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Predictive Ecological Risk Assessment Methodology
Environmental Restoration Program
Sandia National Laboratories, New Mexico

prepared by

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Predictive Ecological Risk Assessment Methodology
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Sandia National Laboratories, New Mexico

1.0 Introduction

Sandia National Laboratories, New Mexico (SNL/NM) is located on the Kirtland Federal Complex (KFC), immediately south of Albuquerque, New Mexico. KFC comprises over 52,000 acres of federally-owned land that is used and/or managed by several agencies and affiliated organizations, including the U.S. Air Force (Kirtland Air Force Base), the U.S. Department of Energy (DOE), and the U.S. Forest Service. SNL/NM, which is currently managed by Lockheed Martin Corporation for the DOE, has operated at this location since 1945. Over its history of operation, SNL/NM and its predecessor organization (Sandia Laboratory) have conducted a wide variety of test programs, primarily related to national defense, at many locations within the KFC boundaries. Test activities have included open detonations, shock tube and contained detonations, weapons firing, high velocity impact tests, open burning, and others. These tests have involved a wide variety of materials, including high explosives, various metals and radionuclides, some of which remain as residues at the test sites. In addition, waste materials resulting from the testing operations (including fabrication processes) have been disposed of in above- and below-ground landfills, pits, trenches, storage yards, or septic systems.

The SNL/NM Environmental Restoration (ER) Program was initiated to identify, delineate, characterize, and remediate those sites that have been used by SNL/NM and Sandia Laboratory that may contain materials which are potentially hazardous to human health or the environment. Identification of these sites has involved records searches as well as interviews with personnel who took part in the operations. Once identified, the potential boundaries of the affected area are delineated and the site is characterized for suspected hazardous constituents. If no such materials are detected, the site is designated for no further action (NFA). If potentially hazardous materials are detected, predictive level risk assessments are performed on the characterization data to determine whether they occur at levels that are not potentially hazardous to human health or the environment. If this is the case, an NFA designation for the site is pursued. Otherwise, either corrective actions or further investigation of the site will be pursued. In some cases, principally where the removal of the potentially hazardous material is readily achievable, a voluntary corrective measure (VCM) may be pursued before the full characterization process is completed.

Over 240 sites at KFC have been identified for investigation by the SNL/NM ER program, including historic and active test sites, landfills, disposal pits and trenches, storage areas, and septic systems. These have been grouped into "batches" based on

their potential for NI A [illegible] assessments are performed [illegible] determine [illegible] warranted. The purpose [illegible] present [illegible] for performing the ecological [illegible] for the Site. [illegible] addition, the method for [illegible] based [illegible] (PRGs) for these sites is also presented.

2.0 Ecological Description of KFC

Most of KFC lies on a broad, relatively flat, [illegible] surface [illegible] East Mesa for its elevated position above the Rio Grande drainage to the [illegible] elevations ranging from about 5,300 ft [illegible] about 6,000 ft [illegible] The eastern half of KFC includes the western slope of the Manzanita Mountains which rises to an elevation of 7,716 ft. These mountains are dissected by several [illegible] canyons. Rock exposures along the canyon walls and mountain slopes [illegible] form cliffs of moderate height. A small outlier range known as the Four Hills [illegible] Manzano Base lies in the north-central part of KFC immediately west of the Manzanita Mountains. The highest peak of the Four Hills rises [illegible] 5,958 ft.

The drainages from the three principal canyons of the Manzanita Mountains [illegible] Lurance, Macera, and Sol se Mete) converge in Lurance Canyon and form [illegible] Coyote. This arroyo flows west from the mouth of Lurance Canyon to the [illegible] of the Four Hills, where it turns northwest and flows into Tijeras Arroyo, the largest drainage feature on KFC. Tijeras Arroyo originates in Tijeras Canyon which separates the Manzanita Mountains from the Sandia Mountains to the north. [illegible] flows southwestward to the Rio Grande. About 4 miles of this drainage [illegible] KFC, crossing its northwest corner. Drainages that originate south of the Lurance and Sol se Mete Canyons generally flow westward across the East Mesa [illegible] a broad, internal drainage basin near the western boundary of KFC. All of these drainages (including Tijeras Arroyo and Arroyo del Coyote) are ephemeral.

Perennial surface water at KFC is limited to springs, seeps, and [illegible] wildlife watering devices. About nine springs and seeps have been identified [illegible] Coyote Springs is the largest spring-fed wetland on KFC and is located [illegible] Lurance Canyon, along the south side of Arroyo del Coyote. It [illegible] acres of wetland vegetation including rushes (*Juncus* spp.), cattails (*Typha latifolia*) and several large Fremont cottonwoods (*Populus fremontii*). A [illegible] cedar (*Tamarix pentandra*) marks the contact between the spring [illegible] channel of Arroyo del Coyote. Coyote Springs was historically [illegible] area and continues to be used by the [illegible] as a base for [illegible] the physical modifications [illegible] Coyote Springs [illegible]

wildlife use on KFC due to the year-round presence of surface water and the vertical habitat structure provided by the trees.

Lurance Spring and Sol se Mete Spring are located in the respective canyons. Both have been developed with masonry tubs for wildlife use and both support small amounts of wetland vegetation. Sol se Mete Spring is also used to feed a series of three wildlife watering devices (also called "trick tanks" or "guzzlers") located downcanyon from the spring. G Spring is a groundwater-fed riparian flow in Arroyo del Coyote near Manzano Base (downstream of Coyote Springs) that is typically on the surface for only a few hundred feet before infiltrating back into the sands of the arroyo bed. It is marked by a dense stand of salt-cedars and Fremont cottonwoods along the arroyo. Four small springs and rock seeps occur in the Four Hills and another small spring occurs on the north end of these mountains, near the northern boundary of KFC. None of these support more than a few hundred square feet of wetland vegetation (USACE, 1995).

The habitats on KFC can be divided into four major types: grassland, woodland, riparian scrubland (including small amounts of riparian woodland and wetland), and altered habitats. Grassland habitat dominates the undeveloped areas of the East Mesa. The grassland vegetation on KFC shows a mix of biotic influences that includes the Chihuahuan Semidesert Grassland, the Great Basin Scrub Grassland, and the Plains Grassland (Brown, 1982). The principal grass species are black grama (*Bouteloua eriopoda*), galleta (*Hilaria jamesii*), sand dropseed (*Sporobolus cryptandrus*), purple threeawn (*Aristida purpurea*), and Indian ricegrass (*Oryzopsis hymenoides*). Woodland habitat dominates the mountainous areas in the eastern part of KFC.

The woodland vegetation is principally influenced by the Great Basin Conifer Woodland biome, which is dominated by one-seed juniper (*Juniperus monosperma*) and Colorado pinyon pine (*Pinus edulis*) (Brown, 1982). At lower elevations, the woodland has an open canopy and an understory of grasses (including blue grama [*Bouteloua gracilis*] and side-oats grama [*Bouteloua curtipendula*]) and shrubs (including mountain mahogany [*Cercocarpus montanus*], skunkbush [*Rhus trilobata*], and gray oak [*Quercus grisea*]). At higher elevations, some influence of the Rocky Mountain Montane Coniferous Forest biome is found in the woodland habitat with the presence of ponderosa pine (*Pinus ponderosa*) and Rocky Mountain juniper (*Juniperus scopularum*).

