SEASONAL VARIATION IN RADIOCESIUM CONCENTRATIONS IN THREE TREE SPECIES

CHARLES T. GARTEN, JR., LINDA A. BRIESE, REBECCA R. SHARITZ, and J. B. GENTRY
Savannah River Ecology Laboratory, Aiken, South Carolina

ABSTRACT

Radiocesium concentrations in leaves and stems of black willow (*Salix nigra*), wax myrtle (*Myrica cerifera*), and tag alder (*Alnus serrulata*) trees inhabiting a floodplain contaminated by production-reactor effluents were measured over 1 year. In willow and myrtle trees, leaf radiocesium levels were highest in the spring and declined during the growing season; stem levels remained relatively unchanged or exhibited a slight increase. Seasonal changes in alder tree parts depended on the site examined. The relationship among component parts was essentially consistent across species and collecting sites in the summer. The radiocesium concentrations in order of rank were: roots $\geqslant$ leaves $>$ stems. Species differences in component-part radiocesium levels were dependent on the part sampled and the collecting site examined. Mean soil to plant-part concentration factors in summer ranged from 0.9 to 7.6, and species means across leaves, stems, and roots averaged 2.1, 3.8, and 6.2 for alder, willow, and myrtle trees, respectively.

Radionuclide cycling in woody plants has previously been examined by innoculating vegetation with radioactive isotopes (Witherspoon, 1964; Witkamp and Frank, 1964; Waller and Olson, 1967). Although the behavior of radionuclides injected into vegetation might be different from that of radionuclides entering vegetation through roots from radioactive soil, no such differences have been demonstrated. This study focuses on radiocesium dynamics in three tree species inhabiting a contaminated southeastern flood plain. Radiocesium dynamics in trees has not been appreciably explored in southeastern ecosystems, and studies on radionuclide cycling in contaminated environments will enable us to better assess the potential impact of radioactive releases from the nuclear industry.

The study area was Steel Creek, a 20-km coastal-plain stream located on the U. S. Atomic Energy Commission's (AEC) Savannah River Plant near Aiken,

S. C. During a 9-year period, from 1961 to 1970, approximately 260 Ci of radiocesium, primarily ^{137}Cs, entered Steel Creek from facilities at two nuclear production reactors (Marter, 1970). Releases emanated from storage basins housing defective fuel assemblies. During the time that releases were occurring, large amounts of reactor cooling water also entered Steel Creek and elevated the water level. When water levels were reduced, following shutdown of one reactor and a redirection of flow from the other reactor to a cooling reservoir, the Steel Creek floodplain was exposed. Black willow (*Salix nigra*), wax myrtle (*Myrica cerifera*), and tag alder (*Alnus serrulata*) are the most common tree species now ying on the contaminated floodplain soils (Anderson, Gentry, and Smith, 3).

Previous studies have demonstrated radiocesium uptake by vegetation in the vicinity of Steel Creek (Sharitz et al., 1975; Garten et al., this volume). Our purpose was to answer the following questions: (1) Do the aboveground component parts of trees exhibit seasonal trends in radiocesium concentrations, and are these trends consistent across different locations? (2) Are radiocesium levels in component parts different among species, and are these differences consistent across different locations? (3) Is radiocesium concentrated by the woody vegetation above soil radiocesium levels?

MATERIALS AND METHODS

Individual black willow, wax myrtle, and tag alder trees were selected randomly along transects on the lower portion of Steel Creek. The transects, A, B, and C, were each over 150 m in length and located approximately 15.5, 16.2, and 16.9 km, respectively, downstream from the reactor area (see Brisbin et al., 1974, for illustration). Ten trees of each species were chosen along each transect with the exception of transect C where only willow trees were present. Leaf and stem (twig) samples were taken, when available, from each tree in fall (October 1971), winter (January 1972), spring (April 1972), and summer (July 1972). Soil samples and surface roots were dug to a depth of approximately 15 cm from the base of each tree during summer.

Plant samples were dried in paper bags at 80°C in a forced-draft oven before being ground with a Wiley mill. Subsamples in test tubes were then dried night in a vacuum oven at 50°C to a constant weight. Soil samples were d in an oven at 80°C, pulverized and homogenized, and sifted through a 2-mm-mesh sieve to remove organic matter. Subsamples of soil and plants were counted for radiocesium using two pulse-height analyzers (gamma spectrometers) equipped with sodium iodide well-type detectors. Samples were counted for 30 min or to a preset count of 100 counts in the peak channel depending on the machine used. A nonparametric sign test of paired observations showed there was no significant difference in results from the two machines when both were calibrated against known standards ($P > 0.10$, $n = 15$). Both machines had similar counting efficiencies, and sample activities were calculated on the basis of same-day counts of standards and backgrounds. Calculations were made by an IBM 360 computer, and concentrations are expressed as picocuries per gram dry weight.

