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Ecological Aspects of Decommissioning and Decontamination of Facilities on the Hanford Reservation

by
W. H. Rickard
E. L. Klepper

June 1976

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BATTELLE
Pacific Northwest Laboratories
Richland, Washington 99352

EXECUTIVE SUMMARY

The Hanford environment and biota are described in relation to decommissioning of obsolescent facilities contaminated with low-levels of radioactive materials. The aridity at Hanford limits both the productivity and diversity of biota. Both productivity and diversity are increased when water is added, as for example on the margins of ponds. Certain plants, especially Salsola kali (Russian thistle or tumbleweed), are avid accumulators of minerals and will accumulate radioactive materials if their roots come into contact with contaminated soils. Data on concentration ratios (pCi per gDW of plant/pCi per gDW soil) are given for several native plants for long-lived radionuclides. Plants are generally more resistant than animals to ionizing radiation so that impacts of high-level radiation sources would be expected to occur primarily in the animals. Mammals and birds are discussed along with information on where they are to be found on the Reservation and what role they may play in the long-term management of radioactive wastes. Food habits of animals are discussed and plants which are palatable to common herbivores are listed. Food chains leading to man are shown to be very limited, including a soil-plant-mule deer-man path for terrestrial sites and a pond-waterfowl-man pathway for pond sites. Retention basins are discussed as an example of how an ecologically-sound decommissioning program might be planned. Finally, burial of large volumes of low-level wastes can probably be done if barriers to biological invasion are provided.

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ECOLOGICAL ASPECTS OF DECOMMISSIONING AND DECONTAMINATION OF FACILITIES ON THE HANFORD RESERVATION

CHAPTER I. INTRODUCTION

This report is written to inform persons with little knowledge of the ecological system about major ecological pathways of radioactivity transport which must be considered during decontamination and decommissioning of facilities on the Hanford Reservation (Figure 1). The arid climate, low soil fertility, and low biological productivity of Hanford ecosystems have been highly favorable for biological confinement of buried radioactive wastes and as a result radionuclides have not contributed significantly to the food chains leading to man. There is every indication that the extant ecosystems (climate-soil-biota) will persist for hundreds of years. Thus, if land areas are designated to be safe with the present ecosystem in mind, they will probably be safe for several centuries unless modified by man's activities.

The facilities with which this report has some pertinent relationships are retention basins and ponds and ditches. Major locations for these facilities are shown in Figure 1. Retention basins were used to hold up reactor effluent coolant water before discharge into the Columbia River and are located near the river shore at all 100 Area reactor sites except 100-N. Cribs and trenches are concentrated near the fuels reprocessing plants in the 200 Area control zone but some occur in the 100 and 300 Areas. They were used to dispose of low-level liquid and solid radioactive wastes. Ponds are almost entirely in the 200 Area control zone, but ditches (sewers) occur in both the 200 and 100 Areas. They have been used to dispose of very low-level liquid wastes.

Ecologically, retention basins, cribs, and trenches present similar arid conditions and support similar species of plants while ponds and ditches support aquatic, streamside and pond margin species. Radionuclides in the retention basins include long-lived fission products and activation products, those in cribs and trenches are mostly fission products, transuranics, and activation products. Most of the radionuclides in ponds are fission products, although U-Pond has received transuranics. Thus, we must be concerned with biological mechanisms in both arid and aquatic ecosystems and with a wide variety of radionuclides, especially those with long physical half-times and biological availability and accumulation in tissues.

For the purpose of this report the object of primary concern is the safe burial of large volumes of material with low levels of radioactivity such as concrete rubble from dismantled buildings and other structures or possibly the sediments containing radionuclides from ponds and ditches.

CHAPTER II. THE ABIOTIC ENVIRONMENT

The Hanford environment is arid with precipitation averaging 6.25 inches per year.

Temperatures most favorable for plant growth occur between mid-March when minimum air temperatures rise above freezing and early November when frosts recur. Soil temperatures at 15 inches depth are sufficiently high during the March to October period to permit root growth and function. However, soil water is not sufficient for that long a period. Figure 2 shows that more than two-thirds of the annual precipitation occurs between the beginning of October and the end of March. This water is mostly stored in the upper few feet of the soil profile. At the end of March, when temperatures become favorable for growth, plants absorb most of this water and deplete the supply by the end of May. The small quantities of precipitation which occur in summer are probably not important to plants since the rain only wets the upper few inches of the profile and evaporates rapidly into the warm dry summer air. Evaporation is hastened by winds. Figure 2 shows that during most of the spring and summer winds of over 13 mph were recorded at the 50 foot level during more than 20% of the hours.

Soils in the waste management areas are generally sandier than soils at higher elevations on the Reservation (Hajek, 1966; Rickard *et al.*, 1973). These sandy soils have low water holding capacity and limited cation exchange capacity. The low water holding capacity allows a deeper penetration of soil water than would be the case in less sandy soils. Depth of water penetration varies from year to year but generally does not exceed 9 feet. Since plant roots will not grow very far into dry soil, there is little probability that roots will penetrate deeper than about 10 feet. This fact has been confirmed in studies presently being done for ARHCO. The low cation exchange capacity of the soils indicates that relatively small quantities of minerals are held in the root zone for plant growth. Although the limiting factor for plant growth is probably the limited water supply in the soil profile, mineral deficiencies may play a role under irrigated conditions or during an unusually wet season.

There are two potentially important abiotic mechanisms for the dispersal of radioactive wastes. These are resuspension by wind and movement downward into the root zone by the action of soil water. Soils of the 200 Areas are generally wind erodible, especially in areas where vegetative cover is sparse.

FIGURE 2. Seasonal Progressions of Temperature, Precipitation and Wind Velocity

Certain soils are more erodible than others because of the high proportion of particles in the most readily eroded range, about 0.06 mm to 0.5 mm (Hinds and Sauer, 1975). Radioactivity associated with superficial soils may be resuspended along with soil particles. Resuspension increases with wind speed. For example, (Sehmel, 1975) found that resuspension increased two orders of magnitude when the wind speed at 7 feet increased from 2.9 to 15 mph. Wind speeds at 7 feet cannot be directly related to information in Figure 2 since the relationship between wind speeds at 50 feet and 7 feet is not constant. However, in Stone et al. (1972) Figure 39 shows wind profile data which indicate that the wind speed at 7 feet is generally between about 50% and 80% of the value at 50 feet.

CHAPTER III. BIOTA

PLANTS

Plants play key roles in ecological systems because they provide the source of energy, essential mineral nutrients, vitamins, protein, and sometimes water to wild and domestic animals. Plants can also provide shelter to animals from wind, rain, and intense solar radiation. This kind of shelter is especially important for animals that do not burrow, e.g., black-tailed hare, mule deer, and most birds. Three general kinds of plants occur on the Hanford Reservation:

(1) Deciduous trees - These are always associated with surface water (ponds or streams) or occur because they were planted by people as shade trees, ornamentals, or for fruit. Trees occupy very little acreage on the Reservation. They are important forage for mule deer and provide nest sites for birds that otherwise could not find appropriate nest locations. A list of tree species that occur on the Hanford Reservation is shown below:

Native riparian trees:

Black cottonwood	Willows (several species)
------------------	---------------------------

Introduced shade trees:

Siberian elm	Lombardy poplar
White poplar	Mulberry
Black locust	

Fruit trees

Apple	Apricot
-------	---------

Because shade and fruit tree seedlings do not survive in the natural environment, these species will not replace themselves when parent trees die.

(2) Desert shrubs - These small-statured shrubs are usually less than 4 feet tall and grow abundantly throughout the Reservation. They are all native plants and are represented by only a few species as shown below:

Big sagebrush	Purple sage
Spiny hopsage	Antelope bitterbrush
Rubber rabbitbrush	Greasewood
Green rabbitbrush	Winterfat

Only a few species are important for wildlife and livestock forage. Winterfat is a palatable and nutritious forage for domestic sheep and antelope bitterbrush provides food for mule deer. Rubber rabbitbrush is one of the preferred forages of the black-tailed hare.

(3) Herbaceous plants - These kinds of plants are represented on the Hanford Reservation by more than two hundred species. They dominate burned acreages and abandoned agricultural fields. Although most of these plants are native, a few aggressive alien species dominate the vegetative cover on soils that have been subjected to severe disturbances such as plowing or digging for burial wastes. Three categories of herbaceous plants are shown below:

Winter annuals. These are annuals that arise from seeds in the fall of the year, grow throughout the winter, and bloom and set seed before the onset of summer drought. Although many of these are natives, the abundant species are alien weeds.

Common Name

Cheatgrass
Jagged chickweed
Tumble mustard

Summer annuals. These plants germinate from seeds in the early spring, grow throughout the summer, and flower and set seeds in early autumn. Only a few species are summer annuals. The most common ones are bursage and Russian thistle (also called tumbleweed). Russian thistle (tumbleweed) has a deep root system and can absorb radionuclides from soil more avidly than most other kinds of plants and is of special concern to decommissioning and decontamination.

