ANIMAL BURROWING IN THE WASTE MANAGEMENT ZONE OF HANFORD NUCLEAR RESERVATION

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ABSTRACT: Animal burrowing is critical to the formation of soils, and contributes to the interface between geological materials and organic life. It also threatens the integrity of hazardous waste management sytems using shallow burials. We surveyed Hanford Nuclear Reservation in south-central Washington 3 times, at sites where radioactive wastes from the production of nuclear weapons were released onto the ground surface and within engineered burial structures. We found abundant evidence of burrowing in the soils covering buried waste sites by northern pocket gophers (*Thomomys talpoides*), Great Basin pocket mice (*Perognathus parvus*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*), and other species, and we observed frequent ecological interactions among these fossorial species that likely influence the fate of radionuclides. Our observations contradicted recent Hanford biological surveillance reports, as well as recent legal testimony by biologists and engineers at the Hanford site and by radio-biologists representing the nuclear weapons complex. Radionuclides remain vulnerable to vertical and lateral transport by burrowing animals at Hanford, and when exposed to wind and rain, they risk inhalation and injury to humans and wildlife on and off the site. Scientific oversight and more rigorous sampling and monitoring methods are needed at Hanford Nuclear Reservation.

Key words: burrows, Hanford Nuclear Reservation, nuclear waste, northern pocket gopher, soil, surveillance, *Thomomy talpoides*.

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Burrowing animals have long been recognized as agents of natural soil formation and erosion (Grinnell 1923, 1933; Taylor 1935; Thorp 1949; Hole 1981; Huntly and Inouye 1988). Burrowing characteristics of certain species, such as depth and volume of soil excavated by northern pocket gophers (*Thomomys talpoides*) and harvester ants (*Pogonomyrmex owyheei*), inspired their use in the BIOPORT model (McKenzie et al. 1982, 1986) for predicting releases of radioactive wastes from burial structures. Intrusion of burrowing animals into buried nuclear waste has been documented at multiple sites (Hakonson et al. 1982, Arthur and Markham 1983, Johnson 1984, Arthur et al. 1987). These intrusions can release radionuclides to the environment, where inhalation or ingestion risks genetic damage, birth defects, and mortality among animals, including humans.

The Hanford Nuclear Reservation has 552-995 kg of plutonium in shallow burials (Cochran 1996), as well as many other radioactive elements. The half-life of Pu239 is 24,110 years, thus remaining dangerous forever in terms of human management planning. Most of these radioactive wastes were buried under only 0.6-1.2 m of soil at numerous sites on the Hanford Plateau, within reach of burrowing animals long known to occur on the Hanford Waste Management Zone. Northern pocket gophers have been part of the ecosystem on the Hanford Plateau long enough to form the mima-mound grasslands common there (Landeen 1994). Mima mounds are thought to be created by long-term site occupancy by pocket gophers (Dalquest and Scheffer 1942, Cox et al. 1987). More recently, pocket gophers were reported as abundant locally (ERDA 1975) and across the entire Hanford Plateau (Fitzner and Gray 1991). In 1994, a gopher was trapped from within 100 m of solid waste burial 218-W-4B (Westinghouse Hanford Company Nuisance Animal Control Log, 1989-1995), where a large amount of plutonium and other radioactive elements were buried. Northern pocket gophers have been reported to burrow to >3.5 m depth (Criddle 1930, Dalquest 1948) and to excavate 45 m^3 ha^{-1} yr^{-1} on average (Smallwood and Morrison, unpubl. data), thereby risking environmental damage and excessive costs in remediation efforts by excavating and redistributing the buried wastes.

Sign of animal intrusion, animal burrows, and digging are searched for as part of the environmental surveillance of Hanford's buried waste sites (Brown 1988; Bechtel Hanford Inc. 1995a,b,c, 1996; Markes and McKinney 1995; Hayward 1996). These burrows presumably include those of pocket gophers, although no explicit mention of gophers was made in the surveillance guidelines, nor in the reports (Mix and Winship 1993; Hayward 1996; McKinney and Markes 1996:19-20). Pocket gophers apparently were not part of the routine monitoring of wildlife at Hanford (Conklin et al. 1984, Gray et al. 1989).

