RADIOECOLOGICAL STUDIES OF TRITIUM MOVEMENT IN A TROPICAL RAIN FOREST*

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ABSTRACT

Several experiments on the movement of tritium in a tropical ecosystem have been conducted in the montane rainforest of Eastern Puerto Rico by the Bio-Medical Division of the Lawrence Radiation Laboratory, Livermore, in cooperation with the Puerto Rico Nuclear Center. Tritiated water was used as a tracer for water movement in: a) mature evergreen trees of the climax rainforest; b) soil and substory vegetation and c) rapidly growing successional species.

A feasibility study on the Atlantic Pacific Interoceanic Canal is currently being conducted. If thermonuclear explosives were used in constructing the canal, tritium would be deposited as tritiated water and distributed among the several biological compartments of the tropical ecosystem in that area. The main hydrogen compartments are water in the soil and in leaves, limbs and wood of forest trees. Organic tissue hydrogen comprises another compartment.

In the tree experiment, tritiated water was injected directly into several species of mature, broad leaved evergreen tropical trees. Transpiration and residence time for tritium was determined from analyses of leaves sampled during a several month period. Transpiration ranged from 4 ml/day/gm dry leaf for an understory Dacryodes excelsa to 10.0 and 13.8 ml/day/gm dry leaf for a mature Sloanea berteriana and D. excelsa, respectively. Mean residence time for the S. berteriana was 3.9 ± 0.2 days and the understory and mature D. excelsa values were 9.5 ± 0.4 and 11.0 ± 0.6 days, respectively.

In another experiment, tritiated water was sprinkled over a 3.68 m^2 plot and its movement down into the soil and up into the vegetation growing on the plot was traced. The pattern of water movement in the soil

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was clearly demonstrated. The mean residence time for tritium in the soil and in trees was found to be 42 ± 2 days and 67 ± 9 days, respectively. The residence time for tritium in the trees in this experiment was considerably longer than for the single injected input pulse due to the continuous root uptake of tritium as the diffuse peak moved down into the soil past the root zone. Tritium was removed from the plot by transpiration and by interflow. Using transpiration rates from the previous experiment, rainfall records, tree density data and other measurements, average transpiration for the Puerto Rico rainforest was computed to be 3.64 $kg/m^2/day$. The effective capacity of the soil compartment was calculated to be 280 ± 12 kg/m^2.

In the final experiment, tritiated water was injected directly into several species of successional trees in a cleared plot. After several weeks, the trees were harvested and aliquots selected for bound tritium assay. The amount of tritium incorporated into the tissue was about 0.1 percent of the total amount applied to the tree.

Based on all experimental data, the distribution of tritium from a simulated rainout following a one megaton thermonuclear detonation is presented for a climax tropical rainforest and for successional vegetation. The fraction of input tritium remaining in each compartment as a function of time is tabulated. The residence time for each of the compartments determines the persistence of tritium deposited in a tropical ecosystem.

INTRODUCTION

Since thermonuclear explosives are being considered for a variety of peaceful applications, a study on tritium movement in the environment was initiated in order to determine the persistence and biological significance of this abundantly produced radioisotope in tropical regions. Several experiments on the movement of tritium in a tropical ecosystem have been conducted on the montane rainforest of Eastern Puerto Rico by the Bio-Medical Division of the Lawrence Radiation Laboratory, Livermore, California, in cooperation with the Puerto Rico Nuclear Center. Tritiated water was used as a tracer for water movement in: a) mature evergreen trees of the climax rainforest; b) soil and substory vegetation, and c) rapidly growing successional species.

If thermonuclear explosives were used in constructing a new Atlantic-Pacific Canal in Central America, tritium would be deposited as tritiated water and distributed among the several biological compartments of the tropical ecosystems of that area. The main hydrogen compartments are water in the soil and in forest trees. Organically bound hydrogen in plant tissues comprises another compartment. The flux of water through these compartments is a result of rainfall, soil water movement, plant uptake and transpiration. Previous studies of water and tritium movement in the tropical ecosystem have been based on ecological and hydrological estimates.

A model for the behavior of tritium based on the hydrogen budget of the rainforest was formulated by Odum and Bloom.[1] Charnell *et al.*[2] cited the need for experimental data in their discussion on the hydrologic redistribution of radionuclides deposited in the environment following a nuclear excavation. They present a numerical model to estimate the rate of removal of radionuclides from fallout, ejecta and fallback.

Golley et al.[3] characterized the structure of tropical forests in Panama and Columbia. The tropical moist forest which makes up 75 percent of that area is similar in biomass and rainfall to the montane rainforest in Puerto Rico. McGinnis et al.[4] discuss the hydrologic budgets of the Panamanian tropical moist forest. They list the transfer functions and turnover (mean residence) times for eight water compartments of that ecosystem based on watershed hydrologic data.

The purpose of our experiments was to determine directly the pattern of movement and distribution of tritium in several compartments of the rainforest ecosystem by means of tritiated water tracers. Based on these experiments, the distribution of tritium from a simulated rainout following a hypothetical one megaton thermonuclear detonation can be defined for a climax tropical rainforest and for successional vegetation. The residence time for each of the compartments will determine the persistence and biological significance of tritium deposited in a tropical ecosystem.

EXPERIMENTS

The tree experiment (Experiment A) consisted of the injection of high specific activity tritiated water directly into three broad leaved evergreen tropical trees. One was a mature Dacryodes excelsa, one was a Sloanea berteriana, and one was an understory Dacryodes excelsa. A fifty foot tower erected adjacent to the trees provided access to the canopy top from which leaf samples were collected over a period of three months. Water was extracted from the leaf samples by freeze drying under vacuum. Assay for tritium in the leaf water was done by liquid scintillation counting. Dried tissue residues were also assayed for bound tritium.

