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RADIOACTIVITY IN BOTTOM SEDIMENTS OF THE CLINCH-TENNESSEE RIVERS

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ABSTRACT

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Low-activity radioactive waste waters are released from the Oak Ridge National Laboratory to the Clinch River via White Oak Creek. Part of the released nuclides eventually settle downstream in the bottom sediments in the Clinch-Tennessee Rivers. Analyses of sediment cores from a 21-mile reach of the Clinch River have shown that there are in the bottom sediments, as of 1 July 1962, 154.6 curies of  $^{137}\text{Cs}$ , 17.5 curies of  $^{60}\text{Co}$ , 15.5 curies of  $^{106}\text{Ru}$ , at least 10.2 curies of rare earths, and 2.9 curies of  $^{90}\text{Sr}$ . These quantities (decay taken into account) represent 21% of the  $^{137}\text{Cs}$ , 9% of the  $^{60}\text{Co}$ , 0.4% of the  $^{106}\text{Ru}$ , possibly 25% or more of the rare earths, and 0.2% of the  $^{90}\text{Sr}$  released to the river during the 20 years of laboratory operations. The total volume of radioactive sediment in the 21-mile reach was 84.8 million cubic feet.

Approximately 95% of the identified radioactivity in the sediment occurs in the most-downstream 15 miles of the Clinch River in the backwaters of Watts Bar Dam. In the upstream, swifter-flowing portion of the reach, radioactive sediment was detected along the sides of the stream channel. The maximum concentration of radionuclides was found near the mouth of White Oak Creek, the point at which the wastes enter the river.

Several sediment cores from the downstream section of the river showed the same general pattern of variation of gross gamma radioactivity with depth. This pattern resembled the pattern of annual laboratory releases of  $^{137}\text{Cs}$ , the most abundant radionuclide in the sediment. The vertical distribution of  $^{60}\text{Co}$

39

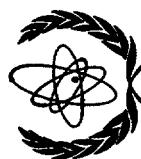
correlated strongly with that of  $^{137}\text{Cs}$ . It is concluded that  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  were incorporated in the sediment by deposition of suspended radioactive solids which entered the river from White Oak Creek.

Cation exchange properties of the sediment are largely controlled by its content of mica and clay minerals. These minerals are found primarily in the finest sediment fraction, but can occur also in the coarser fractions in the form of mineral aggregates and shale particles.

Radioactive nuclides can be released from the sediments only with difficulty and under atypical river conditions. Leaching tests have shown that at pH 6 and 8 with  $\text{HNO}_3$ ,  $\text{HCl}$ ,  $\text{NaCl}$ , and  $\text{NaHSO}_3$  negligible quantities of nuclides, except  $^{90}\text{Sr}$ , were released. At pH 2 and 12 significant amounts of strontium, cobalt, and ruthenium were released.

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downstream from the mouth of White Oak Creek (Fig. 2). Radionuclides detected in the sediment include  $^{137}\text{Cs}$ ,  $^{106}\text{Ru}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ ,  $^{95}\text{Nb}$ , and certain rare earths of the lanthanide series.

The radioactive bottom sediment of the Clinch-Tennessee River system has been investigated as part of the Clinch River Study, a multi-agency effort to evaluate the effect on the river of the introduction of radioactive waste [1, 2, 3, 4, 5, 6]. A knowledge of the amount, distribution, and nature of the radioactive sediment was needed for determining what fraction of the released radionuclides is being retained in the river system, and the locus and duration of retention.

Knowledge of the physical, mineralogical, and chemical composition of the radioactive sediment was required for an understanding of the mechanisms whereby the various radionuclides were incorporated in the sediment.

#### A. Acknowledgements

The information presented in this report represents the collective contribution of the members and staff of the Subcommittee on Bottom Sediment Sampling and Analyses of the Clinch River Study Steering Committee [1]. Contributing agencies include ORNL, the Tennessee Valley Authority (TVA), U. S. Geological Survey (USGS), and the U. S. Public Health Service (USPHS). The study was sponsored by the U. S. Atomic Energy Commission.

Radiochemical analyses of bottom sediment were performed by personnel of the Division of Radiological Health, USPHS, and by personnel of the Low Level Radiochemical Laboratory, Analytical Chemistry Division, ORNL. Other physical and chemical analyses of selected samples of bottom sediment were performed by personnel of the U. S. Geological Survey at the Denver, Colorado laboratories of the Branch of Analytical Laboratories, Geologic Division, and the Raleigh, North Carolina District Water Quality Laboratory, Water Resources Division. The determination of potassium, rubidium, cesium, and strontium in sediment samples were made at the laboratory for X-ray and Spectrochemical Analysis, Analytical Chemistry Division, ORNL. Illustrations for the report were prepared by Graphic Arts Services, ORNL.

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#### 1. INTRODUCTION

Since 1943, when Oak Ridge National Laboratory (ORNL) in eastern Tennessee first began processing radioactive materials, the laboratory has released waste waters containing low-levels of radioactivity to the Clinch River via White Oak Creek (Fig. 1). This waste disposal practice has resulted in the incorporation of some of the introduced radionuclides in fine-grained bottom sediment in the Clinch and Tennessee Rivers

<sup>1/</sup> U. S. Geological Survey; publication of this report authorized by the Director, U. S. Geological Survey.

<sup>2/</sup> Oak Ridge National Laboratory.

<sup>3/</sup> Tennessee Valley Authority.

<sup>4/</sup> U. S. Public Health Service.

<sup>5/</sup> Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

In the interest of brevity, only selected and summary data collected by the Subcommittee are reported here. More complete data can be found in a series of status reports on the Clinch River Study [1, 2, 3, 4, 5], published by ORNL, and in other reports published by the various participating agencies and by individual staff investigators.

Safety aspects of the Clinch River Study have been described in separate reports by the Subcommittee on Safety Evaluation.

## 2. LONGITUDINAL DISTRIBUTION OF RADIONUCLIDES IN RIVER SEDIMENT

Annual surveys of gamma radioactivity at the surface of bottom sediment in the Clinch and Tennessee Rivers have been made by Oak Ridge National Laboratory since 1951, and measurements of the content of the major radionuclides in the surface layer of the sediment at selected cross sections in the two rivers have been made annually since 1954 by ORNL and quarterly from 1959 to 1963 by USPHS. These monitoring surveys have shown that the longitudinal pattern of radioactivity at the surface of the sediment in the two rivers has remained much the same since the first survey was made in 1951. The content of radionuclides in Clinch River bottom sediment upstream from White Oak Creek is minor and is limited to the first two miles upstream from the creek mouth.

The results of radiochemical analyses of samples of the upper portion of the bottom sediment in the Clinch and Tennessee Rivers show that the concentration of total identified radionuclides has varied inversely with cross-sectional area of flowing water. Incorporation of radionuclides in the bottom sediment can take place either through (1) sorption by the sediment of radionuclides carried in solution, or through (2) sedimentation of suspended radioactive solids. With this in mind, downstream decreases in concentration of several individual radionuclides in the Tennessee River were compared with predicted reductions based on: (1) dilution by flow, and (2) dilution by uncontaminated bottom sediment. The observed decreases in concentration of  $^{137}\text{Cs}$ ,  $^{106}\text{Ru}$ ,  $^{60}\text{Co}$ , and rare earths in the sediment were greater than the predicted reduction due to dilution by flow, but not as great as the predicted reduction due to dilution by uncontaminated sediment. Results concerning downstream decreases in concentration of  $^{90}\text{Sr}$  were inconclusive.

The annual monitoring surveys of bottom sediment in the Clinch and Tennessee Rivers have revealed also that concentrations of the major radionuclides in the surface layer of sediment vary with changes in the amounts of the radionuclides released by Oak Ridge National Laboratory.

Figure 3 is a graphical comparison, for the period 1954-63, of annual releases with radionuclide concentrations found annually in the surface layer of sediment. Highest releases of  $^{137}\text{Cs}$  in 1956, 1957, and 1959 are reflected in increased concentrations of the same radionuclide in sediment samples taken during those years. Likewise, the abrupt increase in the amount of  $^{106}\text{Ru}$  released beginning in 1960 is reflected in  $^{106}\text{Ru}$  concentrations in the sediment.

Comparisons of concentrations of  $^{137}\text{Cs}$  measured annually at several cross sections in the Clinch and Tennessee Rivers with annual releases of the radionuclide released by the laboratory, revealed a direct relationship between the two factors. Similar results were obtained using  $^{90}\text{Sr}$ ,  $^{106}\text{Ru}$ , or  $^{141}\text{Ce}$ . It appears that at least as far downstream in the Tennessee River as TRM 349 there is a direct relationship of concentrations of these radionuclides in the sediment to amounts released at White Oak Dam.

Similarities in the longitudinal distributions of several radionuclides in bottom sediment in the Clinch and Tennessee Rivers were studied using data from the 1961 annual survey by ORNL. Preliminary graphical comparison of the concentration of  $^{60}\text{Co}$  with the concentration of  $^{137}\text{Cs}$  at each section indicated a relationship between the two radionuclides. To better measure the relationship, the index of correlation, the standard error of estimate, and the regression coefficient were computed for comparison of the logarithms of the concentrations of these two radionuclides. Similar computations were made for all possible radionuclide pairs. The results of some of these computations, and selected graphical comparisons of radionuclide relationships, are shown in Figure 4. A complete tabulation of the several indices of correlation showed that the choice of other radionuclides, instead of  $^{137}\text{Cs}$ , for use as the independent variable in the graphical comparisons, would have been appropriate.

The slopes of the curves for the logarithmic correlations of  $^{137}\text{Cs}$  to  $^{106}\text{Ru}$ , to the trivalent rare earths, and to  $^{60}\text{Co}$  are nearly the same, and the indices of correlation for these curves are extremely good. These results suggest that similar mechanisms may control the longitudinal distribution of these particular radionuclides. The slopes of the curves for  $^{95}\text{Zr}$ - $^{95}\text{Nb}$  and for  $^{90}\text{Sr}$  in Figure 4 are less than those for  $^{60}\text{Co}$ ,  $^{106}\text{Ru}$ , or the rare earths, indicating that different mechanisms maybe controlling the distribution of zirconium-niobium and strontium in the sediment.

The correlations listed in Figure 4 suggest that the longitudinal distribution in the bottom sediment of several of the radionuclides present may be determined on the basis of the distribution of only one or two of those radionuclides.

### 3. CORE SAMPLING OF CLINCH RIVER SEDIMENT

A series of core samples of relatively undisturbed bottom sediment was taken at 14 sampling sections in the Clinch River during the summer of 1962, in order to study the vertical distribution of radionuclides in the sediment, and to make a complete inventory of radionuclides in the lower Clinch River. The samples were taken by means of a Swedish Foil Sampler [7]. Sampling sections were selected for adequate coverage of the study reach and, wherever possible, were made to coincide with sediment ranges used by the Tennessee Valley Authority (TVA) for periodic measurements of bottom sediment accumulation or erosion.

The most downstream sampling section was at CRM 1.3/<sup>6</sup> and the most upstream section was at CRM 22.8 (Fig. 5). Core samples were taken at two sampling sections in each of two tributary streams, Poplar Creek and Emory River, also. Radioactive waste enters the Clinch River via White Oak Creek at CRM 20.8. The entire study reach of the Clinch River is part of Watts Bar Lake, which is formed by Watts Bar Dam on the Tennessee River (Fig. 2).

<sup>6</sup>/ The abbreviation CRM (Clinch River Mile), followed by a number, has been used in this report to designate distance upstream, in miles, from the mouth of the Clinch River. Similarly, TRM (Tennessee River Mile), followed by a number, also designates distance from the mouth of the stream. This terminology is consistent with prior usage in the Clinch River Study [1,2]. Mileage may be converted to kilometers (approximate) by multiplying by 1.6.

Coring sites at individual sampling sections were selected on the basis of known sediment thicknesses calculated by TVA personnel from sediment range surveys, and the results of sediment-probe measurements and a survey of sediment-surface radioactivity which were made at each sampling section just prior to core sampling.

Radionuclide concentrations in homogenized samples of the radioactive portion of each core were determined and used to compute an inventory of the major radionuclides in the 21-mile study reach. Determinations of gamma-ray emitting nuclides were made by gamma-ray spectrum analysis using a digital computer program developed at ORNL [8]. Determinations of beta-emitting radionuclides were made at ORNL using standard wet chemical separation methods and beta counting.

The vertical distribution of gross gamma radioactivity and of the major gamma-emitting radionuclides in the intact cores was measured by means of a device, known as a core scanner (Fig. 6), that was developed especially for that purpose.

A series of physical and chemical tests, as well as radionuclide analyses, were performed on 23 sediment samples from two cores in order to characterize their compositional variability as an aid in determining the chemical forms and associations of radionuclides in the bottom sediment. Properties measured were the mineralogy, particle-size distribution, cation exchange capacity, leachable cation content, free aluminum oxide content, free iron oxide content, inorganic and organic carbon contents, and the amounts of potassium, rubidium, cesium, and strontium in each of the samples.

#### A. Inventory of radionuclides in Clinch River sediment

Homogenized samples of the radioactive portions of 113 cores from 14 sampling sections in the lower Clinch River were analyzed for radionuclide content. The analytical results were used to compute the total amounts of each of the major radionuclides in the 21-mile reach of river downstream from the mouth of White Oak Creek. Computation of the inventory was facilitated through use of a general purpose digital computer.

The results of the computation of total identified radioactivity in each subreach and in the entire study reach of the river are shown in TABLE I. Total inventoried and identified radioactivity in the 21-mile study reach, from CRM 21.0 to the mouth of the river, is approximately 200 curies, of which  $^{137}\text{Cs}$  constitutes 77 percent;  $^{60}\text{Co}$ , 8.7 percent;

$^{106}\text{Ru}$ , 7.7 percent; rare earths, 5.1 percent; and  $^{90}\text{Sr}$ , 1.5 percent.

The total quantities of individual radionuclides present in the sediment are:  $^{137}\text{Cs}$ , 150 curies;  $^{60}\text{Co}$ , 18 curies;  $^{106}\text{Ru}$ , 16 curies; rare earths, at least 10 curies;  $^{90}\text{Sr}$ , 2.9 curies. The estimated errors (neglecting sampling error) in calculated quantities of individual radionuclides are as follows:  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ , and rare earths, 18 percent;  $^{60}\text{Co}$ , 20 percent;  $^{106}\text{Ru}$ , 29 percent. All quantities have been adjusted for effects of radioactive decay and thus represent the amounts present at the time of sampling (July 1, 1962), except for the rare earths, which are reported as the quantity present at the time of radiochemical analysis (June 1964).