Peak stripping techniques for omitting energies from isotopes other than ^{134}Cs and ^{137}Cs present in the samples were not used. Relative to radiocesium concentrations in Steel Creek, the contribution of other radioactive elements to the total gamma spectrum is negligible. Among the cesium isotopes the ^{134}Cs to ^{137}Cs ratio in Steel Creek is less than 1:20 (Marter, 1970); therefore concentrations presented refer mainly to ^{137}Cs.

Statistical analysis was obtained using the Statistical Analysis Sys (Service, 1972).

RESULTS

Over the study period, data on some component parts were not available. Any trees with missing observations were deleted; so all trees included in the analysis have complete records for all seasons when component parts are expected. With these constraints on the available data, complete records were obtained for seven alder trees, eight myrtle trees, and six willow trees at transect A, five trees of each species at transect B, and nine willow trees at transect C. Analysis of variance was used in the statistical analysis. A log-normal transformation was applied to the data before analysis because radiocesium data on plants from the Savannah River Plant most frequently fit a log-normal distribution (Pinder and Smith, this volume). Statistical significance was indicated by $P \leqslant 0.05$.

Seasonal variation in leaf and stem radiocesium concentrations was apparent to varying degrees in all tree species, and in some instances trends were dependent on environment or the transect sampled. Willow leaves and stems differed significantly in radiocesium concentrations across seasons ($F_{2,43} = 14.0$ and $F_{3,60} = 4.75$, respectively). Willow leaf radiocesium levels declined from spring to fall, but stems exhibited a slight increase in concentrations over the same period (Fig. 1). Radiocesium concentrations in both willow leaves and stems differed significantly among the three transects ($F_{2,43} = 23.7$ and $F_{2,60} = 13.6$, respectively). However, the seasonal changes in concentrati were consistent across these transects (i.e., season × transect interactions w not significant for either leaf or stem data).

Myrtle trees exhibited a pattern that was similar, in some respects, to seasonal changes in willow radiocesium concentrations. Myrtle leaf radiocesium levels differed significantly among seasons ($F_{3,37} = 41.3$) and between transects ($F_{1,37} = 6.1$). Leaf concentrations declined steadily from spring to winter, and the nonsignificant interaction between the season and transect treatment terms demonstrated this seasonal change was consistent across the two sampling

