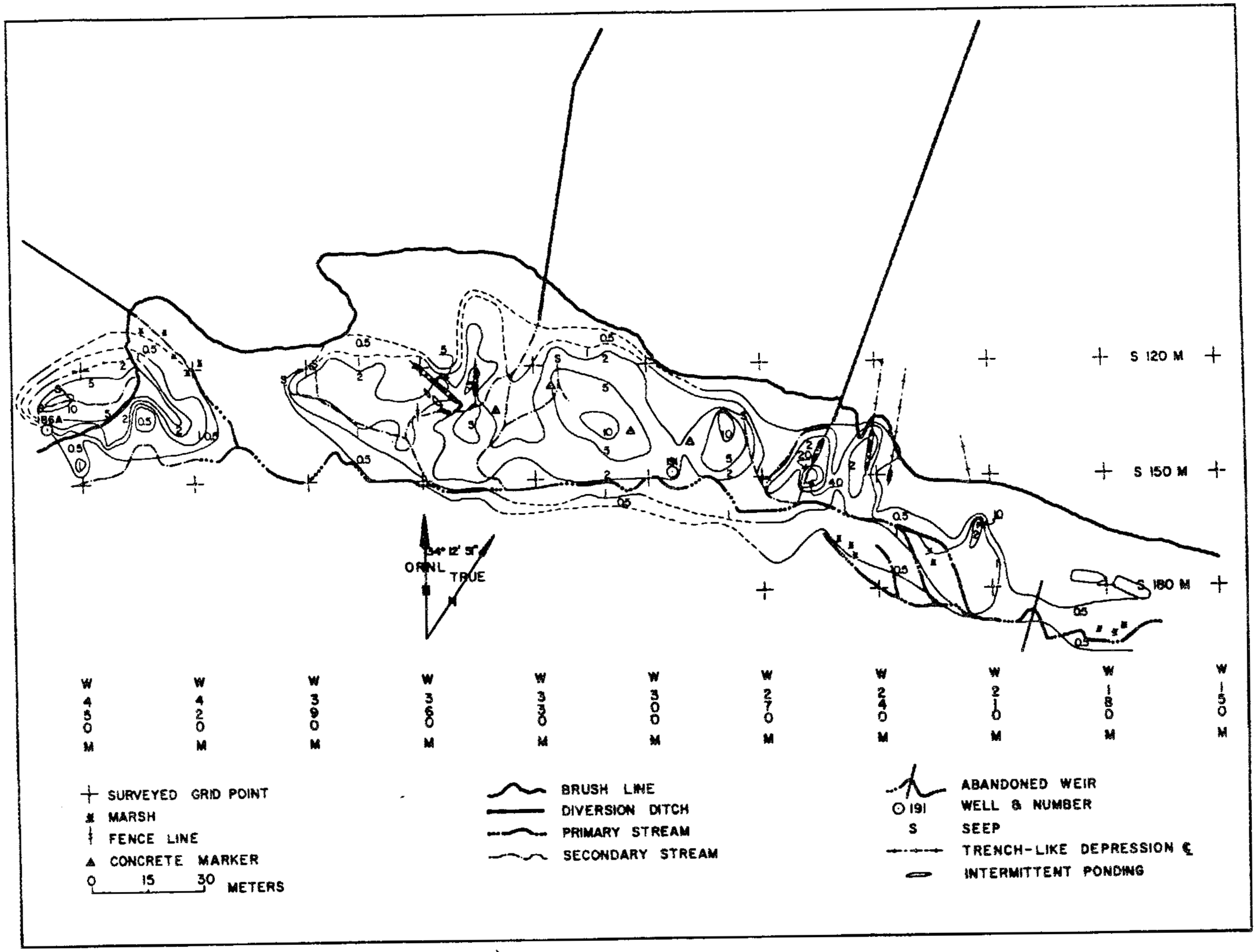

Fig. 6. Surface radiation contour map of the SWSA-4 study area.

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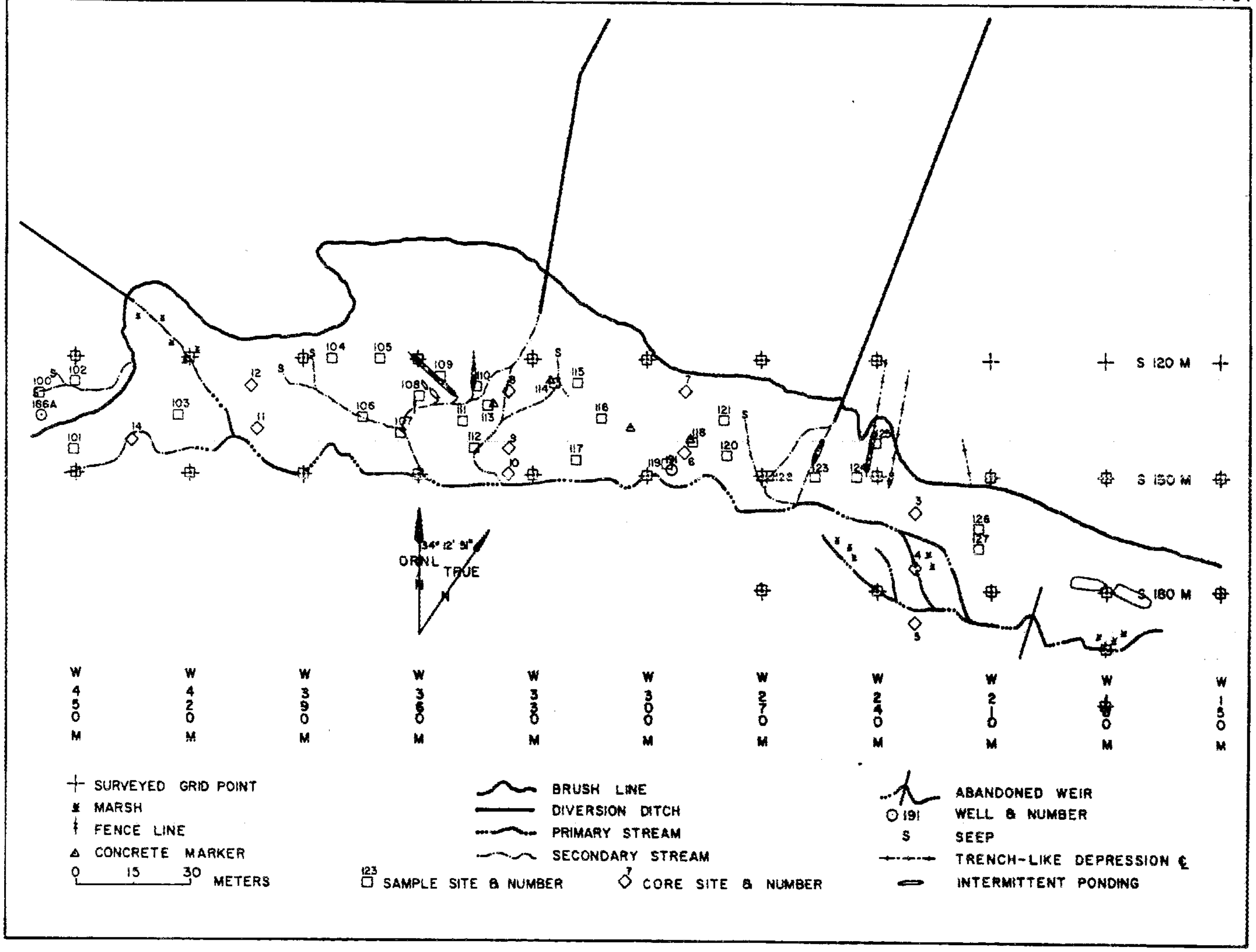

Fig. 7. Location map for surface core samples.

Table 3. Gamma scan results for the SWSA-4 surface soil cores

Sample number	30-m grid coordinates (m) NS	EW	^{137}Cs concentration (pCi/g)[a]	^{60}Co concentration (pCi/g)[a]
100	130	460	17700 ± 200	
101	144	450	294. ± 4.	
102	126	450	6780 ± 80	
103	135	423	4590 ± 100	
104	120	382.5	2.8 ± 0.2	
105	120	370	2.0 ± 0.2	
106	135	375	30.1 ± 0.6	0.5 ± 0.1
107	138	364.5	79.4 ± 1.0	1.3 ± 0.5
108	130	360	105. ± 1.	2.9 ± 0.4
109	124.5	354	22.7 ± 0.5	2.1 ± 0.4
110	127	343.5	132. ± 1.	3.8 ± 0.2
111	136	348	299. ± 2	7.6 ± 6.6
112	144	345	355 ± 2.0	0.6 ± 0.2
113	132	342	841. ± 4.	2.5 ± 1.0
114	126	324.5	63.3 ± 0.8	0.82 ± 0.03
115	126	318	11.4 ± 2.9	
116	135	312	49.4 ± 4.9	
117	146	318	11.4 ± 2.2	
118	141	288	5.4 ± 0.4	6.0 ± 0.1
119	147	294	1.0 ± 1.9	
120	144	279	35.4 ± 4.9	
121	135.5	280	732. ± 15	23.3 ± 6.6
122	150	268	585 ± 15	
123	150	256	10450 ± 130	
124	150	245	702. ± 6.	
125	141	240	1620. ± 5.	
126	163.5	213	19500 ± 200	
127	169	213	124. ± 1.	0.5 ± 0.1

[a]To convert from picocuries per gram to becquerels per gram multiply by 3.7×10^{10}.

