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● ***Paper***

TREES AS INDICATORS OF SUBTERRANEAN WATER FLOW FROM A RETIRED RADIOACTIVE WASTE DISPOSAL SITE

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***Abstract*—Tree sampling helped locate a subterranean flow of tritiated water from a low-level radioactive waste disposal site that had not been detected by well water monitoring alone. Deciduous trees growing in a natural forest on the hillsides downslope from the site were sampled for the presence of tritiated water in sap of maple trees and in leaf water extracted from oak and hickory trees. Elevated concentrations of ^{3}H were detected in the leaf water extracted from several trees located 50 m downslope from the western boundary of the fenced exclusion zone. A 3-m-deep well drilled near these trees indicated that the source of tritiated water was a narrow zone of subterranean flow.**

INTRODUCTION

THE PURPOSE of this investigation was to determine if trees could be used as indicators of subterranean flows of tritiated water into the environment surrounding a shallow land radioactive waste burial site located in the eastern United States. Shallow land burial has been considered a practical and environmentally secure way to dispose of low-level, solid radioactive wastes. Typically, land burial consists of digging a trench about 10 m deep, systematically filling the trench with packaged radioactive wastes delivered to the sites in trucks, and then covering the waste materials with a meter or more of earth. The trench covering is usually planted with grasses and other plants and maintained to resist wind and water erosion. The environment surrounding waste disposal sites is carefully monitored to detect the possible migration of radionuclides into groundwater, soil and local biota. The major route of radionuclide migration from shallow land burial sites is believed to be subterranean water flow. Minor routes of migration have been identified as root uptake and the excavation of buried wastes by burrowing animals (Mc82).

THE SITE

The Maxey Flats Waste Disposal Site (MFDS) is located in Fleming County in the hill country of eastern Kentucky (Fig. 1). The 100 ha property is owned by the Commonwealth of Kentucky and contains a series of waste-filled trenches grouped within a 17-ha fenced exclusion zone. Approximately 160,000 m^3 of solid wastes (Ga76) containing about 2×10^6 Bq (6×10^5 Ci) of ^{3}H have been buried on the site since 1963.* The site has been closed to the reception of radioactive wastes since 1977 (Ze83).

A stylized geological section of the MFDS and the topographic positioning of the burial trenches is illustrated in Fig. 2. The trenches are dug into shale and sandstone strata that characteristically have low water permeability (Ze83). Due to the high annual precipitation (100 cm) at the MFDS and since the earthen trench covers were weakened and disrupted by shrinkage and collapse, water has penetrated the buried waste material. In the past, rainwater and snow melt filled the interstitial spaces to the point of overflow (Ze83). To prevent trench overflow, the radioactive trench water was pumped from the trenches and reduced in volume at an evaporator facility located on the site (Fig. 3). The radioactive sludge was recovered for redisposal; however, ^{3}H, as tritiated water, is released into the air in the evaporator's vapor plumes.

The fenced exclusion zone surrounding the burial trenches is bounded on the east, west and south sides by second growth stands of deciduous trees, mostly oak and hickory (*Quercus* spp. and *Carya* spp.). The trees are rooted in shallow colluvium on the steeply sloping hillsides that direct surface water flows into No Name Creek Hollow and into Drip Springs Hollow (Figs. 1 and 2). The land north of the exclusion zone is gently sloping and it is under cultivation to grow corn and tobacco. The vegetation inside the exclusion zone consists mostly of planted

* Personal communication (1985) with David T. Clark, Dept. for Health Services, Radiation and Product Safety, Cabinet for Human Resources, Commonwealth of Kentucky, Frankfort, KY.