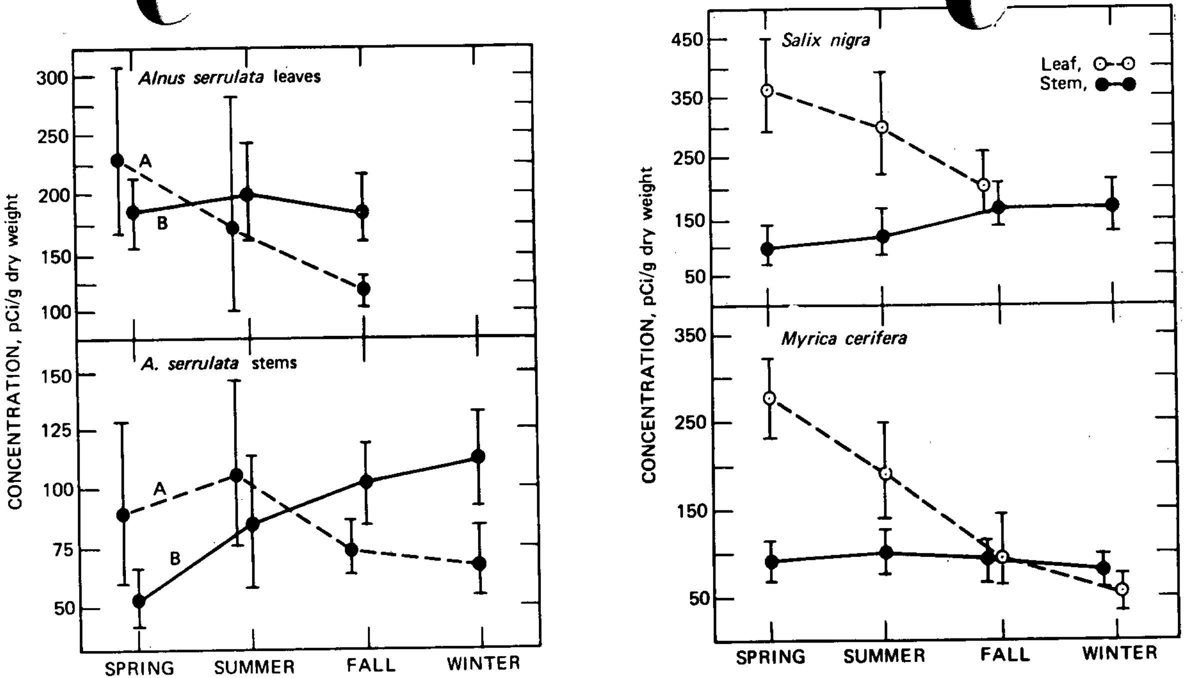

Fig. 1 Seasonal variation in mean radiocesium concentrations in the leaves and stems of black willow (*Salix nigra*), wax myrtle (*Myrica cerifera*), and tag alder (*Alnus serrulata*) trees growing on a contaminated floodplain. Sample size was 20 willow trees, 13 myrtle trees, and 7 alder trees at transect A and 5 alder trees at transect B. Vertical lines on either side of the mean show ±2 SE.

locations. Myrtle stems did not differ significantly among seasons in their radiocesium levels (Fig. 1).

Seasonal differences in alder leaf and stem radiocesium concentrations were observed (Fig. 1), but seasonal trends and differences were dependent on the transect sampled (i.e., season X transect interactions were significant for both leaves and stems, $F_{2,24} = 3.6$ and $F_{3,34} = 8.4$, respectively). Alder leaf levels decreased throughout the growing season at transect A, but concentrations remained relatively unchanged at transect B (Fig. 1). Alder stem concentrations steadily increased from spring to winter at transect B, but at transect A mean stem levels in fall and winter were somewhat lower than in spring or summer. Significant seasonal differences in alder leaf and stem concentrations ($F_{2,24} = 3.6$ and $F_{3,34} = 3.1$, respectively) were therefore a function of the immediate environment in which alders were growing.

The component parts of alder, willow, and myrtle differed significantly in their summer radiocesium concentrations ($F_{2,24} = 29.5$, $F_{2,43} = 41.9$, and $F_{2,25} = 17.8$, respectively). Interaction terms (part X transect) in each univariate analysis were not significant, indicating that component-part differences were consistent across transects A and B. Multiple comparison of group means by a Scheffé test (Morrison, 1967) demonstrated the following significant differences: (1) in both willow and alder trees, root concentrations were usually greater than leaf concentrations, which were greater than stem concentrations, and (2) in myrtle trees, root and leaf concentrations were similar, and both were greater than stem concentrations (Table 1). Relationships among plant-part radiocesium levels are clearly dependent on the season when parts are collected (Fig. 1).

Differences in radiocesium concentrations among species were also assessed. Species differences were affected by habitat as indicated by a significant overall species X transect interaction term in a multivariate analysis of variance of leaf, stem, and root concentrations (Hotelling–Lawley Trace, $F = 4.6$, df = 6,34). Univariate analysis of variance demonstrated that the species X transect interaction was significant in an analysis of both leaf and stem concentrations. When the mean values for these component parts in Table 1 are examined, the source of the interaction becomes apparent. Considering only leaves, at transect A the radiocesium levels in the species rank as follows: willow > myrtle > alder; at transect B the reverse order is observed: alder > myrtle > willow. Mean stem concentrations rank as follows at transect A: willow > alder > myrtle; at transect B the reverse is observed: myrtle > alder > willow. Clearly, interspecific differences in concentrations are dependent on both the part examined and the site sampled.

