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Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal

Phase II Final Report

Prepared by D. H. McKenzie, L. L. Cadwell, W. E. Kennedy, Jr.,
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Pacific Northwest Laboratory
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EXECUTIVE SUMMARY

The results reported here establish the relevance and propose a method for including biotic transport in the assessment and licensing process for commercial low-level waste disposal sites. Earlier work identified the biotic transport mechanisms and process scenarios linking biotic transport with does to man, and developed models for assessment of impacts. In this, the second phase of the project, we focused on a review of the sub-models of the BIOPORT computer code and scenarios that were developed in Phase I. Also site specific assessments of the relevance of biotic transport were conducted for two commercial low-level waste disposal facilities. The resulting dose calculations indicate that the current BIOPORT/MAXII models predict lower doses than the previous order-of-magnitude estimates developed in Phase I. However, the resulting doses, depending on model and scenario assumptions, range from the same order-of-magnitude to an order-of-magnitude lower than the doses from the comparable intruder-agriculture scenario.

The efforts to review and enhance the BIOPORT model resulted in the following:

- no change in the sub-model representing waste package form decomposition
- updating the diet information for the maximally exposed individual to better reflect current information and proportion of total diet raised on the contaminated site
- enhancement of the model to permit inclusion of erosion at the soil surface and burrow collapse within the trench cover
- incorporation of two alternative representations of plant root uptake of radionuclides.

Inclusion of the two sub-models permits the evaluation of alternative assumptions about the uptake of deeply buried wastes by deep-rooted plants. Model 1 is based on the assumption that literature values for concentration ratios (CR) are appropriate for plants whose roots penetrate the buried wastes. Model 2 is based on the assumption that plant uptake of buried wastes is proportional to the percentage of root biomass that penetrates the wastes.

Sensitivity analyses conducted on the BIOPORT model indicates that the maximum concentration of radionuclides in the surface soil and the year of the maximum concentration depends on the site-specific parameters and the plant model selected.

- Selection of the parameters for a reference arid site and plant model 1 for the sensitivity analysis resulted in the following ranking of parameters, from most to least sensitive; plant rooting depth, plant

biomass, plant root-to-shoot ratios, CR values for Ni, Cs and Sr, waste package half-life, and maximum burrowing depth for animals.

- Selection of the parameters for a reference arid site and plant model 2 for the sensitivity analysis resulted in the following ranking of parameters; maximum burrowing depth for animals, waste package half-life, plant rooting depth, and CR values for Ni, Cs and Sr.
- Selection of the parameters for a reference humid site and plant model 1 for the sensitivity analysis resulted in parameter rankings that were dependent on the assumptions made about the animal component. When a composite animal was included, then the model was sensitive to the following parameters: maximum burrowing depth, depth distribution of redistributed soil, amount of soil moved and an activity index for animals; package half-life; and maximum rooting depth for plants. When a composite animal was not included in the analysis, the model was found to be sensitive to the following parameters; plant rooting depth and plant biomass.
- Selection of the parameters for a reference humid site and plant model 2 for the sensitivity analysis also resulted in a dependency upon the presence of the composite animal parameters: maximum burrowing depth, depth distribution of redistributed soil, amount of soil moved and an activity index for animals. In the absence of the composite animal the model was sensitive to plant rooting depth, plant biomass, and depth distribution of roots.

Reasonable larger and smaller values for plant biomass and volume of soil brought to the surface by animals were selected from the range of values for these two parameters in the literature for both the arid and humid sites. Based on the larger values for these two parameters, the dose to man was found to increase by 57% and 24% for the arid and humid sites, respectively.

The US Ecology Richland Low-Level Waste Disposal Facility was selected for the arid site specific evaluation. Site-specific parameters were evaluated for all parameters except for the waste inventory. The reference arid waste inventory was not changed from the inventory used in the earlier order-of-magnitude estimates. In general, the site-specific scenario resulted in lower soil concentrations than were developed for the reference arid site. Comparison of the intruder-agriculture and the biotic transport scenarios, resulted in a dose to the maximally exposed individual that was lower in the biotic transport, but of the same order-of-magnitude for plant model 1 and an order-of-magnitude less for plant model 2.

The Chem-Nuclear Barnwell Low-Level Waste Disposal Facility was selected for the humid site-specific evaluation. With the exception of the reference waste inventory, site-specific parameters were evaluated in the BIOPORT model. The dose resulting from biotic transport at the Barnwell site was lower than our previous estimates for a reference humid site. Within the biotic transport scenario the dose was nearly an order-of-

magnitude less than the dose within the intruder-agriculture scenario at the humid site for plant model 1 and two orders-of-magnitude less for plant model 2.

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1.0 INTRODUCTION

Commercial low-level waste disposal facilities progress through several stages of development during their "lifetimes." Common assumptions are that some lengthy interval, perhaps 100 years, will expire between the time of site closure and the time when institutional control will no longer occur. Over the long term, occupation of the site by generations of plants and animals can result in a redistribution of radioactive contaminants.

Phase I of Pacific Northwest Laboratory's (PNL's) study of biologically redistributed radionuclides (McKenzie et al. 1984) has identified biotic transport as a common phenomenon at shallow-land disposal sites. Order-of-magnitude estimates of dose to humans from biologically redistributed radioactive waste products show that biotic transport processes result in doses comparable to those calculated for an intruder-agriculture scenario (U.S. Nuclear Regulatory Commission 1981).

In this report we present the results of task 1, phase II, which was concerned with 1) making improvements in the biological transport (BIOPORT) model; 2) conducting sensitivity analyses to identify important and controlling parameters in the model; and 3) conducting site-specific evaluations, using the improved model for a humid and an arid site. In task 2 of the phase II work, we transferred the BIOPORT model and its operating instructions to the U.S. Nuclear Regulatory Commission (NRC) (McKenzie et al. 1985).

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2.0 MODEL MODIFICATIONS/IMPROVEMENTS

Biotic transport, as described in the scenario for commercial low-level waste burial sites, is the result of continuous natural biological processes that act to redistribute buried contaminants. During the interval from trench closure until some time after loss of institutional control, a succession of plant and animal populations occupy the site. Plant roots and burrowing animals penetrate the soil caps covering buried waste and transport contaminants to the surface. Plants take up contaminants and move them to the surface through their roots and stems. Animals excavate contaminated soils by burrowing. The BIOPORT computer subprogram estimates the accumulated quantity of contaminant transport based on properties of the waste, the site and the plant and animal populations. Once radioactive materials have been transported to the surface of the waste site, they provide exposure to eventual site occupants by dose to man resulting from biotic transport processes, we compare estimated doses to those calculated for the intruder-agriculture scenario as used in the DEIS in support of 10 CFR 61. The distinction between the two estimated doses occurs only as a result of the processes by which the radioactive materials became available to site occupants. Plants and animals move radioactive materials in the biotic transport scenario, whereas basement digging exposes the wastes in the intruder-agriculture scenario.

To improve the order-of-magnitude modeling estimates provided in Phase I of this study (McKenzie et al. 1982a; 1982b; 1983; 1984), we have considered modifications to selected sub-models and scenarios. In this section we describe our efforts to enhance these specific areas. Sub-models and scenarios under consideration are: 1) a waste-package form decomposition model; 2) an intruder-agriculture scenario; 3) a soil erosion scenario; 4) a burrow collapse scenario; and 5) plant uptake models.

2.1 WASTE-PACKAGE FORM DECOMPOSITION

To account for the integrity of different waste containers and waste forms in the burial trench, a waste availability relationship was assumed in our order-of-magnitude estimates. In this relationship, the fraction of buried waste available for movement was defined by Equation 2.1 as:

$$Q_A(t) = 1 - e^{-\lambda_A t} \quad (2.1)$$

where: $Q_A(t)$ = the fraction of waste available for movement from decomposed containers or waste forms, unitless,

λ_A = the container decomposition constant defined for the waste spectra, yr^{-1} , and

t = the time since burial, in yr.

Container decomposition was assumed to be a function of the time it takes for containers to decompose, as in:

$$\lambda_A = \ln 2 / t_{A1/2} \quad (2.2)$$

where: λ_A is defined for Equation 2.1 and where:

$t_{A1/2}$ = the half-time for container decomposition, in yr.

It is not possible to improve on this statement about the durability of buried waste containers and the associated availability of wastes for biotic transport based on current information. Rough estimates of the durability of waste containers buried at arid and humid sites were made (McKenzie et al. 1982b; 1983; 1984) subsequent to reviewing information from the literature. However, no further information on waste-package form decomposition is currently available. As a result, most assessment studies of low-level waste disposal have had to rely on assumed decomposition relationships or ignore the topic altogether (Pinner, Hemming, and Hill 1984; Pinner and Hill 1982; U.S. Nuclear Regulatory Commission 1981; 1982). Because no improved methods are currently available, the assumed waste decomposition model described above is considered adequate for providing estimates of biotic transport. Descriptions of the site-specific assumptions made for our analysis of the US Ecology Richland Commercial Low-Level Waste Disposal Facility at Richland, Washington and the Chem-Nuclear Barnwell Commercial Low-Level Waste Disposal Facility at Barnwell, South Carolina are found in Sections 3 and 4, respectively. A further discussion of the potential sensitivity of the biotic transport results to the waste-package form decomposition relationship is given in Section 5.

2.2 INTRUDER-AGRICULTURE SCENARIO

In the DEIS in support of 10 CFR 61, NRC identified four radiation exposure scenarios for human intrusion (1981, App. H, P. H-15):

- Intruder-Construction Scenario. An individual excavates at an abandoned disposal site to build a house.
- Intruder-Discovery Scenario. This scenario is a subset of the intruder-construction scenario and also involves excavation into a closed site. The time over which the excavation proceeds is reduced compared to the intruder-construction scenario.
- Intruder-Agriculture Scenario. An individual lives in a house built on a closed disposal site surrounded by contaminated soil resulting from

the intruder-construction scenario. The individual consumes vegetables grown in the contaminated soil.

- Intruder-Well Scenario. An individual uses contaminated water from an onsite well.

In phase I of this biotic transport study we compared the intruder-agriculture scenario with the biotic transport scenarios. In this phase of the study (phase II), we have slightly modified the NRC's intruder-agriculture scenario to improve the order-of-magnitude modeling estimates. A description of characteristics and assumptions that remain unchanged from phase I of the biotic pathways analysis is followed by a discussion of our modifications.

The intruder-agriculture scenario relies on the surface soil concentration developed for the intruder-construction scenario. After loss of institutional controls at the closed burial ground, an intruder is assumed to construct a house over a closed trench. Basement construction is assumed to involve digging a foundation hole 3 m deep. The area of the hole is assumed to be 200 m² (20 m by 10 m) at the bottom, and 320 m² (26 m by 16 m) at the top. Construction of the basement results in the movement of about 230 m³ of buried waste and 680 m³ of cover material (U.S. Nuclear Regulatory Commission 1981, App. G, p. G-57 through G-65). Approximately 310 m² of this mixed material is backfilled around the house with the remaining distributed around the house within a 25 m radius. The resulting area for distribution of the waste, correcting for the area of the house, is about 1800 m². If 150 m³ of waste are mixed in a total of 600 m³ of soil, the resulting soil concentration is 0.25 times the waste concentration.

The maximally exposed individual for the human intrusion scenario is exposed by inhalation of resuspended radionuclides, ingestion of garden crops grown in the soil, and direct, penetrating radiation. In order-of-magnitude estimates for the intruder-agriculture scenario compared with estimates for the biotic transport scenario (McKenzie et al. 1982b; 1983), we assumed that the individual ingests 60 kg/yr of vegetables grown in the contaminated soil. We also assumed that he inhales dust with an airborne concentration of 2×10^{-6} g/m³ for 8 h/d, 5 d/wk, or 2000 h/yr. He was, moreover, assumed to be exposed to penetrating radiation for 2000 h/yr.

In this study, we have revised some of our assumptions to improve the intruder-agriculture scenario and the resulting comparisons with the biotic transport scenario. Specifically, we have developed a modified diet for the maximally exposed individual (Table 2.2-1). The consumption values for the various food product groups, obtained from Regulatory Guide 1.109 (U.S. Nuclear Regulatory Commission 1977), have been prorated according to their fraction of the total diet consumed by an average individual (Napier 1981). In addition, for this modified intruder-agriculture scenario, we have assumed the individual raises 25% of the total diet on the contaminated portion of the site.

TABLE 2.2-1. Consumption of Food Products by the Maximally Exposed Individual of the Intruder-Agriculture Scenario

<u>Food</u>	<u>Consumption (kg/yr)^(a)</u>
Leafy vegetables	9.5
Other above-ground vegetables	9.5
Root vegetables	76
Fruit	42
Wheat and grain	51
Eggs	19
Milk	110
Beef	39
Pork	29
Poultry	8.5

(a) Rates obtained from Regulatory Guide 1.109 (U.S. Nuclear Regulatory Commission 1977) have been prorated by food category using the fraction of total diet consumed by an average individual, as calculated from Napier (1981).

2.3 EROSION

Soil erosion effectively removes soil and the radioactive materials contained in the soil from the surface of the burial site. Because plants and animals redistribute radioactive materials to the surface, moderate erosion serves to decrease the amount of onsite radioactive material that is available for exposing humans. Calculations of quantities of radioactive materials lost by erosion are made based on a prior redistribution of radioactive materials by plants and movement of contaminated soil by animal burrowing.

Although the original version of the BIOPORT model contained a term for periodic erosion, our earlier order-of-magnitude estimates of biotic transport for arid and humid sites (McKenzie et al. 1982a; 1983) assumed that erosion was negligible. Modifications made in the current model permit annual baseline amounts of erosion to occur and also allow for an accelerated rate that may be imposed to simulate infrequent, but more severe erosion events. Parameters required for the erosion portion of the model are: 1) a baseline erosion rate, 2) an accelerated erosion rate and 3) the beginning, frequency and duration of the accelerated erosion.

The model does not readjust relative burrowing and rooting depth distributions to account for large amounts of erosion. Extensive erosion would dramatically decrease the cover thickness. We assume that quantities of radioactive materials transported by biotic processes in the years following greatly decreased cover thickness would be much greater because the fraction of animal burrowing and plant root redistribution occurring in the waste zone would be greater. Also, extensive erosion, if occurring regularly, would remove the biologically transported radionuclides from the site. Thus, large-scale erosion radically alters the scenario, and has not been included in the BIOPORT model.

2.4 BURROW COLLAPSE

Earlier versions of BIOPORT did not account for the gradual filling of subsurface burrow space (collapse of burrows). The result was a calculated accumulation of soil on the surface and a continually increasing void volume in each of the strata in which burrowing occurred. To remove the voids and simulate realistic burrow collapse, we modified the BIOPORT code. The adjustment involves moving enough soil downward from the strata directly above to fill the voids. The process begins with the waste inventory and proceeds upwards, so that there is no calculated soil accumulation on the surface. After soil is added to a stratum, the radionuclide concentration is recalculated to account for the radionuclides present in the redistributed soil.

2.5 PLANT UPTAKE MODELS

The BIOPORT model calculates a quantity of radioactive material that is incorporated into plant tissue as a result of plant roots penetrating an overburden of originally clean soil and intruding into the waste zone. Soil-to-plant concentration factors (Ng et al. 1982), or concentration ratios (CR's), are used to calculate the quantity of a particular radionuclide expected to accumulate in the plant tissue, based on a specified quantity of that radionuclide in the soil. Concentration ratios are empirically derived from laboratory experiments or from field-grown plants.

Not all experimental designs determining concentration ratios have used identical plant root configurations relative to the volume of contaminated soil. Some studies have used small containers, such as pots, in which the nuclide was uniformly mixed. Other studies have used large containers or, in outdoor soils, have mixed the nuclide in the top several centimeters (usually about 20 cm) of soil. These configurations result in all of the roots in contact with the nuclide or the surface roots contacting the waste and some small percentage of the deeper roots extending beyond the contaminated zone.

However, the configuration of plant roots at shallow-land burial facilities is different from the configuration used to obtain estimates of plant uptake of radioactive materials. Under waste burial conditions the waste zone occurs well below the soil surface because uncontaminated soil

is used as "cover." Plants growing on a burial site that have roots deep enough to penetrate the cover will have the majority of their roots in a zone that is originally free from contamination. Only a small fraction of the plant roots would normally penetrate the cover and contact radioactive materials in the waste zone. We therefore question whether or not conventional CR's can be applied to the waste burial site root/waste configuration. Napier (1982) attempted to resolve the issue by assuming that plants having some small fraction of their roots in the waste zone will accumulate a concentration of radioactivity in proportion to the fraction of roots that actually encounter the waste. Yet for elements used in trace quantities by plants, a few roots may be as effective in plant accumulation of contaminants as would the entire root mass. We have found no information in the scientific literature to help answer this question. Clearly, this issue needs to be resolved from a technical standpoint.

We chose to modify the BIOPORT model to allow the user to define either of two options. Plant Model 1 calculates plant uptake independently of the fraction of roots in the waste, i.e., it assumes that a few deep roots in contact with the waste would permit the plant to accumulate the same quantity of radioactivity as would be accumulated if all roots were in contact with the waste. The original model (Plant Model 1) is:

$$Q = \sum_{\ell=1}^P C_{S_X} R B'_{\ell k} K$$

where: Q = quantity of a radionuclide taken up by a plant, Ci/ha yr,
 p = total number of plants (associations),
 C_{S_X} = concentration of a radionuclide in s_X , where s_X is the stratum with the highest concentration of the radionuclide, Ci/m³,
 R = concentration ratio of the radionuclide,
 $B'_{\ell k}$ = total biomass of plant ℓ in successional phase k , kg/ha yr,
 K = constant, density of soil⁻¹ = 1 m³/1.7 x 10⁶ g.

Plant Model 2 effectively reduces the calculated concentration of radioactivity in the plant material in proportion to the fraction of the plant's roots in the waste zone. We suggest use of Model 1 when there is uncertainty as to whether or not plant roots uptake radioactive materials in proportion to the root mass in the waste zone. Plant Model 2 is:

$$Q = \sum_{\ell=1}^P C_{S_X} R B'_{\ell k} K f_{\ell S_X}$$

where all variables except $f_{\ell S_X}$ are defined above, and where:

f_{ls_x} = fraction of the roots of plant x in stratum s_x , unitless.

For either plant uptake model, the soil stratum having the highest radionuclide concentration (usually the waste zone) serves as the source of radionuclides for accumulation by the plants.