Retention of each radionuclide in Clinch River bottom sediment was computed using the total quantity of the radionuclide released to the river since 1943, corrected for decay. Retention of the various radionuclides, expressed in percent, is as follows:  $^{137}\text{Cs}$ , 21 percent;  $^{60}\text{Co}$ , 9 percent;  $^{106}\text{Ru}$ , 0.4 percent;  $^{90}\text{Sr}$ , 0.2 percent. A good estimate of the retention factor for rare earths was not obtained, because rare-earth mixtures of undetermined composition were involved.

Retention of rare earths may approach, and possibly exceeds, 25 percent. Ninety-five percent of the radioactive sediment in the Clinch River occurs downstream from CRM 15, and at least 60 percent occurs downstream from CRM 9 (see TABLE I). A tendency for mean thickness

of radioactive sediment to increase linearly from the head of the study reach to the mouth of the Emory River (CRM 21.0 to CRM 4.5) appears to exist. The general trend for increasing thickness may be explained by considering hydraulic conditions in the study reach. Accretions to

flow in the study reach are negligible, except for inflow from the Emory River, and flow area increases in the downstream direction. Without accretions to flow and with increasing flow area, velocity and intensity of turbulence of the stream decreases, and consequently sediment transport capacity decreases in the downstream direction. This re-

TABLE I

TOTAL IDENTIFIED RADIOACTIVITY AND VOLUME OF RADIOACTIVE SEDIMENT IN THE LOWER CLINCH RIVER, BY SUBREACHES<sup>1/</sup>

Location of subreach	Total identified radioactivity, in curies			Volume in acre-feet		
	From CRM	To CRM	In subreach	Cumulative	In subreach	Cumulative
0	2.80		22	22	340	340
2.80	5.90		42	64	380	720
5.90	8.95		54	118	480	1,200
8.95	10.95		46	164	430	1,630
10.95	12.00		9.3	173	93	1,720
12.00	13.05		10	183	85	1,810
13.05	15.00		6.8	191	38	1,850
15.00	16.75		2.2	193	33	1,880
16.75	18.35		4.7	198	39	1,920
18.35	19.85		0.1	198	4.7	1,920
19.85	20.65		2.3	200	5.9	1,930
20.65	20.90		0.1	200	1.4	1,930
20.90	21.00		0.2	200	0.3	1,930

<sup>1/</sup> As of July 1, 1962.

sults in deposition of more and finer sediment downstream. The net accumulation of sediment observed in the downstream reaches of the Clinch River is no doubt the result of readjustment of channel shape caused by the filling of Watts Bar Lake, which began at about the same time as release of radioactivity to the Clinch River was started by Oak Ridge National Laboratory.

B. Vertical distribution of radionuclides in Clinch River sediment

1. Gross gamma core scanning

Scanning the intact bottom sediment cores for variations in gross gamma radioactivity with depth revealed the general pattern of variation in each core and provided a basis for determining the thickness of radioactive sediment at each coring site. Variations in gross gamma radioactivity in the cores were great enough to permit the base of the radioactive zone to be picked from plots of the gross gamma scans, and to encourage attempts at gamma spectrum core scanning. In addition, the results of gross gamma core scanning indicated that the entire thickness of radioactive sediment had been sampled in most cores.

The results of gross gamma scanning of core samples from CRM 7.5 are shown in Figure 7. Sediment deposition, and therefore accumulation of radioactive sediment, has been largely confined to the more gently-sloping left half of the stream channel which constituted the side of the former stream channel and a portion of the flood plain of the stream prior to inundation by Watts Bar Lake. (Note that the vertical exaggeration of the cross section plot is 10:1). Portions of the cross section showing a water depth of less than 6 feet are not submerged during the low winter lake levels that are maintained by TVA. The resulting non-deposition of sediment and erosion probably account for the very thin layer of radioactive sediment found in cores from such sites (cores 1 and 2).

Cores 4, 5, 6, and 7-1 in Figure 7 show a persistent general pattern of variation of gross gamma radioactivity with depth. Similar distribution patterns of gross gamma radioactivity were observed in several cores from other sampling sections in the portion of the study reach downstream from CRM 18. The general pattern which they exhibit is strikingly similar to the pattern of annual releases of  $^{137}\text{Cs}$  to the Clinch River as measured at White Oak Dam. This similarity is illustrated in Figure 8 for several of the cores. The zone of highest radioactivity in cores 4, 5, 6, and 7-1 in Figure 7 is assumed to correspond to the period during which releases of  $^{137}\text{Cs}$  were highest--i.e., 1956.

2. Gamma spectrum core scanning

Nine cores were selected for gamma-ray spectrum scanning on the basis of gross gamma scan results. Cores selected were those with a zone of radioactive sediment that was several feet thick and that showed the characteristic pattern of variation in gross gamma radioactivity with depth illustrated in Figures 7 and 8.

Three gamma-emitting radionuclides were present in the bottom sediment in concentrations high enough to provide acceptable data for the full thickness of the radioactive zone in each core scanned; they were  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{106}\text{Ru}$ . Because of its short half-life (1 year),  $^{106}\text{Ru}$  was detected in only the upper portions of most of the cores.

Variations in concentrations with depth of the three radionuclides in a core from Hole 6, CRM 7.5 are illustrated in Figure 9 (compare with Fig. 7); values whose standard deviations represented greater than 75 percent of the analytical values computed prior to collimation correction, have been plotted as zero values.

An examination of the first four plots in Figure 9 demonstrates the relative contributions of the three radionuclides to the total gamma-ray radioactivity of the core. Over 80 percent of the radioactivity is contributed by  $^{137}\text{Cs}$ . The contribution of radioactivity from  $^{106}\text{Ru}$  is

confined to the upper portion of the core. (The isolated positive values for  $^{106}\text{Ru}$  below a depth of 20 inches on the plot are questionable).

Similar results obtained for the eight other cores that were scanned are shown in TABLE II.

The similarity between the distributions of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  with depth in the core can be observed with the aid of the fifth plot in Figure 9, which shows variations in  $^{60}\text{Co}$  concentration with depth at an expanded scale. The same relationship was exhibited by the eight other cores gamma spectrum scanned. Statistical treatment of the relationship between  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  in all nine cores further emphasizes the similarity in distribution of the two radionuclides (see TABLE III). The pattern of variation in the content of  $^{60}\text{Co}$  in the sediment does not strongly resemble the pattern of annual releases of  $^{60}\text{Co}$  to the Clinch River.

#### 4. PHYSICO-CHEMICAL COMPOSITION OF RIVER SEDIMENT

In general, radioactive bottom sediment in the Clinch River may be classed, according to particle size and mineralogical composition, as clayey silt [9] composed of approximately 35 percent mica and other clay minerals and 65 percent quartz. The composition of radioactive bottom sediment in the Tennessee River is believed to be similar.

The results of physical and chemical analyses of 23 samples from two cores of Clinch River sediment selected for detailed study are listed in TABLE IV. The mineralogical compositions and cation exchange capacities of all 23 samples studied showed surprisingly little variation.

#### A. Particle-size distribution

The results of particle-size analyses of the 23 samples studied are shown in TABLE V and Figures 10 and 11. Most of the samples fall in the clayey silt portion of the clay-silt-sand diagram (see Figs. 10 and 11). A diameter of 4 microns was used as the lower limit of silt-size particles [10] in the two figures for the purpose of classification of the sediment according to particle size, which is normally based on hydraulic characteristics.

TABLE II  
FRACTIONAL CONTRIBUTIONS OF  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , AND  $^{106}\text{Ru}$  TO  
TOTAL GAMMA-RAY RADIOACTIVITY OF SELECTED CLINCH RIVER

SEDIMENT CORES					
CRM	Hole number	$^{137}\text{Cs}$ fraction	$^{60}\text{Co}$ fraction	$^{106}\text{Ru}$ fraction	
1.3	3	0.82	0.11	0.07	
1.3	6-3	0.77	0.13	0.10	
7.5	5	0.81	0.13	0.16	
7.5	6	0.82	0.12	0.06	
7.5	7-2	0.77	0.13	0.10	
10.0	2	0.79	0.10	0.11	
14.0	2	0.80	0.13	0.07	
14.0	2-2	0.84	0.11	0.05	
17.5	3-1	0.86	0.10	0.04	
Mean value		0.81	0.12	0.07	

TABLE III

RELATIONSHIP OF  $^{60}\text{Co}$  TO  $^{137}\text{Cs}$  IN SELECTED BOTTOM  
SEDIMENT CORES FROM THE LOWER CLINCH RIVER

CRM	Hole number	Correlation coefficient	Regression coefficient	Ratio of mean concentrations ( $\text{Cs}/\text{Co}$ )
1.3	3	0.62	0.09	7.39
1.3	6-3	0.89	0.12	5.83
7.5	5	0.90	0.13	5.77
7.5	6	0.93	0.13	7.34
7.5	7-2	0.91	0.13	5.86
10.0	2	0.87	0.11	7.83
14.0	2	0.90	0.13	6.37
14.0	2-2	0.87	0.13	7.25
17.5	3-1	0.99	0.09	9.11
Mean value		0.88	0.12	6.97

*Amalgamists by wet setting and bottom withdrawal tube;* *savvyest H. E. Reedie.*

GMR 7.5, Hole No. 7-2		GMR 14.0, Hole 2									
Depth (inches)	Interval (inches)	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000
Percent finer than size indicated, in millimetres											
10-12	12	14	16	18	21	24	26	28	31	34	36
12-14	14	16	18	21	23	25	28	31	34	37	39
14-16	16	18	20	22	24	26	28	31	34	37	40
16-18	18	20	22	24	26	28	30	33	36	39	42
18-20	20	22	24	26	28	30	32	35	38	41	44
20-22	22	24	25	26	27	29	30	32	34	36	38
22-24	24	26	27	28	29	30	31	33	35	37	39
24-26	26	28	29	30	31	32	33	34	35	36	38
26-28	28	29	30	31	32	33	34	35	36	37	39
28-30	29	30	31	32	33	34	35	36	37	38	40
30-32	30	31	32	33	34	35	36	37	38	39	41
32-34	31	32	33	34	35	36	37	38	39	40	42
34-36	32	33	34	35	36	37	38	39	40	41	43
36-38	33	34	35	36	37	38	39	40	41	42	44
38-40	34	35	36	37	38	39	40	41	42	43	45
40-42	35	36	37	38	39	40	41	42	43	44	46
42-44	36	37	38	39	40	41	42	43	44	45	47
44-46	37	38	39	40	41	42	43	44	45	46	48
46-48	38	39	40	41	42	43	44	45	46	47	49
48-50	39	40	41	42	43	44	45	46	47	48	50
50-52	40	41	42	43	44	45	46	47	48	49	51
52-54	41	42	43	44	45	46	47	48	49	50	52
54-56	42	43	44	45	46	47	48	49	50	51	53
56-58	43	44	45	46	47	48	49	50	51	52	54
58-60	44	45	46	47	48	49	50	51	52	53	55
60-62	45	46	47	48	49	50	51	52	53	54	56
62-64	46	47	48	49	50	51	52	53	54	55	57
64-66	47	48	49	50	51	52	53	54	55	56	58
66-68	48	49	50	51	52	53	54	55	56	57	59
68-70	49	50	51	52	53	54	55	56	57	58	60
70-72	50	51	52	53	54	55	56	57	58	59	61
72-74	51	52	53	54	55	56	57	58	59	60	62
74-76	52	53	54	55	56	57	58	59	60	61	63
76-78	53	54	55	56	57	58	59	60	61	62	64
78-80	54	55	56	57	58	59	60	61	62	63	65
80-82	55	56	57	58	59	60	61	62	63	64	66
82-84	56	57	58	59	60	61	62	63	64	65	67
84-86	57	58	59	60	61	62	63	64	65	66	68
86-88	58	59	60	61	62	63	64	65	66	67	69
88-90	59	60	61	62	63	64	65	66	67	68	70
90-92	60	61	62	63	64	65	66	67	68	69	71
92-94	61	62	63	64	65	66	67	68	69	70	72
94-96	62	63	64	65	66	67	68	69	70	71	73
96-98	63	64	65	66	67	68	69	70	71	72	74
98-100	64	65	66	67	68	69	70	71	72	73	75
100-102	65	66	67	68	69	70	71	72	73	74	76
102-104	66	67	68	69	70	71	72	73	74	75	77
104-106	67	68	69	70	71	72	73	74	75	76	78
106-108	68	69	70	71	72	73	74	75	76	77	79
108-110	69	70	71	72	73	74	75	76	77	78	80
110-112	70	71	72	73	74	75	76	77	78	79	81
112-114	71	72	73	74	75	76	77	78	79	80	82
114-116	72	73	74	75	76	77	78	79	80	81	83
116-118	73	74	75	76	77	78	79	80	81	82	84
118-120	74	75	76	77	78	79	80	81	82	83	85
120-122	75	76	77	78	79	80	81	82	83	84	86
122-124	76	77	78	79	80	81	82	83	84	85	87
124-126	77	78	79	80	81	82	83	84	85	86	88
126-128	78	79	80	81	82	83	84	85	86	87	89
128-130	79	80	81	82	83	84	85	86	87	88	90
130-132	80	81	82	83	84	85	86	87	88	89	91
132-134	81	82	83	84	85	86	87	88	89	90	92
134-136	82	83	84	85	86	87	88	89	90	91	93
136-138	83	84	85	86	87	88	89	90	91	92	94
138-140	84	85	86	87	88	89	90	91	92	93	95
140-142	85	86	87	88	89	90	91	92	93	94	96
142-144	86	87	88	89	90	91	92	93	94	95	97
144-146	87	88	89	90	91	92	93	94	95	96	98
146-148	88	89	90	91	92	93	94	95	96	97	99
148-150	89	90	91	92	93	94	95	96	97	98	100
150-152	90	91	92	93	94	95	96	97	98	99	101
152-154	91	92	93	94	95	96	97	98	99	100	102
154-156	92	93	94	95	96	97	98	99	100	101	103
156-158	93	94	95	96	97	98	99	100	101	102	104
158-160	94	95	96	97	98	99	100	101	102	103	105
160-162	95	96	97	98	99	100	101	102	103	104	106
162-164	96	97	98	99	100	101	102	103	104	105	107
164-166	97	98	99	100	101	102	103	104	105	106	108
166-168	98	99	100	101	102	103	104	105	106	107	109
168-170	99	100	101	102	103	104	105	106	107	108	110
170-172	100	101	102	103	104	105	106	107	108	109	111
172-174	101	102	103	104	105	106	107	108	109	110	112
174-176	102	103	104	105	106	107	108	109	110	111	113
176-178	103	104	105	106	107	108	109	110	111	112	114
178-180	104	105	106	107	108	109	110	111	112	113	115
180-182	105	106	107	108	109	110	111	112	113	114	116
182-184	106	107	108	109	110	111	112	113	114	115	117
184-186	107	108	109	110	111	112	113	114	115	116	118
186-188	108	109	110	111	112	113	114	115	116	117	119
188-190	109	110	111	112	113	114	115	116	117	118	120
190-192	110	111	112	113	114	115	116	117	118	119	121
192-194	111	112	113	114	115	116	117	118	119	120	122
194-196	112	113	114	115	116	117	118	119	120	121	123
196-198	113	114	115	116	117	118	119	120	121	122	124
198-200	114	115	116	117	118	119	120	121	122	123	125
200-202	115	116	117	118	119	120	121	122	123	124	126
202-204	116	117	118	119	120	121	122	123	124	125	127
204-206	117	118	119	120	121	122	123	124	125	126	128
206-208	118	119	120	121	122	123	124	125	126	127	129
208-210	119	120	121	122	123	124	125	126	127	128	130
210-212	120	121	122	123	124	125	126	127	128	129	131
212-214	121	122	123	124	125	126	127	128	129	130	132
214-216	122	123	124	125	126	127	128	129	130	131	133
216-218	123	124	125	126	127	128	129	130	131	132	134
218-220	124	125	126	127	128	129	130	131	132	133	135
220-222	125	126	127	128	129	130	131	132	133	134	136
222-224	126	127	128	129	130	131	132	133	134	135	137
224-226	127	128	129	130	131	132	133	134	135	136	138
226-228	128	129	130	131	132	133	134	135	136	137	139
228-230	129	130	131	132	133	134	135	136	137	138	140
230-232	130	131	132	133	134	135	136	137	138	139	141
232-234	131	132	133	134	135	136	137	138	139	140	142
234-236	132	133	134	135	136	137	138	139	140	141	143
236-238	133	134	135	136	137	138	139	140	141	142	144
238-240	134	135	136	137	138	139	140	141	142	143	145
240-242	135	136	137	138	139	140	141	142	143	144	146
242-244	136	137	138	139	140	141	142	143	144	145	147
244-246	137	138	139	140	141	142	143	144	145	146	148
246-248	138	139	140	141	142	143	144	145	146	147	149
248-250	139	140	141	142	143	144	145	146	147	148	150
250-252	140	141	142	143	144	145	146	147	148	149	151

