(1, e)

3180

MASTER

THE CLINCH RIVER STUDY: AN INVESTIGATION OF THE FATE OF RADIO-NUCLIDES RELEASED TO A SURFACE STREAM

R. J. Pickering, P. H. Carrigan, Jr., and F. L. Parker,
Oak Ridge National Laboratory, Oak Ridge, Tennessee

CONF-393-3

ABSTRACTED IN NSA

Preprint 18e

Presented at the

Symposium on Pollution Engineering

FIFTY SECOND NATIONAL MEETING

Memphis, Tennessee

February 2-5, 1964

ORINS LIBRARY
WITHDRAWN

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
345 East 47 Street, New York 17, New York

50 cents

Prepublication Copy
Not to be used for publication
in whole or in part without
permission of the author.

THE CLINCH RIVER STUDY: AN INVESTIGATION OF THE FATE OF RADIONUCLIDES RELEASED TO A SURFACE STREAM*

By

R. J. Pickering**
P. H. Carrigan, Jr.**
F. L. Parker***

To be presented at the
52nd National Meeting of the
American Institute of Chemical Engineers
Memphis, Tennessee
February 2-5, 1964

* Work done at the Oak Ridge National Laboratory, operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

** Water Resources Division, U. S. Geological Survey, assigned to the Oak Ridge National Laboratory.

*** Health Physics Division, the Oak Ridge National Laboratory.

ABSTRACT

The Clinch River Study is a multi-agency effort to evaluate the physical, chemical, and biological effects of the release to the Clinch River of low-level radioactive wastes from the Oak Ridge National Laboratory. The major radionuclides released are ruthenium-106, cesium-137, cobalt-60, and strontium-90. Hydrologic and biologic studies have indicated that radiation dosages known to result or assumed to result from direct and indirect means of exposure are below maximum permissible levels. Radionuclide concentrations in river water have been measured at seven sampling stations on the Clinch and Tennessee Rivers. Mass balance calculations for 44 weeks of sampling indicate that losses of radionuclides from the water phase to river bottom sediments represent only a very small portion of the total radioactivity released to the river.

A study of Clinch River bottom sediment cores collected in 1962 has disclosed a recurring pattern of variation in radioactivity with depth which may reflect past events in waste disposal operations at the laboratory. Current investigations are expected to provide information about the chemical forms in which the major radionuclides exist and the mechanisms by which they were incorporated in the sediments.

THE CLINCH RIVER STUDY: AN INVESTIGATION OF THE FATE OF RADIONUCLIDES RELEASED TO A SURFACE STREAM

Introduction

The Clinch River Study is a multi-agency effort to evaluate the physical, chemical, and biological effects caused by the disposal in the Clinch River of low-level radioactive wastes from the Oak Ridge National Laboratory* at Oak Ridge, Tennessee. The study, begun in 1959, has the following objectives:

(1) To determine the fate of the radioactive materials currently being discharged to the river,

(2) To determine and understand the mechanisms of dispersion of radionuclides released to the river,

(3) To evaluate the direct and indirect hazards of current disposal practices in the river,

(4) To evaluate the over-all usefulness of this river for radioactive waste disposal purposes, and

(5) To recommend long-term monitoring procedures.

The study is under the general supervision of a steering committee composed of representatives of the Oak Ridge National Laboratory (ORNL), the Tennessee State Department of Public Health (TDPH), the Tennessee State Game and Fish Commission(TGFC), the Tennessee Valley Authority (TVA), the U. S. Atomic Energy Commission (AEC), the U. S. Geological Survey (USGS), and the U. S. Public Health

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

Service (USPHS) (1). Investigations are carried out by personnel of the various agencies under the direction of four subcommittees of the Steering Committee, namely: Aquatic Biology, Safety Evaluation, Water Sampling and Analysis, and Bottom Sediment Sampling and Analysis.

The Clinch River heads in Virginia and flows southwestwardly to join the Tennessee River at Kingston, Tennessee (Figure 1). At its mouth the drainage area is 4,413 sq. mi. At the most downstream gaging station, 39.0 mi. upstream from its mouth, the average flow of the Clinch River, based on a 26-year period of measurements, is 4,612 cu. ft./sec.

During the first three years of the Clinch River Study, Norris Dam, located at Clinch River Mile (CRM) 79.8, was the only major control structure on the Clinch River. Releases from Norris Reservoir are based largely on demand for electric power. In May, 1963, control of flow was begun at Melton Hill Dam which is located on the Clinch River at CRM 23.1, 2.3 mi. upstream from the mouth of Whiteoak Creek where radioactive waste from ORNL enters the river. The Melton Hill system will be a "peaking" power plant, i.e. it will be operated mainly during periods of peak demand for power and shut down at other times.

The Clinch River below Whiteoak Creek is affected by backwater from Watts Bar Dam, which is on the Tennessee River 37.8 mi. downstream from the mouth of the Clinch River and a total of 58.6 mi. downstream from the mouth of Whiteoak Creek. Before construction

of Melton Hill Dam, thermally stratified flow occurred in the lower Clinch River from spring to fall because the cold water released from Norris Reservoir flowed under the relatively still, warmed backwater of Watts Bar Reservoir. The effect of the operation of Melton Hill Dam on temperature conditions in the river is not yet known.

Since 1943, low-level radioactive wastes derived from the laboratory's process waste water treatment plant, solid waste burial grounds, liquid waste seepage pits, and other minor sources of radioactivity have entered the Clinch River through Whiteoak Creek (Figure 1). The radionuclides in the wastes are largely fission products--cesium-137, strontium-89 and 90, ruthenium-103 and 106, etc.--but also include some activation products such as cobalt-60 and zinc-65. Continuous monitoring of radionuclide concentrations at the point of release to the river, and downstream at CRM 4.5, has shown that concentrations are well within the limits recommended by the National Committee on Radiation Protection.