The riparian scrubland habitat occurs along the drainages of KFC. The principal shrub species of this habitat are rabbitbrush (*Chrysothamnus nauseosus*), Apache plume (*Fallugia paradoxa*), and fourwing saltbush (*Atriplex canescens*). One-seed junipers (as shrubs or small trees) and salt-cedar are also common along the drainages. In the canyons, other shrubs and trees also occur along the drainages. These include New Mexico olive (*Forestiera neomexicana*), New Mexico locust (*Robinia neomexicana*), and

narrow leaf hop-tree (*Ptelea trifoliata*). Because the areas of wetland plants and riparian woodlands on KFC are very small and closely associated with the riparian shrubland they are considered part of this habitat type.

The final habitat type is referred to as altered habitat and includes areas that have been developed or otherwise significantly disturbed by human activity. In many cases, the natural vegetation of these areas has been removed by soil disturbance including grading, excavation, and compaction. Some areas have been paved or covered with gravel. At active sites, the removal of ruderal species (weeds) is a continuing process as part of facility maintenance. At inactive or infrequently used sites, vegetation is allowed to reestablish through natural succession. Common ruderal and early successional species in these areas include Russian thistle (*Salsola kali*), summer cypress (*Kochia scoparia*), and threeawns (*Aristida* spp.).

3.0 Ecological Risk Assessment Methodology

The ecological risk assessment process performed for the SNL/NM ER program sites is a predictive ecological risk assessment. Methodology used is based on general level guidance presented by USEPA (USEPA, 1992, 1996, and 1997) and by Wentsel et al. (1996) and is consistent with a phased approach. It also incorporates basic ideas presented in an earlier SNL/NM ER ecological risk assessment approach document (SNL/NM, 1997). This assessment utilizes conservatism in the estimation of ecological risks; however, ecological relevance and professional judgment are also incorporated as recommended by USEPA (1996) and Wentsel et al. (1996) to insure that the predicted exposures of selected ecological receptors reasonably reflect those expected to occur at the site.

3.1 Data Quality Objectives

Data quality objectives (DQOs) and quality assurance/quality control (QA/QC) of the data used in the ecological risk assessments are based on established criteria and addressed on a site-by-site basis. DQOs are negotiated among SNL/ER task managers who have responsibility for specific ER sites, and managers, representatives from the New Mexico Environment Department (NMED) Department of Energy Oversight Bureau, and representatives from NMED. Data QA/QC is addressed at each site in the NFA proposals. Data QA/QC specific to risk assessment, if not discussed elsewhere, can be found in the uncertainty and summary sections of the risk assessments.

3.2 Constituents of Potential Ecological Concern

The constituents of potential ecological concern (COPECs) evaluated in the ecological risk assessments for SNL/NM ER sites include both organic and inorganic chemicals and at some sites, the latter includes radiologically active materials. These constituents

of test-related materials may have been released into the environment directly as a result of test activities, or as a result of waste management and disposal practices before or after the test. Because many of the inorganic analytes measured at ER sites are common constituents of natural soils, each of these analytes is only considered to be COPECs if its concentration at the ER site is greater than the 95th percentile (or the Upper Tolerance Limit) of the background concentration for that site. However, elements that are essential nutrients (calcium, iron, magnesium, potassium, and sodium) are not considered to be COPECs regardless of their background concentrations.

3.3 Conceptual Model

Figure 1 presents a general conceptual model for the assessment of ecological risk at the SNL/NM ER program sites. The ER sites are terrestrial in nature and the principal media of ecological concern are surface and subsurface soil. Surface soil typically received the initial deposition of material from the testing activities performed at or above ground surface or from material storage or disposal on the ground surface. Because most of this testing occurred on the order of several years to decades ago, infiltration into the subsurface soil is expected for many of these COPECs. Wind may have transported COPECs in the surface soil as dust. Surface runoff following precipitation events may have transported COPECs in surface soils to drainages, where they may have been deposited in sediments, carried with water percolating into groundwater, or be carried into higher order streams. As described above, the surface water flows in the drainages at KFC are ephemeral and do not support aquatic communities or wetland habitat. Site-wide issues associated with downstream surface water bodies will be addressed by the SNL/NM Surface Water Task Force and are outside of the scope of the ER program risk assessments. Because these drainages (arroyos) are dry for most of the year, their sediments are treated as soils in the conceptual model.

Subsurface soils typically receive COPECs through percolation from the surface, burial of materials containing COPECs, or direct release into the subsurface soil such as at leach fields associated with septic tanks or by underground tests (e.g., Thunder Wells). Because of the low rainfall of this area, rooting and burrowing are expected to be concentrated within the first few feet of the soil profile. This is supported by field data on root depths and burrowing depths at other semiarid locations for species that occur at KFC (e.g., Davis, 1966; Reynolds and Wakkinen, 1987; Reynolds and Fraley, 1989). For this reason, COPECs in subsurface soil are not considered to be bioavailable if they occur at depths greater than 5 feet.