Plant radiocesium concentrations were independent of soil concentrations, as indicated by no significant correlations among plant-part and soil radiocesium levels for any of the tree species. Concentration factors of plant-part radiocesium levels to soil radiocesium concentrations were calculated for each tree, using all

TABLE 1

MEAN RADIOCESIUM CONCENTRATIONS (pCi/g DRY WEIGHT) IN THE COMPONENT PARTS OF TREE SPECIES AT TRANSECTS ACROSS A CONTAMINATED FLOODPLAIN IN SUMMER

	Component part								
	Leaf			Stem			Root		
Transect	Willow	Alder	Myrtle	Willow	Alder	Myrtle	Willow	Alder	Myrtle
A	426.4	166.2	207.9	142.9	104.8	96.0	401.2	248.6	480.2
B	147.7	196.2	178.0	59.6	81.6	103.2	269.2	379.3	225.0
C	393.5			166.9			721.3		
Means* across Transects A and B	239.2[a]	183.1[a]	188.7[a]	88.7[b]	90.6[b]	101.7[b]	322.8[c]	318.1[c]	289.7[a]

*Within a species, any two means sharing the same superscript are not significantly different ($P > 0.05$). Sample size was six willow, seven alder, and eight myrtle trees at transect A, five of each species at B, and nine willows at transect C.

available data from the summer sample. Individual concentration factors were extremely variable, ranging from 0.1 to 36.0 across the parts and species examined (Table 2). Mean concentration factors were greater than 1.0 for all species and parts with the exception of alder stems. Mean stem ratios differed significantly among species ($F_{2,50} = 4.2$), the concentration ratio for alder stems being significantly lower than that for myrtle stems. Alder was the only species in which there was a significant difference among parts ($F_{3,57} = 10.9$), stem ratios being significantly lower than leaf or root concentration factors.

TABLE 2

MEAN CONCENTRATION RATIOS ($\bar{X}$) OF RADIOCESIUM IN EACH PLANT PART TO SOIL RADIOCESIUM (pCi/g DRY WEIGHT) AND THE RANGE (R) OF RATIOS FOR EACH COMPONENT PART OF EACH SPECIES*

Component part	Statistic	Concentration ratios† Willow	Alder	Myrtle
Leaves	$\bar{X}$	$3.8^{a,1}$	$2.3^{b,1}$	$7.1^{a,1}$
	R	0.1–30.3	0.5–11.1	0.4–33.9
Stems	$\bar{X}$	$1.3^{a,1,2}$	$0.9^{a,1}$	$3.8^{a,2}$
	R	0.1–6.1	0.2–2.8	0.2–19.8
Roots	$\bar{X}$	$6.2^{a,1}$	$3.2^{b,1}$	$7.6^{a,1}$
	R	0.6–36.0	0.7–10.2	0.9–25.9
Species mean		3.8	2.1	6.2

*Summer concentrations were used for leaves, roots, and stems. The sample size was 24 willow, 16 alder, and 13 myrtle trees.

†Within each row, means sharing the same numerical superscript are not significantly different ($P > 0.05$). Within each column, means sharing the same alphameric superscript are not significantly different ($P > 0.05$).

Despite the relatively low radiocesium concentrations in the component parts of myrtle trees (Table 1), concentration factors were highest for this species owing to the low-level soils on which it was growing ($\bar{X}_{soil} = 121.2$, n = 13). Radiocesium concentrations in the component parts of willow trees were relatively high (Table 1), but, because this species was growing in areas of high soil contamination ($\bar{X}_{soil} = 318.5$, n = 24), the mean concentration factor was lower than that for myrtle trees (Table 2). The mean soil radiocesium level at the base of alder trees was 187.2 (n = 16).

DISCUSSION

Seasonal changes in radiocesium concentrations observed for trees inhabiting the Steel Creek floodplain can be explained by current knowledge of radiocesium dynamics in woody vegetation. The patterns observed in our study are in general agreement with patterns of seasonal change obtained from innoculating vegetation with radioisotopes. The spring maximum in leaf radiocesium concentrations in willow, myrtle, and alder trees (at transect A) probably results from a mobilization of radiocesium and other mineral elements within the plant as a result of actively growing foliar tissue. Witherspoon (1964) found ^{134}Cs to be highly mobile in oak trees in the spring. Once a spring maximum is attained, foliar radiocesium concentrations decline (Auerbach, Olson, and Waller 1964). Radiocesium losses from willow leaves throughout our study ranged from 46 to 61% of the maximum spring concentration, depending on the transect examined. For myrtle trees, 73 to 77% of the maximum spring foliar concentration was lost by winter. Our figures for radiocesium loss from myrtle and willow leaves are in agreement with values reported for oak and poplar trees at other sites. Witherspoon (1964) reported 51% of the total foliar ^{134}Cs content in oak trees may be lost from the leaf tissue prior to leaf abscission in the fall. In tulip poplar trees, a 53% reduction in foliar ^{137}Cs has been observed over a summer growing season (Waller and Olson, 1967).