Whiteoak Creek drains an area of 6 sq. mi., which includes the Laboratory area. Its average discharge is about 10 cu. ft./sec., most of which is surface runoff. At the present time, its waters are impounded in Whiteoak Lake by Whiteoak Dam, which is downstream from all sources of radioactive wastes and 0.6 mi. upstream from the Clinch River. The area covered by Whiteoak Lake at the present elevation of the gates, 744 ft. above mean sea level, is 19.1 acres. The use of Whiteoak Lake for impoundment

of radioactive waste water has been described in more detail in Status Report No. 1 on the Clinch River Study (1).

Aquatic Biology and Safety Evaluation

The radionuclide content of plant and animal life in the Clinch River has been studied by the Ecology Section of the Health Physics Division, ORNL, and the Environmental Studies Group of the Radiological Health Division, USPHS. Preliminary estimates of public consumption of fish, ingestion of water, and exposure as a result of use of the river for recreational purposes, have indicated radiation dosages that are below maximum permissible levels in all cases. Calculation of estimated future dose rates is continuing. Results of the biological studies have been reported in Status Reports Nos. 1, 2, 3, and 4 on the Clinch River Study (1, 2, 3, 4).

Hydraulic Studies

The capacity of the Clinch River to disperse radioactive materials has been assessed through a series of hydraulic tests. Radioactive gold-198 was used as a tracer in the early tests, while "Rhodamine-B" and "Pontacyl Brilliant Pink-B" fluorescent dyes have been used in more recent tests. In these tests, the longitudinal distance downstream to the cross section of complete lateral diffusion, variation of peak concentration with distance, and times of travel have been determined. Times

of water travel observed in the tests compare closely with times computed on the basis of the continuity equation. Nearly uniform lateral mixing is found to occur within 4 to 6 mi. downstream from the mouth of Whiteoak Creek. Variation of concentration with distance is shown in Figure 2 for two of the tracer tests.

Water Sampling and Analysis

A network of seven water sampling stations on the Clinch and Tennessee Rivers was established under the direction of the Subcommittee on Water Sampling and Analysis. Samples were collected regularly at the stations for material balance studies of the radionuclides released to the river system, and for information on the stable-chemical composition of the river water. Station locations are listed in Table 1. Water samples were composited weekly on the basis of water discharge, and analyzed for major and minor radioactive- and stable-chemical constituents. Analyses of stable-chemical constituents were made by personnel of the Tennessee Stream Pollution Control Board at Nashville, Tennessee, and radiochemical analyses by personnel of the Division of Radiological Health of the U. S. Public Health Service at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. The major radionuclides in Clinch River water are ruthenium-106, cesium-137, cobalt-60, and strontium-90.

Table 1. Water Sampling Stations, Clinch River Study.

Station Number	Location	Stream	Stream Mile (above mouth)
1	Oak Ridge Water Treatment Plant Intake	Clinch River	CRM 41.5
2	Whiteoak Dam	Whiteoak Creek	WOCM 0.6
3	Centers Ferry	Clinch River	CRM 5.5
4	Loudon, Tennessee	Tennessee River	TRM 591.8
5	Watts Bar Dam	Tennessee River	TRM 529.9
6	Chickamauga Dam	Tennessee River	TRM 471.0
7	Oak Ridge Gaseous Diffusion Plant Water Treatment Plant Intake	Clinch River	CRM 14.6

Table 1. Water Sampling Stations, Clinch River Study.

Location	Stream	Stream Mile (above mouth)
Whiteoak Dam	Whiteoak Creek	WOCM 0.6
Oak Ridge Water Treatment Plant Intake	Clinch River	CRM 41.5
Oak Ridge Gaseous Diffusion Plant Water Treatment Plant Intake	Clinch River	CRM 14.6
Centers Ferry	Clinch River	CRM 5.5
Loudon, Tennessee	Tennessee River	TRM 591.8
Watts Bar Dam	Tennessee River	TRM 529.9
Chickamauga Dam	Tennessee River	TRM 471.0

Most of the cesium-137 is associated with suspended sediment having a diameter greater than 0.7 micron, while the other three radionuclides are associated with finer suspended sediment or are dissolved in the water.

The amount, or load, of a given radionuclide which passes a sampling point during a short period of time can be assumed to be equal to the product of the average radionuclide concentration at the sampling point during that period of time and the flow of water that passes the point during the same period. If there were no loss of the radionuclide from Clinch River water as it moved downstream, the load passing the "background" station at the Oak Ridge water treatment plant at Clinch River Mile 41.5, plus the load released through the Whiteoak Creek sampling station at Whiteoak Dam, should equal the load passing the sampling station at Clinch River Mile 5.5 (see Figure 1).

The results of mass-balance (load) calculations (Table 2, Figures 3, 4, 5, and 6) indicate that during the

Table 2. Radionuclide Loads in Clinch River Water, November 13, 1960 to September 16, 1961.

study period, essentially all of the ruthenium-106, cesium-137, and cobalt-60 in Clinch River water was transported downstream into the Tennessee River. It appears that a small portion of the strontium-90 in the river water was lost in 15 miles of

Table 2. Radionuclide Loads in Clinch River Water, November 13, 1960 to September 16, 1961.

Radionuclide	Radionuclide Load (curies)		Gain or Loss (percent)
	Mile 41.5 plus Whiteoak Dam	Mile 5.5	
Ruthenium-106	1680	1800	+ 7
Cesium-137	19.9	24.3	+ 22
Cobalt-60	24.8	26.3	+ 6
Strontium-90	27.7	24.1	- 13

downstream movement. Apparent gains in cesium-137 and cobalt-60 between the point of release to the river and the downstream sampling station may be due to the use of a digital computer in the analysis of gamma spectra*. Computed radionuclide concentrations near zero were reported if positive, but were considered undetectable if negative. Hence, a positive bias was introduced before radionuclide loads were calculated. Most of the reported concentrations of cesium-137 (32 of 44 samples) and cobalt-60 (26 of 44 samples) in samples from CRM 5.5 were at or below the lower limit of detectability. Some of the apparent gains may be real gains from local movement of bottom sediment or from desorption reactions, but this cannot be proved or disproved with the available data.