In the plot experiment (Experiment B), 50 mCi of tritium in four liters of water was sprinkled uniformly over a 3.68 m^2 plot containing several substory tree species. Duplicate soil water collectors called Zero Tension Lysimeters (described by Jordan[5]), each with an effective collection area of 154 cm^2, were installed at each of four depths: just below the litter, and at 5", 10" and 15" below the soil surface. Leaf samples of four trees growing on the plot were picked and water extracted as in the tree experiment. Samples were collected daily during the first week and then at increasing intervals for nearly a year. Water vapor from the air was collected during the first week from sites above and around the plot by condensing it in cold traps.

The secondary successional experiment (Experiment C) was conducted in a portion of the rainforest which had been cleared several years earlier. Six successional trees ranging in height from 5 to 15 feet were injected with one millicurie of tritiated water. Leaf disc samples were taken daily to check the uptake of tritium. Two of the six trees were harvested within one week. The others were harvested one month after the tritium injection. Portions of the stem, roots and leaves were freeze dried and free water was vacuum extracted. Tritium assay was done on the free water and on dried tissue of these selected aliquots.

RESULTS AND DISCUSSION

Tree Experiment.

The results of the tree experiment indicate that tritium was incorporated into the tree water and moved with the transpiration stream. Figure 1 is a plot of tritium activity in leaves versus time (activity time curve) for the mature Dacryodes excelsa. The pattern of release represents an exponential removal of tritium from the tree. The mean residence time given in Table I is the fitted straight line portion of the curve beyond the peak. The data may indicate a species dependency as the Sloanea berteriana has a mean residence time of 3.9 ± 0.2 days while the understory and mature Dacryodes excelsa have mean residence times of 9.5 ± 0.4 and 11.0 ± 0.6 days, respectively.

Bergner,[6-11] in his theoretical analysis of tracer dynamics, has shown that the exchangeable mass in a biological system can be formally and exactly defined. Orr and Gillespie[12] recognized the wide applicability of this theoretical treatment in introducing their occupancy principle. The occupancy principle relates the integral of the activity time curve to the occupancy or mean residence time. The occupancy is defined as the total integral, with respect to time, of the tracer that is in the system. The occupancy principle states that the ratio of occupancy to capacity equals the reciprocal of the entry flow. In our analysis, the amount of tritium injected was equated to the product of entry flow or transpiration and the integral of the activity time curve. It is interesting to note that this independent engineering approach to the problem yielded the identical solution which was later recognized as being supported by Bergner's theoretical treatment of the biological system as explained by Orr and Gillespie.

Transpiration, F, (ml/day) for the trees can therefore be computed by dividing the amount of tritium injected, M, (dpm) by the integral, I, (dpm/ml/day) of the activity time curve.

$$F = M/I$$

As Orr and Gillespie show, this calculation does not depend on the manner of transport of the tracer through the biological system or on the usual assumption of instantaneous or complete mixing. The validity of the treatment depends only on the fact that the tracer enters into some relationship with any compartment of the system.

The regressions of Ogawa et al.[13] were used to estimate the dry biomass of the leaf compartment so that transpiration could be expressed as specific transpiration (ml/day/gm dry leaf). Transpiration, estimated leaf biomass and specific transpiration for the three trees, are given in Table I. Specific transpiration can be seen to increase with tree size. The shaded understory Dacryodes excelsa transpires 4.0 ml/day/gm dry leaf compared with 10.0 and 13.8 ml/day/gm dry leaf for the mature canopy trees Sloanea berteriana and Dacryodes excelsa.

No measurable tritium was found in the dried tissue of the leaf samples indicating that the incorporation of tritium in the bound hydrogen compartment was less than 0.1 percent. Kline et al.[14] discuss the tree experiment in greater detail. The value of the tree injection experiment lies in the use of the data to obtain a measure of transpiration in tropical trees which is used later in the analysis of water movement through the entire ecosystem.

Plot Experiment.

The movement of tritiated water down into the soil is illustrated in Figure 2 where the tritium activity of soil water is plotted as a function of depth for selected days following the surface application of tritium. The wave-like pattern is similar to that described by Zimmerman et al.[15] The rate of movement of the peak is slowed considerably after reaching the solum-sub-soil interface where the bulk density changes from 0.57 to 1.02 gm/cc.

A measure of the residence time for tritium in the soil was made by plotting the integral of each activity depth curve (corrected for the percent water) as a function of time. The curves were extrapolated beyond the depth of sampling so that virtually all of the tritium in the profile would be included in the integral. The plot is shown in Figure 3. The mean residence time was determined to 42 ± 2 days by a least squares fit of the data. If the integral is taken only over the sampling depth of surface to 15", the mean residence time is 37 ± 2 days. The intercept value in both cases gives an initial surface concentration of 13 ± 2 mCi/m^2 which agrees with the applied value of 13.6 mCi/m^2. Since the observed residence time in the soil based on the surface to 15" integral was very close to that determined for the total tritium profile integral, most of the loss mechanisms may be considered to be from the top 15" of soil in this ecosystem.

One loss mechanism is by transpiration. The leaf samples of the four tree species showed the same exponential removal of tritium by transpiration as in the tree experiment except that the average apparent residence time is much longer, 67 ± 9 days. A typical response curve is illustrated in Figure 4. The mean residence time is the straight line portion of the curve beyond the peak. The results are given in Table I.

The longer residence time of tritium in the trees of the plot experiment (67 days) compared with that observed in the tree experiment (4 to 11 days) is due to the coupling of the soil and tree water compartments. Rather than receiving a single injection in time as in the tree experiment, the trees in the plot experiment take up tritium over a period of time as the diffuse peak moves down past the root zone. The residence time in the soil will therefore control the residence time in the trees.