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3.0 SITE EVALUATION OF US ECOLOGY RICHLAND LOW-LEVEL WASTE DISPOSAL FACILITY

We selected the US Ecology Richland Low-Level Waste Disposal Facility (RLLWDF) for site-specific biotic transport evaluation because it is an operating commercial facility located in an arid region of the United States. Also, we recognized that the data required for parameterizing the biotic transport model are readily available. Plant and animal species occurring in the vicinity of the site have been thoroughly identified, rooting depths and profiles for deep-rooted plants have been reported, and animal burrowing depth distributions are generally known.

3.1 SITE CHARACTERISTICS AND ENVIRONMENT

The RLLWDF is located on the US Ecology site, approximately 30 km northwest of the city of Richland, Benton County, Washington. The commercial burial facility is in the south central portion of the Hanford Site on a 40.5-hectare tract subleased to US Ecology from the State of Washington which, in turn, leases the property from the U.S. Department of Energy. A detailed characterization of the Hanford site, encompassing the US Ecology site, can be found in the Final Environmental Statement of the Energy Research and Development Administration (1975). US Ecology site operations, approved by the State of Washington and the NRC, began in 1965.

Topography in the vicinity of the site is flat to gently rolling. Surface soils consist of sands and silts with some areas of gravel and cobble. The nearest aquifer lies at about 100 m below the surface of the burial facility.

The site has a semiarid climate with hot dry summers and mild winters. Precipitation averages 16.5 cm per year (Stone et al. 1972) and occurs most often between the months of October and February. The native vegetation is dominated by big sagebrush (Artemisia tridentata) and rabbitbrush (Chrysothamnus nauseosus), with an understory consisting of mixed bunch-grasses and forbs. Disturbed sites are usually dominated by annual grass and forb species. Cheatgrass (Bromus tectorum) is the dominant species, followed by several forbs including western tansymustard (Descurainia pinnata), cryptantha (Cryptantha circumscissa), Russian thistle (Salsola kali), and Jim Hill mustard (Sisymbrium altissimum) (Cline et al. 1975).

3.2 WASTE CHARACTERISTICS AND BURIAL PROCEEDURES

Low-level wastes disposed of at the US Ecology site include solid or solidified contaminated materials from hospitals, laboratories, universities, industry and nuclear power plants.

Waste disposal trenches at the site average about 42 m wide, 13 m deep and 250 m long. Trenches are cut through the sandy soils and the excavated material is stockpiled for later use as fill and cover. Waste contained in

55-gal drums is normally placed randomly in the trenches, in distinct locations separated by stacked metal and wood waste boxes. When filled, the trenches are covered with 2.4 m of soil and topped with gravel to minimize wind erosion.

3.3 RADIONUCLIDE INVENTORY

To ascertain the importance of biotic transported commercial low-level waste (CLLW) at waste disposal burial grounds, McKenzie et al. (1982) defined a reference arid site and an inventory of waste at this generic site. In our study we planned to substitute a radionuclide inventory from the currently operating US Ecology site for information estimated for the generic arid site. However, that information was not available and therefore, we used the reference arid site inventory for our current investigation.

Radioactive wastes that are buried at CLLW sites contain a wide variety of radionuclides from many sources. In the Draft Environmental Impact Statement (DEIS) in support of 10 CFR 61, the U.S. Nuclear Regulatory Commission (NRC) projected the volumes of CLLW from all sources to the year 2000 (U.S. Nuclear Regulatory Commission 1981, Appendix D). In the DEIS, NRC identifies four separate waste groups that include 36 separate waste streams (see Table D.5 of U.S. Nuclear Regulatory Commission 1981), and predicts waste volumes generated by the year 2000 in each region of the United States (see Table D.9 of U.S. Nuclear Regulatory Commission 1981). The NRC estimates that about 6.5×10^5 m³ of CLLW will be generated from the reference arid site.

In the DEIS, the NRC further identified four waste "spectra" that are used to help determine performance of selected waste treatment options. Waste spectrum 1 is based on assumptions that waste volumes are determined by a combination of past or existing waste management practices. Waste spectra 2 through 4 are based on the assumption that increasingly effective waste treatment options are employed. These options include waste compaction, solidification, and evaporation of free liquids. To account for the use of these options, volume reduction and increase factors are identified by NRC for each waste stream considered (U.S. Nuclear Regulatory Commission 1981, Table D.21). In addition, isotopic concentrations corrected for twenty years of radioactive decay are presented for the radionuclide mixtures in each waste stream.

For McKenzie et al. (1982), we used the decayed isotopic concentrations for the western United States prepared by the NRC, with some modifications. In this previous study, we combined the 36 waste streams identified by the NRC into six composite waste streams that had been corrected by the appropriate volume increase and reduction factors for waste spectra 1 and 2. As for McKenzie et al. (1982), we intend waste spectrum 1 to be representative of past and current waste management practices. Some of the waste streams, we assume, are solidified. No volume reduction processes are assumed, and with no reduction in volume, void spaces increase the instability of the container. Waste spectrum 2,

we assume, represents the use of improved solidification and volume reduction methods. All reactor liquid wastes are assumed evaporated to 50 weight percent solids prior to solidifications. All compactible trash waste streams are assumed to be compacted. The net result of these methods is to increase the concentration of radionuclide in the waste.

The six decayed composite waste streams considered in this task were 1) solid reactor wastes, 2) solidified liquid reactor wastes, 3) uranium conversion and fuel fabrication waste, 4) industrial and institutional wastes, 5) liquid scintillations wastes, and 6) biowastes.

A summary of the total waste spectra for the reference arid sites is presented as the average 20-year decayed waste concentrations in Table 3.3-1. The radionuclides in these waste spectra are used to develop soil contamination profiles from intrusion and active biotic transport, and to obtain comparative dose values for the intruder-agriculture scenario presented in the DEIS on 10 CFR 61.

3.4 BIOTIC TRANSPORT PARAMETERS

The biotic transport parameters used to represent the US Ecology site are presented in this section. We grouped parameters into five classifications: waste site cover configuration, soil erosion rates, plant populations, animal populations, and waste package/form integrity. We divided plant population parameters into two groups: composition/abundance and succession.

3.4.1 Cover Configuration

Transport of radionuclides in the BIOPORT model is calculated on a per hectare basis. The disposed wastes on the US Ecology site were assumed to be covered by 1.5 m of soil. For purposes of the BIOPORT model, we assumed this cover to be divided into three layers, each 0.5 m thick. To calculate radionuclide concentrations, a waste inventory volume of $6.5 \times 10^4 \text{ m}^3/\text{ha}$ was assumed.

3.4.2 Erosion Rates

Because the soil in the vicinity of the US Ecology site is sandy, when vegetation is removed as a result of fire the soil becomes erodible by wind. Water erosion is not a problem at this site because of the low amount of precipitation and the absence of any flowing water. The Columbia River, the nearest body of water, is approximately 12 km to the north and 100 m lower in elevation.

The rate of wind erosion has been calculated as high as 2.3 cm per year for similar areas of the site (Phillips et al. 1980). This rate was calculated assuming that all sediment particles are erodible, homogeneous, and isotropic. The reestablishment of vegetation, however, reduces this rate drastically in a relatively short time. In our analysis we assumed that the erosion rate will drop to zero, four years after a fire.

TABLE 3.3-1. Decayed Radionuclide Concentrations for Reference Arid Waste Spectra at the US Ecology Site^(a)

Radionuclide	Total for Waste Spectrum 1 (Ci/m ³)	Total for Waste Spectrum 2 (Ci/m ³)
³ H	4.0E-02 ^(b)	6.2E-02
¹⁴ C	4.0E-03	5.3E-03
⁵⁵ Fe	5.0E-01	6.2E-01
⁵⁹ Ni	1.7E-03	2.1E-03
⁶⁰ Co	1.4E+00	1.7E+00
⁶³ Ni	1.4E-01	1.7E-01
⁹⁴ Nb	5.4E-05	6.7E-05
⁹⁰ Sr	4.1E-03	5.2E-03
⁹⁹ Tc	6.4E-05	7.8E-05
¹²⁹ I	1.7E-04	2.1E-04
¹³⁵ Cs	6.4E-05	7.8E-05
¹³⁷ Cs	1.4E+00	1.8E+00
²³⁵ U	2.9E-05	8.7E-05
²³⁸ U	2.9E-05	5.4E-04
²³⁷ Np	9.6E-11	1.2E-10
²³⁸ Pu	5.2E-04	5.8E-04
^{239/240} Pu	4.4E-04	5.9E-04
²⁴¹ Pu	1.4E-02	1.9E-02
²⁴² Pu	9.7E-07	1.3E-06
²⁴¹ Am	3.8E-04	5.3E-04
²⁴³ Am	2.3E-05	3.2E-05
²⁴³ Cm	4.2E-07	6.1E-07
²⁴⁴ Cm	2.7E-04	3.8E-04
Totals	3.5E+00	4.2E+00

(a)Based on information in Appendix D of U.S. Nuclear Regulatory Commission 1981.

(b)Where 4.0E-02 = 4.0×10^{-2} .

3.4.3 Plant Populations

The vegetation of the US Ecology site is typical of the Great Basin semiarid region and consists, primarily, of shrub-steppe species. A few

grass and forb species introduced to the region from Eurasia when the area was settled have persisted; they have become important components of local plant populations. Two of these species, cheatgrass (Bromus tectorum) and Russian thistle (Salsola kali), are so well adapted to this region that when soil disturbance occurs, they often become established and out-compete native species for dominance during the early years of plant succession.

Plant succession is a gradual change in species composition which, in this area, causes a change from annual to perennial species. Daubenmire (1968) estimated this process to take about 100 years. For the purposes of this study, we have designated three phases of succession to reflect how the plant community might change and how these changes will affect the translocation of radionuclides by plants. Table 3.4.3-1 shows the expected

TABLE 3.4.3-1. Aboveground Phytomass Production for Successional Stages at the US Ecology Site (g dry/m²/yr)

<u>Species</u>	<u>Range</u>	<u>Mean</u>	<u>Reference</u>
<u>PHASE 1 - 0-10 YR</u>			
Cheatgrass	132-328	224	Rickard et al. 1976; Rickard and Gano 1979.
Russian Thistle ^(a)	17-68	38	Rickard et al. 1976.
Others	0.4-37	<u>9.8</u>	Rickard et al. 1976; Rickard and Gano 1979.
Total		272	
<u>PHASE 2 - 10-30 YR</u>			
Rabbitbrush	1.7-14.6	4.8	Pearson 1965.
Cheatgrass	18-109	76	Cline et al. 1975; Rickard and Gano 1979.
Others	6-35	<u>23</u>	Cline et al. 1975; Rickard and Gano 1979.
Total		104	
<u>PHASE 3 - AFTER 30 YR</u>			
Rabbitbrush	1.7-14.6	4.8	Pearson 1965.
Sagebrush	4.1-24.5	13.2	Pearson 1965; Rickard et al. 1976.
Cheatgrass	18-109	76	Cline et al. 1975; Rickard and Gano 1979.
Others	6-35	<u>23</u>	Cline et al. 1975; Rickard and Gano 1979.
Total		117	

(a) Estimates based on data from tumble mustard (Sisymbrium altissimum), a plant with similar physiognomy.

dominant species and the range of aboveground phytomass produced per year for each species during our three different phases of succession.

Belowground phytomass can be calculated from root-to-shoot ratios for each successional phase. Table 3.4.3-2 gives root-to-shoot ratios for each phase based on published values for the three community types.

Rooting depths of plants are assumed to have an important influence on the extent of translocation of buried radionuclides. If most roots of a plant community remain near the surface in the layer of uncontaminated overburden, then translocation of buried wastes will be minimal. When roots enter the waste zone, radionuclides in soluble forms are redistributed in the soil profile and also brought to the surface and stored in aboveground plant parts.

Table 3.4.3-3 provides rooting depths for many of the dominant plants that occur in the areas surrounding the US Ecology site. Shrub species are generally the deepest rooted plants with average depths ranging from 150 to 296 cm (Table 3.4.3-3). Forbs are next deepest with averages ranging from 67 to 257 cm. Grasses are usually the shallowest, with average depths ranging from 70 to 139 cm.

Very few studies have estimated the distribution of root biomass in the soil profile for native species. Estimates of root biomass distribution for the dominant species in each of our three successional phases are given in Table 3.4.3-4. The distributions are given as reported in the literature and also after our modification to include some percentage of roots that are recorded from other sources at greater depths (Table 3.4.3-3). The values used in the model are those from our modified distributions. The majority of root biomass for the plant species in this area are within the top meter of soil. A smaller, yet most important, fraction of total root biomass continues to penetrate to depths of 1.5 to 2.5 m (Table 3.4.3-3).

TABLE 3.4.3-2. Range of Root to Shoot Ratios for Plant Successional Stages

<u>Root/Shoot</u>	<u>Successional Phase</u>	<u>Reference</u>
.5 - 1.0	0 - 10 yr	Hinds 1975.
1.0 - 5.0	10 - 30 yr	Branson et al. 1976; Pearson 1965; Barbour 1973.
1.0 - 9.0	after 30 yr	Barbour 1973; Fernandez and Caldwell 1975.

TABLE 3.4.3-3. Rooting Depths of Plants on the US Ecology Site

Species	Mean Rooting Depth (cm)	Range (cm)	Number of Samples	References
<u>SHRUBS</u>				
<u>Artemisia tridentata</u> (Big Sagebrush)	200 248	114-250 110-914	11 9	Klepper et al. 1985 Foxx et al. 1984
<u>Purshia tridentata</u>	296	283-300	4	Klepper et al. 1985
<u>Chrysothamnus nauseosus</u> (Grey Rabbitbrush)	183 285	147-250 100-457 87-224	9 5 2	Klepper et al. 1985 Foxx et al. 1984 Klepper et al. 1979
<u>Chrysothamnus viscidiflorus</u> (Green Rabbitbrush)	153	145-160	2	Klepper et al. 1985
<u>Atriplex spinosa</u>	195	--	1	
<u>Eriogonum niveum</u>	150	--	1	
<u>FORBS</u>				
<u>Salsola kali</u> (Russian Thistle)	172 257 107 67	118-209 238-275	8 2 1 1	Klepper et al. (a) 1985 Price, K. R. Selders 1950 Foxx et al. 1984
<u>Aster canescens</u>	143	136-155	4	Klepper et al. 1985
<u>Aster spp.</u>	154	15-335	5	Foxx et al. 1984
<u>Cymopterus terebinthinus</u>	145	124-160	4	Klepper et al. 1985
<u>Lactuca serriola</u>	85	--	1	" "
<u>Balsamorhiza careyana</u>	140	--	1	" "
<u>GRASSES</u>				
<u>Stipa comata</u>	139 110	122-160 63-168	4 10	Klepper et al. 1985 Foxx et al. 1984
<u>Agropyron spicatum</u>	95	50-136	*	Harris 1967
<u>Oryzopsis hymenoides</u>	83 119	45-122 112-125	2 3	Foxx et al. 1984 Klepper et al. 1985
<u>Poa spp.</u>	89	35-213	9	Foxx et al. 1984
<u>Bromus tectorum</u> (Cheatgrass)	70 91	20-110 105-117 75-200 72-77	2 * * 	Harris 1967 Hulbert 1955 Hironaka 1961 Hull 1963

(a) K. R. Price, personal communication, Pacific Northwest Laboratory, Richland, Washington.
 * Not Available

TABLE 3.4.3-4. Percent Root Biomass Distribution by 0.5 m Profiles for the Dominant Species in Each Successional Phase

		Depth of Each Profile (m)					
		<u>0-0.5</u>	<u>0.5-1.0</u>	<u>1.0-1.5</u>	<u>1.5-2.0</u>	<u>2.0-2.5</u>	<u>References</u>
		<u>PHASE 1 0-10 YR</u>					
Cheatgrass	73	14	13	0	0		Hulbert 1955
Cheatgrass	73	14	10	3	0		OM ^(a)
Russian Thistle	72	22	5	1	0		Klepper et al. 1985
Russian Thistle	70	20	5	3	2		OM
		<u>PHASE 2 10-30 YR</u>					
Rabbitbrush	32	53	11	4	0		Klepper et al. 1985
Rabbitbrush	40	35	17	5	3		OM
Cheatgrass	73	14	10	3	0		OM
		<u>PHASE 3 AFTER 30 YR</u>					
Rabbitbrush	40	35	17	5	3		OM
Sagebrush	70	24	5	1	0		Klepper et al. 1985
Sagebrush	70	20	5	3	2		OM
Cheatgrass	73	14	10	3	0		OM

(a) Our modification to account for some reports of roots at greater depths from other studies (see Table 3.4.3-3).

3.4.4 Animal Populations

There are four species of burrowing mammals and one insect species that present a clear potential for intrusion at the US Ecology site, based on an assumed 1.5 m depth of soil cover. These species, however, are capable of excavating relatively deep burrows and moving considerable quantities of soil (Table 3.4.4-1). The four mammals are the Townsend ground squirrel (*Spermophilus townsendi*), the Great Basin pocket mouse (*Perognathus parvus*), the northern pocket gopher (*Thomomys talpoides*), and the badger (*Taxidea taxus*) (Table 3.4.3-1). The insect species, the harvester ant (*Pogonomyrmex owyheei*), is common on the site and is capable of excavating deep tunnel systems. Fitzner et al. (1979) reported maximum tunnel depths of 1.7 to 2.7 m in five colonies excavated on the Hanford site. A list of the references used for the various parameters in Table 3.4.4-1 is included in the Appendix.

The data presented in Table 3.4.4-1 are representative of burrow systems made by single individuals or one colony per burrow for ants. Burrow volumes represent soil excavated belowground and brought to the surface.

TABLE 3.4.4-1. Burrowing Habits of Potential Animal Intruders in the Vicinity of the US Ecology Site

Animal	Percent of Burrow in Each 0.5 m Profile					Density Animals/ha		Burrow Volume m ³ /nest		Estimated Soil Volume Brought to Surface in First Year (m ³ /ha)	Proportion of New Burrow Systems/yr
	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	Range	X	Range	X		
Townsend Ground Squirrel	50	30	15	5	0	7.4-17	12	.031-0.53	0.025	0.30	0.50-1
Great Basin Pocket Mouse	70	20	5	5	0	33-35	34	.001-.007	0.003	0.10	0.75-1
Northern Pocket Gopher	85	15	0	0	0	6-40	--	1.55-12.00 ^(a)	8.170 ^(a)	8.17	0.75-1
Badger	70	15	5	5	5	--	--	--	0.170	0.21 ^(b)	1.00
Harvester Ants	70	10	10	5	5	12-96	50 ^(c)	.007-.003	0.002 ^(d)	0.10	0.10

(a) Estimate of volume of soil excavated per hectare.