Stable-chemical analyses of Clinch River water from the sampling station at the Oak Ridge water treatment plant show the water to have an average hardness of 106 p.p.m. (as calcium carbonate), dissolved solids content of 125 p.p.m., and pH of 7.7. Clinch River water may be classed as moderately hard. On the basis of its chemical composition, which does not vary greatly, it may be called a calcium-bicarbonate type of water.

---

* Concentrations of ruthenium-106, cesium-137, and cobalt-60 in water samples were determined by gamma spectrum analysis programmed through a digital computer. Strontium-90 concentrations were determined by wet-chemical separation and beta counting.

Bottom Sediment Sampling and Analysis

Samples obtained from five cross sections in the Clinch River downstream from Whiteoak Creek have shown the particle size distribution in the bottom sediments to be 15-20 % clay ($< 2\mu$), 50-60 % silt ($2\text{-}62\mu$), and 25-30 % sand ($> 62\mu$) (3). The clay-size fraction of the sediment is composed largely of vermiculite, mica*, kaolinite, randomly interstratified vermiculite-mica, and fine quartz. The sand and silt fractions of the sediment are composed almost entirely of quartz. An appreciable content of calcium carbonate in the sediment has been indicated by indirect evidence, but relative concentrations have not yet been determined.

Uptake of chemical constituents from liquid systems by sediment-forming minerals has been investigated extensively during the past several years. Of the processes by which uptake can be accomplished, one of the most important is sorption (5). Sorption of radionuclides by river sediments has been studied by Carritt and Goodgal (6), Barker (7), Jacobs and Tamura (8), and others. The importance of radiocesium uptake by the clay minerals has been well-established, and Tamura and Jacobs (9) have shown that the 2:1 layer clay minerals with a c-spacing of 10 Å selectively sorb cesium. Tamura (10) has further shown that hydrous iron oxides and aluminum oxides, common minor constituents in many sediments, selectively sorb strontium.

---

* No distinction is made here between "mica" and "illite".

The well-known fact that certain radionuclide sorption reactions are reversible has been emphasized by Reynolds' description of desorption reactions which occur when fresh water sediments enter a radically different chemical environment, such as the ocean (11). Work on radionuclide uptake by river sediments has been summarized by Sayre, et al. (12), and by Kornegay, et al. (13).

Surveys of radioactivity in Clinch River bottom sediments, conducted annually since 1951 by the Applied Health Physics Section of the Health Physics Division, ORNL, have indicated that a portion of the radionuclides released to the river have been retained in the bottom sediments (14, 15). Samples collected by the Applied Health Physics Section and the U. S. Public Health Service, and a bottom sediment coring program conducted in 1960 by personnel of the Radioactive Waste Disposal Research Section of the Health Physics Division, ORNL (Table 3), have provided a

Table 3. Concentrations of Specific Radionuclides in the Upper Portion of Clinch River Bottom Sediments.

measure of the content of cesium-137, ruthenium-106, cerium-144, zinc-65, cobalt-60, zirconium-niobium-95, strontium-90, and the trivalent rare earths in the upper portion of the sediments (3).

Although material balances computed from analyses of water samples indicate that the mass of radionuclides in bottom sediments represents only a small portion of the total mass

Table 3. Concentrations of Specific Radionuclides in the Upper Portion of Clinch River Bottom Sediments.

Clinch River Mile	Radionuclide Concentration (10^{-2} μc/kg)				
	Ru^{106} [b]	Cs^{137} [b]	Co^{60} [b]	Sr^{90} [c]	TRE [c,d]
4.7	1.05	6.22	0.788	0.086	0.99
5.8	1.91	10.6	1.42	0.194	2.28
6.9	1.43	7.21	0.995	0.158	1.30
8.0	4.13	11.2	1.55	0.189	4.86
9.0	3.34	9.95	1.03	0.171	4.42
10.0	1.81	7.97	0.752	0.113	2.14
11.0	4.50	19.7	1.89	0.423	7.03
12.0	2.81	11.9	1.24	0.212	5.40
13.0	3.12	17.6	1.84	0.252	7.66
14.0	1.33	10.6	1.19	0.194	2.90
14.6	4.41	18.1	1.85	0.347	5.63
15.3	2.16	9.77	0.977	0.149	3.11
16.0	0.815	3.54	0.347	0.077	1.50
16.9	5.99	13.2	1.22	0.140	5.86
18.1	2.12	16.1	1.29	0.230	3.59
19.5	2.79	7.12	0.923	0.108	2.28
20.8	3.90	106	8.32	1.68	20.4
21.6	2.54	7.03	0.653	0.144	3.07
22.5	1.36	2.48	0.334	0.009	1.40

[b] Gamma spectrometer analysis.

[c] Chemically separated before counting.

[d] Trivalent rare earths plus yttrium-90.

released to the river, physical and chemical processes in the river have concentrated the radionuclides in the bottom sediments enough to make them easily measurable. In areas of the river where continuous sedimentation has taken place, the sediments provide a record of net radionuclide removal from river water as it passed downstream throughout the period of release from the laboratory.

In the summer of 1962, a comprehensive sampling of Clinch River bottom sediments through the entire thickness of the radioactive zone was conducted by personnel of the U. S. Geological Survey and ORNL. The samples were obtained through the use of the "Swedish Foil Sampler" (16), a device which takes undisturbed sediment cores 2½ in. in diameter. The sampler utilizes a piston and thin steel strips (foils) to decrease compaction due to friction between the sample tube and the sediment while coring is proceeding, and to prevent loss of core while the core tube is being raised to the surface. More than 150 cores were obtained at fourteen cross sections on the Clinch River and four cross sections on two tributary streams. Core recovery was excellent at most sites. The longest core obtained was 14 ft. in length.

