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MASTER

CHARACTERIZATION OF THE HANFORD 300 AREA BURIAL GROUNDS

TASK IV - BIOLOGICAL TRANSPORT

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PREFACE

The United States Department of Energy (DOE) is considering decontamination and decommissioning alternatives for its retired nuclear facilities in order to provide adequate protection from radioactive and other hazardous materials potentially originating from such sources. Decontamination and decommissioning of these facilities may involve the selective removal of radioactive or other materials from retired nuclear facilities and selection of the ultimate disposition of the facilities. Among the facilities being evaluated are retired radioactive waste burial grounds at DOE's Hanford Site, Richland, Washington.

The "Characterization of the Hanford 300 Area Burial Grounds" project was initiated to provide an assessment of retired radioactive waste burial grounds prior to selection of decontamination and decommissioning alternatives at the Hanford Site. The project was sponsored by the U.S. Department of Energy, Division of Environmental Control Technology and was conducted by Pacific Northwest Laboratory from 1975 through 1978.

The original intent of this project was to develop technology and methods for characterization of waste burial sites and to apply them to the 300 Area Burial Grounds. During the course of the study, the scope was broadened to include development of recommendations pertaining to buried waste disposition alternatives.

Project tasks were initiated to provide the necessary technology and to characterize burial ground sites. These tasks included:

Task I - Geophysical Evaluation
Task II - Geochemical Analysis
Task III - Fluid Transport Characterization and Modeling
Task IV - Biological Transport

Topical reports from each of these tasks have been issued under separate cover.

Two other reports have been issued: "Decontamination and Decommissioning" provides an overview of the 300 Area Burial Grounds, project results and recommendations. "Decontamination and Decommissioning Regulatory Issues" details regulatory issues to be considered when evaluating the alternatives.

SUMMARY

An accurate description of the characteristics of radioactive waste burial sites is important when evaluating the potential for radionuclide transport to the biota. The Biological Transport task developed and expanded methods for providing an ecological description of burial grounds. Specifically, the study involved the 300 Area Burial Grounds on the Department of Energy's Hanford Site, southeastern Washington. The potential vectors of transport studied were: vegetation (grasses, forbs, and shrubs) and animals (ants, reptiles, mammals, and birds).

The overall results showed a low potential for uptake and transport of radionuclides from the 300 Area sites. However, additional methods to control physical and biological mechanisms may contribute to the effectiveness of waste burial practices. Field testing of techniques is needed to determine the optimal measures. From the results of the Biological Transport task, recommended field studies include reduction of soil erosion and addition of biobarriers to plants and animals.

Vegetation plays a major role in reducing soil erosion, and thereby maintaining the backfill over the burial sites. However, radioanalyses of plant tissues collected during the study, as well as results from previous studies, indicate that different plants have different potentials for radionuclide uptake and/or transport. Of the several species found on the 300 Area sites, cheatgrass (*Bromus tectorum*) appears to be the most desirable as a cover. Besides retarding erosion, it has a shallow root system (does not easily penetrate buried material); it has a low affinity for radionuclide uptake; and its tissues are not easily blown away.

Of the animals observed on the study sites, small mammals (specifically, mice) appear to have the most potential for radionuclide exposure and uptake. Small mammals were live-trapped within 10 x 10-meter trap grids. Each animal trapped was surgically implanted with a thermoluminescent dosimeter. When the animal was recaptured, the dosimeter was removed and read for exposure. Exposures were reported in milli-Roentgens.

The most consistently trapped small mammals were the Great Basin pocket mouse (Perognathus parvus) and the deer mouse (peromyscus maniculatus). Results from the dosimeter readings showed that some of those animals had higher than background exposures. These exposures are an indication that the mice had come in proximity to gamma-emitting radionuclides. Consequently, biobarriers to animals could be considered as a mechanism to reduce the potential for radionuclide transport.

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INTRODUCTION

Plants have the ability to convert solar energy into organic material (photosynthesis) which serves as the basis for food chains leading to the consumers and decomposers. The consumer organisms (herbivores, omnivores, and carnivores) physically transport organic and inorganic materials within and between ecosystems. Decomposers (primarily fungi and bacteria) exploit dead organisms as a food source and serve to prevent the buildup of organic detritus and to recycle essential mineral elements needed for healthy plant growth.

The producers, consumers and decomposers are interrelated in a food web, with producers forming the basis for all food chains leading to consumers. Nutrients associated with the soil and within the rooting zone are used by green plants and become incorporated into their tissues. Plant tissues are eaten by primary consumers, and energy and nutrients tied up in the producer tissues are released to the primary consumer in the digestion process. Successive trophic levels have access to these nutrients which eventually return to the soil by way of the decomposers.

This simple description of mineral nutrient behavior indicates the general mechanism by which radionuclides are cycled through ecosystems. Since certain radionuclides are isotopes of elements commonly used by plants, they also become incorporated into the plant tissues along with naturally occurring stable elements and are transferred to other components of the food web if they are physically accessible to biota.

The practice of shallow land burial of radioactive waste in 300 Area Burial Grounds on the Hanford Site in southeastern Washington has, for the most part, been successful in sealing the debris and the radioactive emissions from biota. However, detectable amounts of radioactivity have appeared in a few samples of aboveground plant tissues, apparently through contact of plant roots with contaminated soil. Also, a few small mammals, such as pocket mice and deer mice, living on the burial grounds have received radiation exposures greater than background levels, apparently by burrowing into the contaminated

waste or backfill or by entering through caveins. In doing so, they reach the zone of external radiation emitted by buried wastes for extended periods of time.

This report provides an ecological description of the waste burial sites of the 300 Area and discusses major ecological pathways of radionuclide transport important to consider in the decontamination and decommissioning of dryland waste burial sites in the DOE Hanford Site 300 Area. The Hanford environs are typified by an arid climate, low soil fertility, low biological productivity and low species diversity. These features have generally been favorable for biological confinement of buried radioactive waste. This detailed characterization study of plant and animal populations complete with radiochemical analyses further illustrates the efficacy of shallow land burial of radioactive wastes in the 300 Area as related to biota that use the burial site and its vicinity. This report also contains some recommendations concerning environmental management practices which may be useful in controlling the transport of radioactivity from waste burial sites.

CONCLUSIONS

The conclusions relevant to this study are:

- Field techniques and methodologies used in the Biological Transport task proved to be highly successful in providing a concise description of the biota and the transport mechanisms existing on the 300 Area burial sites.
- The potential for biological uptake and transport of buried waste in the 300 Area waste burial sites is low but does exist.
- The principal ecological mechanisms of radionuclide uptake and transport involve:
  1. plant root penetration to buried waste
  2. small mammal exposure to ionizing radiation, injestion of contaminated plant material, and direct external contamination by utilization of caveins for shelter.
- Shallow waste burial has, in general, been quite effective in containing the waste buried therein. This effectiveness may be enhanced through the control of physical and biological mechanisms. Field testing of enhancement techniques is needed in order to derive measures which will be effective at containing waste.
- Recommended field studies include:
  1. reduction in wind-induced soil erosion through soil additives, alteration of surface texture, and plantings of shallow-rooted plants
  2. establishment of biobarriers to plants and animals.

STUDY AREAS

For the ecological studies, representative sites were chosen since detailed field investigations of plants and animals require considerable researcher time. Table 1 lists all the retired solid waste storage sites along with size, date of deactivation, general description of the contents and the depth to the water table. A more detailed explanation can be found in Paas (1955). Table 2 lists the individual investigations and indicates those burial grounds which served as study sites. Figure 1 provides a map of most of the burial sites examined, and Figures 2 through 8 provide photographs of the plant communities established on these burial sites.

RELATED STUDIES

Ecological research has been an ongoing effort on the Hanford Site for about three decades. However, intensified field investigations related to characterization of plant and animal population has taken place only during the 1970s. Many of these studies provide ecological information relevant to the 300 Area burial site study. For example, the Radioecology of Waste Management Areas program (funded by DOE) has provided data on plants, small mammal population dynamics, reptile and lizard population dynamics, and shrub inhabiting invertebrates on the Hanford Site in general. These study plots are located in dominant habitat types throughout the Hanford Site with two study sites located near power reactor installations. Ecological studies have also provided new information on birds of prey nesting near the 300 Areas. Other studies have provided baseline ecological information on plants and small mammals living near commercial power reactors now under construction on the Hanford Site. Figure 9 is a map of the Hanford Site showing the 300 Area, and locations where related field ecological research is being or has been conducted.

TABLE 1. 300 Area Storage and Disposal Sites

Site	Size Acres	Description	Terminated Service in Year	Depth to Water Table (ft)	Monitored by Well Number
(1)	1.1	200 ft long trenches 15 ft wide by 8 ft deep on N-S axis and some 20 ft wide by 15 ft deep on E-W axis. Covered with 4 ft layer of clean dirt, and marked in 1961. Markers 3-61-51 through 3-61-90. Contains all 300 Area solid radioactive waste generated from 1945-1956, including uranium, plutonium, and fission products.	1956	41	399-1-2
2	1.7+	Pits 150 ft long by 51 ft wide by 15 ft deep. Covered with clean soil and marked in 1961. Markers 3-61-1 through 3-61-50. Contains uranium contaminated equipment and material.	1961	41	399-1-2
3	1.3+	An expansion to the west of No. 2 with similar contents and deactivation procedures.	1961	41	399-1-2
4	2.9+	Elongated pits containing uranium contaminated miscellaneous materials from 300 Area manufacturing facilities. Filled and covered with clean dirt. Marked in 1961 with markers 3-61-137 through 3-61-189	1961	33	--
5	1.2+	Elongated pits to 15 ft deep containing uranium contaminated trash. Covered, filled with 4 ft of clean dirt. Marked in 1962, 3-62-1 through 3-62-38	1962	38	
6	--	No longer exists. Wastes moved to other sites. Contained solid uranium waste from 6 mo in 1944. Filled with clean dirt.	1944	--	
7	~16.7	Two drive-in trenches and a V-shaped pit, containing materials primarily from 300 Area fuel manufacturing process contaminated slightly with uranium or thorium Backfilled and covered with clean dirt.	1971	52	399-8-2
(8)	~1.4	Long trenches filled with low level uranium bearing waste from fuel manufacturing areas filled and covered with clean dirt and a parking lot (North). Marked in 1961, 3-61-91 through 136.	Prior	52	--

TABLE 1. (contd)

Site	Size Acres	Description	Terminated Service In Year	Depth to Water Table (ft)	Monitored by Well Number
300 West	0.1	A long trench filled with drums of uranium contaminated organic solvent from the 321 Building in 1955 and 1956. Terminated and marked in 1963, 3-63-1 through 18.	1956	55	--
(Contaminated Equipment Storage Area)		All equipment removed. Ground slightly contaminated.			
300 North	6.1	Located about 4 miles northwest of 300 Area. Terminated. Broad spectrum of low-to high-level solid radioactive waste, primarily fission products and plutonium. Cartoned low-level waste in caissons or buried pipe facilities.	1963	65	
(300 North)	<1	A stainless steel tank with an open bottom, about 150 ft southeast of the 300 North burial ground, into which was dumped uranium contaminated liquid waste from the 321 Building.	1956	65	
300 WYE	8.6	Located about 7-1/3 miles north of the 300 Area. Retired--filled and marked. Broad spectrum of low-to high-level solid radioactive waste, primarily fission products and plutonium. Cartoned low-level waste was buried in trenches; medium to high-level waste in caissons or buried pipe facilities.	1967	45	

( ) Sites in parenthesis were not examined in this investigation.

TABLE 2. 300 Area Burial Sites Used for Ecological Studies

	Site 2	3	4	5	6	7	300 West	300 North	300 WYE
Plant Studies	X	X	X	X		X	X	X	X
Insect (ant) Studies						X			
Reptiles and Amphibian Studies			X			X		X	X
Bird Studies			X			X		X	X
Small Mammal Studies						X		X	X