(b) Estimated 0.17 m³ burrow (Lindzey 1976) x 124 burrows/ha/yr (Messick and Hornocker 1981) = 21.08 m³/ha/yr. However, most of the digging is done in existing prey burrows and the burrow density figure was from an area of very high badger density. For our purposes, we used an estimate of 10% new soil excavation and 10% of reported badger density, therefore 21.08 x .01 = .211 m³/ha/yr.

(c) Colonies per hectare.

(d) Represents average burrow volume per colony.

-- Information not available.

Belowground redistribution of soil by burrowing animals has been observed (Winsor and Whicker 1980); however, no means was found for estimating, for most species, quantities of redistributed soil. The volume of soil brought to the surface by pocket gophers was estimated based on the measured volumes of surface soil deposited near burrow entrances (see Appendix).

Since badgers are predatory species generally preying on fossorial rodents, much of their burrowing activity is done during prey capture in existing prey burrow systems. Therefore, the volume of soil moved to the surface by badgers would be less than actual burrow dimensions. We used a value of 10% of the estimated badger burrow volume as representing new soil brought to the surface by the badger. This low value (10%) was selected because the only data we could find for the number of badger burrows per hectare was from a region of high badger density (Messick and Hornocker 1981) and badger burrow volumes based on natal rearing dens (Lindzey 1976), which are likely to be considerably larger than burrows dug while hunting prey.

3.4.5 Waste-Package Form Integrity

Waste-package form decomposition half-lives of 35 years for waste spectrum 1 and 70 years for waste spectrum 2 are used to characterize waste-package integrity at the US Ecology site. These half-lives are the ones used in the reference arid site calculations in McKenzie et al. (1982). No modifications to these assumptions are made for the site because no better modeling data have been found in the literature, as discussed in Section 2.0. However, the sensitivity of the modeling result to the durability of the waste-package form is discussed and reported in Section 5.0.

Based on our review of the reference arid site assumptions used in McKenzie et al. (1982), we have modified the assumed mean age of the waste at the time of closure of the US Ecology site. For the reference arid site we assumed that all the waste packages had been buried for 20 years at the time of site closure. We currently assume that the US Ecology site operates for 20 years, receiving 1/20 of its total waste inventory per year. Thus, the mean age of the waste-package form at site closure is assumed to be ten years.

3.5 BIOTIC TRANSPORT ESTIMATES

Radionuclide concentrations in the surface soil resulting from our study of the reference arid site (McKenzie et al. 1982) scenario have been compared with concentrations from our current study of the US Ecology site, as shown in Table 3.5-1. Parameters are defined in McKenzie et al. (1982) for the reference arid site scenarios that have been simulated with BIOPORT prior to model enhancements. The calculations for the US Ecology site, however, have been performed with the enhanced version of BIOPORT. A comparison of the modeling results has been made at year 100 after site closure, the assumed end of institutional controls. Radionuclides that have

TABLE 3.5-1. Comparison of Surface Soil Concentrations Resulting from Intrusion and Active Biotic Transport Processes at the Reference Arid Site and the US Ecology Site^(a)

Radionuclide	Waste Spectrum 1 ^(b) (pCi/m ²)		Waste Spectrum 2 ^(b) (pCi/m ²)	
	Reference Arid Site	US Ecology Site	Reference Arid Site	US Ecology Site
³ H	7.0E+4 ^(c)	3.7E+4	7.3E+4	3.7E+4
¹⁴ C	1.4E+6	9.2E+5	1.2E+6	8.0E+5
⁵⁵ Fe	1.4E-3 ^(d)	8.0E+2	1.1E-3	6.3E+2
⁶⁰ Co	2.9E+3	4.9E+3	2.3E+3	3.9E+3
⁵⁹ Ni	3.1E+6	4.0E+6	2.6E+6	3.3E+6
⁶³ Ni	1.3E+8	1.6E+8	9.9E+7	1.3E+8
⁹⁰ Sr	5.7E+6	8.2E+6	4.8E+6	6.9E+6
⁹⁰ Y	5.7E+6	8.0E+6	4.8E+6	6.8E+6
⁹⁹ Tc	1.3E+6	1.8E+6	1.0E+6	1.5E+6
⁹⁴ Nb	0 ^(e)	8.3E+4	0 ^(e)	6.8E+4
¹²⁹ I	3.2E+5	4.4E+6	2.6E+5	3.6E+5
¹³⁵ Cs	3.3E+4	4.3E+4	2.6E+4	3.5E+4
¹³⁷ Cs	7.3E+7	6.4E+7	6.1E+7	5.4E+7
^{137m} Ba	7.0E+7	6.1E+7	5.8E+7	5.2E+7
²³⁵ U	1.7E+4	2.9E+4	3.1E+4	4.1E+4
²³¹ Th	1.7E+4	2.9E+4	3.1E+4	4.1E+4
²³⁷ Np	5.3E-2	1.4E+4	4.4E-2	1.1E+4
²³⁸ U	1.7E+4	2.9E+4	2.0E+5	1.9E+5
²³⁴ Th	1.7E+4	2.9E+4	2.0E+5	2.0E+5
²³⁸ Pu	9.0E+4	7.1E+4	6.5E+4	5.3E+4
²⁴⁴ Cm	3.5E+3 ^(f)	7.5E+3	3.1E+3	6.4E+3
²⁴⁰ Pu	8.3E+4	7.0E+4	7.4E+4	6.2E+4
²⁴³ Cm	2.1E+1	6.4E+3	1.9E+1	5.1E+3
²⁴³ Am	8.7E+3	2.0E+4	7.8E+3	1.7E+4
²³⁹ Pu	8.4E+4	7.0E+4	7.4E+4	6.2E+4
²⁴¹ Pu	4.4E+4	3.3E+4	3.9E+4	2.9E+4
²⁴¹ Am	2.8E+5	2.0E+5	2.4E+5	1.8E+5

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 3.3 are used in the intrusion/active biotic transport scenario. The resulting concentrations, in pCi/m², are assumed to be mixed in the top 0.5 m of soil.

(c) Where 7.0E+4 = 7.0×10^4 .

(d) Where 1.4E-3 = 1.4×10^{-3} .

(e) Not considered.

(f) Correction from value of 2.1E+1 in McKenzie et al. (1982).

been transported to the surface are assumed to be uniformly mixed in the top 0.5 m of soil. Plant uptake of radionuclides is assumed to rely on any contact with the roots (Model 1) in both scenarios.

For most radionuclides, the biotic transport estimates for the US Ecology site are generally larger than those obtained for the reference arid site. Of particular note are the increased surface soil concentrations of ^{55}Fe , ^{90}Sr , ^{237}Np , and ^{243}Cm . As part of the modeling improvements made to the BIOPORT computer program, ^{94}Nb has been added to the data libraries.

Surface soil radionuclide concentrations from the intruder-agriculture scenario and from the biotic transport scenario are given for waste spectrum 1 in Table 3.5-2 and waste spectrum 2 in Table 3.5-3. Results from a comparison of the two plant uptake models for the biotic transport scenarios are included. Because of the differences in plant uptake among the different radionuclides, the relative concentrations of radionuclides are variable between the human intrusion and biotic transport scenarios. Recall also that the human intrusion scenario results in a rather small area of contaminated soil (a 25-m radius circle), whereas the biotic transport scenario uniformly contaminates the entire surface of the site (about 70 ha).

In general, the soil concentrations of radionuclides estimated for the biotic transport scenario are less than those estimated for the human intrusion scenario. Notable exceptions to this general finding are ^{55}Fe , ^{237}Np , and ^{243}Cm , where the biotic transport concentrations exceed the human intrusion concentrations. In addition, the biotic transport surface soil concentrations estimated using plant uptake Model 2 are less than those estimated using plant uptake Model 1. This is an expected result because the quantity of radionuclides moved in plant uptake Model 2 is proportional to the fraction of the roots that enter the buried waste zone.

3.6 DOSE CALCULATIONS

Because the mixtures of the radionuclides resulting from the human intrusion scenario and the biotic transport scenario are different, we have performed dose calculations to determine the relative impacts of the two scenarios. By using the same environmental pathway and dose analysis model for the source terms defined in Tables 3.5-2 and 3.5-3, a direct comparison of the scenarios can be made. This section contains a discussion of the pathway and dose models used, the calculated doses for the human intrusion and the biotic transport scenarios, and a comparison of the critical organ doses from the two scenarios.

The PNL computer program MAXII (Napier, Peloquin and Kennedy 1984; McKenzie et al. 1985) calculates the maximum annual dose to an exposed individual from multiple exposure pathways. The annual dose is calculated for each organ of concern for 50 years of exposure, and the maximum annual dose is determined by inspection. The radionuclide inventories in soil are adjusted for radioactive decay and daughter-product buildup during the

TABLE 3.5-2. Comparison of the Surface-Soil Concentrations Resulting from the 10 CFR 61 Intruder-Agricultural Scenario and from the Biotic Transport Processes at the US Ecology Site, Waste Spectrum 1^(a,b)

Radionuclide	Surface Soil Concentrations (pCi/m ²)		
	Intruder/ Agriculture Scenario	Biotic Transport Scenario Model 1 ^(c)	Biotic Transport Scenario Model 2 ^(d)
³ H	1.1E+7 ^(e)	3.7E+4	3.4E+4
¹⁴ C	2.9E+8	9.2E+5	9.0E+5
⁵⁵ Fe	2.9E-1 ^(f)	8.0E+2	3.9E+1
⁶⁰ Co	1.9E+5	4.9E+3	8.2E+2
⁵⁹ Ni	1.3E+8	4.0E+6	5.7E+5
⁶³ Ni	5.0E+9	1.6E+8	2.3E+7
⁹⁰ Sr	2.7E+7	8.2E+6	4.9E+5
⁹⁰ Y	2.7E+7	8.0E+4	4.8E+5
⁹⁹ Tc	4.0E+6	1.8E+6	1.1E+4
⁹⁴ Nb	4.7E+6	8.3E+4	1.6E+5
¹²⁹ I	1.3E+7	4.4E+6	5.9E+4
¹³⁵ Cs	4.7E+6	4.3E+4	1.6E+4
¹³⁷ Cs	1.0E+1	6.4E+7	3.4E+7
^{137m} Ba	9.9E+9	6.1E+7	3.2E+7
²³⁵ U	2.2E+6	2.9E+4	7.7E+3
²³¹ Th	2.2E+7	2.9E+4	7.7E+3
²³⁷ Np	7.4	1.4E+4	6.8E+2
²³⁸ U	2.2E+7	2.9E+4	7.7E+3
²³⁴ Th	2.2E+6	2.9E+4	7.7E+3
²³⁸ Pu	1.8E+7	7.1E+4	5.5E+4
²⁴⁴ Cm	4.4E+5	7.5E+3	1.6E+3
²⁴⁰ Pu	1.7E+7	7.0E+4	5.1E+4
²⁴³ Cm	2.7E+3	6.4E+3	3.2E+2
²⁴³ Am	1.7E+6	2.0E+4	5.9E+3
²³⁹ Pu	1.7E+7	7.0E+4	5.1E+4
²⁴¹ Pu	8.4E+6	3.3E+4	2.6E+4
²⁴¹ Am	5.4E+7	2.0E+5	1.7E+5

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 3.3 are used in the intrusion/active biotic transport scenario. The resulting concentration, in pCi/m², are assumed to be mixed in the top 0.5 m of soil.

(c) Plant uptake of radionuclides relies on any contact with plant roots.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Where 1.1E+7 = 1.1×10^7 .

(f) Where 2.9E-1 = 2.9×10^{-1} .

TABLE 3.5-3. Comparison of the Surface Soil Concentrations Resulting from the 10 CFR 61 Intruder-Agriculture Scenario and from the Biotic Transport Processes at the US Ecology Site, Waste Spectrum 2^(a,b)

Radionuclide	Surface Soil Concentrations (pCi/m ²)		
	Intruder/ Agriculture Scenario	Biotic Transport Scenario Model 1 ^(c)	Biotic Transport Scenario Model 2 ^(d)
³ H	1.3E+7 ^(e)	3.7E+4	3.5E+4
¹⁴ C	2.9E+8	8.0E+5	7.9E+5
⁵⁵ Fe	2.7E-1 ^(f)	6.3E+2	3.1E+1
⁶⁰ Co	1.8E+5	3.9E+3	6.6E+2
⁵⁹ Ni	1.2E+8	3.3E+6	4.7E+5
⁶³ Ni	4.6E+9	1.3E+8	1.8E+7
⁹⁰ Sr	2.6E+7	6.9E+6	4.1E+5
⁹⁰ Y	2.6E+7	6.8E+6	4.1E+5
⁹⁹ Tc	4.4E+6	1.5E+6	8.6E+4
⁹⁴ Nb	3.7E+6	6.8E+4	1.3E+4
¹²⁹ I	1.2E+7	3.6E+5	4.8E+4
¹³⁵ Cs	4.4E+6	3.5E+4	1.3E+4
¹³⁷ Cs	1.0E+10	5.4E+7	2.9E+7
^{137m} Ba	9.5E+9	5.2E+7	2.7E+7
²³⁵ U	4.9E+6	4.1E+4	1.5E+4
²³¹ Th	4.9E+6	4.1E+4	1.5E+4
²³⁷ Np	6.9	1.1E+4	5.4E+2
²³⁸ U	2.9E+7	1.9E+5	8.7E+4
²³⁴ Th	2.9E+7	2.0E+5	8.7E+4
²³⁸ Pu	1.4E+7	5.3E+4	4.1E+4
²⁴⁴ Cm	4.6E+5	6.4E+3	1.5E+3
²⁴⁰ Pu	1.7E+7	6.2E+4	4.6E+4
²⁴³ Cm	2.9E+3	5.1E+3	2.6E+2
²⁴³ Am	1.8E+6	1.7E+4	5.4E+3
²³⁹ Pu	1.7E+7	6.2E+4	4.6E+4
²⁴¹ Pu	8.6E+6	2.9E+4	2.4E+4
²⁴¹ Am	5.5E+7	1.8E+5	1.5E+5

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 3.3 are used in the intrusion/active biotic transport scenario. The resulting concentration, in pCi/m², are assumed to be mixed in the top 0.5 m of soil.

(c) Plant uptake of radionuclides relies on any contact with plant roots.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Where 1.3E+7 = 1.3×10^7 .

(f) Where 2.7E-1 = 2.7×10^{-1} .

50-year calculation period, but are not increased by continuing biotic transport during this period.

The diet and exposure conditions used for the calculation of radiation doses from the various pathways for the intruder-agriculture scenario are defined in Section 2.2. The biotic transport scenario parameters are provided in Section 3.4. In both the intruder-agriculture and the biotic transport scenarios, the maximally exposed individual is exposed by inhalation of resuspended radionuclides, ingestion of garden and farm crops grown in the soil, and direct, penetrating radiation.

Because of the limited contaminated area considered for the intruder-agriculture scenario, we have assumed that only 25% of the maximally exposed individual's diet is grown in contaminated soil. This diet includes milk, meats, and eggs. Also, because the biotic transport scenario can uniformly contaminate a much larger surface area (about 70 ha), the maximally exposed individual's entire diet (including milk, meats, and eggs) is assumed to be grown in contaminated soil. In both scenarios, the maximally exposed individual is assumed to reside on the site and to inhale dust with an airborne concentration of 2×10^{-6} g/m³ for 8 h/d, 5 d/wk or 2000 h/yr. In addition, he is assumed exposed to penetrating radiation from the contaminated soil surface for 2000 h/yr. Doses are calculated for total-body, bone, lung, thyroid, and the lower large intestine (GI-LLI) of the maximally exposed individual.

For the intruder-agriculture scenario, the resulting maximum annual organ doses and the year during a 50-year continuous exposure period in which the doses peak are listed in Table 3.6-1 for the radionuclides of waste spectra 1 and 2. For both waste spectra, the dominant exposure pathway is direct exposure resulting from ¹³⁷Cs and its daughter, ^{137m}Ba. The maximum annual dose from external emitters decreases annually because the soil concentration continues to diminish by radioactive decay. The resulting maximum annual total-body doses were 28 rem for waste spectrum 1 and 29 rem for waste spectrum 2. The resulting maximum annual bone doses are 31 rem and 32 rem for waste spectra 1 and 2, respectively. The maximum annual organ doses for waste spectrum 2 are higher than those previously calculated for the intruder-agriculture scenario at the reference arid site (McKenzie et al. 1982). This increase is a result of modifications made to the exposure scenario and data libraries.

For the biotic transport scenario, the resulting maximum annual organ doses and the year during a continuous 50-year exposure period in which the doses peak are given in Table 3.6-2 for waste spectra 1 and 2. For both waste spectra, the dominant organ is bone and the maximum annual dose is controlled by ingestion of food products grown in the contaminated soil. The peak bone dose after the start of continuous exposure is at year 31 for plant uptake Model 1 and year 28 for plant uptake Model 2, for both waste spectra. The organ doses for waste spectrum 2 are slightly smaller than those reported for waste spectrum 1, because of the longer package decomposition half-time (70 years) assumed for waste spectrum 2 (compared with 35 years for waste spectrum 1). The net impact of the longer

TABLE 3.6-1. Maximum Annual Doses to the Maximally Exposed Individual from the Intruder-Agriculture Scenario at the US Ecology Site^(a)

Waste Spectrum	Maximum Year ^(b)	Organ of Reference	Dominant Radionuclide Contributors To Dose	Dominant Exposure Pathway	Maximum Annual Organ Dose (rem)
1 ^(c) (Past Wastes)	1	Total-body	¹³⁷ Cs + D ^(d)	External	28
	1	Bone	¹³⁷ Cs + D	External	31
	1	Lungs	¹³⁷ Cs + D	External	28
	1	Thyroid	¹³⁷ Cs + D	External	28
	1	GI-LLI	¹³⁷ Cs + D	External	28
2 ^(e) (Future Wastes)	1	Total-body	¹³⁷ Cs + D	External	29
	3	Bone	¹³⁷ Cs + D	External	32
	1	Lungs	¹³⁷ Cs + D	External	28
	1	Thyroid	¹³⁷ Cs + D	External	28
	1	GI-LLI	¹³⁷ Cs + D	External	28

- (a) The doses are calculated over a 50-year continuous exposure period for the waste spectra shown in Tables 3.5-2 and 3.5-3 starting 100 years after closure of the low-level waste burial ground.
- (b) The year in which the maximum annual dose occurs during the 50-year continuous exposure period, starting 100 years after final closure of the CLLW waste burial ground.
- (c) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radionuclides (U.S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.
- (d) The +D notation indicates that the decay energy of a short-lived daughter product is included.
- (e) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U.S. Nuclear Regulatory Commission 1981), with an assumed 70-year container decomposition half-time.

decomposition half-time is to permit more decay of the inventory before biotic transport, effectively reducing the source term. The doses estimated for plant uptake Model 2 are about 10% of the doses estimated for plant uptake Model 1. Again, this result is anticipated because the quantity of radionuclides moved in plant uptake Model 2 is dependent on the fraction of roots that enter the buried waste zone.