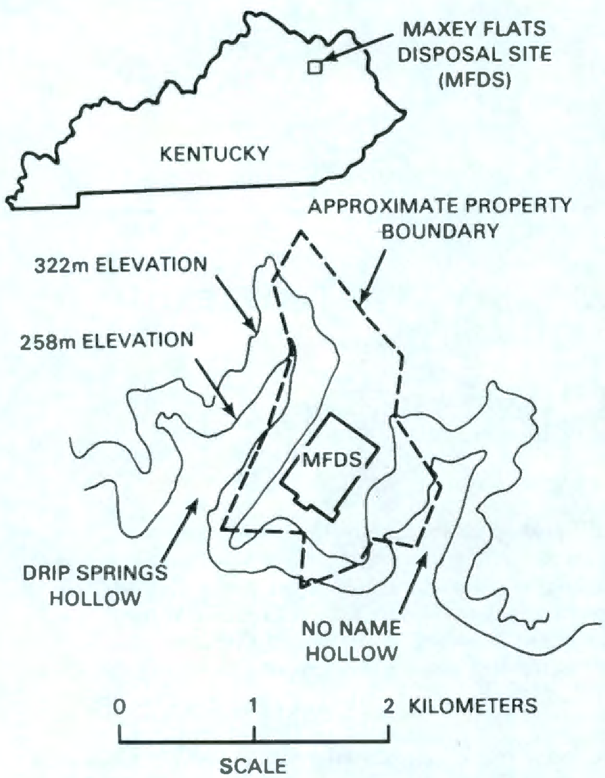

Fig. 1. Maps of the Maxey Flats Disposal Site located in eastern Kentucky.

pasture grasses, especially *Festuca arundinacea*. The grasses are periodically mowed during the spring and summer months to discourage the natural invasion by trees.

METHODS

Two general sources of tree water were available for field sampling. Free-flowing tree sap was obtained by tapping the trunks of maple trees (*Acer* spp.). Sap was only available from maples and only for a short period of time in late winter. Leaf water was available for all tree species throughout the leaf-bearing season, May to October.

Sap was obtained from maple trees by augering a hole through the bark and into the sapwood and fitting the hole with a spigot. The spigot directed the sap to drip into a vial, hand-held to the spigot. Twenty to 100 ml of sap was usually obtained in a few minutes.

Leaves were collected by clipping small tree branches from the lower canopy with the aid of long-handled pruning shears. Leaf-bearing twigs were trimmed from the branches and placed into large translucent plastic bags. The bags were closed and set out in direct sunlight for several hours. Water vapor released from the leaves and twigs condensed on the inside walls of the bags and formed water droplets which could be directed by gravity flow into one corner of the bag and then drained into a vial after making a small incision in the bag. A sample of 20 to 40 mL of water was usually obtained.