Perennials. These plants live for several to many years and do not rely on annual seed production to sustain viable populations. Perennial forbs and grasses are represented by many species, some of which are preferred foods of wildlife and domestic livestock. Others are seldom eaten by these kinds of animals. Some of the more common grasses that are of concern to decommissioning and decontamination are shown below:

Sandberg bluegrass	Sand dropseed
Needle-and-thread grass	Thickspike wheatgrass
Indian ricegrass	

Some of the common forbs (broad-leaved plants) are shown below:

Yarrow	Cluster lily
Balsamroot	Sego lily
Phlox	Pale evening primrose
Scurf pea	Desert mallow
Sand dock	Turpentine cymopterus

Some plants grow only in habitats where the soil is moist all year round, such as the margins of ponds and ditches. These plants are listed below:

Russian knapweed	Cudweed
Common mullein	Goldenrod
Barnyard grass	Horsetail
Rabbitfoot grass	Sweet clover

Ponds and ditches have special complements of aquatic plants (macrophytes). The important plants are cattail, bulrush, watercress, duckweed, and several species of pond weeds (Potamogeton sp.) (Emery et al., 1974). A list of the vascular plants of waste storage sites in the 200 Areas of the Hanford Reservation is available (Price and Rickard, 1973).

Plant Communities

Three different kinds of terrestrial plant communities are associated with decommissioning and decontamination activities. Two of these are dryland communities comprised of desert shrubs and the other is a moist soil community associated with pond and river shoreline (riparian) communities.

The dryland communities occupy large areas on the more or less level terrain of the Hanford Reservation (Figure 3). The big sagebrush-antelope bitterbrush community-type occupies the southeastern portion of the Hanford Reservation and is characterized by the presence of antelope bitterbrush (Purshia tridentata). Bordering to the west is the big sagebrush (Artemisia tridentata) community type. Soils of these two community types are similar as to soil texture but the bitterbrush sites tend to be more sandy.

The riparian community types occupy little land area and are confined to the Columbia River shoreline and pond margins. In general the older the ponds, the better developed are the riparian communities which consist of broad-leaved trees, especially peach-leaf willow (Salix amygdaloides) growing on soils with few rocks. The Columbia River shoreline consists of coarse gravels and cobbles with relatively few trees. The important plants growing in the cobbles and gravel substrates are wild onions (Allium spp), wiregrass (Eleocharis spp) and species of showy flowered perennial forbes (e.g. Coreopsis and Lupinus).

The primary productivity of a Hanford dryland community is low (Table 1). The productivity of several common kinds of natural communities for comparison purposes is shown below (Odum, 1957).

	<u>g/m²/yr</u>
Desert	40
Shortgrass prairie	69
Tall grass prairie	446
Pine forest	3180

The low primary productivity of arid lands is of great significance to decontamination and decommissioning because this is a strong indication that the landscape can only sustain a small population of herbivorous animals therefore providing fewer chances for transfer of radionuclides beyond the reservation boundaries.

FIGURE 3. Geographic Extent of Sagebrush and Sagebrush-Bitterbrush Communities on the Hanford Reservation

TABLE 1. Annual Yield of Herbaceous Plants in a Sagebrush Community in the Spring of 1973 Expressed as Grams per Square Meter Dry Weight $\pm$ Standard Error.
(Modified from Cline et al. 1975)

	<u>g/m²</u>	<u>% of Total</u>
Annual grasses	25	61
Annual forbs	11	27
Perennial grasses	5	12
Perennial forbs	<u><1</u>	<u><1</u>
Total	41 $\pm$ 4.3	100

Plant Uptake of Minerals from Soil

Plant roots absorb mineral elements from the soil substrate in the normal course of growth and development. The same absorptive mechanisms also apply to radionuclides associated with soil. Once taken into roots, minerals are moved to aboveground parts, stems, leaves, and flowers. Generally, forbs accumulate minerals and radionuclides more avidly than grasses. Minerals may be associated with living tissues for many years as in the case of woody stems of trees or the association may be ephemeral as it is when minerals are incorporated into short-lived plants or the leaves and flowers of deciduous perennials. In any event, minerals eventually are returned to the soil upon plant death. Minerals are released to the soil through breakdown of dead tissues accelerated by weathering and microbial decomposition processes. Eventually they may become reabsorbed by living plants unless they are leached out of the rooting profile. Radionuclides can become associated with soil through direct surface contamination as in spills or through purposeful releases below the ground surface as in trenches or cribs and be available for plant uptake through root systems.

Not all minerals are taken into roots with equal facility. Some elements are strongly concentrated while others are actively excluded. The data of Table 2 show concentration factors for various mineral elements as determined for crop plants. The concentration ratio (C.R.) is determined by dividing the concentration of the element of concern expressed on a per gram dry weight basis by the measured concentration in the soil expressed upon a per gram dry weight basis. C.R. values are obtained from laboratory experiments by growing

TABLE 2. Relative Concentration Ratios (C.R.)
Determined for Crop Plants. Data
are from Menzel (1965).

Strongly Concentrated Elements
CR 10-1000

K	P	Br
Rb	S	Na
N	Cl	Li

Slightly Concentrated Elements
CR 1-100

Mg	B	Mn
Ca	Se	Zn
Sr	Te	Mo

Not Concentrated Elements
CR 0.1-10

Ba	F	Ni
Ra	I	Cu
Si	Co	

Slightly Excluded Elements
CR 0.01-1

Cs	Fe	
Be	Ru	

Strongly Excluded Elements
CR < 0.01

Sc	Ta	Pm
Y	W	Pb
Zr	Ce	Pu
	Sb	

plants in soils spiked with known amounts of selected radionuclides. Usually isotopes are added to the soil individually to facilitate radiochemical analyses, but sometimes multiple-tracers are added. The C.R. values obtained in the laboratory are useful only for making general predictions of the behavior of mineral uptake in the event of soil contamination in real situations. The actual values measured in field may not agree with laboratory values because of non-uniform mixing of radionuclides in soils and a lack of definite knowledge concerning the lateral and vertical distribution of root systems. Plants also vary in physiological uptake functions at different seasons of the year and different stages of growth and development. Some kinds of plants do not lend themselves to indoor experiments, e.g., trees, shrubs, and vines.

Concentration ratios are not applicable to those plants that tap buried radiocontaminants through deeply penetrating root systems nor to plants that are rooted in standing water, e.g., cattails and bulrushes. C.R. values are probably most applicable to cultivated crops where soil is mixed by annual plowing. They are not a suitable substitute for field measurements where radiocontaminants are foliar deposited, either directly or from resuspended soil-radionuclide mixtures. Although there are many different radionuclides to be considered in decontamination procedures, long-lived radionuclides are environmentally of major importance because they have the potential to become involved in food chain transfers and mineral cycling behavior. Radiocesium, radiostrontium, and plutonium are radionuclides that have this potential.

Because Salsola kali (tumbleweed) is an important plant in the waste management zones at Hanford, concentration ratios for this plant have been determined (Routson, 1975). The C.R. for radiostrontium concentrations in soil encompassing 5 orders of magnitude was 8-11 as compared to 0.031-0.039 for radiocesium. Concentration ratios also increased as plants matured. There was an average 98% increase in the C.R. for strontium as compared to only 61% for radiocesium.

An experimental field plot surface contaminated with ^{90}Sr for 16 years and with ^{137}Cs for 8 years was studied by Cline and Rickard (1972). After 16 years ^{90}Sr was still available for plant uptake. The major loss of ^{90}Sr was through physical decay. Less than 2% of the initial spike was removed in plant harvests. Strontium was taken up by plants up to 100 times more effectively than ^{137}Cs which is in agreement with Routson's values for tumbleweed. Strontium-90 was more or less uniformly distributed in soil that had

been tilled several times. Untilled soil showed that ^{90}Sr tended to move downward in the soil profile with time.

Cesium-137 remained mostly in the surface inch of untilled soil after 8 years had elapsed. Cline and Rickard (1972) did not calculate concentration ratios; however, experimental plots with high amounts of added ^{90}Sr always grew plants with higher ^{90}Sr concentrations in their tissues as compared to experimental plots with lower amounts of added ^{90}Sr .

Relatively few plant uptake studies have been conducted on alpha-emitting elements other than those related to geobotanical prospecting where uptake was noted to be in the order radium > uranium > thorium. Short-term studies have reported less than 10% uptake of neptunium, plutonium, americium, or curium which agrees with the uptake of heavy metals (Price, 1971).

Wilson and Cline (1966) compared the uptake of plutonium from soil by barley with that of tungsten and lead. Uptake of plutonium from an acid soil was greater than uptake from alkaline or calcareous soils, but plutonium uptake was less than either tungsten or lead. Cline (1968) later reported the uptake of americium and plutonium from two of the same soils and indicated C.R. values of 0.003 for americium uptake from either soil and 0.0002 and 0.0001 for plutonium uptake from the acid and alkaline soil, respectively.