The plaintiffs in a large legal action directed against the U.S. nuclear weapons complex asked Smallwood to assess the accuracy of the BIOPORT parameter values. Based on research experience with gophers and his re-

*Consulting in the Public Interest, WWW.CIPI.COM view of the literature, Smallwood (1996a) offered alternative parameter values for animal burrowing at Hanford and predictions of larger impact than did BIOPORT. Biologists and engineers at Hanford and the larger nuclear weapons complex disagreed. They denied the existence of northern pocket gophers on the 200 Area solid waste burial grounds (Auxier 1996, Johnson et al. 1996, Whicker 1996). We traveled to Hanford in June 1996, and counted burrows made by gophers and other species across the solid waste burial grounds (Smallwood 1996b). Our findings during this first visit to Hanford prompted 2 more visits. Our objectives for these visits were to (1) improve BIOPORT's parameter values for estimating release quantities of waste due to animal burrowing, (2) compare our reconnaissance-level findings with surveillance results of Hanford personnel, and (3) assess the potential impact of animal burrowing on the Hanford facilities.

STUDY AREA

The Hanford Nuclear Reservation occupies the Hanford Plateau south and west of the Columbia River near Richland, Washington. The Plateau is arid and supports shrub-steppe vegetation and mima-mound grasslands. Hanford began producing weapons-grade plutonium for the United States military services during the early 1940s. Hanford produced about 67.4 t of plutonium, of which 1,522 kg is reported to be in wastes (U.S. Department of Energy 1996) at 1,391 sites across the Hanford Nuclear Reservation (U.S. Department of Energy 1995). Many of the sites and much of the wastes occur on the 200 Areas, which covers about 40 km^2 in the central part of the Hanford Nuclear Reservation. The hazardous wastes and residual materials produced by the 9 breeder-reactors and various process buildings were deposited across large areas following stack releases. They were also contained in inactive reactor effluent retention basins, leach trenches, french drains, diversion boxes, underground pipes, storage tanks, solid burial grounds, cribs, covered ponds and ditches, and in soil following unplanned releases. These buried waste structures were usually covered by 0.6-1.2 m of soil "caps." Some caps were composed of cobble, such as on the inactive reactor effluent retention basins in the 100 Areas next to each breeder reactor, and on service ditches of the 300 Areas near the Columbia River on Hanford Nuclear Reservation's east side.

METHODS

We conducted reconnaissance-level surveys of Hanford's buried waste structures for signs of animal burrowing and reduced integrity of the waste structures during 5-6 and 19-20 June, and 21-23 August. We adapted the sampling methods of Smallwood and Erickson (1995) to count burrows of pocket gophers, pocket mice, and of other species, mostly along the perimeter of underground waste sites. Except in 1 instance, we were not allowed to walk on the soil caps over buried waste. Animal burrows were counted along about 2 km of selected stretches of transect during the first trip, along 3.5 km during the second trip, and along 10 km during the third trip. Our observations of Great Basin pocket mice (*Perognathus parvus*) using gopher burrows during our first visit warranted further investigation so the BIOPORT parameter values could be reconsidered. Therefore, we estimated the proportion of pocket mouse burrows occurring on pocket gopher burrows, based on obvious coincidence of their sign observed during our second and third trips. We also counted the number of excavations into gopher burrows by coyote (*Canis latrans*), badger (*Taxidea taxus*), and other mammals. Also, we reviewed in-house Hanford documents for records of animal burrow excavation.

RESULTS

Northern pocket gophers and Great Basin pocket mice were evident around the buried waste sites of the 100, 200, and 300 Areas, and on the soil overfill atop waste sites of the 200 and 300 Areas (Tables 1 and 2). We noticed multiple excavations of gopher burrows by coyote, badger, and small mammals (Tables 2 and 3). Gopher mounds and badger excavations also occurred around the edges of the cobble caps on the 100 Areas.