Table 4. Radiochemical analytical results for the SWSA-4 soil cores

Sample location coordinates[a]		^{90}Sr concentration (Bq/kg dry wt)[b]	Measurement sensitivity (Bq/kg dry wt)[b]
S120	W382.5	53000	2000
S126	W324.5	430000	10000
S127	W343.6	500000	10000
S169	W213.0	9600	300
S141	W240	5700	200
S124.5	W354	320000	10000
S135	W375	61000	2000
S150	W245	15000	1000
S132	W342	140000	10000
S144	W450	6700	400
S118	W288	47000	2000
S144	W345	61000	3000
S180	W180	12000	1000
S138	W364.5	60000	2000
S210	W180	6100	100
S150	W450	950	50
S120	W450	150000	10000
S150	W270	20000	1000
S120	W300	27000	1000
S130	W360	95000	3000
S150	W390	1000	100
S120	W390	16000	1000
S120	W270	310	40
S150	W360	7900	200
S150	W330	28000	1000
S120	W360	120000	10000
S120	W330	19000	1000
S195	W180	26000	1000
S150	W300	61000	2000
S150	W180	48	18
S120	W420	11000	1000
S150	W420	360	50
S180	W150	52	17
S150	W240	11000	1000
S120	W240	1600	100
S180	W240	23000	1000
S180	W270	130	30
S180	W210	56000	2000
S150	W210	290	40
S120	W370	110000	10000
S150	W150	48	17
S130	W460	44000	2000
S126	W450	140000	10000
S135	W423	58000	3000
S136	W348	330000	10000
S126	W318	1900000	100000
S135	W312	670000	10000
S146	W318	110000	10000
S147	W294	530000	10000
S144	W279	620000	10000
S135.5	W280	22000	1000
S150	W268	150000	10000
S150	W256	5100	200
S163.5	W213	79000	2000

[a]SWSA-4 30-m grid system coordinates.

[b]1 Bq/kg = 0.02703 pCi/g.

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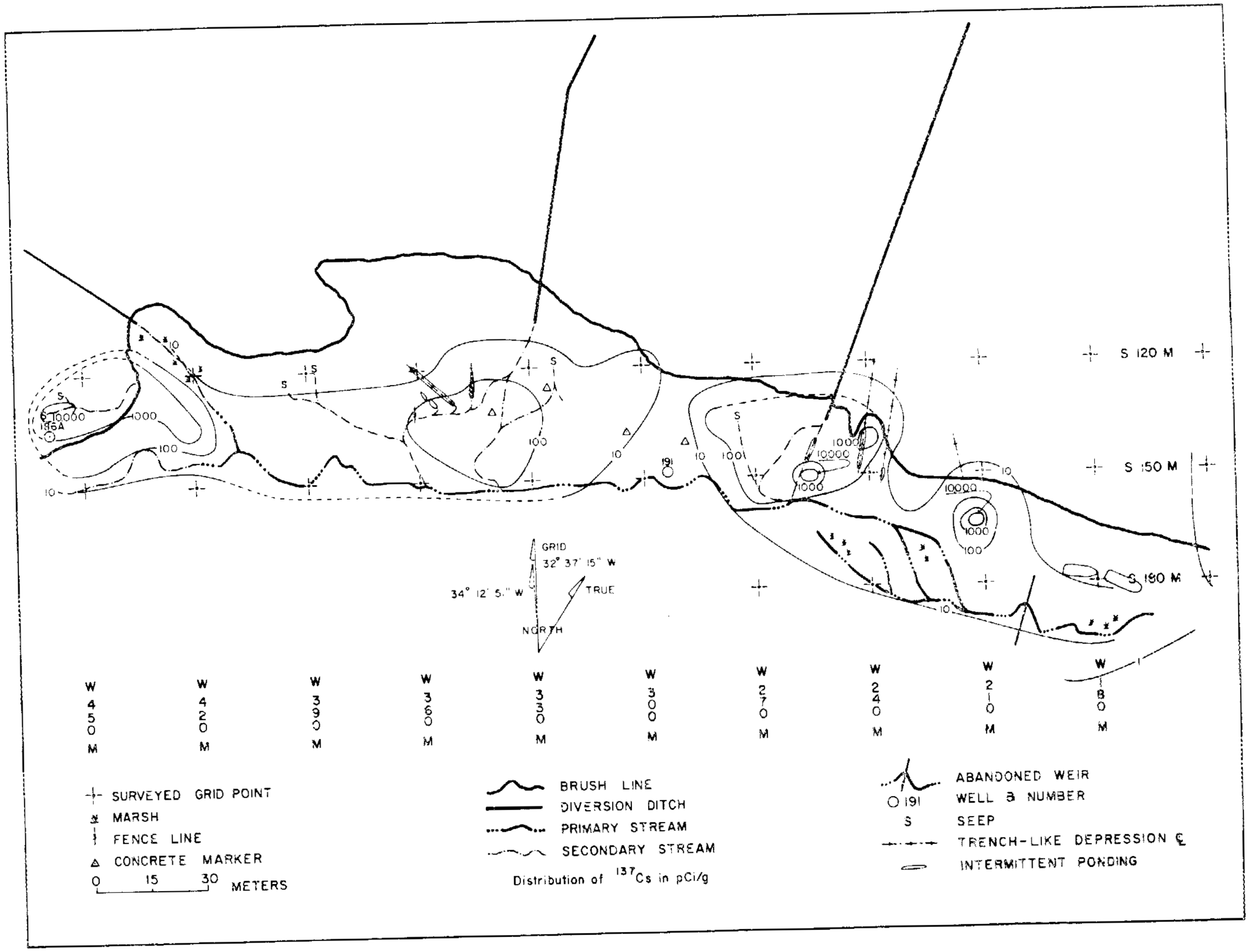

Fig. 8. Surface distribution contour map for ^{137}Cs at the SWSA-4 study area.

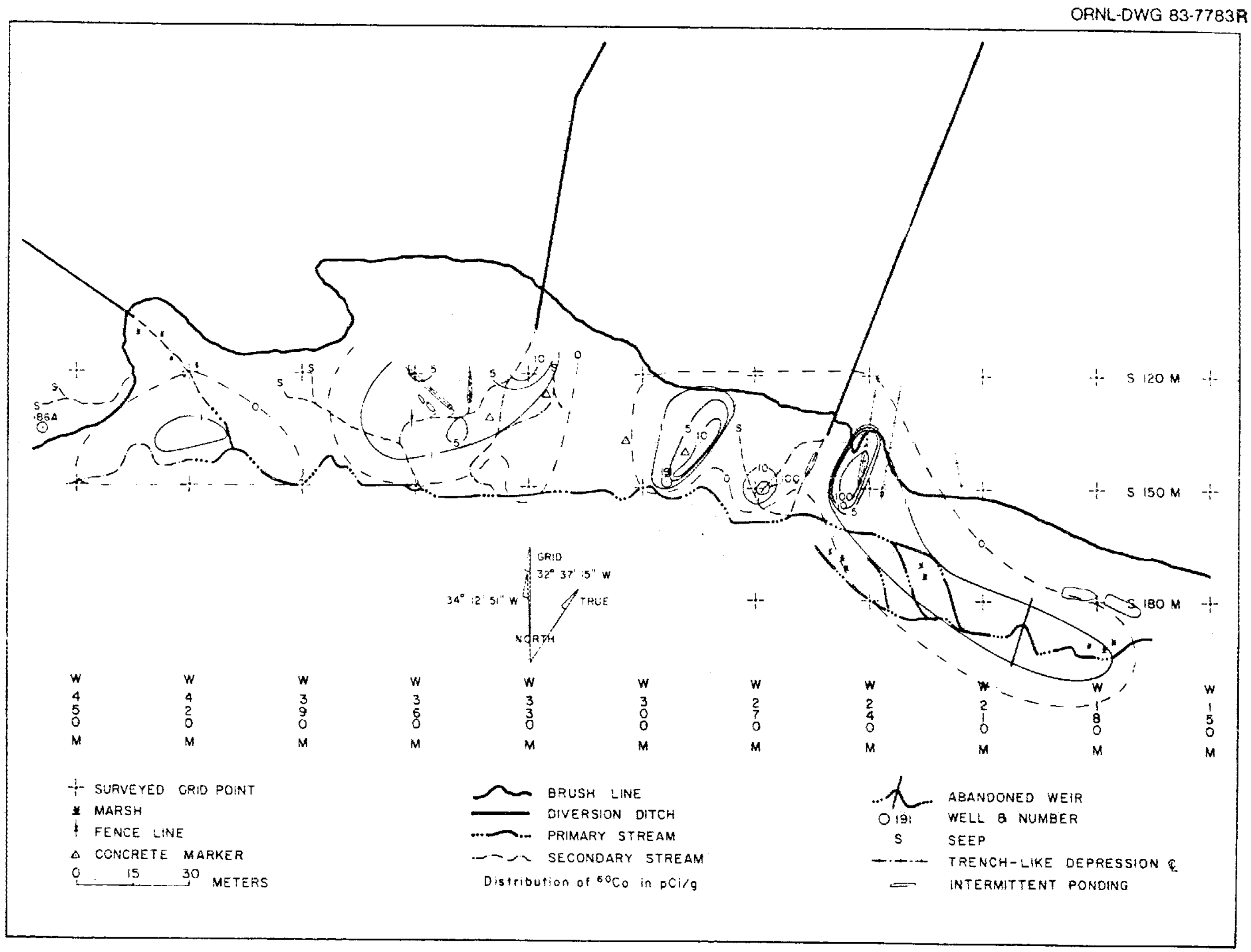

Fig. 9. Surface distribution contour map for ^{60}Co at the SWSA-4 study area.