PARTICLE-SIZE ANALYSES OF SELECTED SAMPLES OF BOTTOM SEDIMENT FROM THE CLINCH RIVER

A TYPICAL

Results are on a dry-weight basis except in the case of adsorbed water. Analyses: Osses-E., B. Brackmann, H. C. Stärke, H. K. Meeder, E. J. Remmely, L. C. Frost.

CRM 7.5, Hole No. 7-2														
Depth (m)	Absorbed Dose (mrem/100 g)	Capacitance Content (mrem/100 g)	Capacitance Content (mrem/100 g)	Mineral Content (%)	Total Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	K	Rb	Cs	Sr	<sup>88</sup> Sr	<sup>137</sup> Cs	<sup>90</sup> Co	<sup>138</sup> Ra
10-12	34.0	12.6	0.82	0.85	2.2	2.55	1.89	0.93	1.07	0.0067	0.00044	0.0093	~0.45	37.07
12-20	32.4	12.2	0.75	1.95	5.7	0.28	2.5	2.50	2.22	1.22	1.41	1.98	0.0097	0.81
22-24	35.1	15.1	0.62	0.62	5.6	0.15	2.4	2.8	2.97	2.51	1.61	1.96	0.0098	0.00038
34-36	36.2	16.3	0.63	0.63	5.6	0.15	2.4	2.8	3.05	2.32	1.62	2.02	0.0107	0.00047
36-39	39.7	17.9	0.64	0.64	5.4	0.14	2.4	2.8	3.06	2.48	1.63	2.04	0.0101	0.00048
39-42	40.9	18.8	0.65	0.65	5.3	0.14	2.4	2.8	3.07	2.51	1.64	2.05	0.0102	0.00049
44-46	45.3	19.7	0.66	0.66	5.2	0.14	2.4	2.8	3.08	2.52	1.65	2.06	0.0103	0.00050
46-49	46.2	20.2	0.67	0.67	5.1	0.14	2.4	2.8	3.09	2.53	1.66	2.07	0.0104	0.00051
49-52	47.0	20.7	0.68	0.68	5.0	0.14	2.4	2.8	3.10	2.54	1.67	2.08	0.0105	0.00052
52-55	47.8	21.2	0.69	0.69	4.9	0.14	2.4	2.8	3.11	2.55	1.68	2.09	0.0106	0.00053
55-58	48.6	21.7	0.70	0.70	4.8	0.14	2.4	2.8	3.12	2.56	1.69	2.10	0.0107	0.00054
58-61	49.4	22.2	0.71	0.71	4.7	0.14	2.4	2.8	3.13	2.57	1.70	2.11	0.0108	0.00055
61-64	50.2	22.7	0.72	0.72	4.6	0.14	2.4	2.8	3.14	2.58	1.71	2.12	0.0109	0.00056
64-67	51.0	23.2	0.73	0.73	4.5	0.14	2.4	2.8	3.15	2.59	1.72	2.13	0.0110	0.00057
67-70	51.8	23.7	0.74	0.74	4.4	0.14	2.4	2.8	3.16	2.60	1.73	2.14	0.0111	0.00058
70-73	52.6	24.2	0.75	0.75	4.3	0.14	2.4	2.8	3.17	2.61	1.74	2.15	0.0112	0.00059
73-76	53.4	24.7	0.76	0.76	4.2	0.14	2.4	2.8	3.18	2.62	1.75	2.16	0.0113	0.00060
76-79	54.2	25.2	0.77	0.77	4.1	0.14	2.4	2.8	3.19	2.63	1.76	2.17	0.0114	0.00061
79-82	55.0	25.7	0.78	0.78	4.0	0.14	2.4	2.8	3.20	2.64	1.77	2.18	0.0115	0.00062
82-85	55.8	26.2	0.79	0.79	3.9	0.14	2.4	2.8	3.21	2.65	1.78	2.19	0.0116	0.00063
85-88	56.6	26.7	0.80	0.80	3.8	0.14	2.4	2.8	3.22	2.66	1.79	2.20	0.0117	0.00064
88-91	57.4	27.2	0.81	0.81	3.7	0.14	2.4	2.8	3.23	2.67	1.80	2.21	0.0118	0.00065
91-94	58.2	27.7	0.82	0.82	3.6	0.14	2.4	2.8	3.24	2.68	1.81	2.22	0.0119	0.00066
94-97	59.0	28.2	0.83	0.83	3.5	0.14	2.4	2.8	3.25	2.69	1.82	2.23	0.0120	0.00067
97-100	59.8	28.7	0.84	0.84	3.4	0.14	2.4	2.8	3.26	2.70	1.83	2.24	0.0121	0.00068
100-103	60.6	29.2	0.85	0.85	3.3	0.14	2.4	2.8	3.27	2.71	1.84	2.25	0.0122	0.00069
103-106	61.4	29.7	0.86	0.86	3.2	0.14	2.4	2.8	3.28	2.72	1.85	2.26	0.0123	0.00070
106-109	62.2	30.2	0.87	0.87	3.1	0.14	2.4	2.8	3.29	2.73	1.86	2.27	0.0124	0.00071
109-112	63.0	30.7	0.88	0.88	3.0	0.14	2.4	2.8	3.30	2.74	1.87	2.28	0.0125	0.00072
112-115	63.8	31.2	0.89	0.89	2.9	0.14	2.4	2.8	3.31	2.75	1.88	2.29	0.0126	0.00073
115-118	64.6	31.7	0.90	0.90	2.8	0.14	2.4	2.8	3.32	2.76	1.89	2.30	0.0127	0.00074
118-121	65.4	32.2	0.91	0.91	2.7	0.14	2.4	2.8	3.33	2.77	1.90	2.31	0.0128	0.00075
121-124	66.2	32.7	0.92	0.92	2.6	0.14	2.4	2.8	3.34	2.78	1.91	2.32	0.0129	0.00076
124-127	67.0	33.2	0.93	0.93	2.5	0.14	2.4	2.8	3.35	2.79	1.92	2.33	0.0130	0.00077
127-130	67.8	33.7	0.94	0.94	2.4	0.14	2.4	2.8	3.36	2.80	1.93	2.34	0.0131	0.00078
130-133	68.6	34.2	0.95	0.95	2.3	0.14	2.4	2.8	3.37	2.81	1.94	2.35	0.0132	0.00079
133-136	69.4	34.7	0.96	0.96	2.2	0.14	2.4	2.8	3.38	2.82	1.95	2.36	0.0133	0.00080
136-139	70.2	35.2	0.97	0.97	2.1	0.14	2.4	2.8	3.39	2.83	1.96	2.37	0.0134	0.00081
139-142	71.0	35.7	0.98	0.98	2.0	0.14	2.4	2.8	3.40	2.84	1.97	2.38	0.0135	0.00082
142-145	71.8	36.2	0.99	0.99	1.9	0.14	2.4	2.8	3.41	2.85	1.98	2.39	0.0136	0.00083
145-148	72.6	36.7	1.00	1.00	1.8	0.14	2.4	2.8	3.42	2.86	1.99	2.40	0.0137	0.00084
148-151	73.4	37.2	1.01	1.01	1.7	0.14	2.4	2.8	3.43	2.87	2.00	2.41	0.0138	0.00085
151-154	74.2	37.7	1.02	1.02	1.6	0.14	2.4	2.8	3.44	2.88	2.01	2.42	0.0139	0.00086
154-157	75.0	38.2	1.03	1.03	1.5	0.14	2.4	2.8	3.45	2.89	2.02	2.43	0.0140	0.00087
157-160	75.8	38.7	1.04	1.04	1.4	0.14	2.4	2.8	3.46	2.90	2.03	2.44	0.0141	0.00088
160-163	76.6	39.2	1.05	1.05	1.3	0.14	2.4	2.8	3.47	2.91	2.04	2.45	0.0142	0.00089
163-166	77.4	39.7	1.06	1.06	1.2	0.14	2.4	2.8	3.48	2.92	2.05	2.46	0.0143	0.00090
166-169	78.2	40.2	1.07	1.07	1.1	0.14	2.4	2.8	3.49	2.93	2.06	2.47	0.0144	0.00091
169-172	79.0	40.7	1.08	1.08	1.0	0.14	2.4	2.8	3.50	2.94	2.07	2.48	0.0145	0.00092
172-175	79.8	41.2	1.09	1.09	0.9	0.14	2.4	2.8	3.51	2.95	2.08	2.49	0.0146	0.00093
175-178	80.6	41.7	1.10	1.10	0.8	0.14	2.4	2.8	3.52	2.96	2.09	2.50	0.0147	0.00094
178-181	81.4	42.2	1.11	1.11	0.7	0.14	2.4	2.8	3.53	2.97	2.10	2.51	0.0148	0.00095
181-184	82.2	42.7	1.12	1.12	0.6	0.14	2.4	2.8	3.54	2.98	2.11	2.52	0.0149	0.00096
184-187	83.0	43.2	1.13	1.13	0.5	0.14	2.4	2.8	3.55	2.99	2.12	2.53	0.0150	0.00097
187-190	83.8	43.7	1.14	1.14	0.4	0.14	2.4	2.8	3.56	3.00	2.13	2.54	0.0151	0.00098
190-193	84.6	44.2	1.15	1.15	0.3	0.14	2.4	2.8	3.57	3.01	2.14	2.55	0.0152	0.00099
193-196	85.4	44.7	1.16	1.16	0.2	0.14	2.4	2.8	3.58	3.02	2.15	2.56	0.0153	0.00100
196-199	86.2	45.2	1.17	1.17	0.1	0.14	2.4	2.8	3.59	3.03	2.16	2.57	0.0154	0.00101
199-202	87.0	45.7	1.18	1.18	0.0	0.14	2.4	2.8	3.60	3.04	2.17	2.58	0.0155	0.00102
202-205	87.8	46.2	1.19	1.19	-0.9	0.14	2.4	2.8	3.61	3.05	2.18	2.59	0.0156	0.00103
205-208	88.6	46.7	1.20	1.20	-0.8	0.14	2.4	2.8	3.62	3.06	2.19	2.60	0.0157	0.00104
208-211	89.4	47.2	1.21	1.21	-0.7	0.14	2.4	2.8	3.63	3.07	2.20	2.61	0.0158	0.00105
211-214	90.2	47.7	1.22	1.22	-0.6	0.14	2.4	2.8	3.64	3.08	2.21	2.62	0.0159	0.00106
214-217	91.0	48.2	1.23	1.23	-0.5	0.14	2.4	2.8	3.65	3.09	2.22	2.63	0.0160	0.00107
217-220	91.8	48.7	1.24	1.24	-0.4	0.14	2.4	2.8	3.66	3.10	2.23	2.64	0.0161	0.00108
220-223	92.6	49.2	1.25	1.25	-0.3	0.14	2.4	2.8	3.67	3.11	2.24	2.65	0.0162	0.00109
223-226	93.4	49.7	1.26	1.26	-0.2	0.14	2.4	2.8	3.68	3.12	2.25	2.66	0.0163	0.00110
226-229	94.2	50.2	1.27	1.27	-0.1	0.14	2.4	2.8	3.69	3.13	2.26	2.67	0.0164	0.00111
229-232	95.0	50.7	1.28	1.28	0.0	0.14	2.4	2.8	3.70	3.14	2.27	2.68	0.0165	0.00112
232-235	95.8	51.2	1.29	1.29	-0.9	0.14	2.4	2.8	3.71	3.15	2.28	2.69	0.0166	0.00113
235-238	96.6	51.7	1.30	1.30	-0.8	0.14	2.4	2.8	3.72	3.16	2.29	2.70	0.0167	0.00114
238-241	97.4	52.2	1.31	1.31	-0.7	0.14	2.4	2.8	3.73	3.17	2.30	2.71	0.0168	0.00115
241-244	98.2	52.7	1.32	1.32	-0.6	0.14	2.4	2.8	3.74	3.18	2.31	2.72	0.0169	0.00116
244-247	99.0	53.2	1.33	1.33	-0.5	0.14	2.4	2.8	3.75	3.19	2.32	2.73	0.0170	0.00117
247-250	99.8	53.7	1.34	1.34	-0.4	0.14	2.4	2.8	3.76	3.20	2.33	2.74	0.0171	0.00118
250-253	100.6	54.2	1.35	1.35	-0.3	0.14	2.4	2.8	3.77	3.21	2.34	2.75	0.0172	0.00119
253-256	101.4	54.7	1.36	1.36	-0.2	0.14	2.4	2.8	3.78	3.22	2.35	2.76	0.0173	0.00120
256-259	102.2	55.2	1.37	1.37	-0.1	0.14	2.4	2.8	3.79	3.23	2.36	2.77	0.0174	0.00121
259-262	103.0	55.7	1.38	1.38	0.0	0.14	2.4	2.8	3.80	3.24	2.37	2.78	0.0175	0.00122
262-265	103.8	56.2	1.39	1.39	-0.9	0.14	2.4	2.8	3.81	3.25	2.38	2.79	0.0176	0.00123
265-268	104.6	56.7	1.40	1.40	-0.8	0.14	2.4	2.8	3.82	3.26	2.39	2.80	0.0177	0.00124

TABLE II. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SELECTED SAMPLES OF BOTTOM SEDIMENT FROM THE CLINTON RIVER.