There is some indication that plutonium uptake by plants may be enhanced with successive cropping and the passage of time. For instance, Romney *et al.* (1970) studied the uptake of fallout plutonium by clover over a period of 5 years. A 7-fold increase was noted in plutonium uptake into foliage tissue, under greenhouse conditions. It was postulated that the increase in uptake was due to either more roots coming into contact with plutonium particles as the plants aged or that natural organic materials resulting from root tissue decay formed chemical complexes with the plutonium resulting in increased uptake.

In a field experiment using wild and crop plants, the uptake of ^{238}Pu was measured from spiked soils contained in special lysimeters. The results of this experiment are shown in Table 3. Plutonium-238 uptake was very similar in cheatgrass and in barley leaves + stem and caryopses. Cheatgrass was grown under natural rainfall condition but barley was irrigated and fertilized. Tansy mustard accumulated

TABLE 3. Comparison of ^{238}Pu Concentrations in Wild and Crop Plants Grown in Spiked Hanford Reservation Soil Under Outdoor Conditions. (Picocuries per Gram Dry Weight (data from BNWL-1950, Pt. 2)

	Stems Plus Leaves	Stems	Leaves	Seeds (Caryopsis)
Wild Plants				
Cheatgrass (Graminae)	19 ± 1.4	-	-	2.5 ± 0.36
Tansy mustard (Cruciferae)	77 ± 12	-	-	-
Crops (a)				
Barley (Graminae)	20 ± 1.9	-	-	2.7 ± 0.30
Peas (Leguminosae)	-	155 ± 37	250 ± 48	3.2 ± 0.3
(a) irrigated				

more ^{238}Pu per gram of dry stems + leaves than did cheatgrass. Forbs growing on contaminated soil could deliver more plutonium per gram of tissue than grasses. The most avid accumulator studied was the garden pea. Leaves had particularly high concentrations of ^{238}Pu , but the pea seeds were relatively low in plutonium.

The concentration ratios for neptunium, plutonium, americium, and curium were determined for cheatgrass and tumbleweed by Price (1972). The results are shown below as average C.R. values $\pm$ one standard error.

<u>Radionuclide</u>	<u>Tumbleweed</u>	<u>Cheatgrass</u>
^{237}Np	112 $\pm$ 20	13 $\pm$ 0.5
^{239}Pu	0.046 $\pm$ 0.007	0.017 $\pm$ 0.002
^{241}Am	1.4 $\pm$ 0.16	0.60 $\pm$ 0.10
^{244}Cm	2.2 $\pm$ 0.31	0.48 $\pm$ 0.05

These data indicate that plutonium is not as readily absorbed by plants as other transuranics and that tumbleweed is more active than cheatgrass in accumulating transuranics.

Plant Palatability to Herbivores

Although species lists are important in biological characterization of plant communities, animals that utilize plants as food often show selectivity as to species, age of plants, and plant parts. Dietary habits of animals determine the role of plants in food chain transfers of radiocontaminants.

The diet of the black-tailed hare has been determined by microscopic examination of fecal pellets (Uresk et al., 1975). A summary of palatability rankings of Hanford plants is shown in Table 4. Although yarrow is not an abundant plant in the plant communities of the Hanford Reservation, it was highly selected by hares. On the other hand, cheatgrass is the most abundant plant in plant communities in waste management zones and was only sparingly eaten by hares.

Insects are important consumers of plants. One of the most abundant insects is the migratory grasshopper (Melanoplus sanguinipes). The diet of grasshoppers living in a cheatgrass community was investigated by Rogers and Uresk (1974). Relative palatability is shown in Table 5.

TABLE 4. Relative Plant Species Selectivity of Black-Tailed Hares on the Hanford Reservation at 500 Feet Elevation Sites

<u>High Selectivity</u>	
Yarrow	Tumble mustard
Turpentine cymopteris	Needle-and-thread grass
Fleabane	

<u>Moderate Selectivity</u>	
Sandberg bluegrass	Big sagebrush
Matted cryptantha	Rabbitbrush
Scurf pea	

<u>Low Selectivity</u>	
Balsamroot	Spring draba
Wing-nut cryptantha	Blazing star
Spiny hopsage	Cheatgrass
Russian thistle (tumbleweed)	

TABLE 5. Selectivity of Plants by Grasshoppers Living in a Cheatgrass Community on the Hanford Reservation at 1700 Feet Elevation

<u>High Selectivity</u>	
Prickly lettuce	Yellow salsify
<u>Moderate Selectivity</u>	
Bluebunch wheatgrass	Cheatgrass
Lanceleaf microseris	Russian thistle (tumbleweed)
<u>Low Selectivity</u>	
Jagged chickweed	Spring draba
Sandberg bluegrass	Tumble mustard

Ionizing Radiation

Most plant species are less sensitive to ionizing radiation than animals, but there is a range of about 500-fold among plant species and of as much as 50-fold for a given species irradiated under different conditions and at different life stages. Table 6 shows LD₅₀ values for plants of

TABLE 6. LD₅₀ (kR) Values for 30 Crop Plants After ⁶⁰Co Gamma Irradiation of Plant Seed (a)

<u>Common Name</u>	<u>Dose Rate, R/min</u>	<u>LD₅₀, kR</u>
Alfalfa	844	38-62
Barley	844-850	13-20
Clover, button	844	21
Clover, crimson	844-1240	25->64
Clover, red	795-1270	35->108
Clover, sweet	844	59
Cowpea	1260	11
Dallisgrass	710	>32
Fescue	844	19
Grape	790-1240	<4-<5
Guava	1240	17
Lespedeza, Korean	795	<40
Lupine, blue	750	>40
Maize	840	<15
Millet, German	760	14
Oats	840	17-27
Orchardgrass	844	11
Papaya	650	12
Peanut	1260	10
Pepper	1260	24
Pigeon pea	1260	15
Rice	650-1260	<15-42
Rye	714-840	8-16
Sericea	795-840	37-46
Sorghum, grain	1260	>40
Soybean	1260	11
Tomato	609-1240	13-37
Vetch, hairy	840	17
Watermelon	1280	60
Wheat	670-840	14-25

(a) From Sparrow et al., 1971

economic value after irradiation as dry seeds. Woody species have a range of LD₅₀'s from 0.4 - 8 kR. Values for pines and other gymnosperms are mostly <2 kR. The most important single factor affecting LD₅₀ values is the volume of the cell nucleus and chromosomes (Sparrow and Miksche, 1961).

At lower doses, ionizing radiation causes reductions of growth and yield rather than death. The dose, expressed as a percent of the LD₁₀₀, required to produce a number of plant responses is given in Table 7. Exposures required to reduce yield by given percentages are expressed as YD₁₀ and YD₅₀. Generally, the LD₁₀ gives a good approximation of the YD₅₀. Table 8 shows YD₅₀ estimates for crop plants.

Native plants occur in communities made up of different plant species. Radiation can cause changes in community composition as components are affected differently by radiation. Generally, the life forms are radio-sensitive in decreasing order as trees > shrubs > herbs > mosses and lichens. The dryland plant communities at Hanford are probably relatively radioresistant when compared to plant communities of other areas (Table 9).

TABLE 7. Plant Responses to Radiation Doses and the Percent of the LD₁₀₀ Required to Produce Various Effects^(a)

<u>Plant Response</u>	<u>Percent of LD₁₀₀ Required to Produce Response</u>
No obvious effect	11
Growth reduction - 10%	26
Failure to set seed	31
Growth reduction - 50%	34
Pollen failure	41
Flower abortion	44
Growth reduction - severe	58
Lethal dose - 50%	75
Lethal dose - 100%	100

(a) Adapted from Sparrow and Woodwell, 1961

TABLE 8. Estimates of Exposure (kR) for 50 Percent Yield Reduction (YD₅₀) for Gamma Exposures of Economic Plants. (a)

<u>Group 1 (<1)</u>		
broadbean		pea
<u>Group 2 (1-2)</u>		
barley	leek	onion
chives	lentil	rye
<u>Group 3 (2-4)</u>		
lima bean	cucumber	reed fescue
maize	oats	field pea
ryegrass	spinach	wheat
bearded wheatgrass	crested wheatgrass	
<u>Group 4 (4-6)</u>		
alfalfa	kidney bean	smooth brome
sheep fescue	hops	lettuce
millet	orchard grass	peanut
rhubarb	safflower	sorghum
sunflower	wheatgrass	
<u>Group 5 (6-8)</u>		
asparagus	little bluestem	buckwheat
cauliflower	celery	cotton
cowpea	dill	kale
muskmelon	parsnip	bush pepper
squash	sugar cane	swiss chad
timothy	tobacco	watermelon
<u>Group 6 (8-12)</u>		
artichoke	mung bean	beet
broccoli	Chinese cabbage	cantalope
castorbean	red clover	eggplant
black mustard	white mustard	parsley
radish	bird rape	rutabaga
oriental sesame	sisal hemp	soybean
<u>Group 7 (12-16)</u>		
brussels sprout	dallisgrass	flax
bluegrama	India mustard	sweet potato
rice	spearmint	strawberry
turnip		
<u>Group 8 (16-20)</u>		
big bluestem	peppermint	butternut squash
<u>Group 9 (20-24)</u>		
Winter squash		zucchini squash
<u>Group 10 (724)</u>		
okra		winter rape

(a) Data from Sparrow et al., 1971.

