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THE DISTRIBUTION OF TRANSURANIC ELEMENTS IN A FRESHWATER POND ECOSYSTEM

by

Richard M. Emery* and Donald C. Klopfer

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Ecosystems Department
Battelle
Pacific Northwest Laboratories
Richland, WA 99352

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R. M. Emery and D. C. Klopfer
Battelle Northwest Laboratories
Richland, Washington 99352

Abstract

During the past 2 years a unique study has been initiated on the Hanford Reservation concerning the ecological behavior of plutonium and americium in a freshwater environment. This study involves a waste pond which has been receiving Pu processing wastes for about 30 years. The pond has a sufficiently established ecosystem to provide an excellent location for limnological characterization. In addition, the ecological distribution of Pu and Am is being investigated. The purpose of this work is to explain Pu and Am concentrations at specific ecological sites, important export routes out of the pond, and potential pathways to man. The pond is also highly enriched with nutrients, thus supporting a high level of algal and macrophyte production. Seston (30% diatoms) appears to be the principal concentrators of Pu transuranics in the pond system. The major sink for Pu and Am in this system is the sediments. Organic floc, overlaying the pond sediments, is also a major concentrator of transuranics in this system. Aside from the seston and floc, no other ecological components of the pond appear to have concentrations significantly greater than those of the sediment. Dragonfly larvae, watercress, and snails show concentrations which approximate those of the sediments but nearly all other food web components have levels of Pu and Am which are lower that those of the sediments. Thus, Pu and Am seem to be relatively immobile in the aquatic ecosystem. However, the role of algae as a potential mechanism for the long-range ecological transport of Pu and Am will receive additional attention.

Introduction

The transuranic elements plutonium (Pu) and americium (Am) are present at very low levels in many of the world's ecosystems. When detectable in aquatic systems these extremely low concentrations are usually less than 1 pCi per liter of water or kilogram of solid material. Until recently, very limited attention has been given to the ecological activity of transuranics in fresh water. For large aquatic systems Bowen and Noshkin (3), Yaguchi et al. (20 and 21), and Waller et al. (17) have published Pu data, pertaining mainly to biota in the Laurentian Great Lakes. In connection with this, Wahlgren and Nelson (14, 15, and 16) have reported on biogeochemical aspects of Pu in Lake Michigan and other Great Lakes.

In rare instances transuranics may occur in freshwater ecosystems at levels higher that 1 pCi per liter or kilogram. Such systems would include isolated ponds and lagoons used to receive low-level wastes from Pu processing operations. Waste lagoons used for this purpose at Rocky Flats, Colorado, have been studied since 1970, and Johnson et al. (6, 7, and 8) have reported on the ecological distribution of Pu in these lagoons.

On the Hanford Reservation near Richland, Washington, there is a 14-acre pond that receives occasional low-level quantities of Pu and Am from processing operations. This pond (specifically called U-Pond) has an established ecosystem and provides an unusual opportunity for studying the behavior of transuranics in fresh water. It is estimated that about 8 kg of Pu have been discharged into waste trenches feeding U-Pond over the past 30 years.

Hence, this pond contains substantially higher levels of transuranics than those aquatic systems contaminated by fallout only. Since mid 1973 this pond has been studied to characterize its limnology and determine the distribution of Pu and Am in the ecosystem.

Methods

Samples collected from the pond for Pu and Am analyses were sent to LFE Environmental Laboratories (Richmond, California). This laboratory analyzed for ^{238}Pu, $^{239,240}Pu$ and ^{241}Am using isotope dilution methods with high purity ^{236}Pu and ^{243}Am preparations as tracers. Final measurements were made using alpha spectroscopy methods described by Major et al. (9), Wessman et al. (18), and Major et al. (10). Results are expressed in terms of dry weights unless stated otherwise. Sediment samples were taken using a 1/4 ft^2 Ekman dredge and a coring tube yielding a 0.18ℓ (10.8 in^3) sediment plug having a depth of 10 cm. Further details regarding sampling and analytic methods may be found in a report by Emery et al. (4)

Statistical analyses of distributions of transuranics occurring in the sediments were made using analysis of variance with a factorial design, and statistically significant differences of isotopic ratios between sediments and biota were determined using the Chi-square test for independence (13)

Results and Discussion

Description of the Pond

In 1944 U-Pond was created in a shallow depression in the arid steppe-land of the Hanford Reservation to receive low-level rad-wastes from Pu processing and reclamation facilities (Fig. 1). U-Pond has a surface area of 56,000 m^2 (14 acres), a volume of 22,700 m^3 (18 acre-ft), a mean depth