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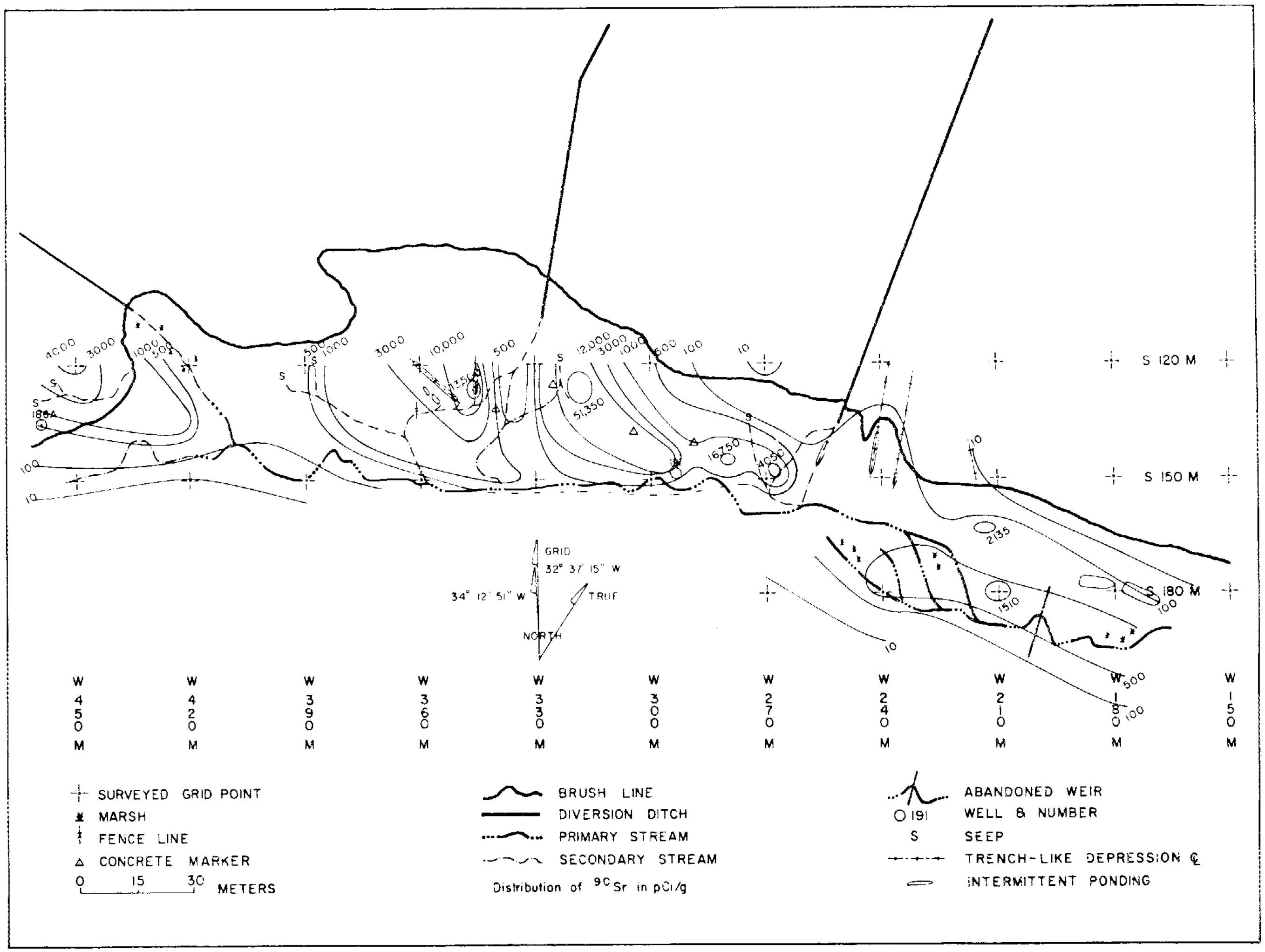

Fig. 10. Surface distribution contour map for ^{90}Sr at the SWSA-4 study area.

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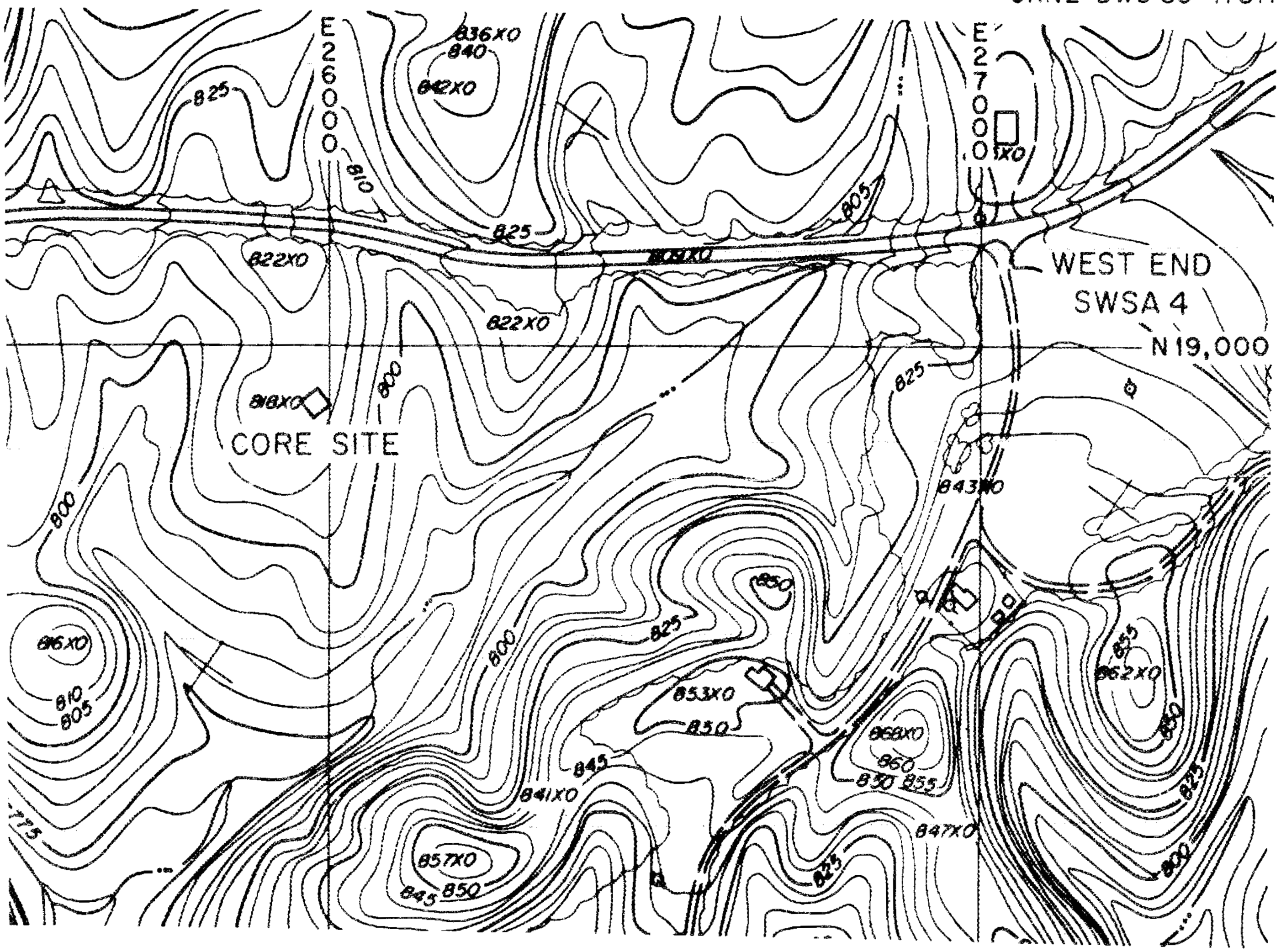

Fig. 11. Location map of the SWSA-4 study initial cores.

true depth increment for sections of a core. The background cores were taken in July, and the study cores were taken between August and December 1982.

The cores were taken using two drill rigs (a Giddings Manufacture Rig and a Mobile Drill) and a motorized cathead tripod. Both drills were operated using standard 73-kg (160-lb) fixed drop-distance hammers, with the same drive rods and core barrels. Core barrels (8 cm diam) were used, with a heat-treated, threaded drive shoe for the cutting edge. The interior of the core barrel was lined with a thin-walled section of PVC pipe. The core barrel was connected to size 'E' drill rods. The hammers were operated manually using a drill-operated cathead, mast or portable tripod, and a sheave (Fig. 12).

The procedure used during coring was to drive the core barrel in 50-cm increments. The barrel was then pulled and the core retrieved from the PVC liner. The soil material from the drive shoe (not contained within the PVC liner) was also collected and used as the soil sample at the bottom of that increment. During the coring, a blow-count record was kept. Refusal was indicated when the drive rate slowed to greater than 10 blows/cm driven. Earlier experience indicated that any attempt to drive deeper resulted in damage to the drive shoe, or loss of the shoe and core barrel due to damage to the connector between the drive rod and core barrel.

After a core was completed, all contaminated parts were thoroughly decontaminated before another core was taken. The completed core holes were held open with 7.6-cm (3-in.) PVC pipe.

To obtain an accurate measure of the core length, the following procedure was followed:

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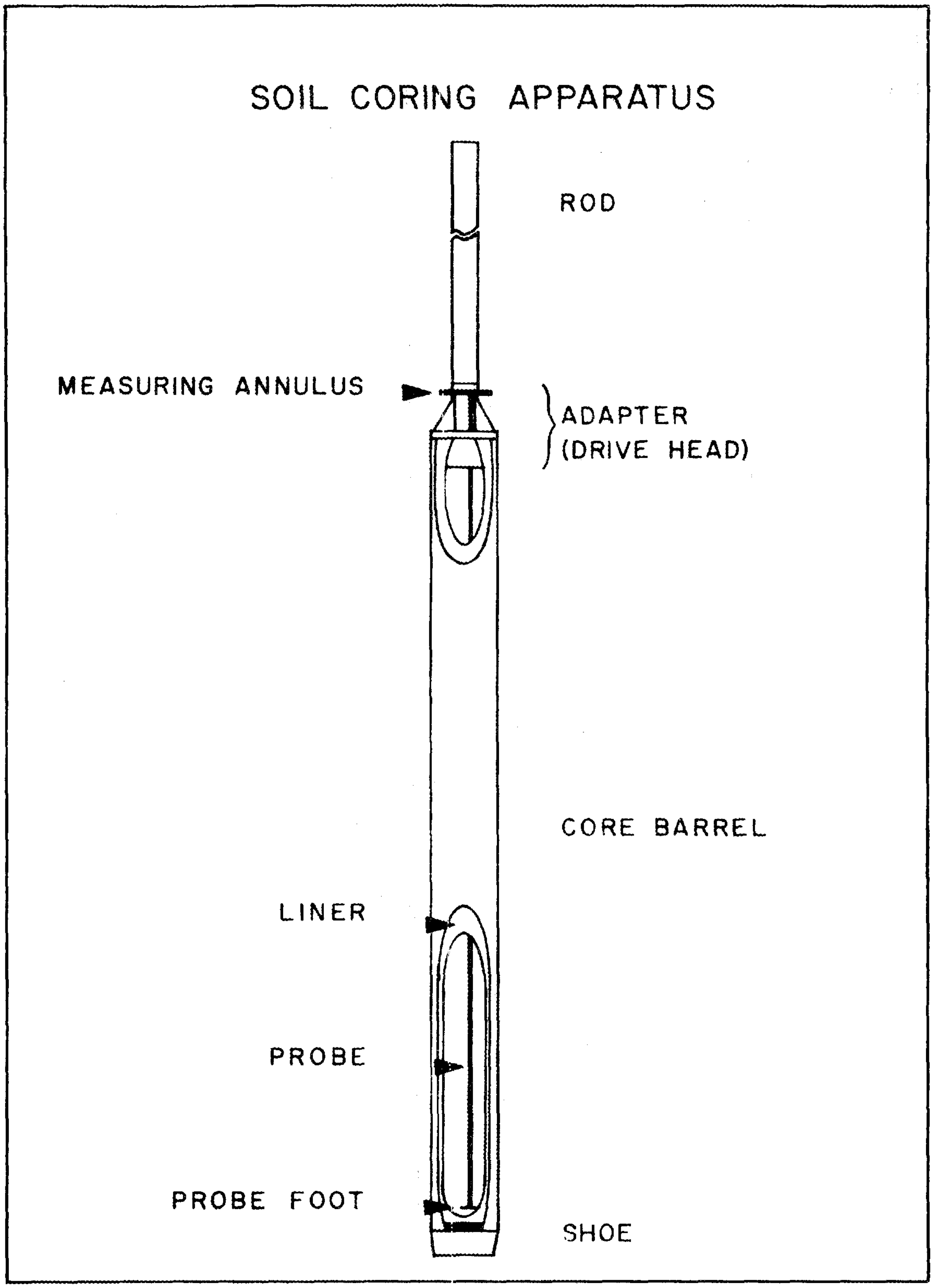