Particle-size analyses were made also of composite samples of 45 Clinch River bottom sediment cores used in computing the inventory of radionuclides in the bottom sediment. Figure 12 is a plot of the results of these analyses. It is apparent that the particle-size distributions in the composite samples, which represent the radioactive portions of cores that were taken throughout a 21-mile reach of river, are more variable than those in the 2-inch thick incremental samples of the two cores studied in detail. Nevertheless, more analyses fall in the clayey silt field of the diagram than in any of the other fields.

#### B. Cation exchange capacity

The cation exchange capacities of the unsized samples from the two cores studied in detail do not vary greatly (see TABLE IV). The cation exchange capacities of the clay- and silt-size fractions of the same samples vary even less (TABLE VI), suggesting that most of the variation in cation exchange capacity of the unsized samples may be due to variations in content of clay-size material, the size fraction with the highest cation exchange capacity.

In the two samples for which the cation exchange capacity of the sand-size sediment fraction was determined, the cation exchange capacity of the silt-size sediment fraction exceeds that of the sand-size fraction. In all samples the cation exchange capacity of the clay-size fraction exceeds that of the silt-size fraction by a ratio of nearly 3:1 (see TABLE VI). These relationships between the various size fractions of the sediment can be largely explained by the relative content of layered aluminosilicate minerals in each size fraction. The ratio of the content of these aluminosilicate minerals in the clay-size fraction to that in the silt-size fraction is also almost 3:1. The higher specific surface area of the clay-size fraction no doubt has modified somewhat the effect of mineralogy on the cation exchange capacity of the sediment.

Because of the methods used for particle-size separation, the data reported in TABLE VI represent the exchange capacities not of the ultimate particle-size fractions of the sediment, but of the size fractions approximately as they existed in the natural environment. A lower limit of 2 microns was used for particle-size separations for exchange capacity and mineralogical determinations because it was believed that data on the

TABLE VI

CATION EXCHANGE CAPACITIES OF CLAY-, SILT-, AND SAND-SIZE FRACTIONS OF SELECTED SAMPLES OF CLINCH RIVER BOTTOM SEDIMENT<sup>1/</sup>

Depth interval (inches)	CRM 7.5, Hole No. 7-2			CRM 14.0, Hole No. 2		
	Sand	Silt	Clay <sup>2/</sup>	Depth interval (inches)	Sand	Silt
10-12	n.d. <sup>3/</sup>	11.7	42.4	4-6	n.d. <sup>3/</sup>	12.0
14-16	n.d.	13.8	33.5	8-10	n.d.	13.5
18-20	n.d.	9.6	37.1	12-14	n.d.	13.2
22-24	n.d.	10.2	33.2	16-18	n.d.	15.1
30-32	n.d.	10.9	33.5	20-22	n.d.	14.2
34-36	7.8	13.9	33.8	24-26	10.5	12.3
40-42	n.d.	8.9	39.2	28-30	n.d.	11.0
44-46	n.d.	14.1	33.4	32-34	n.d.	11.5
50-52	n.d.	14.9	39.1	36-38	n.d.	12.2
52-54	n.d.	12.6	30.0	40-42	n.d.	9.3
56-58	n.d.	11.6	33.4			30.4
60-62	n.d.	10.1	34.2			
62-64	n.d.	11.1	32.2			

1/ Cation exchange capacities determined by means of ammonium chloride leach and measurement of sorbed ammonium after extraction by distillation; separation of sand-size particles by wet sieving of previously dried sample, separation of silt- and clay-size particles by centrifugation; analyst Harry C. Starkey.

2/ Maximum diameter, 2 microns.

3/ n.d., not determined.

finer particles would be more useful in relating particle-size distribution to the physical and chemical characteristics of the sediment.

### C. Mineralogical characteristics

Semi-quantitative determinations of the mineralogical compositions of the clay-, silt-, and sand-size fractions were made for all 23 sediment samples studied in detail. Results of the mineralogical analyses showed that the sand-size sediment fractions of all samples were composed of 70-80 percent quartz with lesser amounts of feldspar, dolomite, and mica. Kaolinite was detected in seven samples.

The silt-size fraction of each sample contained 60-70 percent quartz and lesser amounts of mica, mixed-layered mica-vermiculite, vermiculite (trioctahedral), aluminum-interlayered vermiculite (dioctahedral), kaolinite, feldspar, and dolomite. Calcite was reported in three samples.

The clay-size fractions of each sample contained much less quartz than did the other two size fractions -- 10-20 percent. Mica and kaolinite occurred in approximately the same abundance as quartz, along with slightly lesser amounts of vermiculite (trioctahedral), aluminum-interlayered vermiculite (dioctahedral), and mixed layered mica-vermiculite. Traces of chlorite, montmorillonite, and feldspar were present in many of the samples.

Dolomite was present in the sand-size fraction of the sediment as a minor constituent, probably in the form of detrital grains, and was present in the silt-size fractions of all but 4 of the 23 samples.

Calcite was detected in only a few of the samples; however, calcium carbonate can precipitate in river sediment in a poorly-crystallized form which is not susceptible to detection by X-ray methods.

In order to investigate the possible presence of poorly-crystallized calcium carbonate in Clinch River bottom sediment, the content of carbonate minerals (mineral carbon) in the raw sediment samples was determined by chemical analysis. In all samples, the content of mineral carbon was very low compared to the content of organic carbon (TABLE IV). The presence of dolomite as sand- and silt-size particles suggests that much of the mineral carbon content, as well as the excess of leachable calcium over the cation exchange capacity of the sediment (TABLE IV), was derived from the coarser sediment fractions. Thus, it appears that poorly-crystallized calcium carbonate is not abundant in the finer size fractions of Clinch River bottom sediment. However, its presence even in very small amounts may be significant in retention of radionuclides by the sediment.

Organic matter is an important minor component of Clinch River bottom sediment. Both vegetal material, consisting of individual leaves and leaf mats, twigs, and other woody material, and metabolic products and remains of aquatic animals, are present in the river. Coal is an obvious constituent of the coarser sediment fractions in many places throughout the study reach.

### 5. SORPTION AND RETENTION OF RADIONUCLIDES BY RIVER SEDIMENT

The quantity of a radionuclide sorbed on river sediment might be expected to increase with decreasing particle size of the sediment for two reasons: (1) the relative content of layered aluminosilicate minerals, the mineral group with the highest sorption capacities for many cations, usually increases as the mean particle size of the sediment decreases; (2) in some reactive materials, including several of the layered aluminosilicate minerals and organic matter, sorption capacity varies directly with surface area, which increases as particle size decreases. Dilution of radioactive sediment by non-radioactive sediment is a complicating factor in a study of the relationship of sediment composition to radionuclide content, if some of the sorbed radionuclides are assumed to remain fixed on sediment particles under normal river conditions. Because the proportions of the two kinds of sediment can be expected to vary considerably from place to place, and from time to time at the same place, only a rather imperfect correlation of radionuclide content and sediment composition can be expected at best. The reflection of variations in annual releases by the radionuclide content of the sediment further complicates this relationship. In spite of these complicating factors, a study of variation in radionuclide content of bottom sediment samples from the Tennessee River revealed that more than half of the variation could be explained on the basis of particle size and content of organic matter in the samples. Less than half of the variation in samples from the Clinch River could be explained by the same variables.

The form in which radionuclides have been incorporated in bottom sediment was investigated by means of leaching studies using sediment samples from the Clinch River. Samples of bottom sediment obtained from the mouth of White Oak Creek were leached with tap water at several different

pH values, and with solutions of several different chemical compounds.

Removal of  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{106}\text{Ru}$ , and  $^{90}\text{Sr}$  from the sediment by the various reagents is shown in TABLE VII.

Solutions of salts such as potassium chloride, sodium chloride, and calcium chloride, with concentrations up to 1 M and pH between 6 and 8, removed less than 10 percent of the  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{106}\text{Ru}$  from the sediment. On the other hand, between 30 percent and 77 percent of the  $^{90}\text{Sr}$  in the sediment was removed by the salt solutions, depending on their concentration and pH. Such behavior suggests that strontium is held on the sediment primarily by simple ion exchange, whereas cesium, cobalt, and ruthenium are not. In strong solutions of nitric acid or hydrochloric acid,  $^{60}\text{Co}$  and  $^{90}\text{Sr}$  were released, but  $^{137}\text{Cs}$  and  $^{106}\text{Ru}$  resisted removal. In strongly basic solutions, approximately one-half of the  $^{106}\text{Ru}$  and approximately 15 percent of the  $^{60}\text{Co}$  were removed;  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  were not removed at the high pH. (The 20 percent removal of  $^{90}\text{Sr}$  at pH 8 using ammonium hydroxide was not confirmed by later tests.)

Cesium sorption by river sediment may be regarded as an ion-exchange reaction complicated by exchange sites that have extremely high affinity for cesium. These sites are present in layered aluminosilicate minerals that have a c-spacing of 10 angstroms [1]. For example, in the mineral illite, potassium at the edges of the crystallite can be exchanged for cesium. Actually less than one percent of the potassium is exchangeable, and this comprises only 10 percent of the exchange capacity. But once bonded in the interlayer site near the edges, cesium is difficult to replace or remove, and with longer contact time the cesium diffuses further into the lattice and removal becomes even more difficult. The minerals illite and muscovite can even resist the attack of acids and retain their cesium. It is believed that the cesium in the river is fixed in such exchange sites on illite and mica.

Neutral salt solutions were not effective in removing  $^{60}\text{Co}$  from the sediment, thus indicating that simple ion exchange is probably not the primary manner of uptake of  $^{60}\text{Co}$  by the sediment. In other, independent studies, Jenne and Wahlberg [2] have noted that during the progressive extraction of manganese and iron oxides from bottom sediment from White Oak Creek,  $^{60}\text{Co}$  was extracted also. A study of extraction rates indicated that more of the  $^{60}\text{Co}$  occurred in association with manganese oxides than with iron oxides. Tiller and Hodgson [3] have shown that cobalt can

TABLE VII  
REMOVAL OF  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{106}\text{Ru}$ , AND  $^{90}\text{Sr}$  FROM CLINCH RIVER  
BOTTOM SEDIMENT BY SELECTED REAGENTS<sup>1/</sup>

Reagent	Concentration (molarity)	pH	Percent removed			
			$^{60}\text{Co}$	$^{137}\text{Cs}$	$^{106}\text{Ru}$	$^{90}\text{Sr}$ <sup>2/</sup>
Tap water	6 ( $\text{HNO}_3$ )	2.8	---	3.0	21.3	
Tap water	2 ( $\text{HNO}_3$ )	64.6	---	3.1	80.9	
Tap water	1 ( $\text{HNO}_3$ )	78.1	3.3	5.5		
Tap water	6 ( $\text{HCl}$ )	---	---	3.5	19.4	
Tap water	2 ( $\text{HCl}$ )	65.6	---	4.1	89.9	
Tap water	7.7 (Natural)	---	---	4.5	11.0	
$\text{NaHSO}_3$	6	16.8	---	9.8	37.7	
$\text{K}_2\text{Cr}_2\text{O}_7$	0.1	5.6	5.9	1.7	4.7	73.1
$\text{CaCl}_2$	0.1	7	6.4	---	4.1	58.6
$\text{CaCl}_2$	1.0	7	4.7	---	4.4	76.9
$\text{NaCl}$	0.1	6	3.5	0.8	4.1	39.2
$\text{NaCl}$	0.1	8	---	5.7	6.8	30.1
$\text{NaCl}$	1.0	6	---	0.7	3.9	63.1
$\text{NaCl}$	1.0	8	---	0.6	5.1	56.0
$\text{KCl}$	0.1	6.2	---	0.7	2.8	53.0
$\text{KCl}$	1.0	6.2	3.0	1.7	2.5	68.7
$\text{NaOH}$	8	---	0.4	5.9	6.0	
$\text{NaOH}$	12	16.5	3.1	46.6	4.9	
$\text{NH}_4\text{OH}$	8	---	0.7	8.2	20.0 <sup>4/</sup>	
$\text{NH}_4\text{OH}$	11.8	17.2	4.5	45.1	3.5	
Ethyl alcohol				0.9	<1	
Acetone				1.0		

<sup>1/</sup> 50 grams (oven-dry equiv.) of sediment from CRM 20.8 contacted for 24 hours with 400 ml of solution. Sediment contained (in dis/min 50g, oven-dry basis):  $^{60}\text{Co}$ , 16,600;  $^{137}\text{Cs}$ , 118,000;  $^{103-106}\text{Ru}$ , 129,000;  $^{90}\text{Sr}$ , 2,405;  $^{144}\text{Ce}$ , 4,145; trivalent rare earths, 24,190. Sediment remained moist prior to leaching tests.

<sup>2/</sup> Determinations of  $^{90}\text{Sr}$  performed at the Low Level Radiochemistry Laboratory, Analytical Chemistry Division, ORNL -- J. H. Moneyham, analyst.