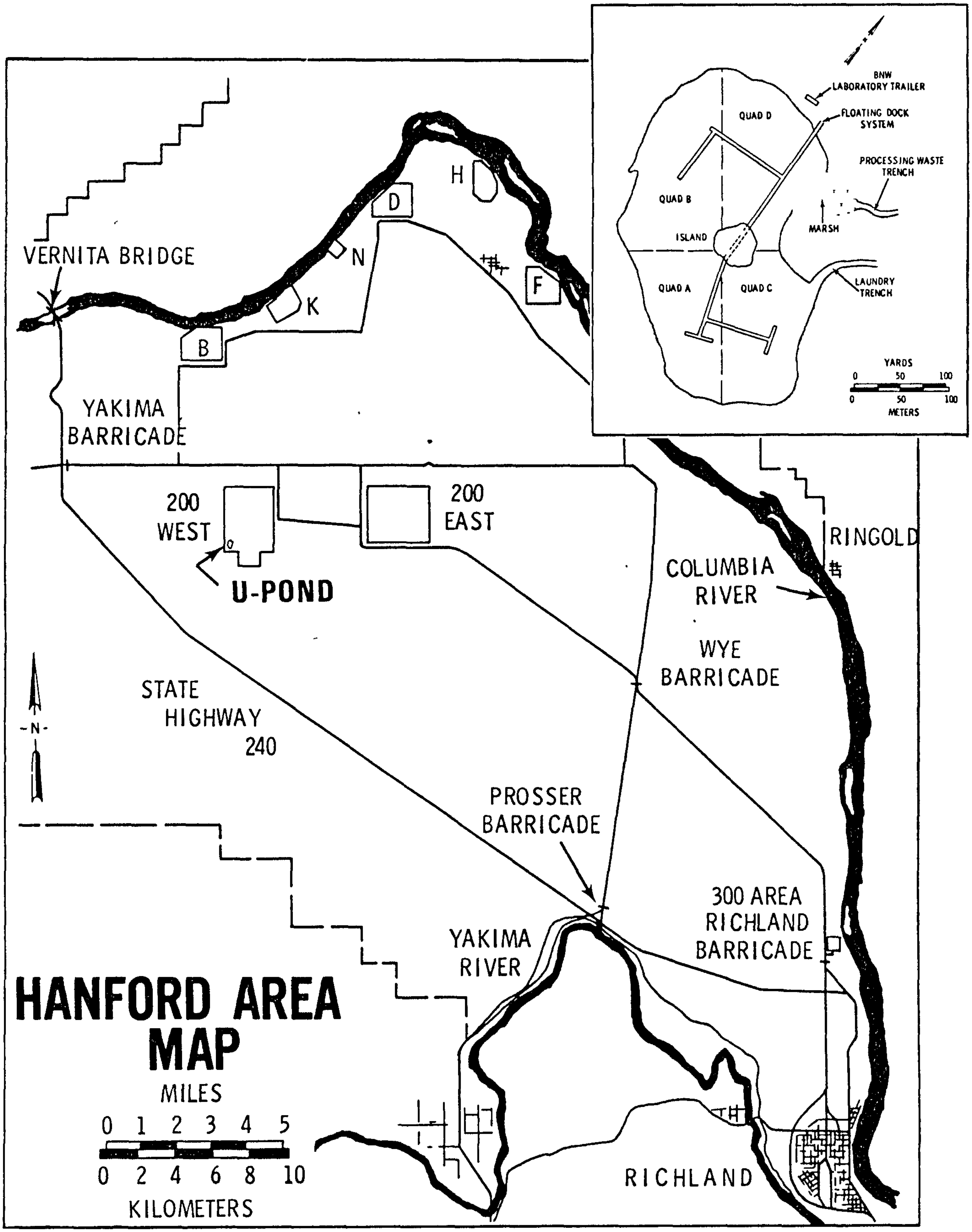

Figure 1. Map of Hanford area showing the location and an enlarged diagram of U-Pond.

of about 0.4 m (1.3 ft), and a water income of about 10 m^3/min (5.9 cfs). Water flowing into the pond comes from a cooling system of an evaporator-crystallizer plant, a Pu processing plant, and a laundry. The pond has no surface outflows and most of the water (> 95%) leaves the pond via percolation through the desert soil. Evaporative loss is less than 5% of the incoming rate. The mean residence time for pond water is about 40 hours, thus, the downward movement of water is very rapid.

Transuranics have reached the pond principally from accidental releases in Pu processing and reclamation operations. These releases were discharged into waste trenches flowing to the pond, and the total historic release of Pu is estimated to be about 8 kg (2 and 5). Over the past 30 years several trenches have been used to carry processing effluents to U-Pond. Since these waste trenches are about 885 m (970 yds) long it is likely that substantial amounts of Pu were deposited in the trenches before they reached the pond. It is not known how much Pu actually reached U-Pond, but a survey of the pond basin showed only about 21 g of Pu is present in the pond's sediments. There are some preliminary indications which suggest that the processing waste trench and marsh (at its mouth, Figure 1) have acted as a sedimentation-filtration system, removing a large percentage of transuranics from the processing effluents by sedimentation and filtration before they reach the pond.

