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NUCLEAR FUEL-CYCLE RADIONUCLIDES IN RAPTOR CASTINGS: IMPLICATIONS FOR ENVIRONMENTAL MONITORING†

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Abstract—Our sampling results indicate that raptor castings (regurgitated material containing the nondigestible remains of prey) faithfully reflect the composition of known environmental γ-emitting radionuclides. The castings are easily obtainable and provide a way to monitor for the presence of biologically available radionuclides. Raptor castings can also provide a useful adjunct to existing monitoring programs where small mammal burrowing into buried waste may occur.

INTRODUCTION

LARGE isolated land areas set aside for the development of energy technology have benefited wild animal populations. Birds of prey, being particularly sensitive to human disturbance, have responded favorably to the protection afforded at such sites, e.g. the Idaho National Engineering Laboratory (INEL) in southeastern Idaho (Cr79a) and the Hanford Site in southcentral Washington (Ol73). Nuclear fuel-cycle activities conducted on these and other U.S. sites provide sources of radionuclides that can enter food chains leading to birds of prey. Raptors consume a variety of prey including small mammals, birds, reptiles, amphibians and invertebrates. According to Fitzner, mice and other small mammals comprise 76, 93 and 97% of the diets of great horned owls (*Bubo virginianus*), barn owls (*Tyto alba*) and long-earned owls *Asio otus*), respectively, on the Hanford Site (Fi78). The balance of these owls' prey consists of rabbits and birds. Fitzner also reported that red-tailed hawks (*Buteo jamaicensis*) and Swainson's hawks (*Buteo swainsoni*) differ from the owls by frequently consuming snakes (35–50% of diet items) and by eating relatively more rabbits and fewer mice. The composition of prey in raptor's diets are probably influenced by the fact that owls are nocturnal and have a greater availability of nocturnal prey species than do the diurnal hawks. Also these 2 hawks and the great horned owl are relatively large (≥ 1 kg) whereas, the long-eared and barn owls are approximately one-half that size (Jo78) and thus are not capable of consistently taking the larger prey.

Rates of feeding are not well established for free-flying raptors. However, Johnson summarized feeding rates for captive birds (Jo78). In general, his summary showed that larger hawks and owls consume the equivalent of 10% of their body weight per day. The smaller sized owls were reported to eat approx. 15% of their body weight daily. If we assume that free-flying raptors consume at least as much food as captive birds, then an individual snake or rabbit weighing several hundred grams would provide more than one day's food requirements (portions of edible prey may be wasted) for a 1 kg hawk or great horned owl. The smaller owls, themselves weighing 0.5 kg or less, probably require several 15–20 g mice or some other combination of small animals daily.

Few data are available indicating radionuclide concentrations in tissues of birds of prey

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(Os68), probably because raptorial birds have protected status and are not part of the human diet. Craig *et al.* reported on whole-body counts of live nestling raptors near nuclear facilities at the INEL and found low levels of γ-emitting radionuclides (Cr79b). They indicated that small mammals living near the facilities contain similar radionuclides and provide a food-chain pathway for contaminants observed in the birds.

Contaminated raptor castings have occasionally been located during radiological surveys near nuclear facilities (EES72; OF75). In addition, castings from snowy owls (*Nyctea scandiaca*) showed low concentrations of ^{90}Sr derived from early weapons testing fallout (Ha60).

This study analyzed the remains of prey in raptor castings to obtain information on the bioavailability of environmental radionuclides.

METHODS

Castings were collected from beneath roosting and nesting sites used by great horned owls, barn owls, long-eared owls, red-tailed hawks and Swainson's hawks from the Hanford Site from 1975 through 1978. Two off-site locations were also sampled, one 6.4 km east of the Hanford Site and the other 161 km east, near Pullman, WA (Fig. 1). An individual sample consisted of 15–30 castings from a single location collected at one time. Some sites were sampled repeatedly. Individual samples were teased apart to allow identification of major prey components