<sup>3/</sup> --- Concentration below detectable limits.

<sup>4/</sup> Not confirmed by subsequent tests.

penetrate into the crystal lattices of several minerals. Precipitation of cobalt hydroxide from solutions with a pH above 9, and co-precipitation with calcium carbonate are still other possible means of incorporation of  $^{60}\text{Co}$  in bottom sediment. But data concerning these processes are not yet sufficient for an evaluation of their relative importance.

Tap water at pH 2 (treated Clinch River water from CRM 41.5)

removed more  $^{90}\text{Sr}$  from Clinch River bottom sediment than did solutions of 1 M calcium chloride, 1 M sodium chloride, or 1 M potassium chloride.

Previous studies have suggested that  $^{90}\text{Sr}$  held by simple ion exchange should be removed equally or perhaps more efficiently by calcium chloride than by tap water adjusted to pH 2. The observed results suggest that another mechanism, in addition to ion exchange on aluminosilicate minerals, is operative in the incorporation of  $^{90}\text{Sr}$  in the river sediment.

Studies of removal of  $^{90}\text{Sr}$  from simulated waste solutions have shown that precipitation of calcium carbonate from the solution is effective in removing  $^{90}\text{Sr}$  from solution. Because dissolution of the precipitate is required to release the  $^{90}\text{Sr}$ , neutral salt solutions would not be very effective in removing the  $^{90}\text{Sr}$  that is incorporated in precipitated calcium carbonate. Solutions containing calcium ions would be even less effective than solutions containing other cations because of the common ion effect. Leaching of Clinch River sediment containing  $^{90}\text{Sr}$  associated both with aluminosilicate minerals and with precipitated calcium carbonate, with salt solutions, would remove only the  $^{90}\text{Sr}$  associated with the aluminosilicate minerals. Leaching with tap water at pH 2 would remove the  $^{90}\text{Sr}$  from both sources, thus accounting for the results shown in TABLE VII.

Leaching experiments with calcium chloride solutions have indicated the relative importance of the two mechanisms of  $^{90}\text{Sr}$  retention in sediment samples. Leaching of a sample of bottom sediment from White Oak Lake with 1 M calcium chloride released only 35 percent of the  $^{90}\text{Sr}$  in the sample, but leaching of a sediment sample from the mouth of White Oak Creek removed 77 percent of its  $^{90}\text{Sr}$ . These results suggest that a greater percentage of the  $^{90}\text{Sr}$  in the White Oak Lake sediment sample was incorporated in calcium carbonate than in the sample from the mouth of White Oak Creek. A chemical analysis of the two samples revealed

that the sediment from White Oak Lake contained 4.22 percent calcium carbonate, and the sediment from the mouth of the creek, 0.6 mile further downstream, contained only 1.77 percent calcium carbonate.

Further evidence of the importance of calcite in retention of radionuclides in Clinch River bottom sediment was provided by a deposit of calcite that precipitated from Clinch River water on a bimetallic object. A radiochemical analysis of the calcite showed it to contain 123.9 picocuries per gram of  $^{103-106}\text{Ru}$  and 10.1 picocuries per gram of  $^{90}\text{Sr}$  [14]. This radionuclide content is within the range commonly found in suspended sediment in Clinch River water downstream from the mouth of White Oak Creek. In the case cited, precipitation of the calcite may have been the result of local electrochemical action between the two metals and the river water.

The results of the studies described above, and the significant content of  $^{90}\text{Sr}$  and  $^{106}\text{Ru}$  in calcium carbonate precipitated in the Clinch River, illustrate the need for further study of the role which calcium carbonate plays in incorporation of radionuclides in bottom sediment in the Clinch and Tennessee Rivers.

Basic solutions were found to be most effective for removal of  $^{106}\text{Ru}$  from the sediment. Previous studies of ruthenium from waste seepage systems at ORNL have shown that the ruthenium is not present as ruthenium nitrate or ruthenium chloride salts. Paper partition chromatography methods for the identification of ruthenium complexes have indicated that the ruthenium in the waste is either nitrosyl ruthenium hydroxide —  $(\text{RuNO(OH)}_3(\text{H}_2\text{O})_2$  — or mono nitroato nitrosyl ruthenium hydroxide —  $(\text{Ru}(\text{NO}_3)_3\text{OH})(\text{H}_2\text{O})_2$ . The mono nitroato nitrosyl ruthenium is reported by Story and Glynn [15] to be cationic and exchangeable. The low desorption of  $^{106}\text{Ru}$  from the sediment in neutral salt solutions suggests that the ruthenium is not easily exchangeable and thus implies that the sorbed  $^{106}\text{Ru}$  may be in the nitrosyl ruthenium hydroxide form, which could be present in the sediment as a fine-grained precipitate. The analysis of calcium carbonate that was precipitated in the Clinch River has indicated that  $^{106}\text{Ru}$  can be incorporated in precipitated calcite, also.

## 6. CONCLUSIONS

Radiochemical analyses of water samples collected weekly at White Oak Dam for a period of two years indicate that on the average nearly 70 percent of the  $^{137}\text{Cs}$  present in the water is associated with suspended

radiochemical analyses of water samples collected weekly at White Oak Dam for a period of two years indicate that on the average nearly 70 percent of the  $^{137}\text{Cs}$  present in the water is associated with suspended

solids having a diameter greater than 0.7 micron [16]. Cesium is known to be preferentially sorbed by layered aluminosilicate minerals in which the c-axis spacing is 10 angstroms [1]. Such minerals are abundant in White Oak Creek basin [17, 18]. Furthermore, this sorption reaction is known to be time dependent and only slowly reversible. It is safe to assume, then, that incorporation of  $^{137}\text{Cs}$  in Clinch River bottom sediment is primarily a result of sedimentation of suspended radioactive aluminosilicate minerals which enter the river in water from White Oak Creek.

The year of highest release of  $^{137}\text{Cs}$  to the Clinch River was 1956. This high release resulted from the draining of White Oak Lake during the latter half of 1955 [19], and exposure to erosion of the accumulation of fine sediment on the lake bottom. Rapid erosion of the exposed radioactive lake sediment during the subsequent period of high winter rainfall resulted in an increase in the quantity of radioactive sediment entering the Clinch River, and higher content of  $^{137}\text{Cs}$  in bottom sediment deposited in the river during 1956. Through the operation of processes such as this, variations in annual releases of  $^{137}\text{Cs}$  have been recorded as variations in the vertical distribution of the  $^{137}\text{Cs}$  in the bottom sediment in portions of the river where more or less regular and persistent deposition of sediment has taken place.

The pattern of variation in the content of  $^{60}\text{Co}$  in the sediment does not strongly resemble the pattern of annual releases of  $^{60}\text{Co}$  to the Clinch River. The most striking feature of the pattern of  $^{60}\text{Co}$  variation in the cores which were gamma spectrum scanned is its great similarity to the pattern of  $^{137}\text{Cs}$  variation. This similarity suggests that  $^{60}\text{Co}$ , like  $^{137}\text{Cs}$ , was incorporated in Clinch River bottom sediment primarily by sedimentation of suspended solids that had obtained their content of  $^{60}\text{Co}$  before entering the Clinch River. It also suggests that a rather small fraction of the total  $^{60}\text{Co}$  released to the river became incorporated in Clinch River bottom sediment; otherwise, distribution of  $^{60}\text{Co}$  in the cores would resemble the pattern of annual releases of  $^{60}\text{Co}$  to the river. This second suggestion is supported by the results of the inventory of radionuclides in Clinch River bottom sediment. The  $^{60}\text{Co}$  in bottom sediment in the Clinch and Tennessee Rivers is not necessarily associated with the same type of solids as that with which  $^{137}\text{Cs}$  is associated, however.

On the basis of the information reported in this paper, the following conclusions can be drawn:

- (1) There were in the Clinch River, as of July 1, 1962, approximately 200 curies of identified radionuclides. This total includes 150 curies of  $^{137}\text{Cs}$ , 18 curies of  $^{60}\text{Co}$ , 16 curies of  $^{106}\text{Ru}$ , at least 10 curies of rare earths, and 2.9 curies of  $^{90}\text{Sr}$ . These quantities represent 21 percent of the  $^{137}\text{Cs}$ , 9 percent of the  $^{60}\text{Co}$ , 0.4 percent of the  $^{106}\text{Ru}$ , possibly 25 percent or more of the rare earths, and 0.2 percent of the  $^{90}\text{Sr}$  released to the river during the 20 years of laboratory operations. Approximately 95 percent of the identified radioactivity in the sediment occurs in the most downstream 15 miles of the river. The maximum concentration of radionuclides is located near the mouth of White Oak Creek, where the radioactive waste waters enter the Clinch River.
- (2) Variations in gross gamma radioactivity with depth in Clinch River bottom sediment largely reflect variations in the content of  $^{137}\text{Cs}$  in the sediment. A similar pattern of variation with depth in the content of  $^{137}\text{Cs}$  in the sediment at several coring sites in the reach of river downstream from CRM 18 indicates more or less regular, persistent deposition of sediment at those particular sites, and thus long-term net accumulation of sediment at those sampling sections.
- (3) Incorporation of  $^{137}\text{Cs}$  in Clinch River bottom sediment by sedimentation of cesium-bearing aluminosilicate minerals entering the Clinch River from the Oak Ridge National Laboratory is indicated by: (a) the similarity of the patterns of variations with depth in  $^{137}\text{Cs}$  content of bottom sediment cores to the pattern of annual releases of  $^{137}\text{Cs}$  from the Laboratory to the Clinch River, (b) the knowledge that at least 70 percent of the  $^{137}\text{Cs}$  released from the Laboratory to the Clinch River was associated with suspended solids, and (c) the known preferential sorption of cesium by certain layered aluminosilicate minerals.

- (4) The similarity of the distribution pattern of  $^{60}\text{Co}$  to that of  $^{137}\text{Cs}$  in Clinch River bottom sediment suggests that  $^{60}\text{Co}$  may be incorporated in the sediment by deposition of suspended solids entering the Clinch River from White Oak Creek. The two radionuclides are not necessarily associated with the same solids, however. The fact that the distribution pattern of  $^{60}\text{Co}$  does not reflect the pattern of annual releases of  $^{60}\text{Co}$  from White Oak Creek implies that most of the  $^{60}\text{Co}$  released to the Clinch River is not associated with suspended sediment large enough to be deposited in the Clinch River. This is confirmed by the results of an inventory of radionuclides in Clinch River bottom sediment, which indicates that a rather small fraction of the total  $^{60}\text{Co}$  released to the river becomes incorporated in Clinch River bottom sediment.
- (5) Incorporation of  $^{90}\text{Sr}$  in Clinch River bottom sediment is primarily by simple cation exchange reactions, but significant quantities may be present in calcium carbonate that has precipitated from the river water.
- (6) The  $^{106}\text{Ru}$  that is contained in bottom sediment in the Clinch and Tennessee Rivers probably was incorporated through one or more of the following mechanisms: (1) sedimentation of radioactive solids suspended in White Oak Creek water, (2) precipitation of a ruthenium-bearing compound from Clinch River water, (3) an ion-exchange reaction between Clinch River water and bottom sediment. Some or all of the  $^{106}\text{Ru}$  in bottom sediment may be present in the form of nitrosyl ruthenium hydroxide-- $\text{Ru}(\text{NO(OH})_3(\text{H}_2\text{O})_2$ <sup>-</sup> which is presumed to have formed as a result of the high nitrate content of the original waste solutions.
- (7) Cation exchange properties of Clinch River bottom sediment are largely controlled by its content of mica and other clay minerals. These minerals are found primarily in the finest sediment fraction, but occur also in the coarser fractions in the form of mineral aggregates and shale particles. Calcium and magnesium are the major leachable cations in the sediment; potassium and sodium are not present in measurable quantities.
- (8) Most radionuclides in the sediment are released only in solutions whose compositions are outside the range of river water. Only  $^{90}\text{Sr}$  is susceptible to leaching by solutions in the compositional range expected in river water.

## REFERENCES

- 1 MORTON, R. J., ed., Status report no. 1 on Clinch River Study, U. S. Atomic Energy Comm. ORNL-3119 (1961).
- 2 MORTON, R. J., ed., Status report no. 2 on Clinch River Study, U. S. Atomic Energy Comm. ORNL-3202 (1962).
- 3 MORTON, R. J., ed., Status report no. 3 on Clinch River Study, U. S. Atomic Energy Comm. ORNL-3370 (1962).
- 4 MORTON, R. J., ed., Status report no. 4 on Clinch River Study, U. S. Atomic Energy Comm. ORNL-3409 (1963).
- 5 MORTON, R. J., ed., Status report no. 5 on Clinch River Study, U. S. Atomic Energy Comm. ORNL-3721 (1965).
- 6 PICKERING, R. J., CARRIGAN, P. R., Jr., PARKER, F. L., The Clinch River Study--an investigation of the fate of radionuclides released to a surface stream, U. S. Geol. Survey Circular 497 (1965).
- 7 PICKERING, R. J., "Use of the Swedish Foil Sampler for taking undisturbed cores of river bottom sediments", Proc. of Federal Inter-Agency Sedimentation Conf., 1963, U. S. Dept. of Agriculture Miscellaneous Publication No. 970 (1965) 586.
- 8 SCHONFIELD, E., KIBBEY, A. H., DAVIS, W., Jr., Determination of nuclide concentrations in solutions containing low levels of radioactivity by least-squares resolution of the gamma-ray spectra, U. S. Atomic Energy Comm. ORNL-60-6-93 (1965).
- 9 SHEARD, F. P., Nomenclature based on sand-silt-clay ratios, J. Sediment. Petrology 24 (1954) 151.
- 10 LANE, E. W., chm., Report of the Subcommittee on Sediment Terminology, Am. Geophys. Union Trans. 28 6 (1947) 937.
- 11 TAMURA, T., JACOBS, D. G., Structural implications in cesium sorption, Health Physics 2 (1960) 391.

