Clams as Indicators of Strontium-90

Abstract. Fresh-water clams concentrate strontium-90 in their shells and may be used as indicators of the Sr^{90} contamination of their environment. Analysis of data derived from the specific activity of Sr^{90} in shells showed that Sr^{90} released to the Tennessee River system remained in solution and that concentrations to a distance of 500 miles from the release site can be predicted on the basis of the dilution of contaminated White Oak Creek water by uncontaminated Clinch-Tennessee River water.

Low-level radioactive wastes, including small amounts of strontium-90, have been released from Oak Ridge National Laboratory via White Oak Creek to the Clinch River and subsequently the Tennessee River since 1943 (*1*). The waste releases to White Oak Creek have been small, and when wastes are diluted an average of 450 times, as they are by Clinch River water (*2*), the measurement of released radionuclides in water is exceedingly difficult. Therefore, organisms which concentrate specific radionuclides can be useful indicators of radioactive contamination in the environment. It was hypothesized that Sr^{90} should be concentrated in the shells of fresh-water clams (Unionidae) since the shells contain stable strontium (*3*). This report presents an interpretation of the analyses of Tennessee River system clam shells for Sr and Sr^{90}.

Laboratory releases of Sr^{90} were considered to be a tracer, and the specific activity of Sr^{90} (atoms of Sr^{90}/atoms of Sr) in clam shells was used to interpret the behavior of Sr^{90} released to the river system. This treatment of data is dependent upon (i) the concentration of Sr^{90} by clams; (ii) determination of the specific activity of Sr^{90} by stable chemical and radiochemical analyses; (iii) knowledge of factors for dilution of contaminated water by uncontaminated water at the several collecting sites; and (iv) knowledge of the stable strontium content of river water. Clam samples were taken upstream from White Oak Creek (the control point), immediately downstream from White Oak Creek (the index point), and at three other downstream locations (Fig. 1). The control point was used to evaluate levels of fallout Sr^{90}, and the index point was used as the basis for interpreting data from other downstream sampling locations.

When Sr^{90} is released to the river, a specific activity is established with stable strontium in the water mass passing the creek outlet at the time of release. Temporal changes in specific activity of the water mass may result either from the release of different amounts of Sr^{90} or from a variation in the strontium content of river water. When uptake data are related to an index, temporal changes in the specific activity may be ignored. The specific activity of the water mass at downstream locations is changed by further dilution of contaminated water by uncontaminated water and at the confluence of tributary streams having different strontium concentrations. In these instances, it is possible to correct the specific activity of the water for dilution of Sr^{90} and for differences in the concentration of strontium. Specific activity was corrected for dilution by using U.S. Geological Survey river discharge data (*4*). The strontium content of the Clinch and Tennessee River waters is relatively constant (*2*, *5*), hence no correction was made for this factor.

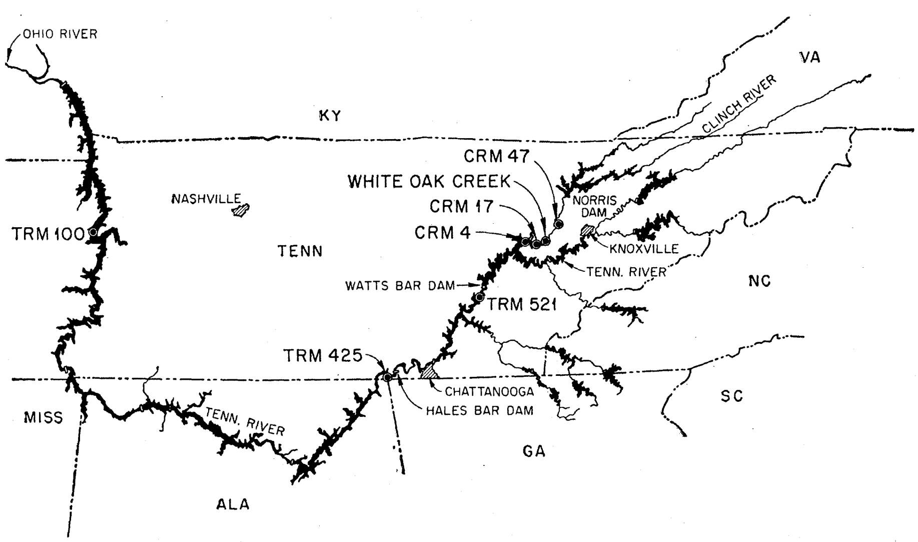

Fig. 1. Tennessee River drainage, showing the location of White Oak Creek and clam collection sites.