TABLE 9. Estimated Short-term^(a) Radiation Exposures Required to Damage Various Plant Communities^(b)

Community Type	Exposures (kR) to Produce		
	Minor Effects	Intermediate Effects	Severe Effects
1. Coniferous forest	0.1 - 1	1 - 2	>2
2. Deciduous forest	1 - 5	5 - 10	>10
3. Shrub	1 - 5	5 - 20	>20
4. Tropical rain forest	4 - 10	10 - 40	>40
5. Rock outcrop (herbaceous)	8 - 10	10 - 40	>40
6. Old fields (herbaceous)	3 - 10	10 - 100	>100
7. Grassland	8 - 10	10 - 100	>100
8. Moss-lichen	10 - 50	50 - 500	>500

(a) Short-term exposures range from about 8 to 30 days according to the literature from which this table was derived. Exposures might be reduced by factors of 2-4 for acute or fallout-decay irradiation.

(b) Source: Whicker and Fraley, 1974.

MAMMALS

Some of the mammals associated with the Hanford Reservation, due to their habitat requirements, burrowing behavior, food habits, potential for long distance travel, and status as game animals, can serve as pathways for transportation of radioactive materials from the Reservation to man. The role of mammals in relation to radionuclides in Hanford environments is discussed in the following text.

Twenty-five species of Hanford mammals, excluding bats, should be considered in evaluating alternative decommissioning and decontamination modes. These are listed by scientific and common names in Table 10. This same assemblage of mammals is categorized into groups based upon the kind of habitats they usually prefer, their food habits, and their size class (Table 11).

Nine mammals are considered as especially important to decommissioning and decontamination and these are shown in Table 12.

TABLE 10. Taxonomic List of Mammals of the Hanford Reservation

<u>Family</u>	<u>Scientific Name</u>	<u>Common Name</u>
Soricidae	<u>Sorex vagrans</u>	Vagrant shrew
Leporidae	<u>Lepus californicus</u> <u>Sylvilagus nuttallii</u>	Black-tailed hare Nuttall cottontail
Sciuridae	<u>*Citellus townsendii</u>	Townsend ground squirrel
Geomyidae	<u>Thomomys talpoides</u>	Northern pocket gopher
Heteromyidae	<u>Perognathus parvus</u>	Great Basin pocket mouse
Castoridae	<u>Castor canadensis</u>	Beaver
Cricetidae	<u>Reithrodontomys megalotis</u> <u>Peromyscus maniculatus</u> <u>Onychomys leucogaster</u> <u>Neotoma cinerea</u> <u>Lagurus curtatus</u> <u>Microtus montanus</u> <u>Ondatra zibethica</u>	Western harvest mouse Deer mouse Northern grasshopper mouse Bushy-tailed wood rat Sagebrush vole Montane meadow mouse Muskrat
Muridae	<u>Rattus norvegicus</u> <u>Mus musculus</u>	Norway rat House mouse
Erethizontidae	<u>Erethizon dorsatum</u>	Porcupine
Canidae	<u>Canis latrans</u>	Coyote
Procyonidae	<u>Procyon lotor</u>	Raccoon
Mustelidae	<u>Mustela vison</u> <u>Mustela frenata</u> <u>Taxidea taxus</u> <u>Mephitis mephitis</u>	Mink Long-tailed weasel Badger Striped skunk
Felidae	<u>Lynx rufus</u>	Bobcat
Cervidae	<u>Odocoileus hemionus</u>	Mule deer

* Spermophilus townsendii

TABLE 11. Hanford Mammals Grouped According to Habitat-type, Food Habits and Size Classes

<u>Habitat-Type</u>	<u>Food Habits</u>	<u>Size Classes</u>
<u>Shrub-steppe</u>	<u>Herbivores</u>	<u>Large Mammals</u>
Black-tailed hare	Mule deer	Mule deer
Great Basin pocket mouse	Great Basin pocket mouse	
Deer mouse	Muskrat	<u>Medium Mammals</u>
Grasshopper mouse	Beaver	Coyote
Sagebrush vole	Western harvest mouse	Beaver
Bush-tailed wood rat	Sagebrush vole	Porcupine
Western harvest mouse	Black-tailed hare	Bobcat
Cottontail	Cottontail	Raccoon
Badger	Bush-tailed wood rat	Badger
Northern pocket gopher	Porcupine	Striped skunk
	Townsend ground squirrel	Black-tailed hare
	Northern pocket gopher	Cottontail
	Montane meadow mouse	Muskrat
	House mouse	
	Norway rat	
<u>Riparian-aquatic</u>	<u>Insectivores</u>	<u>Small Mammals</u>
Muskrat	Deer mouse	Mink
Beaver	Vagrant shrew	Norway rat
Raccoon	Grasshopper mouse	Townsend ground squirrel
Mink	Bats	Long-tailed weasel
House mouse		Bushy-tailed wood rat
Montane meadow mouse		Northern pocket gopher
Vagrant shrew		Montane meadow mouse
Porcupine		Sagebrush vole
	<u>Carnivores</u>	Grasshopper mouse
<u>Shrub-steppe and Riparian</u>	Coyote	Deer mouse
Mule deer	Striped skunk	House mouse
Coyote	Weasel	Great Basin pocket mouse
Bobcat	Badger	Western harvest mouse
Striped skunk	Raccoon	Bats
Weasel		Vagrant shrew
<u>Buildings and Caves</u>		
Bats		
Norway rat		

TABLE 12. Hanford Mammals that Warrant Special Consideration in Evaluating Decommissioning and Decontamination Alternatives.

Muskrat	Muskrats occur in waste ponds and ditches and have opportunity to ingest radionuclides through aquatic plants and direct ingestion of pond sediments attached to plants. Muskrats are prey for the large mammalian predators and raptors.
Raccoon	Raccoons occur around waste ponds along the Columbia River and have opportunity to ingest vegetation, fish, frogs, birds, and other aquatic-oriented organisms. Raccoons can be a nuisance because of their agility and curiosity.
Mule deer	Mule deer have access to and often eat vegetation associated with pond margins. Mule deer are mobile enough to leave the Reservation and be killed by hunters outside the Reservation boundaries.
Coyote	The coyote is the most important abundant mammalian predator on the Hanford Reservation.
Badger	Not nearly as abundant as the coyote, but the badger has the ability to dig deep into burial sites and expose buried material.
Townsend ground squirrel	Ground squirrels are burrowing animals with potential to dig into buried wastes.
Black-tailed hare	The hare is abundant in waste management zones and provides prey for large predators. The black-tailed hare is responsible for biotic dispersion of ⁹⁰ Sr and ¹³⁷ Cs in the B-C Crib area after surface exposure by burrowing animals.
Pocket mouse	The pocket mouse is the most abundant mammal on the Hanford Reservation and is prey for all class of mammalian predators.
House mouse Norway rat	These animals are usually associated with buildings, especially the experimental farm in the 100-F Area.

The most notable case of dispersal of radionuclides by mammals occurred in the B-C Crib Area (200 E Area) when radioactive salts buried in a trench were brought to the soil surface by a deep burrowing animal, probably a badger. The exposed salts were subsequently ingested by black-tailed hares which distributed salt and attendant radionuclides, mostly ^{90}Sr and ^{137}Cs over a broad zone in the B-C Crib Area (O'Farrell et al., 1975). Today discrete patches of radioactivity are scattered throughout the area associated with hare urine spots and fecal pellets.

When the source of salt was covered by a thick, asphalt pad, the spread of radiocontamination stopped. Black-tailed hares living in the vicinity of the B-C Cribs at the time when salts were available probably assimilated ^{137}Cs and ^{90}Sr in their bodies. The number of individual hares that became contaminated is unknown. The number of hares eaten by coyotes and golden eagles, the principal hare predators, is also unknown. Although the black-tailed hare probably has a limited range of movement, in terms of daily foraging activities and seasonal migration, the coyote normally ranges much farther afield easily moving off the Hanford Reservation as the situation dictates (Springer, 1976). The golden eagle is even more mobile with ability to travel hundreds or even thousands of miles from the Hanford Reservation.

One of the objectives of decontamination procedures is to place the radioactivity associated with decommissioning debris beyond the reach of wild mammals.