Declining leaf radiocesium concentrations throughout the growing season have been attributed to both foliar leaching by rainfall (Auerbach et al., 1964; Waller and Olson, 1967) and to the translocation of radiocesium back into woody tissue prior to leaf fall (Witherspoon, 1964). In tulip poplar trees as much as two-thirds of the maximum ^{137}Cs in a summer tree canopy may be moved to the soil via root death, root exudation, and leaching by soil water (Waller and Olson, 1967). Radiocesium transport from foliage to roots and soil cannot be demonstrated from our data. However, increasing radiocesium concentrations in willow and in some alder stems (Fig. 1) over the growing season suggest resorption of radiocesium from leaves by the stem tissue as leaf senescence approaches. Leaching of radiocesium from willow and alder leaves is probably more important than translocation in decreasing concentrations throughout the spring and summer seasons. The cause of declining leaf concentrations in myrtle trees is unclear. Translocation of radiocesium into woody tissue is not indicated by the unchanging stem concentrations. Appreciable leaching of myrtle leaves by rainfall also seems unlikely because of the thick waxy cuticle layer characteristic of this species.

Seasonal changes in radiocesium concentrations have two consequences for the floodplain ecosystem. First, the high foliar radiocesium levels in spring and summer suggest that, per unit weight, significantly more radiocesium will be ingested by herbivores at that time. Spring and summer are times when consumers may be undergoing net growth, and consequently greater amounts of radionuclide might be incorporated into the consumer biomass during the growing season than in the fall when foliage concentrations are low. Second, the translocation of radiocesium back into woody tissue in fall will promote retention of the element within the ecosystem and reduce the magnitude of the release of cesium in leaf fall to the decomposer food chain.

In this study we found that environment or collecting site affected both seasonal changes in radiocesium concentration in one species and the nature of species differences in the summer. The interaction of season and transect treatment terms in the analysis of alder tree radiocesium levels indicates that the microhabitat in which alders are growing has some influence on radiocesium dynamics within this species. It is not known what differences exist between transects A and B which would lead to the observed interaction. The interaction of species and transect treatment terms in the analysis of component parts of these trees suggests that the degree of uptake by a species depends on the environment it occupies. Even within a site, microenvironmental differences may be important in determining species differences. For example, myrtle and alder trees appear to be growing in drier areas on the floodplain than are willows, which grow in poorly drained soils and are the major tree species inhabiting the water-saturated delta sediments of Steel Creek. Radiocesium uptake by herbaceous vegetation has been shown to be related to the amount of soil water (Pendleton and Uhler, 1960), and soil-moisture differences may contribute to differences in radiocesium levels among species and transects on Steel Creek. Such edaphic factors as soil composition, pH, and soil nutrient content, which set limits on the distribution of a species on the floodplain, are probably also important in determining the radiocesium concentrations found in each species.

Nonsignificant correlations between soil radiocesium levels and plant component-part concentrations were observed in this study. A similar result has been reported for herbaceous plants inhabiting the Steel Creek delta (Sharitz et al., 1975). Differences between collecting sites or differences among species do not arise from differences in mean soil radiocesium concentrations alone. However, concentration factors for these species indicate an accumulation of radiocesium in the component parts of woody vegetation. In addition to considerable individual variation, soil-to-plant concentration factors can be expected to exhibit seasonal variation. Each concentration ratio reported in this study is merely a static index of radiocesium concentrations in vegetation relative to soil concentrations. Concentration-ratio data from Steel Creek are in contrast to vegetation growing on White Oak Lake bed sediments in Tennessee, where Crossley (1967) reported concentration factors of 0.027 for radiocesium. Accumulation of radiocesium in vegetation has been observed at another stream system flowing parallel to Steel Creek at the Savannah River Plant (Ragsdale and Shure, 1973). At Lower Three Runs Creek, vegetation-to-substrate radiocesium ratios range from 0.3 to 8.3 for roots and 0.1 to 5.5 for leaves (Ragsdale and Shure, 1973). Concentration factors of soil-to-plant radiocesium levels from 2.5 to 32.6 were recently reported for other areas of the world (Marei et al., 1972).

Studies are needed to determine if radionuclide concentration by vegetation in Steel Creek may be characteristic of southeastern coastal-plain streams.