U-Pond is highly enriched with plant nutrients from the laundry plant and the pond is considered a eutrophic system. The trophic structure of the pond involves a simple food web with most of the feeding activity being detritivorous. Organic detritus is composed of loosely-compacted decomposing plant material (floc) and covers most the pond bottom (Figure 2). Non-filamentous algae (mainly <u>Tetraspora</u> and diatoms) and filamentous algae (mainly <u>Cladophora</u> and <u>Hydrodictyon</u>) are principal constituents of the floc (Figure 2). Seston

U-POND

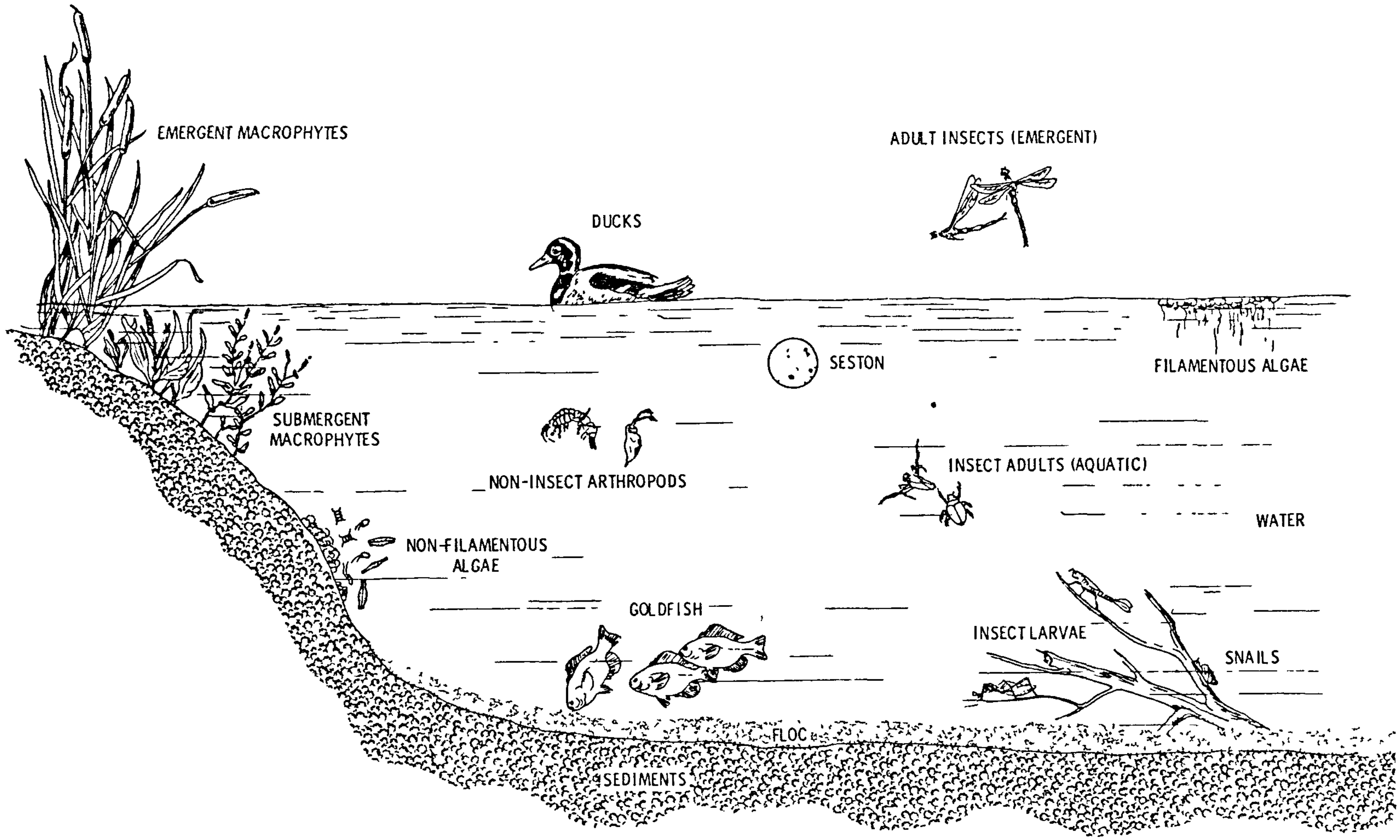

Figure 2. A pictoral expression of the U-Pond ecosystem.