- 12 JENNE, E. A., WAHLBERG, J. S., Manganese and iron oxide scavenging  
of cobalt 60 in White Oak Creek sediment (Oak Ridge, Tenn.) [abs.] ,  
Am. Geophys. Union Trans. 46 1 (1965) 170.
- 13 TILLER, K. G., HODGSON, J. F., "The specific sorption of cobalt and  
zinc by layer silicates", Internat'l. Ser. of Monographs on Earth  
Sci. 11, Proc. of 9th Natl. Conf. on Clays and Clay Minerals,  
1960, Pergamon Press, New York (1962) 393.
- 14 PARKER, F. L., BLANCO, R. E., Waste treatment and disposal progress  
report for November-December 1962, and January 1963, U. S. Atomic  
Energy Comm. ORNL-TM-516 (1963) 105.
- 15 STORY, A. H., GLOOMA, E. F., Radioactivity transport in water,  
environmental behavior of nitrosylruthenium, Univ. of Texas, Tech.  
Rept. 3 (1963).
- 16 CHURCHILL, M. A., CRAGWALL, J. S., Jr., ANDREW, R. W., Jr., JONES,  
S. L., Concentrations, total stream loads, and mass transport of  
radionuclides in the Clinch and Tennessee Rivers, U. S. Atomic  
Energy Comm. ORNL-3721, Supplement 1 (1965).
- 17 JACOBS, D. G., Sorption of cesium by Conasauga shale, Health  
Physics 4 (1960) 157.
- 18 MCMASTER, W. M., WALLER, H. D., Geology and soils of White Oak  
Creek basin, Tennessee, U. S. Atomic Energy Comm. ORNL-TM-1108  
(1965).
- 19 CORRELL, W. D., Radioactivity in silt of the Clinch and Tennessee  
Rivers, U. S. Atomic Energy Comm. ORNL-2847 (1959) 39.

## LIST OF FIGURE CAPTIONS

- Figure 1. Map of Clinch River in the vicinity of Oak Ridge  
National Laboratory-----
2. Map of Tennessee River system in eastern Tennessee-----
3. Graphs showing releases of major radionuclides  
from Oak Ridge National Laboratory and concentra-  
tions found in Clinch and Tennessee River bottom  
sediment, 1954-63 monitoring years. Monitoring  
year extends from July 1 of preceding year to  
June 30 of year shown. Sediment samples were  
collected in June of year shown-----
4. Correlations showing similarity in the relative  
concentrations of radionuclides in bottom sediment  
in the Clinch and Tennessee Rivers. Rare earths  
include  $^{90}\text{Y}$ , but not  $^{144}\text{Ce}$ -----
5. Map showing locations of bottom sediment core  
sampling sections in the Clinch River-----
6. Diagrammatic representation of core scanner-----
7. Section at CRM 7.5 showing penetration, recovery,  
and gross gamma radioactivity variations with  
depth for 1962 bottom sediment core samples  
(vertical exaggeration 10:1)-----
8. Graphical comparison of patterns of variation with  
depth of gross gamma radioactivity in four bottom  
sediment cores to variations in annual releases  
of  $^{137}\text{Cs}$  to the Clinch River. Annual releases  
on calendar year basis-----
9. Graphs showing variations in concentrations of  
 $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{106}\text{Ru}$  with depth in Hole 6,  
CRM 7.5-----

Figure captions - continued

- Figure 10. Diagram showing results of particle-size analyses of selected samples from Hole 7-2, CRM 7.5.  
Nomenclature after Shepard [9]. Sand >62 microns-----diameter, silt 4-62 microns, clay <4 microns-----
- II. Diagram showing results of particle-size analyses of selected samples from Hole 2, CRM 14.0.  
Nomenclature after Shepard [9]. Sand >62 microns-----diameter, silt 4-62 microns, clay <4 microns-----
12. Diagram showing results of particle-size analyses of composite samples of the radioactive portions of 45 cores of Clinch River bottom sediment.  
Nomenclature after Shepard [9]. Sand >62 microns-----diameter, silt 4-62 microns, clay <4 microns-----