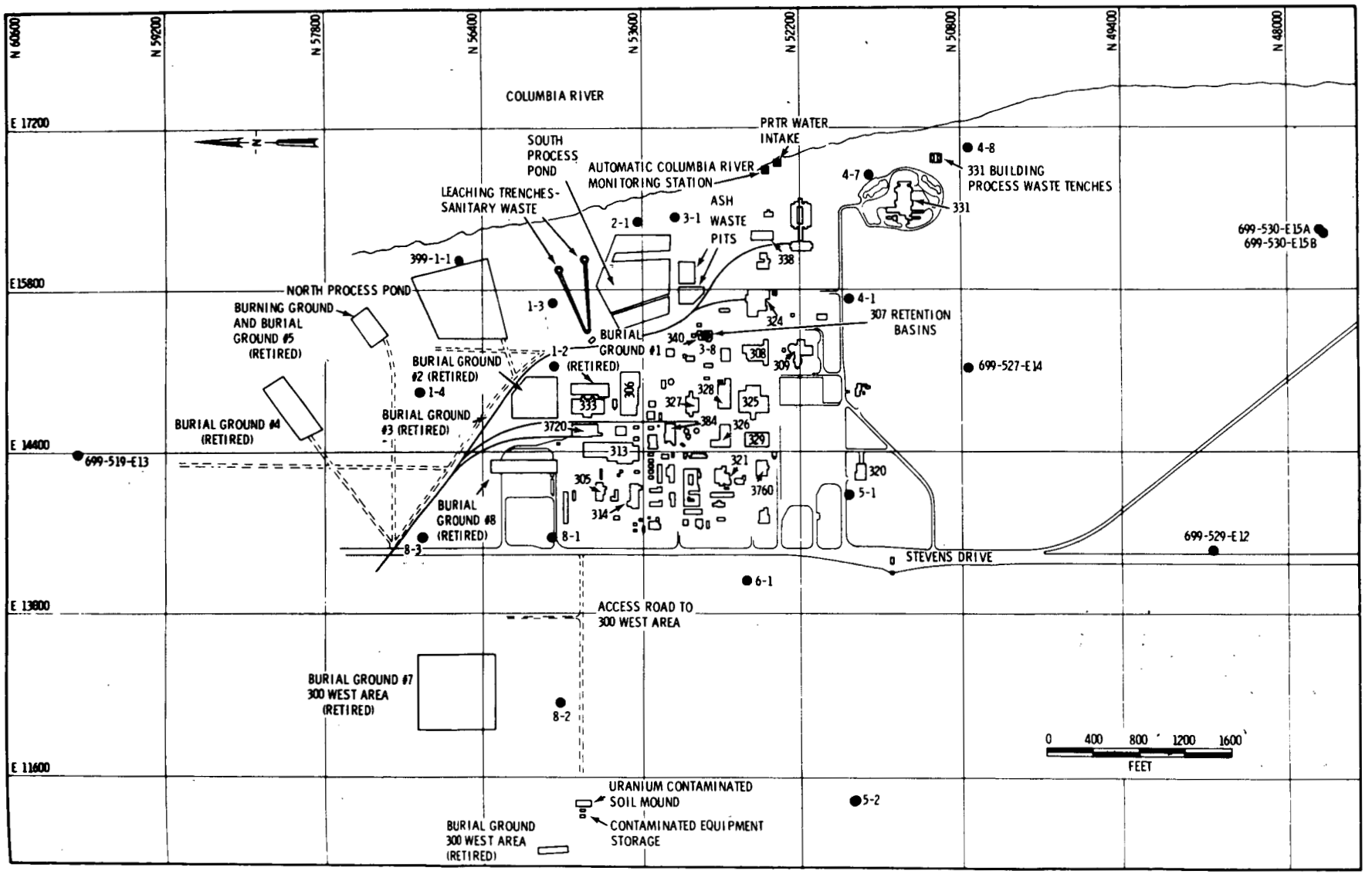


FIGURE 1. 300 Area Waste Storage Facilities

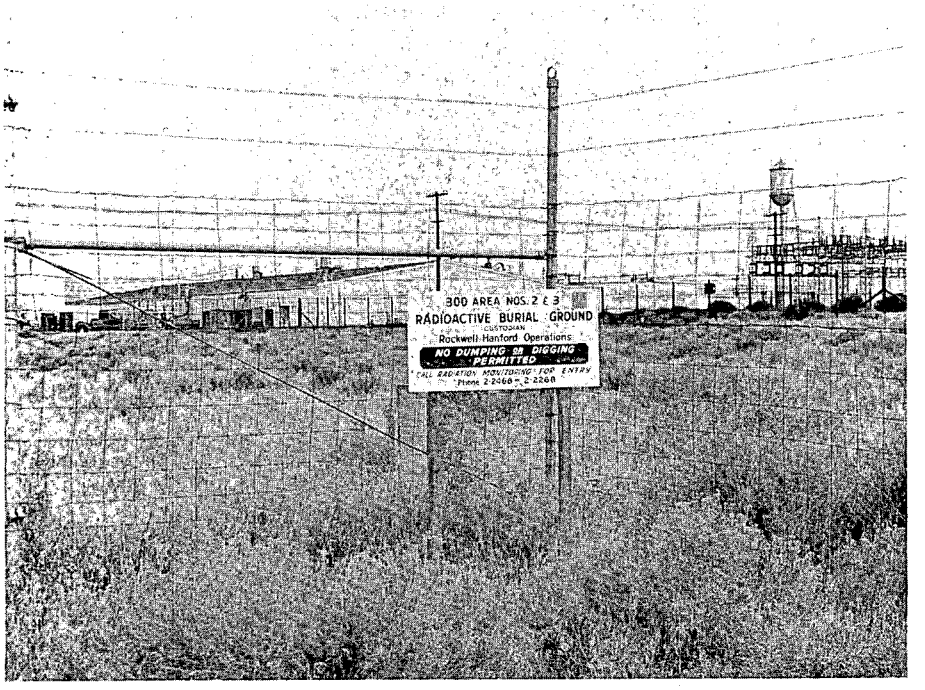
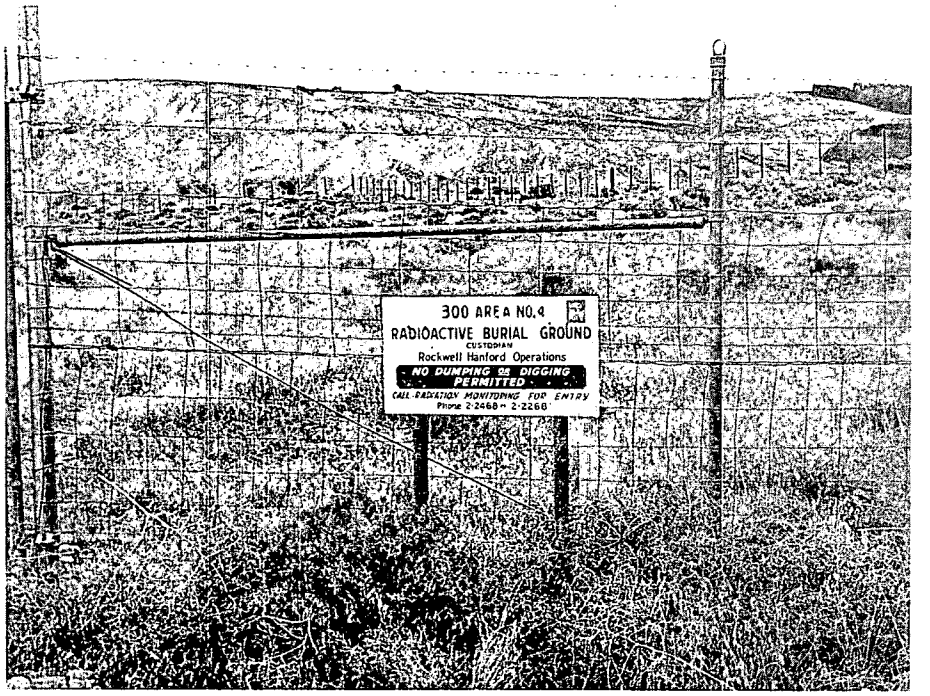


FIGURE 2. Waste Burial Sites No. 2 and 3. Note well established stand of deep-rooted shrubs.



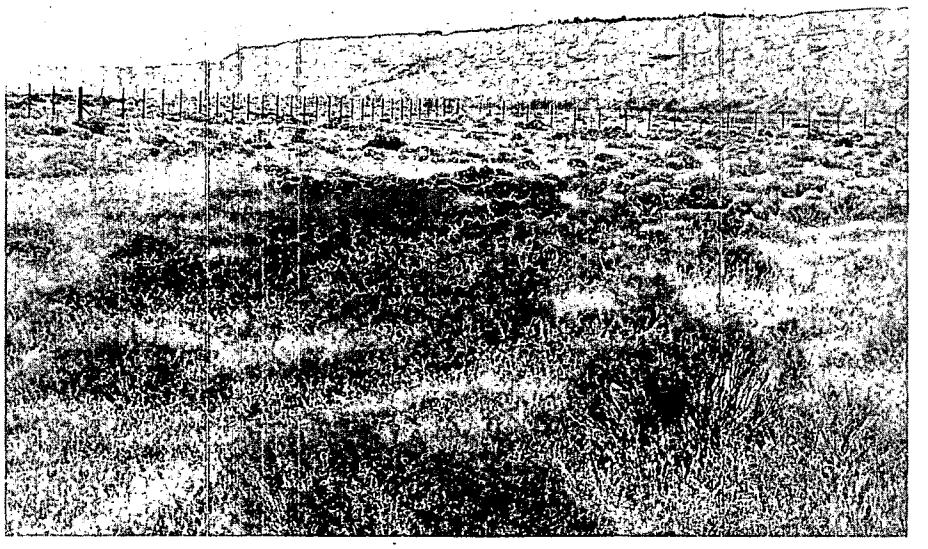


FIGURE 3. Waste Burial Site No. 4. Annual grasses, annual forbs, and shrubs are present.

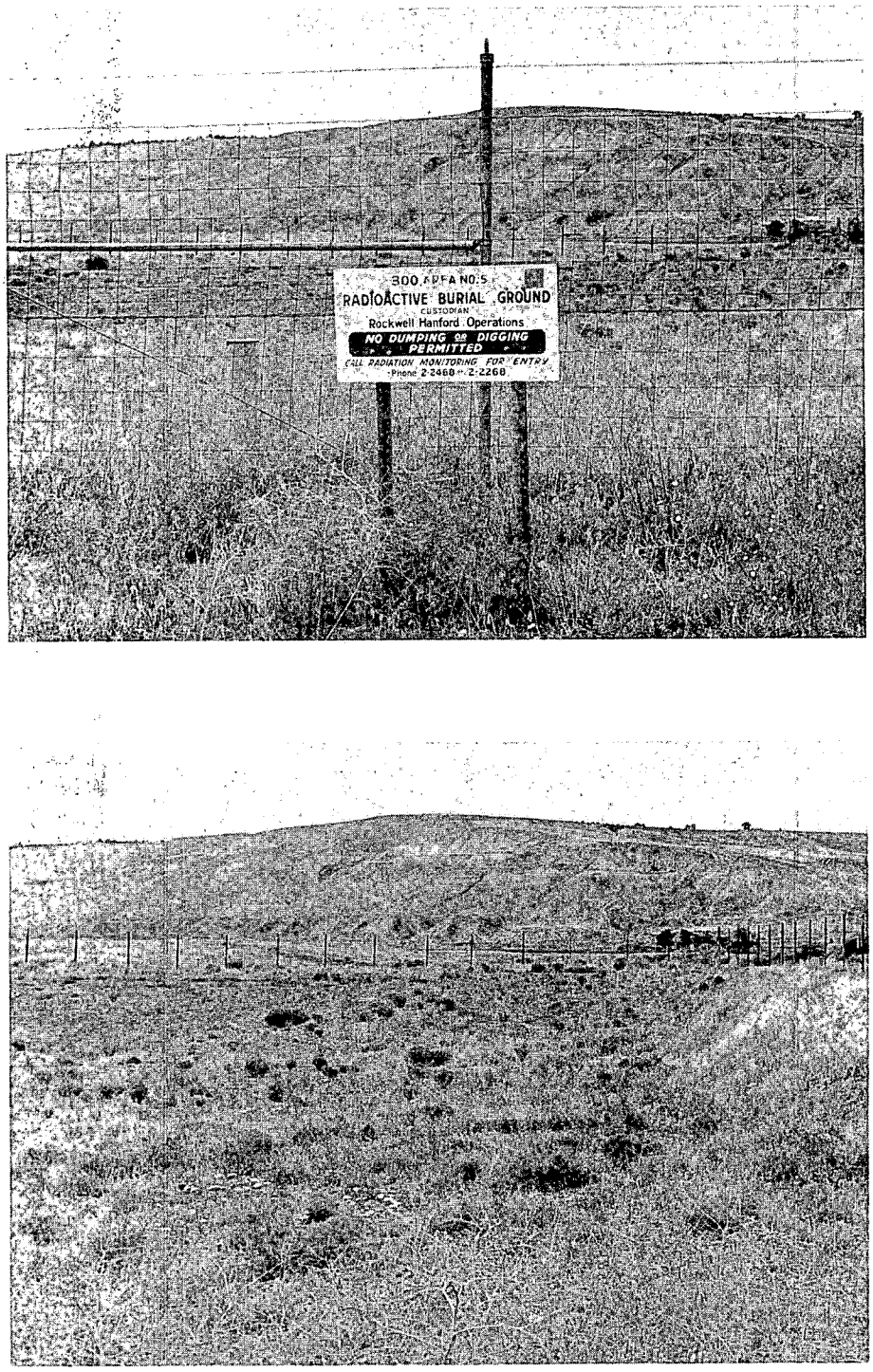
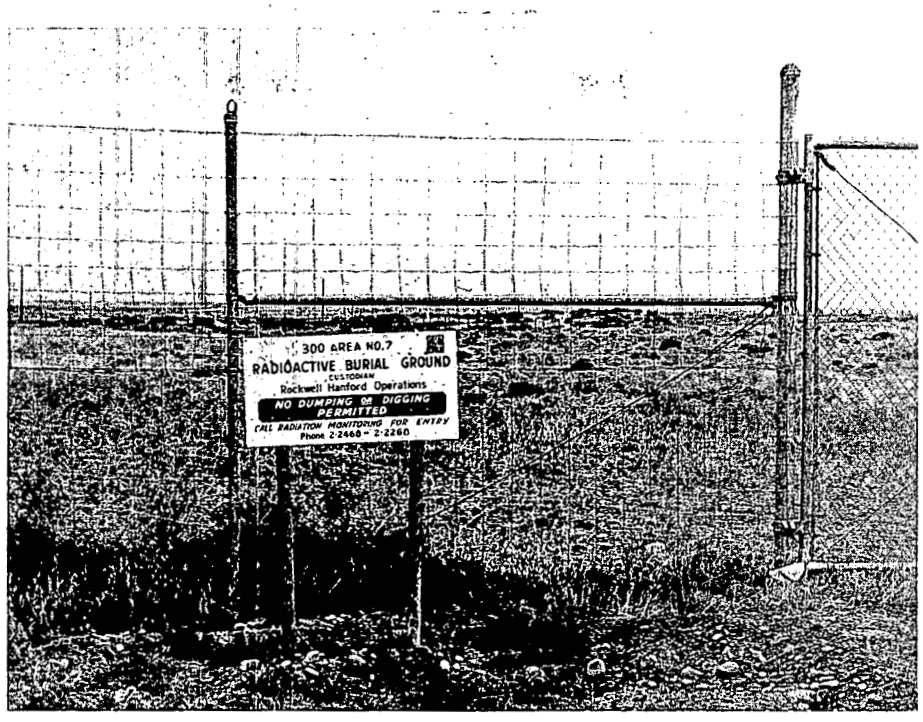


FIGURE 4. Waste Burial Site No. 5. The annual deep-rooted forb, Salsola kali, dominates the canopy cover on this burial site.



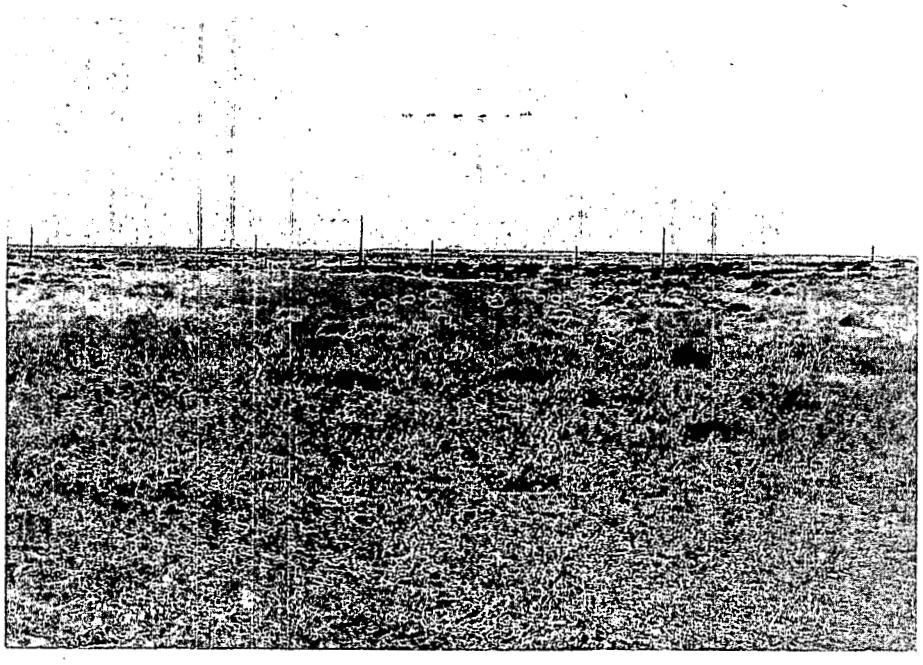


FIGURE 5. Waste Burial Site No. 7. Annual grasses and annual forbs are present, but there is no invasion by shrubs.

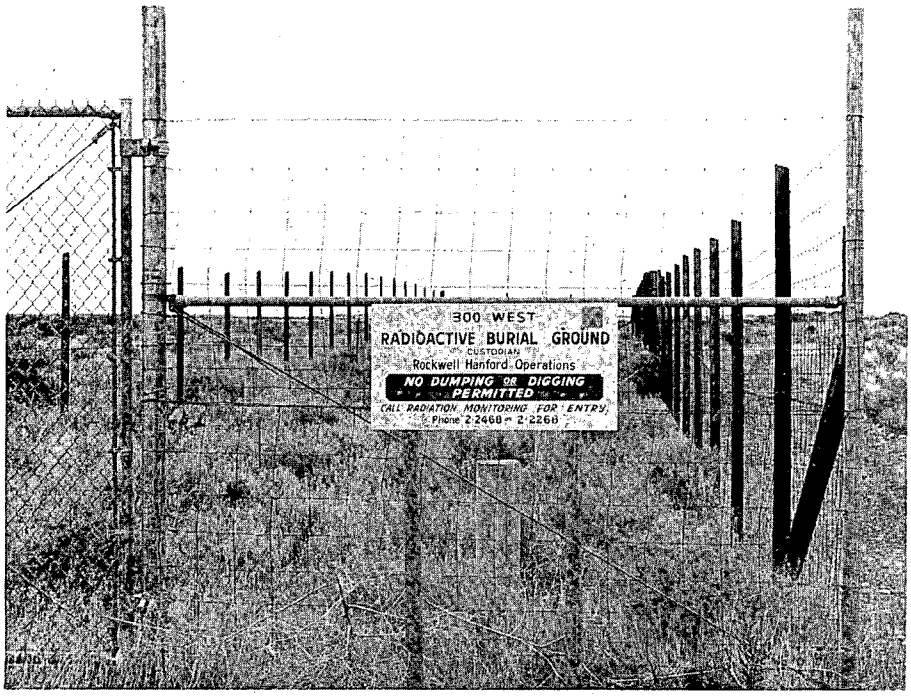
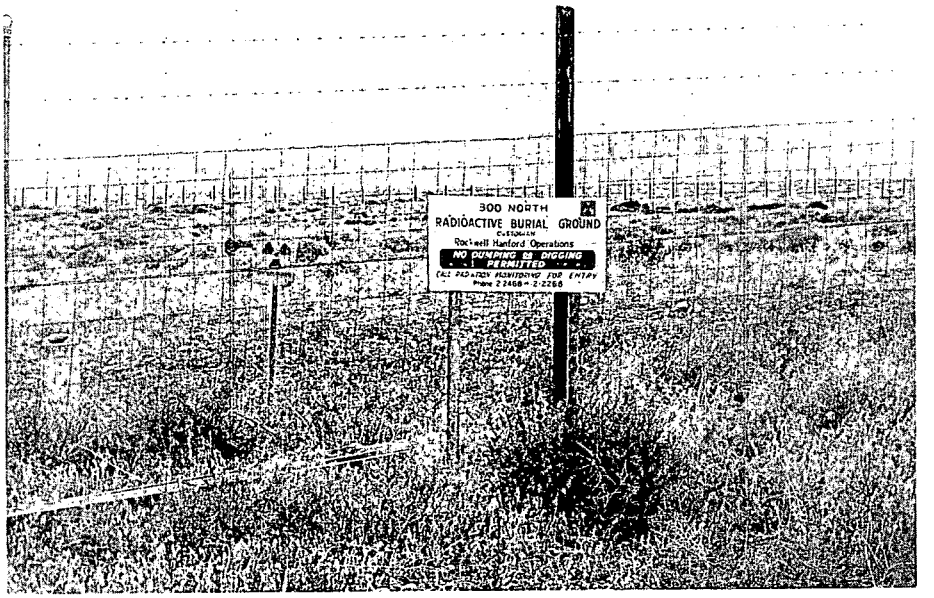


FIGURE 6. 300 W Burial Site. Annual grasses and shrubs dominate the canopy cover in this burial site.