Plans for processing the cores are indicated diagrammatically in Figure 7. It is expected that the analyses listed will provide sufficient information to determine:

(1) The total load of each of the major radionuclides in Clinch River bottom sediments,

(2) The distribution of the major radionuclides in the sediments,

(3) The distribution of the various size, mineralogical, and organic fractions of the sediments,

(4) The relationships between the distribution of the major radionuclides and the composition of the sediments, and

(5) The chemical form of each of the major radionuclides in the sediments.

Determination of the total load of radionuclides in Clinch River bottom sediments, when compared with releases to the river from Whiteoak Creek since 1943 (14,000 curies), will permit a quantitative estimate of the effectiveness of the sediments in removing radionuclides from the river water. It will also provide a check on material-balance calculations based on analyses of water samples. The other determinations listed in Figure 7 are directed primarily toward an understanding of the mechanisms by which the radionuclides were incorporated in the sediments. It is presently believed that particle sedimentation, sorption, and chemical precipitation were the principal mechanisms involved.

The lower limit of the radioactive zone and the vertical distribution of gross gamma radioactivity in the cores collected in 1962 have been determined by scanning each intact core with a device known as a "core scanner" (Figure 8). The "core scanner" consists of a 3-in. by 3-in. sodium iodide scintillation crystal and matched phototube enclosed in a 4-in. thick cylindrical lead shield. A collimating opening, 2-in. by 2-in. by 2-in., leads from

the core "well" to the scintillation crystal. A calibrated hoist automatically moves the core vertically past the collimator in 2-in. increments. The phototube output can be routed through a scaler for determination of gross gamma radioactivity, or to a multichannel analyzer for determination of the concentration of individual gamma-emitting radionuclides in each increment.

Results of gross gamma scanning of cores from CRM 7.5 are shown in Figure 9. Note the distribution in the cross section of the radioactive sediments and the repetitive pattern of gross gamma activity with depth in several of the cores. It is hoped that the results of visual logging, and the determination of the vertical distribution of individual radionuclides in selected cores, will provide information which can be used to correlate specific sediment horizons in some of the cores with specific past events in waste disposal operations at the laboratory. The existence of other "dateable" physical or chemical properties of the sediments will also be investigated.

Status of the Clinch River Study

In the four years since the Clinch River Study was initiated, considerable progress has been made toward meeting the objectives listed in the introduction of this paper. It has been shown by material-balance studies that most of the radioactivity discharged to the Clinch River is transported downstream in the Clinch and Tennessee Rivers in the water phase. Very low radionuclide

concentrations in the lower Tennessee River make detection farther downstream impractical. A small percentage of the radioactivity has been incorporated in bottom sediments of the two rivers. A portion of the radioactivity in both the water and bottom sediments is associated with organic matter.

Time of travel and dispersion studies have outlined some of the hydrologic characteristics of the Clinch River which affect the concentration of radioactive wastes passing downstream points. A few additional tests after power releases begin at Melton Hill Dam will satisfactorily complete this phase of the study.

Laboratory and field studies have indicated that cesium-137 is introduced to the river and transported largely as a sorbed ion on clay mineral particles. Because this particular sorption reaction is not readily reversible under fresh-water conditions, the incorporation of cesium in river bottom sediments is believed to be controlled largely by sedimentation processes. Results of desorption, exchange capacity, and other tests currently being performed on Clinch River bottom-sediment samples will provide further information on the chemical form of the other radionuclides in the sediments and on the over-all usefulness of the river for disposal of radioactive wastes.

Literature Cited

1. Morton, R. J., ed., ORNL-3119*, Oak Ridge Natl. Lab., 81 p. (1961).

2. _____, ORNL-3202*, Oak Ridge Natl. Lab., 97 p. (1962).

3. _____, ORNL-3370*, Oak Ridge Natl. Lab., 123 p. (1962).

4. _____, ORNL-3409*, Oak Ridge Natl. Lab., 115 p. (1963).

5. McBain, J. W., "Colloid Science", 450 p., D. C. Heath and Co., New York (1950).

6. Carritt, D. E., and S. H. Goodgal, NYO-4591, Dept. of Sanit. Eng., Johns Hopkins Univ., 97 p. (1953).

7. Barker, F. B., Am. Water Works Assoc. Journal, 50, 603-612 (1958).

8. Jacobs, D. G., and Tsuneo Tamura, 7th Internatl. Cong. Soil Science, 2, 206-214 (1960).

9. Tamura, Tsuneo, and D. G. Jacobs, Health Physics, 2, 391-398 (1960).

10. Tamura, Tsuneo, in Proc. of Conf. on Movement of Radionuclides through the Soil and Waste Disposal, Saclay, France, Oct., 1962 (in press).

11. Reynolds, T. D., in TID-7664*, U. S. Atomic Energy Comm., 127-144 (1963).

12. Sayre, W. W., H. P. Guy, and A. R. Chamberlain, U. S. Geol. Survey Prof. Paper 433-A, 35 p. (1963).

13. Kornegay, B. H., W. A. Vaughan, D. K. Jamison, and J. M. Morgan, Jr., eds., TID-7664*, U. S. Atomic Energy Comm., 406 p. (1963).

14. Garner, J. M., and O. W. Kochtitzky, Journal Sanit. Eng. Div., Proc. Am. Soc. Civil Engrs., 82, SA 4, 1-20 (1956).

15. Cottrell, W. D., ORNL-2847*, Oak Ridge Natl. Lab., 50 p. (1959).

16. Pickering, R. J., in Proc. of 1963 Federal Inter-Agency Sedimentation Conf. (in press).

* Available from the Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D.C.

ILLUSTRATIONS

Figures

1. Map of Clinch River Basin Showing Locations of Sampling Stations.
2. Reduction of Maximum Concentration of Gold-198 with Distance during Two Tracer Studies in the Clinch River.
3. Cumulative Load of Ruthenium-106 in Clinch River Water for 44-week Period.
4. Cumulative Load of Cesium-137 in Clinch River Water for 44-week Period.
5. Cumulative Load of Cobalt-60 in Clinch River Water for 44-week Period.
6. Cumulative Load of Strontium-90 in Clinch River Water for 44-week Period.
7. Diagram of Analysis of Bottom Sediment Cores.
8. Diagram of Core Scanner.
9. Cross Section at CRM 7.5 Showing Penetration, Recovery, and Gross Gamma Radioactivity Variations with Depth for 1962 Bottom Sediment Core Samples (Vertical Exaggeration 20:1).