Mule Deer

The mammal with the greatest potential for transferring radioisotopes directly to man is the mule deer. Deer travel to and from the Reservation and during the big-game hunting season they may be shot by hunters and their meat consumed. Deer are mainly browsers. Their diet consists mostly of non-cultivated plants. Because of this, body burdens of radioisotopes are often significantly higher than domestic animals living in the same region. Whicker et al. (1968) reported that the concentration of fallout derived ^{137}Cs in deer flesh was approximately 10 times higher than that observed in beef.

The radioisotope of most concern in dispersal in this manner is ^{137}Cs , which is concentrated in muscle tissues (Hakonsen, 1967). Therefore, consumption of venison can be a potential source of ^{137}Cs . Whicker et al. (1968) and

Johnson et al. (1969) noted that the transfer coefficient (percentage of the daily ^{137}Cs intake per kg meat at equilibrium) in deer was approximately 15-30% as compared to only 4% in beef cattle. About 75% of ingested Cs is assimilated from the gastrointestinal tract. The effective half-time of ^{137}Cs in deer is approximately 14 days. During the last few years the ^{137}Cs content of Hanford deer has been measured at approximately 0.1 pCi/g wet weight (Bramson et al., 1973). Similar values have been reported by Whicker (1973) for deer collected in the mountains of Colorado far removed from nuclear production and processing facilities. Therefore, it would seem that Hanford deer are obtaining very low amounts, if any, of ^{137}Cs from existing Hanford facilities.

Another radioisotope of environmental importance is ^{90}Sr which is concentrated in mammalian bone. If absorbed in large amounts, it can be harmful to the health of the deer. The effective half-time of ^{90}Sr in deer is about 190 days with an assimilation factor of approximately 10% (Schreckhise, 1974). The levels of ^{90}Sr in deer collected on the Hanford Reservation during the past few years are at or near background levels (Bramson et al., 1973).

A significant amount of ^{90}Sr is transferred from the deer's diet and from the bone to developing antlers. This has promoted the idea of using deer antlers which are produced and shed each year as a way to monitor ^{90}Sr levels in the deer's environment. However, this is only feasible if many variables are known. It is doubtful that antlers can be used to quantify contamination levels, but they might be useful for the detection of gross amounts of various bone-seeking pollutants in the deer's environment.

Iodine-131 has been measured in the thyroids of deer at times when levels associated with forage plants is not high enough to detect (Whicker, 1968). The effective half-time for ^{131}I in deer is 6-7 days with about 25% of the ingested iodine being incorporated into the thyroid gland (Gist and Whicker, 1971). In mammals, the thyroid gland accumulates iodine with smaller amounts associated with the circulatory and urinary systems. As far as ^{131}I is concerned, the consumption of deer meat does not present a health hazard to man. The varying levels of ^{131}I in deer from the Hanford Reservation are very closely related to the levels in deer observed in Colorado (Hanson et al., 1963). This suggests that the ^{131}I observed in Hanford deer is primarily from fallout sources rather than from operations on the Reservation.

Very little is known about the kinetics of plutonium and other transuranic elements in deer. Since Pu is a bone-seeker, antlers might be useful indicators for the presence of Pu in the deer's environment. Plutonium-239 has been observed in liver and bone of deer collected on the Hanford Reservation (Bramson et al., 1973), but the concentrations (less than 1 pCi/g wet weight) are very similar to the fallout values as reported by Whicker (1973).

Mammals Other Than Deer

The effective half-times for radiocesium in selected Hanford mammals as reported by Winsor and O'Farrell (1970) are presented in Table 13 and range between 5 and 9 days. The biological half-time for mammals not listed in Table 3 can be estimated, according to Reichle et al. (1970), with the following equation:

$$Y_{Cs} = 3.458 X^{0.2061}$$

where,

$$Y_{Cs} = \text{Biological half-time (days),}$$

$$X = \text{Live body weight (grams).}$$

The biological half-times for ^{90}Sr and ^{131}I can also be approximated according to the expressions:

$$Y_{Sr} = 107.4 X^{0.2612}$$

and,

$$Y_I = 6.819 X^{0.1341}$$

where,

$$Y_{Sr} = \text{Biological half-time for } ^{90}\text{Sr (days),}$$

$$Y_I = \text{Biological half-time for } ^{131}\text{I (days),}$$

$$X = \text{Live body weight (grams).}$$

The assimilation factor for ^{137}Cs in the majority of these smaller mammals ranges from 70 to 100 percent and approximately 10 to 40 percent for ^{90}Sr and ^{131}I .

TABLE 13. Biological Half-times of ^{137}Cs in Various Small Mammals Native to the Hanford Reservation.
Modified from Winsor and O'Farrell (1970)

<u>Species</u>	<u>Half-time (days)</u>
Sagebrush vole	4.4
Montane meadow mouse	4.5
Great Basin pocket mouse	5.3
Western harvest mouse	5.4
Northern grasshopper mouse	5.6
Deer mouse	6.3
House mouse	9.4

Very little is known about the assimilation and retention of ingested plutonium for Hanford Reservation wild animals.

Inhalation of radioactive materials can also be of concern. The retention half-times for lung-absorbed material for certain compounds of ^{131}I and ^{90}Sr are only a few days, while the half-time for plutonium and uranium can range from 100 to 1500 days (Reichle *et al.*, 1970).

With the exception of deer, and possibly rabbits and hares, the mammals associated with the Hanford Reservation are not considered as potential pathways for the transfer of radioactive materials from waste management zones to man. However, consideration should be given to the animals themselves in terms of radionuclide body burdens and radiation doses.

The $\text{LD}_{50/30}$ of the more common small mammals of the Hanford Reservation has been determined and the results are shown in Table 14.

Mammal Populations

Accurate censuses of mammals are difficult to obtain because mammals are wary, mobile and some spend much of the time belowground where they are not available for observation. The most abundant mammal on the Hanford Reservation is the Great Basin pocket mouse (O'Farrell *et al.*, 1975). Maximum populations occur in the Autumn. Population sizes ranged between 206 and 437 individuals per 2.7 hectares. There are no estimates of the number of blacktailed hares or mule deer.

TABLE 14. LD50/30 for Small Mammals of the Hanford Reservation (Modified from O'Farrell and Hedlund, 1970)

<u>Species</u>	<u>LD_{50/30} (RAD)</u>
Northern grasshopper mouse	534
Western harvest mouse	701
Northern pocket gopher	756
House mouse	795
Great Basin pocket mouse	856
Deer mouse	919

BIRDS

Large numbers of waterfowl regularly use the Hanford reaches of the Columbia River as a resting stop during the fall migration. However, the birds of interest are those that actually use Hanford waste ponds and ditches as feeding stations. Ponds are often used by waterfowl and the maximum number of waterfowl by species counted on all ponds on any given day are presented in Table 15. These data show that maximum numbers of birds are in the hundreds. Waterfowl are free to mix with the tens of thousands that utilize the Columbia River and the established wildlife refuges such as the Saddle Mountain Wildlife Refuge in Franklin County and the McNary Wildlife Refuge in Walla Walla County. The average number of waterfowl harvested in Benton and Franklin counties during the decade 1961-70 is shown in Table 16.

Mallards are the preferred target of local hunters and the seasonal fluctuation of mallard use of waste ponds over a 2-year period is shown in Figure 4. Although mallards raise a few young each year on the waste ponds, some birds, such as the American coot, are much more abundant as nesting pairs. Because nesting birds and their young derive much of their food and water from the immediate pond environment, it is logical to expect them to assimilate body burdens of radionuclides in amounts greater than individuals that spend little time and procure little food of pond origin. The seasonal variations in utilization of waste ponds by coots is shown in Figure 5.

TABLE 15. Maximum abundance of Waterfowl Observed at any
One Time on Five Ponds in the 200 Area

(Data derived from BNWL-1885)

	<u>B-Pond</u>	<u>U-Pond</u>	<u>REDOX</u>	<u>Gable</u>	<u>West Lake</u>
	Pond and Field Feeders				
Mallard	72	170	60	128	60
Wigeon	15	250	125	137	140
Green-winged teal	25	20	25	20	50
Blue-winged teal	12	8	15	7	50
Cinnamon teal	20	6	5	20	30
Shoveler	50	36	6	30	25
Pintail	20	13	7	100	75
Canada goose	300	0	0	800	175
American coot	100	20	8	335	95
	Pond Feeders				
Redhead	30	6	0	50	20
Scaup	50	36	24	110	75
Canvasback	0	4	0	40	17
Ringnecked duck	125	24	24	320	100
Goldeneye	55	6	1	150	100
Bufflehead	77	5	8	52	50
Ruddy duck	11	5	4	34	19
American merganser	1	2	6	132	0

TABLE 16. Average Numbers of Waterfowl Harvested During the 1961-70 Hunting Seasons in Benton and Franklin Counties, South-Central Washington^(a)

Species	Benton	Franklin
-----Dabbling Ducks-----		
Mallard	7,401	19,237
Gadwall	210	149
American wigeon	1,259	1,645
Green-winged teal	1,224	1,327
Other teal	16	9
Shoveler	130	277
Pintail	720	1,210
Wood duck	51	0
-----Diving Ducks-----		
Redhead	0	99
Canvasback	0	7
Greater scaup	0	27
Lesser scaup	0	33
Ringneck	34	89
Common goldeneye	76	172
Barrows goldeneye	0	92
Bufflehead	62	148
Ruddy duck	11	32
Old squaw	0	13
Common merganser	0	8
-----Geese-----		
Canada goose	3,711	2,601

(a) United States Department of the Interior Fish and Wildlife Service, Special Scientific Report--Wildlife No. 187. Distribution in states and counties of waterfowl species harvested during 1961-70 hunting seasons. 1975.