Clams should be excellent organisms with which to study the behavior of Sr^{90} in the environment. They would be expected to assimilate and deposit stable Sr and Sr^{90} atoms in their shells in the same proportions in which the atoms occur in water. The shell is deposited in distinct annual layers which are not subject to subsequent metabolism; consequently, the shell represents a history of the deposition of strontium. Because clams are relatively immobile on the river bottom (*6*), their Sr^{90} content is representative of the quality of water at that section in the river. Clams pump water through their siphons most of the year and may be considered integrating water samplers.

All the clams used in this study were identified by comparison with a reference collection. Strontium was determined by flame spectrophotometry,

Table 1. Observed and expected specific activities (atoms of Sr^{90} per atoms of Sr) in clams as a function of the dilution of Clinch River water by Tennessee River water.

Collection site*	Distance (mi) from White Oak Creek	Dilution factor for Clinch River water	Specific activity (atoms $\times 10^{-11}$): Expected on the basis of dilution	Specific activity (atoms $\times 10^{-11}$): Observed by stable chemistry and radiochemistry†	Shells analyzed (No.)
CRM 47	26 upstream (control point)			1.67 ± 0.50	12
CRM 17–4.7	4–17 downstream (index point)	1	(130.8)‡	130.80 ± 22.7	12
TRM 521	68 downstream	5.6	23.4	25.74 ± 3.36	19
TRM 425	163 downstream	7.05	18.6	19.78 ± 1.71	19
TRM 100	489 downstream	12.3	10.6	10.14 ± 1.81	14

* *CRM*, Clinch River mile; *TRM*, Tennessee River mile; the Clinch River joins the Tennessee River at TRM 568 (river miles are measured from the mouth of the river). † All averages $\pm$ 1 standard error. ‡ The specific activity in clams from the index point is the basis for specific activities expected because of dilution.

and the results were verified by spectographic analyses of duplicate aliquots. Strontium-90 was separated from calcium by precipitation prior to counting in a low-background counter. The age of the clams was determined by the annual ring method (*7*). Clams may live 30 or more years, but none of those used in the study had lived in the river prior to 1943. In addition, clams within a given age distribution were selected in order to minimize the effects of radioactive decay and variations in specific activity of the water.

The strontium content of 190 shells representing 15 species ranged from 150 to 550 parts per million and varied with species, age of individuals within a species, and shell growth rate (*8*). The average concentration factor (ratio of strontium per gram of shell to strontium per milliliter of water) for strontium in shells from the Clinch River immediately downstream from White Oak Creek was 4.8 $\times$ 10^3 and that for Sr^{90}, based on monitoring data for water (*9*), was 6.5 $\times$ 10^3. This agreement is good in view of the analytical difficulties in determining low concentrations of Sr^{90} in water. The concentration factors show that clams are sensitive indicators of Sr^{90}, and that because of the observed differences in strontium concentrations, specific activities in clam shells could be used as quantitative indicators of Sr^{90} behavior.

The behavior of Sr^{90} in the Clinch and Tennessee rivers was inferred by comparing the specific activity of Sr^{90} in clam shells from downstream locations with that of the samples from the index point (Table 1). Since the specific activity in the shells as predicted solely from the downstream dilution was approximately the same as the observed activity, the Sr^{90} loss from the river water may be considered negligible, and it may be assumed that the living and nonliving components of the stream ecosystem are in equilibrium with both Sr^{90} and stable strontium. Apparently, Sr^{90} concentrations in the Tennessee River to a distance of 500 river miles from the release point may be predicted on the basis of dilution.

Clams, because of their life span, are useful as long-term indicators of Sr^{90}. If seasonal phenomena affect the downstream movement of Sr^{90}, this would not have been detected in the analysis reported here. Short-lived mollusks such as physid snails or sphaeriid clams may be useful as short-term indicators of Sr^{90}.