(suspended particulate material) is composed of diatoms (20-30%) and unidentifiable organic and inorganic particles. The seston also joins the floc as it settles out. The pond supports luxuriant growths of emergent macrophytes including cattails (Typha) and bulrushes (Scirpus), and the submergent pond weed (Potamogeton) (Figure 2). These plants are a direct food source for pond fauna and provide substrates for periphytic algae which are fed upon by invertebrates. They also contribute to the floc at the bottom of the pond when they decompose.

Non-insect arthropods that live in the pond are mainly scuds (Hyalella) and water fleas (Daphnia). Insect larvae are prolific and include the midges Pseudochironomus and Cricotopus and the dragonflies Aeschna and Libellula (Figure 2). These dragonfly larvae are the principal predators in the pond and feed primarily on other arthropods and goldfish larvae. Adult insects living in the pond are mainly back swimmers (Notonectidae), waterboatmen (Corixidae), and beetles (Dytiscidae). Snails (Lymnaea and Physa) are periodically abundant in the pond. Goldfish (Carassius) have been abundant in U-Pond for many years and were probably planted there by Hanford workers. They feed primarily on the organic floc. Larval insects emerge from the pond seasonally and become associated with the adjacent terrestrial environment. Of these the most conspicuous are the dragonflies Aeschna and Libellula and the damselfly Ischnura (Figure 2). Mallard ducks (Anas) and coots (Fulica) are found on the pond in moderate numbers and feed mainly on organic debris and algae.

Pu and Am in the Pond Ecosystem

Of the 15 ecological components designated for U-Pond the seston has the highest concentrations of Pu and Am (Table I). Mean concentrations ranged from about 3-6 nCi/g. It was possible to estimate transuranic

TABLE I. Concentrations and ranges of Pu and Am in the ecosystem components shown in Figure 2. Numbers of samples analyzed are shown in brackets. Concentrations are expressed as pCi/g (dry weight), except for water where levels are expressed as pCi/ml.

	^{238}Pu		$^{239,240}Pu$		^{241}Am	
	Mean	Range	Mean	Range	Mean	Range
Sediments (n=103)	169.2	0.20-1144.1	176.9	1.20-1072.1	81.3	0.95-620.7
Water (n=8)	0.0051	0.0002-0.0185	0.0033	0.0001-0.0118	0.0042	0.0002-0.0170
Seston (n=8)	4541.2	44.1-29279.2	2902.1	23.0-18468.5	6345.9	36.0-45495.5
Floc (n-14)	1032.8	343.7-2490.0	652.4	212.1-1470.0	281.3	118.9-594.6
Algae (filamentous) (n-13)	45.76	40.8-167.1	33.6	0.4-123.4	38.7	N.D.-137.8
Algae (non-filamentous) (n=25)	140.9	1.1-564.9	101.8	2.6-407.2	143.8	2.7-630.6
Macrophytes (Submergent) (n=16)	108.3	0.58-824.3	68.8	0.49-500.0	55.2	0.61 509.0
Macrophytes (Emergent) (n=8)	9.44	0.20-41.9	8.10	0.17-31.5	27.8	0.67-63.0
Non-insect arthropods (n=8)	8.52	0.49-30.7	7.41	N.D.-25.6	6.16	1.10-14.4
Insect Larvae (n=63)	33.6	4.7-231.1	22.6	3.2-130.1	33.7	6.7-169.8
Insect Adults (Aquatic) (n=9)	5.47	0.47-10.7	4.39	0.50-7.2	5.63	1.0-8.11
Snails (n=2)	59.0	35.6-82.4	39.1	26.5-51.8	63.7	35.1-92.3
Goldfish (n=2)	11.25	11.1-11.4	7.8	7.4-8.1	12.0	9.4-14.6
Ducks (n=1)	0.029	-	0.022	-	0.028	-
Adult Insects (Emergent) (n=15)	6.45	0.27-57.6	4.14	0.23-31.7	1.38	0.32-3.65

concentrations in the pond water by expressing the seston Pu and Am values for the amount of water that was filtered in obtaining the seston samples. By dividing these concentrations by the volume of water filtered, an expression for particulate transuranics in water was made in pCi/ml. Hence, mean water levels of Pu and Am are much lower than any of the other pond components, from about 3-5 fCi/ml (Table I). The seston is usually composed of about 30% diatoms, and indications are beginning to emerge that diatom frustules (siliceous shells) act as good adsorption surfaces for transuranics. The floc also concentrated relatively high levels of Pu and Am with means ranging from about 300 to 1000 pCi/g (Table I). This has particular ecological significance since the floc is the primary food source for many animals associated with the pond. Diatoms were microscopically identified in the floc, but most of the other constituents are decomposed beyond recognition. Autoradiographs were made of floc samples to investigate the locations of alpha-emmitting particles. Alpha tracks could be found leading away from diatom frustules, but without convincing consistency. Further autoradiography studies will be made using floc and seston samples to investigate the relationship between diatoms and transuranics.