FIGURE 4. Number of Mallard Ducks Utilizing Hanford Ponds at Different Months of the Year

FIGURE 5. Number of American Coots Utilizing Ponds at Different Months of the Year

Although waterfowl are the birds of most immediate concern to waste management, there are other birds that can be important in the nuisance spread of contaminants. Among these are the great blue heron. These birds are of concern because they frequent waste ponds, not in large numbers, and are residents (Figure 6). Great blue herons feed upon a variety of plant and animal foods including goldfish.

FIGURE 6. Number of Great Blue Herons Using Ponds at Different Months of the Year

A summary of the birds observed on and near waste ponds and their potential as biological vectors of radioactivity is presented in the following paragraphs.

Birds of Waste Management Zones

The following birds are strongly aquatic in habitat and derive most of their foods from pond-dwelling plants and animals or the immediate shoreline environment. These birds can be expected to have a high potential for uptake of radio-nuclides associated with waste ponds and ditches.

*Pied-billed grebe
Common merganser
Ring-necked duck
Bufflehead
Redhead

*American coot
*Scaup
Goldeneye
Ruddy duck
Canvasback

The following birds, although strongly aquatic-oriented, derive their food from both pond and terrestrial habitats and therefore are not expected to assimilate radionuclides as rapidly as the group of birds above.

*Mallard
American wigeon
*Blue-winged teal
Shoveler
Canada goose

Gadwall
Green-winged teal
*Cinnamon teal
Pintail

The following birds are associated with the shallow water zones and mud flats of ponds where they feed on aquatic insects. In foraging, these birds may have access to radioactive material associated with sediments. These birds are not regarded as game birds.

Northern phalarope
Wilson's phalarope
Pectoral sandpiper
Dunlin
Sanderling
Lesser yellowlegs
Killdeer plover

*American avocet
Wilson's snipe
Least sandpiper
Western sandpiper
Greater yellowlegs
Spotted sandpiper

The following birds use mud in nest construction and could transport radionuclides from pond and ditch margins along with the transported mud.

*Black-billed magpie
*Robin

*Barn swallow
*Cliff swallow

*nesting species

The following birds nest in patches of cattails and rushes (reeds) and, although they are not aquatically oriented, they do feed upon aquatic insects, especially the newly hatched adults. This group of birds could be expected to assimilate radioactivity into their bodies from their insects foods during the nesting season.

*Red-winged blackbird	Yellow-headed blackbird
*Marsh wren	

The following birds are seed and insect eaters but spend considerable time foraging on the ground near waste ponds and ditches and could be expected to obtain some radioactivity from radioactive soil.

Oregon junco	Goldfinch
*Song sparrow	Water pipit
*House finch	*Red-shafted flicker
White-crowned sparrow	*Mourning dove
*Brewer's blackbird	*Common starling

The following birds are aerial feeders and obtain their food by catching adult insects on the wing. These birds forage upon both terrestrial and aquatic insects, but especially on the hatches of aquatic insects.

*Cliff swallow	*Barn swallow
*Common nighthawk	

The following birds kill and eat other birds, small mammals, and reptiles or eat the carcasses of dead animals. These birds are highly mobile, travel great distances in search of food and have the potential to eat animals that are, in turn, closely allied to waste pond and ditch habitats.

*Swainson's hawk	*Common crow
*Marsh hawk	*Kestrel
*Great horned owl	*Prairie falcon
*Red-tailed hawk	*Red-billed gull
*Burrowing owl	*California gull
*Loggerhead shrike	*Great blue heron
*Black-billed magpie	*Black-crowned night heron
*Raven	

* nesting species

The following birds frequent the riparian tree-shrub plant communities and derive most of their food by foraging for insects living on leaves, flowers, and beneath the bark of deciduous trees and shrubs. These kinds of birds would not be expected to obtain much radioactivity from the pond or ditch environment.

Western wood pewee	Nashville warbler
Lewis woodpecker	Orange-crowned warbler
Hairy woodpecker	Yellow warbler
Downy woodpecker	Myrtle warbler
*Eastern kingbird	Audubon's warbler
*Western kingbird	Townsend warbler
Ash-throated flycatcher	McGillivray's warbler
*Bullock's oriole	Wilson's warbler
Red-eyed vireo	Golden-crowned kinglet
Warbling vireo	Ruby-crowned kinglet
Hutton's vireo	Rufous-sided towhee
Western tanager	

The following birds are strongly associated with the dryland or desert shrub habitats and are not expected to derive much food from the waste pond and ditch habitats. These birds are seed and insect eaters.

*Horned lark	*Chukar partridge
*Meadow lark	*Savannah sparrow
*Sage sparrow	Lark sparrow
Sage thrasher	*Say's phoebe
*Long-billed curlew	

Radiation Effects

Measurements of radionuclides in various tissues of wild-living birds ultimately raises the question as to whether or not radionuclide burdens are deleterious to the well-being or health of birds, especially those species which live and raise broods in or near waste management zones (Mellinger and Schultz, 1975). Hanson and Browning (1959) and Hanson and Eberhardt (1971) studied a nesting population of the Canada goose from the Hanford Reservation and showed no

* nesting species

adverse effects of Hanford reactor operations on egg hatchability over a 20-year period. Willard (1960) studied bird populations at White Oak Lake, Tennessee, and reported no apparent gross radiation effects to birds. He concluded that in outdoor environments the stress of ionizing radiation is added to and inseparable from the universal stresses imposed by weather, food availability, predators, disease, etc.

Tester et al. (1967) studied the effects of ionizing radiation on waterfowl. These studies concern pair-formation in the green-winged teal, territorial behavior of the shoveler and renesting of the blue-winged teal. Preliminary conclusions were that duck courtship behavior appears to be unaffected by a high sublethal dose of irradiation and that male-male chasing did not change markedly after irradiation treatment, although there were some trends towards a reduction in chasing. The LD_{50/30} for ducks exposed to radiation results are summarized below. The data for shoveler, green-winged teal, and blue-winged teal are from Tester et al. (1968); the data for mallards are from Abraham (1972).

<u>Species</u>	<u>LD_{50/30}</u>
Shoveler	894 R
Green-winged teal	485 R
Blue-winged teal	715 R
Mallard	704 R

Radiation effect studies are scarce for upland game birds, but a few data are available for pheasants and quail. Maloney and Mraz (1969) compared egg laying performance of irradiated and non-irradiated bobwhite and coturnix quail and found that irradiated birds laid fewer eggs. They also observed that quail were less sensitive to whole-body gamma radiation than the white leghorn chicken.

In a study with pheasants, six adult females receiving a localized dose of 2025 R survived 1-8 days post treatment (Greb, 1955). Observations on non-game birds are limited. The following LD_{50/30} doses are from the papers of Kushniruk (1962).

Greenfinch	(<u>Chloris chloris</u>)	600 R
Goldfinch	(<u>Carduelis carduelis</u>)	600 R
Linnet	(<u>Acontis cannabia</u>)	400 R

House sparrow	(<u>Passer domesticus</u>)	625 R
Serin	(<u>Serinus canarius</u>)	500 R

Willard (1963) found that nestling bluebirds receiving 800-900 R were usually able to leave the nest box at normal time, but their weakened condition and reduced flying ability rendered them more vulnerable to predation. He also concluded that nestling bluebirds seemed to be more resistant to gamma radiation than young chickens. Norris (1958) indicated that week-old songbirds might also have greater radioresistance than laboratory chicks and ducklings of the same age. He also exposed several groups of adult female eastern bluebirds and several eggs to a dose rate of 23.5 R/m for accumulated doses of 200-600 R. The number of eggs laid, incubation period, hatching success, nestling period, and general reproductive success were essentially the same for treated and control females. In addition, he observed second and third broods in both groups and that embryos were more vulnerable to ionizing radiation (Avg. 420 R). He also hypothesized that the LD_{50/30} for bluebirds might exceed 1000 R. In an outdoor experiment Wagner and Marples (1966) studied song birds nesting in the vicinity of a powerful radiocesium source experimentally located in a pine-oak forest at Brookhaven National Laboratory on Long Island, New York. The forest was irradiated 20 hours each day. The chronic dose affect over a 30-day nesting period beyond 66 yards from the source (330 R/30 day during the nesting period) was presumed negligible. Nests of five bird species were located inside the 60-yard radius. These were the tree swallow, rufous-sided towhee, brown thrasher, Baltimore oriole, and eastern bluebird. It was concluded that the LD₁₀₀ for eggs is between 500 and 1000 R delivered at a dose rate up to 50 R/day and that the LD₁₀₀ for adults may be as high as 2000 R at a dose rate up to 150 R/day.