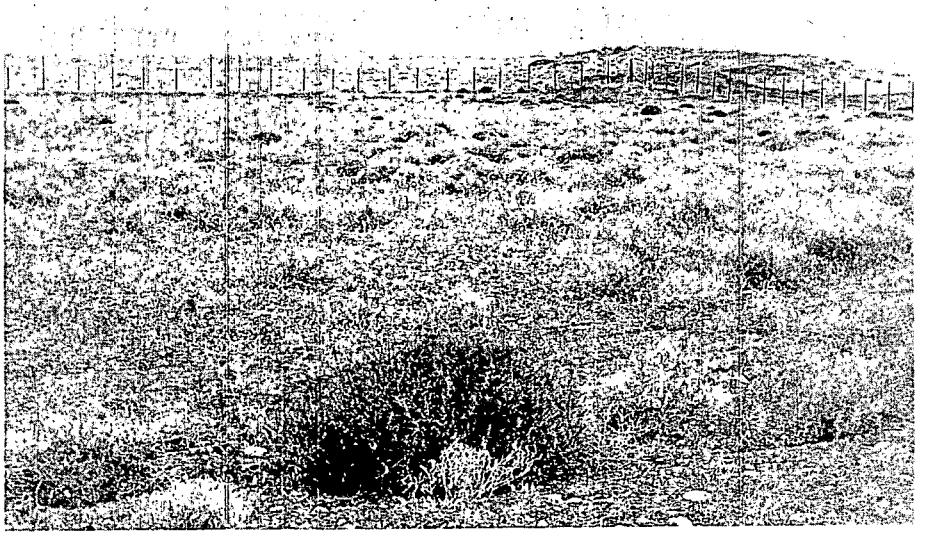


FIGURE 7. 300 N Burial Site. Shrubs are noticeably absent on this burial site.

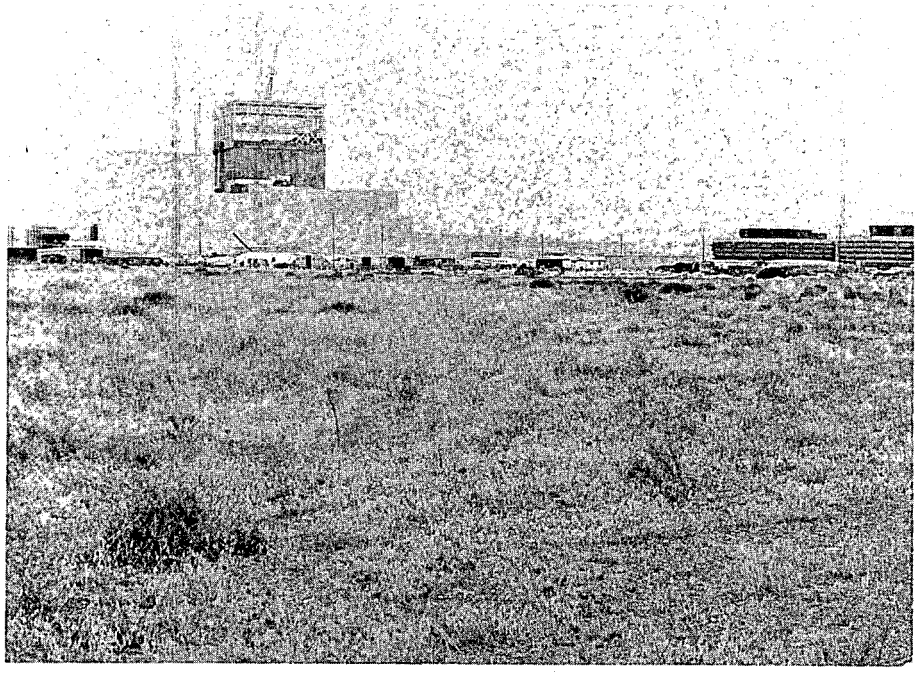


FIGURE 8. 300 WYE Burial Site. Annual forbs, and annual grasses dominate the vegetation composition.

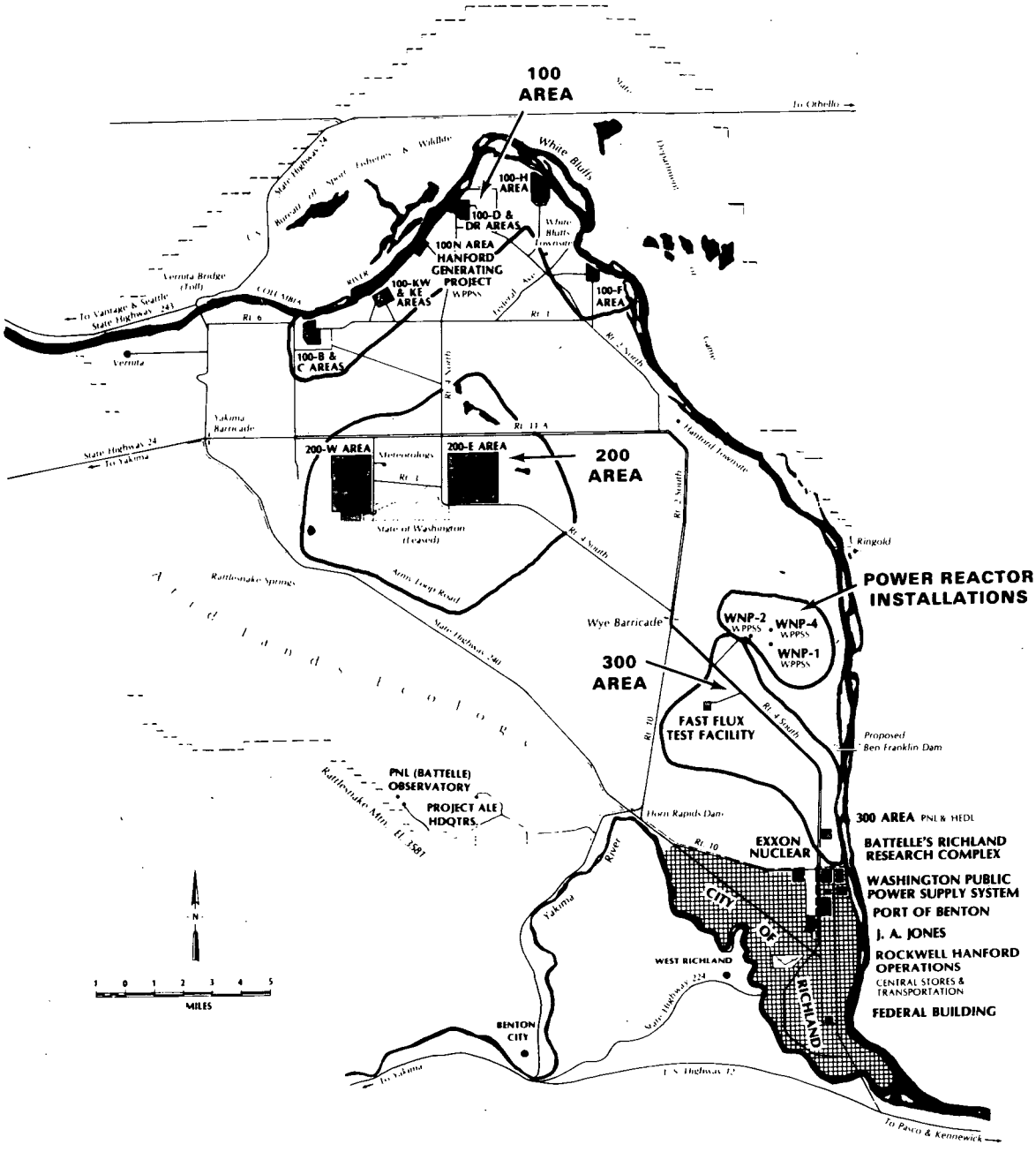


FIGURE 9. General Locations of Ecological Study Sites on the Hanford Site

VEGETATION STUDIES

Vegetative cover plays an important role on retired burial grounds. It serves as a way to reduce soil erosion by wind and water, thereby helping to maintain sufficient depth of backfill over buried material. Vegetation can play an important role in helping to prevent rainfall from percolating deeply into burial ground backfill by returning meteoric soil water to the atmosphere via leaf transpiration. Water returned to the atmosphere is not available to percolate through buried waste with a potential to move to ground water. Vegetative cover in addition to providing a practical use also can be more aesthetic than artificial wind erosion covers such as asphalt or concrete.

Annual grasses, annual forbs, perennial grasses, perennial forbs, and shrubs are the five categories of vascular plants growing on portions of the 300 Area Burial Grounds (Tables 3 and 4). Cheatgrass, *Bromus tectorum*, an annual, is the most important single contributor to plant canopy cover. There are more taxa (species) of annual forbs than any other category and collectively they contribute substantially to total plant canopy cover. Perennial grasses are scarce and provide little canopy cover. Perennial forbs are represented by five species but provide very little in the way of canopy cover. The two shrub species encountered in the study transects are snowy eriogonum, *Eriogonum niveum* and rabbitbrush, *Chrysothamnus nauseosus*.

Total canopy cover varied from 8 to 76% and averaged 39% over all burial grounds in 1976. In 1977 total canopy cover on Burial Grounds No. 7, 300 North, and WYE varied from 42 to 68%. Cline et al. (1977) reported canopy cover for undisturbed soil at 56% elsewhere on the Hanford Site. The herbaceous canopy cover provided by cheatgrass and by annual forbs will vary greatly from year to year depending upon weather, but the perennial forbs and shrub cover would not change greatly from one year to the next. Canopy cover could increase dramatically over a 10- to 20-year period if shrub seedlings become established and grow to maturity on the backfill.

TABLE 3. Canopy Cover (percent) and Species Composition of the Vegetative Cover on 300 Area Burial Grounds

Taxa	Burial Ground Designation										Fidelity
	West	#5	#3	North	#7a	#7b	#4	2	WYEa	WYEb	
Annual Grasses											
Bromus tectorum	29	0.8	39	4.7	9.1	9.9	20	24	43	13	100
Festuca sp.	1.2	0	1.2	0.1	0.5	T	T	1.0	0	1.8	80
Total Ann. grasses $\bar{x}$ = 20%	30.0	0.8	40.0	4.8	9.6	9.9	20	25	43	15	
Annual Forbs											
Draba verna	2.4	0.7	2.2	5.3	2.2	2.5	3.1	3.2	2.5	1.2	100
Holosteum umbellatum	2.7	0.8	13	0.5	3.6	2.6	17	3.8	5.0	6.7	100
Salsola kali	0.1	3.8	1.4	3.5	3.8	1.8	0.2	1.7	0.4	2.3	100
Erodium cicutarium	0.5	0	3.6	0	0	0	0	T	0	0	30
Cryptantha circumscissa	0.6	0	0	T	1.2	0.3	0	0.3	1.5	0.6	70
Sisymbrium altissimum	0.5	2.1	T	1.0	2.0	9.3	0.4	0.5	2.5	0.5	100
Amsinckia lycopsoides	0	0	0	0	0.4	0	0	0	1.9	0	20
Lepidium sp.	0	T	0	0	0	0	0	0	1.3	T	30
Lactuca sp.	0	0.5	0	0	0	0	0	0	0	0	10
Plantago patagonica	0	0	0.1	0	0	0	0	0	0	0	10
Ambrosia acanthicarpa	0	0	0.1	0.7	0.4	0	0.1	0.6	0.1	0.2	70
Microsteris gracilis	0	0	0	0.1	0.2	0	0	0	1.0	0.7	40
Descurainia pinnata	0	0	0	0.1	0.2	0	0	0	0.2	0.3	40
Myosurus aristatus	0	0	0	0	0.1	0	0	0	0	0	10
Cryptantha pterocarya	0	0	0	0	0.2	0	0	0.1	0.1	0	30
Total Ann. forbs $\bar{x}$ = 13%	6.8	7.9	20.0	11.0	14.0	16.0	21	10.0	16.0	12.0	
Perennial Grasses											
Poa sandbergii $\bar{x}$ = 0.1%	0	0	0.8	0	0	0	0	0.1	0	0.1	30
Perennial Forbs											
Psoralea lanceolata	0.7	0	0	0	0	0	0	0	0	0	10
Phlox longifolia	0.2	0	0.2	0.2	0.1	0.2	0.1	0.3	0.6	1.1	90
Aster canescens	0	0	0.7	0	0	0	0	0	0	0	10
Rumex venosus	0	0	0	0	0	0	0	0	0	0.1	10
Astragalus sp.	0	0	0	0	0	0	0	0	0	0.8	10
Total Pern. forbs $\bar{x}$ = 0.6%	0.9	0	1.7	0	0.1	0.2	0.1	0.4	0.6	2.1	
Shrubs											
Eriogonum niveum	0.1	0	0	0	0.9	0	17.9	0.2	0	0	40
Chrysothamnus nauseosus	13.5	0	15.4	0	0	0	0.3	6.9	0	0	40
Total Shrubs $\bar{x}$ = 5.5%	14.0	0	15.0	0	0.9	0	18.0	7.1	0	0	
Total Canopy Cover	52	8.7	77	16	25	26	59	42	60	29	

T = Trace, #7a and #7b = two transects, WYEa and WYEb = two intersects

TABLE 4. 300 Burial Ground Mammal Trapping Plot
1978 Percent Cover

	No. 7				
	Line 1	Line 2	Line 3	Line 4	Mean
Annual Grasses					
Bromus tectorum	42.7	32.4	13.8	27.4	29.1
Festuca octoflora	0.4	0.4	0	0.4	0.3
Total Ann. grasses $\bar{x}$ =	43.1	32.8	13.8	27.8	29.4
Annual Forbs					
Salsola kali	2.1	2.4	1.8	2.3	2.2
Holosteum umbellatum	4.1	2.5	2.2	4.4	3.3
Sisymbrium altissimum	1.5	2.6	1.7	6.6	3.1
Cryptantha circumcissa	0.5	0	1.4	0	0.5
Draba verna	0.9	0.3	0.3	0.7	0.6
Descurainia pinnata	0.2	0	0.1	0.3	0.2
Cryptantha pterocarya	0	0.4	0.2	0.3	0.2
Ambrosia acanthicarpa	0	0.2	1.9	0.4	0.6
Polemonium micranthum	0	0	0	0.1	T
Plantago patagonica	0	0	0	0.2	0.1
Erodium cicutarium	0	0	0	4.7	1.1
Microsteris gracilis	0	0	0	0.1	T
Total Ann. forbs $\bar{x}$ =	9.3	6.4	9.6	20.1	11.9
Perennial Forbs					
Oenothera pallida	0	0	1.6	0	0.4
Brodiaea douglasii	0	0	0.4	0	0.1
Total Pern. forbs $\bar{x}$ =	0	0	2.0	0	0.5
Shrubs					
Artemesia tridentata	0	0	0	0.1	T
Eriogonum niveum	0.5	0.2	0.2	0.2	0.3
Total shrubs $\bar{x}$ =	0.5	0.2	0.2	0.3	0.3
Total Canopy Cover	53	39	26	48	42

TABLE 4. (contd)