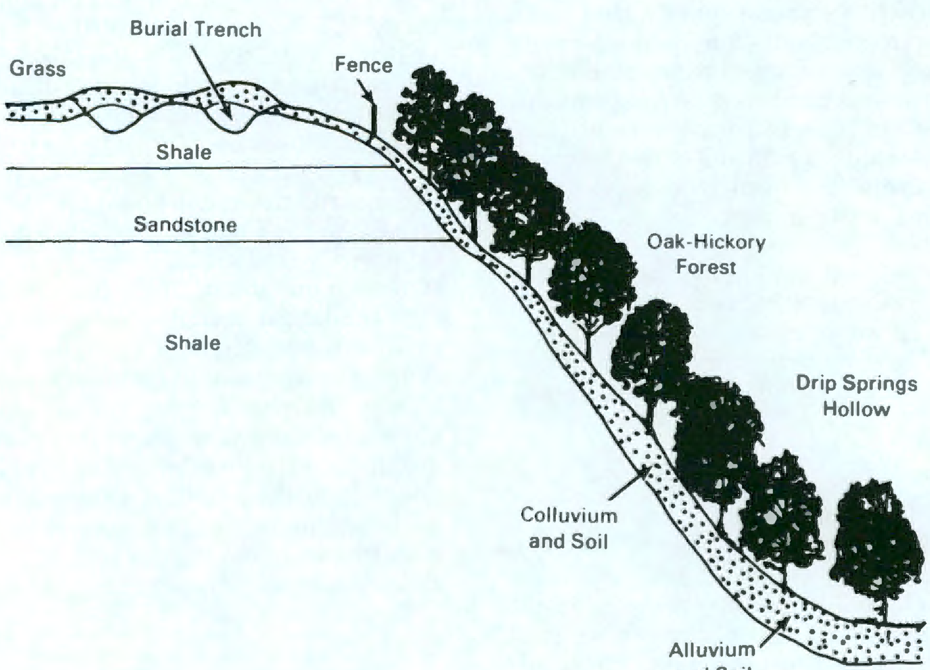

Fig. 2. Diagrammatic geologic representation of the Maxey Flats Waste Disposal Site (modified from Zehner, 1983).

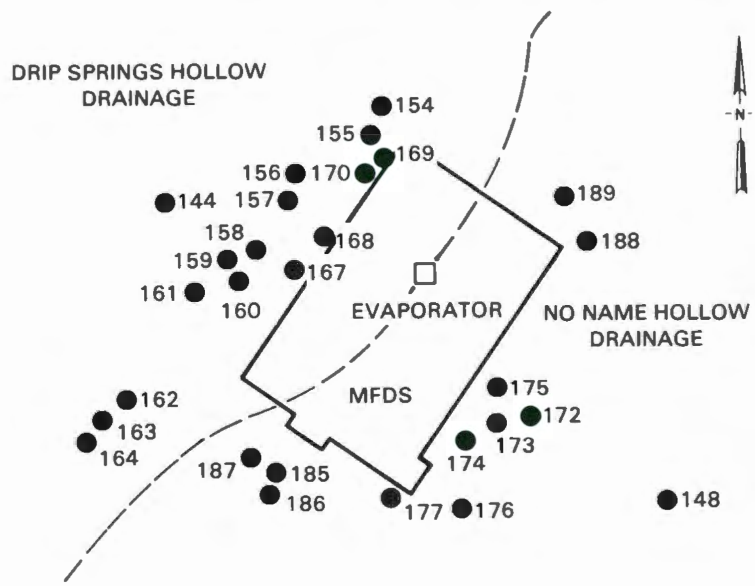

Fig. 3. Approximate locations of maple trees (*Acer* spp.) sampled for sap in March 1983.

The collected sap and leaf water was distilled to obtain a water sample free of inorganic or organic chemical contaminants. Tritium concentrations were determined on 4 mL aliquots by liquid scintillation spectrometry (USDHEW67).

RESULTS

Tritiated water as it is released from the evaporator facility is washed into the soil by rainfall and snow melt, and in this way it is believed to be available for root absorption with a potential to reappear in tree sap and leaf water via root uptake and stem transport processes. Although soil water is believed to be the principal source of ^{3}H to trees at the MFDS, tritiated water under experimental conditions has been known to enter the leaf water of pine trees directly from the air (Mu75).

The evaporator facility at MFDS was shut down for a 17-mo period between December 1982 and May 1984, and all sampling in this study was conducted during the shut down period.

The first tree sampling was made in March 1983. It consisted of extracting sap from maple trees (Table 1, Fig. 3). Some of the trees located on the western side of the exclusion zone showed enhanced levels of ^{3}H in their sap as compared to trees located elsewhere around the site. This finding did not necessarily indicate that the source of enhanced ^{3}H was a subterranean flow containing tritiated water because the source could have been the evaporator plume. The data did show a broad zone of enhanced ^{3}H concentrations in the forest around the MFDS as compared to samples taken in a forest located 10 km away (Table 1).