Radionuclides in Birds Inhabiting Waste Management Zones

Brisbin, Geiger, and Smith (1973) studied the accumulation of radiocesium in aquatic birds that inhabit Parr Pond, a cooling water reservoir, on the Energy Research and Development Administration's Savannah River Reservation in South Carolina and found that migratory American coots obtained increasing amounts of ¹³⁷Cs according to the length of time they spent on the pond. Newly arrived coots averaged 4-8 pCi/g live weight (whole-body count) and increased to an average of 15-20 pCi/g at the time of departure. They concluded that migratory birds could remove up to 3.75×10^{-5} curies of radiocesium from Parr Pond each year and redistribute it along their migratory routes.

Krumholz (1954) studied radionuclide uptake of aquatic birds inhabiting White Oak Lake, an impoundment on White Oak Creek located on the Oak Ridge National Laboratory property in Tennessee. Birds that obtained their foods from White Oak Lake had more radioactivity than the birds using the lake as a sanctuary and feeding elsewhere. It is interesting to note that Krumholz found that the tissues of kingfishers and herons both fish-eating birds, did not accumulate as much radioactivity as ducks although they spent some time feeding at the lake.

When White Oak Lake was drained, Willard (1960) studied the uptake of ^{90}Sr and ^{137}Cs in birds utilizing the drained basin and its immediate environment. He found a pronounced seasonal difference in radionuclide uptake. This was apparently correlated with foodweb dynamics. Radionuclide uptake in summer was mostly through insects; but in winter, contamination occurred from ingestion of contaminated soil obtained from foraging on the ground in search of seeds.

Birds frequenting waste management ponds on the Hanford Works Reservation in South-central Washington were studied in the 1940's (Herde, 1947). Many birds utilizing a shallow waste pond contained at least traces of alpha and beta-emitting radionuclides, 5-30% of the alpha activity was attributed to plutonium and the remainder to uranium.

Hanson and Browning (1959) examined coots and waterfowl utilizing waste ponds and obtained total beta activity averaging 0.6 microcuries in muscle and 1.7 microcuries in bone. The major radionuclides in muscle were ^{137}Cs and in bone ^{90}Sr . Silker (1958) studied the ^{90}Sr content of bird bones as related to Hanford Operations and made the following set of observations.

<u>Fish Eaters</u>	<u>Picocuries</u> <u>⁹⁰Sr per g dry ash</u>	
American merganser	0.34	} Average = 0.43
California gull	0.22	
Common loon	0.73	
Ring-billed gull	0.42	
<u>Shorebirds</u>		
Baird's sandpiper	8.63	} Average = 4.88
Greater yellowlegs	3.59	
Killdeer plover	2.41	

<u>Puddle Ducks</u>	<u>Picocuries 90Sr per g dry ash</u>	
Mallard	6.76	} Average = 4.12
American wigeon	1.49	

Silker suggests that these results are a reflection of feeding habits. Shorebirds feed by probing their beaks into wet mud in shallow waters and the puddle ducks feed on aquatic plants and invertebrates such as snails. The fish-eating birds are highly mobile and feed at many different locations on and off the Hanford Reservation.

Hanson and Watson (1960) summarized the relative concentration of beta emitters in six major groups of birds using the Columbia River at Hanford and these are shown below.

<u>Group</u>	<u>Relative Concentration</u>
Shorebirds	45
Diving ducks	30
Grebes	20
Gulls	7
Mergansers	6
River ducks	<u>1</u>
Total	100

Shorebirds again showed the highest concentration of radionuclides.

A radiological incident involving only two ducks occurred in December 1975 and attracted much public attention (Wilson and Essig, 1970). Both ducks were collected at the 100 K reactor area on the Hanford Reservation. The ducks were found in a ditch that contained undiluted reactor effluent water. The ducks were killed in a routine radioecological monitoring survey and had radionuclide concentrations significantly higher than previously measured. The abundant radionuclide in duck flesh was ^{32}P (physical half-life 14 days) and it measured 0.003 and 0.110 microcuries per gram. Since this incident, the ditch has been made inaccessible to ducks by covering the ditch with a wire mesh.

The existence of open ponds and ditches on the Hanford Reservation provides new habitats used by many species of birds (Fitzner and Rickard, 1975). Not only does the water attract birds, but the luxuriant shoreline vegetation provides nesting sites and also provides a source of bird foods in the form of seeds and insects.

AQUATIC BIOTA

Aquatic studies have been conducted at U-Pond (Emery et al., 1974) and at Gable Mountain Pond. U-Pond has received the most attention. The active predators of U-pond are dragonfly larvae, diving beetles, and water scorpions. Non-predaceous animals are benthic invertebrates and common goldfish. U-Pond supports luxuriant algal growth, rooted submergent macrophytes (Potamogeton spp.) and emergent cattails and rushes. The algal population is dominated by sessile filamentous green algae (Cladophora) and colonial green algae (Tetraspora). The planktonic algal population is ephemeral with diatoms and Pediastrum as important contributors to the population. A list of algal genera is presented below.

Benthic Algae

(Blue-green)

Oscillatoria

(Green)

Cladophora

Hydrodictyon

Tetraspora

Characium

Mougeotia

Planktonic Algae

(Blue-green)

Chroosoccus

Anabaena

Aphanizomenon

(Green)

Scenedesmus

Cosmarium

Pediastrum

Selenastrum

Sphaerocyctis

(Diatoms)

Fragillaria

Synedra

Nitzschia

Navicula

Eipthemia

Stauroneis

Cyceotella

Cocconeis

Campylodiscus

Gomphonema

Cymbella

Melosira

Ropaloclia

The pond has a substantial population of goldfish, but other fish species are absent. The source of introduction of goldfish is not known with certainty, but they could have been introduced by Hanford personnel.

Although goldfish feed upon algal and organic detritus with relatively high concentrations of plutonium and americium, they accumulate only small amounts in their body tissues. In situ experiments indicate that uptake is rapid during the first few days when uncontaminated goldfish are introduced to the pond, but an equilibrium level is soon reached which is maintained for months (Cushing and Watson, 1974).

Goldfish are eaten by mammalian and avian predators and this provides a means of radionuclide dispersal from the pond through fecal droppings and in body burdens. However, this route of transport could be reduced or eliminated by applying rotenone or other selective fish toxicant.

FOOD CHAINS TO MAN

The transfer of radionuclides along food chains is of importance because food chains are recognized as a primary input of radioactivity to the body burdens of animals including mankind. The Hanford Reservation has been a good place for the storage and handling of radioactive materials in the past because of the absence of a resident human population and the absence of cultivated agriculture and domestic livestock grazing. Both of these activities are principal contributors of food. Wild plants and animals are less important contributors of food for man when considered as the total amount of food available for consumption but wild plants and animals sometimes can have higher levels of radioactivity than domestic plants and animals and for this reason these kinds of organisms are collected periodically for radiochemical analyses in conjunction with established radiological monitoring programs.

Terrestrial ecological systems (soils, plants, animals) of the Hanford Reservation are inherently low in biological productivity unless artificially irrigated and fertilized. Under natural conditions the mule deer is the most important animal with the potential for taking up radionuclides from native vegetation, accumulating them in flesh with subsequent movement off the reservation where deer may be killed by hunters and the meat eaten (Hedlund, 1975). However, the total number of deer residing on the reservation is small probably in the order of a few hundred animals. The animals do have free access to most of the Hanford Reservation area but most can be excluded by appropriate fencing such as that built around 300-Area burial grounds.

Jackrabbits also can be killed and eaten by people but these animals are not as mobile as mule deer and are seldom eaten as human food. These are more important as a food base for coyotes and golden eagles (Figure 7).

Aquatic ecological systems (other than the Columbia River) are scarce on the Hanford Reservation and for the purpose of potential for radionuclide transfers to people interest is centered on the ponds located in the 200 Areas (Figure 8). These ponds provide a biological means of transfer of many kinds of radionuclides to man through those waterfowl that frequent the ponds, and certain body burdens of radionuclides through ingestion of vegetation, water, sediment and small animals (e.g. snails). Waterfowl then have the ability to fly off the reservation and join a larger population of birds that are hunted for sport and ultimately the meat may be eaten as food. Once these birds become mixed with other migrating birds they are not identifiable except for the differences in radioactivity.

Ponds and their associated shoreline vegetation are extremely attractive to birds (Fitzner and Rickard, 1975). As a result the release of even low levels of radioactivity to surface ponds results in widespread biological diffusion of radionuclides within and outside the pond boundaries.