Tables

1. Water Sampling Stations, Clinch River Study.
2. Radionuclide Loads in Clinch River Water, November 13, 1960 to September 16, 1961.
3. Concentrations of Specific Radionuclides in the Upper Portion of Clinch River Bottom Sediments.

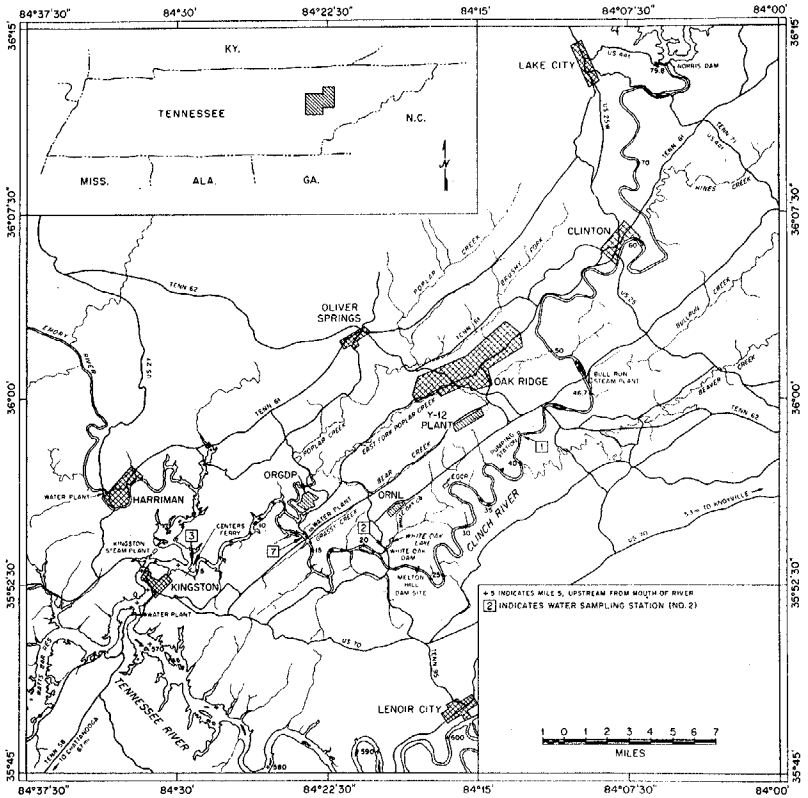

Figure 1. Map of Clinch River Basin Showing Locations of Sampling Stations.

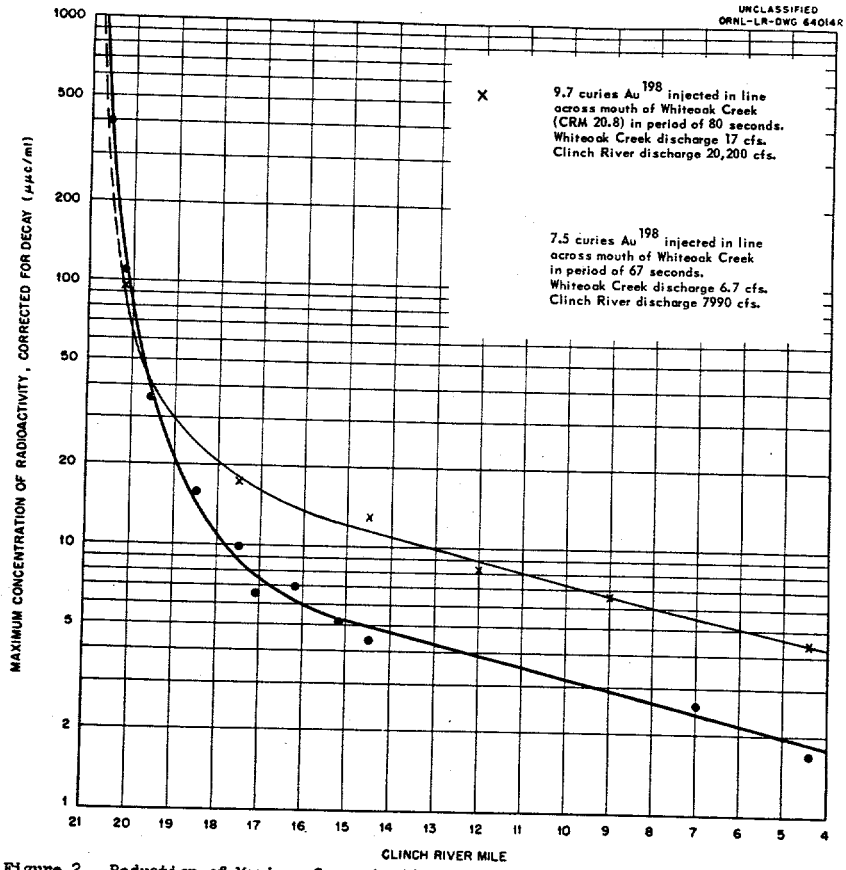

Figure 2. Reduction of Maximum Concentration of Gold-198 with Distance during Two Tracer Studies in the Clinch River.