In July 1983, a number of trees growing along the edge of the forest at the western fence-line of the MFDS were sampled for leaf water. Tritium concentrations in tree leaf water ranged between 0.37 and 12 Bq/mL (Fig. 4). These values were similar to those measured in maple

Table 1. Tritium concentrations (Bq/mL) in sap collected from maple trees growing in the vicinity of the Maxey Flats Waste Disposal Site (MFDS), 2–3 March 1983. The concentrations are arranged in decreasing order

Western boundary Drip Springs Hollow drainage				Eastern boundary No Name Creek drainage			
Tree no.	Bq/mL	Tree no.	Bq/mL	Tree no.	Bq/mL	Tree no.	Bq/mL
156	11.0	170	3.20	188	3.4	177	1.20
168	10.0	161	2.90	174	2.8	176	1.00
155	6.7	160	2.60	175	2.7	186	0.44
159	6.3	149	0.89	189	2.4	187	0.37
158	5.6	162	0.37	172	2.0	185	0.33
167	4.4	163	0.33	173	1.8	148	0.33
154	4.1	164	0.30				

Trees located at distances of 10 km from MFDS had tritium concentrations of $<3.7 \times 10^{-2}$ Bq/mL.

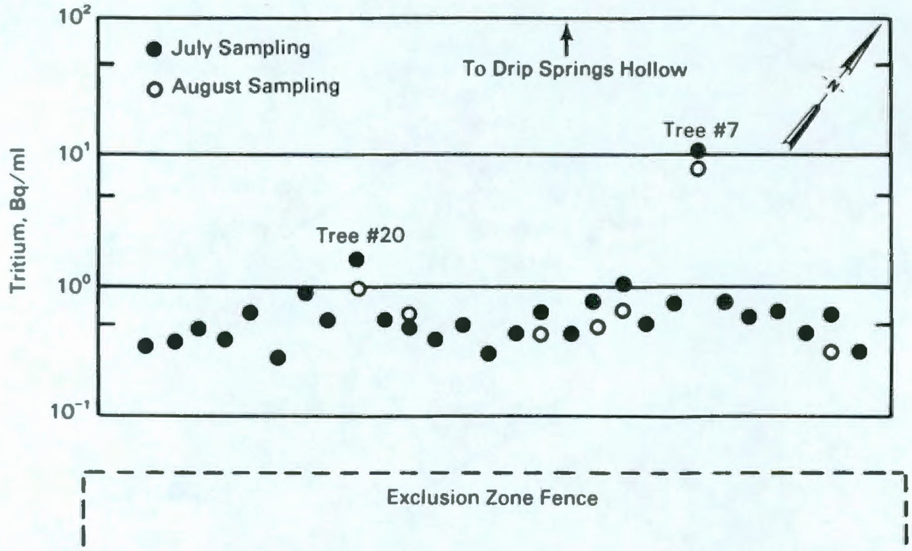

Fig. 4. Tritium concentrations, Bq/mL, in leaf water samples collected in July and August 1983 from 28 trees growing along the western exclusion zone fence.

sap in March. One tree, number 7, showed slightly elevated levels of ^3H in comparison to other trees growing along the fence line. This suggested that this single tree might be accessing a subterranean source of tritiated water. To explore this general area in more detail, other trees were sampled along a line located at a right angle to the western fence and extending downslope into Drip Springs Hollow and a short distance up the opposing slope. At 50-m intervals along this line, three trees located 10 m apart but at the same elevational contour were sampled. Figure 5 shows that the trees located 50 m downslope from the fence had the greatest concentrations of ^3H. Tree number 055 had a ^3H concentration of 120 Bq/mL, indicating that the evaporator was probably not the source of all the ^3H measured in this tree.

In August 1983, tree 055 was resampled along with trees growing along the fence line (Fig. 4). Concentrations of ^3H in leaf water showed an increase from 220 Bq/mL in July to 400 Bq/mL in August. As shown in Fig. 6, another tree, 097, located about 10 m from tree 055 had an even higher ^3H concentration of 1000 Bq/mL. The presence of enhanced concentrations of ^3H in only two trees suggested a narrowly restricted zone of tritiated water within the root zone. The ^3H concentrations approached the levels measured in water samples pumped directly from some of the trenches (Sc81). The limited zone of tree contact with tritiated water suggested that the source was a restricted flow of trench water, probably moving through small seams and fractures in the underlying rock strata but at a depth that was shallow enough to be tapped by tree roots.