Finally, Table 3.6-3 compares the order-of-magnitude dose estimate at the reference arid site (McKenzie et al. 1982) with the dose estimate for Plant Model 1 and Plant Model 2 at the US Ecology site. The results show smaller site-specific doses when compared to the reference arid site doses. This table also illustrates the importance of the particular plant uptake model used for the critical organ doses estimates. For total body and bone, the root uptake Model 1 doses for the US Ecology site are about 40% of the

TABLE 3.6-2. Maximum Annual Doses to the Maximally Exposed Individual from the Biotic Transport Scenario at the US Ecology Site^(d)

Waste Spectrum	Maximum Year ^(d)	Organ of Reference	Dominant Radionuclide Contributors To Dose	Dominant Exposure Pathway	Model 1 ^(b) Maximum Annual Organ Dose (rem)	Model 2 ^(c) Maximum Annual Organ Dose (rem)
1 ^(e) (Past Wastes)	28/19	Total-body	⁹⁰ Sr + D ^(f)	Ingestion	1.6	.15
	31/28	Bone	⁹⁰ Sr + D	Ingestion	6.4	.47
	1/1	Lungs	¹³⁷ Cs + D	External	.18	.095
	1/1	Thyroid	¹³⁷ Cs + D	External	.26	.10
	1/1	GI-LLI	¹³⁷ Cs + D	External	.31	.11
2 ^(g) (Future Wastes)	28/18	Total-body	⁹⁰ Sr + D	Ingestion	1.3	.13
	31/28	Bone	⁹⁰ Sr + D	Ingestion	5.3	.40
	1/1	Lungs	¹³⁷ Cs + D	External	.15	.080
	1/1	Thyroid	¹³⁷ Cs + D	External	.22	.088
	1/1	GI-LLI	¹³⁷ Cs + D	External	.26	.088

- (a) The doses are calculated over a 50-year continuous exposure period for the waste spectra shown in Tables 3.5-2 and 3.5-3 starting 100 years after closure of the low-level waste burial ground.
- (b) Plant uptake of radionuclides independent of fraction of root mass in contact with waste.
- (c) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.
- (d) The year in which the maximum annual dose occurs during the 50-year continuous exposure period, starting 100 years after final closure of the CLLW waste burial ground. Year for root uptake Model 1 followed by year for root uptake Model 2.
- (e) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radionuclides (U. S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.
- (f) The +D notation indicates that the decay energy of a short-lived daughter product is included.
- (g) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U. S. Nuclear Regulatory Commission 1981), with an assumed 70-year container decomposition half-time.

reference arid site doses, whereas the plant uptake Model 2 doses at this site are about 4% of the reference arid site doses. Thus, the net impact of our model modification efforts and utilization of available site-specific data for the US Ecology site is to obtain lower dose estimates compared to our original order-of-magnitude estimates for a reference arid site.

TABLE 3.6-3. Comparison of the Maximum Annual Doses for the Reference Arid Site and the US Ecology Site^(a)

Waste Spectrum	Organ of Reference	Maximum Annual Organ Dose (rem)		
		Reference Arid Site ^(b)	US Ecology Site Model 1 ^(c)	US Ecology Site Model 2 ^(d)
1 ^(e) (Past Wastes)	Total-body	3.7	1.6	.15
	Bone	15	6.4	.47
	Lungs	0.22	.18	.095
	Thyroid	0.38	.26	.10
	GI-LLI	0.20	.31	.11
2 ^(f) (Future Wastes)	Total-body	3.1	1.3	.13
	Bone	13	5.3	.40
	Lungs	0.18	.15	.080
	Thyroid	0.31	.22	.088
	GI-LLI	0.17	.26	.088

(a) The doses are calculated over a 50-year continuous exposure period starting 100 years after closure of the low-level waste burial ground.

(b) As reported in McKenzie et al. 1982.

(c) Plant uptake of radionuclides relies on any contact with plant roots.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radio nuclides (U.S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.

(f) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U.S. Nuclear Regulatory Commission 1981), with an assumed 70-year container decomposition half-time.

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4.0 SITE EVALUATION OF CHEM-NUCLEAR BARNWELL LOW-LEVEL WASTE DISPOSAL FACILITY

We selected the Chem-Nuclear Barnwell Low-Level Waste Disposal Facility (BLLWDF) for site-specific biotic transport evaluation because it is the only currently operating commercial low-level waste disposal facility in the humid eastern part of the United States.

4.1 SITE CHARACTERISTICS AND ENVIRONMENT

The BLLWDF is located on the Barnwell site in Barnwell County, South Carolina, approximately 8 km west of the city of Barnwell. The State of South Carolina authorized CLLW burial at the site in 1971.

Much of the area adjacent to the Barnwell site is recent growth forest land. Some agricultural lands are interspersed among the forest immediately east of the facility. To the west, forest lands predominate on property occupied by the Savannah River Plant. The facility is situated on South Carolina's coastal plain where elevation ranges from 73 to 80 m (240 to 260 ft) MSL. Site topography is generally flat to gently rolling.

Precipitation at the site averages 119 cm per year (U.S. Nuclear Regulatory Commission 1982). The topsoil on the site is very sandy, ranging in depth from 0.61 to 4.6 m (2 to 15 ft). Below the sand lies 15 to 18 m (49 to 59 ft) of Miocene sediment made up of sandy dense clay mixed with coarse gravel. The surrounding vegetation is made up of pine-scrub oak forest, loblolly and mixed pine forest, pine-oak forest and old fields (Ragsdale 1980). Planted pine forests are also abundant in the area.

4.2 WASTE CHARACTERISTICS AND BURIAL PROCEDURES

The NRC has recently characterized the waste buried at Barnwell (U.S. Nuclear Regulatory Commission 1982). In general, a broad spectrum of nuclear wastes, including both low and high specific activity materials, have been disposed of at the site. Wastes going to the site have originated at commercial and institutional facilities as well as at commercial nuclear power generating plants. The latter provides about 75%, by volume, of the waste received, while medical, academic, industrial and research facilities generate the remaining 25%.

Tritium and carbon-14 constitute the principal radionuclides in the non-fuel cycle wastes. Although this waste accounts for a large percent of the total waste by volume, it is but a small fraction of the total radioactivity buried there. The NRC staff has characterized the waste typically disposed of at the Barnwell facility (Table 4.2-1).

In 1981, the state imposed volume restrictions limiting the quantity of waste buried at the Barnwell site to 2832 m³/mo (100,000 ft³/mo). Burial procedures at the site include cutting trenches with heavy

TABLE 4.2-1. Characteristic Waste Material at the Barnwell Site*

<u>Typical Contaminated Material</u>	<u>Waste^(a) (m³)</u>	<u>Volume (%)</u>	<u>Specific Activity^(b) (Ci/m³)</u>
<u>Fuel-Cycle Waste</u>			
Solidified liquids ^(c)	2832	50.0	2.0
Ion-exchange resin ^(c)	317	5.6	160.0
Filter/demineralizer sludge ^(c)	498	8.8	10.0
Cartridge filters	35	0.6	20.0
Trash	<u>566</u>	<u>10.0</u>	0.1
Subtotal	4248	75.0	
<u>Non-Fuel-Cycle Waste</u>			
Trash	<u>1416</u>	<u>25.0</u>	0.1
Total	5664	100.0	

(a) Values are based on 1979 values and were estimated by the NRC staff.

(b) Specific activity based on data taken from NUREG/ICR-0570, Vol. 1, Table 2.5.1.

(c) Solidified in concrete, urea formaldehyde, or other approved solidification media.

Source: Oak Ridge National Laboratory.

*From: Staff. 1982. Environmental Assessment for the Barnwell Low-Level Waste Disposal Facility. NUREG-0879, U.S. Nuclear Regulatory Commission, Washington, D.C.

equipment, placing waste in the trenches and backfilling with excavated soil, and covering the trenches with .91 m (3 ft) of sand and a .61 m (2 ft) clay cap. Although grass covers have normally been maintained on the closed trenches, experimental pine plantings have recently been made on some burial trenches.

4.3 RADIONUCLIDE INVENTORY

At the Barnwell site, as at the US Ecology site, we planned to define a radionuclide inventory based on site-specific rather than on generic site data. Because we received no site-specific information from the Barnwell site operator, we have relied on our prepared radionuclide inventory for the generic humid site (McKenzie et al. 1983).

Section 3.3 of this report discusses NRC's Draft Environmental Impact Statement (DEIS), predicting waste volumes and identifying waste groups in regions of the United States through the year 2000 (U. S. Nuclear Regulatory Commission 1981). The NRC predicts, in the eastern United States, that approximately $9.7 \times 10^5 \text{ m}^3$ of waste will be generated. Other assumptions and also our methods in preparing a radionuclide inventory for the eastern site are the same as those discussed in relation to the western site, in section 3.3. Table 4.3-1 represents a summary of the total waste spectra for the eastern site and reveals the average 20-year decayed waste concentrations.

4.4 BIOTIC TRANSPORT PARAMETERS

The biotic transport parameters used to represent the Barnwell site are presented in this section. We grouped parameters into five classifications: waste site cover configuration, soil erosion rates, plant populations, animal populations, and waste-package form integrity. Plant population parameters have been divided into two groups: composition/abundance and succession.

4.4.1 Cover Configuration

Transport of radionuclides in the BIOPORT model is calculated on a per hectare basis. The Barnwell site was assumed to be covered by 1.5 m of soil. For purposes of the BIOPORT model, this cover was assumed to be divided into three layers, each 0.5 m thick. To calculate radionuclide concentrations, a waste inventory volume of $6.5 \times 10^4 \text{ m}^3/\text{ha}$ was assumed.

4.4.2 Erosion Rates

We elected not to include erosion (exercise the erosion option in the model) for the Barnwell site because plant succession and natural revegetation occurs at a pace rapid enough to preclude significant wind erosion. Water erosion is also negligible due to the sandy soil and distance from flood prone areas.

4.4.3 Plant Populations

The vegetation of the Barnwell site is typical of the eastern coastal plain, where disturbed sites contain mixtures of forbs and grasses. If left undisturbed, these areas eventually become mixed pine forests interspersed with hardwoods. For the purpose of our analysis, we have divided plant succession in this area into three phases beginning with a mixed forb stage, next developing into a grass shrub stage, and followed by a pine-oak forest stage. Revegetation, after a disturbance, occurs in a relatively short time in this area when compared to the arid Hanford Site. The rate of succession will depend on many factors. If bermuda grass (*Cynodon dactylon*) becomes established, pine seeds have difficulty reaching the mineral soil and germinating. This will delay the establishment of the pine forest stage (Oosting 1942). The distance to the nearest seed source will also determine the time it takes for a pine stand to develop (Colley

TABLE 4.3-1. Decayed Radionuclide Concentrations for Reference Humid Site Spectra at the Barnwell Site^(a)

Radionuclide	Total for Waste Spectrum 1 (Ci/m ³)	Total for Waste Spectrum 2 (Ci/m ³)
³ H	2.8E-02 ^(b)	3.6E-02
¹⁴ C	2.2E-03	3.0E-03
⁵⁵ Fe	6.3E-01	7.8E-01
⁵⁹ Ni	2.2E-03	2.6E-03
⁶⁰ Co	1.7E+00	2.1E+00
⁶³ Ni	1.8E-01	2.1E-01
⁹⁴ Nb	6.8E-05	8.4E-05
⁹⁰ Sr	4.1E-03	4.7E-03
⁹⁹ Tc	7.8E-05	9.8E-05
¹²⁹ I	2.2E-04	4.2E-06
¹³⁵ Cs	8.0E-05	9.8E-05
¹³⁷ Cs	1.8E+00	2.2E+00
²³⁵ U	2.2E-05	6.3E-05
²³⁸ U	1.3E-04	3.9E-04
²³⁷ Np	1.2E-10	1.4E-10
²³⁸ Pu	6.3E-04	8.3E-04
^{239/240} Pu	5.5E-04	7.0E-04
²⁴¹ Pu	1.8E-02	2.3E-02
²⁴² Pu	1.2E-06	1.5E-06
²⁴¹ Am	4.8E-04	6.1E-04
²⁴³ Am	2.8E-05	3.7E-05
²⁴³ Cm	5.1E-07	6.9E-07
²⁴⁴ Cm	3.2E-04	4.3E-04
Totals	4.5E+00	5.3E+00

(a)Based on information in Appendix D of U.S. Nuclear Regulatory Commission 1981.

(b)Where 2.8E-02 = 2.8×10^{-2} .

and Gentry 1965). It is common for an even aged stand of young pines to develop after only 10 years in small fields (Oosting 1942). However, in large fields, 121.5 to 202.5 hectares (300 to 500 acres) and larger, succession may be delayed during the grass-shrub stage (Golley and Gentry 1965) because of the distance to the seed source.

In our analysis we will assume the mixed forb stage will last for the first six years, followed by the grass-shrub stage until year 29, and the pine-oak forest stage from year 29 to maturity. If a forest stand in the southeastern coastal plain is allowed to grow undisturbed, the climax community will become a mixed hardwood forest with interspersed relic pines after 150 to 200 years (Odum 1959; Quarterman and Keever 1962; Gano 1917; Whittaker 1970). However, no virgin forest of such composition exists at present because of the development of the land for agricultural and forest product industries. Only occasional hardwood stands exist and are invariably found on sites that are unfavorable for development (Oosting 1942). Therefore, a mixed pine-oak forest is the most probable later successional community for this area and is the one we have used in the BIOPORT model.

The duration of these successional phases is not as distinct as the phases described above, nor are they always for specified lengths of time. However, the values we have chosen for the model are within the ranges given in the literature (Golley and Gentry 1965; Oosting 1942; Odum 1959).

Plants that are typical of each successional phase are given in Table 4.4.3-1, along with ranges of annual phytomass produced during each phase. To calculate belowground phytomass, we used median values taken from Table 4.4.3-2, which give ranges for root to shoot ratios from each phase.

The maximum rooting depth used in our assessment for the Barnwell site is 2 m for all phases. This figure is based on reports taken from the literature. Rooting depths for pitch pine (Pinus rigida) range from 91 to 274 cm (McQuilkin 1935). Loblolly pine (P. taeda) roots are reported to range from 168 to 183 cm (Hoover 1952; Hoover et al. 1953) and roots from short-leaf pine (P. echinata), from 91 to 366 cm (Lull and Axley 1958). The eastern deciduous tree is relatively shallow-rooted. Stout (1956) excavated root systems of 25 trees, representing nine species, and reported a range of root depths from 30 to 152 cm, with a mean depth of 77 cm. Broomsedge (Andropogon virginicus), a grass species, also has shallow roots which may reach 91 cm (Hoover 1952).

We derived a root phytomass depth distribution from data found in a variety of sources (Kochenderfer 1973; Whittaker and Woodwell 1969; Leaf et al. 1971; Van Hook et al. 1977; Kimmins and Hawkes 1978; Borman and Likens 1979; and Coile 1937). Approximately 60% of the root biomass (both the standing crop and the roots that die each year) was assumed to occur between the soil surface and 0.5 m deep; 30%, between 0.5 and 1.0 m; 7%, between 1.0 and 1.5 m; 2%, between 1.5 and 2.0 m; and 1%, deeper than 2 m. The depth distribution of root phytomass at the Barnwell site was assumed to remain constant throughout the successional phases.

TABLE 4.4.3-1. Ranges of Phytomass Produced for Representative Species During Successional Phases for the Barnwell Site

<u>Representative Species</u>	<u>Annual Productivity</u> <u>(g dry/m²/yr)</u>	<u>References^(a)</u>
<u>Mixed Forb Phase; Year 1-6</u>		
<u>Erigeron canadensis</u>		Pinder 1975
<u>Haplopappus divaricatus</u>		Golley and Gentry 1965
<u>Gnaphalium purpureum</u>	350 - 586	Odum 1960
<u>Heterotheca subaxillaris</u>		Whittaker 1970
<u>Digitaria sanguinalis</u>		Wiegert and McGinnis 1975
<u>Grass-Shrub Phase; Year 7-28</u>		
<u>Andropogon virginicus</u>		Whittaker 1970
<u>A. ternarius</u>		Wiegert and McGinnis 1975
<u>Lespedeza cuneata</u>	300 - 970	Golley and Gentry 1965
<u>Aristida purpuracens</u>		Pinder 1975
<u>Leptoloma cognatum</u>		Oosting 1942
<u>Heterotheca subaxillaris</u>		
<u>Pine - Oak Forest Phase; Year 29-500</u>		
<u>Pinus taeda</u>		Odum 1959
<u>P. palustris</u>		Whittaker 1970
<u>P. echinata</u>		Quarterman and Keever 1962
<u>Quercus laevis</u>	1200 - 1400	U.S. Nuclear Regulatory Commission 1982
<u>Q. laevis</u>		Hadgwick 1968
<u>Q. falcata</u>		
<u>Q. stellata</u>		
<u>Carya alba</u>		

(a) References used to assemble information for each successional phase.

TABLE 4.4.3-2. Root-to-Shoot Ratios for Successional Phases at the Barnwell Site

<u>Mixed Forb Phase; Year 1-6</u>	<u>References</u>
0.1 - 0.4	Bray 1963 Monk 1966a
<u>Grass-Shrub Phase; Year 7-28</u>	
0.2 - 0.5	Monk 1966a
<u>Pine-Oak Phase; Year 29-500</u>	
0.2 - 1.0	Monk 1966a, Monk 1966b, Monk 1967, Bray 1963, Whittaker and Woodwell 1969, Santantonio et al. 1977

4.4.4 Animal Populations

The number of animal species capable of constructing deep burrow systems and redistributing buried waste at the Barnwell site is limited. We identified seven burrowing species in this area (Table 4.4.4-1). Four of these, the old field mouse (Peromyscus polionotus), the short-tail shrew (Blarina brevicauda), the Florida harvester ant (Pogonomyrmex badius), and the pyramid ant Dorymyrmex pyramicus, are now present in habitats adjacent to the Barnwell facility. The other three species, the eastern mole (Scalopus aquaticus), gopher tortoise (Gopherus polyphemus), and earthworms are not now present but could exist in this area if favorable habitat becomes available through plant succession. Habitation by these animals would also require either a natural extension of the animal's range or introduction by man.