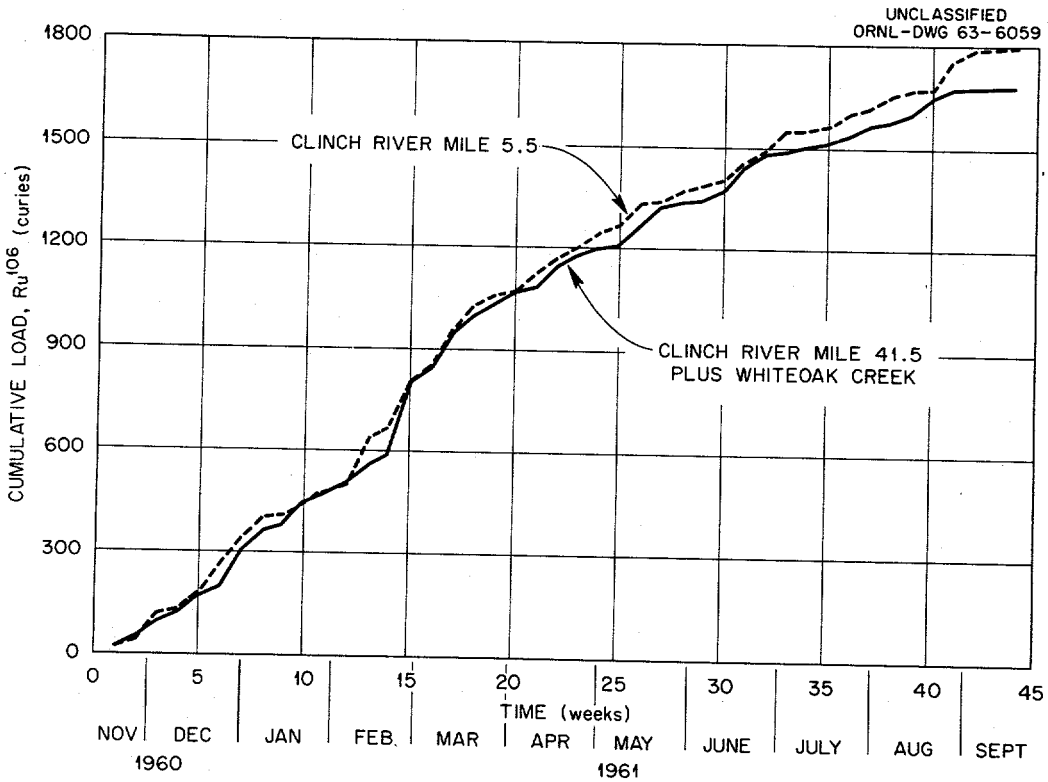

Figure 3. Cumulative Load of Ruthenium-106 in Clinch River Water for 44-week Period.

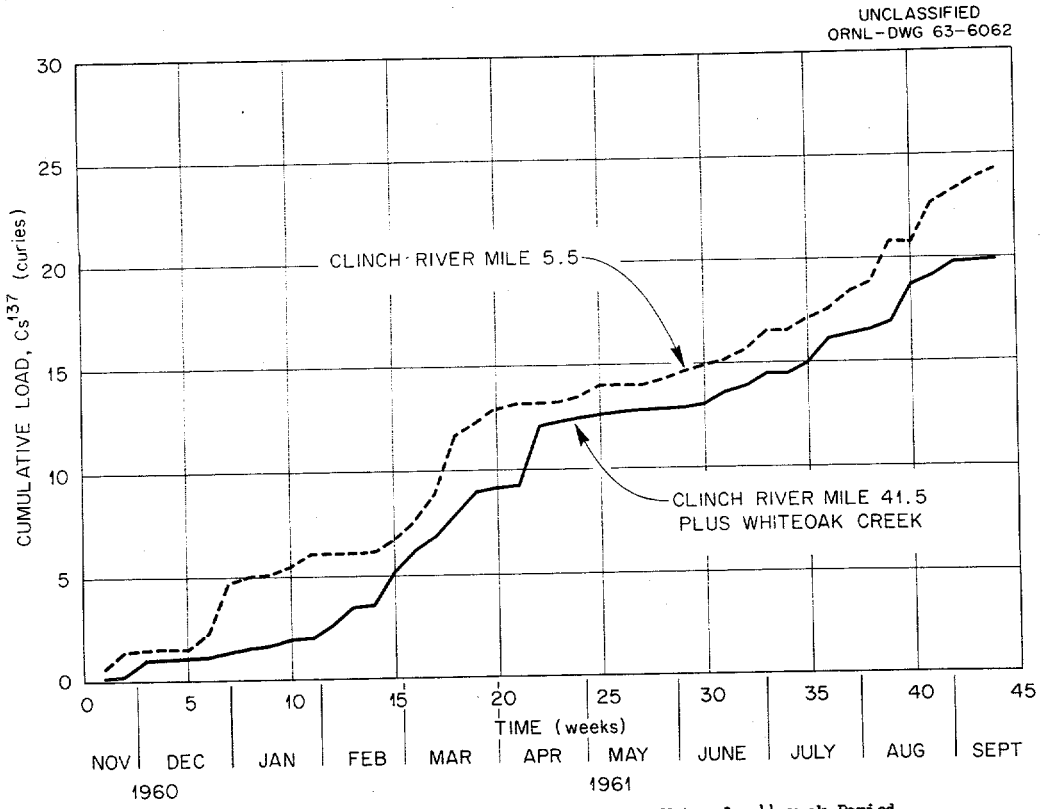

Figure 4. Cumulative Load of Cesium-137 in Clinch River Water for 44-week Period.