Fig. 12. Soil-coring apparatus.

(1) A level surface was established over the area to be cored to act as a reference point. Two stakes were driven into firm ground near the core site, and a level line was established between the two stakes.

(2) The distance from the reference level to the ground surface (R) was determined.

(3) The first core was driven and pulled. The distance from the reference level (R) to the bottom of the core hole (M_1) was measured.

(4) The core length (L_1) for the first core was determined to be the difference between the reference level and the bottom of the core hole:

$$L_1 = M_1 - R_1 .$$

(5) The core and liner were removed from the barrel and the length of the core remaining in the liner (CL_1) was measured. The plug length (P_1) was computed as the difference between the core length (L_1) and the length of core in the liner (CL_1):

$$P_1 = L_1 - CL_1 .$$

(6) The next core was then driven and pulled. The distance from the reference level (R) and the bottom of the core was measured (M_n). The core length (L_n) was then computed:

$$L_n = M_n - M_{n-1} .$$

(7) The core and liner were removed from the barrel and inverted to 'pour off' any loose material on top. This loose top material consists of an aggregate of fallout from the previous core, wall material dislodged during coring, and surface material dislodged into core hole.

(8) The core length (CL_n) was measured, and the plug length (P_n) was then computed:

$$P_n = L_n - CL_n.$$

(9) To check the integrity of the core, the final measured distance from the reference level to the core-hole bottom was compared to the sum of core lengths and the plug measurements:

If	$CL + P + R > M$,	then loose material accumulated in hole;
if	$CL + P + R < M$,	then compression of the core occurred.

The core samples were packaged in aluminum cans and subjected to gamma scan and radiochemical analysis. The results are presented in Table 5.

RESULTS AND DISCUSSION

The results of the surface radiation survey (Figs. 8-10) strongly suggest that several distinct sources of contamination exist, probably associated with bathtubbing trenches that overflow. One example of this is near the S-120-m/W-450-m grid point (Fig. 10), where an elongated contamination plume of ^{90}Sr originates near an observed

Table 5. Radioactivity of the SWSA-4 soil-core samples (C - concentration, S - sensitivity, in Bq/kg)

Site Id	^{90}Sr C	S	^{239}Pu C	S	^{238}Pu C	S	^{244}Cm C	S	^{241}Am C	S
01000	28	15	0.085	0.076	0.005	0.006	0.023	0.013	0.76	0.27
01065	22	16	2.1	0.4	0.065	0.041	0.16	0.09	0.19	0.11
01160	35	17								
02000	47	19	1.9	0.3	0.002	0.001	0.13	0.07	0.61	0.16
02135	5	11	0.061	0.030	<0.01		0.18	0.07	0.22	0.07
03000	4100	200	13	1	0.23	0.06	0.58	0.16	17	1
03060	7400	300	1.8	0.3	0.017	0.008	0.14	0.07	0.85	0.19
03122	4700	200								
03270	1600	100								
04000	25000	1000	95	4	2.2	0.4	0.47	0.22	110	10
04050	7200	200	0.77	0.18	0.03	0.03	0.047	0.021	0.70	0.18
04142	390	50								
04183	170	30								
05000	1200	100	9.6	0.9	0.32	0.17	0.37	0.21	15	2
05072	160	30	0.046	0.028	<0.08		0.55	0.24	0.13	0.08
05083	2000	100								
05147	68	20								
06000	35000	1000	8.6	2.1	0.15	0.11	1.3	1.0	6.1	2.2
06085	36000	1000	8.4	1.9	0.32	0.21	<0.1		15	4
06095	32000	1000								
06150	17000	1000								
6A000	29000	1000	5.1	1.7	1.3	0.7	1.2	0.8	6.1	2.5
6A030	22000	1000	6.7	1.8	0.24	0.28	0.70	0.37	4.4	1.5
6A060	32000	1000								
6A090	26000	1000								
6A120	13000	1000								
6A150	32000	1000								
6A169	9800	600								
07000	11000	1000	11	2	<0.3		<0.3		2.2	1.2
07088	1000	200	0.16	0.06	<0.1		21	4	41	5
07147	11000	1000								
08000	11000	1000	260	20	4.8	1.9	6.6	2.2	47	6
08074	2400	300	1.8	1.1	0.6	0.6	4.2	1.9	5.8	1.8
08097	190	100								
09000	26000	1000	120	10	1.800	1.1	1.2	0.7	12	3
09070	9800	600	3.4	1.4	<0.3		<0.3		1.5	0.7
09160	620	150								
09230	240	90								
10000	47000	1000	1900	300	23	11	1.5	0.8	190	20
10059	21000	1000	4.7	1.8	<0.3		0.61	0.55	3.4	0.6
10210	2200	300								
10A120	9600	500								
108000	36000	1000	320	20	7.0	1.6	0.28	0.13	140	10
108120	10000	1000	<0.5		<0.4		<0.1		2.8	1
108225	670	180	7.6	2.4	<0.2		<0.2		2.7	1.2
11000	4000	400	51	6	5.2	1.8	<0.1		110	10
11075	1500	200	2.0	1.5	<0.6		<0.2		7	2.2
11080	840	170								
11110	1900	200								
11120	1100	200								
11135	1200	200								
11150	1600	200								
11225	140	80								
11250	120	90								
11244	150	80								
11260	1.7	1.6								
11350	18	3								
12000	5500	400	18	3	29	3	5.4	1.8	35	5
14114	3200	300	38	5	0.47	0.25	3.0	1.3	3.8	1.7
14182	1000	200								
14231	1700	300								
14FI	3000	300								

seep. During storm events, flow has been observed from these seeps, supporting the concept of an overflowing trench.

The surface distribution of ^{137}Cs and ^{60}Co (Figs. 8 and 9) indicates four distinct regions of contamination. Concentrations over 370 Bq/g (10,000 pCi/g) of ^{137}Cs were evident at three locations. The concentration of ^{60}Co was generally less than 3.7 Bq/g (100 pCi/g).

Additional evidence of overflowing trenches may be observed in the vertical radionuclide distributions. During the coring process, soil samples were collected at various depths and analyzed for ^{90}Sr content. From these data (Table 5), concentration profiles were drawn. The core-hole profiles are presented in Figs. 13 to 22 and each profile is discussed below.

Core-hole 3 (Fig. 13) shows only a slight change in ^{90}Sr concentration with depth, with the concentration ranging between 1.6 to 7.4 Bq/g (43-200 pCi/g). A slight increase occurs in the first 75 cm, with the concentration decreasing thereafter.

Core-hole 4 (Fig. 14) shows a very distinct exponential profile, with a very high surface concentration [25.0 Bq/g (676 pCi/g)]. The concentration drops rapidly with depth, to less than 0.37 Bq/g (10 pCi/g) 183 cm below the surface.

Core-hole 5 (Fig. 15) displays a relatively constant profile, with concentrations between 0.07 to 2.0 Bq/g (2-54 pCi/g). A slight increase in concentration occurs 83 cm from the surface.