During our second visit, we noticed new gopher sign where it was previously not seen during our first trip. Previously observed old sign was also augmented by fresh sign. Two of the holes we dug into gopher burrows during our first trip were now plugged by gophers; these gophers were therefore either present when we opened the tunnels during our first visit, or they had since invaded the burrows. However, much of the gopher sign observed during our first visit was barely visible after a wind storm moved loose soil from a shallow waste burial cap across one of our transects (the eastern fence of 218-W-1 to -4B). We counted 20 burrows along this transect during our first visit and 39 burrows during our June 19 visit (Table 2). Overall during 19-20 June, we spotted more than 107 gopher burrows, most of which were on the buried waste caps beyond the radiological control signs. Some of the burrows were so conspicuous atop waste caps that we could spot them from a moving vehicle.

During our August visit, we counted 198 gopher burrows along 10 km of transect around the perimeter of buried waste sites (Table 3). At this time, measured linear gopher density had increased 19% on the BC cribs,

Table 1. Frequency of pocket mouse burrows on and around buried waste sites, and in association with northern pocket gopher burrows during 19-20 June 1996.

Hanford shallow waste burial site	Transect distance (m)	Number of pocket mouse burrows		
		Sampled	In gopher burrow	Off gopher burrow
216-A-29 ditch	372	8	3	5
216-B-3-1, -2 ditches	265	5	5	0
218-E-12A solid waste trenches, west edge	294	9	9	0
216-BC cribs	869	24	16	5
216-U-10 pond, north rim	296	17	11	5
216-Z-11 & 19 ditches	—	1	1	0
216-Z-18 crib	—	1	1	0
218-E-12A solid waste trenches, north edge	—	1	1	0
218-W-1 to -4B solid waste trenches, along east fence	815	13	10	2
218-W-1 to -4B solid waste trenches, 25 m east of fence	287	13	9	2
218-W-1 to -4B solid waste trenches, along dirt road	225	9	8	1
Total	3423	101	74 (73%)	20 (20%)

32% along the west edge of 218-E-12A, and 36% along the eastern fence of 218-W-1 to -4B. Due to its small size and narrow shape, we were able to estimate a spatial density of 40 gophers ha^{-1} on 216-B-12 crib, which matched Smallwood's (1996b) predicted density based on our document review and second visit. By calibrating this density to the linear density, and assuming the linear density decreases with transect length at the same rate that spatial density decreases with spatial extent of observation (Smallwood and Morrison, unpubl. data), we found that spatial densities were similar on 8 other buried waste sites (Table 3).

We noticed during our first visit that pocket mice had burrowed into abandoned pocket gopher burrows. During 19-20 June, 73% of the 101 pocket mouse burrows occurred in abandoned gopher burrows (Table 1), and 76% of the 107 gopher burrows was invaded by pocket mice (Table 2). Additionally, 9% of the gopher burrows were excavated by badgers, and about 9% were excavated by coyotes, accounting for the 40 predator holes dug into the 107 gopher burrows sampled (Table 2). The rate of gopher burrow intrusion by coyotes and badgers during August was about the same as observed during June, so there were more predator excavations overall (Table 3). However, the percentage of burrows invaded by pocket mice decreased from 76% in June to 51% in August, during which time gopher burrows with recent soil excavation increased from 16% in June to 56% in August.

Hanford Document Review

The Hanford Surveillance personnel used essentially the same sampling methods we used; that is, recording whether animals dug holes or burrows into the waste site (Hayward 1996), thus indicating "animal or insect intrusion." However, of the 69 Surveillance Reports

Table 2. Frequency of intrusion into gopher burrows by pocket mice, badgers, coyotes, and other mammals during 19-20 June 1996.