Desorption studies show that radiocesium is not tightly bound by Steel Creek sediments (Brisbin et al., 1974), and radiocesium fixing capacities of soils are apparently poor throughout the entire southeast (Cummings et al., 1971). Radiocesium uptake by plants in the vicinity of Steel Creek may be related to mineral-deficient soils characteristic of southeastern ecosystems.

ACKNOWLEDGMENTS

Richard A. Geiger and Mary Elam collected samples in the field. Technical assistance in the laboratory was provided by Carol Edwards and William Lewis. William Strack and John E. Pinder III assisted in the data analysis. Jean Coleman plotted the curves. Ken W. McLeod and John E. Pinder III critically reviewed the manuscript. We thank all these persons for their efforts in behalf of this project. Support was provided by contracts AT(38-1)-708 and AT(38-1)-819 between the University of Georgia and the U. S. Atomic Energy Commission.

REFERENCES

Anderson, G. E., J. B. Gentry, and M. H. Smith, 1973, Relationships Between Levels of Radiocesium in Dominant Plants and Arthropods in a Contaminated Streambed Community, *Oikos,* **24:** 165-170.

Auerbach, S. I., J. S. Olson, and H. D. Waller, 1964, Landscape Investigations Using Cesium-137, *Nature,* **201:** 761-764.

Brisbin, I. Lehr, Jr., et al., 1974, Patterns of Radiocesium in the Sediments of a Stream Channel Contaminated by Production Reactor Effluents, *Health Phys.,* **27:** 19-27.

Crossley, D. A., Jr., 1967, Comparative Movement of ^{106}Ru, ^{60}Co, and ^{137}Cs in Arthopod Food Chains, in Proceedings of the Second National Symposium on Radioecology, D. J. Nelson and F. C. Evans (Eds.), USAEC Report CONF-670503, pp. 687-695.

Cummings, S. L., J. H. Jenkins, T. T. Fendley, L. Bankert, P. H. Bedrosian, and C. R. Porter, 1971, Cesium-137 in White-Tailed Deer as Related to Vegetation and Soils of the Southeastern United States, in Radionuclides in Ecosystems, Proceedings of the Third National Symposium on Radioecology, D. J. Nelson (Ed.), USAEC Report CONF-710501-P2, Vol. 2, pp. 123-128.

Marei, A. N., R. M. Barkhudarov, N. J. Novikova, E. V. Petukhova, L. D. Dubova, and V. M. Briganina, 1972, Effect of Natural Factors on Cesium-137 Accumulation in the Bodies of Residents in Some Geographical Regions, *Health Phys.,* **22:** 9-15.

Marter, W. L., 1970, Radioactivity in the Environs of Steel Creek, USAEC Report DPST-70-435, Savannah River Laboratory.

Morrison, D. F., 1967, *Multivariate Statistical Methods,* pp. 32-35, McGraw-Hill Book Company, New York.

Pendleton, R. C., and R. L. Uhler, 1960, Accumulation of Cesium-137 by Plants Grown in Simulated Pond, Wet Meadow, and Irrigated Field Environments, *Nature,* **185:** 707-708.

Ragsdale, H. L., and D. J. Shure, 1973, Floodplain Transfer and Accumulation of ^{137}Cs from a Reactor Effluent Stream, in *Environmental Behavior of Radionuclides Released in the Nuclear Industry,* Symposium Proceedings, AIX-en-Provence, France, 1973, pp. 243-253, International Atomic Energy Agency, Vienna, 1973 (STI/PUB/345).

Service, J., 1972, *A User's Guide to the Statistical Analysis System,* North Carolina State University, Raleigh, N. C.

Sharitz, R. R., S. L. Scott, J. E. Pinder III, and S. K. Woods, 1975, Uptake of Radiocesium from Contaminated Floodplain Sediments by Herbaceous Plants, *Health Phys.*, **28:** 23-28.

Waller, H. D., and J. S. Olson, 1967, Prompt Transfers of Cesium-137 to the Soils of a Tagged *Liriodendron* Forest, *Ecology*, **48:** 15-25.

Witherspoon, J. P., 1964, Cycling of Cesium-134 in White Oak Trees, *Ecol. Monogr.*, **34:** 403-420.

Witkamp, M., and M. L. Frank, 1964, First Year of Movement, Distribution, and Availability of ^{137}Cs in the Forest Floor Under Tagged Tulip Poplars, *Radiat. Bot.*, **4:** 485-495.