Supportive evidence for this association has been found by Yaguchi et al. (20) in plankton samples from Lake Michigan and other Great Lakes. They found good correlation between the ^{239}Pu concentrations and the ash content of the plankton. Diatoms are major constituents of Lake Michigan plankton and their frustules would survive the ashing process. Of course, concentrations of Pu in Lake Michigan plankton were much lower than those in seston samples from U-Pond. Levels of ^{239}Pu in Lake Michigan plankton were about 4 fCi/g (wet weight), as compared to about 800 pCi/g (wet weight equivalent) in U-Pond.

Sediments, the principal repository for transuranics in U-Pond, contain about 170 pCi each of ^{238}Pu and $^{239,240}Pu/g$, and about 80 pCi of $^{241}Am/g$ (Table I). The amount of Pu in the pond's sediments (down to 10 cm) is about 21 g, representing a small percentage of that which was released into the processing waste trenches since 1944. It seems likely that waste water reaching the pond by way of the trenches has had most of its Pu and Am removed by either sedimentation or adsorption onto plant material in the ditch and marsh (Figure 1).

All of the biotic components of the pond's ecosystem have Pu and Am levels lower that the sediments (Table I). Plant material, principally non-filamentous algae and submergent macrophytes, had Pu and Am concentrations which approached those of the sediments. Included among the non-filamentous algae are diatoms, and among the submergent macrophytes is watercress (Rorippa), both of which are specifically high concentrators of transuranics, relative to the sediments. Filamentous algae, mainly Cladophora, dominate the plant biomass in the pond but concentrate only moderate levels of Pu and Am (Table I). Emergent macrophytes, mainly cattails (Typha) and bulrushes (Scirpus), show mean levels of Pu and Am in ranges of 8-28 pCi/g. These plants provide an important ecological connection between the aquatic environment of the pond and the adjacent terrestrial environment.

Levels of transuranics in insect larvae provide interesting results. Most of the larvae have mean Pu and Am levels ranging from 10-40 pCi/g. Non-predaceous insect larvae never exceeded 40 pCi/g for either Pu or Am. However, for the two principal predators in the pond, the dragonfly larvae Aeschna and Libellula, there is a striking difference in transuranic accumulation. Aeschna have mean levels of Pu and Am ranging from 5 to 80 pCi/g, whereas the range for *Libellula* is from 50 to 230 pCi/g. *Aeschna* generally finds its niche *under* the *bark* of submerged tree limbs or on other objects which rest above the sediments. *Libellula*, conversely, may be found partially burrowed into the sediments, or in some other location where sediments are proximal. It may be the difference in niches which accounts for the higher Pu and Am content of *Libellula* rather than a process of concentration by predation. However, there were eleven occasions, in the months November, December, and April, where collections of *Libellula* and *Aeschna* were made from the same substrate. Each collection usually involved 10 to 30 individuals with a minimum of 6 for *Aeschna* and 4 for *Libellula*. In every collection *Libellula* showed substantially higher Pu content than *Aeschna* with a mean ratio of Pu in *Libellula* to Pu in *Aeschna* of 6.3:1 (Figure 3). The consistency with which this occurred was remarkable, and indicates that the physiological and/or behavioral differences of these organisms may affect their ability to accumulate Pu. There also exists the possibility that sessile algae, which often grow on the exterior of *Libellula* but not *Aeschna*, are concentrating Pu independent of *Libellula*. These sessile algae, which include diatoms, are not easily removed in the sample preparation steps and may have high burdens of Pu, but the relatively small weight of attached algae to that of the larva would require that the algae have very high concentrations of Pu to account for the high levels in *Libellula*. This matter remains an interesting puzzle.

Both aquatic adult insects (beetles, waterboatmen, etc.) and emergent adult insects (dragonflies, damselflies, midges, etc.) have mean concentrations of Pu ranging from 4 to 7 pCi/g and mean concentrations of Am ranging from 1 to 6 pCi/g (Table I). These levels are lower than any of the other biotic components, except for ducks. Snails show mean concentrations of Pu from about 40 to 60 pCi/g, and for Am the mean concentration is about 64 pCi/g (Table I).