The longer apparent residence time in the trees (67 days) compared with the soil (42 days) of the plot may be explained by the unequal depth distribution of tritium shown in Figure 2. If deep tree roots take up a greater fraction of water than shallow roots, the early tree data will be relatively low with respect to the soil integral because a greater fraction of the transpiration will contain less tritium. At later times, as the tritium peak moves down past the deep roots, the transpiration will contain a greater fraction of higher specific activity tritiated water and the observed tree water will be relatively higher. The net effect would be a straight line with less slope and a longer residence time for the tree water.

Another possible explanation can be given if one considers that the soil compartment also loses tritium in lateral flow through the soil

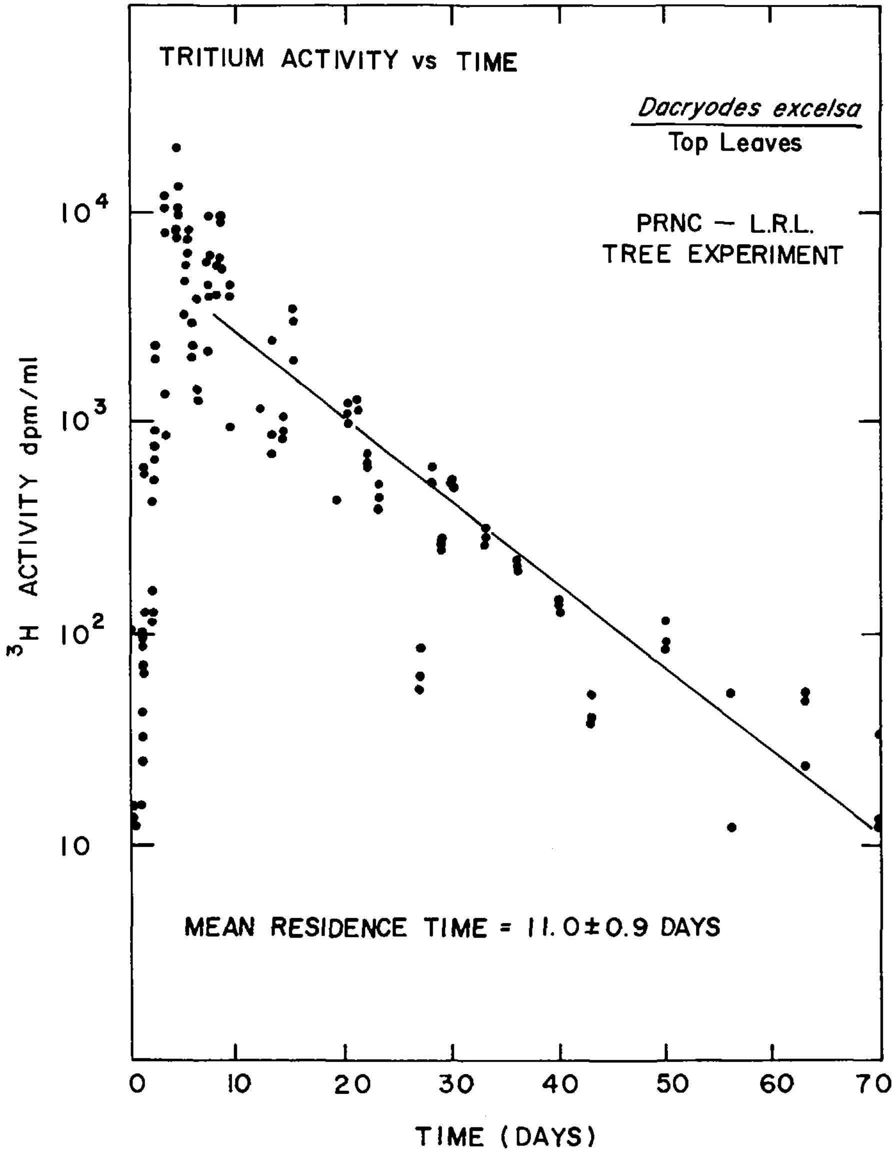

Figure 1

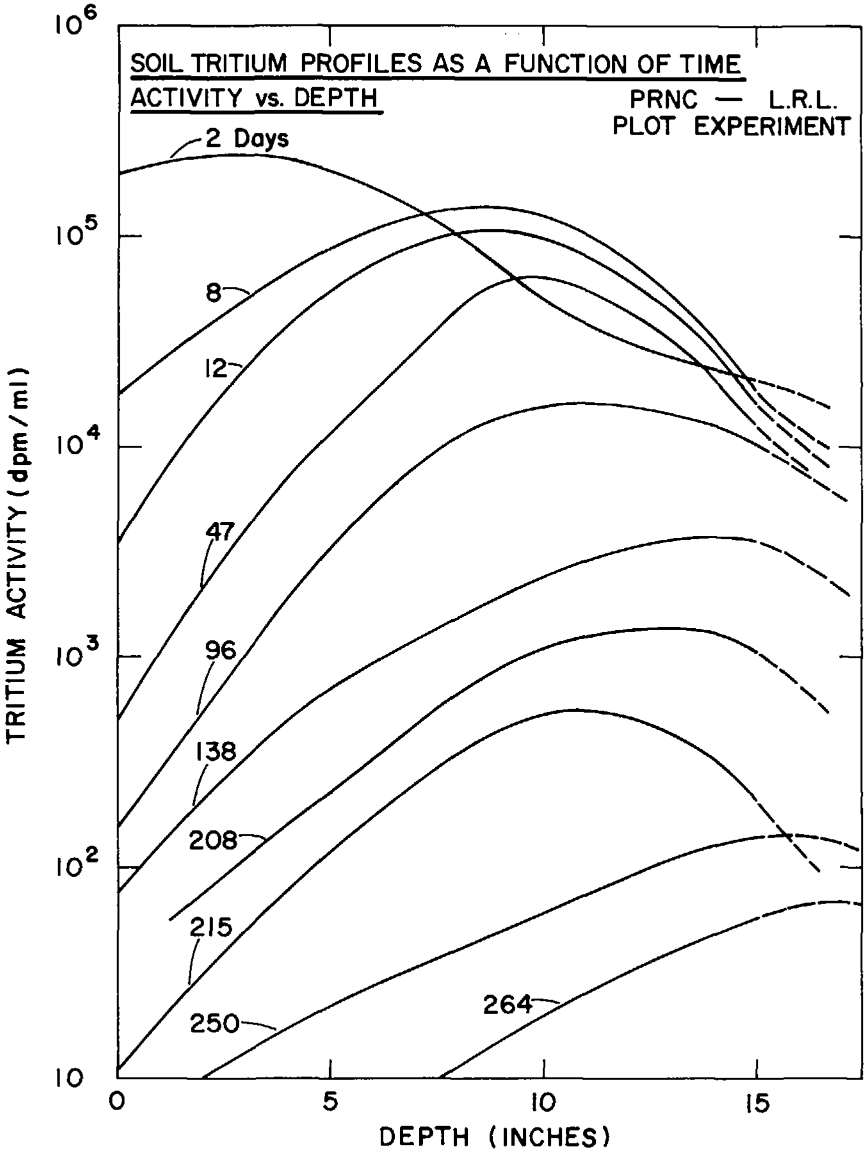

Figure 2

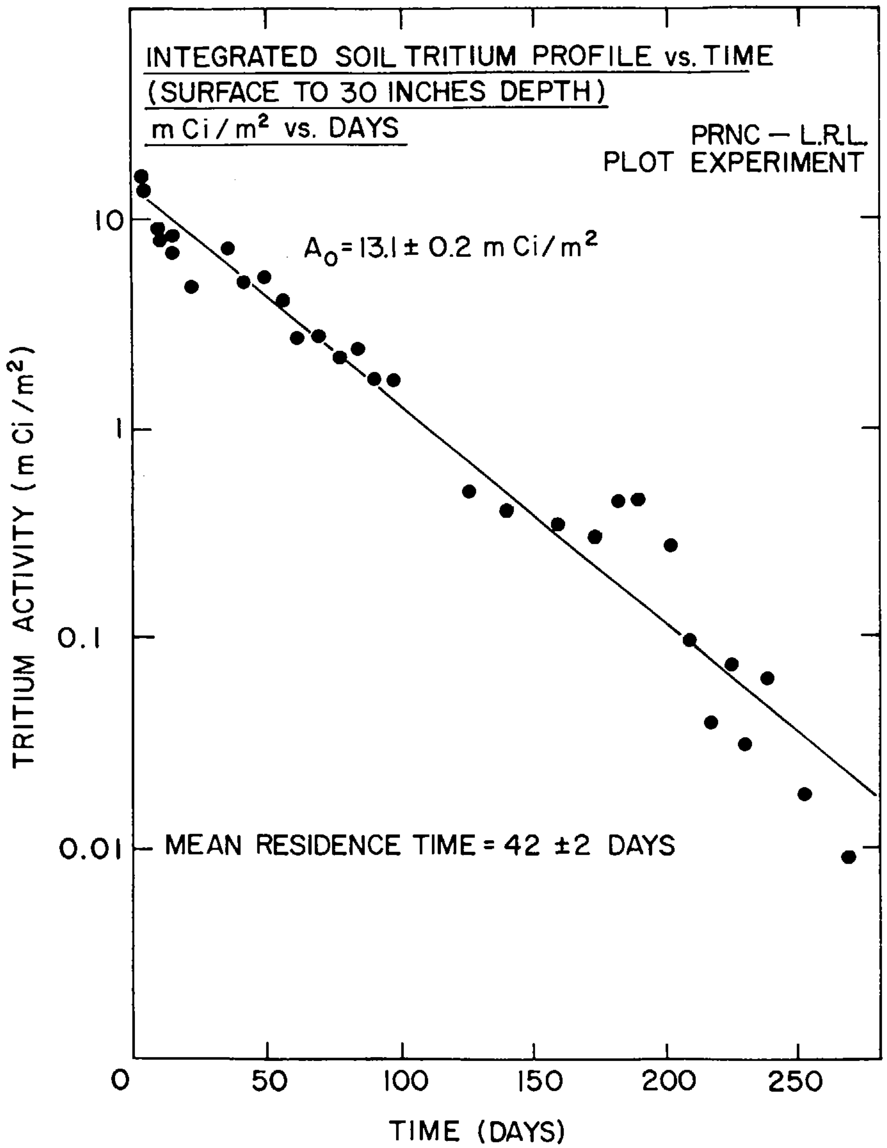

Figure 3

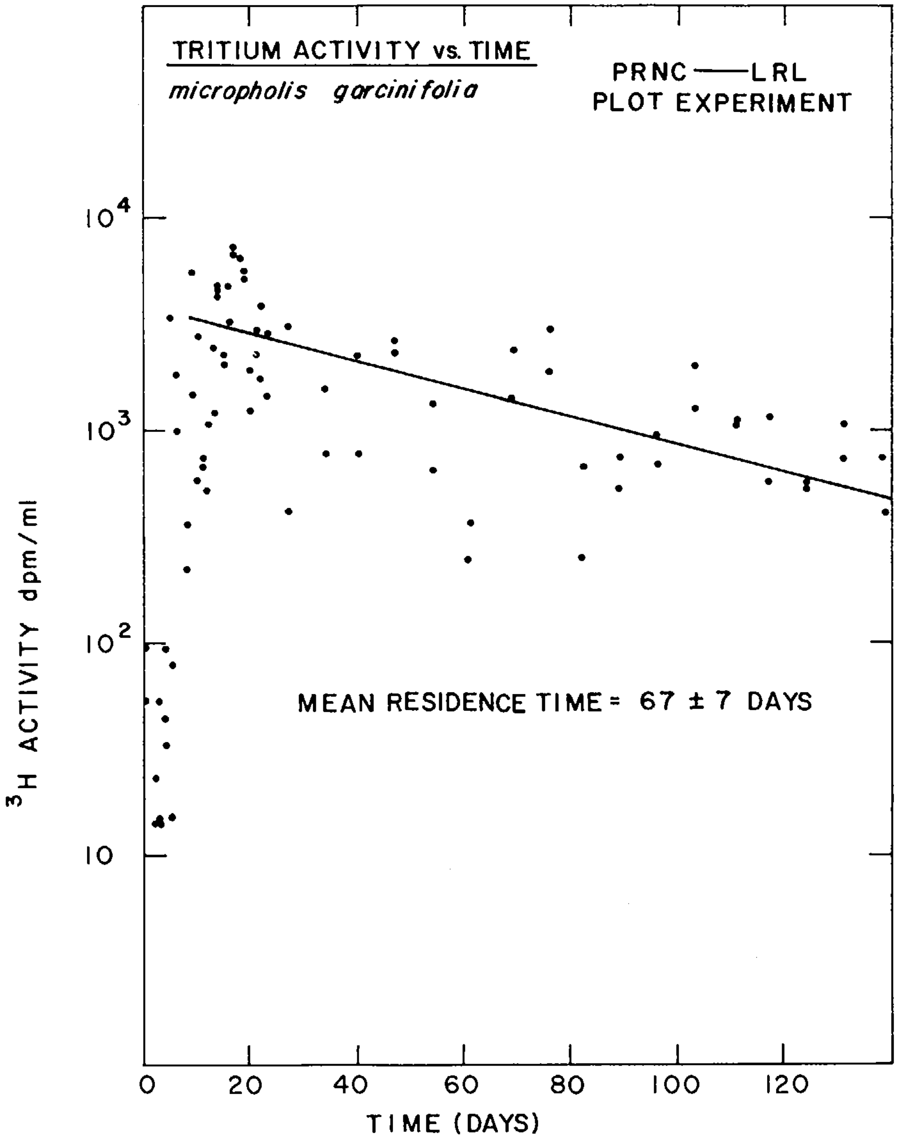

Figure 4

called subsurface runoff or interflow. The soil layer or solum of the rainforest is only 5 to 20 inches deep. Below the solum is a relatively impervious layer of higher bulk density sub-soil. The observed soil loss rate (λ_S) can be considered to be the sum of two loss rates, transpiration (λ_T) and interflow (λ_R).