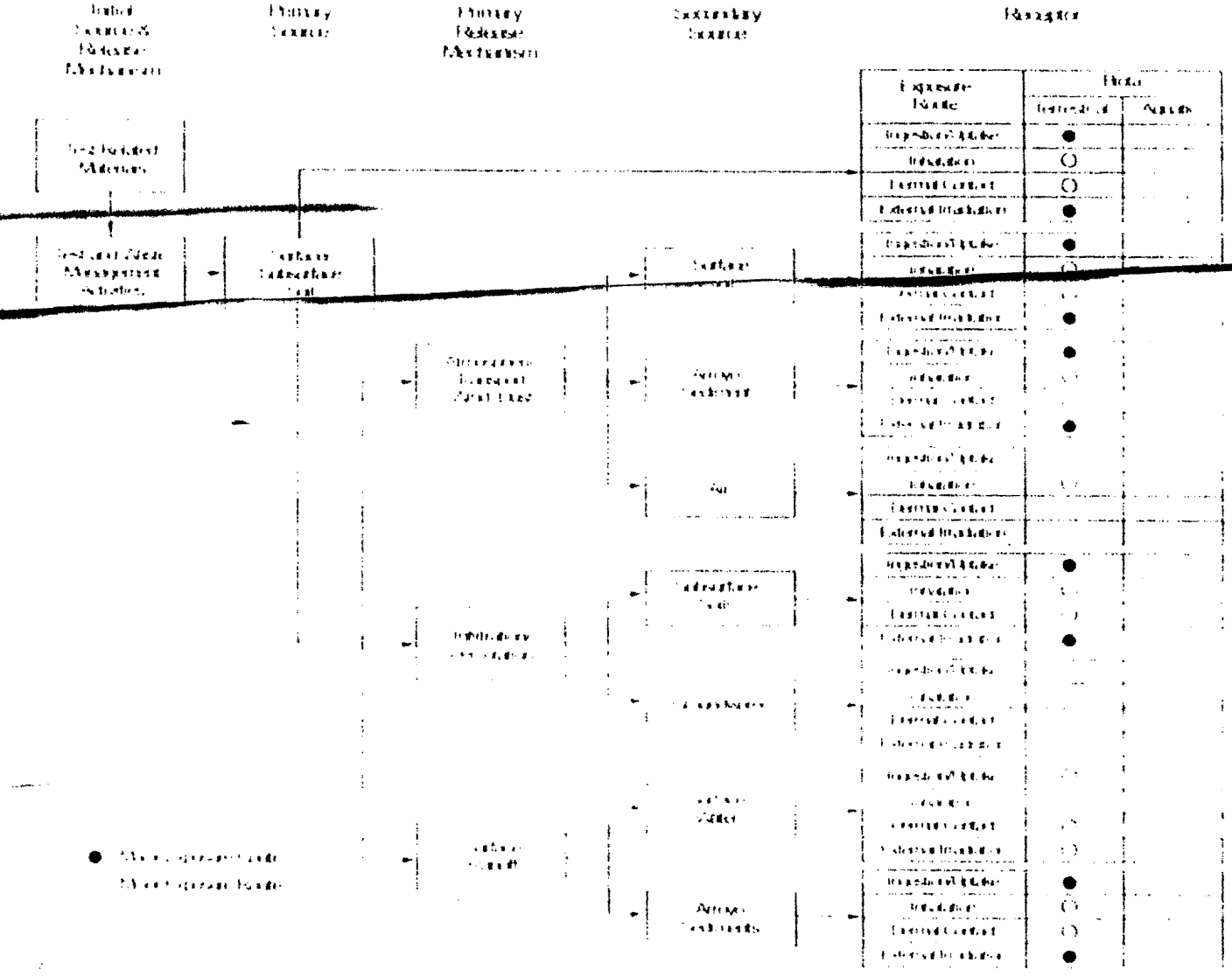


Figure 1

Generic Conceptual Model for a SNL/NM Environmental Restoration Site

Most SNL/NM ER program sites occur in altered habitats on the alluvial surface of the East Mesa. Therefore, the original vegetation of these sites was grassland. Several of these sites include areas of relatively undisturbed grassland habitat within their boundaries, while others are entirely within altered habitat, being sparsely vegetated with ruderal species, devoid of vegetation, or entirely developed with buildings, pavement, or landscaping. However, some sites (especially the larger sites, such as Sites 54, 58, 68, and 102) are dominated by relatively undisturbed grassland habitat. Similarly, most of the sites in the mountain area (most of which are within the canyons) are in altered habitat which was formerly woodland. Some of the larger of these sites include significant areas of relatively undisturbed woodland habitat. A small number of SNL/NM ER program sites include areas of riparian scrubland habitat. No ER sites with identified COPECs (i.e., sites other than those designated for no further action [NFA]) include springs or wetland habitat.

The principal exposure pathways at the SNL/NM ER program sites are direct contact and uptake by organisms in the soil (e.g., plants and soil invertebrates) and ingestion of soil, plants, or prey from these sites by wildlife. Exposure in wildlife through inhalation and dermal contact pathways are not considered to be significant pathways for COPECs in the soil (Sample and Suter, 1994). Although both of these pathways may lead to additional absorption of the COPECs, both are also linked to ingestion by the ingestion of inhaled soil particles that have been entrapped in the mucus lining of the nasal cavity and throat and the ingestion of soil through grooming. The absorption of COPECs from soil particles directly through the lungs or skin is expected to be insignificant with respect to that from the daily dietary intake of soil. The drinking water ingestion pathway is also expected to be minor. Surface water in this area is ephemeral and extremely limited (IT, 1996), allowing little opportunity for COPECs to partition from soil to surface water. Ephemeral surface water may exist as runoff from precipitation events, but no ER sites are known to be sources of surface water that is available for consumption by wildlife. For radiological COPECs, both internal and external dose pathways are evaluated as potential routes of exposure to the receptors. Internal dose is the result of ingestion of COPECs with soil and food items. External dose is the result of exposure to radiation originating from COPECs in *in situ* soils.

3.4 Food Webs at SNL/NM

Because of the general absence of water over most of the area, the wildlife community is limited in its diversity and the complexity of the food web. Food chains are relatively short. These conditions are especially true at past and present operational sites where the coverage, diversity, and productivity of the vegetation is typically low due to the physical disturbance of the soil resulting from the site development and operational activities. Figures 2 through 4 show the generalized food webs for the wildife communities in the three major habitats of KFC, grassland, woodland, and riparian scrubland, respectively. Although not all species of wildlife known to occur at KFC are shown in these figures, examples of the known species or taxonomic groups are given for the major taxonomic/trophic types, or guilds. With the exception of scavengers (e.g.,

turkey vultures [illegible] these [illegible] expected [illegible] wildlife species [illegible] named

Wildlife, especially [illegible] often [illegible] opportunistic [illegible] feeding habits [illegible] carnivores) are the [illegible] material (omnivores) or [illegible] vertebrate prey. The [illegible] vary widely between seasons and locations according to availability. The [illegible] arrows in these food web diagrams are generalized to show the major links [illegible] possible links. If all links, including scavenging, were included in these figures, the number of potential links would make the diagrams needlessly complex and [illegible] unreadable.

Several wide ranging species, such as bats, coyotes, bobcats, and red-tailed hawks, are shown in all three habitat types, and the same individuals may be [illegible] habitats. Many bats, for example, will range widely from their roosting sites, feeding wherever flying insects are available, regardless of the habitat conditions on the ground. Similarly, the other species are opportunistic in hunting and foraging and are not individually bound to a particular habitat type.

The grassland food web (Figure [illegible]) shows the basic structure [illegible] food webs found in terrestrial habitats of KF[illegible]. The primary productivity of the plant community provides the basis for the food web. Invertebrate communities, which include herbivores, predators, and detritivores, are closely linked to the plant community. Among the vertebrates, strict herbivores are probably rare [illegible] species) and may be limited to lagomorphs (rabbits and hares) and [illegible] (doves and pigeons). Although some birds and rodents are primarily [illegible], most of these eat invertebrates in small amounts. Most rodents [illegible] family Cricetidae, which includes deer mice and harvest mice) and passerine birds [illegible] perching birds or "songbirds") are [illegible] eatingly significant [illegible] invertebrates, at least seasonally. Grasshopper mice are cricetids that specialize in insectivory and may occasionally eat small vertebrates. Other wildlife [illegible] specialized in insectivory include lizards, [illegible] flycatchers, swallows, and bats (the last [illegible] specialized in catching [illegible] flight). The diets of some non-raptorial predatory birds (e.g., shrikes and roadrunners) principally consist of invertebrates, but also include small vertebrates such as rodents, lizards, small snakes, and small birds. [illegible] specialize in small vertebrate [illegible].