	North				
	Line 1	Line 2	Line 3	Line 4	Mean
Annual Grasses					
Bromus tectorum	22.2	8.7	69.0	26.5	31.6
Festuca octoflora	0	0	0	0.2	0.1
Total	22.2	8.7	69.0	26.7	31.7
Annual Forbs					
Salsola kali	2.6	2.5	8.0	2.5	3.9
Holosteum umbellatum	1.0	2.4	1.1	2.9	1.9
Sisymbrium altissimum	0.3	0	2.1	1.7	1.0
Cryptantha circumcissa	0.9	0	0	0	0.2
Draba verna	2.2	2.5	1.8	1.6	2.0
Descurainia pinnata	0.2	0.7	0.1	0	0.3
Cryptantha pterocarya	0.1	0	0	0	T
Ambrosia acanthicarpa	0.4	0.2	0	0.1	0.2
Microsteris gracilis	0	0.2	0.2	0.1	0.1
Total	7.7	8.5	13.3	8.9	9.6
Perennial Forbs					
Oenothera pallida	2.3	0.8	0	0	0.8
Epilobium paniculatum	0	0	0	0.1	T
Total	2.3	0.8	0	0.1	0.8
Shrubs					
Eriogonum niveum	2.0	0.4	0	0	0.6
Total Canopy Cover $\bar{x}$ =	34	18	82.3	36	42

TABLE 4. (contd)

	WYE Control				
	Line 1	Line 2	Line 3	Line 4	Mean
Annual Grass					
Bromus tectorum	38.7	34.6	38.7	22.4	33.6
Festuca octoflora	0.1	0.1	1.3	0.1	0.4
Total	38.8	34.7	40.0	22.5	34.0
Perennial Grass					
Poa sandbergii	9.1	5.2	4.4	1.8	5.1
Annual Forbs					
Salsola kali	2.6	4.2	2.5	5.9	3.8
Ambrosia acanthicarpa	0.3	0.8	0.1	0.7	0.5
Sisymbrium altissimum	6.8	3.7	7.2	6.7	6.1
Microsteris gracilis	1.2	1.7	1.0	1.6	1.4
Draba verna	1.5	4.3	2.8	1.3	2.5
Polemonium micranthum	2.5	6.1	0.9	1.0	2.6
Descurainia pinnata	0.5	1.0	0.4	1.3	0.8
Holosteum umbellatum	2.2	0.3	0.1	1.0	0.9
Plantago patagonica	0.1	1.9	0	0.5	0.6
Cryptantha pterocarya	0	0.1	0.1	0.4	0.1
Cryptantha circumcissa	0	0.1	0.1	0	T
Amsinckia lycopsoides	0	0	0.1	0	T
Erodium cicutarium	0	0	0	4.3	1.1
Total	17.7	24.2	15.3	24.7	20.4
Perennial Forbs					
Rumex venosus	0.9	0.2	0	2.1	0.8
Brodiaea douglasii	1.0	1.1	1.5	1.1	1.1
Oenothera pallida	0.1	0.9	1.0	0.9	0.7
Phlox longifolia	0	0.1	0	0	T
Cymopterus terebinthinus	0	1.3	0	0	0.3
Epilobium paniculatum	0	0	0	0.2	T
Achillea millefolium	0	0	0	1.9	0.5
Total	2.0	3.6	2.5	6.2	3.4
Shrubs					
Eriogonum niveum	0	0.1	0	0	T
Total Canopy Cover	67	68	62	55	63

Several plant species have a high affinity for burial ground backfill as indicated by 100% fidelity (occurring on all burial sites) (Table 3). These are Bromus tectorum, cheatgrass; Draba verna, spring draba; Holosteum umbellatum, jagged chuckweed; Salsola kali, Russian thistle; and Sisymbrium altissimum, tumble mustard. All of these weeds were introduced to North America from Eurasia.

CHEMICAL AND PHYSICAL PROPERTIES OF SURFACE SOIL

The chemical and physical properties of the surface soil are of importance to the establishment of plants because seeds are usually confined to a few millimeters of the surface. The seedling stage of development is the critical stage of the life cycle. Seedlings are vulnerable to heat and drought and to the abrasive action of sand particles during wind storms as well as predation by rodents and insects that also reside in the soil.

The soil pH in the 300 Area Burial Grounds is neutral or slightly alkaline, which indicates that soil is well within the range of growth tolerances of most plants (Table 5). The low soluble salts indicate that salt concentration is not a factor to be considered as far as inhibiting plant growth. Furthermore, the sandy soil texture indicates a susceptibility to wind erosion, low water retention capacity and poor mineral nutrition.

RADIONUCLIDE ANALYSIS OF PLANTS GROWING ON BURIAL GROUNDS

Leaf and stem tissues from various species were collected, dried, and analyzed for ^{137}Cs by gamma spectroscopy. Plants were collected on backfill and also from adjacent soil outside the burial grounds. Shrubs, perennial forbs and annuals were collected and analyzed (Table 6). Three shrubby plants growing outside burial ground exclosures had amounts of ^{137}Cs at levels identifiable as derived from worldwide fallout originating from nuclear explosions ($\bar{x}$ = 0.85 pCi/g). Of the samples collected within the burial sites, only two had detectable levels. One sample of cheatgrass had 9 pCi/g of ^{137}Cs which may have been derived in part from burial ground operations such as a

TABLE 5. Physical and Chemical Characteristics of Surface Soil (0-1) dm on 300 Area Burial Grounds

	WYE	North	West	#2&3	#4	#5	#6&7	Average
% Sand	68.5	63.5	68.5	82.5	72.7	80.7	79.5	73.7
% Silt	21.5	28.5	25.7	12.2	23.4	16.4	17.9	20.8
% Clay	10.0	8.0	5.8	5.3	3.9	2.9	2.6	5.5
Soil Type*	SaLo	SaLo	SaLo	LoSa	LoSa	LoSa	LoSa	---
pH	8.0	7.1	7.5	7.8	8.0	8.5	8.3	7.9
mmhos/cm sol. salts	0.25	0.34	0.25	0.33	0.32	0.25	0.26	0.29

*Textural class SaLo = sandy loam, LoSa = loamy sand.

TABLE 6. Radionuclide Analysis (gamma scan) for ^{137}Cs in Plant Tissues Collected from 300 Area Burial Grounds and from Adjacent Land

Taxa	Burial Ground Designation							Adjacent Land	
	North	2&3	4	5	6&7	West	WYE	West	WYE
Shrubs									
Eriogonum niveum	NS	-	NS	-	NS	-	*300 pCi/g	*1.07	-
Chrysothamnus nauseosus	NS	-	NS	NS	NS	NS	-	NS	NS
Lycium halmilifolium	-	NS	-	-	-	-	-	-	-
Purshia tridentata	-	-	NS	-	NS	NS	-	*0.2	-
Artemisia tridentata	-	-	-	-	-	NS	NS	*0.5	-
Chrysothamnus viscidiflorous	-	-	-	-	-	-	-	NS	-
Perennial Forbs									
Aster canescens	-	NS	NS	NS	NS	NS	NS	-	NS
Achillea millifolium	NS	NS	-	-	-	-	-	-	-
Annuals									
Bromus tectorum	NS	NS	NS	NS	NS	NS	*9.4	-	-
Ambrosia acanthicarpa	NS	NS	-	NS	NS	NS	NS	-	-
Salsola kali	NS	NS	-	NS	-	NS	NS	NS	NS
Sisymbrium altissimum	NS	NS	NS	NS	NS	NS	-	-	-
Amsinckia lycopsoides	NS	NS	-	NS	NS	NS	-	-	-

NS = Count not statistically significant. - = no sample taken
*pCi/g dry wt.

surface soil contamination. One sample of snowy buckwheat had 300 pCi/g ^{137}Cs, which indicates that the plant's roots may have penetrated buried waste. In previous studies elsewhere on the Hanford Site, Klepper et al. (1975) observed that rabbitbrush contacted ^{137}Cs at least 8 ft (2.7 m) below the ground surface. The ability of deep-rooted plants to reach buried wastes indicates that plants with shallow-rooted systems would be advisable as vegetative cover for burial sites. However, additional research is needed to determine the optimal cover.

SECONDARY PLANT SUCCESSION

The self-reestablishment of vegetation on disturbed ground follows a more or less predictable pattern. Early plant invaders are annuals that are copious seed producers with efficient seed dispersal mechanisms. These annual plants over time are replaced or suppressed in abundance by perennial species that occupy the ground indefinitely unless they in turn are destroyed by man, fire or disease. This assemblage of mostly perennial species is the stable or "climax" plant community. The climax species of the 300 Area are believed to be sagebrush, *Artemisia tridentata*, and bitterbrush, *Purshia tridentata*. The time required for these shrubs to reinvade disturbed ground can be very long. Abandoned agricultural fields in the Hanford Site have not been invaded by shrubs even after 35 years. It is expected that sagebrush and bitterbrush will be slow to reinvade 300 Area Burial Ground backfill because of the general absence of nearby seed sources (parent plants). This is a desirable vegetal feature since shrubs are not regarded as desirable species on shallow burial grounds because of their deep root systems.

ANIMAL STUDIES

Several species of animals were characterized in terms of both burrowing and nonburrowing activities.

ANTS

Burrowing activities have long been known to result in the pulverization, granulation and transfer of soil between soil layers (Buckman and Brady, 1979). Soil transfer is of particular interest for the 300 Area Burial Grounds. Ants were studied to provide a preliminary assessment concerning what effects, if any, they might have while living within the fenced exclosures of the 300 Area Burial Grounds.

The ant population was characterized by searching out colonies and by collecting specimens attracted to baits. Bait stations and searches were conducted on two separate dates during both morning and afternoon periods for the No. 7 Burial Ground. Species actually occupying this burial ground were *Solenopsis molesta* and *Pogonomyrmex owyheei*. Two additional species, *Formica subpolita* and *Formica manni*, were collected from areas adjacent to the exclosure but were not found on the burial ground itself.

Solenopsis molesta is very small (∿1.3 mm) and is scarce on the 300 Area Burial Grounds. They are generally regarded to be thief ants, constructing their colonies near those of other larger species and pilfering food from them. Most of the foraging of *Solenopsis* takes place below ground. They frequently construct their nests beneath rocks or pieces of debris. Wheeler and Wheeler (1963) reported that *Solenopsis molesta* constructs nests in North Dakota that extend to a maximum depth of 12.7 cm. Therefore, the occurrence of this ant species on 300 Area Burial Grounds should not affect the isolation of the wastes.

Formica manni and *F. subpolita* are both approximately 4.5 mm in length. *Formica manni* is restricted to sandy or gravelly locations in the semi-arid regions of the West. They tend to construct their nests beneath stones.

Little is known about the nest construction habits of F. subpolita or F. manni, but the low density of specimens collected near burial zones probably precludes any impact from their activities on waste sites.

Pogonomyrmex owyheei, a harvester ant, is the dominant ant at lower elevations at Hanford. These ants are relatively large (5.6 mm) and their habit of invading disturbed soil (Wheeler, 1963) makes their inhabitance of the 300 Area Burial Grounds of particular interest. Colony densities were obtained for Pogonomyrmex owyheei from several burial grounds since it was the only species found to be abundant within the 300 Areas. Results are shown in Table 7 for equivalent sized areas located within and adjacent (control) to the burial grounds. Clearly, harvester ants prefer to establish their colonies within disturbed areas such as the 300 Area Burial Grounds.

TABLE 7. Pogonomyrmex owyheei Colony Densities in Burial Grounds

Location	Total Number Colonies	
	Inside Exclosure	Control
WYE	358	90
300-North	86	38
300- 7	244	8
300-West	0	0
300-4	20	15
TOTAL	708	141

The nest construction habits of harvester ants, Pogonomyrmex sp., are much better known than for other ant species. Table 8 summarizes the reported tunneling depths for various species of the harvester ants and shows a range of maximum tunneling depths extending from 2.0 to 3.0 m.

Soil Transport

There are only a few estimates in the literature concerning the amount of soil ants can move to the surface. Lyford (1963) studied the importance of ants in soil genesis in New England and estimated that 50 g/yd^2 were brought to the surface each year. The ant, Lasius neoniger Emery, brought 86 g/m^2

TABLE 8. Harvester Ant Maximum Tunneling Depths

Harvester Ant Species	Maximum Depth	Location	Reference
P. owyheei	2.4 m	Central Oregon	Willard, 1964
P. californicua	2.0 m	California	Erickson, 1972
P. occidentalis	3.0 m	Kansas	Headlee and Dean, 1908
P. occidentalis	2.4 m	South Dakota	Severin, 1955
P. occidentalis	2.3 m	Wyoming	Lavigne, 1969

of soil to the surface in an old field in Michigan. A species of ant in eastern Algeria was observed to bring 295.7 g of soil to the surface in 34 days (Pickles, 1944).

The total amount of soil excavated by the harvester ant, P. occidentalis, was estimated to average 3.8 kg over the life of the colony in eastern Colorado (Rogers, 1972). This estimate was based on the volume of soil excavated from tunnels and chambers (2000 cm^3) and bulk density of the soil (1.4 g/cm^3). Recent excavations at Hanford indicate a similar volume of soil excavated by P. owyheei.

Extrapolating soil volume estimates from Table 9 with colony densities shown in Table 7 permits an estimation of total soil movement (Table 10). About 11% of this soil is moved from depths greater than 1.5 m. This means that the harvester ant colonies located on the WYE Burial Ground move about 8.4 kg of soil material each year from depths exceeding 1.5 m. Clearly, harvester ants possess the potential for moving small particles of contaminated material to the surface where it could be further distributed by wind and by biota. Burial procedures could probably be developed to make the 300 Area Burial Grounds less attractive to harvester ants, but at the present time the only means of preventing their possible movement of contaminated soil particles would be through chemical control. Control of harvester ants through pesticide applications has not been particularly successful in the past.

TABLE 9. Maximum Depths and Volumes of Soil Excavated by Five *P. owyheei* Colonies

Colony	Amount (cm^3)	Maximum Depth (m)
1	2468	2.7
2	3147	2.5
3	1518	2.5
4	713	2.0
5	1027	1.7
$\bar{x} \pm$ S.E.	1774 ± 453	2.3 ± 0.2

TABLE 10. Total Soil Movement by Harvester Ants on 300 Area Burial Grounds

Burial Ground	Soil Movement/year(1) Volume (cm^3)	Mass (kg)(2)
WYE	63,509	76.2
300 North	15,256	18.3
300 6 and 7	42,286	51.9
300-West	0	0
300-4	3,548	4.3
TOTAL	125,599	150.7

(1) Assumes colony life span = 10 years

(2) Assumes soil bulk density = 1.2 g/cm^3

REPTILES AND AMPHIBIANS

General studies of reptile and amphibian populations associated with the 300 Area burial sites were conducted. A survey path immediately adjacent to each burial ground studied (Table 2) was walked during two mornings in each of the months of March, April, May, June, and July, 1978, and all reptiles observed were recorded to species. Table 11 lists the species encountered at the four study sites.

TABLE 11. Reptiles Observed at 300 Area Burial Sites

Species	Burial Site 4	7	300 North	300 WYE
Western Yellow-bellied Racer (*Coluber constrictor*)	X		X	X
Gopher Snake (*Pituophis melanoleucus*)		X		X
Side-blotched Lizard (*Uta stansburiana*)				X X
Sagebrush lizard (*Sceloporus graciosus*)	X	X	X	

Amphibians were never observed during the burial site studies. The western toad, *Bufo boreas*; Woodhouse's toad, *Bufo woodhouseii*; and Great Basin spadefoot toad, *Scaphiopus intermontanus*, may occasionally use burial sites, but these animals are generally associated with moist riparian habitats rather than dry sites such as the burial grounds.

All of the burial sites are used by reptiles for feeding and reproduction. Reptiles, particularly lizards, may be the most important carnivorous consumer group associated with the burial sites. Studies conducted in habitats on Hanford sites similar to the 300 Area habitats indicate that the side-blotched lizard, *Uta stansburiana*, is the most abundant lizard in the big sagebrush/cheatgrass association, while the sagebrush lizard, *Sceloporus graciosus*, is dominant in sandy areas supporting mostly antelope bitterbrush, *Purshia tridentata*, and cheatgrass. Biomass estimates of between 52.5 and 87.5 g of lizard per hectare are reported for the Hanford Site (Rogers and Rickard, 1977). Of the burial sites studied, No. 4, 7 and 300 N are located in sandy areas where *Purshia* is the dominant shrub. These burial sites were the locations of all *Sceloporus* sightings. The WYE Burial Ground situated in sagebrush dominated habit contained no *Sceloporus* but did provide observations of *Uta*.

The only snakes observed at the 300 Area Burial Grounds were the western yellow-bellied racer, Coluber constrictor, and gopher snake, Pituophis melanoleucus, (Table 11). Studies conducted on the Hanford Site in areas similar to 300 Area habitats indicate that these two species are the most common snakes. Since these two snakes feed mostly on mice and lizards, they occupy a trophic level higher than the insectivorus lizards.