Hanford shallow waste burial site	Number burrows sampled	Number of gopher burrows intruded by (# holes)			
		Pocket mice	Badger	Coyote	Other mammals
216-A-29 ditch	4	2	0	0	1
216-B-3-1, -2 ditches	11	5	0	0	0
218-E-12A solid waste trenches, west edge	11	9	0	0	0
216-BC cribs	23	17	7 (15)	2	0
216-U-10 pond, north rim	12	12	0	0	1
216-Z-11 & 19 ditches	2	1	0	0	0
216-Z-18 crib	2	1	0	0	0
218-E-12A solid waste trenches, north edge	3	1	3 (5)	0	0
218-W-1 to -4B solid waste trenches, east fence	20	10	0	0	3
218-W-1 to -4B solid waste trenches, 25 m east	19	18	0	7 (20)	0
Total	107+	76	10 (20)	9 (20)	5

made during April and May 1996, only 5 reported evidence of animal or insect intrusion. Of the 21 sites mutually visited by the surveillance personnel and ourselves in June, only 2 surveillance reports acknowledged evidence of animal or insect intrusion where we also observed it, leaving 19 in disagreement with our observations. The Hanford Surveillance Reports did not include the numerous bank swallow (*Riparia riparia*) nests we sighted during 19 June on the active waste trench of 218-W-4C.

DISCUSSION

We found abundant evidence of burrowing by gophers and other species in the soil overfill covering buried nuclear waste. Burrows of pocket mice were so abundant during our August visit that we were unable to sample them reliably while also sampling for gopher burrows. Likewise, burrow evidence of deer mice (*Peromyscus maniculatus*) was too abundant for sampling in the time available. There is every reason to expect these species have burrowed into these waste sites since soon after burial of the waste.

According to ERDA (1975), the ecological community types have remained unchanged on the 200 Areas and elsewhere except for disturbances caused by construction activities during the last 50 years. Shrub-steppe vegetation extends east and west in a broad band across the Hanford Plateau and the waste burial grounds (Fayer and Walters 1995). According to Rickard et al. (1974), this vegetation supported gophers wherever it occurred at Hanford. It would have supplied gophers for invasion of the buried waste sites, and it would have served as the landscape-scale dispersal pathway from other potential source areas, such as the Arid Lands Ecology Reserve, the Columbia River corridor, and nearby field crops. Alfalfa stands, which attract and support gophers, comprised 30% of the irrigated area within 50 miles of Hanford during the early 1970s, and 40% of this area was in crops highly suitable for gopher population growth (acreage from ERDA [1975]). Some young animals can disperse up to several kilometers (Criddle 1930), and Vaughan (1963) actually measured dispersal distances of 240-800 m. The excavation and construction activities would have made the buried waste sites susceptible

Table 3. Gopher burrows sampled during 21-23 August 1996, and frequency of intrusion by other mammals.

Hanford shallow waste burial site	Transect distance (m)	Burrows sampled	Number of gopher burrows (# holes) intruded by			
			Pocket mice	Badgers	Coyotes	Others
216-A-24 crib	255	8	7	0	0	1
216-B-3-1, -2 ditches	1080	19	6	6 (8)	1	0
216-B-3 pond, west shore	188	4	2	0	0	0
218-E-12A solid waste trenches, west edge	303	15	4	0	0	1
218-E-12A solid waste trenches, south edge	324	4	2	0	0	0
216-BC Cribs	1017	32	2	14 (32)	2 (3)	2
216-U-10 Pond	2138	7	2	2 (4)	1	0
216-B-12 crib	207	8	1	0	0	0
216-Z-11 & 19 ditches	640	16	7	0	0	0
216-Z-20 ditch	640	11	2	1	0	0
216-Z-18 crib	100	2	0	0	0	0
218-W-3 solid waste trenches, south, west edges	452	0	0	0	0	0
218-W-2A solid waste trenches, south edge	160	0	0	0	0	0
218-W-1 to -4B solid waste trenches, east fence	780	26	6	0	2	0
218-W-1 to -4B solid waste trenches, 25 m east	877	19	2	1	1 (4)	0
Gable Mt. Pond, north shore	264	6	1	1	0	0
118-F-1 reactor effluent retention basin	284	0	0	0	0	0
118-F-6 reactor effluent retention basin	165	1	0	1	0	0
618-4 solid waste trenches	446	20	7	0	2	0
Total	10,320	198	51	26 (48)	9 (13)	4

to gopher invasion within one year of completion, which is typical of how small mammal populations respond to disturbance (Hedlund and Rickard 1981, Anderson and MacMahon 1985, Sullivan 1986, Howard et al. 1990).