In mid-May 1984, a few days before the restart of the evaporator facility, trees 055 and 097 were sampled for a third time. Tritium concentrations of 90 and 220 Bq/mL, respectively, were measured indicating that the

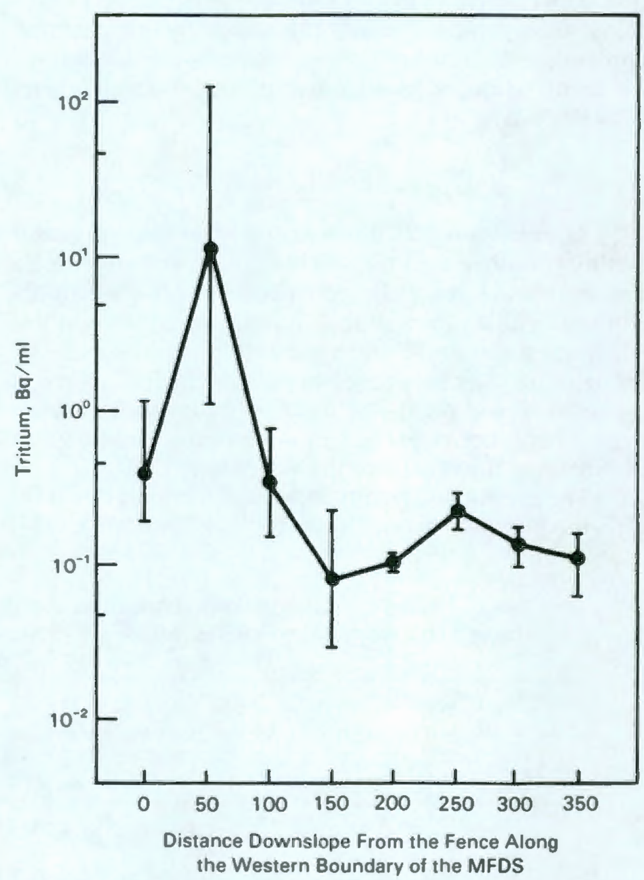

Fig. 5. Tritium concentrations, Bq/mL, in leaf water collected in July 1983 along a transect downslope from the western exclusion zone fence. Three trees were sampled at 50-m intervals along the transect. The vertical bars represent the range of ^3H concentrations in three different trees.