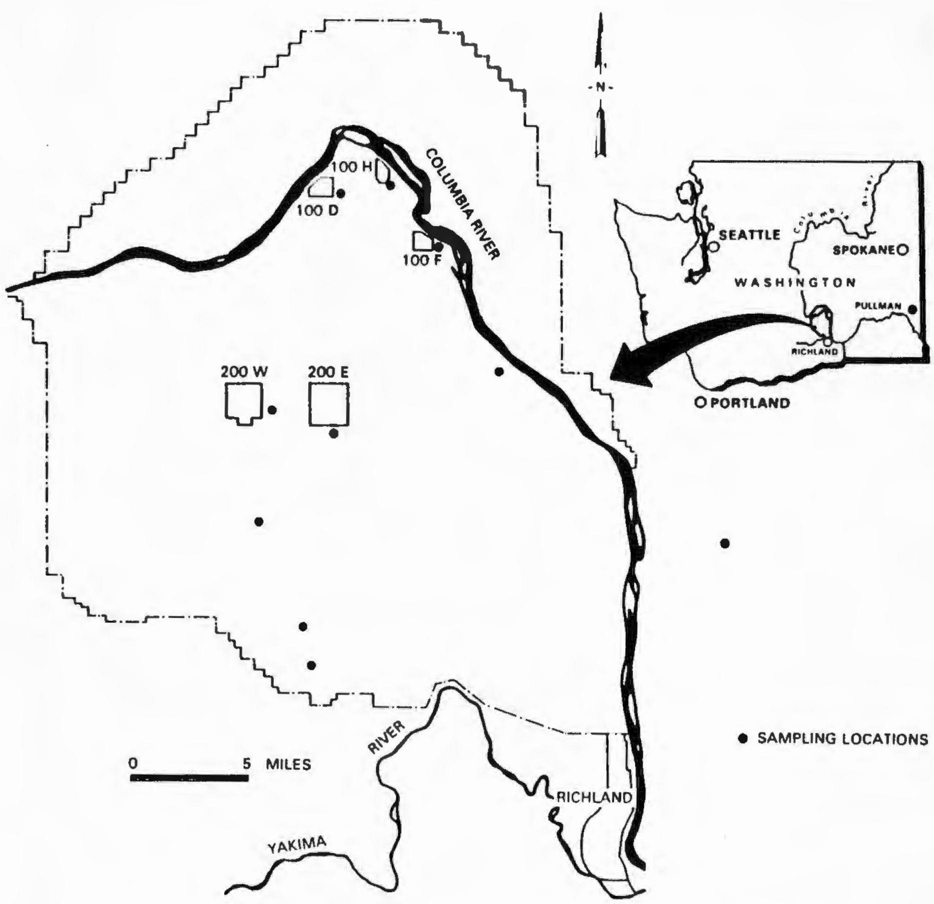

FIG. 1. Hanford Site and southeast Washington sampling locations.

by characteristics of bone, feather, hair, etc. (Er32). Aliquots of approx. 50 g oven dry wt (50°C for 48 hr) were analyzed for ^{137}Cs with a NaI (Tl) detection system. Selected samples with easily measurable ^{137}Cs concentrations, collected from sites having previously characterized nuclear fuel-cycle comtaminants, were analyzed using an anticoincident, shielded, Ge diode γ-ray spectometer (Wo76, Wo81).

RESULTS AND DISCUSSION

Forty-two samples were analyzed for ^{137}Cs. Thirty-six of these were collected from within the bounderies of the Hanford Site, and 6 samples were from off-site locations. Twenty-four of the 36 samples (67%) collected on the Hanford Site contained detectable ^{137}Cs; whereas, ^{137}Cs was measured in 3 of the 6 samples (50%) collected off-site. All 3 of those, however, were collected from the same site, adjacent to Hanford.

Cesium-137 concentrations in several of our samples (Table 1), including both Swainson's hawk samples from Pullman, WA, were below detection limits; these limits ranged from about 0.1 to 0.4 pCi/g, depending on sample size. Thus, fallout ^{137}Cs concentrations were generally below 0.4 pCi/g in raptor castings from eastern Washington.

Measurable ^{137}Cs in raptor castings ranged from 0.1 to 9.1 pCi/g dry wt. The greatest concentration of ^{137}Cs was observed in a Swainson's hawk casting sample (Table 1), but barn owl castings contained the greatest average ^{137}Cs concentration. The mean ^{137}Cs concentrations ($\pm$S.E.) for samples collected on the Hanford Site were in barn owl, 3.1 ($\pm$ 1.1) pCi/g; Swain-