Gophers are known to prefer the disturbed soils associated with buried waste sites (Hakonson 1986, Gonzales et al. 1995) and buried wire and cable trenches (Connolly and Landstrom 1969). They also prefer soil and topographic edge structure (Criddle 1930), which is often created by the buried waste trenches and other constructions. Gophers were suspected of being attracted to waste sites at Hanford (Rogers and Rickard 1977, Gano and States 1982). They can readily penetrate biobarrier materials (Wing 1992) and many hard materials meant to protect sensitive equipment, especially soft metals such as lead and aluminum (Connolly and Landstrom 1969). Therefore, gophers could have infiltrated at least some of the buried waste containers prior to package degradation, and some of this waste material would likely have been actively sought and transported to den chambers for use as nesting material (Connolly and Landstrom 1969). The early waste burial caps consisted of only 15 cm of loose soil (Johnson et al. 1994), easily within reach of virtually all burrowing animals at Hanford. Pocket mice have been found to burrow deeper into backfill over buried waste (Landeen and Mitchell 1982), and harvester ants are known to prefer the disturbed soils of buried waste sites (Uresk and Cline 1978, Fitzner et al. 1979).

Pocket mice also burrowed extensively into gopher burrows at Hanford, consistent with the commensal relationship reported by Barnes (1973) in forest environments. Pocket mice using old pocket gopher burrows could influence the amount of plutonium and other fission products transported from buried waste to the soil surface and to the animal food chain. The use of abandoned pocket gopher burrows would: (1) effectively increase the functional life of the gopher burrow, (2) extend the maximum burrow depth of the pocket mouse to that of the deeper gopher burrow, and (3) expedite and possibly increase the excavation of backfilled soil from gopher tunnels to the ground surface. Other small mammals similarly burrowed into gopher burrows.

Where small mammals burrow into buried waste, their mammalian predators are likely to excavate even larger foraging burrows. Badgers excavated gopher burrows on the 200 Areas at nearly twice the rate of their foraging into Townsend ground squirrel (*Spermophilus townsendii*) burrows on the Arid Lands Ecology Reserve (Voth 1976). Almost all predator excavations at Hanford were into gopher burrows. A notable exception was an apparent badger attack of bank swallow nests on the dirt wall of active trench 33 within the 218-W-4C solid waste burial grounds. Following our discovery of the nests in June, drums of waste were stacked under the bank swallow colony, and soil was backfilled over the drums to about half the depth of the trench. The drums were still partly visible at 1 end of the stack. The badger was able to access the bank swallow nests from the top of the backfill. It excavated large holes into the nests 0.3 to 3 m below grade, and collapsed a 1-2 m3 portion of the trench wall. The intrusion of the trench wall occurred before the trench was fully constructed, leaving large cavities that could exacerbate animal burrowing into the waste. Previously constructed waste trenches remained open for years, as evidenced by historical aerial photos, so their integrity could have been similarly breached by burrowing animals. Animal burrowing at Hanford has been intense and diverse in character and origin, and the full impacts have yet to be estimated.

Burrowing animals were repeatedly referred to as serious threats to the integrity of waste barriers and to radionuclide transport at Hanford (e.g., Wheeler 1978, Gano and States 1982, Law 1982, Van Luik and Smith 1982, Link et al. 1994). Out of 101 rankings of buried waste sites during 1990-92, 88 sites (87%) were identified with waste mobility problems (Mix and Winship 1993: Appendix). Among these sites, 21 were rated as having a history of spreading contamination, 18 showed evidence of bio-uptake or contamination beginning to move around, 28 were rated as having a 20-50% chance of migration or uptake by plants or animals, and 21 were rated as having a 10% chance of migration or uptake by plants or animals. With these admissions of animal intrusion problems, we therefore are surprised at the lack of focused research and surveillance efforts at Hanford.