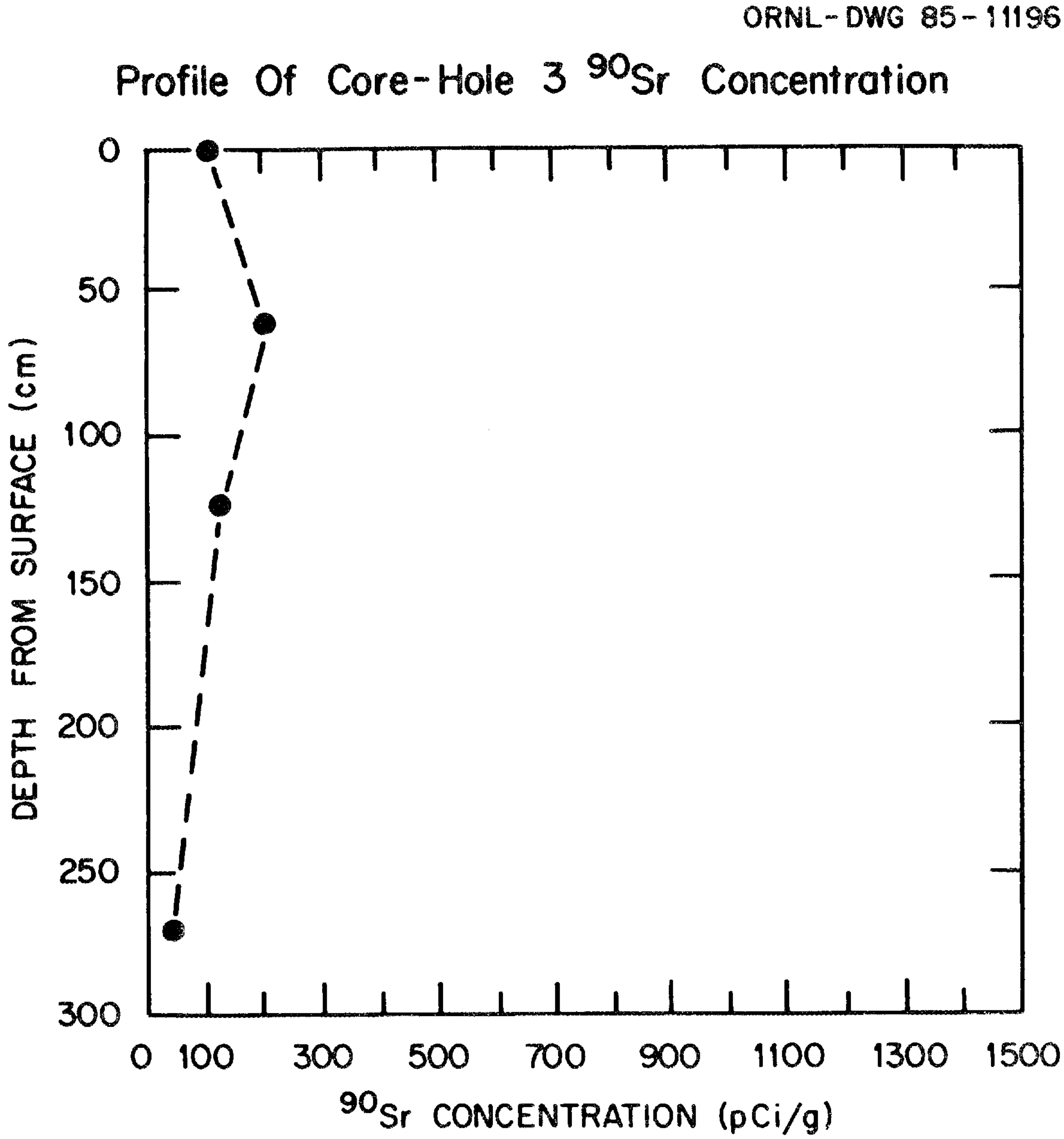

Fig. 13. ^{90}Sr concentration profile for core-hole 3 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

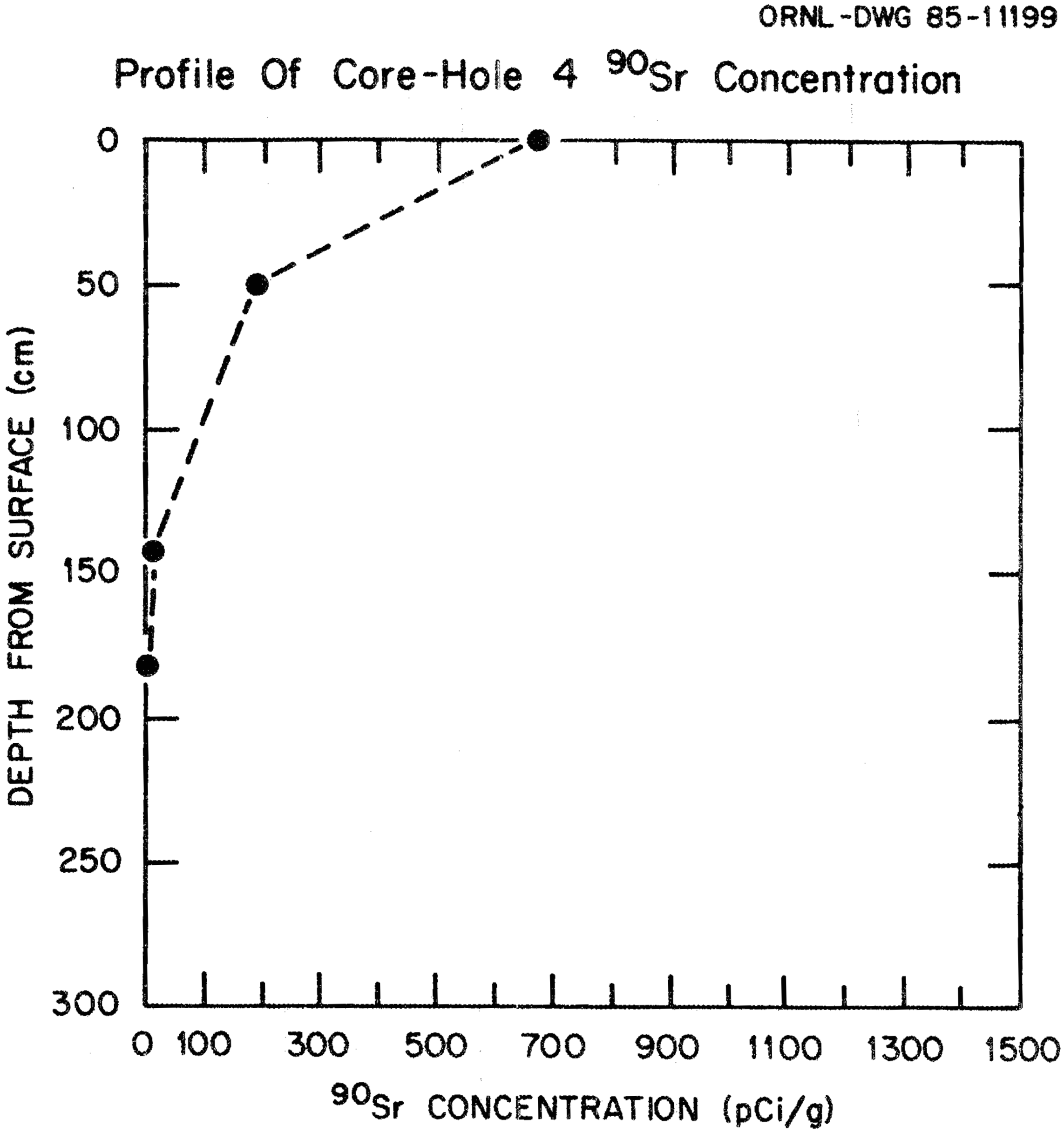

Fig. 14. ^{90}Sr concentration profile for core-hole 4 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

ORNL-DWG 85-11201

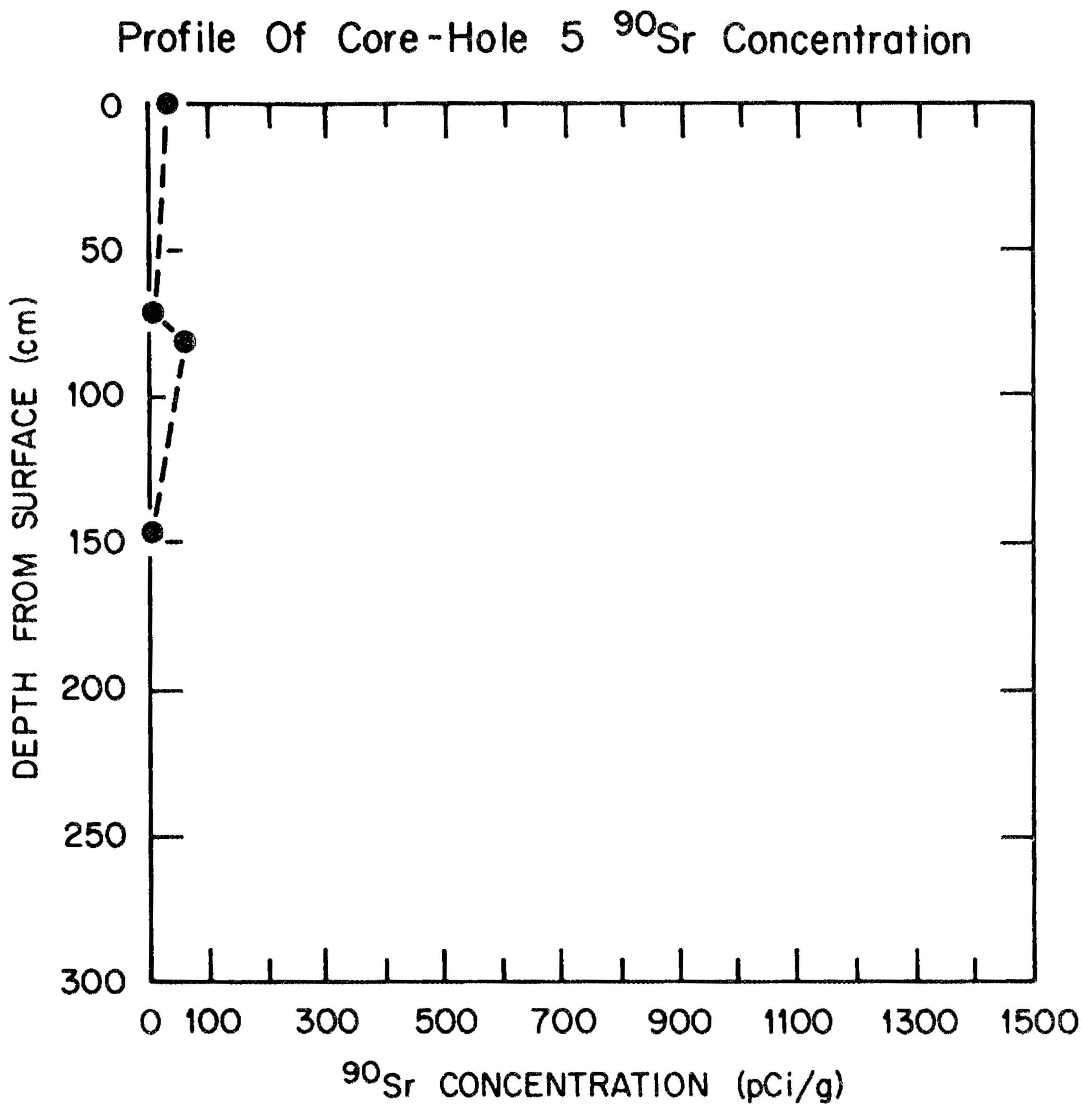

Fig. 15. ^{90}Sr concentration profile for core-hole 5 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