$$\lambda_S = \lambda_T + \lambda_R$$

The loss rate, λ, is the reciprocal of the mean residence time (T) so that,

$$1/T_S = (1/T_T) + (1/T_R)$$

and

$$T_R = (T_T T_S)/(T_T - T_S)$$

The interflow soil residence time T_R for the 3.68 m^2 plot in this study is computed to be 111 ± 40 days in order to account for the difference between the tree residence time and the observed soil residence time. The relatively large uncertainty in T_R is due to the combination of uncertainties of T_S and T_T in the difference term ($T_T - T_S$). There would be no way to physically isolate the interflow and transpiration loss mechanisms. This analysis is given merely as a possible explanation for the difference in the observed residence times of tritium in the trees and soil.

The air moisture samples showed that the tritiated water vapor remained essentially at ground level. The samples at 100 cm above the plot were 100 times less than the level at 4 cm, and 5 to 10 times higher than the activity at 175 cm. Figure 5 shows the tritium activity at 4 cm and at 100 cm above the plot. The highest activity sampled at 4 cm above the center of the plot was 0.3 μCi/ml which corresponds to about 6×10^{-7} μCi/cc air.

In the discussion of the ecology of tritium movement in this plot experiment, Jordan et al.[16] show that the amount of tritium released to the air by evaporation from the soil surface was less than 0.1% of the total amount applied. Of this, 50% took place during the first half hour and 87% by the end of the first day after the application.

No measurable tritium was found in the dried leaf tissue of a large representative selection of samples.

Successional Experiment.

In contrast with the tissue sample analyses of the previous experiments, leaf, wood and root tissue of all the secondary successional species spiked with tritiated water showed measurable tritium concentrations. The amount of tritium incorporated into the tissue was about 0.1 percent of the total amount applied to the tree. The results are given in Table II. If trees of the mature forest incorporate tritium into the tissue at the same rate as the successional species, the tissue samples in the tree experiments would have been below the limit of detection of the bound tritium analysis. On the other hand, the large tritium activity to tree weight ratio of the successional experiment made the 0.1 percent value easily detectable.