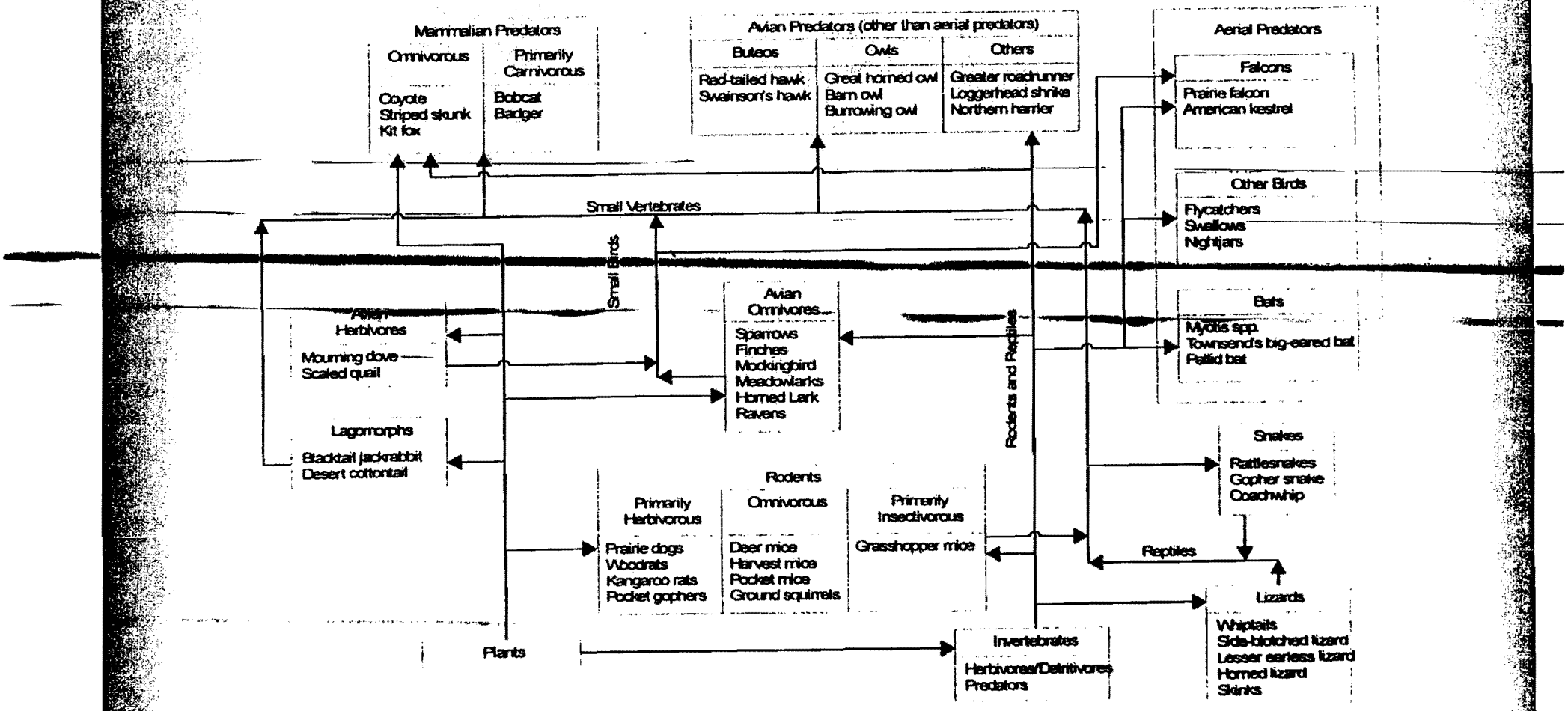


Figure 2

Generalized Foodweb of the Grassland Habitat at Sandia National Laboratories, New Mexico

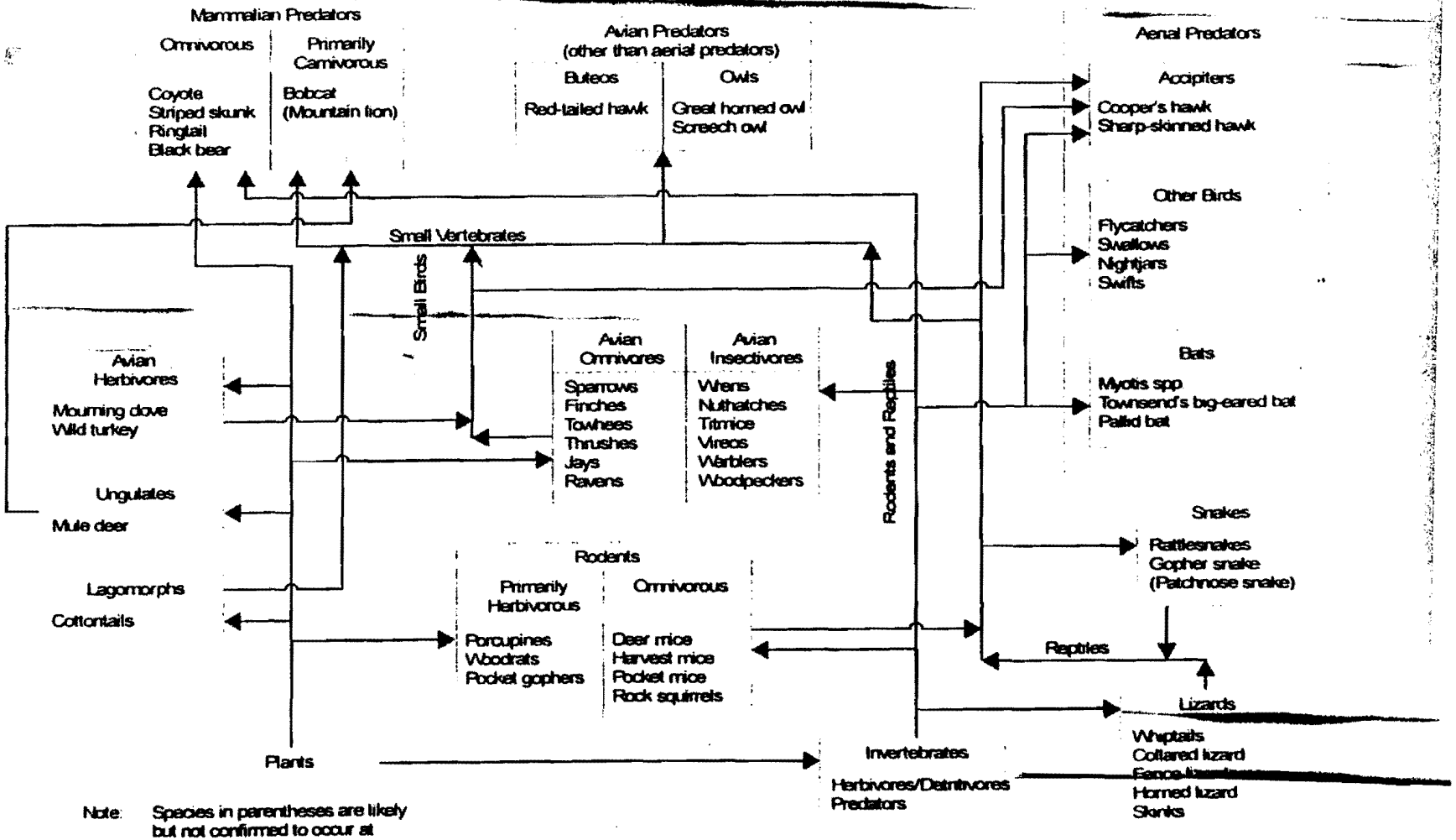
Among the raptors are the buteos which are able to take larger vertebrates such as lagomorphs, ground squirrels and large snakes, falcons which specialize in aerial prey such as birds and insects and owls (which typically specialize in hunting nocturnal species especially rodents Burrowing owls are less nocturnal than the other owls at KFC and will eat invertebrate prey as well as vertebrates) Large mammals in the grassland habitat are omnivores or predators The former includes coyotes skunks and possibly kit foxes The latter includes badgers and possibly bobcats that wander into the grasslands from the woodland or arroyo habitats

The food web of the woodland community (Figure 3) is structurally similar to that of the grasslands, but with some changes in species composition Especially with passerine birds, the increase in trees and shrubs results in a higher diversity of insectivores both aerial hunters (swallows and flycatchers) and gleaners (e g , wrens vireos and warblers) Woodpeckers are also more prevalent as avian insectivores in the woodland habitat Accipiters (Cooper's hawks and sharp-shinned hawks) are more prevalent as aerial predators in the woodlands than are falcons (which are generally uncommon in all habitats at KFC). There are also changes in the large mammal guilds including the addition of mule deer (the only ungulate or hooved mammal on KFC) as an herbivore black bear as an omnivore, and mountain lion (potentially present but not confirmed on KFC) as a predator

The food web of the riparian scrubland habitat (Figure 4) is essentially a cross between that of the grassland and woodland. The high diversity of passerines found in the woodlands is expected to extend into the grassland along the corridors of riparian woodland and shrubland of the arroyos of KFC This diversity is supplemented by grassland species that use this habitat as part of their home range (e g quail jackrabbits, badgers, roadrunners, shrikes, mockingbirds, etc) In general, the influence of the woodland wildlife community diminishes with increasing distance from that habitat along the arroyos and the influence of the grassland wildlife community increases along the same gradient

3.5 Receptors

The receptor species used to assess risk at SNL/NM ER program sites are selected to conservatively represent those key elements of the trophic webs in each of the three major habitat types (grassland, woodland and riparian scrubland) that are most likely to be affected by COPECs in the soils at these sites Vascular plants are the principal primary producers in the habitats at KFC and plant productivity is key to the diversity and productivity of the wildlife community in each habitat. Risk to plants resulting from contact with COPECs in surface and subsurface soil is evaluated for a nonspecific perennial, herbaceous plant (such as a perennial grass)



Note: Species in parentheses are likely but not confirmed to occur at Sandia National Laboratories, New Mexico.