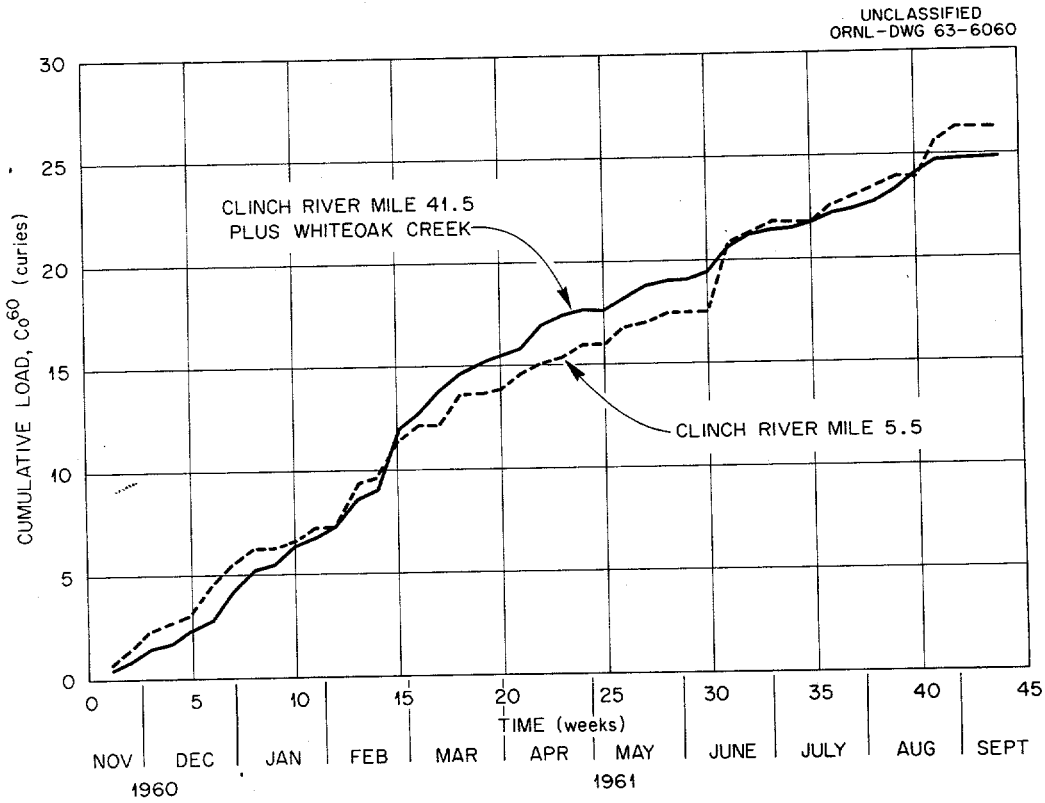

Figure 5. Cumulative Load of Cobalt-60 in Clinch River Water for 44-week Period.

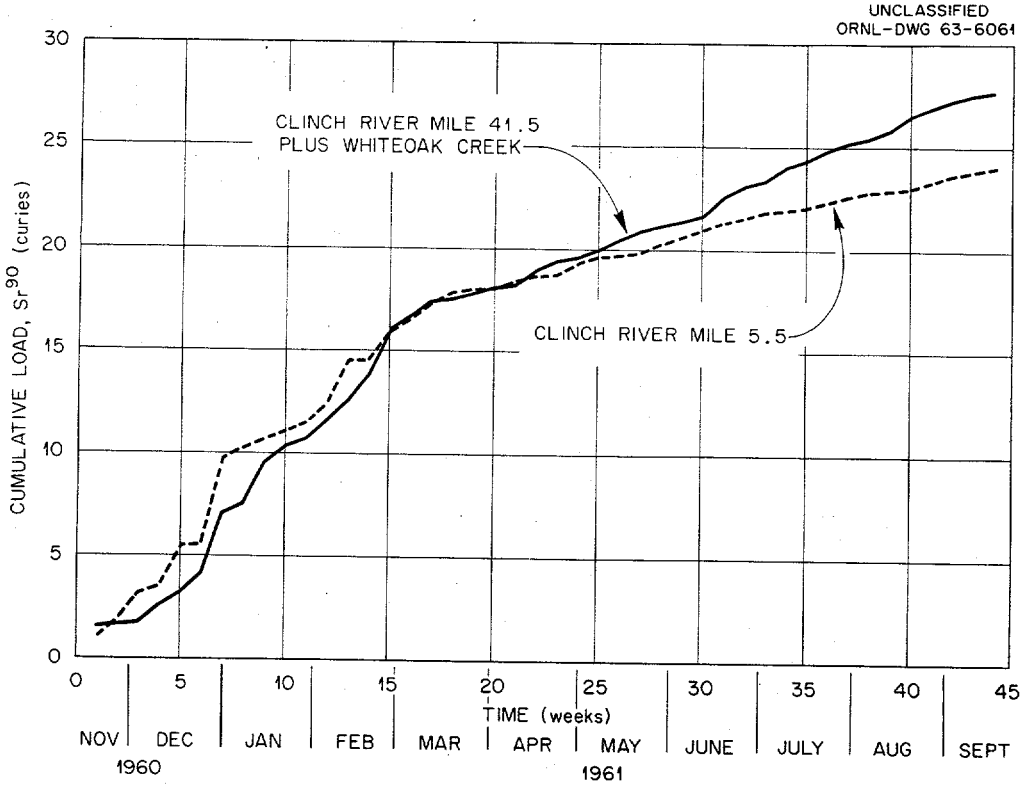

Figure 6. Cumulative Load of Strontium-90 in Clinch River Water for 44-week Period.