The specific activity in new leaves and growing stem tips was 2 to 10 times higher than the old leaves or main portion of stems. In the Cecropia, for example, the new leaves were 4.8×10^3 dpm/gm compared

TABLE I

TRANSPIRATION AND MEAN RESIDENCE TIME FOR TRITIUM IN TROPICAL TREES

Tree Experiment Tree Species	Transpiration liters/day	Leaf Biomass* kg	Specific Transpiration ml/day/gm dry leaf	Mean Residence Time Days
Dacryodes excelsa (canopy)	372	27	13.8	11.0 ± 0.6
Dacryodes excelsa (understory)	1.8	0.44	4.0	9.5 ± 0.4
Sloanea berteriana (canopy)	140	14	10.0	3.9 ± 0.2

Plot Experiment Tree Species		Mean Residence Time Days
Palicourea riparia		59 ± 7
Manilkara bidentata		80 ± 7
Dacryodes excelsa		62 ± 5
Micropholis garcinifolia		67 ± 7
	Average	67 ± 9

*Leaf biomass estimated from regression of Ogawa *et al.*[13]

TABLE II

TRITIUM UPTAKE AND BOUND TRITIUM IN YOUNG SUCCESSIONAL TREES

Tree	Harvest Time $T-T_0$ Days	Leaves New dpm/gm	Leaves Old dpm/gm	Stem Tip dpm/gm	Stem Average dpm/gm	Precent Tritium Uptake Into Tissue - %
Psychotria (O)	15			2.9×10^3	1.5×10^3	0.027
Psychotria (R)	55	1.4×10^3	5.0×10^2			0.014
Heliconia (Y)	49	9.0×10^4	1.1×10^4	2.0×10^4	3.0×10^3	0.16
Cecropia (P)	55	4.8×10^3	8.0×10^2	6.3×10^3	1.6×10^3	0.14

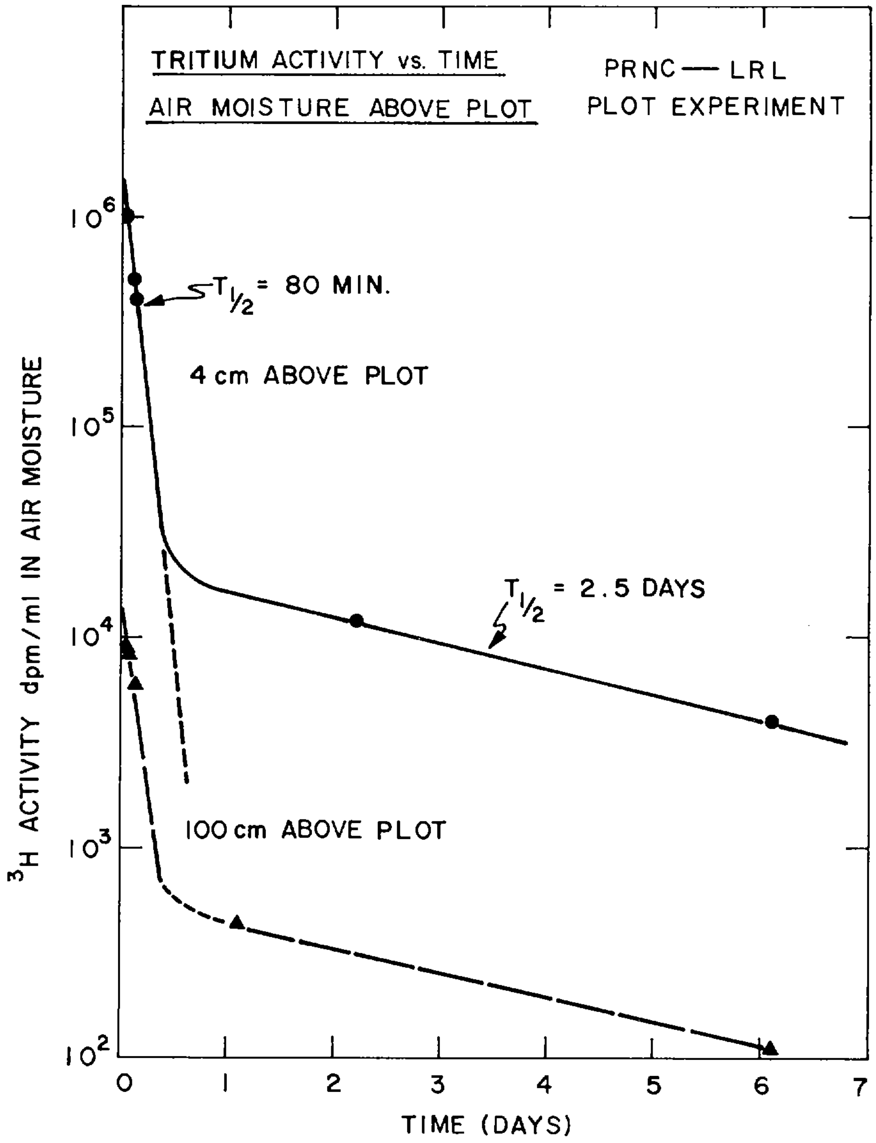
TRITIUM ACTIVITY vs. TIME
AIR MOISTURE ABOVE PLOT
PRNC — LRL
PLOT EXPERIMENT
$T_{1/2}$ = 80 MIN.
4 cm ABOVE PLOT
$T_{1/2}$ = 2.5 DAYS
100 cm ABOVE PLOT
^{3}H ACTIVITY dpm/ml IN AIR MOISTURE
10^6
10^5
10^4
10^3
10^2
0
1
2
3
4
5
6
7
TIME (DAYS)

Figure 5

with 800 dpm/gm for the old leaves. The tissue of the tip of the stem had 6.3×10^3 dpm/gm compared with an average value of 1.6×10^3 dpm/gm for the remainder of the stem. These data are also summarized in Table II.

ECOLOGICAL AND HYDROLOGICAL RELATIONSHIPS

The dry leaf biomass for the Puerto Rico rainforest was estimated to be 0.6 kg/m^2 by using the regressions of Ogawa et al.[13] on tree density data given in Table III.