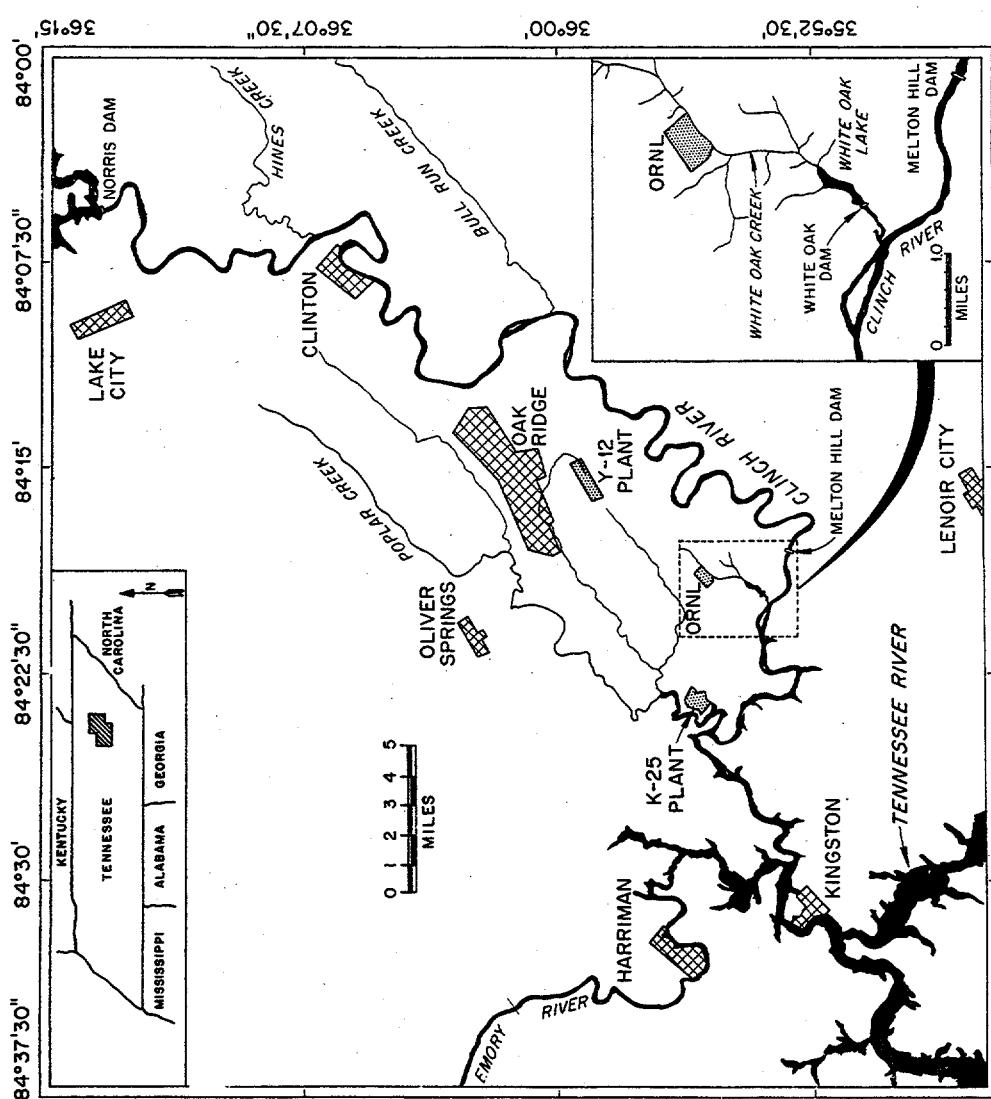


Fig. 1

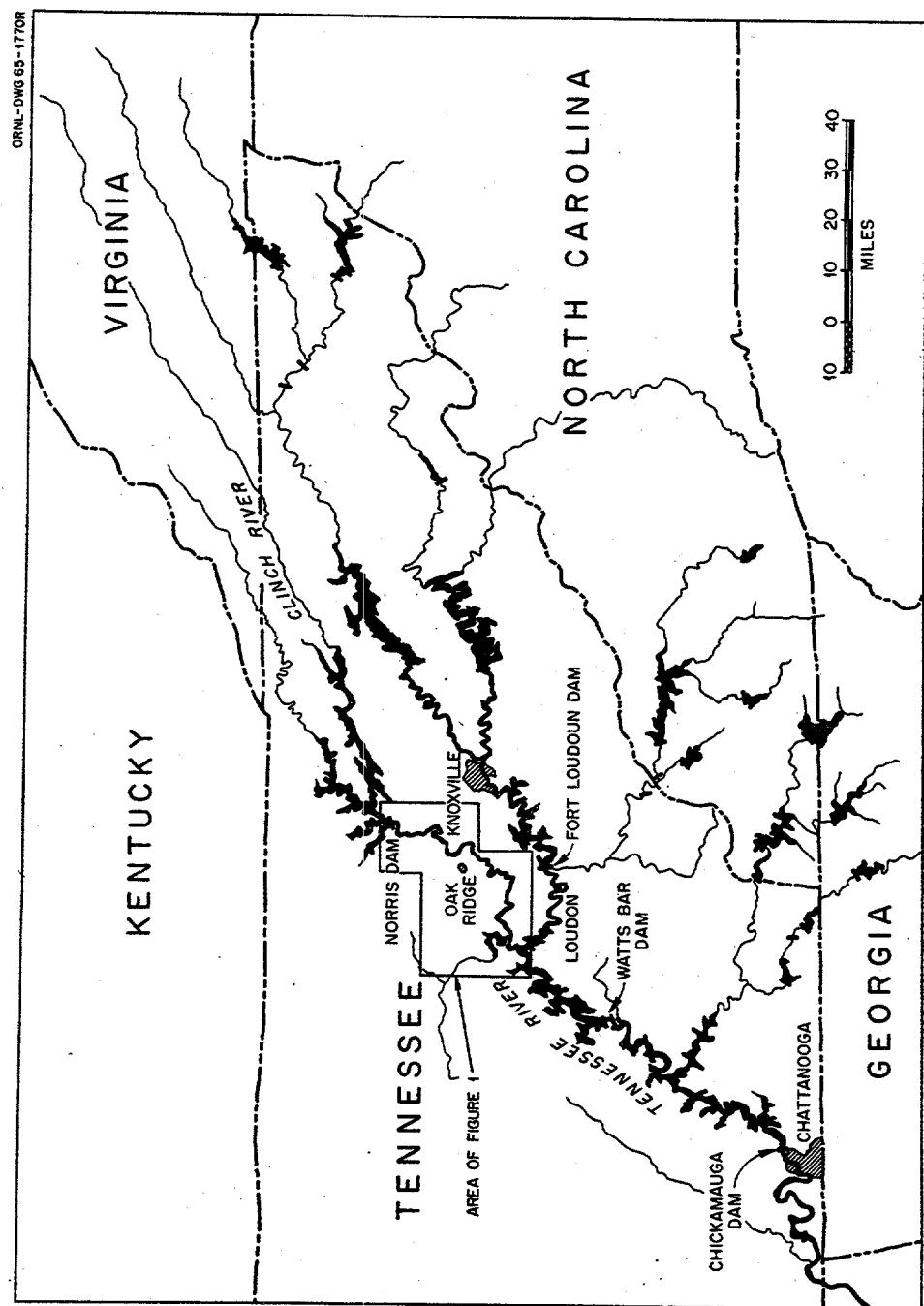


Fig. 2

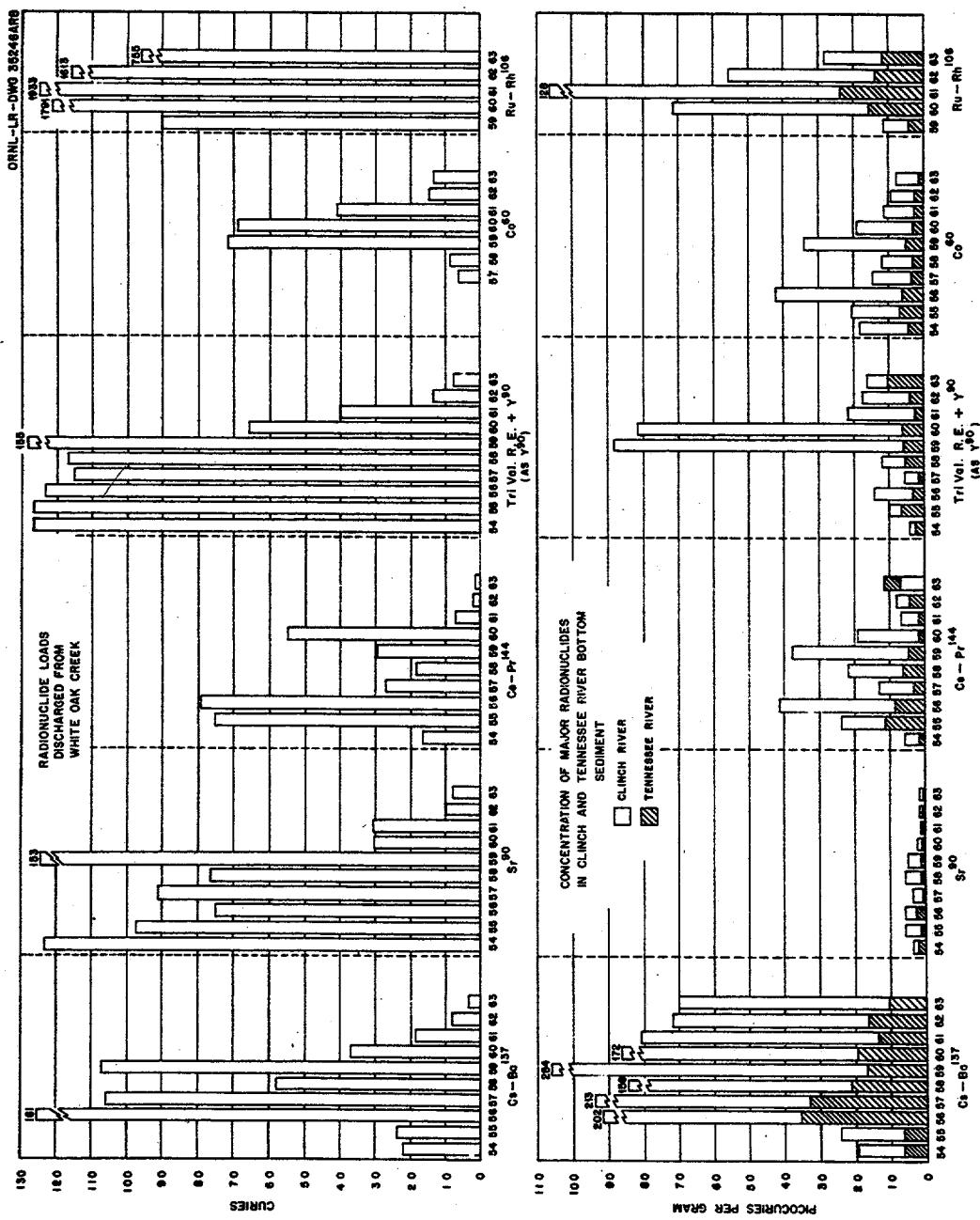
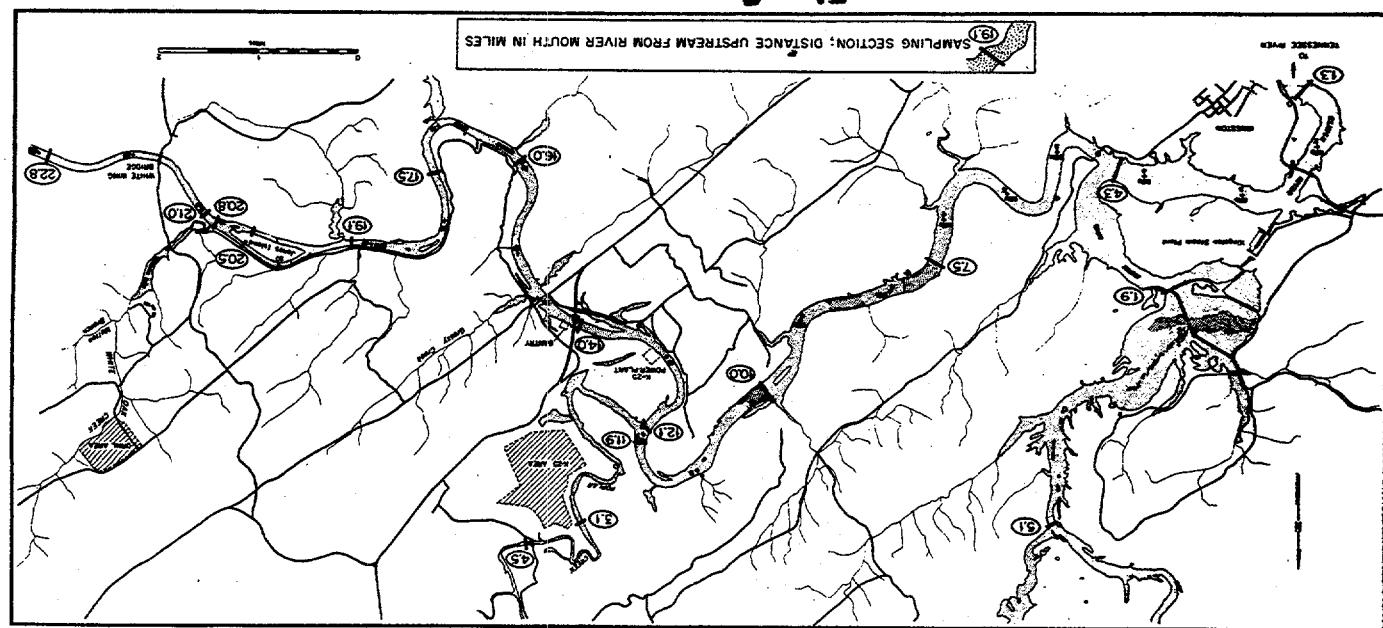
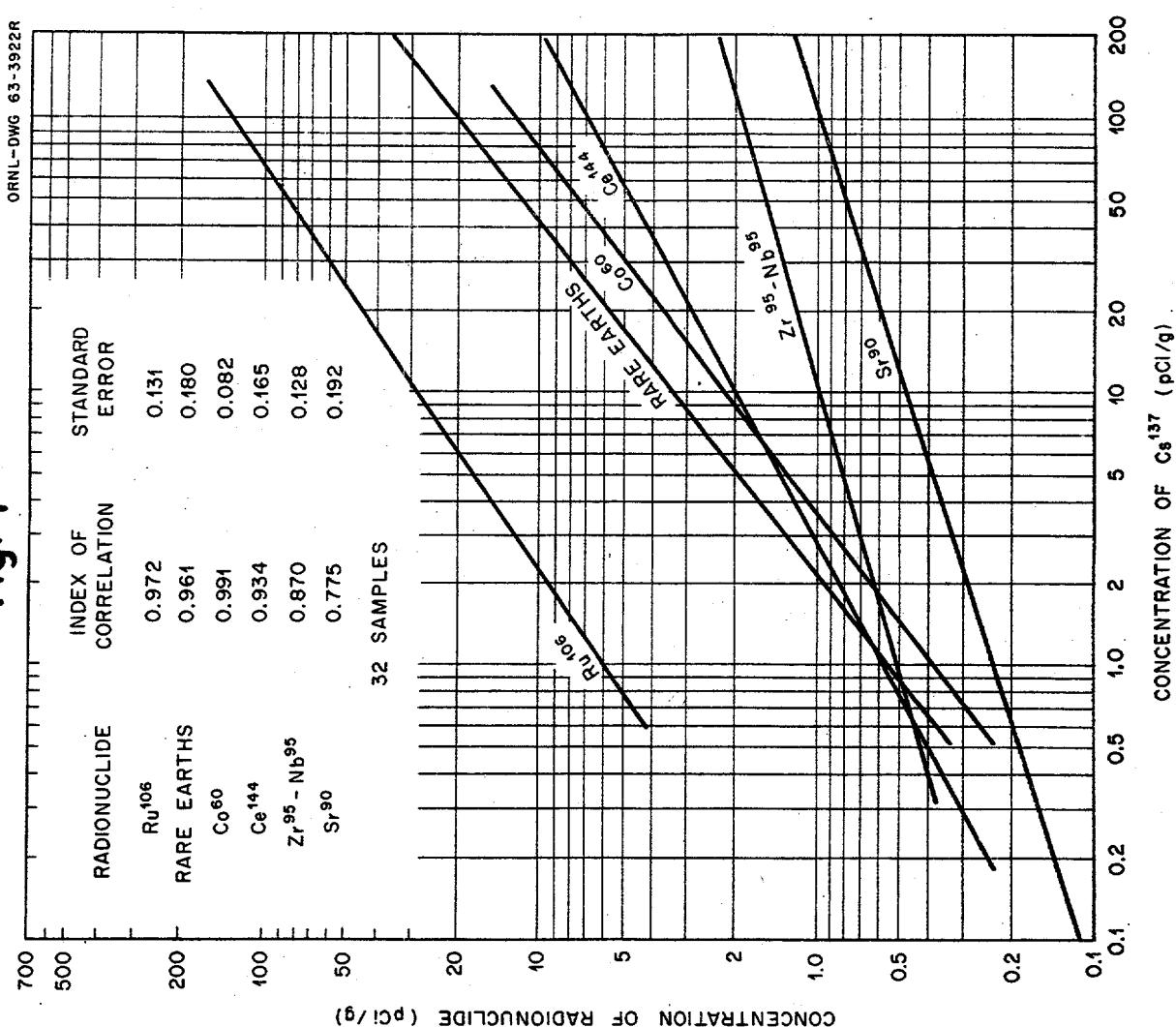


Fig. 3

Fig. 5



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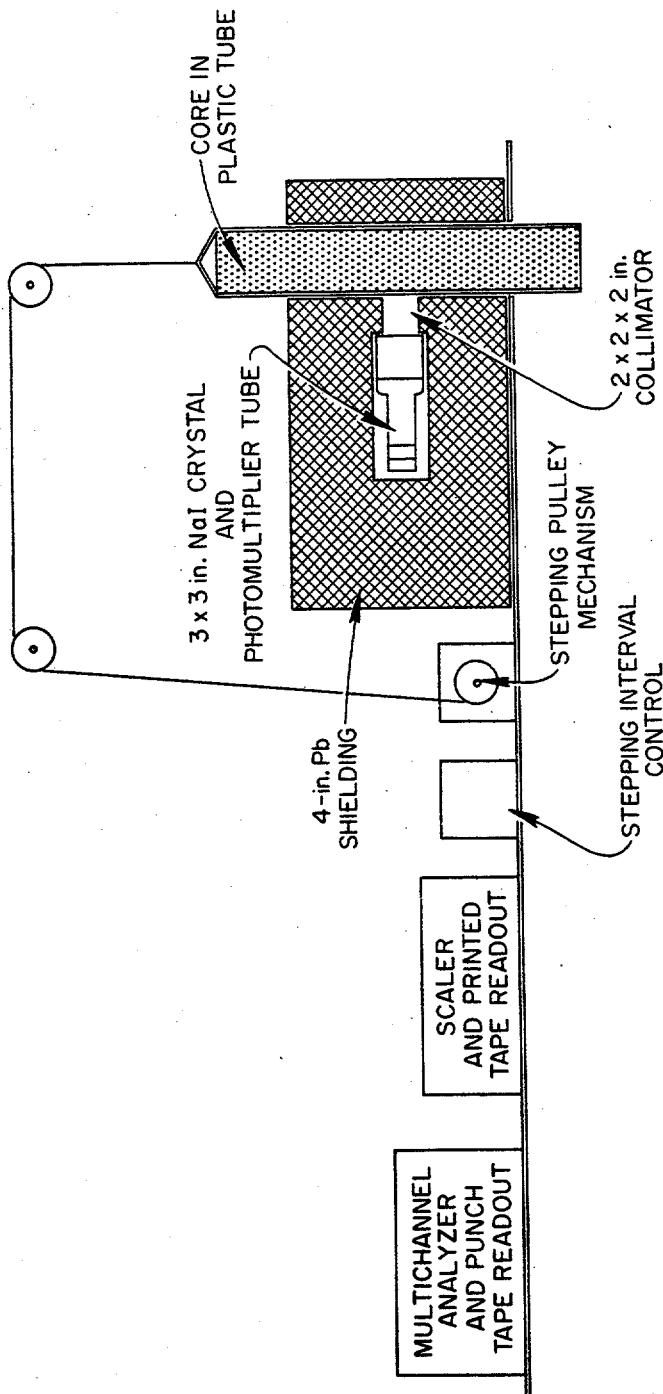