Table 1. Cesium-137 concentrations (pCi/g) in raptor castings

	Hanford Site			Offsite	
Species	Fuel Processing and Low-level Waste Disposal Areas (200E)	Retired (Pu) Production Reactor Areas 100D, 100F, 100H	Away from Facilities	Adjacent to Hanford	Distant Pullman, WA
Great Horned Owl	1.2 ± 0.4	{1.5 ± 0.2	0.9 ± 0.4		
		1.4 ± 0.1	<0.4		
		1.4 ± 0.2}	<0.2		
		{0.8 ± 0.2			
		0.6 ± 0.2}			
		<0.4			
Barn Owl		0.9 ± 0.2		{0.4 ± 0.1	
		0.4 ± 0.1		0.4 ± 0.1	
		5.9 ± 2.9		0.3 ± 0.1}	
		4.9 ± 2.0			
		3.9 ± 1.7			
Long-eared Owl	{0.8 ± 0.2		<3.2		
	0.6 ± 0.2		0.9 ± 0.3		
	0.6 ± 0.1		<0.2		
	0.4 ± 0.1}		0.4 ± 0.2		
			<0.3		
Red-tailed Hawk		<0.4	0.8 ± 0.4		
			<0.4		
Swainson's Hawk	9.1 ± 0.4	<0.1		<0.1	<0.2
		<0.1			<0.1
	0.2 ± 0.1				
	<0.2				
	0.2 ± 0.0				
	<0.2				
	0.1 ± 0.0				
	0.1 ± 0.0				

< Indicates less than detectable radioactivity in sample.

{ } Include repeated samples taken through time at a single location.

son's hawk, 1.7 (±1.5) pCi/g; great horned owl, 1.1 (±0.1); red-tailed hawk, 0.8 pCi/g (a single sample); and long-eared owl, 0.6 (±0.1) pCi/g.

At least 2 factors contribute to the range of observed ^{137}Cs concentrations in raptor castings. The location of a bird's foraging territory in relation to waste burial sites and nuclear facilities is 1 probable explanation. The Swainson's hawk casting sample with the highest ^{137}Cs concentration was collected near a chemical processing facility and adjacent waste disposal area, whereas the Swainson's hawk samples with lowest measurable ^{137}Cs concentration were collected 24 km from potential local sources of radiocesium. Craig *et al.* (Cr79b) reported that the number of distinct radionuclides and the radionuclide concentrations in nestling raptors on the INEL site were greater from nests near the Test Reactor Facility.

Prey selection also dictates, in part, the availability of radionuclides to raptorial birds. A comparison of ^{137}Cs concentrations in owl castings collected near nuclear facilities on the Hanford Site showed that only 1 of 16 samples had ^{137}Cs concentrations less than 0.4 pCi/g (Table 1). In contrast, 8 of 9 Swainson's hawk samples contained less than 0.4 pCi/g. Our dietary analysis of the casting showed that the 3 owl species included in our Hanford Site samples fed primarily on small rodents with Great Basin pocket mice (*Perognathus parvus*) comprising 53 to 87% of the diet. The Swainson's hawk fed on the larger prey such as snakes (50% of the diet); pocket mice made up only 1% of their diet. Waste management areas at Hanford include shallow waste-burial sites and other locations where surface contamination has been covered with layers of uncontaminated soil to prevent redistribution of contaminants (Do78; Pa79; Kl79; USERDA75). Burrowing mammals penetrate shallow earthen covers, and move contaminants to the surface (Ga82; Ar78). Pocket mice in particular have been identified as biotic vectors of buried radiocontaminants (La81; La82) on the Hanford Site. Thus, our general observation that owl castings contain greater concentrations of ^{137}Cs than do Swainson's hawk castings seems to be related to the greater abundance of burrowing pocket mice in the owl's diets.

Known γ-emitting radionuclides associated with Hanford Site facilities were reflected in the raptor castings collected near these facilities. Two casting samples, 1 from barn owls and a second from great horned owls, were obtained in the vicinity of 2 retired production reactor sites. The samples contained ^{60}Co, ^{152}Eu, ^{154}Eu, ^{155}Eu and ^{54}Mn in addition to ^{137}Cs and 3 primordial radionuclides ^{40}K, ^{226}Ra (as ^{241}Bi) and ^{232}Th/^{228}Th (as ^{208}Tl). Characteristic radionuclides reported for the sites (Do78) include ^{60}Co, ^{152}Eu, ^{154}Eu, ^{137}Cs, ^{90}Sr, ^{63}Ni, ^{14}C and ^{3}H. The last 4 radionuclides are β emitters and therefore were not detected in our γ spectral analysis. The appearance of these radionuclides in the owl castings showed that radioactive materials were being mobilized by small animals (prey species of owls) inhabiting the environs of the reactor sites.