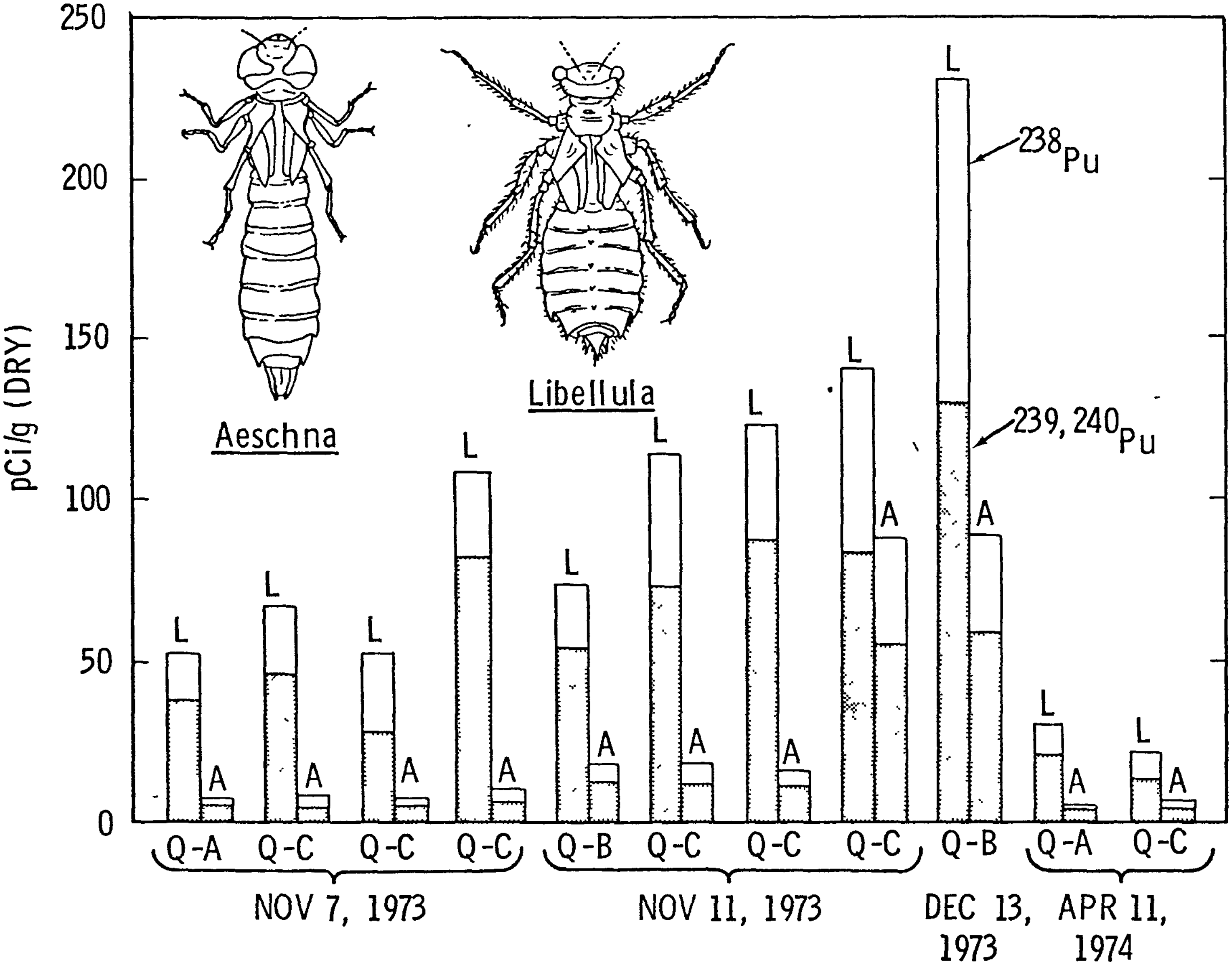

Figure 3. A comparison of Pu levels in the dragonfly larvae <u>Aeschna</u> (A) with <u>Libellula</u> (L) for specific sampling dates and locations. Sampling quads and dates are shown below the columns (see Fig. 1). Levels of ^{238}Pu are shown by the top of each column, and $^{239,240}Pu$ levels are designated by the top of the shaded columns.

Goldfish (Carassius, without gut contents) have mean concentrations of transuranics ranging from 7.8 to 12.0 pCi/g (Table I). These fish remain in the pond longer that any other biotic component and feed primarily on the floc. Yet, despite their food source being relatively high in transuranic content, goldfish appear to reach total body equilibrium concentrations of about 10 pCi of Pu and Am/g. Experimental goldfish were placed in the pond to measure uptake rates of transuranics. These imported goldfish were previously unexposed to transuranics, yet within 2 weeks they had reached the same equilibrium levels for Pu and Am as those appearing in resident goldfish.