Even though only four species of reptiles were observed on or adjacent to the 300 Area Burial Grounds, a number of other cold-blooded vertebrates may occur there. Table 12 provides a list of all of the reptiles and amphibians of the Hanford Site and indicates their relative abundance and habitat preferences.

Since lizards and snakes associated with the burial sites are carnivores, they may be valuable indicators of the bioavailability of radionuclides in local ecosystems. Unlike birds and many mammals, most reptiles are sedentary in nature and seldom move more than a few kilometers in their lifetimes (Fitch, 1949; Hirth et al., 1969). Any radionuclides found in individuals living on or adjacent to a burial site would therefore provide an indication that the source of radionuclides was the burial site itself. For example, burrows or crevices formed from caveins may provide pathways to buried waste and serve as hibernation sites for lizards.

Reptiles associated with burial sites can also serve as vectors of radioactivity. For example the Swainson's hawk, Buteo swainsoni, feeds heavily on snakes. Table 13 provides a list of the reptilian and other prey species consumed by Swainson's hawks on the Hanford Site (Fitzner, 1978).

Since burial sites are open above, hawks can freely catch and remove reptile prey from the area. Tall fence posts surrounding each burial site tend to attract hunting raptors by providing hunting perches and would increase the opportunity for the top consumer hawks to capture prey associated with burial sites. After capturing the prey item, the raptor may take it to its nest to feed young hawks. These nest sites would therefore be useful spots to monitor for evidence of radionuclide transport by birds of prey. All of the burial grounds on the Hanford Site are frequented by birds of prey. If contaminated prey are present on the burial sites, a raptor can be expected to consume it

TABLE 12. Amphibian and Reptile Species Occurring on the Hanford Site

Common Name	Scientific Name	Occurrence[a]	Habitats[b] Utilized
Amphibians			
Great Basin Spadefoot	*Scaphiophus intermontanus*	U	R + S + P
Western Toad	*Bufo boreas*	U	R
Pacific Treefrog	*Hyla regilla*		R
Reptiles			
Sagebrush Lizard	*Sceloporus graciosus*	U	P
Side-blotched Lizard	*Uta stansburiana*	C	S
Pigmy Short-horned Lizard	*Phrynosoma douglassi*	U	P + S
Striped Whipsnake	*Masticophis taeniatus*	U	P + S
Western Yellow-bellied Racer	*Coluber constrictor*	C	P + S
Gopher Snake	*Pituophis melanoleucus*	C	P + S
Desert Night Snake	*Hypsiglena torguata*	R	B
Northern Pacific Rattlesnake	*Crotalus viridus*	C	R + B + S + P
Reptiles and Amphibians which may occur on the Hanford Site but sightings have not yet occurred			
Long-toed Salamander	*Ambystoma macrodactylum*		
Tiger Salamander	*Ambystoma tigrinum*		
Woodhouse's Toad	*Bufo woodhousei*		
Leopard Frog	*Rana pipiens*		
Bullfrog	*Rana catesbeiana*		
Painted Turtle	*Chrysemys picta*		
Western Fence Lizard	*Sceloporus occidentalis*		
Western Skunk	*Eumeces skiltonianus*		
Common Garter Snake	*Thamnophis sirtalis*		
Western Terrestrial Garter Snake	*Thamnophis elegans*		

(a) U = Uncommon, C = Common, R = Rate

(b) R = Riparian, B = Basalt outcroppings, S = Sagebrush dominated areas, P = Purshia dominated areas.

and distribute the radionuclides contained in the prey organism away from the burial site. This vector for radionuclide removal can be eliminated by ensuring that prey organisms do not come in contact with buried waste.

TABLE 13. Food Habits of Swainson's Hawks on the Hanford Site (Prey Fed to Young Hawks by Parent Birds) - 1973-76

Species	Number	% Frequency
Mammals		21.8
Black-tailed Hare (*Lepus californicus*)	11	6.5
Nuttall's Cottontail (*Sylvilagus nuttallii*)	8	4.7
Townsend's Ground Squirrel (*Spermophilus townsendii*)	8	4.7
Pocket Gopher (*Thomomys talpoides*)	3	1.8
Pocket Mouse (*Perognathus parvus*)	5	2.9
Unidentified small mammal	2	1.2
Birds		14.6
Magpie (*Pica pica*)	4	2.4
Mallard (*Anas platyrhynchos*)	4	2.4
Meadowlark (*Sturnella neglecta*)	5	2.9
Pheasant (*Phasianus colchicus*)	2	1.2
Sage Sparrow (*Amphispiza belli*)	2	1.2
Ring-billed Gull (*Larus delawarensis*)	6	3.5
Long-billed Curlew (*Numenius americanus*)	1	0.5
Starling (*Sturnus vulgaris*)	1	0.5
Reptiles and Amphibians		63.6
Western Yellow-bellied Racer (*Coluber constrictor*)	86	50.6
Gopher Snake (*Pituophis melanoleucus*)	18	10.6
Whipsnake (*Masticophis taeniatus*)	2	1.2
Western Toad (*Bufo boreas*)	2	1.2
	N = 170	

SMALL MAMMALS

The purpose of the mammal study was to characterize the small mammal populations inhabiting three of the 300 Area Burial Grounds. The study was also directed at determining gamma exposure rates, if any, to the mice living in these areas. This was accomplished using dosimeter implantation techniques. An animal having an exposure above normal background level could be assumed to have come within close proximity to a gamma radiation source; in this case buried wastes.

Tissue samples were also taken from representative small mammal species and analyzed for ^{137}Cs to provide an indication of the potential transfer from burial grounds to small mammals. The determination of the presence or absence of radionuclides is important when considering their transfer to higher trophic levels (ERDA, 1975).

Four study sites were selected including three retired burial grounds and one control site located in a similar habitat. The burial grounds studied were WYE Burial Ground, 300 North, and 300 Area Burial Ground No. 7. The control site was established approximately 1/2 mile west of the WYE Burial Ground in an area previously burned by fire. The vegetation and soil depth there are very similar to the burial grounds.

On each of the study sites a trap grid containing 100 Sherman live traps was established. The traps were spaced at 10-m intervals in a 10 x 10 grid pattern. Each trap was placed inside a sheet metal can slightly larger than the trap and covered with a sheet metal tent (Figure 10). This covering was to help protect against overheating while the animals were confined. Batting was placed in each trap for nesting material and the traps were baited at the entrance of each trap. Each trapping session was normally 3 consecutive days.

FIGURE 10. Sherman Live Traps Used to Capture Small Mammals

When an animal was captured for the first time, it was given an individual identification number using a series of toe amputations. The data collected included the trap location, species, sex, identification number, reproductive condition, relative age, and weight. In addition, each animal was surgically implanted with a dosimeter packet, 7 mm x 10 mm, containing 2 LiF dosimeters. The animals were anesthetized while the packet was inserted under the loose dorsal neck skin (Figure 11). The incision was sutured to help prevent infection and promote healing. Dosimeters used in this study were Harshaw TLD-700s®[a] (thermoluminescent dosimeters) and were sealed in plastic to prevent fouling by the animal's body fluids. Following the operation the animals were returned to their capture location and released. When an animal was recaptured, the old dosimeter packet was removed and replaced with a new one. All returned dosimeters were read for exposure and reported in milli-Roentgens.

Occasionally an animal would die during the dosimeter implant operation from an overdose of anesthesia. These animals provided tissue samples that would later be used for radiochemical analysis. Two tissue types were used for this analysis. The hide including the fur, feet, and tail made up one sample representing an exterior tissue and the remaining carcass represented an interior tissue sample. These tissues were dried in an oven at 75°C for at least 48 hr and then analyzed by gamma spectrometry. Additional animals were trapped for this analysis from each site in an effort to represent the species present at each area (Appendix A).

Results

Two species of mice were consistently trapped on all four study sites. These were the Great Basin pocket mouse, *Perognathus parvus*, and the deer mouse, *Peromyscus maniculatus*. Two other species were occasionally captured during this study but did not provide a population that could be useful

(a) The manufacturer's name is given for the convenience of the reader; however, use of this name does not imply PNL endorsement.

FIGURE 11. Implantation of Dosimeter Packet in Pocket Mouse

for study purposes. These were the townsend ground squirrel, Spermophilus townsendii, and the western harvest mouse, Reithrodontomys megalotis, (Table 14). The presence of these two species was interpreted as representing dispersal movements since no recaptures were recorded for either species.

TABLE 14. Small Mammal Species Captured on the Four Study Sites

Species	Control	WYE	#7	North
Pocket Mouse	X	X	X	X
Deer Mouse	X	X	X	X
Ground Squirrel	X	X	X	
Harvest Mouse		X		

Pocket mice were the most frequently trapped small mammal on the control plot, WYE Burial Ground, and 300 North Burial Ground, while deer mice were the most often trapped small mammal on Burial Ground No. 7 (Appendix A). The WYE Burial Ground was initially trapped in February 1975 and dosimeters were first implanted in April 1976. At this time the control plot was established to give corresponding TLD exposure data. Trapping on the WYE Burial Ground was terminated in June 1977 with a total of 22 trapping sessions, 8 of which included TLD implantation. The control plot trapping was maintained to match the trapping efforts on 300 North and No. 7 Burial Grounds. These two areas were trapped from September 1976 to June 1978 yielding 7 trapping sessions. The control plot ended with 11 trapping sessions.

The two species, pocket mice and deer mice, were the only ones to yield dosimeter returns from the overall effort. All areas except WYE Burial Ground had returns from both species and only pocket mice were represented there. Overall recovery success of implanted TLDs ranged from 29.2% on WYE Burial Ground to 49.1% on 300 North (Table 15). On the three plots where deer mice and pocket mice containing TLDs were recaptured, pocket mice had the best recovery percentage. This is attributed to the successful retrapability of pocket mice (O'Farrell et al., 1975).

TABLE 15. Recovery Success of Implanted Dosimeter Packets

Location	TLD Packets Implanted	TLD Packets Recovered	%[a] Recovery
WYE Burial Ground			
Pocket Mouse	61	21	34.4
Deer Mouse	5	0	
Ground Squirrel	3	0	
Harvest Mouse	3	0	
Total	72	21	29.2
300 North B.G.			
Pocket Mouse	68	40	58.8
Deer Mouse	42	14	33.3
Total	110	54	49.1
300 No. 7			
Pocket Mouse	72	30	41.7
Deer Mouse	147	57	38.8
Ground Squirrel	4	0	
Total	223	87	39.0
Control Site			
Pocket Mouse	85	34	40.0
Deer Mouse	9	3	33.3
Ground Squirrel	2	0	
Total	96	37	38.5

(a) The TLD's implanted during the last trapping session of a plot were not included in the calculation of % recovery because there was no follow-up trapping session to collect implanted TLD's.

Gamma exposures measured by TLDs remained quite low for pocket mice. Their average exposure for all areas including the control plot was less than 2 mR/wk (Table 16). The highest exposure received by a pocket mouse was 8.7 mR/wk on 300 North Burial Ground. This exposure is slightly higher than the highest pocket mouse exposure on the control plot, 4.0 mR/wk. Deer mice trapped on 300 North and No. 7, however, had average exposures significantly higher than the controls with 28.5 mR/wk and 38.1 mR/wk, respectively. The deer mouse exposures on the control plot matched the pocket mouse exposures with less than 2 mR/wk. In a similar study on the Hanford Site, 13 deer mice living in an uncontaminated area had mean exposures of 1.3 mR/wk (Gano, 1978). These values were assumed to be normal background exposures.

The highest exposure rate to a deer mouse came from Burial Ground No. 7 with 476 mR/wk. The highest exposure rate received by a deer mouse on 300 North was 112 mR/wk. There were 28 deer mice on No. 7 and 5 on 300 North Burial Ground with exposure rates greater than 19.2 mR/wk or 1 R/yr (Table 17 and Appendix B). The maximum permissible dose to radiation workers is 100 mrem/wk or 5 rem/yr.

Radiological analysis of small mammal tissues yielded very small concentrations of ^{137}Cs. Thirty-eight animals were analyzed for external and internal tissue concentrations of ^{137}Cs. A sodium iodide scintillation detector was used for the analysis. All values for external tissues (skin, fur, feet, and tail) were below detection limits, while in four of the internal samples (remaining carcass) concentrations ranged from 2.3 to 9.8 pCi ^{137}Cs/g dry weight. Three of these internal samples were pocket mice and one was a deer mouse.

Discussion

Pocket mice are the most abundant mammal living on the Hanford Site. They are especially well adapted to the dry environment of this area. Habitats containing deep sandy soil free from rocks generally produce the highest densities of this small mammal (Hedlund et al., 1975). Their diet consists mostly of dry seeds; however, they do eat some green vegetation during winter

TABLE 16. Mean Gamma Exposure Rates to Mice Captured on 300 Area Burial Grounds (mR per week)

Study Site	Pocket Mouse n	Pocket Mouse $\bar{x} \pm$ S.E.	Pocket Mouse Range	Deer Mouse n	Deer Mouse $\bar{x} \pm$ S.E.	Deer Mouse Range
WYE Burial Ground	21	1.11 ± 0.10	0.42 to 1.75			
300 North B.G.[a]	40	1.96 ± 0.18	1.23 to 8.66	14	28.5 ± 11.1	1.21 to 112.0
300 #7 B.G.[a]	30	1.89 ± 0.07	1.47 to 3.00	57	38.1 ± 9.31	1.30 to 476.0
Control Plot	34	1.57 ± 0.11	0.63 to 4.04	3	1.96 ± 0.09	1.81 to 2.12

(a) Burial Ground

TABLE 17. Exposure Rates Greater than 19.2 mR/wk for Deer Mice Captured on 300 Area Burial Grounds North and No. 7

Number 7 Burial Ground			North Burial Ground
19.3	35.0	58.1	30.0
19.7	35.0	74.6	42.0
20.0	35.0	79.0	95.5
22.0	38.3	100.7	96.5
22.1	38.6	101.6	112.0
22.3	42.0	117.2	
24.1	46.5	236.6	
24.3	49.7	476.0	
24.6	51.6		
28.5	54.8		

and spring when available (Schmidt-Nielson et al., 1948). E. B. Kritzman (1970) reported finding a moderate amount of green vegetation and a large amount of insect material in pocket mouse stomachs during May 1969. Later in the summer she found their diet shifting to seeds and a small amount of green plant matter.

Deer mice accounted for a high percentage of the captures on 300 North and No. 7 Burial Grounds. Their numbers on these plots greatly exceeded those trapped on other plots in undisturbed vegetation on the Hanford Site (Hedlund and Rogers, 1976). This animal is extremely adaptive and can subsist in nearly all local habitats. One factor on the Hanford Site which may influence the size of a deer mouse population is the availability of a water source. Free water is not necessary for this species providing there is an ample supply of green vegetation and arthropods. These two food items make up a large part of the deer mouse diet, especially during the growing season (Flake, 1973; Johnson, 1975).

Deep-rooted plants growing on a burial ground could provide a pathway for radionuclides to deer mice if the roots grow deep enough to reach the buried waste. Animals relying on green plant material for a major part of their diet would be the first link in a food web transporting radionuclides away from a burial site. The results of this study indicate that deer mice are the most abundant rodent likely to initiate this transport. Ground squirrels are almost entirely dependent on plant material for their diet and also should be considered here. At present there are no resident colonies of ground squirrels on the burial grounds, but the possibility of immigration onto them does exist since the exclosure fence provides no obstacle.

Other primary consumers to consider on burial grounds include the black-tailed hare, Lepus californicus, and the Nuttal cottontail, Sylvilagus nuttallii. A young cottontail was found in a mouse trap on one occasion on Burial Ground No. 7. These two Lagomorph species are entirely herbivorous and although not examined in this investigation could be a vector for radionuclide

transport (O'Farrell et al., 1973). The presence of fecal pellets on the burial grounds is evidence that cottontails and jackrabbits are utilizing these areas.

The badger, Taxidea taxus, and coyote, Canis latrans, are the two common mammalian predators which occur in the 300 Area. These two species are proficient burrowers and can burrow into the ground of waste burial sites, thereby exposing buried waste to the surface (O'Farrell et al., 1973). Exposed waste could then be available to plants and animals, and could possibly be transported by wind erosion. In this situation, elimination of subterranean or digging animals from the waste management sites would prevent transfer of radioactive waste to biota or transport offsite. Placement of suitable biobarrier material would be effective for interim periods of time.