Our γ analysis also detected ^{137}Cs at above background concentrations (9.1 pCi/g-dry) in a Swainson's hawk casting sample collected near a waste disposal crib. That crib had previously yielded ^{137}Cs and ^{90}Sr to the surrounding landscape. Animal burrowing exposed contaminants that were subsequently ingested by jackrabbits and dispersed in their excrement (OF75). Thus, the occurrence of ^{137}Cs in the raptor food chain at that site, as indicated by our sample analysis was not surprising.

IMPLICATIONS FOR MONITORING

Raptor castings provide an effective and economical means for sampling biologically mobile contaminants in the environment as demonstrated by our radionuclide results.

Castings are easily obtainable since the birds return to nest and roost locations daily and regurgitate the non-digested remains of their prey. Raptors tend to maintain nest faithfulness by returning annually to the same nest site (Cra56). Five of 6 adult nesting Swainson's hawks marked on the Hanford Site in 1976 returned to nest at the same location in 1977 (Fi78). In general, we have observed that quality nesting sites are used repeatedly. Thus, once nesting locations are found, little additional searching is required in subsequent years to maintain a sampling program. Also, consistency in nest site use permits year-to-year comparisons of contaminant concentrations in samples at individual locations. The technique is acceptable from the resource conservation standpoint since it does not require killing the animal that provides the sample.

The raptors, in their daily foraging, capture small mammals and other prey in a limited hunting territory around the nest or roost site. The occurrence of radionuclides in raptor castings at individual nest sites is evidence that a source of contaminants is nearby. Although we didn't measure the size of territories for the birds in this study, that information is generally available in the literature. For example, Swainson's hawks on the Hanford Site have a reported average home range of approx. 6.2 km^2 (Fi78). Home ranges for great horned owl pairs have been reported on the order of 3.9–5.2 km^2 from Utah (Sm73) and from approx. 1.0–3.9 km^2 in Wisconsin (Pe79). Barn owl pairs have been observed hunting over areas up to 2.4–3.7 km from nest and roosting locations (Sm74). Home ranges average 5.7 km^2 for red-tailed hawk pairs, 4.4 km^2 for marsh hawk pairs and 0.8 km^2 for sparrow hawks in the Great Basin Desert of north-central Utah (Sm73). Thus, the birds' feeding behavior provides reasonable certainty that the source of any contaminants found in raptor castings within a short distance of the nest or roost.

Radionuclides detected in raptor castings are associated with bone, hair, feathers, scales, etc. from the prey. The observation that raptor castings reflect radionuclides known to be in the immediate environment of the nest or roost has important implications for environmental monitoring programs. One objective of monitoring near radioactive waste disposal sites is to detect the mobilization of existing contaminants in the environment. The raptor casting approach appears to be particularly useful in identifying biological transport pathways from buried wastes that are unlikely to be detected by routine monitoring methods. For example, sampling burrowing small mammals to detect radionuclide transport would be an arduous and expensive task if conducted on a scale appropriate for large or diverse facilities.

Potential users are cautioned that the quantitative relationship between the radionuclide concentration in raptor castings and the general level of environmental contamination is unknown. The concentration of radionuclides observed in raptor castings depends in part on the chemical and biological availability of the contaminant, the location of the contaminant on the prey (e.g. whether on surface pelage, incorporated into tissues or contained within the prey's digestive tract), the composition of prey in the raptors' diet, and the relative availability of contaminants to the prey.

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REFERENCES

Ar78 Arthur W. J. and Markham O. D., 1978, "Radioecological research at two solid radioactive waste disposal areas on the Idaho National Engineering Laboratory", in: *Idaho National Engineering Laboratory, Hanford Site and Los Alamos National Laboratory, Symposium on Radioecology and Ecology*, U.S. Department of Energy, Idaho Falls, ID, IDO-12095.

Cr79a Craig T. H., 1979, *The Raptors of the Idaho National Engineering Laboratory Site*, Radiological and Environmental Sciences Laboratory, U.S. Department of Energy, Idaho Falls, ID, IDO-12089.

Cr79b Craig T. H., Halford D. K. and Markham O. D., 1979, "Radionuclide concentrations in nestling raptors near nuclear facilities", *Wilson Bull.* **91**, 72–77.

Cra56 Craighead F. C. and J. J. Craighead, 1956, *Hawks, Owls and Wildlife*, p. 222 (Harrisburg, PA: Stackpole Company).