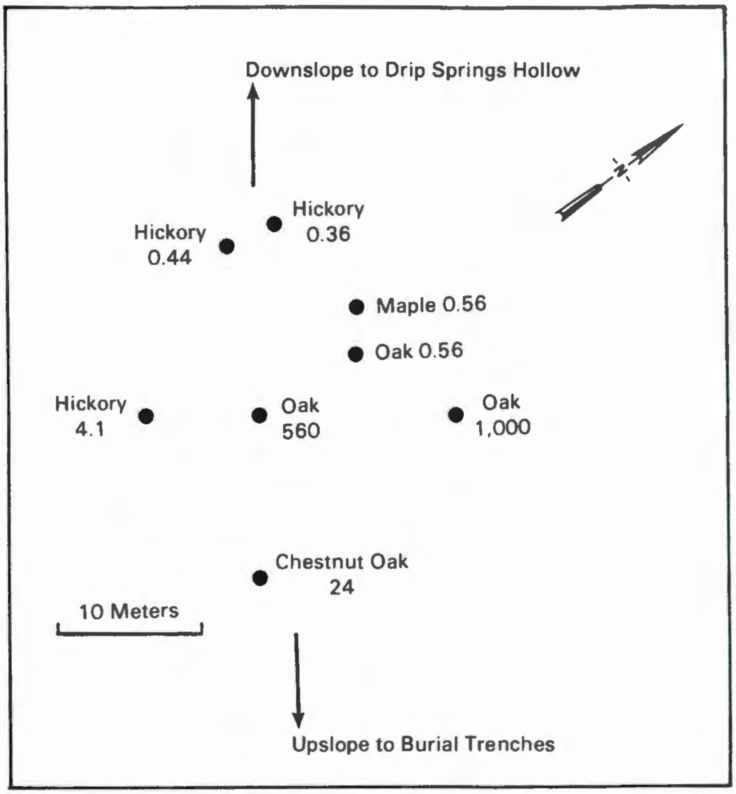

Fig. 6. The concentration of ^3H (Bq/mL leaf water) in eight trees located approximately 50 m downslope from the western exclusion zone fence in August 1983.

source of ^3H to these trees was persistent and not greatly diluted by the inputs of rainwater and snow melt to the upper parts of the root zone during the fall and winter months.

In late summer, a 3-m-deep well was dug at a distance of 11 m from tree 097. This well yielded samples of water with ^3H concentrations ranging from 3,700 to 7,400 Bq/mL (Cl85). This discovery provided additional evidence of a subterranean pathway of water movement from the trenches to a point at least 43 m downslope from the western boundary of the fenced exclusion zone. In this case trees tapped a subterranean flow of tritiated water that had not been previously discovered by well water monitoring alone. Since this initial discovery, other wells have been drilled to more fully determine the direction, distance and amount of subterranean water flow and its radionuclide concentrations.

IMPLICATIONS FOR SHALLOW LAND DISPOSAL

Burial of low-level radioactive wastes is intended to protect the nearby human population from radiation exposure. Site stability is intended to restrict the access of rainwater and snow melt to the buried wastes and in this way minimize radionuclide migration by water flow. Site stability needs to be maintained for a sufficiently long time to allow radioactive decay to reduce the radionuclide inventory of short- and moderately long-lived radionuclides to innocuous levels. Environmental monitoring is intended to test the efficacy of containment and to detect migration of radionuclides before they cross site boundaries.

Remedial actions to restrict the migration of radionuclides by water flow at the MFDS have been practiced for 12 y. Nevertheless, tritiated water has moved from the trenches a short distance beyond the boundaries of the fenced exclusion zone. The flow of tritiated water, as far as is known, is still confined to the site property. Preliminary indications are that subterranean movement of radionuclides other than ^3H in trench water has not occurred beyond the fenced exclusion zone (Ki84).

However, additional sampling is needed to determine if other radionuclides (e.g., ^{60}Co, ^{238}Pu, ^{90}Sr and ^{14}C, ^{99}Tc and ^{129}I) have followed the path of subterranean water flow as indicated by ^3H. Additional sampling is also needed to determine if there are other places at the MFDS where subterranean water flows may be carrying tritiated water. Tree water sampling as an indicator of the presence of subterranean flow of tritiated water in the root zone at the MFDS was somewhat confounded by the release of tritiated water via the operating evaporator facility. This practice tended to elevate the ^3H levels in trees in a broad zone around the site.

The difficulties experienced at the MFDS in stopping subterranean movement of tritiated water suggest that site stabilization needs to be directed towards the installation of a long-lasting (100-y), water repellent trench cover. Such a cover should shed rainwater and snow-melt to direct water flow away from the waste-filled trenches.

The levels of ^3H, which has a half-life of about 12 y, will be reduced considerably via physical decay within a time span of 100 y—a reasonable time frame to expect a water repellent trench cover constructed of common materials to maintain its integrity with only a modicum of maintenance.

The future of shallow land disposal as an environmentally acceptable way to dispose of low-level radioactive wastes in the moist climates of the eastern United States may be determined by the effectiveness and the cost of providing water repellent trench covers that are durable enough to withstand the rigors of weathering and moderate amounts of trench subsidence for one hundred years or more following site closure.

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