Figure 3

Generalized Foodweb of the Woodland Habitat at Sandia National Laboratories, New Mexico

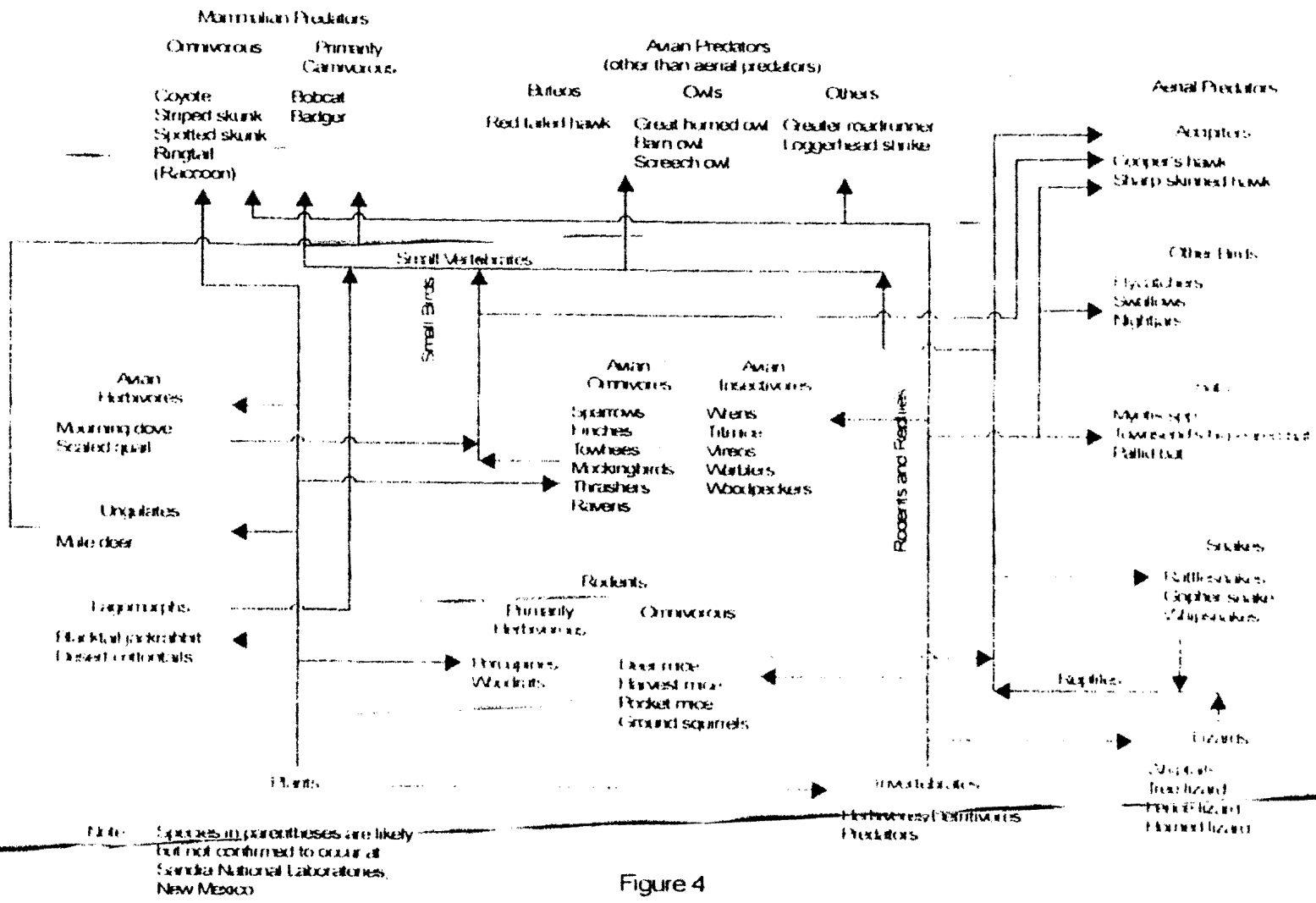


Figure 4

Generalized Foodweb of the Riparian Scrubland Habitat at Sandia National Laboratories, New Mexico

The deer mouse (*Peromyscus maniculatus*) and burrowing owl (*Speotyto cunicularia*) are the receptors selected to represent consumers in the food web at KFC. Parameters used to model exposures in these two receptors are presented in Table 1. These receptors represent mammalian and avian wildlife, respectively. The deer mouse represents lower trophic levels, and is modeled as an omnivore that eats both plants and soil invertebrates. In particular, the deer mouse represents small rodents, which are ubiquitous to all habitats on KFC. Deer mice have a broad ecological amplitude and can be found in a wide variety of habitats, and are especially prevalent in disturbed habitats and in association with buildings and other structures. The rodents at KFC, which include deer mice and other species of *Peromyscus*, pocket mice (*Perognathus* spp. and *Chaetodipus* spp.), kangaroo rats (*Dipodomys* spp.), harvest mice (*Reithrodontomys* spp.), grasshopper mice (*Onychomys* spp.), woodrats (*Neotoma* spp.), ground squirrels (*Spermophilus* spp.), prairie dogs (*Cynomys* spp.), and others, exhibit various degrees of omnivory, from almost pure herbivory (e.g., prairie dogs and wood rats) to highly insectivorous (grasshopper mice) (Findley, 1987). The fraction of the diet of deer mice consisting of insects varies seasonally, but has been found to average about 38.5% over the year in semiarid grasslands of Colorado (USEPA, 1993). For the purposes of risk assessment, an omnivorous diet for this receptor species is conservatively estimated at 50% insect and 50% plant material. Pure herbivorous and insectivorous diets (i.e., 100% plant or 100% insect diets, respectively) are used as bounding limits of exposure to this receptor. Incidental soil ingestion is not included as part of the food ingestion rate, but is included as part of the ingestion pathway in addition to the ingestion of food (plants and insects). The rate of soil ingestion (in kilograms per day) is conservatively estimated at 2% of the ingestion rate of dry food matter based on data for the closely related white-footed mouse (*Peromyscus leucopus*) presented by Beyer et al. (1994). Thus, the total dry-matter ingestion rate for the deer mouse is 102% of the ingestion rate for dry food matter.

The burrowing owl is modeled as a predator on omnivorous rodents, as represented by the deer mouse (100% of its diet). Burrowing owls are found in the grassland habitat at SNL/NM, and are particularly common in association with prairie dog colonies which are commonly found on the margins of developed areas. The burrowing owl is designated as a species of management concern by the U.S. Fish and Wildlife Service in Region 2, which includes New Mexico (USFWS, 1995). In addition to their special status designation, burrowing owls were selected to represent predators because of their small size (0.155 kg [Dunning, 1993]) and the consequently small home range (34.6 acres [Haug et al., 1993]). Therefore, they conservatively represent the risk to larger wildlife species of the same class and trophic level. They are also not dependent upon trees or above-ground structures for nesting and have a high tolerance for altered habitats and human activity, often nesting near roads, runways, golf courses, and buildings. Although they are not likely to occur at ER sites in woodland habitats, such as in the canyons, they are used in this risk assessment to represent other small avian predators that may be present in this habitat (e.g., western screech-owls [*Otus kennicottii*]).