The use of specific activities to determine the behavior of mineral elements in natural waters affords an excellent opportunity to further our knowledge of the chemistry and biology of these waters. This knowledge may be used for predicting the fate of radioactive contaminants in the environment as well as for adding to our understanding of mineral nutrition required for biological productivity (*10*).

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References and Notes

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10. This research was conducted in the Radiation Ecology Section, Health Physics Division, of Oak Ridge National Laboratory (ORNL), operated by Union Carbide Corporation for the U.S. Atomic Energy Commission. I wish to acknowledge the assistance of T. C. Rains, J. A. Norris, and C. L. Burros (Analytical Chemistry Division, ORNL), who did the chemical analyses; H. W. Van der Schalie, J. B. Burch, and B. C. Dazo (University of Michigan), who prepared the reference collection of clams; and Paul Bryan (Tennessee Valley Authority) and John Conder (Tennessee Game and Fish Commission), who collected some of the clams. Profitable discussions with other members of the Radiation Ecology Section, ORNL, have contributed to the interpretation of results, and R. C. Early and N. A. Griffith assisted in sample preparation.

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Radiotelemetry of the Respiration of a Flying Duck

Abstract. Respirations of a flying wild mallard duck, *Anas platyrhynchos*, appear to be synchronized with wing beat in a ratio of 1 to 2. Wing beats come during exhalation and between respirations. The average number of respirations was 14 per minute for a resting duck and 96 per minute for a flying duck.

There has been considerable speculation by various workers about the synchrony or lack of it between respiration and wing beat in birds (*1*). Tomlinson and McKinnon (*2*) appear to have evidence that respiration and wing beat in the pigeon, *Columba livia*, are synchronized in 1-to-1 relationship.

While engaged in radio tracking of wild mallard ducks, *Anas platyrhynchos*, for studies of bird orientation, we accidentally discovered that the miniature radio transmitter being used was telemetering respiration. The transmitter was originally designed for tracking wild rabbits, *Sylvilagus floridanus* (*3*). Electrically, it is a one-transistor, crystal-controlled Colpitts oscillator (see circuit diagram, Fig. 1). The tank coil for the oscillator acts also as a magnetic dipole transmitting antenna. In the present study, the antenna was a loop constructed of a thin (0.008-inch thick), flexible, copper strip 0.25 inch wide and 12 inches long. A slight change in the shape of the loop causes a change in the frequency and output (microwatts) of the transmitter, which may be heard and recorded through a sensitive receiver. We used a Collins R-390A receiver, and the recorder was a Sanborn eight-channel unit.

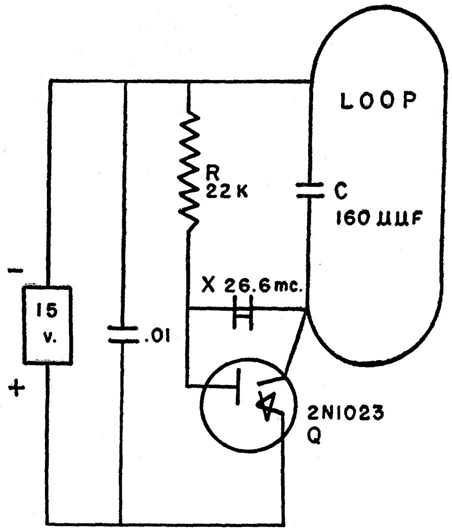

Fig. 1. Circuit diagram of the transmitter used to telemeter respiration from ducks. The values of *R* and *C* may vary considerably, both being dependent on slight differences in the transistor and the loop.

The transmitter was attached to the duck by plastic electrical tape which was wrapped once around the battery and several times around the duck's body just behind the wings. The transmitter thus rode on the center of the duck's back, while the antenna loop encircled the body immediately anterior to the legs. The total weight of the transmitter including the battery and loop antenna was 38 grams, most (25 grams) of which was battery.

Upon release, the duck (an adult male) flew north, then circled east of the tracking station to fly eventually out of tracking range to the southwest. Within 5 minutes of leaving tracking range, the duck returned on a straight