Fig. 6

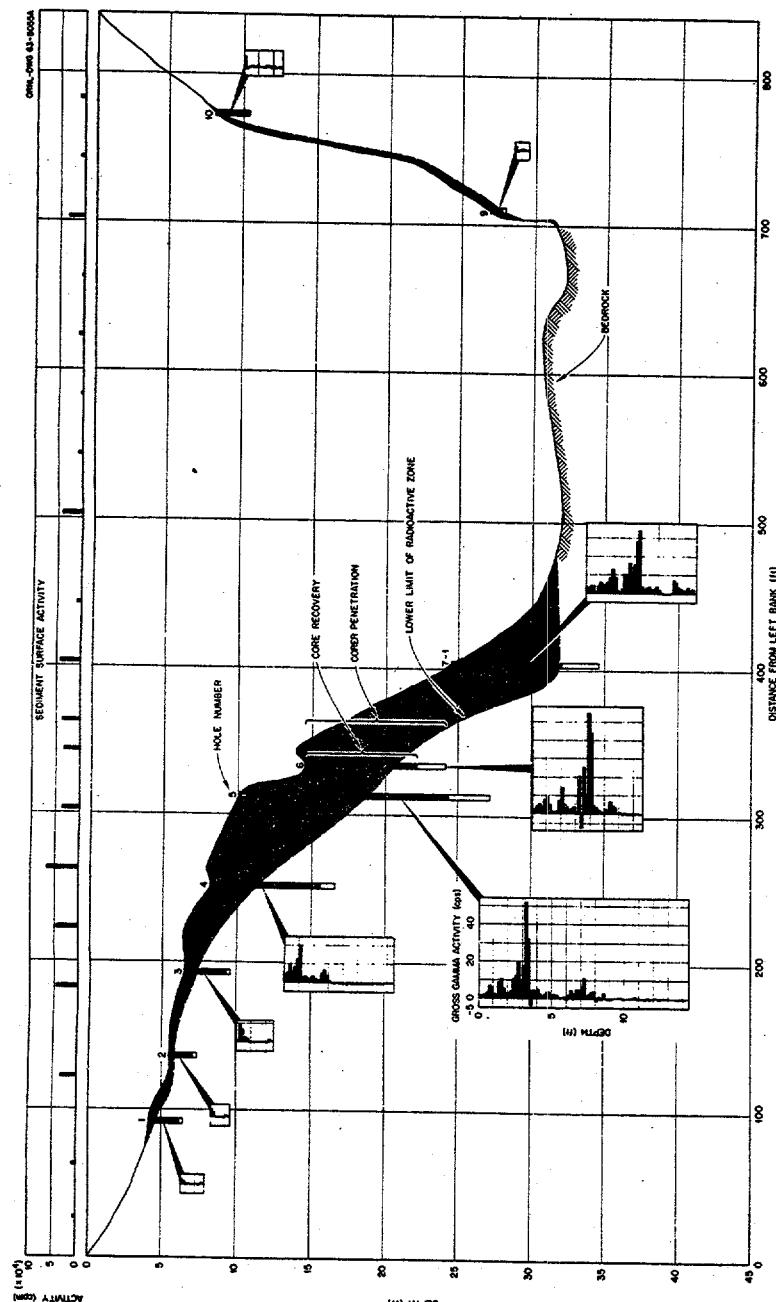


Fig. 7

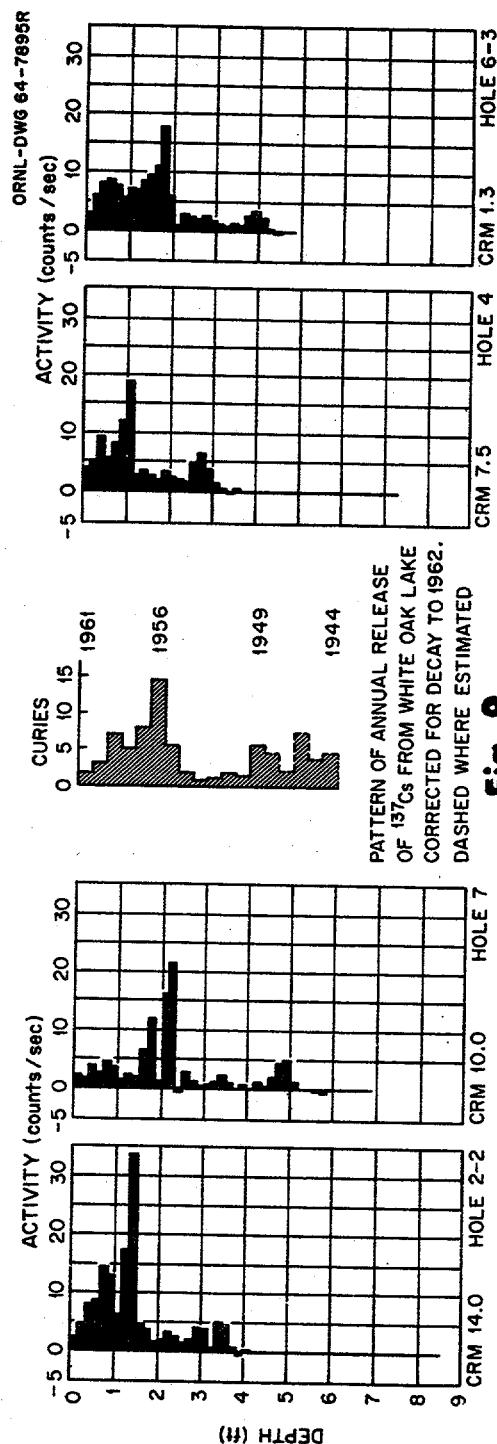


Fig. 8

ORNL-DWG 64-44637

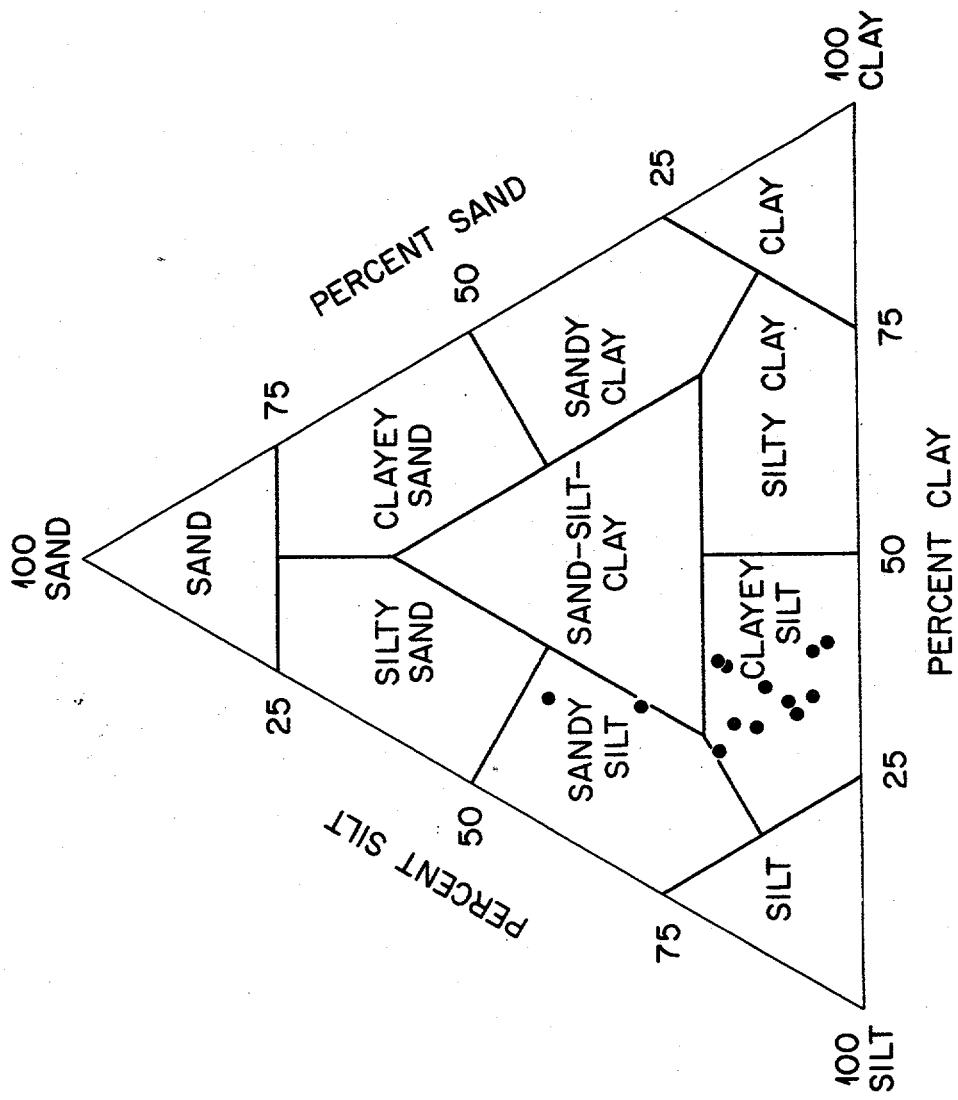
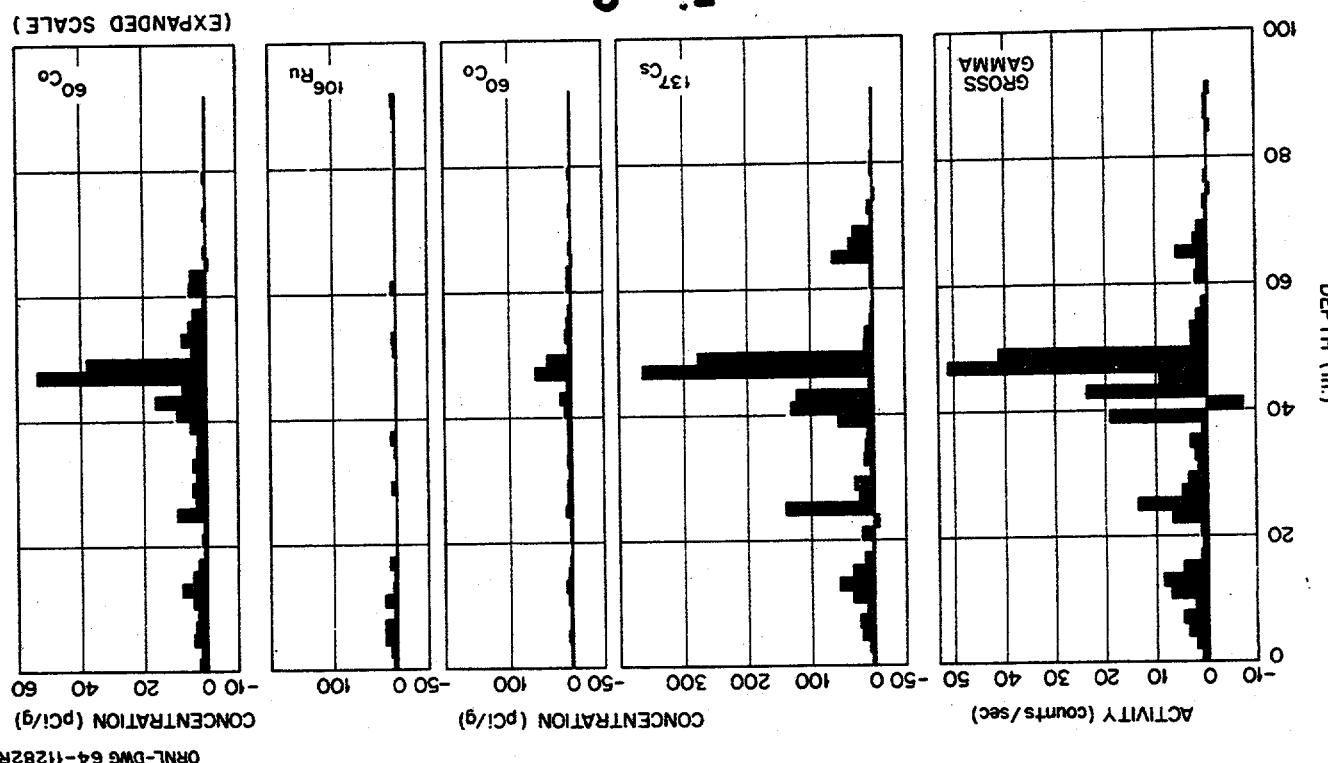


Fig. 10

Fig. 9



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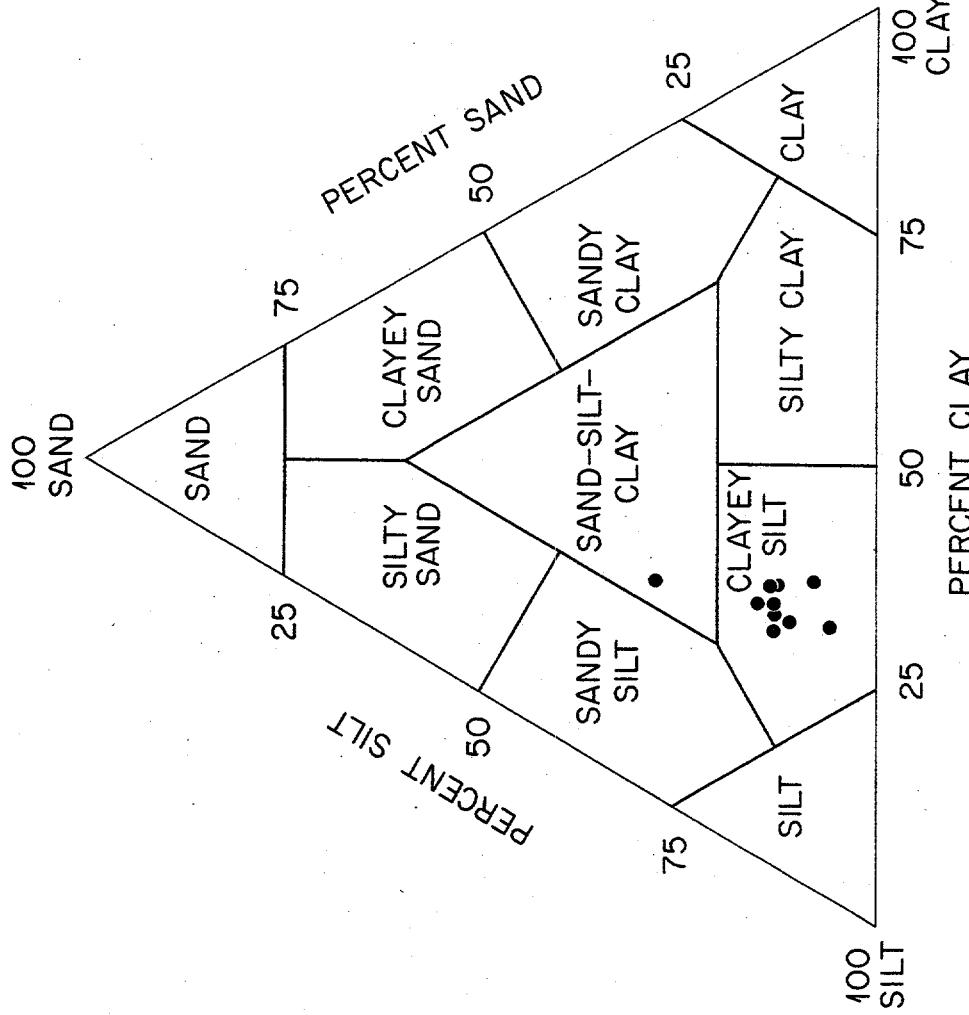


Fig. 11

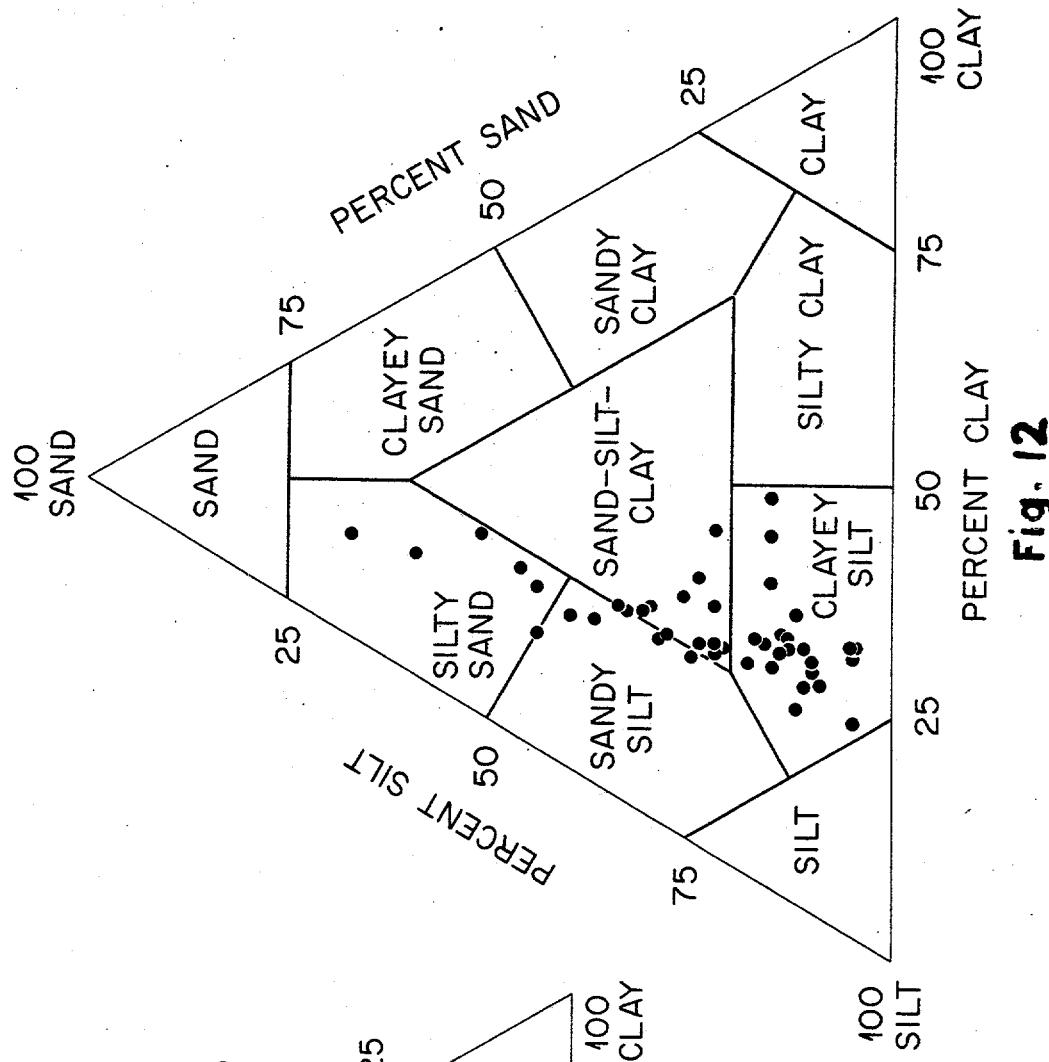


Fig. 12