Table 1
Exposure Factors for Ecological Receptors
Sandia National Laboratories, New Mexico

Receptor species	Class/Order	Trophic level	Body weight (kg)[a]	Food intake rate (kg/d)[b]	Dietary Composition[c]	Home range (ha)[d]
Deer Mouse (*Peromyscus maniculatus*)	Mammalia/ Rodentia	Omnivore	0.0239[e]	0.00372	Plants 50% Invertebrates 50 (+ Soil at 2% of intake)	0.11[f]
Burrowing owl (*Speotyto cunicularia*)	Aves/ Strigiformes	Carnivore	0.155	0.0173	Rodents 100% (+ Soil at 2% of intake)	14

[a]Body weights are in kilograms wet weight
[b]Food intake rates are estimated from the allometric equations presented in Nagy (1987). Units are kilograms dry weight per day
[c]Dietary compositions are generalized for modeling purposes. Default soil intake value of 2% of food intake
[d]Home ranges are in hectares
[e]From Silva and Downing (1995), average of both sexes for New Mexico
[f]From USEPA (1993), based on the average home range measured in semi-arid shrubland in Idaho
[g]From Dunning (1993), average of both sexes for North America
[h]From Haug et al. (1993)

Table 1 presents the parameters used in this risk assessment to model exposure in the burrowing owl. Data were not found for the incidental soil ingestion rate for this species or other raptorial birds; therefore, a rate of 2% of the food ingestion rate (on a dry weight basis) was used to estimate this part of the ingestion pathway, which (as with the deer mouse) is in addition to the food ingestion rate.

3.6 Exposure and Risk Characterization for Nonradiological COPECs

3.6.1 Exposure assessment for nonradiological COPECs

For the predictive ecological risk assessment at SNL/NM ER program sites, exposures to COPECs in soils for the plant and wildlife receptors are estimated from the maximum measured soil concentration for each COPEC at each site. Plant exposure is through direct contact between the roots and the soil. For wildlife receptors, exposure through ingestion pathways is modeled using the methods described in the U.S. EPA's "Wildlife Exposure Factors Handbook" (USEPA, 1993). For simplicity in describing the exposure models in this section, ingested soil is considered a "food item" in the receptors diet, even though it may not be deliberately consumed. The basic model for estimating the daily intake of a COPEC per kilogram of body weight (i.e., the estimated daily dose of the COPEC) through the ingestion pathway is:

$$D_x = \sum_{k=1}^{m} (C_k \cdot F_k \cdot I_k) / W$$

where:

D_x = the estimated daily dose (mg/kg-day) of COPEC x
C_k = the concentration of COPEC x in the kth food type (mg/kg dry weight)
F_k = the fraction of the kth food type that is comes from the ER site
I_k = the ingestion rate of the kth food type (kg dry weight/day)
m = the number of food items in the receptor's diet (including soil)
W = the body weight of the receptor (kg wet weight)

The calculation of C_k for dietary items other than soil is based on the maximum measured soil concentration (C_{max}), as described below. I_k is determined by multiplying the total food ingestion rate of the receptor (I_{tot}) by the fraction of the diet composed of food item k, or in the case of soil, by the ratio of the soil ingestion rate to the total food ingestion rate (0.02 for both the deer mouse and burrowing owl). F_k is commonly assumed to be the area use factor (the area of the site divided by the home range of the receptor or 1, whichever is smaller), but may also be modified by a seasonal use factor (number of days at the site divided by 365 days per year) if the home range is

used for only part of the year [illegible] assessment, both area use [illegible] are assumed [illegible] therefore F_a is 1

Thus, the model for estimating dietary exposure in the deer mouse with an herbivorous diet (50% plant and 50% invertebrate [illegible] ingestion equal [illegible] ingestion [Table 1]) is

[illegible]

where

D_a = the estimated daily dose (mg/kg-day) of COPEC X in the deer mouse
I_{tot} = the total food ingestion rate of the deer mouse (kg dry weight/day)
C_{soil} = the maximum measured soil concentration of COPEC X (mg/kg)
C_{plant} = the estimated concentration of COPEC X in plant tissue at the site (mg/kg dry weight)
C_{inv} = the estimated concentration of COPEC X in soil invertebrate tissue at the site (mg/kg dry weight)
0.0239 = the average body weight for the deer mouse (kg wet weight)

For a deer mouse with a completely herbivorous diet, the ingestion rate of plant material would be equal to I_{tot} and the ingestion rate of invertebrates would be 0. Conversely, for a completely insectivorous mouse, the ingestion rate of invertebrates would be equal to I_{tot} and the ingestion rate of plant material would be 0. For the burrowing owl diet of 100% deer mice, soil ingestion equaling 2% of the food ingestion (Table 1), the model for estimating dietary exposure is

[illegible]

where

D_a = the estimated daily dose (mg/kg-day) of COPEC X in the deer mouse
C_{soil} = the maximum measured soil concentration of COPEC X (mg/kg)
C_{mouse} = the estimated concentration of COPEC X in deer mouse tissue at the site (mg/kg dry weight)

I_{tot} = the total ingestion rate of the deer mouse (kg dry weight/day)
0.155 = the average body weight for the burrowing owl (kg wet weight).

The COPEC concentrations in plants (C_{plant}) and soil invertebrates (C_{inv}) are determined from the the maximum measured soil concentration using soil-to-organism transfer factors. For organic COPECs in plants, the regession equation developed by Travis and Arms (1988) is used to derive the soil-to-plant transfer factor from the logarithm of the octanol/water partition coefficient (log K_{ow}) value of the compound. The soil-to-plant transfer factors for inorganics are taken to be the maximum value reported among three reference sources: IAEA (1994) (uptake specific to grasses), NCRP (1989), and Baes et al. (1984). The latter two are based on unspecified agricultural plants.

For organic COPECs in soil invertebrates, the transfer factor was derived from the equation developed by Connell and Markwell (1990) for bioaccumulation in earthworms:

$$BF = \frac{y_L \cdot K_{ow}^{b-a}}{x \cdot f_{oc}}$$

where:

BF = the bioaccumulation factor (unitless)
y_L = the fractional lipid content of the organism
K_{ow} = the octanol/water partition coefficient
(b-a) = a nonlinearity constant
x = a proportionality constant
f_{oc} = the fractional organic carbon content in the soil

Although derived from earthworm data, the values for the nonlinearity constant (0.05) and proportionality constant (0.66) were applied to modeling uptake in all soil invertebrates, which probably consist primarily of insects and other arthropods at KFC. Because of differences in integument, it is expected that the uptake by earthworms will generally be greater than that of insects; therefore, transfer factors derived by this model are expected to yield conservative estimates of insect uptake. The lipid content in insects was estimated at 3.1% fresh weight (Taylor, 1975), which is 7.9% of dry weight, using a value of 61% water content in beetles (USEPA, 1993). Based on the method described in Brady (1974), the fraction of organic carbon in the soil was estimated by dividing the organic matter content by the value 1.7. The average organic matter content of 21 Southern Great Plains soils (1.55%) (Brady, 1974) was used to estimate the organic carbon content in SNL/NM soils (0.91%). For inorganic COPECs, literature-derived values of soil-to-invertebrate transfer factors are used as available, and a default value of 1.0 when no transfer factor could be found.