Do78 Dorian J. J. and Richards V. R., 1978, *Radiological Characterization of the Retired* 100 *Areas*, United Nuclear Industries Inc., Richland, WA, UNI-946.

EES72 Environmental Evaluations Staff, 1972, *Environmental Status of the Hanford Reservation for* 1970, Battelle, Pacific Northwest Laboratory, Richland, WA, BNWL-C-96.

Er32 Errington P. O., 1932, "Technique of raptor food habits study", *Condor* **34**, 75–86.

Fi78 Fitzner R. E., 1978, *Behavioral Ecology of the Swainson's Hawk* (*Buteo Swainsoni*) *in Southeastern Washington*, Ph.D. Dissertation, Washington State University, Pullman, WA.

Ga82 Gano K. A. and States J. B., 1982, *Habitat Requirements and Burrowing Depths of Rodents in Relation to Shallow Waste Burial Sites*, Pacific Northwest Laboratory, Richland, WA, PNL-4140.

Ha60 Hardy E. P. and Klein S., 1960, *Strontium Program, Quarterly Summary Report* (*Sept.* 1-*Dec.* 13 1959), Health and Safety Laboratory, USAEC, New York Operations Office, HASL-77.

Jo78 Johnson D. R., 1978, *The Study of Raptor Populations*, p. 40 (Moscow, ID: University Press of Idaho).

Kl79 Klepper E. L., Rogers L. E., Hedlund J. D. and Schreckhise R. G., 1979, *Radioactivity Associated with Biota and Soils of* 216-*A*-24 *Crib*, Pacific Northwest Laboratory, Richland, WA, PNL-1948.

La81 Landeen D. S. and Mitchell R. M., 1981, *Intrusion of Radioactive Waste Burial Sites by the Great Basin Pocket Mouse* (Perognathus parvus), Rockwell International, Rockwell Hanford Operations, Richland, WA, RHO-SA-211.

La82 Landeen D. S. and Mitchell R. M., 1982, *The Role of Burrowing Activities of the Great Basin Pocket Mouse* (Perognathus parvus) *in the Dispersal of Radionuclides on a Decommissioned Pond*, Rockwell International, Rockwell Hanford Operations, Richland, WA, RHO-HS-SA-10P.

OF75 O'Farrell T. P. and Gilbert R. O., 1975, "Transport of radioactive materials by jackrabbits on the Hansford Reservation", *Health Phys.* **29**, 9–15.

Os68 Osburn W. S., 1968, "Forecasting long-range recovery from nuclear attack", in: *Proc. Symp. Postattack Recovery from Nuclear War* (Washington, DC: National Academy of Science, National Academy of Engineering, National Research Council).

Ol73 Olendorff R. R., 1973, *Raptorial Birds of the U.S.A.E.C. Hanford Reservation, South-Central Washington*, Battelle, Pacific Northwest Laboratories, Richland, WA, BNWL-1790.

Pa79 Paine D., Price K. R. and Mitchell R. M., 1979, *Evaluation of a Decommissioned Radwaste Pond*, Rockwell International, Rockwell Hanford Operations, Richland, WA, RHO-SA-99.

Pe79 Peterson L., 1979, *Ecology of Great Horned Owls and Red-tailed Hawks in Southeastern Wisconsion*, Department of Natural Resources, Madison, WI, Technical Bulletin No. 111.

Sm74 Smith D. G., Wilson C. R. and Frost H. H., 1974, "History and ecology of a colony of barn owls in Utah", *The Condor* 76, 131–136.

Sm73 Smith D. G. and Murphy J. R., 1973, "Breeding ecology of raptors in the Eastern Great Basin of Utah", *Brigham Young University Sci. Bull.* **18**(3).

USERDA75 United States Energy and Research Development Administration, 1975, *Final Environmental Statement-Waste Management Operations, Hanford Reservation, Richland, WA*, U.S. Energy Research and Development Administration Report, ERDA-1538 (Springfield, VA: NTIS).

Wo76 Wogman N. A., 1976, "Current methods for laboratory analysis of environmental levels of radioactivity", *IEEE Trans. Nucl. Sci.* **23**, 1214–1223.

Wo81 Wogman N. A., 1981, "Design and environmental applications of an ultralow background, high efficiency intrinsic germanium gamma ray spectrometer", in: *Methods of Low-Level Counting and Spectroscopy* (Vienna: IAEA).