ORNL-DWG 85-11203

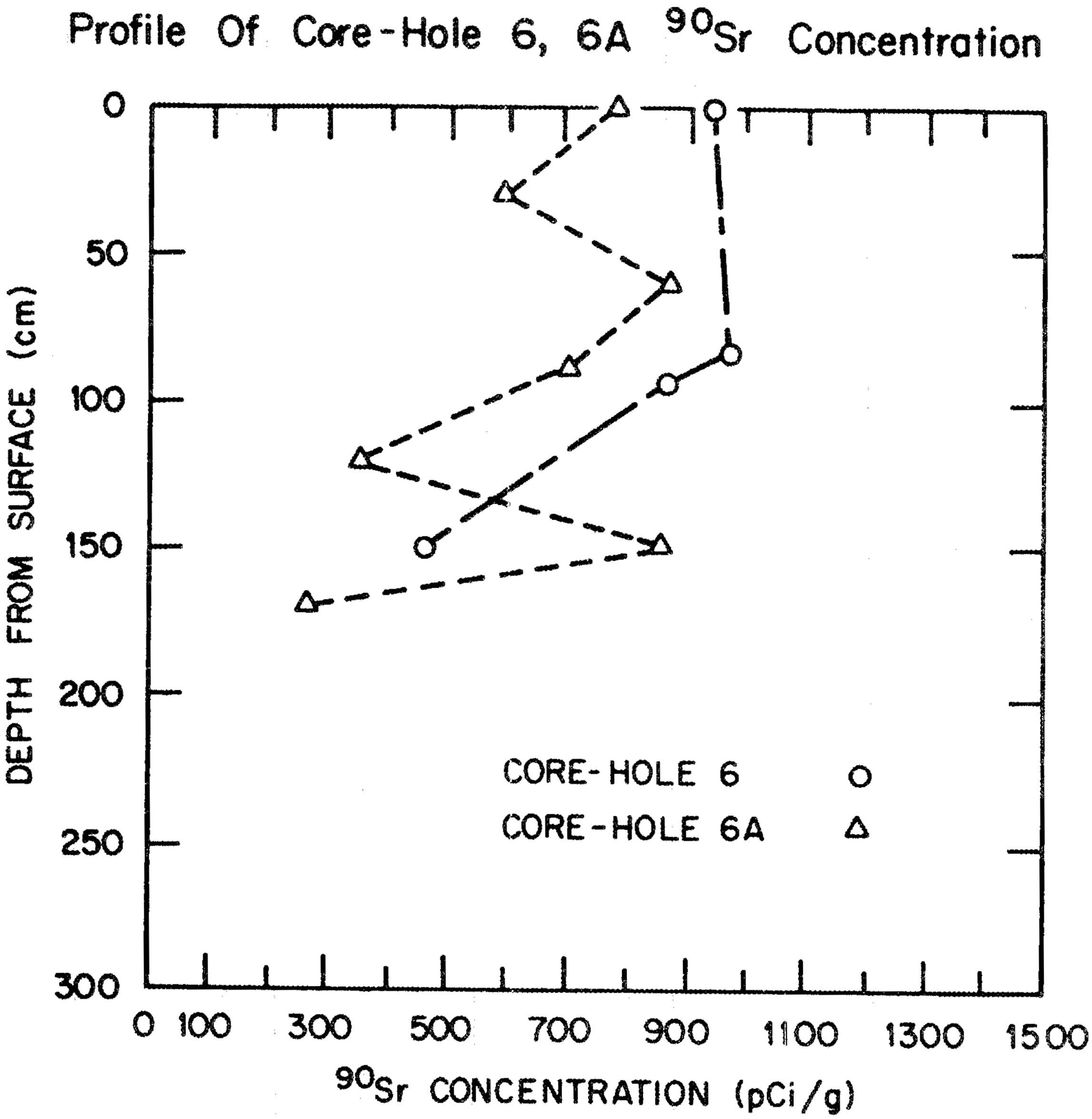

Fig. 16. ^{90}Sr concentration profile for core-hole 6 and 6A at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

ORNL-DWG 85-11197

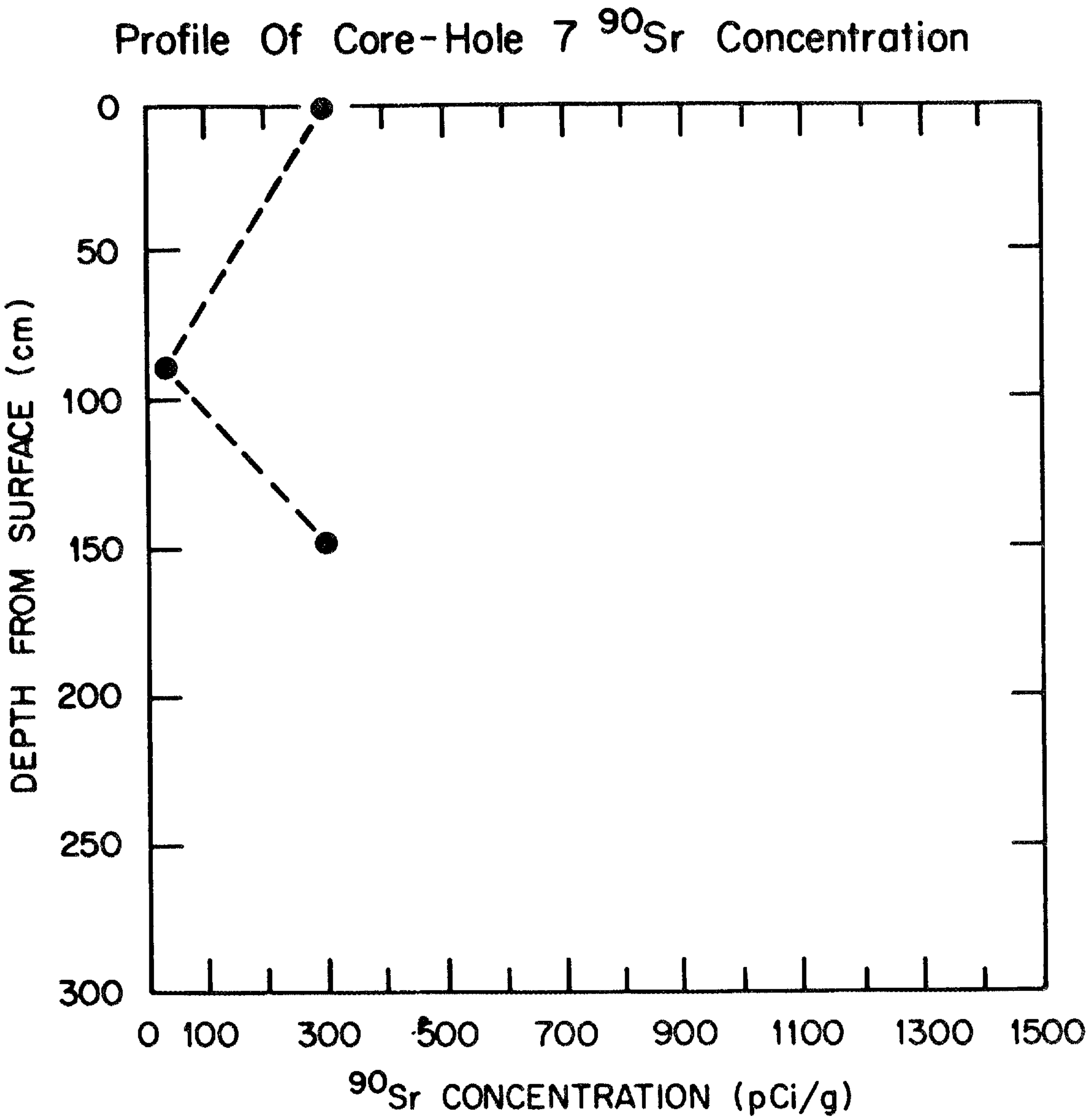

Fig. 17. ^{90}Sr concentration profile for core-hole 7 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

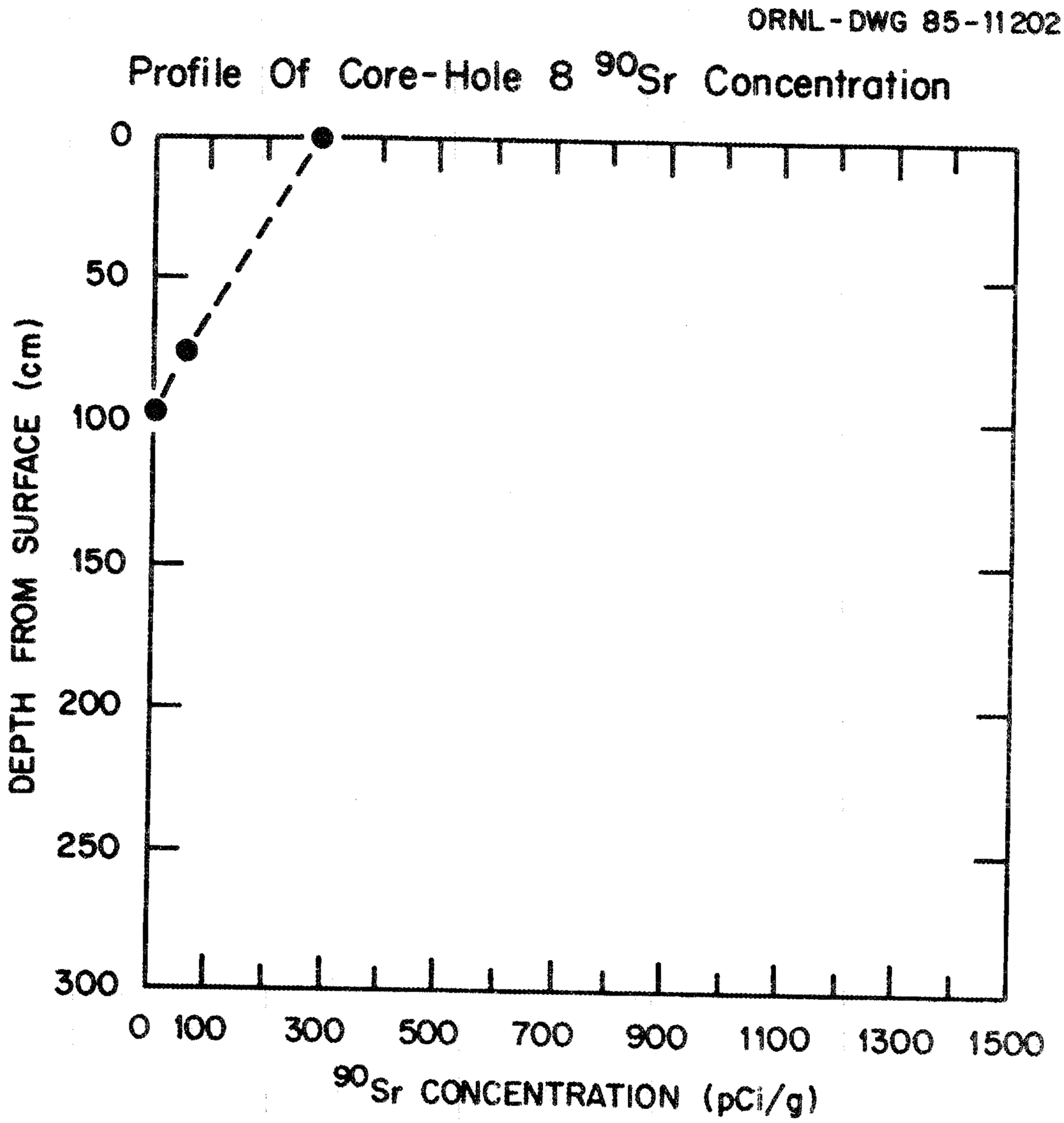

Fig. 18. ^{90}Sr concentration profile for core-hole 8 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