BIRDS

Bird survey paths located adjacent to four burial sites were walked twice each month during the months of March, April, May, June, and July 1978. Birds observed within or immediately adjacent to the fenced burial ground were identified to the species level and records were kept on the numbers observed.

Table 18 provides a list of bird species observed on the 300 Area Burial Grounds. Four of the species, the sage sparrow, common night hawk, long-billed curlew and mourning dove were found nesting on either the WYE or No. 7 Burial Grounds. The dependence of the sage sparrow on sagebrush shrubs (Rotenberry, 1978) for nesting sites limits its nesting to these burial grounds which have a remnant of sagebrush cover that was not removed during the burial operation. The other three species often select nest sites in areas with little or no shrubs present (Fitzner, J. N., 1978; Rotenberry, 1978). All other species listed in Table 19 probably use the burial sites for feeding.

TABLE 18. Breeding Bird Survey of the 300 Area Burial Grounds[a]

Species	Location			
	300 North	No. 4	No. 7	"Y"
Western Meadow Lark[b] (*Sturnella neglecta*)	C	C	C	C
Horned Lark[b] (*Eremophila alpestris*)	C	C	C	C
Sage Sparrow[b] (*Amphispiza belli*)	U	U	U	U
Long-billed Curlew[b] (*Numenius americanus*)	U	U	U	U
Ring-billed Gull (*Larus delawarensis*)	C	C	C	C
California Quail (Lophortyx californicus)	U	U	C	U
Black-billed Magpie (*Pica Pica*)	C	C	C	C
American Kestrel (*Falco sparverius*)	U	U	U	U
Loggerhead Shrike (*Lanius ludovicianus*)	U	U	U	U
Mourning Dove[b] (*Zenaidura macroura*)	C	C	C	C
House Sparrow (*Passer domesticus*)	U	U	U	U
Killdeer[b] (*Charadrius vociferus*)	U	U	U	U
Swainson's Hawk (*Buteo swainsoni*)	U	U	U	U
Western Kingbird (*Tyrannus verticalis*)	U	C	C	C
Burrowing Owl (*Speotyto cunicularia*)	U	U	C	U
House Finch (*Carpodacus mexicanus*)	U	C	U	U

(a) Four surveys were conducted at each burial site. All surveys conducted during early morning hours on the following days---April 17, May 5, June 2, July 5.
(b) Species found or believed to be nesting on the burial grounds.
C = Observed on at least three surveys.
U = Observed on at least one survey.

Birds other than those listed in Table 18 probably use the 300 Area burial sites seasonally. A list of bird species associated with the 200 Area waste ponds and adjacent shrub steppe areas can be found in Fitzner and Rickard (1975). However, many of the species in this publication are associated with aquatic or riparian habitats. If moisture increased in any of the burial sites, the introduction of riparian vegetation and animal species associated with it could be expected.

CONSIDERATIONS AND RECOMMENDATIONS FOR MANAGEMENT OF 300 AREA WASTE BURIAL SITES

To effectively minimize radionuclide transport through biota, the characteristics of the plants and animals must be taken into account. This section provides some recommendations on desirable vegetation and barriers, and an integrated approach to management of burial sites. To show how the recommendations were derived, some of the major points of the previous text are emphasized.

VEGETATION

The 300 Area Burial Grounds are located in the bitterbrush-cheatgrass vegetation type which occupies about 78,000 acres in the southeastern part of the Hanford Site (Figure 12). Undisturbed vegetation is dominated by desert shrubs, sagebrush and bitterbrush usually in mixtures of about equal amounts. The understory to the shrubs is dominated by cheatgrass an annual grass that reestablishes itself from seeds each year. Seeds usually germinate in the fall with the onset of autumn rain and the plants reach maturity in early May. Standing dead cheatgrass provides ground cover throughout the summer months and retards soil erosion by wind.

Bitterbrush-cheatgrass vegetation is susceptible to fire, and wildfire in 1961 and 1970 burned over an estimated 17,000 acres on the Hanford Site. Burning also kills the shrubs. Cheatgrass reinvades the burned area from seeds that survive burning and from seeds imported from adjacent unburned areas. Heavily burned areas are often initially invaded by Russian thistle. Russian thistle can dominate the plant cover for several years until cheatgrass can reestablish itself. Russian thistle persists but in reduced amounts. Shrubs are slow to reinvade burned areas.

Burial of solid wastes destroys all the existing vegetation in the burial zones. Russian thistle and cheatgrass are the early invaders of burial ground backfill and the backfill of 300 Area Burial Grounds is occupied in a few years by a sparse cover of cheatgrass and Russian thistle. In most cases shrubs are slow to establish themselves on backfill.

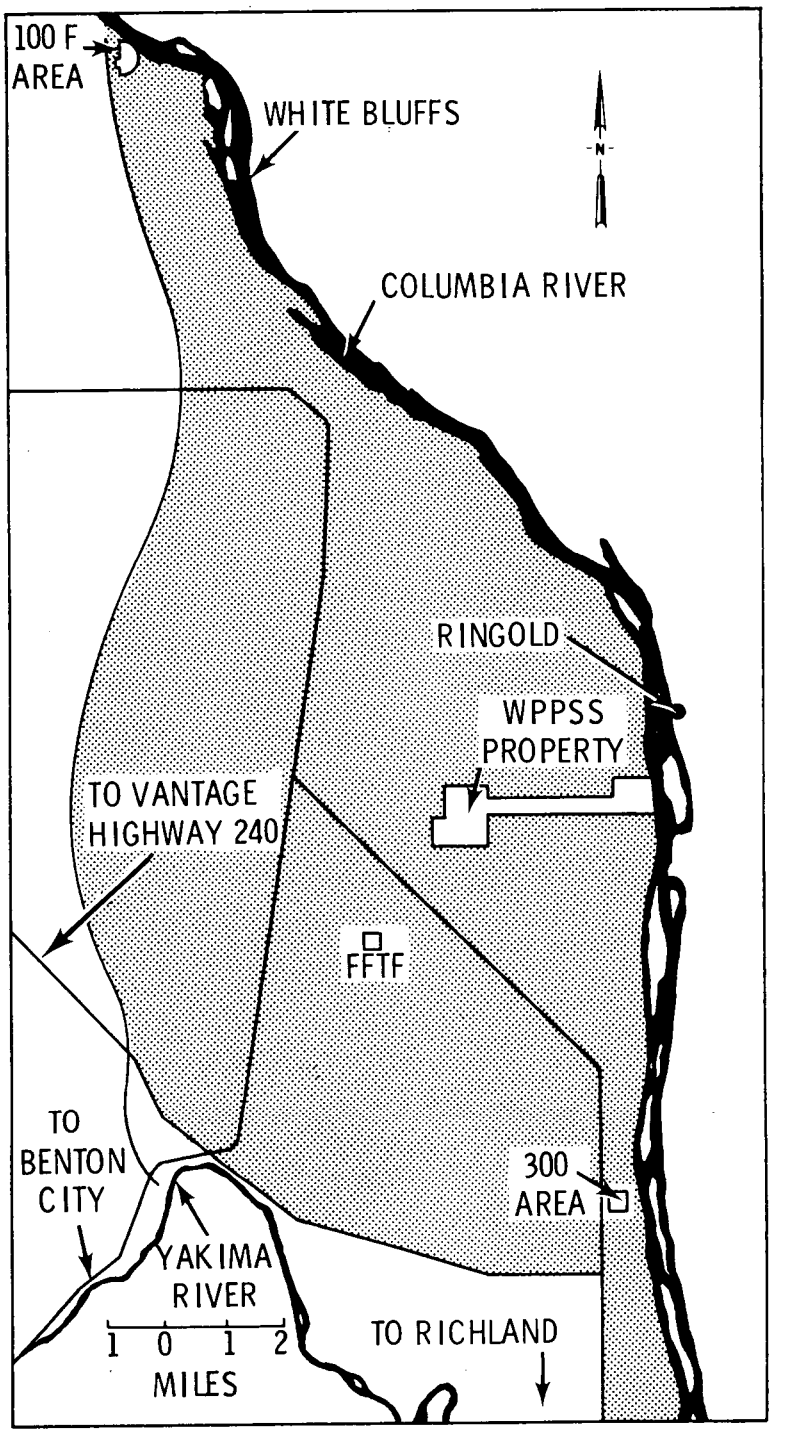


FIGURE 12. Bitterbrush-Cheatgrass Vegetation in the Hanford Site (Shaded Area)

Plants as Transporters of Radionuclides from 300 Area Burial Grounds

One of the aims of waste burial is to eliminate the contact of plant roots with radioactive material. Plants have the ability to assimilate radionuclides incorporated into soil if the roots are in direct contact with the buried material. As a general rule shrubs have deeper penetrating root systems than herbaceous species, partly because shrubs live much longer than herbaceous species. Perennial herbs generally have deeper roots than annual herbs. In order to eliminate the potential for plants with deep root systems to reach buried waste, shallow-rooted annual plants are the most desirable species. Cheatgrass and Russian thistle are both annuals, but Russian thistle has a deeper root system than cheatgrass which makes it less desirable from the point of view of deep soil penetration. Also, Russian thistle has a greater affinity for incorporating radionuclides into its tissues than cheatgrass as indicated by laboratory studies of the two species grown in contaminated soils. Furthermore, Russian thistle has the undesirable feature of the entire plant breaking off at ground level at maturity and being moved from burial grounds by the wind, sometimes as far as several miles.

Some of the more desirable features of plants growing on burial grounds are shown below:

Desirable Features	Burial Ground Species		
	Cheatgrass	Russian Thistle	Shrubs
Shallow root system (6 ft deep)	yes	no	no
Low radionuclide uptake from soil[a]	yes	no	Unknown
Low potential for wind transport of tissues	yes	no	yes
Retards soil erosion	yes	yes (until plant blows away)	yes

(a) Refers to selected transuranic elements (Price, 1973)

Most natural plant communities are mixtures of plant species. Management strategies can usually be devised to obtain the desired species. Results of this study indicate that very few individual plants growing on the 300 Area

Burial Grounds have been able to contact buried wastes and bring waste materials into aboveground tissues. However, if shrubs become established and grow for many years incidents of uptake may increase.

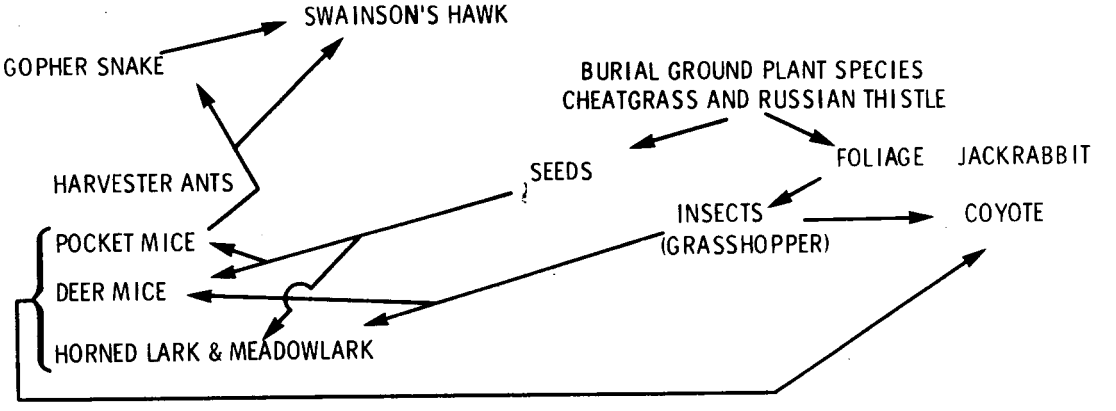
Deeper burial and long-lasting barriers to prevent plant roots and burrowing mammals and ants from penetrating the burial waste could more effectively isolate shallow buried waste from the biota. Management of vegetative cover on backfill through soil and plant species selection and devising ways to prevent establishment of Russian thistle would also be useful in limiting radionuclide uptake by plants on existing burial grounds.

ANIMALS

There are usually more birds, mammals, insects, and reptiles associated with the kinds of vegetation dominated by shrubs than vegetation dominated by cheatgrass and Russian thistle alone. Nevertheless, backfill covered by a sparse stand of cheatgrass and Russian thistle is still acceptable as habitat for pocket mice, deer mice, jackrabbits, horned larks, meadow larks, long-billed curlew, lizards, and many kinds of insects including the harvester ant.

Food Chains Associated with 300 Area Burial Grounds

Food chain transfers from 300 Area Burial Grounds are illustrated below. In the absence of grazing livestock, food chains do not lead to man. Mule deer are a potential source of food to man but are excluded from burial grounds by wire fences.



ANIMALS AS VECTORS OF RADIONUCLIDES FROM 300 AREA BURIAL GROUNDS

Mammals (Burrowers)

The mammals of most concern for radionuclide transport from burial grounds are those species that are able to burrow deep into the backfill and bring radioactive debris to the soil surface. The mammal that is the most proficient burrower is the badger. Badgers can dig several feet below the surface, creating holes 15 cm or more in diameter and piles of earth 0.3 m in diameter and 0.3 m or more thick. Although badgers are residents of the Hanford Site, they occur in low numbers. They have not been observed to dig into the backfill of the 300 Area Burial Grounds. However, unless barriers are purposefully placed in burial grounds to prevent deep burrowing, 3 m or more, the possibility exists for badgers to exhume waste debris. Badgers dig for two purposes: 1) as den sites for rearing young and 2) to capture small mammals as food, e.g., pocket mice and ground squirrels.

Pocket mice and ground squirrels are burrowing animals that spend much of their lifetimes below ground. Ground squirrels occur in localized colonies throughout the Hanford Site and have been observed on the 300 Area Burial Grounds although in very small numbers. Pocket mice are found everywhere including the 300 Area Burial Grounds.

Mammals (Nonburrowers)

Some mammals do not burrow and may have access to plants growing on backfill as forage. Such animals are mule deer, *Odocoileus hemionus*, and jackrabbits. Mule deer are present in the bitterbrush-cheatgrass vegetation type and are excluded from entry into most of the 300 Area Burial Grounds by a 3-m-high wire mesh fence.

Discussions with M. G. White (Richland DOE) revealed that mule deer have entered several of the 300 Area Burial Grounds through large holes in the fencing and/or by jumping over the fencing. Periodic checking of fence conditions for holes would probably eliminate most deer from the burial sites. Longhurst et al. (1962) indicate that some mule deer are capable of jumping

fences higher than 3 m, particularly if the fence is located on sloping ground. In these situations, the fencing may need to be 4 m high in order to effectively exclude deer.

Jackrabbits (blacktailed hares) are also present in the bitterbrush-cheatgrass vegetation type. The wire mesh fencing is not so effective at excluding jackrabbits because they can slip beneath the fence at various places along its perimeter. Jackrabbits are of concern in the 300 Area Burial Grounds only if they consume plants contaminated with burial ground derived radionuclides or if they interfere with revegetation efforts to stabilize backfill with selected plant cover.

Deer mice are found throughout the Hanford Site but they are not nearly as abundant as pocket mice. Deer mice commonly reside on 300 Area Burial Grounds. Fences are not a barrier to the movement of deer mice.

BIRDS

There are only a few birds that accept the revegetated backfill of the 300 Area Burial Grounds as nest sites. It is expected that the western meadowlark, horned lark, mourning dove, western night hawk and long-billed curlew would find the 300 Area Burial Grounds acceptable. Nests of all but the meadowlark and curlew were found. These birds are of concern only if they obtain radionuclides of burial ground origin from plant seeds, grit, or insects that constitute dietary items of adult and nesting birds.

Birds of prey occur on the Hanford Site over all seasons of the year. Some nest on the Hanford Site. The most abundant birds of prey associated with the bitterbrush-cheatgrass vegetation-type are the Swainson's hawk; red-tailed hawk, *Buteo jamaicensis*; marsh hawk, *Circus cyaneus*; sparrow hawk; golden eagle, *Aguila chrysaetos*; burrowing owl; great horned owl, *Bubo virginianus*; and long-eared owl, *Asio otus*. These are of concern only if they

eat jackrabbits, mice, lizards, snakes, small birds and insects that have derived body burdens of radioactivity from buried waste. Some birds, i.e., magpies and ravens, Corvus corax, eat dead animals that are killed by automobiles.