One goldfish was completely dissected to separate its major body parts for Pu and Am analyses (Table II). The alimentary canal, flushed of its contents, had Pu levels of 27 and 41 pCi/g (^{239,240}Pu and ^{238}Pu, respectively), and about 33 pCi of ^{241}Am/g. These levels are from 3-4 times higher than those found in whole goldfish (without gut contents). Gills showed levels of Pu and Am that were similar to those for the whole body (Table II). However, transuranics may have been captured by the mucus coating of the gills as water circulated around them, much the same as would occur inside the alimentary canal as food material passed through it. It was interesting to see that liver and heart tissue had levels of Pu and Am of 2 to 3 pCi/g. These concentrations would reflect internal body transport and accumulation of transuranics in specific locations. All other goldfish tissue had levels of Pu and Am below 1 pCi/g. The most significant of any of these parts was adipose tissue, with Pu and Am levels of about 0.4 to 0.6 pCi/g (Table II).

A single mallard duck (Anas) was collected while feeding on the pond and analyzed for transuranic content. It was not determined how long the duck had been on the pond. In terms of its entire body it had from

TABLE II. Transuranic contents in specific locations of a dissected goldfish (*Carassius*).

	pCi/g		
	^{238}Pu	$^{239,240}Pu$	^{241}Am
Alimentary Canal	41.44	27.00	32.88
Gills	7.07	4.90	6.89
Liver and Heart	2.65	3.10	2.16
Adipose Tissue	0.61	0.40	0.47
Muscle	0.40	0.24	0.72
Skin and Scales	0.33	0.18	0.30
Eggs	0.30	0.14	0.23
Skeleton	0.14	0.09	0.21
Reproductive Organs	0.08	0.04	1.30
Remaining Parts	0.15	0.08	0.08

0.02 to 0.03 pCi of Pu and Am/g (Table I). This duck was dissected and separated into specific body parts for Pu and Am analyses (Table III). The gut contents of this duck were relatively high in Pu concentrations, as compared to the whole duck, having levels from about 3 to 6 pCi/g. Levels for Am were surprisingly low in the gut contents. The gut contents, however, were much lower in transuranic concentrations than the floc upon which the duck was feeding. This indicates that the duck had been on the pond for only a short time, but it may have had other contacts with U-Pond prior to our sampling. As in the goldfish the flushed alimentary canal had the highest concentrations of transuranics, from about 0.2 to 0.3 pCi/g (Table III). The liver and heart of this duck were analyzed separately and similar to the goldfish, the liver had high concentrations of Pu and Am relative to the other body parts. All remaining parts had Pu and Am levels which were lower that 0.1 pCi/g (Table III).

Viewing this duck as an ecological transport mechanism, had it not been sampled it would have transported about 10 pCi each of ^{238}Pu, ^{239,240}Pu and ^{241}Am away from the pond. This is about the same amount that would be carried away by 2-4 g of emerging insects, or by 1 g of goldfish (carried away by a heron or coyote). The extent of all ecological transport activities from the pond involves very small quantities of transuranics, less than 1 mCi of Pu and Am/yr. Such low quantities of these transuranics do not constitute an environmental hazard.

For the ecological components shown in Figure 1 concentration factors (CF's) have been developed. Mean water concentrations of Pu and Am shown in Table I were used as the ecological source terms for the CF's shown in Table IV. The CF's shown here are considerably lower than those reported earlier by Emery et al. (4) because more recent data for water concentrations of transuranics have been used. At this time we still have reason to

TABLE III. Transuranic contents in specific locations of a dissected mallard duck (*Anas*).

	pCi/g		
	^{238}Pu	^{239,240}Pu	^{241}Am
Gut Contents	6.396	3.401	0.038
Alimentary Canal	0.324	0.171	0.288
Liver	0.122	0.212	0.096
Head and Beak	0.090	0.059	0.086*
Kidney	0.060	<0.054	0.066*
Heart	0.059	0.036	0.060*
Testicle	0.052	0.014	0.038*
Feet	0.018	0.032	0.029*
Lungs	0.014	<0.014	0.024
Muscle	0.014	0.005	0.011*
Skin (w/o feathers)	0.014	0.014	0.011
Adipose Tissue	0.010	<0.005	0.009*
Neck (with bone)	0.009	0.005	0.008*
Bone	0.009	0.007	0.008

*Estimated values, based on Pu/Am ratios in other tissues.

TABLE IV. Concentration factors for the ecological components in Figure 2. CF's are based on water values shown in Table I by dividing the activity in the component (pCi/g wet weight) by the activity in the water (pCi/ml). Dry weight to wet weight conversion factors for sediments is 0.38, for seston and floc it is 0.22, and for biota it is 0.26.