Ogawa et al.[13] give the tree leaf biomass (W_L) in kg and stem biomass (W_S) as a function of height (H) in meters and diameter (D) in cm. of the trees in a tropical rainforest in Thailand.

$$W_L = W_S/(13.75 + 0.025\ W_S)$$

$$W_S = 0.0396\ (D^2H)^{0.9326}$$

These regression equations were used to compute the leaf biomass of the individual trees (W_{LT}) for which transpiration (F_T) in liters/day was measured in Experiment A. Any systematic error introduced by the biomass estimate is cancelled because the same regression equations are used to determine the leaf biomass for a typical unit area of Puerto Rico rainforest in calculating its average transpiration (F_P).

$$F_P = W_{LP}(F_T/W_{LT})$$

The specific transpiration (F_T/W_{LT}) for the trees in Experiment A are given in Table I.

Average transpiration was computed by taking a weighted average of the substory and canopy tree specific transpiration rates determined in the tree experiment by assuming the transpiration rate to be a continuous function of tree size. Average transpiration for the rainforest was determined to be 3.64 kg/m^2/day.

The annual water budget for the Puerto Rico rainforest was reported by Jordan.[17] Rainfall was measured as 281 cm which corresponds to 7.7 kg/m^2/day. Throughfall represented 69% of the total and stemflow accounted for an additional 18%. The net input to the litter-soil layer is therefore 6.70 kg/m^2/day. Of this, 3.64 kg/m^2/day (54.5%) is transpired and 0.04 kg/m^2/day (0.5%) evaporated directly leaving 3.02 kg/m^2/day (45%) for interflow.

The water capacity in the surface to 10" deep layer is 128 kg/m^2. Below the 10" depth, the capacity is 23 kg/m^2/inch of depth. By the occupancy principle of Orr and Gillespie,[12] the capacity is the product of occupancy or mean residence time, T, and the flow, F. The effective capacity of the soil compartment may then be calculated for the observed 42 ± 2 day occupancy of the coupled soil compartment where F = 6.66 kg/m^2/day. The calculated effective capacity is 280 ± 12 kg/m^2 which corresponds to an effective depth of 16.6" or 42 cm. If transpiration were the only loss rate, the residence time for tritium in the soil would be

$$T = C/F = 280/3.64 = 77 \text{ days.}$$

TABLE III

TRANSPIRATION AND BIOMASS ESTIMATES FROM TREE DENSITY DATA

	Tree Class		Density*	Dry Leaf Biomass	Transpiration†	Transpiration
	dia.*	ht. (est.**)	Trees/Hectare	(est.**)		
in.	cm	m		kgm/m^2	ml/day/gm leaf	kgm/day/m^2
4	10.2	8.3	355	0.0539	3.0	0.1617
6	15.2	11.1	425	0.1668	4.0	.6672
8	20.3	13.5	118	0.0864	5.0	.4320
10	25.4	15.4	81.4	0.0906	6.0	0.5436
12	30.4	17.0	33.3	0.0484	7.0	.3388
14	35.6	18.4	20.9	0.0385	8.0	.3080
16	40.6	19.6	22.2	0.0478	9.0	.4302
18	45.7	20.6	12.33	0.0294	10.0	.2940
20	50.8	21.6	4.93	0.0129	11.0	0.1419
22	55.9	22.3	3.70	0.0104	12.0	.1248
24	61.0	23.1	2.46	0.0073	13.0	.0949
26	66.0	23.8	2.46	0.0076	14.0	.1064
			Total	0.600 kgm/m^2		3.64 kgm/day/m^2

*Tree density for each diameter from Wadsworth.[20]

†Determined in tree experiment where T ranged from 4 for substory tree to 14 for largest canopy tree.

**Estimates derived from regressions of Ogawa *et al.*[13]

The importance of this will be seen in the discussion on the simulated tritium rainout in the following section.

TRITIUM RAINOUT SIMULATION

For a simulated rainout of tritium, we shall assume that a one megaton explosive gives a tritium cloud burden of 4×10^6 curies. Furthermore, if it is dispersed in a 100 square mile cloud, a rainout would deposit 15.4 mCi/m^2. In a tropical rainforest, the canopy leaves will intercept and evaporate about 13 percent of the incoming rain or 2 mCi/m^2. The net input to the soil litter layer would be 13.4 mCi/m^2 as stemflow and throughfall. This value is nearly identical to that applied in the systems experiment. These input values are approximations based on information available in the open literature. While they are believed to be reasonable, any arbitrary values could have been used because the mechanisms governing the movement of fallout tritium into the tropical ecosystem described in this report are independent of the initial values.

Although the tritium was applied to a small plot in the plot experiment, a rainout of tritium as simulated, would occur over a much wider area. Nevertheless, in this analysis the data from the plot experiment will be used to describe the movement of tritium following a rainout. Allowances for the effect of a large area deposition will be made where it is possible to do so.

Immediately after deposition, a small amount of tritium would be evaporated from the litter layer. The tritium concentration in air at the ground surface would be about 0.3 μCi/ml or 6×10^{-7} μCi/cc air. The air concentration would decrease rapidly as the tritium moved down into the soil. In the plot experiment, a two component exponential decrease of tritium in the air shown in Figure 5 was observed. The short component half-time was 80 minutes while the longer component showed a tritium removal half-time of 2.5 days.

The tritiated water vapor remained essentially at ground level and followed the natural air drainage down the side of the mountain. The activity at 100 cm above the plot was 100 times less than at the 4 cm level. Air sampling was discontinued after a week at which time the activity levels were at least two orders of magnitude lower than at the time of the application of tritium.

Since the rainout would occur over a large area of the rainforest, the removal of tritium from the air at a particular location would be longer because incoming air would contain tritium from above that site. Despite this, evaporation of tritium from the soil surface would decrease rapidly with time and the highest concentrations in air would remain close to the ground surface.