To estimate amount of soil moved by each species, we obtained representative values from the literature for animal densities and burrow volumes (Table 4.4.4-1). For the vertebrates, we assumed one animal inhabited each burrow; we also assumed that the entire soil volume excavated was brought to the surface. For the two species of ants, burrow volumes were assumed excavated by entire colonies and density was represented as colonies per hectare. The percent distribution of the burrows in the soil profile is given in Table 4.4.4-1.

Some of the needed information on burrowing characteristics was not available in the literature. Therefore, we made estimates, which have been identified in the table, based on the animals' life histories. References used for constructing Table 4.4.4-1 are identified in the Appendix by animal and type of information obtained.

TABLE 4.4.4-1. Burrowing Characteristics^(a) of Potential Animal Intruders at the Barnwell Low-Level Waste Facility

Animal	Percent of Burrow in Each 0.5 m Profile					Density (n/ha)	Mean Burrow Vol. (m ³)	Estimated Soil Volume Brought to Surface in First Year (m ³ /ha)	Proportion of New Burrow Systems/yr
	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0				
Old Field Mouse	95	5	0	0	0	123-178 ^(b)	.002	0.3-0.4	0.90 ^(c)
Short-tail Shrew	100	0	0	0	0	--	--	23-74	1.00 ^(c)
Eastern Mole ^(d)	90	10	0	0	0	10	1.5	15	1.00
Copher Tortoise ^(d)	25	25	20	20	10	7	.15	1.05	0.10
Florida Harvester Ant	70	10	10	5	5	27 ^(e)	.002	0.05	0.90
Pyramid Ant	80	15	5	0	0	3700-6500 ^(e)	.0005 ^(e)	1.85-3.25 ^(c)	1.00 ^(c)
Earthworm ^(d)	100	0	0	0	0	--	--	0.7	1.00

(a) See Appendix A for references used in constructing this table.

(b) Values from population estimates.

(c) Our estimates.

(d) Not on site at present but possible residents with advanced plant succession.

(e) Colonies per hectare.

-- Information not available.

4.4.5 Waste-Package Form Integrity

Waste-package form decomposition half-lives of 15 years for waste spectrum 1 and 35 years for waste spectrum 2 characterize waste package integrity at the Barnwell site. These half-lives are the ones used in the reference humid site calculations in McKenzie et al. (1983). No modifications to these assumptions have been made for the Barnwell site because no additional data have been found in the literature, as discussed in Section 2.0. However, sensitivity analysis of the modeling result to the assumed durability of the waste-package form is discussed and reported in Section 5.0.

Based on a review of the reference humid site assumptions used in McKenzie et al. (1983) we have modified the assumed mean age of the waste at the time of closure of the Barnwell site. For the reference humid site, we assumed that all the waste packages had been buried for 20 years at the time of site closure. We currently assume that the Barnwell site operates for 20 years, receiving 1/20 of its total waste inventory per year. Thus, the mean age of the waste form/package at site closure is assumed to be 10 years.

4.5 BIOTIC TRANSPORT ESTIMATES

Radionuclide concentrations in the surface soil resulting from our study of the reference humid site (McKenzie et al. 1983) have been compared with concentrations from our current study of the Barnwell site, as shown in Table 4.5-1. Parameters are defined in McKenzie et al. (1983) for the reference humid site scenario that has been simulated with BIOPORT prior to model enhancements. The calculations for the Barnwell site, however, have been performed with the enhanced version of BIOPORT. A comparison of the modeling results has been made for year 100 after site closure, the assumed end of institutional controls. Radionuclides that have been transported to the surface are assumed to be uniformly mixed in the top 0.5 m of soil. Plant uptake of radionuclides is assumed to rely on any contact with the roots (Model 1) in both scenarios.

For most radionuclides, the biotic transport estimates for the Barnwell site are generally smaller than those for the reference site for waste spectrum 1, and generally larger than those for the reference humid site for waste spectrum 2.

Surface soil radionuclide concentrations from the intruder-agriculture scenario and from the biotic transport scenario are given for waste spectrum 1 in Table 4.5-2 and waste spectrum 2 in Table 4.5-3. Results from a comparison of the two plant uptake models for the biotic transport scenario are included. Because of the different mobilities of the radionuclides through the plant intrusion pathway, the relative concentrations of radionuclides are variable for the human intrusion and biotic transport scenario. The human intrusion scenario results in a rather small area of contaminated soil (a 25-m radius circle), whereas the biotic transport scenario uniformly contaminates the entire surface of the site (about 70 ha).

TABLE 4.5-1. Comparison of the Surface Soil Concentrations Resulting from Biotic Transport Processes at the Reference Humid Site^(a) and the Barnwell Site

Radionuclide	Waste Spectrum 1 ^(b) (pCi/m ²)		Waste Spectrum 2 ^(b) (pCi/m ²)	
	Reference Humid Site	Barnwell Site	Reference Humid Site	Barnwell Site
³ H	7.1E+3 ^(c)	4.0E+3	5.9E+3	3.8E+3
¹⁴ C	1.3E+5	8.5E+4	1.0E+5	8.6E+4
⁵⁵ Fe	4.9E-4 ^(d)	4.1E-4	3.6E-4 ^(e)	3.8E-4
⁶⁰ Co	4.4E+3	4.0E+3	3.1E+3	3.5E+3
⁵⁹ Ni	5.9E+6	5.4E+6	4.2E+6	4.8E+6
⁶³ Ni	2.3E+8	2.2E+8	1.7E+8	1.9E+8
⁹⁰ Sr	9.9E+6	9.1E+6	6.9E+6	7.9E+6
⁹⁰ Y	9.7E+6	9.0E+6	6.8E+6	7.8E+6
⁹⁴ Nb	0.0 ^(f)	8.4E+4	0.0 ^(f)	7.8E+4
⁹⁹ Tc	2.7E+6	2.5E+6	2.1E+6	2.3E+6
¹²⁹ I	6.2E+5	5.7E+5	4.5E+5	8.2E+3
¹³⁵ Cs	2.7E+4	2.3E+4	2.0E+4	2.2E+4
¹³⁷ Cs	6.0E+7	5.3E+7	4.5E+7	4.9E+7
^{137m} Ba	5.8E+7	5.1E+7	4.4E+7	4.7E+7
²³⁵ U	8.9E+3	7.9E+3	1.5E+4	1.7E+4
²³¹ Th	9.0E+3	7.9E+3	1.6E+4	1.7E+4
²³⁷ Np	4.8E-2	4.3E-2	3.4E-2	3.8E-2
²³⁸ U	5.3E+4	4.6E+4	9.6E+4	1.0E+5
²³⁴ Th	5.3E+4	4.7E+4	9.7E+4	1.0E+5
²³⁸ Pu	2.7E+4	2.0E+4	2.1E+4	2.0E+4
²⁴⁴ Cm	2.8E+3	2.5E+3	2.3E+3	2.5E+3
²⁴⁰ Pu	2.5E+4	2.0E+4	1.9E+4	1.8E+4
²⁴³ Cm	1.8E+1	1.6E+1	1.5E+1	1.6E+1
²⁴³ Am	2.6E+3	2.0E+3	2.0E+3	1.9E+3
²³⁹ Pu	2.5E+4	2.0E+4	1.9E+4	1.8E+4
²⁴¹ Pu	1.4E+4	1.0E+4	1.0E+4	9.9E+3
²⁴¹ Am	8.7E+4	6.6E+4	6.6E+4	6.3E+4

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 4.3 are used in the biotic transport scenario. The resulting concentrations in pCi/m² are assumed to be mixed in the top 0.5 m of soil.

(c) Where 7.1E+3 = 7.1×10^3 .

(d) Where 4.9E-4 = 4.9×10^{-4} .

(e) Correction from value of 3.6E+4 in McKenzie et al. (1983).

(f) Not considered.

TABLE 4.5-2. Comparison of Calculated Surface Soil Concentrations Resulting from the 10 CFR 61 Intruder-Agriculture Scenario and from the Biotic Transport Scenario at the Barnwell Site, Waste Spectrum 1^(a,b)

Radionuclide	Surface Soil Concentrations (pCi/m ²)		
	Intruder/ Agriculture Scenario	Biotic Transport Scenario ^(g) Model 1	Biotic Transport Scenario ^(g) Model 2
³ H	8.4E+6 ^(e)	4.0E+3	4.0E+3
¹⁴ C	1.8E+8	8.5E+4	8.5E+4
⁵⁵ Fe	3.7E-1 ^(f)	4.1E-4	1.8E-4
⁶⁰ Co	2.7E+5	4.0E+3	2.4E+2
⁵⁹ Ni	1.8E+8	5.4E+6	2.5E+5
⁶² Ni	7.3E+9	2.2E+8	9.8E+6
⁹⁰ Sr	2.9E+7	9.1E+6	2.9E+5
⁹⁰ Y	2.9E+7	9.0E+6	2.9E+5
⁹⁴ Nb	5.6E+6	8.4E+4	5.1E+3
⁹⁹ Tc	6.4E+6	2.5E+6	7.8E+4
¹²⁹ I	1.8E+7	5.7E+5	2.5E+4
¹³⁵ Cs	6.7E+6	2.3E+4	3.7E+3
¹³⁷ Cs	1.5E+10	5.3E+7	8.4E+6
^{137m} Ba	1.4E+10	5.1E+7	8.0E+6
²³⁵ U	1.8E+6	7.9E+3	1.1E+3
²³¹ Th	1.8E+6	7.9E+3	1.1E+3
²³⁷ Np	1.1E+1	4.3E-2	5.8E-3
²³⁸ U	1.1E+7	4.6E+4	6.3E+3
²³⁴ Th	1.1E+7	4.7E+4	6.3E+3
²³⁸ Pu	2.4E+7	2.0E+4	1.1E+4
²⁴⁴ Cm	5.8E+5	2.5E+3	3.4E+2
²⁴⁰ Pu	2.3E+7	2.0E+4	1.1E+4
²⁴³ Cm	3.7E+3	1.6E+1	2.2
²⁴³ Am	2.3E+6	2.0E+3	1.1E+3
²³⁹ Pu	2.3E+7	2.0E+4	1.1E+4
²⁴¹ Pu	1.2E+7	1.0E+4	5.6E+3
²⁴¹ Am	7.7E+7	6.6E+4	3.7E+4

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 4.3 are used in the biotic transport scenario. The resulting concentrations are assumed to be mixed in the top 0.5 m of soil.

(c) Plant uptake of radionuclides independent of root mass in contact with waste.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Where 8.4E+6 = 8.4×10^6 .

(f) Where 3.7E-1 = 3.7×10^{-1} .

TABLE 4.5-3. Comparison of Calculated Surface Soil Concentrations Resulting from the 10 CFR 61 Intruder-Agriculture Scenario and from the Biotic Transport Scenario at the Barnwell Site, Waste Spectrum 2^(a,b)

Radionuclide	Surface Soil Concentrations (pCi/m ²)		
	Intruder/ Agriculture Scenario	Biotic Transport Scenario ^(g) Model 1	Biotic Transport Scenario ^(g) Model 2
³ H	9.7E+6 ^(e)	3.8E+3	3.8E+3
¹⁴ C	2.2E+8	8.6E+4	8.6E+4
⁵⁵ Fe	0.4	3.8E-4 ^(f)	1.7E-4
⁶⁰ Co	2.8E+5	3.5E+3	2.1E+2
⁵⁹ Ni	1.9E+8	4.8E+6	2.2E+5
⁶³ Ni	7.6E+9	1.9E+8	6.5E+6
⁹⁰ Sr	3.1E+7	7.9E+6	2.5E+5
⁹⁰ Y	3.1E+7	7.8E+6	2.5E+5
⁹⁴ Nb	6.1E+6	7.8E+4	4.7E+3
⁹⁹ Tc	7.2E+6	2.3E+6	7.3E+4
¹²⁹ I	3.1E+5	8.2E+3	3.6E+2
¹³⁵ Cs	7.2E+6	2.2E+4	3.4E+3
¹³⁷ Cs	1.7E+10	4.9E+7	7.7E+6
^{137m} Ba	1.5E+10	4.7E+7	7.3E+6
²³⁵ U	4.6E+6	1.7E+4	2.3E+3
²³¹ Th	4.6E+6	1.7E+4	2.3E+3
²³⁷ Np	1.0E+1	3.8E-2	5.1E+3
²³⁸ U	2.8E+7	1.0E+5	1.4E+4
²³⁴ Th	2.8E+7	1.1E+5	1.4E+4
²³⁸ Pu	2.8E+7	2.0E+4	1.1E+4
²⁴⁴ Cm	6.9E+5	2.5E+3	3.4E+2
²⁴⁰ Pu	2.6E+7	1.8E+4	1.0E+4
²⁴³ Cm	4.5E+3	1.6E+1	2.2
²⁴³ Am	2.7E+6	1.9E+3	1.1E+3
²³⁹ Pu	2.6E+7	1.8E+4	1.0E+4
²⁴¹ Pu	1.4E-7	9.9E+3	5.6E+3
²⁴¹ Am	8.7E+7	6.3E+4	3.5E+4

(a) The calculations are performed for 20-year decayed waste after loss of institutional controls 100 years later, for a total of 120 years of radioactive decay.

(b) The decayed waste spectra defined in Section 4.3₂ are used in the biotic transport scenario. The resulting concentrations in pCi/m² are assumed to be mixed in the top 0.5 m of soil.

(c) Plant uptake of radionuclides independent of root mass in contact with waste.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Where 9.7E+6 = 9.7 x 10⁶.

(f) Where 3.8E-4 = 3.8 x 10⁻⁴.

In general, the soil concentrations of radionuclides estimated for the biotic transport are less than those estimated for the human intrusion scenario. In addition, the biotic transport surface soil concentrations estimated using plant uptake model 2 are less than those estimated using plant uptake model 1 (see Tables 4.4-2 and 4.4-3). This is an expected result since the quantity of radionuclides moved in plant uptake model 2 is proportional to the fraction of the roots that enter the buried waste zone.

4.6 DOSE CALCULATIONS

Because the mixtures of the radionuclides resulting from the human intrusion scenario and the biotic transport scenario are different, we have performed dose calculations to determine the relative impacts of the two scenarios. By using the same environmental pathway and dose analysis model for the source terms defined in Tables 4.5-2 and 4.5-3, a direct comparison of the scenarios can be made. This section contains a discussion of the pathway and dose models used, the calculated doses for the human intrusion and the biotic transport scenarios, and a comparison of the critical organ doses from the two scenarios.

The PNL computer program MAX11 (Napier, Peloquin and Kennedy 1984; McKenzie et al. 1985) calculates the maximum annual dose to an exposed individual from multiple exposure pathways. The annual dose is calculated for each organ of concern for 50 years of exposure, and the maximum annual dose is determined by inspection. The radionuclide inventories in soil are adjusted for radioactive decay and daughter-product buildup during the 50-year calculation period, but are not increased by continuing biotic transport.

The diet and exposure conditions used for the calculation of radiation doses from the various pathways for the intruder-agriculture scenario are defined in Section 2.2. The biotic transport scenario parameters are provided in Section 4.4. In both the intruder-agriculture and the biotic transport scenarios, the maximally exposed individual is exposed by inhalation of resuspended radionuclides, ingestion of garden and farm crops grown in the soil, and direct, penetrating radiation.

Because of the limited contaminated area considered for the intruder-agriculture scenario, we have assumed that only 25% of the maximally exposed individual's diet is grown in contaminated soil. This diet includes milk, meats, and eggs. Because the biotic transport scenario can uniformly contaminate a much larger surface area (about 70 ha), the maximum individual's entire diet (including milk, meats, and eggs) is assumed to be grown in contaminated soil. In both scenarios, the maximally exposed individual is assumed to reside on the site and inhale dust with an airborne concentration of 2×10^{-6} g/m³ for 8 h/d, 5 d/wk or 2000 h/yr. In addition, he is exposed to penetrating radiation from the contaminated soil surface for 2000 h/yr. Doses are calculated for total-body, bone, lung, thyroid, and the lower large intestine (GI-LLI) of the maximally exposed individual.

TABLE 4.6-1. Maximum Annual Doses to the Maximally Exposed Individual from the Intruder-Agriculture Scenario at the Barnwell Site^(a)

Waste Spectrum	Maximum Year	Organ of Reference	Dominant Radionuclide Contributors To Dose	Dominant Exposure Pathway	Maximum Annual Organ Dose (rem)
1 (c) (Past Wastes)	1	Total-body	$^{137}\text{Cs} + \text{D}^{(d)}$	External	42
	2	Bone	$^{137}\text{Cs} + \text{D}$	External	45
	1	Lungs	$^{137}\text{Cs} + \text{D}$	External	41
	1	Thyroid	$^{137}\text{Cs} + \text{D}$	External	42
	1	GI-LLI	$^{137}\text{Cs} + \text{D}$	External	41
2 (e) (Future Wastes)	1	Total-body	$^{137}\text{Cs} + \text{D}$	External	48
	2	Bone	$^{137}\text{Cs} + \text{D}$	External	51
	1	Lungs	$^{137}\text{Cs} + \text{D}$	External	46
	1	Thyroid	$^{137}\text{Cs} + \text{D}$	External	46
	1	GI-LLI	$^{137}\text{Cs} + \text{D}$	External	46

- (a) The doses are calculated over a 50-year continuous exposure period for the waste spectra shown in Tables 4.5-2 and 4.5-3 starting 100 years after closure of the low-level waste burial ground.
- (b) The year in which the maximum annual dose occurs during the 50-year continuous exposure period, starting 100 years after final closure of the CLLW waste burial ground.
- (c) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radionuclides (U.S. Nuclear Regulatory Commission 1981), with an assumed 15-year container decomposition half-time.
- (d) The +D notation indicates that the decay energy of a short-lived daughter product is included.
- (e) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U.S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.

For the intruder-agriculture scenario, the resulting maximum annual organ doses and the year during continuous exposure in which the doses peak are listed in Table 4.6-1 for the radionuclides of waste spectra 1 and 2. For both waste spectra, the dominant exposure pathway is direct exposure resulting from ^{137}Cs and its daughter, ^{137m}Ba . The maximum annual dose from external emitters decreases annually because the soil concentration continues to decrease by radioactive decay.