Although birds are highly conspicuous animals, they provide relatively little biomass per unit area as compared to other kinds of animals and are of relatively little concern in 300 Area Burial Ground transfers of radionuclides. The migratory habits of certain species like the long-billed curlew and Swainson's hawk do, however, place these species in a position to spread radiocontaminants several thousand miles in a time frame of only a few weeks. Since neither of these species is frequently eaten by man little chance exists for direct radionuclide transfer to man. However, the transported radioactivity goes somewhere into the environment and may become a problem through another pathway. Upland and migratory bird species associated with the 300 Area burial sites (California quail and mourning dove) do provide an avenue for radioactive transport offsite to man but only if their food sources and grit are contaminated. California quail and doves are primarily seed eaters (Crispens et al., 1960; Davis et al., 1971), and probably feed on Russian thistle and cheatgrass seeds on the 300 Area burial sites.

INTEGRATED APPROACH TO THE MANAGEMENT OF WASTE BURIAL SITES

The control of movement and resuspension of particles carrying radioactivity into an environment is an important but difficult waste management responsibility. The literature is widely documented showing the relationships of abiotic factors that affect the rate which radionuclides are transferred by wind and plants and animals when studied as separate vectors. Additional studies are needed to integrate the abiotic and biotic factors to establish environmental management practices for optimal control of possible removal of radioactivity from terrestrial storage centers.

One management scheme would be to determine the optimal vegetation cover and density that is needed to stabilize the sandy soil of the Hanford 300 Area waste sites from wind and other abiotic factors that cause resuspension of soil particles. Chepil (1945) relates the velocity of wind required to move

soil particles with physical size and surface characteristics. Table 19 shows the wind velocity in cm/sec that will cause movement of the fine sandy loam soil of this study area when the vegetative cover has been removed. Chepil (1946) shows that wind velocities can be reduced greatly at the soil surface by some plant cover that will reduce wind velocities at various heights above the soil surface to prevent soil movement.

TABLE 19. Maximal Fluid Threshold Velocities from Dry Quartz Particles (from Chepil, 1945)

Size of Particle, mm	Specific Gravity	Threshold Velocities: Off a Level Layer of Loose Particle, cm/sec	Threshold Velocities: Off Smooth Glass Surface, cm/sec
0.005 - 0.01	2.65	1,655	1,655
0.01 - 0.02	2.65	1,060	1,655
0.02 - 0.05	2.65	645	985
0.05 - 0.10	2.65	412	390
0.10 - 0.15	2.65	381	358
0.15 - 0.25	2.65	497	452

D'Aquino (1974) and Bartlett et al. (1974) using linear programming techniques developed a model to establish management plans for livestock grazing on various pastures. This technique can be modified to establish the amount of vegetative cover required to maintain a stable soil surface during high wind velocities. After optimal plant cover is determined, this technique can be used as a guide for revegetating storage sites. These guidelines may be related with the amount of rainfall and soil nutrients that are available, and determine the amount of water needed for optimal growth that can be added by controlled irrigation.

An unknown factor is the amount of time (years) required to establish adequate plant cover of a disturbed soil surface. Figure 13 shows the amount of rainfall of the successive biological years since 1950. These records

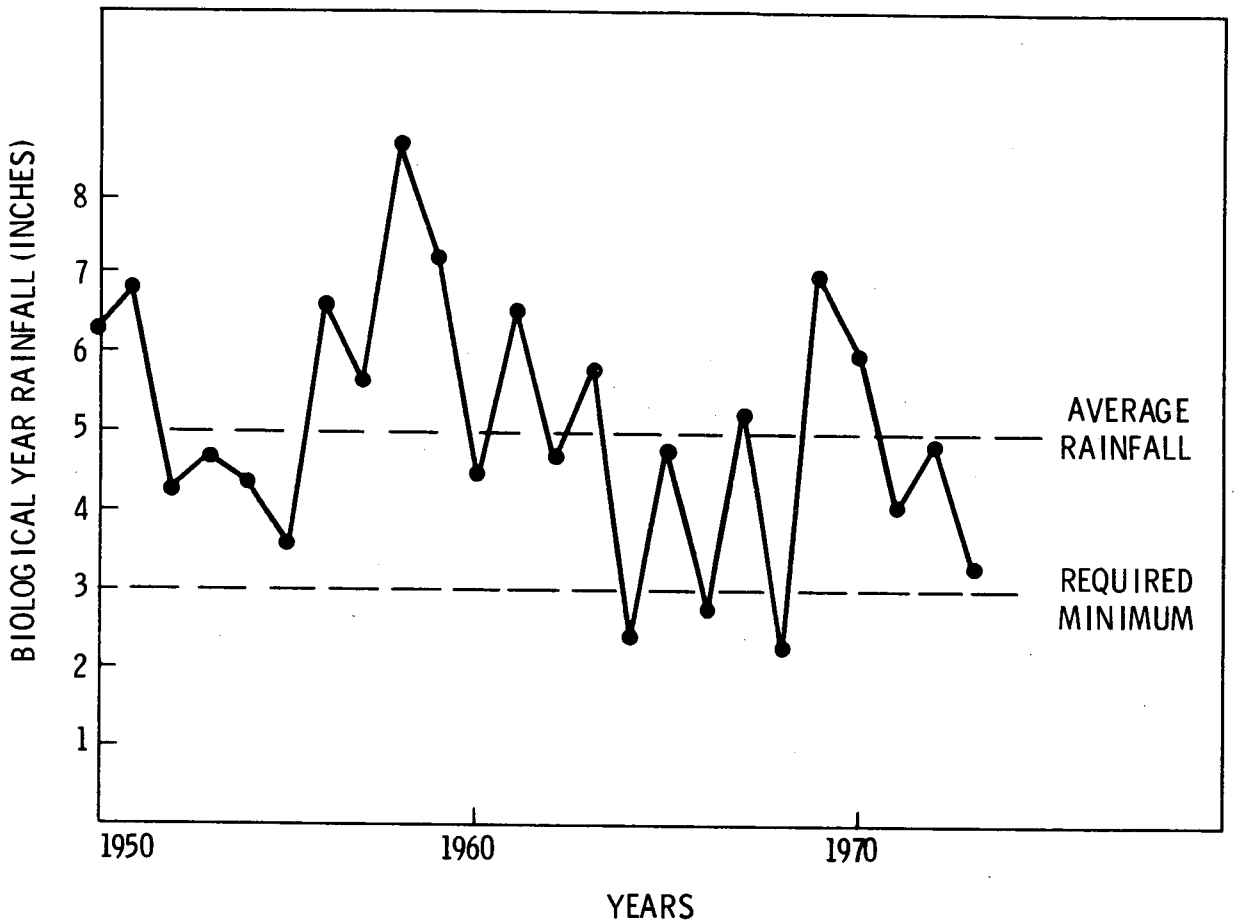


FIGURE 13. Biological Rainfall at the Meteorological Tower During the Past 23 Years

indicate that the precipitation for several years was too low to produce plant growth. According to W. T. Hinds and J. M. Thorp of PNL, rainfall over the years was related to growth of sagebrush. They correlated the width of annual growth rings with the amount of precipitation occurring during the biological year. Biological year is defined as the period from the time growth first occurred in the fall until it stopped in late spring.

Utilizing the rainfall data it can be estimated that 30 to 40 years would be required to establish a stand similar to a natural ecosystem. Cline and Rickard (1973) showed that 1 cm of available soil water produced approximately 20 g of cheatgrass per m^2. Study plots on the Arid Lands Ecology Reserve on the Hanford Site that are similar to the 300 Area waste burial sites had yields averaging 50 g of dry matter per m^2 during 1971 and 1972. However, in 1973, a very dry year, only 10 g/m^2 was produced. These data show that it would be nearly impossible to revegetate a disturbed area during a succession of dry years without some type of irrigation.

With the above facts in mind, research should attempt to establish the optimal amount of cover and density of plants that would prevent resuspension and movement of radioactivity particles and soil by wind in the area. Additional work is needed to accomplish this task.

Finally, decommissioning of Hanford facilities needs to consider the amount of land required for shallow land burial, and whether or not the land will be restored to biologic productivity equal to or better than its existing state. It is particularly important to decide whether or not the land will be left wild (natural) or converted to agricultural use at some future date.

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APPENDIX A

NUMBER OF SMALL MAMMAL CAPTURES AND AVERAGE INDIVIDUAL WEIGHTS FOR EACH MONTH ON 300 AREA BURIAL GROUNDS

Number of Captures and Average Weights for Each Month on WYE Burial Ground, Plot #41

Species	Feb 75		Mar 75		Apr 75		May 75		Jun 75	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	3	18.2 ± 1.4	24	17.9 ± 0.6	24	18.2 ± 0.4	15	17.9 ± 0.6	11	17.0 ± 1.3
Female	0		1	17.5 ± 0.0	6	17.1 ± 0.8	9	19.4 ± 1.2	5	19.0 ± 1.1
Total	3	18.2 ± 1.4	25	17.9 ± 0.5	30	18.0 ± 0.4	24	18.5 ± 0.6	16	17.7 ± 1.0
Deer Mouse										
Male	1	20.0 ± 0.0	2	22.3 ± 0.0	2	23.3 ± 0.0	2	15.0 ± 0.0		
Female	1	30.0 ± 0.0	1	31.0 ± 0.0	1	28.5 ± 0.0	2	18.0 ± 0.0		
Total	2	25.0 ± 0.0	3	25.2 ± 3.0	3	25.0 ± 1.9	4	16.5 ± 3.2		

	Jul 75		Aug 75		Sep 75		Oct 75		Nov 75	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	5	16.3 ± 1.6	5	16.1 ± 1.0	9	16.6 ± 0.9	11	16.6 ± 0.7	4	16.5 ± 1.0
Female	1	20.5 ± 0.0	3	16.7 ± 1.7	5	14.5 ± 1.9	4	13.5 ± 0.9	2	14.0 ± 0.0
Total	6	17.0 ± 1.5	8	16.3 ± 0.8	14	15.8 ± 0.9	5	15.8 ± 0.7	6	15.7 ± 0.8

	Dec 75		Jan 76	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse				
Male	0		0	
Female	1	14.0 ± 0.0	1	15.0 ± 0.0
Total	1	14.0 ± 0.0	1	15.0 ± 0.0
Deer Mouse				
Male	2	18.0 ± 0.0	1	21.0 ± 0.0
Female	0		0	
Total	2	18.0 ± 0.0	1	21.0 ± 0.0

Number of Captures and Average Weights for Each Month
on WYE Burial Ground, Plot #41 (contd)

Species	Feb 76		Mar 76		Apr 76		May 76		Jul 76	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	8	16.8 ± 0.6	17	16.8 ± 0.7	13	18.1 ± 0.6	9	16.4 ± 1.1	4	16.3 ± 1.2
Female	1	14.5 ± 0.0	3	16.0 ± 1.2	6	16.5 ± 1.3	7	17.1 ± 1.3	0	
Total	9	16.6 ± 0.6	20	16.7 ± 0.6	19	17.6 ± 0.6	16	16.7 ± 0.8	4	16.3 ± 1.2
Deer Mouse										
Male	1	20.0 ± 0.0	1	15.5 ± 0.0	3	15.3 ± 0.3				
Female	0		1	24.0 ± 0.0	0					
Total	1	20.0 ± 0.0	2	19.8 ± 0.0	3	15.3 ± 0.3				
Ground Squirrel										
Male					0					
Female					2	121.0 ± 0.0				
Total					2	121.0 ± 0.0				

Number of Captures and Average Weights for Each Month
on WYE Burial Ground, Plot #41 (contd)

Species	Aug 76		Oct 76		Mar 77		Apr 77		Jun 77	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	4	14.6 ± 2.0	4	16.8 ± 0.6	8	19.1 ± 0.3	3	19.3 ± 0.9	5	14.8 ± 1.8
Female	0		0		0		3	19.2 ± 1.3	2	15.8 ± 0.0
Total	4	14.6 ± 2.0	4	16.8 ± 0.6	8	19.1 ± 0.3	6	19.3 ± 0.7	7	15.1 ± 1.3
Deer Mouse										
Male					1	22.0 ± 0.0	1	11.5 ± 0.0		
Female					0		0			
Total					1	22.0 ± 0.0	1	11.5 ± 0.0		
Ground Squirrel										
Male					1	160.0 ± 0.0				
Female					0					
Total					1	160.0 ± 0.0				
Harvest Mouse										
Male			1	10.0 ± 0.0			0			
Female			1	14.5 ± 0.0			1	7.5 ± 0.0		
Total			2	12.3 ± 0.0			1	7.5 ± 0.0		

Number of Captures and Average Weights for Each Month on 300 Area Burial Ground No. 7, Plot #45

Species	Sep 76		Mar 77		Jun 77		Mar 78		Apr 78	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	6	12.8 ± 1.1	15	17.9 ± 0.6	10	18.3 ± 1.0	6	17.2 ± 1.6	9	17.6 ± 1.1
Female	4	12.9 ± 0.8	4	13.6 ± 1.1	10	15.7 ± 0.9	0	±	8	14.5 ± 0.8
Total	10	12.9 ± 0.7	19	17.0 ± 0.6	20	17.0 ± 0.7	6	17.2 ± 1.6	17	16.1 ± 0.8
Deer Mouse										
Male	4	15.6 ± 1.1	12	16.6 ± 1.6	7	17.9 ± 0.5	20	17.7 ± 0.9	20	17.4 ± 0.8
Female	1	16.5 ± 0.0	13	19.4 ± 1.4	5	19.9 ± 2.5	16	21.1 ± 1.4	23	19.3 ± 1.1
Total	5	15.8 ± 0.9	25	18.1 ± 1.1	12	18.8 ± 1.1	36	19.2 ± 0.8	43	18.5 ± 0.7
Ground Squirrel										
Male									0	
Female									1	158.0 ± 0.0
Total									1	158.0 ± 0.0

	May 78		Jun 78	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse				
Male	4	18.5 ± 1.3	5	16.6 ± 1.6
Female	6	17.3 ± 1.2	4	13.8 ± 1.7
Total	10	17.8 ± 0.9	9	15.3 ± 1.2
Deer Mouse				
Male	11	18.5 ± 0.7	7	19.1 ± 0.7
Female	20	19.6 ± 1.1	7	18.3 ± 1.7
Total	31	19.2 ± 0.7	14	18.7 ± 0.9
Ground Squirrel				
Male	2	117.5 ± 0.0	1	no wt.
Female	1	107.0 ± 0.0	0	
Total	3	114.0 ±10.7	1	no wt.