Hedland and Rogers (1976) and Paine et al. (1979) regarded density estimation of small mammal populations to be the required first step in understanding whether and how small mammals contribute to human exposure of radionuclides from buried waste. We agree, and we suggest that sampling methods at Hanford be designed and implemented to estimate gopher populations and their burrowing impacts. Above-ground snap-traps and Sherman live-traps were used for small mammal studies at Hanford (e.g., Johnson 1975, O'Farrell et al. 1975, Gano 1979, Fitzner et al. 1979, Hedlund and Rickard 1981), and radiological monitoring involved use of snap-traps (Law 1982). However, gopher population estimates can be made using soil mounds (Smallwood and Erickson 1995), and captures for radiological monitoring require careful placement of special traps within gopher tunnels (Dixon and De Ong 1917, Howard 1952). Rickard et al. (1988) acknowledged their inability to catch pocket gophers known to occur on the above-ground trapping grid.

Adding to the likelihood of not detecting contamination among pocket gophers using existing methods, Johnson et al. (1994:21) reported that animals and plants were sampled only if known to be radioactive. Radiological monitoring would seldom, if ever, detect radiation doses on or within gophers because the animals reside and perish below ground. Detection of radioactivity declines rapidly with distance between the detection probe and the source (Boothe 1979), so contaminated gophers in their burrows would probably not be detected. To our knowledge, the first pocket gopher collected and sampled for radioisotope contamination was from a burrow we discovered in June 1996 on solid waste burial 218-W-4A. This gopher had 89/90Sr concentrations about 3 orders of magnitude greater than in surface soils on the Waste Management Zone (Thomas D. McGinnis Validated Results Short Report, June 28th, 1996, Sample # S96E000756). A reasonable sample of gophers from the Hanford Waste Management Zone would reveal whether further contamination has occurred.

MANAGEMENT IMPLICATIONS

Hanford researchers and surveillance personnel had ample reason to study and monitor the abundance and radiology of northern pocket gophers and other burrowing animals on the Hanford Waste Management Zone. Gophers, pocket mice, badgers, black-tailed hares (*Lepus californicus*), harvester ants, and other burrowing animals have been repeatedly documented as transport agents of radionuclides out of stored buried waste. Radionuclides are known to be mobile at Hanford, and surface contamination continues to be discovered on and around the buried waste sites. Gophers and other burrowing animals are known to prefer the backfilled soil caps on buried waste, and we documented abundant evidence of burrowing animals on these caps. Furthermore, gophers regularly penetrate hard, protective materials and transport materials to their den chambers, which means they probably encounter buried waste actively rather than passively. Therefore, pocket gophers and other burrowing animals warrant the greatest surveillance focus among species of wildlife at Hanford.

DOE and EPA regulations require the study of animal burrowing. The surveillance instructions for Hanford personnel need revision to explicitly include northern pocket gophers as a subject of the surveillance. Morrison et al. (in press) provided monitoring guidelines useful for wildlife on hazardous waste management sites such as at Hanford, where gopher monitoring and population studies are especially needed. Gophers, pocket mice, and deer mice living and reproducing in contaminated soils over buried nuclear waste should be studied for health effects of radiological exposure to individuals, populations, and the ecological community. Careful excavations, measurements, and radiological sampling are needed of burrows made by gophers and other species into Hanford's buried waste structures. The fate of particles within excavated soil mounds needs determination by studying their lateral and vertical movement due to wind, precipitation, and animal activities. All these steps would enable more rigorous assessments of transport pathways, magnitude of transport, and environmental and waste management impacts.

Furthermore, scientific oversight is needed of research and surveillance conducted by DOE and their contractors at Hanford and other facilities of the nuclear weapons complex. Following a tour of the 200 Area burial grounds by T.E. Hakonson, the leading pocket gopher researchers of the nuclear weapons complex (e.g., Winsor and Whicker 1980, Hakonson et al. 1982), concluded "any potential pocket gopher activity was certainly minor, if not non-existent" (Whicker et al. 1997). His conclusion contradicted the numerous in-house reports of gophers at Hanford, the capture of a gopher contaminated with radionuclides on 218-W-4C, and our provision of videotape and photographic evidence of many gopher burrows on the waste caps. Independent oversight of Hanford's biological surveillance appears warranted.

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