For the biotic transport scenario, the resulting maximum annual organ dose and the year during continuous exposure in which the doses peak are given in Table 4.6-2 for waste spectra 1 and 2. For both waste spectra, the dominant organ is bone and the maximum annual dose is controlled by

TABLE 4.6-2. Maximum Annual Doses to the Maximally Exposed Individual from the Biotic Transport Scenario at the Chem-Nuclear Services Barnwell Site^(a)

Waste Spectrum	Maximum Year ^(d)	Organ of Reference	Dominant Radionuclide Contributors To Dose	Dominant Exposure Pathway	Model 1 ^(b) Maximum Annual Organ Dose (rem)	Model 2 ^(c) Maximum Annual Organ Dose (rem)
1 ^(e) (Past Wastes)	29/25	Total-body	⁹⁰ Sr + D ^(f)	Ingestion	1.7	.067
	31/30	Bone	⁹⁰ Sr + D	Ingestion	7.1	.24
	1/1	Lungs	¹³⁷ Cs + D	External	.15	.024
	1/1	Thyroid	¹³⁷ Cs + D	External	.26	.028
	1/1	GI-LLI	¹³⁷ Cs + D	External	.29	.028
2 ^(g) (Future Wastes)	29/24	Total-body	⁹⁰ Sr + D	Ingestion	1.5	.058
	31/30	Bone	⁹⁰ Sr + D	Ingestion	6.2	.21
	1/1	Lungs	¹³⁷ Cs + D	External	.14	.022
	1/1	Thyroid	¹³⁷ Cs + D	External	.14	.022
	1/1	GI-LLI	¹³⁷ Cs + D	External	.26	.026

- (a) The doses are calculated over a 50-year continuous exposure period for the waste spectra shown in Tables 4.5-2 and 4.5-3 starting 100 years after closure of the low-level waste burial ground.
- (b) Plant uptake of radionuclides independent of fraction of roots in contact with waste.
- (c) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.
- (d) The year in which the maximum annual dose occurs during the 50-year continuous exposure period, starting 100 years after final closure of the CLLW waste burial ground. Year for root uptake Model 1 followed by year for root uptake Model 2.
- (e) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radionuclides (U.S. Nuclear Regulatory Commission 1981), with an assumed 15-year container decomposition half-time.
- (f) The +D notation indicates that the decay energy of a short-lived daughter product is included.
- (g) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U.S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.

ingestion of food products grown in contaminated soil. The year of peak bone dose after the start of continuous exposure is 31 for plant uptake Model 1 and 30 for plant uptake Model 2, for both waste spectra. The organ doses for waste spectrum 2 are slightly smaller than those reported for waste spectrum 1, because of the longer package decomposition half-time (35 years) assumed for waste spectrum 2 (compared to 15 years for waste spectrum 1). The net impact of the longer decomposition half-time is to permit more decay of the inventory before transport, effectively reducing the source term. With plant uptake Model 1 the resulting maximum annual total body doses are 1.7 rem for waste spectrum 1 and 1.5 rem for waste spectrum 2. The resulting maximum annual bone doses are 7.1 rem and 6.2

rem for waste spectra 1 and 2, respectively. Maximum annual organ doses for waste spectrum 2 are higher than those previously calculated for the intruder-agriculture scenario at the reference humid site (McKenzie et al. 1983). This increase is a result of modifications made to the exposure scenario and data libraries.

The doses estimated for plant uptake Model 2 that are controlled by external exposure are about 10% of the doses estimated for plant uptake Model 1. Of particular note is the significant total-body and bone dose reduction for plant uptake Model 2. Again, this result is anticipated because the quantity of radionuclides moved in plant uptake Model 2 is proportional to the fraction of roots entering the buried waste zone.

Finally, Table 4.6-3 shows a comparison of the order-of-magnitude dose estimates at the reference humid site (McKenzie et al. 1983) and the current dose estimate for the Barnwell site. The results show a general reduction in the site-specific doses compared to the reference humid site doses. This table shows the importance of the plant uptake model used for the critical organ dose estimates. For total body and bone, assuming the plant uptake Model 1, the resulting doses are about 30% of the reference humid site doses, and assuming plant uptake Model 2 produces doses that are about 1% of the reference humid site doses. Thus, the net impact of our model modification efforts and utilization of available site-specific data the Barnwell site is to obtain lower dose estimates compared to our original order-of-magnitude estimates.

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TABLE 4.6-3. Comparison of the Maximum Annual Doses for the Reference Humid Site and the Barnwell Site^(a)

Waste Spectrum	Organ of Reference	Reference Humid Site ^(b)	Barnwell Site Model 1 ^(c)	Barnwell Site Model 2 ^(d)
1 ^(e) (Past Wastes)	Total-body	6.3	1.7	.067
	Bone	26	7.1	.24
	Lungs	0.18	.15	.024
	Thyroid	0.52	.26	.028
	GI-LLI	0.17	.29	.028
2 ^(f) (Future Wastes)	Total-body	4.4	1.5	.058
	Bone	18	6.2	.21
	Lungs	0.13	.14	.022
	Thyroid	0.38	.14	.022
	GI-LLI	0.13	.26	.026

(a) The doses are calculated over a 50-year continuous exposure period for the waste spectra shown in Tables 4.5-2 and 4.5-3 starting 100 years after closure of the low-level waste burial ground.

(b) As reported in McKenzie et al. 1983.

(c) Plant uptake of radionuclides relies on any contact with plant roots.

(d) Plant uptake of radionuclides modified by the fraction of roots in contact with waste.

(e) Waste spectrum 1 was based on the current mixture and specific activity of CLLW radionuclides (U.S. Nuclear Regulatory Commission 1981), with an assumed 15-year container decomposition half-time.

(f) Waste spectrum 2 was based on estimates of future CLLW mixtures and specific activities (U.S. Nuclear Regulatory Commission 1981), with an assumed 35-year container decomposition half-time.

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5.0 SENSITIVITY ANALYSIS

We conducted a sensitivity analysis on the BIOPORT model to identify the parameters that most strongly influence the behavior of the model. The results of this were to 1) provide information that leads to a better understanding of how the model works; 2) identify influential model parameters requiring careful measurement to avoid errors most likely to result in inappropriate model output; and 3) indicate where further research efforts should be directed to better understand and quantify the biological transport of radionuclides at the CLLW site.

5.1 METHODS

We performed the sensitivity analysis using the individual parameter perturbation (IPP) method. This method is appropriate for testing BIOPORT because there are minimal interactions between the model input parameters. To minimize the number of computer runs needed for the analysis, we used the megaparameter approach (Kleignen 1975). Similar parameters were grouped together into the larger megaparameters. In the course of the sensitivity analysis the values of the component parameters within each megaparameter were varied simultaneously, with all other parameters held constant. In this way, groups of parameters to which BIOPORT is not sensitive could be identified. The sensitivity analysis was then continued for component parameters of those megaparameters demonstrating the most substantial impact on the output of the BIOPORT model.

We established nine megaparameters for the BIOPORT parameters: ANIMAL, PLANT, PACKAGE, SOIL, EROSION, SUCCESSION, GROUP 1 CR'S, GROUP 2 CR'S and GROUP 3 CR'S. A list of the megaparameters, their component parameters and a short description of each component parameter are presented in Table 5.1-1. Briefly, ANIMAL and PLANT contain parameters pertaining to the abundance of plants and animals on the site and their rooting and burrowing characteristics; PACKAGE includes radionuclide package durability and age parameters, which control the availability of radionuclides in the inventory to the plants and animals; SOIL contains soil layer depth and volume parameters; EROSION includes parameters describing the site erosion characteristics; SUCCESSION contains plant successional phase parameters; and GROUP 1 CR'S, GROUP 2 CR'S and GROUP 3 CR'S include concentration ratios for uptake of three groups of radionuclides by plants. The radionuclides in the BIOPORT/MAXI master library were divided into these three groups on the basis of similarity of behavior and half-life. Group 1 contains strontium, cesium and nickel isotopes and their daughter products; Group 2 contains iodine, carbon, hydrogen, technetium and cobalt isotopes; and Group 3 contains uranium, plutonium, neptunium and curium isotopes and their daughter products.

We measured the influence of each megaparameter and, then, the influence of each component parameter on the model in two ways: 1) by the amount of change in the maximum concentration of radionuclides in the surface soil layer, and 2) by the change in the year in which this maximum

TABLE 5.1-1. BIOPORT Megaparameters

Megaparameter	Component Parameters	Description
ANIMAL	AMT	Volume of soil brought to surface in first year of activity
	PACTIVE	Activity index
	RANGC	Maximum burrowing depth
	PMOVE	Proportion of soil moved from each soil layer
PLANT	PROOT	Root-to-shoot ratio
	RANGP	Maximum rooting depth
	SROOT	Proportion of roots in each soil layer
	BIOMAS	Total net annual production
PACKAGE	PL	Waste storage package half-life
	PL1	Waste Storage package age
GROUP 1 CR'S	Sr90, Y90, Cs135, Cs137, Ba137m, Ni59, Ni63	Concentration ratios
GROUP 2 CR'S	I129, C14, Tc99, H3, Co60	Concentration ratios
GROUP 3 CR'S	U235, Th231, Pa231, Ac227, Th227, Fr223, Ra223, U238, Th234, Pa234m, Pa234, Pu241, Am241, Pu242, Np238, Pu238, Np237, Pa223, U233, Th229, Ra225, Ac225, Cm243, Pu243, Am243, Np239, Pu239, Cm244, Pu244, U240, Pu240	Concentration ratios
SOIL	DEPTH	Depth of three soil layers
	VOL	Volume of three soil layers
EROSION	ERU	Maximum erosion constant
	ERL	Minimum erosion constant
	NER	Duration of periods of maximum erosion
	JER	Frequency of periods of maximum erosion
SUCCESSION	NYSUC	Endpoint years for three successional phases

value was achieved. Both of these influences were examined in response to a 50% change in the megaparameter (or component parameter) over a 500-year simulation period.

We performed separate sensitivity analyses on the arid site and the humid site data. For each site, plant uptake models 1 and 2 were analyzed separately. Plant model 1 is based on the assumption that plants take up radionuclides independently of the root mass in contact with the waste, whereas plant model 2 is based on the assumption that uptake is proportional to the mass of roots in direct contact with the waste.

5.2 SENSITIVITY ANALYSIS RESULTS FOR THE ARID SITE

As the first step in this sensitivity analysis, we examined the output from the model using the arid site reference (base) case as input. For convenience in the sensitivity analysis, a single composite plant and a single composite animal were constructed from data on the individual arid site plant and animal species. Therefore the base case output shown here may differ slightly from the results that would be obtained using the default arid site reference data. The modified arid site base case input is shown in Table 5.2-1.

5.2.1 Plant Uptake Model 1

Figure 5.2.1-1 shows the concentrations of Group 1, 2 and 3 radionuclides in the top soil layer throughout the 500-year simulation period, using plant model 1 and the arid site base case as input. The overall behavior of the model during this period is dominated by the shortest-lived Group 1 radionuclides, which are present in the surface soil layer in concentrations an order of magnitude higher than those of Group 2 or 3 radionuclides. (If the simulation period were extended beyond the 500 years, however, the longer-lived Group 2 and Group 3 radionuclides would eventually predominate.)

Before we could perform the sensitivity analysis on the model, two modifications had to be made in the analysis protocol to accommodate the BIOPORT input parameters. First, not all of the component parameters within the megaparameters could be strictly increased and decreased by 50%. There is no straightforward way to vary the distribution of plant roots and animal burrows (SROOT and PMOVE) by a set percentage. Therefore we chose to vary, by 50%, the combined percent of burrow volume and plant roots in the inventory layer and the layer immediately above. Second, within the PACKAGE megaparameter, the package half-life (PL) and package age (PL1) have opposing effects on the model output. Altering these parameters simultaneously in the same direction would have opposite effects on the model output and create difficulties in the interpretation of the PACKAGE parameter results. Therefore, the 50% increase in the PACKAGE megaparameter is actually a 50% increase in package half-life and a 50% decrease in package age. Both these changes would be expected to lower the maximum surface layer radionuclide concentration. The opposite is true of the 50% decrease in the PACKAGE megaparameter.

The results of the megaparameter sensitivity analysis on plant model 1 are shown in Tables 5.2.1-1 and 5.2.1-2. The entries in Table 5.2.1-1 are the percent change in the maximum surface soil layer radionuclide concentrations in Ci/ha relative to a 1% change in each megaparameter. We calculated these numbers using the formula:

$$C = \{[(N - B)/B] \times 100\}/50$$

TABLE 5.2-1. Arid Site Base Case Input

Simulation Period (years)	:	500			
Strata Identification	:	DEPTH	VOLUME	CODE	
		surface	0.00E+00	(0)	
		0.5m	0.50E+04	(1)	
		1.0m	0.50E+04	(2)	
		1.5m	0.50E+04	(3)	
		inventory	0.65E+05	(4)	
Number of plant associations	:	1	Number of animal species	:	1
Erosion constant m^3/yr (high)	:	2.30000	(low)	:	0.00000
High erosion - starting year	:	1	duration	:	4
frequency (yr)	:	600			
Conversion for m^3 to gm	:	0.170000E+07			
Conversion for Ci/ha to pCi/m ²	:	1.00E+08			
Radionuclide input inventory	ELT. WT.	(Ci/H ³)			
	H 3	0.400E-01			
	C 14	0.400E-02			
	FE 55	0.500E+00			
	NI 59	0.170E-02			
	CO 60	0.140E+01			
	NI 63	0.140E+00			
	NB 94	0.540E-04			
	SR 90	0.410E-02			
	TC 99	0.640E-04			
	I 129	0.170E-03			
	CS 135	0.640E-04			
	CS 137	0.140E+01			
	U 235	0.290E-04			
	U 238	0.290E-04			
	NP 237	0.960E-10			
	PU 238	0.520E-03			
	PU 239	0.220E-03			
	PU 240	0.220E-03			
	PU 241	0.140E-01			
	PU 242	0.970E-06			
	AM 241	0.380E-03			
	AM 243	0.230E-04			
	CM 243	0.420E-06			
	CM 244	0.270E-03			

Title of radionuclide master library:
 ONSITE/BIOPORT RADIONUCLIDE MASTER DATA LIBRARY 1-JUN-84 RAP

Decomposition half time of package (years): 35.0
 No. of years of package storage prior to beginning of scenario: 10.0

TABLE 5.2-1. (Continued)

PLANT ASSOCIATION - Western		Dry/wet weight ratio =		0.1500
Number of Successional Phases	3			
Intervals for succession (yr)	:	10	30	500
Root/shoot ratio	:	0.75	3.0	5.0
Range of roots (m)	:	2.0	2.0	2.0
Net annual production [gm(dry)/m ² /yr]	:	272.0	104.0	117.0
Recycle rate for each phase	:	1.0	1.0	1.0
Linear change (biomass) (0=no,1=yes)	:	0	0	0
Linear change (recycle) (0=no,1=yes)	:	0	0	0
% Root distribution by strata	:			
Strata :	1	0.715	0.565	0.610
Strata :	2	0.170	0.245	0.230
Strata :	3	0.075	0.135	0.107
Strata :	4	0.040	0.055	0.053
ANIMAL SPECIES - Cmpptz				
Amount of material moved (m ³ /ha)	0.411	Activity range (m) = 2.0		
Degree of activity by phase	= 1.0	0.5		
Proportion of material moved to surface by strata				
1	2	3	4	
0.70000	0.150	0.067	0.083	

TABLE 5.2.1-1. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Megaparameters. (Sign indicates direction of change.) Arid site, plant model 1.

Megaparameter	Megaparameter Increased 50%	Megaparameter Decreased 50%
ANIMAL	+0.67	-0.22
PLANT	+1.56	-1.68
PACKAGE	-0.44	+0.59
GROUP 1 CR'S	+0.89	-0.89
GROUP 2 CR'S	0.00	0.00
GROUP 3 CR'S	0.00	0.00
SOIL	0.00	0.00
EROSION	0.00	0.00
SUCCESSION	-0.07	+0.07

TABLE 5.2.1-2. Year of Maximum Surface Radionuclide Concentrations as Compared to Base Case Value (Year 111, Arid Site, Plant Model 1).

Megaparameter	Megaparameter Increased 50%	Megaparameter Decreased 50%
ANIMAL	93	127
PLANT	119	68
PACKAGE	136	88
GROUP 1 CR'S	116	103
GROUP 2 CR'S	112	110
GROUP 3 CR'S	111	111
SOIL	111	111
EROSION	112	111
SUCCESSION	117	106

FIGURE 5.2.1-1. Surface Soil Radionuclide Concentrations for Group 1, 2 and 3 Radionuclides. Arid site base case, plant model 1.

where C is the entry in Table 5.2.1-1, B is the maximum surface layer concentration using the modified arid site base case as input, and N is the maximum surface layer concentration for the case in which the megaparameter is perturbed by 50%. This value for C is not meaningful for megaparameters that contain non-continuous variables, such as PLANT and ANIMAL, which contain RANGP, and also RANGC, which can take on only three values corresponding to the three soil layer depths. Therefore, C should be used for comparative purposes only. Because N, and therefore C, did not change symmetrically when the megaparameter was increased and decreased by 50%, we show the results for both directions of change.

The years in which these maximum surface values occurred are shown in Table 5.2.1-2. The changes in the maximum year approximately reflect the changes in the maximum radionuclide concentrations. However, the maximum year for each case is less readily predictable than the maximum concentration, because the location of the maximum year is a result of a complex interaction of factors, including the identity and amounts of the radionuclides brought to the surface by the plants and animals, the radionuclide half-lives and their relative concentrations in the inventory, and the timing of the successional stages.

Of the nine megaparameters, the BIOPORT model was most sensitive to PLANT, GROUP 1 CR'S, ANIMAL and PACKAGE, in that order. A 1% change in the PLANT megaparameter produced about a 1.5% change in the maximum surface radionuclide concentrations, while a 1% change in PACKAGE produced about a .5% change. The remaining five megaparameters, GROUP 2 CR'S, GROUP 3 CR'S, SOIL, EROSION and SUCCESSION, had no significant impact on the model output; we therefore eliminated these from further analysis.