	^{238}Pu	$^{239,240}Pu$	^{241}Am
Sediments	1×10^4	2×10^4	7×10^3
Water	1	1	1
Seston	2×10^5	2×10^5	3×10^5
Floc	4×10^4	4×10^4	1×10^4
Algae (filamentous)	2×10^3	2×10^3	2×10^3
Algae (non-filamentous)	7×10^3	8×10^3	9×10^3
Macrophytes (submergent)	5×10^3	5×10^3	3×10^3
Macrophytes (emergent)	5×10^2	6×10^2	2×10^3
Non-insect Arthropods	4×10^2	6×10^2	4×10^2
Insect Larvae	2×10^4	2×10^4	2×10^4
Insect Adults (aquatic)	3×10^2	3×10^2	3×10^2
Snails	3×10^4	3×10^4	4×10^4
Goldfish	6×10^2	6×10^2	7×10^2
Ducks	1×10^0	2×10^0	2×10^0
Adult Insect (emergent)	3×10^2	3×10^2	8×10^1

question the accuracy of these values, and studies are currently underway to determine reasonable estimates for mean annual Pu and Am concentrations in water. Since valid interpretation of the ecological mobility and the CF's for transuranics are highly dependent upon the accuracy with which Pu and Am concentrations are measured in water, the CF's reported here are to be considered only tentative. At this point in our studies we will base the CF's on mid-summer levels of Pu and Am in the pond water. Because these levels are the highest yet to be determined for pond water, the CF's shown in Table IV are the lowest that could be reported for the ecological components in this pond.

Seston was the highest concentrator of transuranics in the pond's ecosystem with CF's of 10^5 (Table IV). (In this pond it is possible that Pu hydroxide and oxide particles are themselves constituents of the seston.) Because of the short residence time for water in the pond (40 hrs), and the rapid downward movement of water through the sediments, the seston probably reflects the particulate material that enters the pond from the processing waste trench. A CF of 10^5 was also determined for ^{239}Pu in seston in freshwater waste lagoon system by Johnson et al. (8), whereas, Yaguchi et al. (21) found a CF of 6 x 10^3 for ^{239}Pu in plankton samples from Lake Michigan. Floc and sediments had CF's of about 10^4. These materials constitute the principal growing and feeding substrates for most of the pond's biota. Insect larvae and snails which are in almost continuous contact with the floc and sediments concentrated Pu and Am to a similar degree, 10,000 times. Yaguchi et al. (21) found CF's of ^{239}Pu in benthic invertebrates in Lake Michigan to be about the same. CF's of ^{239}Pu for mollusks in seawater were reported to be about 10^2 by Wong et al. (19), and Noshkin et al. (12), and 10^3 by Aarkrog (1). Submergent aquatic plant material (algae and macrophytes) in U-Pond had CF's of around 10^3. Emergent plant material showed CF's closer to 10^2. Johnson et al. (8) found algae in their waste lagoons to concentrate ^{239}Pu at a level 10^4 times that of the water. CF's of about 10^3 are reported for ^{239}Pu in marine plants by Aarkrog (1), Noshkin (12), and Wong et al. (19). Non-insect arthropods, adult insects (emergent and aquatic), and goldfish in U-Pond had Pu and Am CF's of about 10^2. Waller et al. (17) reported CF's for ^{239}Pu in Lake Michigan fishes ranging from 10^0 to 10^2. For marine fishes CF's for ^{239}Pu have a similar range (12 and 19). The duck that was sampled from U-Pond had a CF for Pu and Am of from 1-2.

Summary

A freshwater waste pond has been studied for the past 2 years to relate the distribution of transuranics to ecological components and activities occurring in the pond. This 14-acre pond has received small amounts of Pu processing wastes since 1944. The pond is highly enriched with plant nutrients, creating an ultra-eutrophic ecosystem with sufficient complexity and stability to permit a sophisticated ecological study of the unique conditions. The principal repository of Pu and Am in this system is the sediments, but seston (suspended particulate material) is the most active concentration of these transuranics in the pond. An organic floc that covers the pond's bottom is the primary food source for the aquatic animals, and also a major concentrator of transuranics in the pond. Mean levels of Pu and Am in the pond water range from 3 to 5 fCi/ml during mid-summer, whereas mean Pu and Am concentrations in the sediments and floc range from 80 to 1000 pCi/g. Of the biotic components in the pond, non-filamentous algae are the main concentrators of Pu and Am, having mean concentrations of from 100 to 140 pCi/g. Submergent macrophytes

also accumulate relatively high levels of transuranics, from about 50 to 100 pCi/g. Filamentous algae, emergent macrophytes, invertebrates, and goldfish had mean Pu and Am levels ranging from about 5 to 50 pCi/g. A duck showed transuranic concentrations of around 0.03 pCi/g. The accumulation of transuranics by pond biota provided concentration factors which were in general agreement with those for aquatic organisms in other systems. However, these concentration factors change by orders of magnitude as water concentrations of Pu and Am change seasonally.

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