Tissue concentrations in deer [illegible] determined [illegible] concentration of the COPEC [illegible] the deer mouse [illegible] muscle transfer factors derived for [illegible] concentrations [illegible] COPECs the regression equation developed by Travis and [illegible] based on the log K_{ow} value of the COPEC is used to derive food-to-deer transfer factors. Food-to-muscle transfer factors for the inorganic COPECs are taken as the maximum reported value from IAEA (1994), NCRP (1989), [illegible] Baes et al. (1984). [illegible] of a particular COPEC in the food of the deer mouse is estimated by summing the daily intake of the COPEC from all food items and ingested soil [illegible] the dose model for the deer mouse as shown above and dividing by the daily food intake (IR) for the deer mouse.

Appendix A presents the transfer factors for organic and inorganic COPECs at SNL NM ER program sites. The soil-to-plant and soil-to-invertebrate transfer factors are based on dry-weight to dry-weight concentration conversions. Therefore, the equation for calculating COPEC concentrations in dry plant materials is

where

C_{pl} = the concentration of the COPEC in plant tissue (mg/kg dry weight)
TF_{pl} = the soil-to-plant transfer factor (unitless)
C_{soil} = the maximum measured soil concentration of the COPEC (mg/kg dry weight)

and the equation for calculating COPEC concentrations in invertebrate tissue is

where

C_{inv} = the concentration of the COPEC in invertebrate tissue (mg/kg dry weight)
TF_{inv} = the soil-to-invertebrate transfer factor (unitless)
C_{soil} = the maximum measured soil concentration of the COPEC (mg/kg dry weight)

Because the food-to-muscle transfer factor is based on a dry-weight to dry-weight concentration conversion, the equation for calculating COPEC concentrations in deer mouse tissue is

where:

C_{mouse} = the concentration of the COPEC in deer mouse tissue (mg/kg dry weight)
TF_{fm} = the food-to-muscle transfer factor (unitless)
C_{food} = the concentration of the COPEC in the food of the deer mouse (mg/kg dry weight)
3.125 = the wet weight to dry weight conversion factor, based on a water content of 68% (USEPA, 1993).

3.6.2 Nonradiological toxicity benchmarks

No-Observed-Adverse-Effect-Levels (NOAELs) for chronic oral exposure are used as benchmarks for toxic effects to wildlife. NOAELs are defined as the maximum dosage tested that produced no effect that would be considered adverse to the long-term viability of the population. Therefore, the endpoints of particular interest in the underlying studies are those associated with reproductive health, development, and mortality. Because the NOAELs for the wildlife receptor species are based on NOAELs from test species, the latter are scaled to NOAELs specific to the wildlife receptor species using a power function of the ratio of body weights, as described by Sample et al. (1996), and supported by recent research in the fractal geometry of circulatory systems (Brown et al., 1997). Thus:

$$NOAEL_W = NOAEL_T \left(\frac{BW_T}{BW_W}\right)^s$$

where:

$NOAEL_W$ = the No-Observed-Adverse-Effect-Level for the wildlife receptor species (mg/kg-day)
$NOAEL_T$ = the No-Observed-Adverse-Effect-Level for the test species (mg/kg-day)
BW_T = the body weight of the test species (kg)
BW_W = the body weight of the wildlife receptor species (kg)
s = a body weight scaling factor (s = 0.25 for mammals and s = 0 for birds)

Toxicity studies were considered to be chronic if they are conducted over a period of 26 weeks (one-half year) or more. This period represents the period of seasonal use by the burrowing owl (and other migratory species) and is sufficient time for two generations of deer mice (and other small mammals) to be added to the population

(USEPA 1993). Studies of [illegible] 1 to 26 weeks [illegible] subchronic unless they specifically included reproductive effects [illegible] (Sample et al. 1996). When only subchronic NOAEL values are available, these are converted to chronic NOAEL values by applying an uncertainty factor of [illegible] (Sample et al. 1996).

A Lowest-Observed-Adverse-Effect-Level (LOAEL) is defined as the lowest dosage tested that produced an adverse effect as described above. In cases where only a chronic LOAEL value is available for test data, an uncertainty factor of [illegible] is used to convert it to the chronic NOAEL. If only a subchronic LOAEL was available, then an uncertainty factor of 0.01 is used to estimate the chronic NOAEL. This uncertainty factor is the product of two uncertainty factors of 0.1, one to convert the subchronic value to a chronic value and the other to convert the LOAEL to an NOAEL.

In cases where only an acute (i.e., single or short duration dose) toxicity value is available for a COPEC (e.g., a lethal dose to 50 percent of the test population [LD_{50}]) but both a NOAEL and LD_{50} value are available for a closely related compound in the same test species, then the NOAEL for the COPEC was estimated using the relationship from Sample et al. (1996):

$$NOAEL_{X,T} = \frac{NOAEL_{Y,T} \times LD_{50X,T}}{LD_{50Y,T}}$$

where

$NOAEL_{X,T}$	=	the No-Observed-Adverse-Effect-Level for COPEC X in test species T (mg/kg-day)
$LD_{50X,T}$	=	the acute lethal dose to 50 percent of the test population in test species T for COPEC X (mg/kg)
$NOAEL_{Y,T}$	=	the No-Observed-Adverse-Effect-Level for compound Y (closely related to COPEC X) in test species T (mg/kg-day)
$LD_{50Y,T}$	=	the acute lethal dose to 50 percent of the test population in test species T for compound Y

When possible, NOAELs for the wildlife receptor species are derived from test species that are taxonomically close to the target receptor. Therefore, for the deer mouse, data from other rodent species is preferentially chosen over that from non-rodents (e.g., mink, dogs, and rabbits), and for the burrowing owl, data from owls is preferentially chosen over that from other birds (e.g., waterfowl, chickens, and quail). NOAELs are not determined if toxicity data could not be found for test species within the same class. Therefore, deer mouse NOAELs come only from mammalian test species and burrowing owl NOAELs come only from avian test species.

When toxicity information is available for different forms of the COPEC, such as organic and inorganic forms of mercury, NOAELs are generally derived from the most toxic form, unless data are available that are specific to the form in question. In this regard, chromium VI is measured and assessed directly; therefore, total chromium is assumed to be chromium III. For ecological risk assessment purposes, however, mercury is assumed to be in organic form and arsenic in trivalent (arsenite) form rather than pentavalent (arsenate) form. Also for the predictive level ecological risk assessments, the bioavailability of the COPEC at the ER sites is assumed to be the same as that for the laboratory studies, although in the latter, the chemical is typically added to food or water in a highly available form and with little opportunity for behavioral rejection of the chemical.

Plant toxicity benchmarks are based primarily on the information provided in Will and Suter (1995). These benchmarks are based on LOAELs using 20% reduction in growth as the endpoint and are limited to tests in soil rather than tests using solutions. Although based on LOAELs, these benchmarks are considered conservative and appropriate to the predictive level assessment. The endpoint is sublethal and reductions in plant growth may have no significant effect on the reproductive potential or the continued existence of a plant population. Furthermore, these benchmarks are primarily based on studies in which the chemical of interest in added freshly to a soil (in the case of inorganics, often as a soluble salt) and is typically more bioavailable than the COPECs that have had a chance to bind with soil particles or are in a less soluble form.

Appendix B presents the chronic oral NOAELs and LOAELs for COPECs at SNL/NM ER program sites for the deer mouse and burrowing along with the test species information used to derive these benchmarks. This appendix also presents the plant benchmarks used for screening COPEC concentrations in soil that may be potentially phytotoxic.

3.6.3 Risk characterization for nonradiological COPECs

The potential for risk to ecological receptors is determined through hazard quotients (HQs). HQs are specific to a particular receptor for exposure to a particular COPEC. An HQ is defined by:

$$HQ = \frac{Exposure}{Benchmark}$$

where:

HQ	=	the hazard quotient (unitless)
Exposure	=	the estimated oral dose of the COPEC for the receptor (in mg/kg-day)
Benchmark	=	the toxicological benchmark for the COPEC and receptor (in mg/kg-day).