We then divided the PLANT, GROUP 1 CR'S, ANIMAL and PACKAGE megaparameters into their component parameters for further testing. The results of the tests, in which each parameter was increased and decreased by 50%, are shown in Tables 5.2.1-3 and 5.2.1-4. Table 5.2.1-3 shows the percent change in maximum surface layer radionuclide concentrations per a 1% change in each parameter, calculated as described for the megaparameters above. The maximum years for each case are presented in Table 5.2.1-4. We discuss the parameter sensitivity results below, in descending order of importance of the megaparameters.

Among the PLANT parameters, RANGP had the greatest influence on the BIOPORT output, with a 1% decrease resulting in a change of -1.68% in the maximum surface radionuclide concentration. RANGP accounted for almost all the decrease in maximum value caused by the decrease in the PLANT megaparameter, and was the single most influential parameter in the model using the arid site data and plant model 1. RANGP can take on only three values, corresponding to the depths of the three soil layers. The zero increase in the maximum surface layer concentration with the increase in RANGP reflects the fact that the plant roots already penetrate the inventory in the base case; therefore increasing this parameter does not affect the model output. When we decreased RANGP in the analysis, plant roots no longer entered the

TABLE 5.2.1-3. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations per 1% Change in Parameter. (Sign indicates direction of change.) Arid site, plant model 1.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	+0.15	-0.15
	PACTVE	+0.15	-0.15
	PMOVE	+0.15	-0.15
	RANGC	0.00	-0.22
PLANT	PROOT	+0.67	-0.67
	SROOT	-0.15	+0.15
	BIOMAS	+0.89	-0.89
	RANGP	0.00	-1.68
PACKAGE	PL	-0.37	-1.68
	PL1	+0.07	-0.07
GROUP 1 CR'S	SR90+d	+0.07	-0.07
	CS135, CS137, BA137M	+0.22	-0.22
	NI59, NI63	+0.67	-0.52

TABLE 5.2.1-4. Year of Maximum Surface Radionuclide Concentrations as Compared to Base Case Value (year 111, arid site, plant model 1)

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	106	118
	PCTVE	106	118
	PMOVE	106	118
	RANGC	111	127
PLANT	PROOT	116	103
	SROOT	110	112
	BIOMAS	116	102
	RANGP	111	68
PACKAGE	PL	128	92
	PL1	118	106
GROUP 1 CR'S	SR90+d	107	116
	CS135, CS137, BA137M	100	130
	NI59, NI63	133	88

inventory, which drastically reduced the amount of activity contributed to the surface layer by plants.

BIOPORT was fairly sensitive to plant biomass (BIOMAS) and the root-to-shoot ratio (PROOT), with C values of 0.89% and 0.67%, respectively, for these parameters. BIOPORT showed, however, little sensitivity to plant root distribution. The decrease in the maximum value with an increase in SROOT can be explained by noting that, according to plant model 1, as long as the roots penetrate the inventory, the actual proportion of roots in the inventory does not affect the amounts of radionuclides taken up by the plants. In other words, the elements are taken up in proportion to the mass of the entire plant. Further, an increase in SROOT requires a corresponding decrease in the mass of roots in the top soil layer. The plants contribute activity to the surface soil by the decomposition of roots and aboveground plant biomass. The amount of activity contributed to each layer by plant roots is proportional to the root mass in that layer. Therefore, the decrease in root mass in the surface layer results in a decrease in the maximum value for radionuclide concentration transported by plants to that layer.

Within the GROUP 1 CR'S megaparameter, the effect of each radionuclide concentration ratio on the model is a result of the interaction of the concentration ratio itself, the radionuclide half-life, and the amount of the radionuclide present in the inventory. A change in the plant uptake concentration ratio of the nickel isotopes had a greater impact on the model results than change in the cesium isotope concentration ratios, which, in turn, had a greater effect than the concentration ratios for ^{90}Sr and its daughter product ^{90}Y .

BIOPORT was almost equally sensitive to all of the component parameters of the ANIMAL megaparameter. A 1% change in AMT, PACTIVE and PMOVE all caused a 0.15% change in the maximum surface radionuclide concentrations. The depth range of animal activity had a slightly greater impact on the model output; a 1% decrease in RANGC yielded a 0.22% decrease in the maximum concentration. RANGC also can take on only three values, corresponding to the depths of the three soil layers. The zero increase in the maximum surface value with the increase in RANGC reflects the fact that the animal burrows already penetrate the inventory in the base case; thus an increase in this variable does not affect the model output. When RANGC was decreased, the animals no longer burrowed into the buried wastes, thereby dramatically decreasing the amounts of activity they bring to the surface.

BIOPORT was more sensitive to package durability than to any single ANIMAL parameter; a 1% change in PL produced a 0.4-0.5% change in the maximum surface layer concentration. BIOPORT was almost completely insensitive to package age; a 1% change in PL1 resulted in only a 0.07% change in model output.

5.2.2 Plant Uptake Model 2

Figure 5.2.2-1 shows the concentrations of Group 1, 2 and 3 radionuclides in the surface soil layer throughout the 500-year simulation period, using plant model 2 and the modified arid site base case as input. This graph can be contrasted with that in Figure 5.2.1-1, which shows the base case output using plant model 1. The maximum surface layer radionuclide concentrations with plant model 2 were five times lower than those with plant model 1, because with plant model 2 the plants take up radionuclides in proportion to a much smaller mass than with plant model 1. For plant model 2, the amounts of radionuclides taken up are proportional to the mass of roots in direct contact with the wastes, as opposed to the mass of the entire plant as in plant model 1. As with plant model 1, the Group 1 radionuclides dominated the BIOPORT model behavior with plant model 2. However, the Group 3 radionuclides were proportionately more important with plant model 2 than with plant model 1; the ratio of Group 1 to Group 3 radionuclides in the maximum year was 10:1 with plant model 1, as opposed to 3:1 with plant model 2. Because Group 1 radionuclides are more readily taken up by plants than Group 3 radionuclides, plant model 2, in comparison to plant model 1, took up relatively smaller amounts of Group 1 radionuclides.

FIGURE 5.2.2-1. Surface Soil Radionuclide Concentrations for Group 1, 2 and 3 Radionuclides. Arid site base case, plant model 2.

The results of the megaparameter sensitivity analysis on plant model 2 are shown in Tables 5.2.2-1 and 5.2.2-2. Table 5.2.2-1 contains the percent changes in maximum radionuclide concentrations per 1% change in each megaparameter, and Table 5.2.2-2 shows the years in which these maxima were achieved for each case. ANIMAL was the most influential megaparameter for plant model two (in contrast to PLANT for plant model 1), with an increase of 3.56% in maximum surface radionuclide concentration per a 1% increase in the megaparameter. PACKAGE, PLANT and GROUP 1 CR'S followed in descending order of impact on the model output. BIOPORT was not sufficiently sensitive to GROUP 2 CR'S, GROUP 3 CR'S, SOIL, EROSION or SUCCESSION to warrant further investigation of the component parameters of these megaparameters.

We then divided the ANIMAL, PACKAGE, PLANT and GROUP 1 CR'S megaparameters into their component parameters, for further analysis. Tables 5.2.2-3 and 5.2.2-4 contain the results of the tests in which the individual parameters were increased and decreased by 50%.

Within the ANIMAL megaparameter, BIOPORT was highly sensitive to whether or not the animal burrows penetrated the waste zone (RANGC), and slightly less sensitive to AMT, PACTIVE and PMOVE. The C value for RANGC was 1.56, while the other three parameters had C values of approximately 0.80. Again, RANGC can take on only three values corresponding to the soil layer depths. The zero increase in the maximum surface activity with an increase in RANGC reflects the fact that the animal burrows penetrate the inventory already in the base case; therefore, an increase in this parameter does not affect the model output. The decrease in RANGC means that the burrows no longer enter the inventory, thereby drastically reducing the amounts of radionuclides brought to the surface by animals.

As with plant model 1, BIOPORT was more sensitive to package half-life than package age. BIOPORT showed greater sensitivity to PL than to any single plant parameter, with a maximum C value of 0.70%. The maximum C value for package age (PL1) was only 0.15%.

Within the PLANT megaparameter, BIOPORT was moderately sensitive to whether or not the plant roots infiltrated the waste zone. RANGP showed a C value of 0.41%. BIOPORT was much less sensitive to BIOMAS, SROOT and PROOT, in descending order of important. The C values for these parameters were 0.22% or less.

Within the GROUP 1 CR'S megaparameter, BIOPORT was more sensitive to changes in the concentration ratios of ^{90}Sr and its daughter products than to those of the nickel or cesium isotopes, with maximum C values of 0.41, 0.11 and 0.07%, respectively. This analysis of plant model 2 sensitivity is in contrast to the plant model 1 results, where nickel was the most influential element.

TABLE 5.2.2-1. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Megaparameter. (Sign indicates direction of change.) Arid site, plant model 2.

<u>Megaparameter</u>	<u>Megaparameter Increased 50%</u>	<u>Megaparameter Decreased 50%</u>
ANIMAL	+3.56	-1.56
PLANT	+0.74	-0.41
PACKAGE	-0.59	+0.85
GROUP 1 CR'S	+0.19	-0.22
GROUP 2 CR'S	0.00	-0.03
GROUP 3 CR'S	0.00	0.00
SOIL	-0.03	0.00
EROSION	-0.03	0.00
SUCCESSION	-0.03	0.00

TABLE 5.2.2-2. Years of Maximum Surface Radionuclide Concentrations. Compare to Base Case Value: Year 75. Arid site, plant model 2.

<u>Megaparameter</u>	<u>Megaparameter Increased 50%</u>	<u>Megaparameter Decreased 50%</u>
ANIMAL	70	128
PLANT	85	68
PACKAGE	86	62
GROUP 1 CR'S	78	72
GROUP 2 CR'S	75	75
GROUP 3 CR'S	75	75
SOIL	75	75
EROSION	76	75
SUCCESSION	76	74

TABLE 5.2.2-3. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations per 1% Change in Parameter. (Sign indicates direction of change.) Arid site, plant model 2.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	+0.78	-0.81
	PACTIVE	+0.78	-0.32
	PMOVE	+0.78	-0.81
	RANGC	0.00	-1.56
PLANT	PROOT	+0.11	-0.15
	SROOT	+0.15	-0.19
	BIOMAS	+0.19	-0.22
	RANGP	0.00	-0.41
PACKAGE	PL	-0.48	-0.70
	PL1	-0.15	-0.11
GROUP1 CR'S	SR90+d	+0.15	-0.41
	CS135, CS137, BA137M	+0.04	-0.07
	NI59, NI63	+0.11	-0.11

TABLE 5.2.2-4. Years of Maximum Surface Radionuclide Concentrations. Compare to base case value: Year 75. Arid site, plant model 2.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	73	81
	PACTIVE	73	81
	PMOVE	73	81
	RANGC	75	128
PLANT	PROOT	78	73
	SROOT	77	72
	BIOMAS	78	72
	RANGP	75	68
PACKAGE	PL	81	65
	PL1	80	71
GROUP 1 CR'S	SR90+d	77	68
	CS135, CS137, BA137M	75	75
	NI59, NI63	79	72

5.3 SENSITIVITY ANALYSIS RESULTS FOR HUMID SITE

The humid site base case data used in the sensitivity analysis are shown in Table 5.3-1. This base case differs from the default humid site reference case provided in the BIOPORT model in that the plants and animals from the default reference case have been combined into a single composite plant and a single composite animal for convenience in conducting the humid site sensitivity analysis.

5.3.1 Plant Uptake Model 1

Figure 5.3.1-1 shows the concentrations of Group 1, 2 and 3 radionuclides in the top soil layer throughout the 500-year simulation period, using plant model 1 and the modified humid site base case as input. The peak surface concentration for the humid site with plant model 1 was approximately 23 times higher than that for the arid site using plant model 1. Again, the Group 1 radionuclides dominate in the response of the model over the simulation period.

We varied the PLANT, ANIMAL and PACKAGE parameters by methods described in Section 5.2.1 for the arid site data. Within the EROSION megaparameter, the maximum erosion constant is $0 \text{ m}^3/\text{yr}$ in the base case; thus it could not be decreased. This value was increased to $1.0 \text{ m}^3/\text{yr}$ to test the effect of an increase in EROSION on the model. The results of the megaparameter sensitivity analysis on plant model 1 are shown in Tables 5.3.1-1 and 5.3.1-2. We next calculated the tabled entries by methods described in Section 5.2.1 for the arid site data. The entries in Table 5.3.1-1 are the percent change in the maximum surface soil layer radionuclide concentrations in Ci/ha per a 1% change in each parameter (C). The years in which these maximum surface values occurred are entered in Table 5.3.1-2.

For plant model 1, we found that BIOPORT is significantly sensitive to only two of the megaparameters, ANIMAL and PACKAGE, in that order. The PLANT parameters have almost no impact on the model output. The animals are responsible for the overwhelming majority of the radioactivity in the surface layer. These results for the humid site data are in contrast to the results obtained with the arid site data and plant model 1, where the PLANT parameters controlled the model output.

We then divided the ANIMAL and PACKAGE parameters into their component parameters for further testing. The results of tests in which each parameter was increased and decreased by 50% are shown in Tables 5.3.1-3 and 5.3.1-4. Table 5.3.1-3 shows the percent increase in maximum surface value per a 1% increase in the parameter, and Table 5.3.1-4 contains the years in which these maxima were achieved for each case.

As with the arid site data for plant model 1, RANGC was the most influential of the ANIMAL parameters in determining model output. The maximum C value for this parameter was 1.87%, making it the most influential parameter in the model. BIOPORT was less, but nearly equally,

TABLE 5.3-1. Humid Site Base Case Input

Simulation Period (yr)	:	500		
Strata Identification	:	DEPTH	VOLUME	CODE
		surface	0.00E+00	(0)
		0.5m	0.50E+04	(1)
		1.0m	0.50E+04	(2)
		1.5m	0.50E+04	(3)
		inventory	0.65E+05	(4)
Number of plant associations	:	1	Number of animal species	:
Erosion constant m^3/yr (high)	:	0.00000	(low)	:
High erosion - starting year	:	0	duration	:
frequency	:	0		
Conversion for m^3 to g	:	0.170000E+07		
Conversion for Ci/ha to pCi/ m^2	:	1.00E+08		
Radionuclide input inventory		ELT.	WT.	(Ci/ M^{*3})
		H	3	0.280E-01
		C	14	0.220E-02
		FE	55	0.630E+00
		NI	59	0.220E-02
		CO	60	0.170E+01
		NI	63	0.180E+00
		NB	94	0.680E-04
		SR	90	0.410E-02
		TC	99	0.780E-04
		I	129	0.220E-03
		CS	135	0.800E-04
		CS	137	0.180E+01
		U	235	0.220E-04
		U	238	0.130E-03
		NP	237	0.120E-09
		PU	238	0.630E-03
		PU	239	0.280E-03
		PU	240	0.280E-03
		PU	241	0.180E-01
		PU	242	0.120E-05
		AM	241	0.480E-03
		AM	243	0.280E-04
		CM	243	0.510E-06
		CM	244	0.320E-03

Title of radionuclide master library:

ONSITE/BIOPORT RADIONUCLIDE MASTER DATA LIBRARY 1-JUN-84 RAP

Decomposition half time of package (years): 15.0

No. of years of package storage prior to beginning of scenario: 10.0

TABLE 5.3-1. (Continued)

PLANT ASSOCIATION - Eastern			
Number of Successional Phases	3	Dry/wet weight ratio = 0.1500	
Intervals for succession (yr)	:	6	28
Root/shoot ratio	:	0.250000	0.350000
Range of roots (m)	:	2.0	2.0
Net annual production [g(dry)/m ² /yr]	:	468.000	635.000
Recycle rate for each phase	:	0.60	0.60
Linear change (biomass) (0=no,1=yes)	:	0	1
Linear change (recycle) (0=no,1=yes)	:	0	1
% Root distribution by strata	:		
Strata :	1	0.6000	0.6000
Strata :	2	0.3000	0.3000
Strata :	3	0.0700	0.0700
Strata :	4	0.0300	0.0300

ANIMAL SPECIES - Cmppt
Amount of material moved (m³/ha) = 51.4500 Activity range (m) = 2.0
Degree of activity by phase = 1.0000 0.9600

Proportion of material moved to surface by strata
1 2 3 4
0.8625 0.0750 0.0375 0.0250

FIGURE 5.3.1-1. Surface Soil Radionuclide Concentrations for Group 1, 2 and 3 Radionuclides. Humid site, plant model 1.

TABLE 5.3.1-1. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Megaparameter. (Sign indicates direction of change.) Humid site, plant model 1.

<u>Megaparameter</u>	<u>Megaparameter Increased 50%</u>	<u>Megaparameter Decreased 50%</u>
ANIMAL	+4.23	-1.86
PLANT	+0.07	-0.13
PACKAGE	-0.46	+0.46
GROUP 1 CR'S	+0.07	-0.07
GROUP 2 CR'S	0.00	0.00
GROUP 3 CR'S	0.00	0.00
SOIL	-0.03	+0.03
EROSION	0.00	--
SUCCESION	0.00	0.00

TABLE 5.3.1-2. Years of Maximum Surface Radionuclide Concentrations. Compare to Base Case Value: Year 57. Humid site, plant model 1.

<u>Megaparameter</u>	<u>Megaparameter Increased 50%</u>	<u>Megaparameter Decreased 50%</u>
ANIMAL	54	113
PLANT	58	56
PACKAGE	67	48
GROUP 1 CR'S	58	56
GROUP 2 CR'S	57	57
GROUP 3 CR'S	57	57
SOIL	57	58
EROSION	57	--
SUCCESION	57	57

TABLE 5.3.1-3. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Parameter. (Sign indicates direction of change.) Humid site, plant model 1.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	+0.89	-0.92
	PACTIVE	+0.89	-0.92
	PMOVE	+0.95	-0.46
	RANGC	0.00	-1.87
PACKAGE	PL	-0.33	+0.39
	PL1	+0.13	-0.10

TABLE 5.3.1-4. Years of Maximum Surface Radionuclide Concentrations. Compare to Base Case Value: Year 57. Humid site, plant model 1.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	56	59
	PACTIVE	56	59
	PMOVE	56	58
	RANGC	57	106
PACKAGE	PL	51	73
	PL1	57	64

sensitive to PMOVE, AMT and PACTIVE. The C values for these parameters were approximately 0.90%. BIOPORT was uniformly less sensitive to the PACKAGE parameters than the ANIMAL parameters and was more sensitive to package half-life than package age. The maximum C values for PL and PL1 are 0.39% and 0.13%, respectively.

The model was insensitive to erosion as tested. We tested the model with a short period of erosion at the beginning of the 500 year evaluation period. Erosion occurring early has very little surface contamination, our result was expected. We felt this was a realistic erosion for the humid site, however.