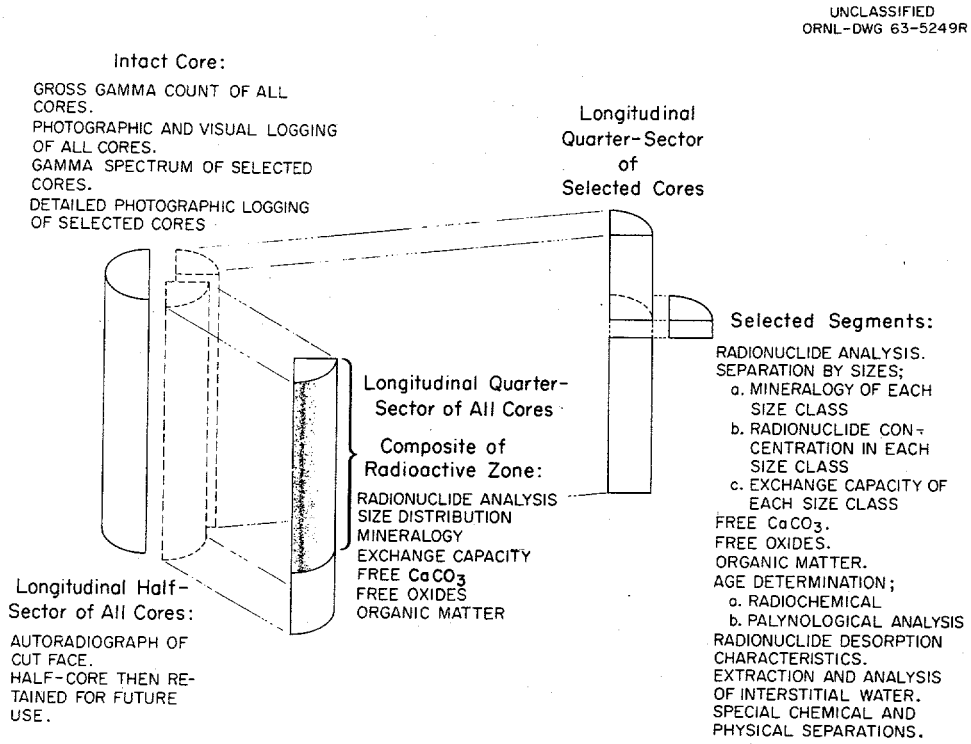

Figure 7. Diagram of Analysis of Bottom Sediment Cores.

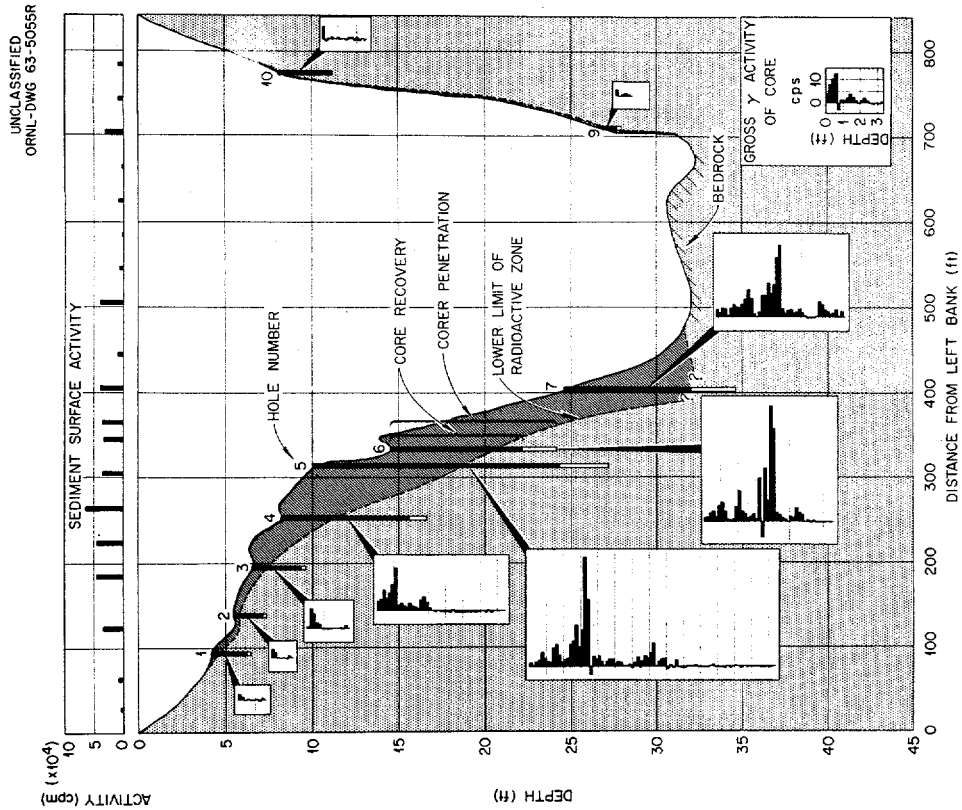

Figure 9. Cross Section at CRM 7.5 Showing Penetration, Recovery, and Gross Gamma Radioactivity Variations with Depth for 1962 Bottom Sediment Core Samples (Vertical Exaggeration 20:1).

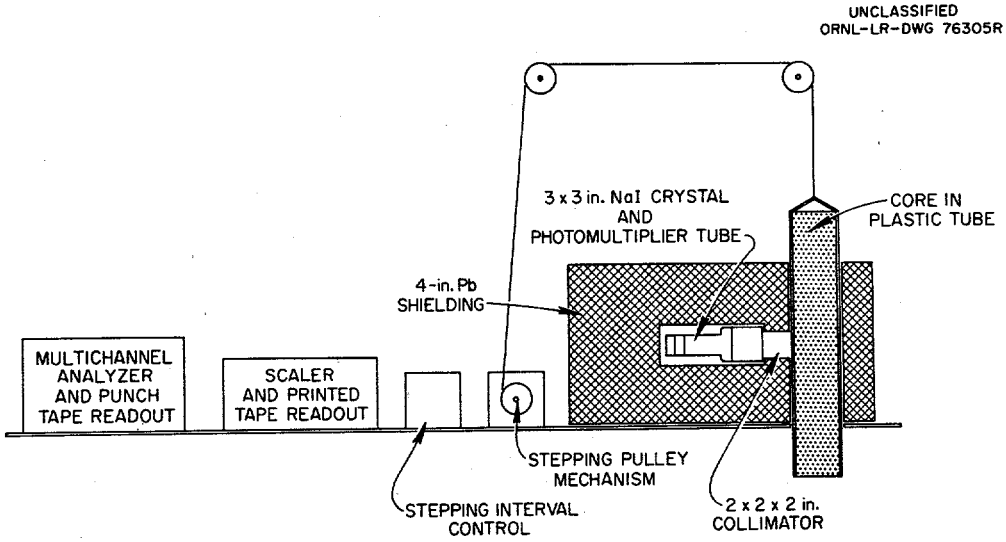

Figure 8. Diagram of Core Scanner.