Number of Captures and Average Weights for Each Month
on 300 Area Burial Ground North, Plot #46

Species	Sep 76		Mar 77		Jun 77		Mar 78		Apr 78	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	4	13.4 ± 1.8	11	16.9 ± 0.7	9	17.1 ± 0.8	10	18.6 ± 0.8	9	18.1 ± 0.4
Female	7	11.6 ± 0.5	2	13.0 ± 0.0	9	15.6 ± 1.0	0		4	17.1 ± 2.3
Total	11	12.3 ± 0.7	3	16.3 ± 0.7	18	16.3 ± 0.7	10	18.6 ± 0.8	13	17.8 ± 0.7
Deer Mouse										
Male	1	17.0 ± 0.0	1	15.5 ± 0.0	2	12.5 ± 0.0	6	17.8 ± 1.0	6	19.4 ± 1.1
Female	0		0		2	16.3 ± 0.0	5	23.4 ± 2.8	10	19.7 ± 1.6
Total	1	17.0 ± 0.0	1	15.5 ± 0.0	4	14.4 ± 1.6	11	20.4 ± 1.6	16	19.6 ± 1.1

	May 78			Jun 78		
	n	$\bar{x}$ wt ± S.E.		n	$\bar{x}$ wt ± S.E.	
Pocket Mouse						
Male	8	18.7 ± 0.3		6	17.4 ± 0.8	
Female	6	16.8 ± 0.7		5	18.0 ± 1.1	
Total	14	17.9 ± 0.4		11	17.7 ± 0.6	
Deer Mouse						
Male	8	17.3	1.3	5	14.9	0.9
Female	2	18.8	0.0	1	21.0	0.0
Total	10	17.6	1.2	6	15.9	1.2

Number of Captures and Average Weights for Each Month
on Control Site, Plot #43

Species	Apr 76		May 76		Jul 76		Aug 76		Oct 76	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	4	16.8 ± 1.0	9	16.6 ± 1.2	5	16.0 ± 1.3	5	15.6 ± 1.7	4	16.8 ± 1.1
Female	4	13.9 ± 0.7	5	15.5 ± 0.7	2	16.5 ± 0.0	4	12.9 ± 1.0	1	14.0 ± 0.0
Total	8	15.3 ± 0.8	14	16.2 ± 0.8	7	16.1 ± 1.2	9	14.4 ± 1.1	5	16.2 ± 1.0
Deer Mouse										
Male										
Female										
Total										
Ground Squirrel										
Male	2	128.0 ± 0.0								
Female	0									
Total	2	128.0 ± 0.0								

Number of Captures and Average Weights for Each Month
on Control Site, Plot #43 (contd)

Species	Mar 77		Apr 77		Mar 78		Apr 78		May 78	
	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.	n	$\bar{x}$ wt ± S.E.
Pocket Mouse										
Male	3	16.2 ± 1.4	4	17.3 ± 1.2	4	17.4 ± 0.9	10	18.3 ± 0.5	9	17.8 ± 0.5
Female	0		3	16.0 ± 2.5	0		3	15.7 ± 1.2	6	14.7 ± 1.4
Total	3	16.2 ± 1.4	7	16.7 ± 1.2	4	17.4 ± 0.9	13	17.7 ± 0.6	15	16.5 ± 0.7
Deer Mouse										
Male			0		2	18.5 ± 0.0	1	18.0 ± 0.0	1	17.0 ± 0.0
Female			2	17.0 ± 0.0	1	17.5 ± 0.0	2	18.8 ± 0.0	0	
Total			2	17.0 ± 0.0	3	18.2 ± 0.4	3	18.5 ± 0.8	1	17.0 ± 0.0

	Jun 78	
	n	$\bar{x}$ wt ± S.E.
Pocket Mouse		
Male	7	15.4 ± 0.5
Female	5	15.1 ± 1.4
Total	12	15.3 ± 0.6
Deer Mouse		
Male		
Female		
Total		
Ground Squirrel		
Male	2	117.0 ± 0.0
Female	0	
Total	2	117.0 ± 0.0

APPENDIX B

GAMMA EXPOSURE RATES TO MICE LIVING ON 300 AREA BURIAL GROUNDS

Gamma Exposure Rates to Mice Living on WYE
Burial Ground (Plot #41)

Species	Animal I.D. #	Sex[a]	Location	mR/wk	R/yr
Perognathus parvus	0044	F	G-2	1.05	0.055
Perognathus parvus	0045	F	J-1	0.77	0.040
Perognathus parvus	0105	M	A-4	0.77	0.040
Perognathus parvus	0110	F	B-2	1.05	0.055
Perognathus parvus	0114	M	C-7	0.77	0.040
Perognathus parvus	0120	M	B-4	0.77	0.040
Perognathus parvus	0125	M	A-5	0.77	0.040
Perognathus parvus	0132	F	G-3	0.91	0.047
Perognathus parvus	0134	M	C-10	1.05	0.055
Perognathus parvus	0135	M	C-3	0.77	0.040
Perognathus parvus	0134	M	A-10	0.42	0.022
Perognathus parvus	0213	M	A-1	0.49	0.026
Perognathus parvus	0105	M	B-4	0.55	0.029
Perognathus parvus	0105	M	D-5	1.75	0.091
Perognathus parvus	0213	M	B-1	1.75	0.091
Perognathus parvus	0235	M	A-5	1.05	0.055
Perognathus parvus	0235	M	A-3	1.61	0.084
Perognathus parvus	0105	M	D-9	1.75	0.091
Perognathus parvus	0300	M	C-10	1.68	0.088
Perognathus parvus	0253	M	D-8	1.75	0.091
Perognathus parvus	0301	M	K-10	1.75	0.091

(a) F = female, M = male

Gamma Exposure Rates to Mice Living on 300 Area
Burial Ground Number 7 (Plot #45)

Species	Animal I.D. #	Sex[a]	Trap Location	mR/wk	R/yr
Perognathus parvus	0003	F	A-7	1.82	0.095
Perognathus parvus	0035	M	A-8	1.82	0.095
Perognathus parvus	0043	M	C-1	1.82	0.095
Perognathus parvus	0042	F	C-2	1.89	0.099
Perognathus parvus	0023	M	C-3	2.59	0.135
Perognathus parvus	0045	F	D-3	1.68	0.088
Perognathus parvus	0041	M	D-6	1.68	0.088
Perognathus parvus	0050	M	J-3	1.47	0.077
Perognathus parvus	0044	M	B-1	1.61	0.084
Perognathus parvus	0035	M	A-9	1.63	0.085
Perognathus parvus	0022	M	A-1	1.99	0.104
Perognathus parvus	0035	M	A-3	1.87	0.097
Perognathus parvus	0041	M	E-7	1.82	0.095
Perognathus parvus	0124	F	H-1	2.71	0.141
Perognathus parvus	0140	M	J-10	1.92	0.100
Perognathus parvus	0151	M	K-3	1.76	0.092
Perognathus parvus	0245	F	F-3	2.33	0.121
Perognathus parvus	0022	M	D-1	1.8	0.091
Perognathus parvus	0035	M	A-8	1.5	0.078
Perognathus parvus	0200	F	C-1	2.0	0.105
Perognathus parvus	0201	F	A-2	1.8	0.091
Perognathus parvus	0204	M	G-1	1.8	0.091
Perognathus parvus	0245	F	F-1	1.5	0.078
Perognathus parvus	0091	F	K-5	1.7	0.088
Perognathus parvus	0151	M	F-1	1.5	0.076
Perognathus parvus	0022	M	C-2	2.75	0.143
Perognathus parvus	0035	M	C-10	3.00	0.156
Perognathus parvus	0151	M	D-2	1.56	0.081
Perognathus parvus	0204	M	F-1	1.75	0.091
Perognathus parvus	0245	F	E-2	1.75	0.091
Peromyscus maniculatus	0020	F	A-9	236.6	12.34
Peromyscus maniculatus	0015	F	C-9	100.7	5.25
Peromyscus maniculatus	0042	F	D-10	21.98	1.15
Peromyscus maniculatus	0032	M	G-5	117.2	6.11
Peromyscus maniculatus	0025	F	K-7	9.17	0.478
Peromyscus maniculatus	0021	M	K-10	74.62	3.89
Peromyscus maniculatus	0104	M	F-6	10.9	0.568
Peromyscus maniculatus	0112	M	F-9	8.21	0.428
Peromyscus maniculatus	0114	M	F-7	17.4	0.906
Peromyscus maniculatus	0115	F	J-6	38.6	2.014
Peromyscus maniculatus	0120	M	C-10	9.85	0.514
Peromyscus maniculatus	0121	M	B-10	2.07	0.108

(a) F = female, M = male

Gamma Exposure Rates to Mice Living on 300 Area
Burial Ground Number 7 (Plot #45) (contd)

Species	Animal I.D. #	Sex[a]	Trap Location	mR/wk	R/yr
Peromyscus maniculatus	0123	F	K-1	1.84	0.096
Peromyscus maniculatus	0124	M	J-7	24.6	1.284
Peromyscus maniculatus	0125	F	G-4	58.1	3.028
Peromyscus maniculatus	0130	M	J-8	35.0	1.825
Peromyscus maniculatus	0131	M	H-4	12.8	0.665
Peromyscus maniculatus	0150	F	A-7	11.3	0.590
Peromyscus maniculatus	0152	F	H-1	9.33	0.487
Peromyscus maniculatus	0153	M	G-5	28.5	1.488
Peromyscus maniculatus	0200	M	J-9	22.1	1.151
Peromyscus maniculatus	0205	M	C-3	5.6	0.292
Peromyscus maniculatus	0212	M	F-10	17.2	0.898
Peromyscus maniculatus	0213	F	E-9	11.0	0.576
Peromyscus maniculatus	0214	F	J-2	1.76	0.092
Peromyscus maniculatus	0114	M	D-10	13.3	0.691
Peromyscus maniculatus	0115	F	F-4	24.3	1.264
Peromyscus maniculatus	0125	F	G-4	46.5	2.425
Peromyscus maniculatus	0130	M	J-9	7.5	0.391
Peromyscus maniculatus	0214	F	K-1	1.3	0.065
Peromyscus maniculatus	0224	M	E-9	13.8	0.717
Peromyscus maniculatus	0225	M	B-7	8.5	0.443
Peromyscus maniculatus	0232	F	C-2	79.0	4.119
Peromyscus maniculatus	0234	F	C-3	22.3	1.160
Peromyscus maniculatus	0104	M	G-7	101.6	5.299
Peromyscus maniculatus	0121	M	A-8	1.93	0.101
Peromyscus maniculatus	0132	M	E-1	4.13	0.215
Peromyscus maniculatus	0202	F	K-10	20.0	1.042
Peromyscus maniculatus	0205	M	F-5	3.5	0.183
Peromyscus maniculatus	0235	F	F-5	24.1	1.259
Peromyscus maniculatus	0243	F	C-7	54.8	2.855
Peromyscus maniculatus	0302	F	E-6	19.7	1.027
Peromyscus maniculatus	0304	F	G-10	12.7	0.662
Peromyscus maniculatus	0131	M	J-9	35.0	1.825
Peromyscus maniculatus	0303	F	B-10	11.0	0.574
Peromyscus maniculatus	0104	M	E-7	16.3	0.852
Peromyscus maniculatus	0130	M	J-9	10.0	0.521
Peromyscus maniculatus	0131	M	G-7	15.4	0.800
Peromyscus maniculatus	0205	M	C-3	12.2	0.635
Peromyscus maniculatus	0234	F	C-4	19.3	1.004
Peromyscus maniculatus	0323	F	A-10	42.0	2.190
Peromyscus maniculatus	0325	F	G-2	51.6	2.690
Peromyscus maniculatus	0212	M	K-2	35.5	1.851
Peromyscus maniculatus	0224	M	C-9	13.5	0.705
Peromyscus maniculatus	0243	F	B-7	476.0	24.820
Peromyscus maniculatus	0302	F	H-6	38.3	1.994
Peromyscus maniculatus	0235	F	F-5	49.7	2.593

(a) F = female, M = male.

Gamma Exposure Rates to Mice Living on 300 North Burial Ground (Plot #46)

Species	Animal I.D. #	Sex[a]	Trap Location	mR/wk	R/yr
Perognathus parvus	0055	M	B-1	2.03	0.106
Perognathus parvus	0100	F	B-5	2.17	0.113
Perognathus parvus	0104	M	D-1	1.82	0.095
Perognathus parvus	0054	M	D-2	1.82	0.095
Perognathus parvus	0031	M	F-3	1.68	0.088
Perognathus parvus	0029	M	H-9	1.47	0.077
Perognathus parvus	0101	M	F-7	1.68	0.088
Perognathus parvus	0031	M	B-5	8.66	0.453
Perognathus parvus	0132	M	A-2	1.23	0.064
Perognathus parvus	0429	M	D-4	1.41	0.073
Perognathus parvus	0113	M	K-4	1.62	0.084
Perognathus parvus	0031	M	A-2	1.85	0.096
Perognathus parvus	0032	F	J-3	1.60	0.084
Perognathus parvus	0100	F	C-5	1.89	0.099
Perognathus parvus	0132	M	B-2	1.98	0.103
Perognathus parvus	0141	M	F-10	2.60	0.136
Perognathus parvus	0142	M	G-8	1.83	0.095
Perognathus parvus	0153	M	E-1	2.34	0.122
Perognathus parvus	0429	M	C-1	2.13	0.107
Perognathus parvus	1141	M	G-4	1.60	0.083
Perognathus parvus	0021	F	F-3	1.75	0.091
Perognathus parvus	0031	M	A-9	1.75	0.091
Perognathus parvus	0032	F	J-4	1.50	0.078
Perognathus parvus	0100	F	D-7	1.75	0.091
Perognathus parvus	0113	M	K-4	1.30	0.068
Perognathus parvus	0141	M	E-1	1.75	0.091
Perognathus parvus	0142	M	F-2	1.50	0.078
Perognathus parvus	0153	M	H-1	1.50	0.078
Perognathus parvus	0429	M	C-2	1.50	0.078
Perognathus parvus	1141	M	K-3	1.25	0.065
Perognathus parvus	0013	F	H-4	1.61	0.084
Perognathus parvus	0013	F	H-5	1.81	0.095
Perognathus parvus	0021	F	G-2	1.50	0.078
Perognathus parvus	0032	F	K-2	1.75	0.091
Perognathus parvus	0100	F	B-7	1.75	0.091
Perognathus parvus	0132	M	B-1	2.29	0.119
Perognathus parvus	0141	M	G-3	2.00	0.104
Perognathus parvus	0429	M	H-3	3.50	0.183
Perognathus parvus	0031	M	A-2	1.45	0.076
Perognathus parvus	0113	M	K-1	1.45	0.076
Peromyscus maniculatus	0035	M	J-4	1.40	0.073
Peromyscus maniculatus	0035	M	D-7	1.61	0.083
Peromyscus maniculatus	0140	F	H-5	95.5	4.980
Peromyscus maniculatus	0143	M	G-3	2.80	0.146
Peromyscus maniculatus	0222	F	E-10	3.34	0.174
Peromyscus maniculatus	0223	F	B-3	2.69	0.141

(a) F = female, M = male

Gamma Exposure Rates to Mice Living on 300
North Burial Ground (Plot #46) (contd)

Species	Animal I.D. #	Sex[a]	Trap Location	mR/wk	R/yr
Peromyscus maniculatus	0135	M	E-2	1.75	0.091
Peromyscus maniculatus	0140	F	J-10	96.5	5.032
Peromyscus maniculatus	0310	M	E-9	1.30	0.068
Peromyscus maniculatus	0314	F	C-7	112.0	5.840
Peromyscus maniculatus	0143	M	B-3	7.24	0.378
Peromyscus maniculatus	0140	F	J-10	42.0	2.190
Peromyscus maniculatus	0332	M	E-9	30.0	1.564
Peromyscus maniculatus	0310	M	D-7	1.21	0.063

(a) F = female, M = male

Gamma Exposure Rates to Mice Living on a Noncontaminated Area (Control Plot #43)

Species	Animal I.D. #	Sex[a]	Trap Location	mR/wk	R/yr
Perognathus parvus	0155	M	J-2	0.77	0.040
Perognathus parvus	0202	M	H-8	0.91	0.047
Perognathus parvus	0203	M	K-10	0.91	0.047
Perognathus parvus	0205	M	K-1	0.70	0.037
Perognathus parvus	0155	M	J-9	0.63	0.033
Perognathus parvus	0202	M	F-10	0.63	0.033
Perognathus parvus	0222	F	D-7	0.63	0.033
Perognathus parvus	0203	M	K-8	0.63	0.033
Perognathus parvus	0222	F	E-10	1.68	0.088
Perognathus parvus	0242	F	D-2	1.33	0.069
Perognathus parvus	0245	M	D-2	1.68	0.088
Perognathus parvus	0240	F	A-10	1.54	0.080
Perognathus parvus	0251	F	A-9	1.40	0.073
Perognathus parvus	0303	M	B-9	2.03	0.106
Perognathus parvus	0242	F	D-2	1.54	0.080
Perognathus parvus	0304	M	J-2	2.24	0.117
Perognathus parvus	0330	M	F-9	2.00	0.105
Perognathus parvus	0331	M	K-1	2.17	0.113
Perognathus parvus	0324	M	B-9	2.05	0.107
Perognathus parvus	0330	M	E-10	1.05	0.055
Perognathus parvus	0331	M	F-3	1.75	0.091
Perognathus parvus	0332	M	D-2	1.75	0.091
Perognathus parvus	0325	M	B-1	4.04	0.212
Perognathus parvus	0334	F	A-6	2.00	0.106
Perognathus parvus	0342	M	K-9	1.62	0.084
Perognathus parvus	0345	F	D-7	1.62	0.084
Perognathus parvus	0350	M	K-10	1.88	0.098
Perognathus parvus	0324	M	E-5	1.69	0.088
Perognathus parvus	0331	M	J-3	1.50	0.078
Perognathus parvus	0332	M	C-2	1.50	0.078
Perognathus parvus	0334	F	A-6	1.75	0.091
Perognathus parvus	0351	M	A-3	1.81	0.095
Perognathus parvus	0400	F	K-9	1.81	0.095
Perognathus parvus	0019	F	B-1	1.93	0.101
Peromyscus maniculatus	0030	F	F-8	1.96	0.102
Peromyscus maniculatus	0032	M	F-8	2.12	0.111
Peromyscus maniculatus	0032	M	K-7	1.81	0.095

(a) F = female, M = male

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