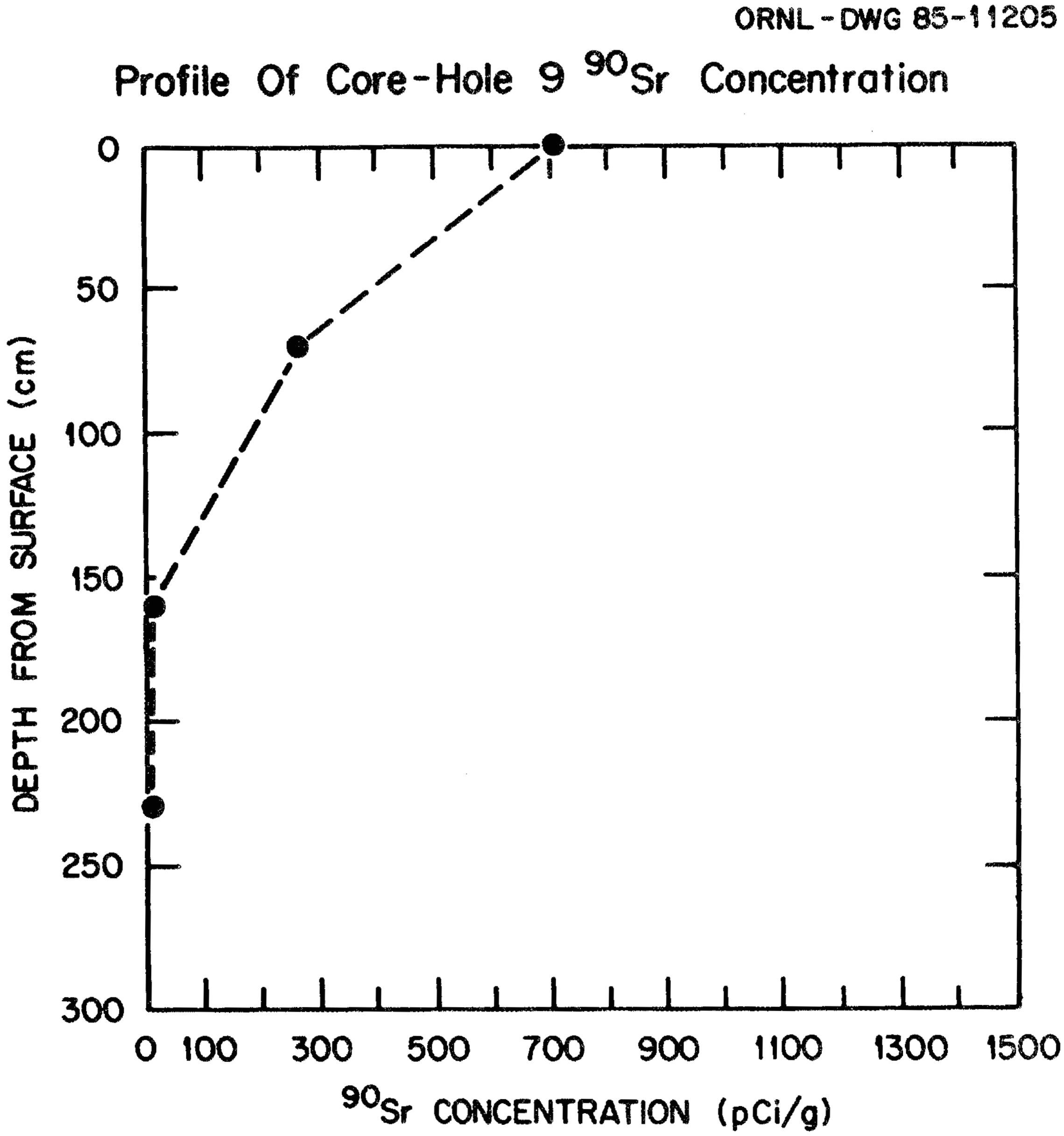

Fig. 19. ^{90}Sr concentration profile for core-hole 9 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

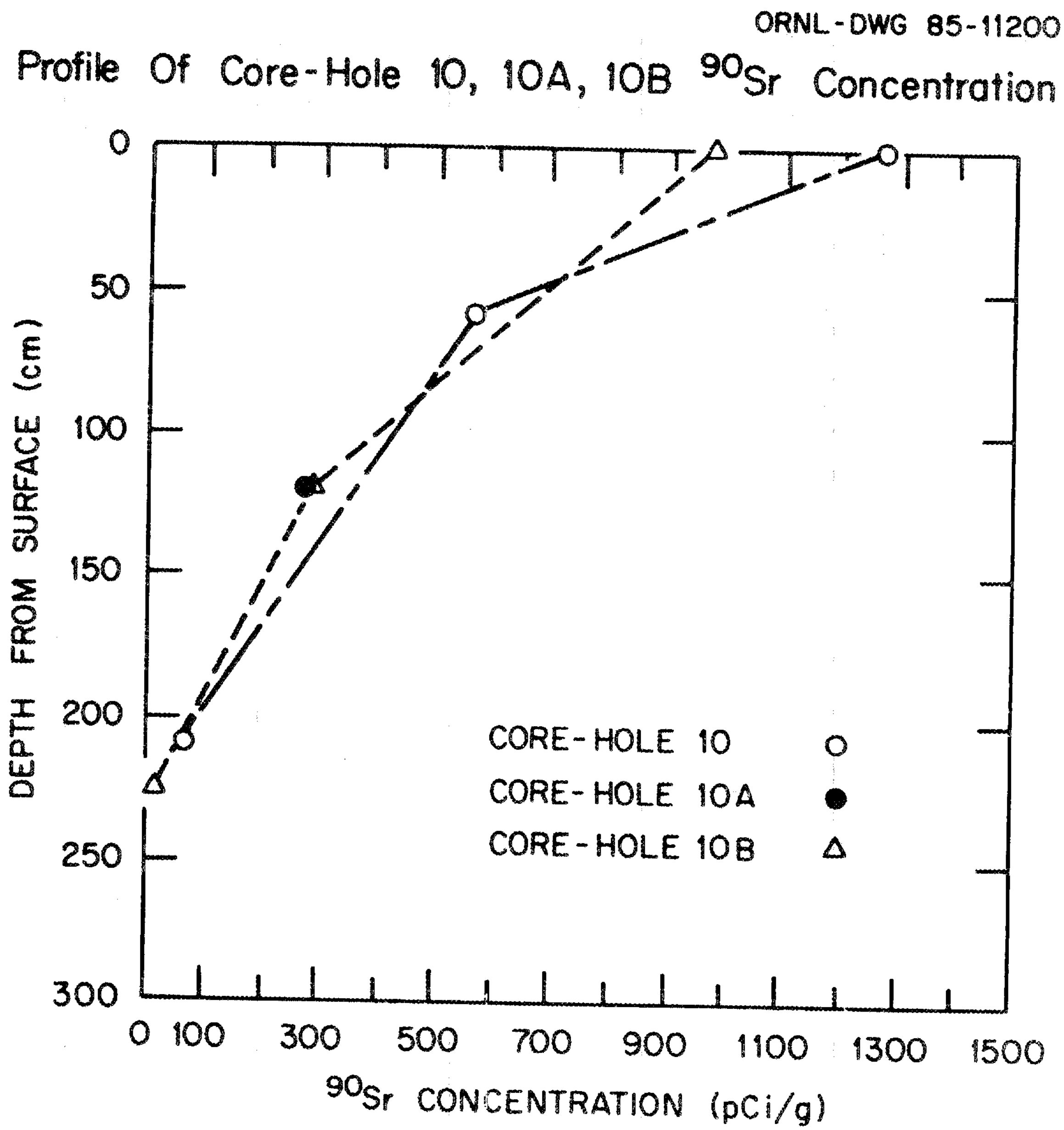

Fig. 20. ^{90}Sr concentration profile for core-hole 10, 10A, and 10B at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