The pattern of movement of tritium in the soil will be that observed in Figure 2. Tritium will be removed from the soil at an exponential rate with a mean residence time of 42 ± 2 days.

If the interflow from the surrounding areas is such that tritium leaving a plot by interflow is balanced by tritium in interflow from above entering the plot, the residence time will be longer. In this case, transpiration will represent the only loss pathway and the residence time for the soil will be 77 days. Since the interflow velocity is low, the rainout area does not have to be very large in order for this equilibrium assumption to be valid with respect to a small plot within the rainout area.

Tritium in the vegetation in the area will increase to a peak in two to three weeks of about 2000 pCi/ml. It will then display an exponential removal of tritium with a mean residence time of 67 ± 9 days. If an equilibrium condition in the interflow exists, the residence time will be the same as for the soil, 77 days. The tissue bound compartment will have a tritium concentration of about 3 pCi/gm.

If the rainout were to occur on a cleared plot or in a food crop area, the growing vegetation could have a tritium concentration in the bound compartment of 6 to 30 pCi/gm. This does not imply any concentration factor but merely reflects the difference between photosynthetic binding of tritium and that which would become bound by exchange. The ratio of net production to plant size is higher in successional trees or growing plants than in mature forest trees.

The high flux of water in the rainforest results in a rapid turnover of water and short residence times compared with other areas. The rainforest vegetation tissue compartment can only incorporate whatever tritium is present during the time it is available. In a desert ecosystem, however, Koranda and Martin[18] have shown that the tissue bound tritium in annual herbaceous and woody perennial plants growing in a tritiated environment is in equilibrium with the relatively stable level of tritium in the water of such plants. In growth chamber studies, Chorney et al.[19] found that tissue bound tritium was essentially the same as that which occurred in tissue water during growth of an herbaceous plant. Because of the short residence time of tritium relative to the growth rate of tropical vegetation, no such equilibrium was observed in the tropical ecosystem.

Tritium in the bound state might be expected to have a longer residence time than the water passing through a plot. For example, bound tritium in leaves would have a mean residence time equal to the mean biological residence time of leaves on the tree. The residence time in the bound state was not determined directly. Since the water compartment has 2 to 4 times as much hydrogen as the tissue compartment of tropical vegetation, and the uptake of tritium from the water compartment into the bound state is a small fraction of the total amount available, the significant compartment would have to be the loose or free water of tropical vegetation.

Based on data obtained in the plot experiment, the distribution of tritium with time in a tropical ecosystem is shown in Table IV. Tritium remaining in the soil of the plot decreases at an exponential rate with a half-time of 29 days. By the end of six months, less than 2% of the original tritium remains in the soil.

Losses via interflow increase with time approaching a maximum value of 45.4% of the input of tritium. The trees take up tritium and reach a peak value at about 14 days after which the fraction of the input tritium remaining decreases at an exponential rate with a half-time of 47 days. During the first two weeks the amount of tritium transpired is small as the tritium rises up the tree stems. The greatest loss occurred during the third week when more than 8% of the original input of tritium was

TABLE IV

FRACTIONAL DISTRIBUTION WITH TIME OF TRITIUM INPUT TO TROPICAL RAIN FOREST SOIL

Time		Fraction in Soil Profile	Fraction in Trees	Fraction Transpired	Fraction Lost as Interflow
days	months				
4		.9092	.0494	.0002	.0412
7		.8465	.0830	.0008	.0697
14		.7165	.1382	.0166	.1287
21		.6065	.1177	.0972	.1786
30		.4895	.1254	.1533	.2318
45		.3425	.1271	.2319	.2985
60	2	.2397	.1211	.2940	.3452
	3	.1173	.0984	.3836	.4007
	4	.0574	.0738	.4409	.4279
	5	.0280	.0524	.4783	.4413
	6	.0138	.0359	.5026	.4477
	7	.0067	.0241	.5182	.4510
	8	.0033	.0156	.5284	.4527
	9	.0016	.0104	.5347	.4533
	12	.0002	.0025	.5434	.4539
→ ∞		→ 0		→ .546	→ .454

transpired. The total transpiration loss increases with time approaching a maximum value of 54.6% of the input pulse.

CONCLUSIONS

Experiments were conducted to determine the pattern of movement and distribution of tritium in a tropical rainforest ecosystem.

An injection of tritiated water directly into understory and canopy evergreen tropical trees was used to determine the transpiration rate and residence time for water in the trees. Transpiration ranged from 2 to 370 liters/day. Mean residence times ranged from 4 to 11 days.

The distribution of tritium in the soil, air and trees was determined following an application of tritium to a 3.68 m^2 plot in the rainforest. The pulse of tritium showed an exponential decrease with time in the soil and in trees growing in the rainforest. The fraction of tritium remaining in the soil and trees as well as the fraction lost through transpiration and interflow are given as a function of time in Table IV. The mean residence time for tritium in the soil and in trees was found to be 42 ± 2 days and 67 ± 9 days, respectively. Using the transpiration rates from the previous experiment, rainfall records, tree density data and other measurements, average transpiration for the Puerto Rico rainforest was computed as 3.64 $kg/m^2/day$. The effective capacity of the soil compartment was calculated to be 280 kg/m^2.

Uptake of tritium into the tissue compartment of successional species was measured as 0.1% of the total amount of tritium applied to several emerging trees in a cleared plot in the rainforest. Because of the short residence time of tritium relative to the growth rate of tropical vegetation, tissue hydrogen does not equilibrate with tritiated water in the ecosystem.

The main hydrogen compartments of the tropical ecosystem are water in the soil and in trees of the forest. The persistence of fallout tritium is determined by the residence time of tritium in these compartments.

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