5.3.2 Plant Uptake Model 2

Figure 5.3.2-1 shows the concentrations of Group 1, 2 and 3 radionuclides in the top soil layer throughout the 500-year simulation period, using plant model 2 and the humid site base case as input. The results of the sensitivity analysis on plant model 2 are virtually identical to those of plant model 1; we refer the reader to Section 5.3.1 for a detailed explanation of the results of the analysis. The percent change in the maximum surface values relative to percent change in the megaparameters are shown in Table 5.3.2-1. The years in which these maxima were achieved for each case are shown in Table 5.3.2-2.

As with plant model 1, ANIMAL and PACKAGE were the only two megaparameters to which BIOPORT showed any sensitivity. The results of the sensitivity tests on each of the parameters are shown in Tables 5.3.2-3 and 5.3.2-4.

FIGURE 5.3.2-1. Soil Surface Concentrations of Group 1, 2 and 3 Radionuclides. Humid site, plant model 2.

TABLE 5.3.2-1. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Megaparameter. (Sign indicates direction of change.) Humid site, plant model 2.

Megaparameter	Megaparameter Increased 50%	Megaparameter Decreased 50%
ANIMAL	+4.67	-2.00
PLANT	+0.04	-0.07
PACKAGE	-0.46	-0.49
GROUP 1 CR'S	+0.04	0.00
GROUP 2 CR'S	0.00	0.00
GROUP 3 CR'S	0.00	0.00
SOIL	0.00	+0.04
EROSION	0.00	---
SUCCESION	0.00	+0.04

TABLE 5.3.2-2. Years of Maximum Surface Radionuclide Concentrations. Compare to Base Case Value: 56. Humid site, plant model 2.

<u>Megaparameter</u>	<u>Megaparameter Increased 50%</u>	<u>Megaparameter Decreased 50%</u>
ANIMAL	53	113
PLANT	56	57
PACKAGE	65	44
GROUP 1 CR'S	56	56
GROUP 2 CR'S	56	56
GROUP 3 CR'S	56	56
SOIL	55	56
EROSION	56	--
SUCCESSION	56	56

TABLE 5.3.2-3. Percent Change in Maximum Surface Soil Layer Radionuclide Concentrations (Ci/ha) per 1% Change in Parameter. (Sign indicates direction of change.) Humid site, plant model 2.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	+0.98	-0.98
	PACTIVE	+0.98	-0.98
	PMOVE	+1.05	-0.46
	RANGC	0.00	-2.00
PACKAGE	PL	-0.32	-0.42
	PL1	+0.14	-0.14

TABLE 5.3.2-4. Years of Maximum Surface Radionuclide Concentrations. Compare to Base Case Value: 56. Humid site, plant model 2.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
ANIMAL	AMT	55	57
	PACTIVE	55	57
	PMOVE	56	56
	RANGC	56	106
PACKAGE	PL	61	49
	PL1	59	53

5.4 EXAMPLE CALCULATIONS OF DOSE TO MAN

During the sensitivity analysis, we varied the BIOPORT input parameters over a range of 50%. This 50%, however, is an arbitrary value chosen largely for convenience in the analysis. Little information is available on the true ranges of these parameter values for arid or humid sites. A survey of the literature indicates that the amount of soil brought to the surface by animals on a site may range over an order of magnitude depending on the type and density of the animals present. In addition, almost nothing is known about the variability of package longevity. Plant rooting characteristics are also poorly documented, although the available literature indicates that the PLANT variables can vary 50-100% (see McKenzie et al. 1982 and 1983 for references). Finally there are sometimes several orders-of-magnitude variability in the radionuclide concentration ratios reported in the literature (Ng et al. 1982). Clearly the parameters which influence the BIOPORT model output can vary substantially from site to site, and, perhaps, over time at a single site. Therefore, for the BIOPORT model to be an effective predictive tool, reasonably accurate data on the animal and plant populations and package characteristics must be obtained for the disposal site to which the model is being applied.

As an example, we calculated dose to man for cases in which parameters to which BIOPORT is sensitive were varied over "reasonable" ranges, as determined from a survey of the literature (McKenzie et al. 1982, 1983). These cases were calculated using both the arid and humid site data, for plant uptake model 1.

For the arid site data, we increased and decreased plant biomass (BIOMAS) by 50%, and we varied the volume of soil brought to the surface by animals (AMT) by an order of magnitude. The maximum human bone doses for these cases are plotted in Figure 5.4-1. Bone accumulated the highest

doses, although doses to other organs follow the same general pattern. The bone dose for the arid site base case is included as well. The 50% change in plant biomass produced about a 4 REM or 57% change in dose from the base case around the maximum dose year. However, even an order-of-magnitude change in AMT causes only a very slight change in dose, for two reasons: 1) according to BIOPORT plant model 1, animals contribute substantially less activity to the surface layer than do plants, and 2) because of their higher concentration ratios plants bring up proportionately greater concentrations of the Group 1 radionuclides, which because of their biological mobility through food chains contribute to human dose more than do the Group 2 and 3 radionuclides.

For the humid site data, we varied AMT by 50%. No plant variables were tested because they do not noticeably affect the output from the BIOPORT model. Figure 5.4-2 shows the variation in maximum bone dose with the 50% variation in AMT. The bone dose calculated using the humid site base case is also shown. The 50% change in AMT produced a 5 REM, or 24% change in dose from the base case around the maximum dose year.

FIGURE 5.4-1. Bone Doses for Arid Site Data

These examples illustrate that reasonable variability in some of the BIOPORT input parameters can have a substantial impact on the dose to humans. This impact underscores the need to have accurate, site-specific input data if the BIOPORT/MAXI models are to produce appropriate output.

5.5 ADDITIONAL SENSITIVITY ANALYSIS ON THE HUMID SITE

Further investigation into the results of the sensitivity analysis for the humid site indicated that the overwhelming effect of the ANIMAL parameters on the BIOPORT model using the humid site data was a consequence of the way in which the different animals on the site were composited into a single animal for convenience in the sensitivity analysis. The composite animal was designed to bring to the surface the same amount of soil as all of the animals present on the site combined, and to have an average burrow distribution with respect to the animals present on the site. One of the animals present on the site in the humid site base case, the Short Tailed Shrew, brings to the surface $48.5 \text{ m}^3/\text{ha}$ of the $51.45 \text{ m}^3/\text{ha}$ brought to the surface annually by all of the animals in the base case, but from the top soil layer only. Compositing the animals and assigning them an average

FIGURE 5.4-2. Bone Doses for Humid Site Data

TABLE 5.5.1-1. Percent Change in Maximum Surface Soil Layer Radionuclides (Ci/ha) per 1% Change in Parameter. (Sign indicates direction of change.) Humid site, plant model 1, ANIMAL not a composite.

Megaparameter	Parameter	Parameter Increased 50%	Parameter Decreased 50%
PLANT		+1.16	-1.90
	PROOT	+0.13	-0.18
	RANGP	---	-1.90
	SROOT	-0.04	0.00
	BIOMAS	+0.93	-0.98

burrow distribution meant that a considerably greater amount of the total soil brought to the surface was coming from the lower soil layers and the inventory than if the animals had remained separate for the analysis.

Because there are no interactions between the BIOPORT parameters, the sensitivity analyses on the component parameters of the ANIMAL and PACKAGE megaparameters were not affected. The major effect that the compositing of the animal parameters had on the model output was to obscure the effects of the PLANT parameters on the model. Therefore, another sensitivity analysis was conducted on the PLANT parameters, only for the humid site data, in which the animals remained separate. The plants were combined into a single composite plant for convenience in the sensitivity analysis.

Leaving the animals separate had the effect of dropping the maximum surface value for the base case from 61 Ci/ha to 4.5 Ci/ha for plant model 1; and from 57 Ci/ha to 0.33 Ci/ha for plant model 2.

5.5.1 Plant Uptake Model 1

Table 5.5.1-1 shows the percent change in maximum surface layer radionuclide concentrations per a 1% change in the PLANT megaparameter and its component parameters, calculated as described in section 5.2.1. The PLANT megaparameter has a maximum C value of (-)1.90%. Comparing this value to those shown in Table 5.3.1-1 (C values for the megaparameters with the animals composited) indicates that the PLANT parameters have a substantial impact on the model output.

Among the PLANT parameters, the BIOPORT model is most sensitive to the RANGP parameter, the value of which determines whether or not the plant roots penetrate the inventory. In fact, the decrease in the RANGP parameter accounts for all of the change in the model output when the PLANT megaparameter is decreased. The model is also relatively sensitive to BIOMAS, with a maximum C value of (-)0.98%. The model is less sensitive to the root/shoot ratio (PROOT), and is almost completely insensitive to the distribution of roots in the soil layers (SROOT). Both have C values less than $\pm 0.2\%$.

TABLE 5.5.1-2. Years of Maximum Surface Radionuclide Concentrations. Compare to base case value: Year 107. Humid site, plant model 1, ANIMAL not a composite.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
PLANT		110	57
	PROOT	108	107
	RANGP	---	57
	SROOT	107	108
	BIOMAS	109	102

Table 5.5.1-2 shows the changes in the years in which the maximum surface soil activity occurred when the PLANT megaparameter and its component parameters were varied by 50%. The maximum year in the base case changed from year 57, when the animals were composited to year 107, when the animals were not composited (compare to Table 5.3.1-2).

5.5.2 Plant Uptake Model 2

Table 5.5.2-1 shows the percent change in maximum surface layer radionuclide concentrations per a 1% change in the PLANT megaparameter and its component parameters, calculated as described in Section 5.2.1. The PLANT megaparameter has a maximum C value of (+)1.03%. Comparing this value to those shown in Table 5.3.2-1 (C values for the megaparameters with the animals composited) indicates that the PLANT parameters have a substantial impact on the model output.

Among the PLANT parameters, the BIOPORT model is most sensitive to the RANGP parameter, the value of which determines whether or not the plant roots penetrate the inventory. Again the decrease in the RANGP parameter accounts for all of the change in model output when the PLANT megaparameter is decreased. The model is less sensitive to plant biomass (BIOMAS) and the distribution of roots in the soil layers (SROOT), both of which have C values of $\pm 0.36\%$. BIOPORT is almost completely insensitive to the root-to-shoot ratio (PROOT), with a C value of $\pm 0.06\%$.

Table 5.5.2-2 shows the changes in the years in which the maximum surface soil activity occurred when the PLANT megaparameter and its component parameters were varied by 50%. The maximum year in the base case changed from Year 57, when the animals were composited, to Year 107, when the animals were not composited (compare to Table 5.3.2-2).

TABLE 5.5.2-1. Percent Change in Maximum Surface Soil Layer Radionuclides (Ci/ha) per 1% Change in Parameter. (Sign indicates direction of change.) Humid site, plant model 2, ANIMAL not a composite.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
PLANT		+1.03	-0.67
	PROOT	+0.06	-0.06
	RANGP	---	-0.67
	SROOT	+0.36	-0.36
	BIOMAS	+0.36	-0.36

TABLE 5.5.2-2. Years of Maximum Surface Radionuclide Concentrations. Compare to base case value: Year 67. Humid site, plant model 2, ANIMAL not a composite.

<u>Megaparameter</u>	<u>Parameter</u>	<u>Parameter Increased 50%</u>	<u>Parameter Decreased 50%</u>
PLANT		77	57
	PROOT	68	66
	RANGP	--	57
	SROOT	71	63
	BIOMAS	71	63

5.5.3 Comparison of Results with Plant Uptake Model 1 and Plant Uptake Model 2

BIOPORT Plant Uptake Model 1 is more sensitive to the PLANT megaparameter than is Plant Uptake Model 2. This is to be expected, since in Model 1 the plants take up radionuclides in proportion to a larger mass than in Model 2.

Both models are very sensitive to whether or not the plant roots penetrate the inventory (the RANGP parameter). In fact, both uptake models give the same result if the roots do not penetrate the inventory: a maximum surface layer value of 0.22 Ci/ha in year 57.

Plant Model 1 is also very sensitive to the total biomass of plants on the site, and not sensitive to the distribution of roots in the top three soil layers (the SROOT parameter). Plant Model 2, on the other hand, is

less sensitive to the total biomass of plants on the site, and more sensitive to the distribution of roots in the soil layer. This is consistent with the structure of the two models. In Model 1, radionuclides are taken up in proportion to the entire mass of the plant, so that the total biomass of plants is an important parameter, and the distribution of roots in the soil is much less important, as long as the roots penetrate the inventory. Model 2 should be more sensitive to the distribution of the roots, since, according to this model, radionuclides are taken up in proportion to the root mass only. Increasing or decreasing the concentration of roots in the layers near and in the inventory would be expected to have a substantial impact on the model output.

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less sensitive to the total biomass of plants on the site, and more sensitive to the distribution of roots in the soil layer. This is in contrast with the structure of the two roots. In Model 1, root biomass is taken up in proportion to the entire mass of the plant, so that the total biomass of plants is an important parameter, and the distribution of roots in the soil is much less important. In Model 2, the distribution of roots in the soil is more sensitive to the distribution of the plants. Model 2 should be more sensitive to the distribution of roots, since, according to this model, root biomass is taken up in proportion to the root mass only. Increasing or decreasing the concentration of roots in the layers near and in the inventory will be expected to have a substantial impact on the model output.

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6.0 SUMMARY AND CONCLUSIONS

Based on these results, we recommend that biotic transport be included in the dose assessment for commercial low-level waste sites. The site-specific parameters that control the contribution of biotic transport to dose to man are the thickness of the trench cover and the burrowing and rooting depth of animals and plants that inhabit the waste disposal site. Conditions that permit biotic intrusion into the waste zone will result in the transport of radionuclides with the overlying soil column and to the surface. Intrusion by burrowing animals will result in the redistribution of waste materials and contaminated soil. Intrusion by plant roots will result in selective movement of individual radionuclides depending on affinity for plant uptake as represented by concentration ratio (CR). Vertical transport of waste materials by plants and animals results in a real and predictable contribution to the dose to future inhabitants of commercial low-level waste disposal sites.

We also recommend that data be collected to permit a resolution between the two plant sub-models. In general, we found an approximate order-of-magnitude difference in the dose that results from selection of the two plant models. Resolution of this aspect could affect the relative contribution from plant root intrusion and transport to the total dose to man.

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APPENDIX

SOURCES OF INFORMATION FOR BURROWING CHARACTERISTICS OF ANIMALS
AT THE US ECOLOGY AND BARNWELL SITES

TABLE A-1. Sources of Information for Burrowing Characteristics of Animals at the U.S. Ecology Site

Animal	Reference	Type of Information Used
Townsend Ground Squirrel <u>Spermophilus townsendii</u>	Hedlund and Rickard 1981 Davis 1939 Alcorn 1940	Density Diameter of tunnels Depth, length and volume
Great Basin Pocket Mouse <u>Perognathus parvus</u>	Schreiber 1978 Lande and Mitchell 1981 Scheffer 1938 Criddle 1915 Hedlund and Rogers 1976	Depth of burrows Depth of burrows Diameter of tunnels and depth of burrow Burrow length and volume Density
Northern Pocket Gopher <u>Thomomys talpoides</u>	Winsor and Whicker 1980 Ellison 1946 Axthelm and Lee 1976 Hickman 1977 Miller 1957	Density, depth, burrow diameter, volume of soil per hectare Density, volume of soil per hectare Depth Depth Distribution of burrow systems
Badger <u>Taxidea taxus</u>	Lindzey 1976 Lindzey 1978 Messick and Hornocker 1981 Sargeant and Warner 1972	Burrow depth and length Number of burrows/badger Animal and burrow density Number of burrows/badger
Ants <u>Pogonomyrmex owyheei</u>	Fitzner et al. 1979 Cline et al. 1980	Colony density, tunnel depth, tunnel volume Tunnel depth and volume

TABLE A-2. Sources of Information for Burrowing Characteristics of Animals at the Barnwell Site

Animal	Reference	Type of Information Used
Old Field Mouse <u>Peromyscus polionotus</u>	Wolfe and Esher 1977 Smith 1971 Smith and Criss 1967 Smith 1968 Briese and Smith 1974 Davenport 1964	Burrowing behavior and soil moved Density of animals per hectare Burrow depths and volume Population estimates using two indices Habitat preferences Burrow depths
Short Tail Shrew <u>Blarina brevicauda</u>	Esher, Wolfe and Ursic 1981	Burrow depths and volumes
Eastern Mole <u>Scalopus aquaticus</u>	Burt and Grossenheider 1976 Gieger 1973 Harvey 1976	Burrow depth, habitat, soil types, distribution Density Burrow length and diameter
Gopher Tortoise <u>Gopherus polyphemus</u>	McRae et al. 1981 Landers, J. L. (personal communication) ^(a)	Density, habitat Burrow depths and lengths
Harvester Ant <u>Pogonomyrmex badius</u>	Golley and Gentry 1964 Van Pelt 1966 Gentry and Stiritz 1972 Harrison and Gentry 1981	Habitat, mound dimensions, turnover rate, soil conditions Density Ants per colony, tunnel depths, turnover rate, soil conditions Nest relocation, density
Pyramid Ant <u>Dorymyrmex pyramicus</u>	Van Pelt 1966	Tunnel depth, density, habitat, list of other species
Earthworms	Gerard 1967 Grant 1956 Reichle et al. 1971	Tunneling depth Density, soil movement Soil movement, tunneling depth

(a) Landers, J. L., Rt. 3, Box 1788, Bainbridge, Georgia 31717.

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13. ABSTRACT (200 words or less) <p>The results reported here establish the relevance and propose a method for including biotic transport in the assessment and licensing process for commercial low-level waste disposal sites. Earlier work identified the biotic transport mechanisms and process scenarios linking biotic transport with dose to man, and developed models for assessment of impacts. Model modification and improvement efforts resulted in enhancing the ability to represent soil erosion and soil transport within the trench cover. Two alternative hypotheses on plant root uptake were incorporated into the model to represent transport of radionuclides by roots that penetrate the buried waste. Enhancements were also made to the scenario for future site intruder activities. Representation of waste package decomposition in the model was confirmed as the best available alternative. Results from sensitivity analyses indicate that additional information is needed to evaluate the alternative hypotheses for plant root uptake of buried wastes. Site-specific evaluations of the contribution from biotic transport to the potential dose to man establish the relevance in the assessment process. The BIOPORT/MAXII computer software package is proposed for dose assessments of commercial low-level waste disposal sites.</p>					
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