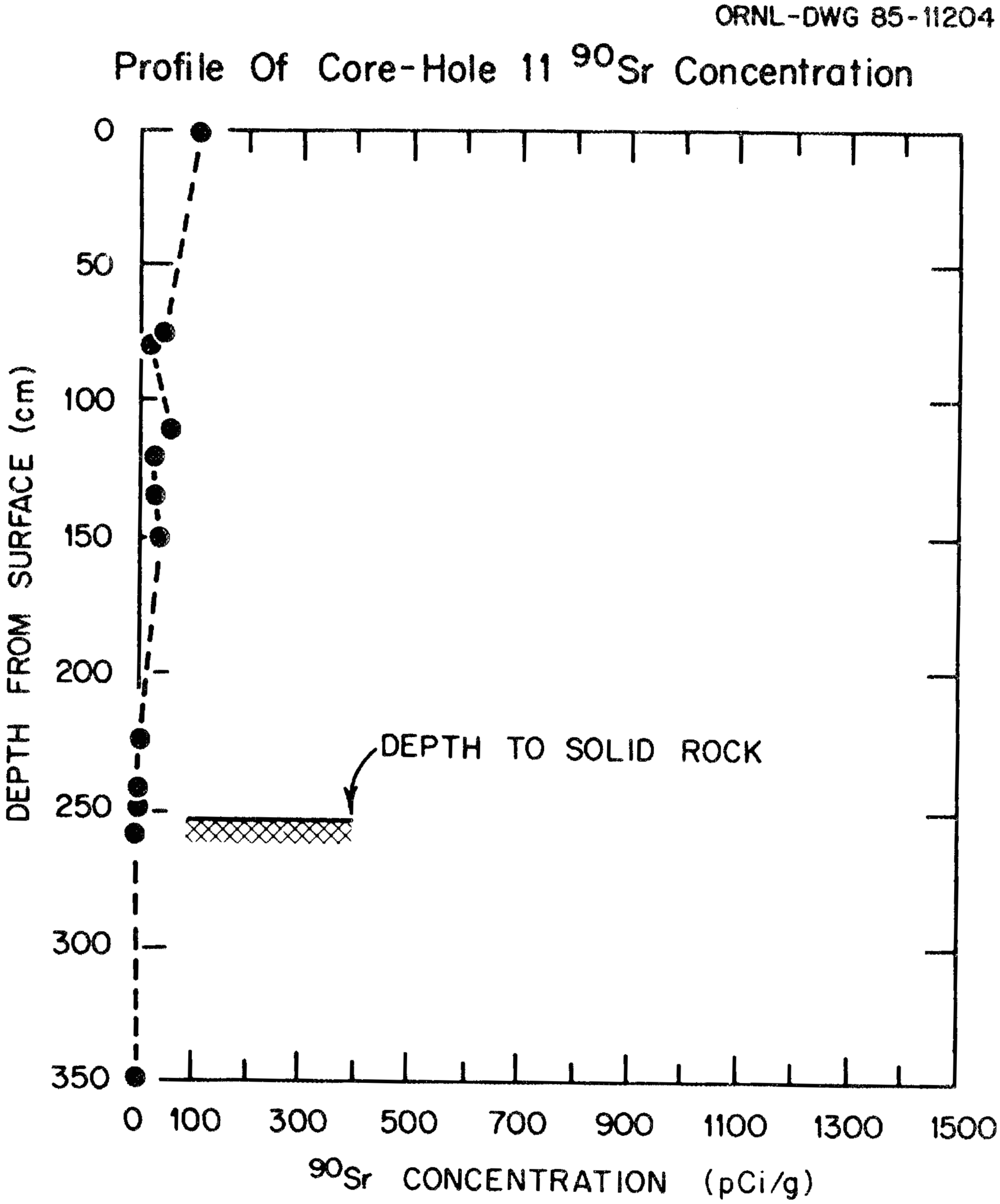

Fig. 21. ^{90}Sr concentration profile for core-hole 11 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

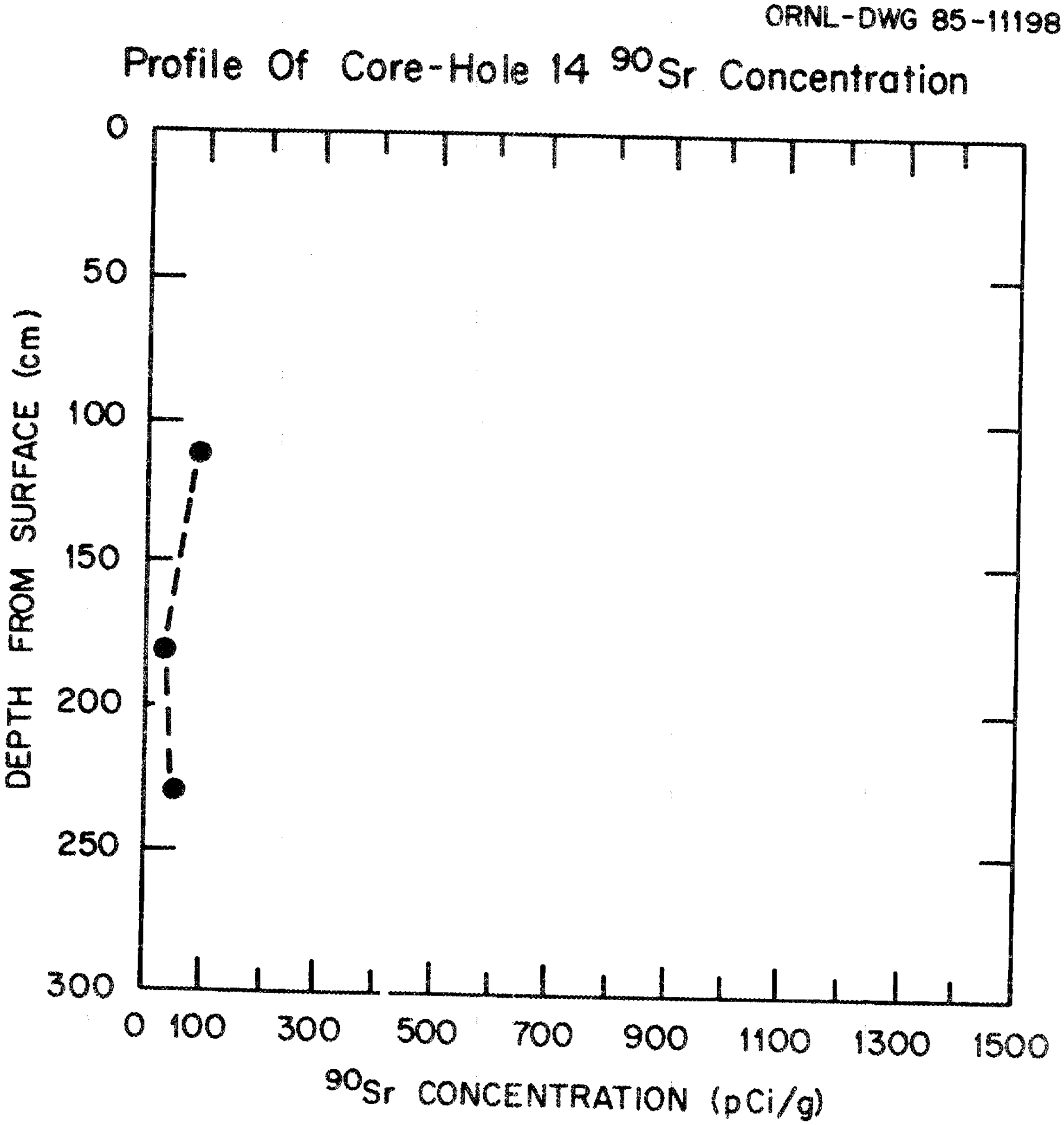

Fig. 22. ^{90}Sr concentration profile for core-hole 14 at the SWSA-4 study area. (1 Bq/kg = 0.02703 pCi/g.)

The ^{90}Sr concentration at core-hole 6 remains relatively constant at approximately 36 Bq/g (960 pCi/g) for the first 80 cm, with the concentration decreasing to 17 Bq/g (460 pCi/g) at 150 cm thereafter. Core-hole 6A shows a widely varying profile, with ^{90}Sr concentrations between 9.81 and 32.0 Bq/g (265 and 865 pCi/g).

The profile from core-hole 7 is somewhat unique in that the concentration decreases from 11.0 to 1.0 Bq/g (297 to 27 pCi/g) in the first 80 cm, and then increases to 11.0 Bq/g (297 pCi/g) again.

The profile at core-hole 8 has a surface concentration of 11.0 Bq/g (297 pCi/g), decreasing to 0.2 Bq/g 5 pCi/g) at 100 cm.

Core-hole 9 shows a very distinct exponential decrease in ^{90}Sr concentration with depth. The surface concentration was 26.0 Bq/g (703 pCi/g), decreasing to 0.2 Bq/g (6 pCi/g) at 250 cm below the surface.

The profiles from core-holes 10 and 10B show a similar exponential effect, with very high surface concentrations of ^{90}Sr [47.0 and 36.0 Bq/g (1270 and 973 pCi/g), respectively].

At core-hole 11, very little change in ^{90}Sr concentration was observed, with the concentration being less than 4.1 Bq/g (110 pCi/g).

At core-hole 14, no surface data were taken, but at 114 cm, the concentration was 3.2 Bq/g (86 pCi/g), and remained relatively constant to a depth of 231 cm.

These profiles show a concentration of ^{90}Sr that is generally greatest at the soil surface and decreases with depth. This pattern would be expected for a bathtubbing trench that overflows and produces contaminated surface runoff that subsequently infiltrates, leading to downward migration.

In addition, some evidence of subsurface transport from trenches exhibiting the bathtub effect does exist. Geologically, SWSA-4 is located in a valley underlain by Pumpkin Valley Shale, a member of the Conasauga Group (Stockdale 1951). The soils generally consist of several layers of varying permeabilities. Data from other studies in a similar geologic setting (Olsen et al 1983) demonstrate flow within very narrow depth intervals such as fractured or weathered layers. The presence of ^{90}Sr profiles such as those for core-holes 6, 6A, and 7 suggests that subsurface migration from bathtubbing trenches is also occurring at SWSA-4.

SUMMARY AND CONCLUSIONS

The data from this study provide clear evidence that the bathtub effect is occurring at some SWSA-4 trenches, and that both surface and subsurface migration pathways exist at the present time. This is in agreement with observations reported in earlier studies (Lomenick and Cowser 1961; Huff et al. 1982; Duguid 1976) and demonstrates the need for further remedial action to control migration at SWSA-4. The contamination patterns shown in Figs. 6, 8-10, and 13-22 give necessary guidance for establishing study sites to quantify the relative importance of the surface and subsurface migration of contaminants from trenches that exhibit the bathtub effect. Now that the surface flow from the drainage headwaters has been diverted, the next step toward further stabilization of contaminant migration from SWSA-4 is to quantify the relative importance of the remaining surface and subsurface pathways. Depending on the results, the most effective corrective measures can be designed. The results presented here provide a firm basis for that work.

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