At least three management schemes are available to land managers: (1) eliminate surface waters as points of low-level radionuclide releases and convert the surface to a dry land status, (2) manipulate the ponds to be less attractive to waterfowl by reducing food availability and (3) determine if existing levels of radionuclide contamination have any significant impact on the health of pond organisms and to people who may eat these organisms.

FIGURE 7. Diagrammatic Sketch of Common Plants and Animals Associated with Dryland Habitats and Major Links in the Food Chain to Man

FIGURE 8. Diagrammatic Sketch of Common Plants and Animals Associated with Waste Ponds and Major Links in the Food Chain to Man

CHAPTER IV. OBSOLESCENT FACILITIES

RETENTION BASINS (An Example)

Retention basins were used to hold up thermally hot reactor effluent water before discharge into the Columbia River. Basins are located near the Columbia River shore at all 100 area sites except 100 N and have low levels of radionuclides associated with porous concrete, cracks and joints.

To prevent concrete disintegration and the subsequent airborne dispersal of radioactivity the walls and floors of the basins have been protected with a layer of clean earth material 1-2 feet deep. The earth material consists of a heterogeneous mix of gravels and cobbles, silt and sand. There is sufficient coarse material to effectively retard the wind export of the fine particulate material. However, the basins do provide a catch-all for imported debris from surrounding areas.

The major means of radionuclide export from the basins would appear to be through root uptake by the sparse plant growth that occurs in the earth fill and the subsequent transport of plant parts by wind. The plant species most adaptable for growth in the basins are Russian thistle, tumble mustard, and cheatgrass. Wind export of tumble mustard and Russian thistle is a chronic problem on the Hanford Reservation. When mature, these plants characteristically break off at ground level and whole plants move across the landscape carried by strong winds. Many of these plants enter the Columbia River and are carried downstream. Others accumulate on fences and need to be periodically removed and burned. Cheatgrass stems do not normally break away from roots, and the dead stems may remain standing in place for several years although small plant fragments, seeds, and pollen are easily carried by wind.

Water is an important mode of radionuclide movement in soils. Water soluble materials move downward and laterally according to soil water flow patterns. If percolation is impeded as it is by the concrete floors of retention basins and insufficient soil material is available to hold all the available precipitation plus the runoff water from the basin walls, then the soluble materials in the soil can be moved upward to the soil surface as the soil becomes water saturated, resulting in salt depositions on the soil surface as residuals from the evaporation process. Dry salts exposed at the surface can then be moved by wind.

Biotic Dispersal Mechanisms

The kinds of plants that can grow and reproduce in the shallow and coarse-textured rooting substrate in retention basins are Russian thistle, Salsola kali; tumble mustard, Sisymbrium altissimum; and cheatgrass, Bromus tectorum. Of these three plants, Russian thistle has the greatest physiological ability to concentrate radionuclides (^{90}Sr , ^{137}Cs , and transuranics), tumble mustard is intermediate and cheatgrass has the least capacity. Once radionuclides are incorporated into plant tissues, they can be dispersed by wind in the case of dead plants, or the green plants can be eaten by herbivorous animals (rodents, hares, rabbits, mule deer) that have access to the basins. Plants are also eaten by insects (grasshoppers) which, in turn, can be ingested by birds (meadowlarks). The rodents, rabbits, and meadowlarks can, in turn, be eaten by carnivorous animals such as the coyote, badger, great-horned owl, and marsh hawk.

Mammals are generally not attracted to retention basins because of a general lack of food and vegetative cover. The back-fill is usually too stony and too shallow to provide a suitable burrowing medium for pocket mice and ground squirrels. Fences could be constructed to exclude mule deer and hares; but mice would probably not be effectively excluded by fencing, especially the house mouse (Mus musculus) and deer mouse, Peromyscus maniculatus, both of which are good climbers.

Birds are not usually attracted to retention basins because of the paucity of food and vegetative cover. Most birds would not accept the sparse vegetation and rocky substrate as a potential nest site; but the killdeer and common nighthawk regularly select these kinds of habitats as nest sites.

Reptiles would generally not find the existing retention basin habitat attractive. However, the gopher snake (Pituophis melanoleucus) and the Pacific rattlesnake (Crotalus viridis) could enter the basin. Once inside the basins, these animals could find it difficult to get out.

The public access into retention basins is not permitted. Occupational workers are required to follow radiation monitoring and decontamination procedures; however, the retention basins are near the Columbia River which may become open to public use in the near future. In this event, recreation seekers could easily enter the basin and perhaps dig into the backfill material, exposing the material to wind movement.

Although much of the residual radioactivity persisting from reactor operations is confined to the immediate retention basin environment, leaks have probably left some low-level contamination on the soil and vegetation surfaces located between the retention basin and the Columbia River.

Breaking up the retention basins and burying the rubble below the expected depth of root penetration probably would provide a more secure containment than the existing system.

There are other obsolescent facilities such as buildings, ditches, shallow trenches and ponds that can be examined in the same fashion as with retention basins.

CHAPTER V. BURIAL STRATEGIES

Decommissioning and decontamination procedures will produce large volumes of low-level waste, such as rubble from building materials. Disposal of these high-volume low-level wastes can most effectively be done by shallow burial. Ideally, burial which is done out of reach of roots and far above the ground water will permit safe long-term storage of large volumes of wastes. Properly engineered burial potentially has the following advantages:

- Overburden provides effective shielding from ionizing radiation
- Wastes are covered sufficiently well to prevent resuspension by wind.
- Wastes will not be available to leaching by precipitation water into ground waters.

Conventional burial provides some of the advantages listed above. Techniques currently in use involve digging a large trench, placing wastes in the bottom of the trench and covering the wastes with backfill material which consists of a mixture of cobbles and top soil. These techniques permit shielding and protection from resuspension by wind, but they do not guarantee that deep-rooted plants will not invade the wastes. No barrier to root penetration is provided. Furthermore, there is nothing to prevent a burrowing mammal from invading the wastes. The conventional technique does provide a suitable substrate for the growth of plants, including Russian thistle and rabbitbrush, both of which can bring radionuclides to the surface (Selders 1950; Klepper et al., 1976). However, the presence of a plant cover does mean that soil water is transpired by the vegetation each year so that leaching into deeper layers of the soil is minimized.

A modified burial technique has been investigated in order to provide barriers to biological invasion of wastes (Cline et al., 1976). One of these techniques is illustrated in Figure 9. Here the cobbles have been stockpiled separately from the topsoil. Gravels are laid into the trench in a deep layer in order to discourage penetration of burrowing animals and plant roots. Sufficient soil is laid over the cobbles to hold water provided by annual precipitation. This topsoil is planted to a stable vegetative cover which will transpire the stored soil water each year and prevent wetting and leaching of the burial wastes. This technique has several advantages as listed below.

FIGURE 9. Experimental Plan for Testing the Efficiency of Cobble Layers as a Barrier to Root Penetration and Rodent Digging

- Biological productivity of the area is maintained
- Soil moisture is retained in the upper part of the profile
- Plants utilize the soil water and prevent it from accumulating in the profile.
- Shallow-rooted plants can be chosen for the revegetation
- A barrier (the cobble layer) is provided to stop plant roots or burrowing animals

Several other buried barriers have been designed to prevent biological invasion of buried wastes (Cline et al., 1976). These include buried asphalt or concrete layers and layers of soil treated with materials toxic to roots.

It would be possible to place barriers at the surface. For example, a concrete slab or an asphalt layer could be installed over buried wastes. These covers would have the advantage that they stop resuspension of soils; they would prevent plants from growing for a number of years and they would probably be difficult for a burrowing mammal to penetrate for many years. However, they would have several disadvantages. They would be unaesthetic and would involve the loss of biological productivity for the area involved. They would cause water to be shed at the edges and would provide an increased supply of water to charge the soil profile at that point. Deep-rooted plants would grow around the periphery of the slabs and would potentially invade wastes if they developed side roots. Cracks would eventually develop in the slabs and water would run down the cracks and set up a place for plants to grow. The slabs would therefore need maintenance and that maintenance requirement would increase with time.

It would be possible to have some of the advantages of a hard cover if the surface were covered with a layer of gravel. However, the gravel would eventually accumulate airborne debris including soil and would eventually become populated with plants like rabbitbrush or tumbleweed which are sufficiently deep-rooted to grow through the gravel layer and penetrate the soil below. This solution would have the added disadvantage that precipitation would percolate through the gravel and would build up in the absence of vegetative cover.

In summary, a modified form of the conventional burial technique is one possible way to dispose of high-volume low-level wastes. The modification should involve the installation

of a below-ground biological barrier. It is important that the surface be revegetated so that it is stabilized against wind erosion and so that the annual precipitation is utilized in plant evapotranspiration. The plant cover should be a self-sustaining crop. Cheatgrass is presently the most useful species available.

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