HQs are used to characterize risk for both plant and wildlife receptors at SNL/NM ER program sites. The methods for modeling exposure in these ecological receptors is described in Section 3.3 and the methods for determining toxicity benchmark values is discussed in Section 3.4. For the predictive assessment of ecological risk to wildlife NOAEL values are used as the toxicological benchmarks. The benchmarks for evaluating risk to plant are based on LOAELs.

The value of the HQ is greater than 1.0 if the magnitude of the exposure is greater than the corresponding benchmark, and conversely, the HQ is less than or equal to 1.0 if the exposure is less than or equal to the benchmark. An HQ value less than or equal to 1.0 is interpreted as evidence of no potential risk to that receptor for that COPEC. If the HQs for a COPEC are less than unity for all receptors, that COPEC is eliminated from further consideration at that site. However, because exposure for the evaluation of COPECs is conservatively estimated (e.g., being based on the maximum measured soil concentration), an HQ value greater than unity is not interpreted as evidence of risk, but only as evidence that the potential for risk can not be ruled out. Therefore, the COPEC is not eliminated from further consideration, pending further evaluation or remedial action.

3.7 Dose Estimation and Risk Characterization for Radiological COPECs

In addition to estimation of exposure to nonradioactive COPECs, as described above, a methodology has been developed to estimate the internal and external radiation dose rates to wildlife receptors that are continuously exposed to radionuclides at SNL/NM ER sites based on their concentrations in the surface and subsurface soil. These calculated dose rates are compared to the International Atomic Energy Agency maximum allowable dose rate of 0.1 rad/day (IAEA, 1992) for terrestrial receptors to evaluate potential risk. This benchmark dose rate represents the threshold where slight effects from radiation doses may become apparent in terrestrial wildlife populations. Because plants and insects are less sensitive to radiation than vertebrates (Whicker and Schultz, 1982), the dose of 0.1 rad/day should be protective of a broad range of species and ecosystem processes. The methodology presented here is used as a evaluation tool to determine if ecological receptors are impacted even when dose rates to humans are considered negligible.

This section also describes the parameters used in the radiation dose model. For screening purposes, this model uses the maximum measured radionuclide concentrations in soil at the SNL/NM ER sites. Significant decay products of each parent radionuclide are considered in the dose rate estimates. Radioactive daughters from parents that contribute significantly to internal dose are considered via radionuclide-specific absorbed energy data available from Baker & Soldat (1992). This absorbed energy data is highly dependent upon the size of the receptor. However, the long half-life of most of the radionuclides present at SNL/NM ER sites result in a

reduced internal exposure due to the fact that the decay constant for long-lived radionuclides is relatively small.

The external dose rate a terrestrial receptor receives due to the presence of various radionuclides is calculated by multiplying the average gamma ray energy in MeV by 2.12 and dividing by the soil density in grams per cubic centimeter (Shleien, 1992) to yield rad/h (multiply by 24 to get rad/day). The average gamma energy per disintegration equals the sum of the probabilities per decay times the gamma energy (in MeV) for each radionuclide considered. This formula for the external exposure rate is based upon the receptor being surrounded by an infinite medium uniformly contaminated by the gamma emitter. The doses from each radionuclide from internal and external pathways are summed to yield the total dose rate in rad/day for comparison with the IAEA (1992) dose rate limit of 0.1 rad/day.

For this model, it was assumed that the geometry of the terrestrial receptor could be approximated by a sphere to simplify the calculation. The entire activity of the radionuclides present are assumed to be concentrated at the center of the organism and treated as a point source (i.e., the receptor is uniformly irradiated from within and the absorbed dose is not organ specific). The deer mouse residing in the location of the maximum contaminant concentrations is assumed to receive its internal radiation exposure from its diet of plants and ingestion of soil. The burrowing owl, also resides in the location of the maximum contaminant concentrations and is assumed to receive its internal radiation exposure from its diet of deer mice and ingestion of soil. Baker and Soldat (1992) provide data on the parameter, E_n, for certain radionuclides, which is the effective absorbed energy based upon the amount of energy the organism, with a certain effective radius, absorbs within its body from radioactive decay. For alpha emitting radionuclides, the effective absorbed energy for any terrestrial receptor is constant for a radius of 10 cm and lower. This is due to the fact that all of an alpha particle's energy is absorbed within the organism. All energy from beta-emitting radionuclides is assumed to be 100% absorbed by the tissues of the receptor. Gamma-emitting radionuclides only transfer a fraction of their energy to a receptor.

The basic methodology is summarized below. Radionuclide-specific parameters used in the dose calculations for the SNL/NM ER program sites are presented in Appendix C. A detailed description of the methodology used to compute the internal and external radiation doses can be found in Appendix D.

3.7.1 Internal total-body dose rate

The following equation defines the internal dose rate to a deer mouse in rad/day: where:

$$R_{ij} = \sum \frac{[CS \cdot PS \cdot Qv \cdot Qs \cdot FI \cdot EF \cdot ED \cdot FR \cdot B \cdot E]_{ij}}{BW \cdot AT}$$

CS = the concentration of radionuclide i in the soil (Ci/kg)

PS = the soil-to-plant conversion factor specific to radionuclide i and chemical form in the soil (Baes et al. 1984, USDOE 1995)

Qv = the ingestion rate of plant (dry weight) by the mouse assumed to be 7.2E-03 kg/day (Nagy 1987).

Qs = the ingestion rate of soil by the mouse assumed to be 1.44E-05 kg/day, or 2% of plant intake (EPA 1994)

FI = the fraction ingested from contaminated source (unitless, given as 1 (assumes consumption of plants and soil from contaminated area only)

EF = the exposure frequency (day/yr) equal to 365

ED = the exposure duration (years) equal to 1.0.

FR = the fraction of the radionuclide retained in the mouse (unitless) which is radioisotope specific (Baker and Soldat 1992)

B is the burden duration factor for radionuclide i (day) which is

$$B = \frac{(1 - \exp(-\lambda_e T_e))}{\lambda_e}$$

where T_e = the period of exposure in days (365 days)

λ_e = $\lambda_r + \lambda_b$

λ_r = the radiological decay constant (day^{-1}) defined as $\ln 2 / T_r$ where T_r is the half-life of the radioisotope in days (Baker and Soldat 1992)

λ_b = the biological removal constant (day^{-1}) defined as $\ln 2 / T_b$ where T_b is the biological half-life after ingestion of a radioisotope in days (Baker and Soldat 1992)

λ_e = the effective decay constant for radioisotope i (day^{-1})

E = the effective energy absorbed constant for radionuclide i (MeV/dis), equal to (USDOE 1995)

$$E_i = 5.12 \cdot 10^{-4} \cdot \varepsilon_i$$

where:

ε_i = the radionuclide energy for a deer mouse with an assumed effective radius of 2 cm (MeV/dis) (Baker and Soldat, 1992).

BW = the body weight (mass) of the mouse assumed to be 0.0239 kg (Silva & Downing, 1995),

AT = the averaging time equal to 365 days.

A similar approach is used for the burrowing owl, with appropriate modifications for diet, body weight, exposure frequency, and exposure duration. The following equation defines the internal dose rate to a burrowing owl in rad/day:

$$R_{owl} = \sum_{i=1}^{N} \frac{Cs_i \cdot FR_i \cdot FI \cdot EF \cdot ED \cdot B_i \cdot E_i \cdot (Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{FR_i \cdot Ps_i \cdot Qv_{mouse} + FR_i \cdot Qs_{mouse}\})}{BW_{owl} \cdot AT}$$

where:

CS_i = the concentration of radionuclide, i, in the soil (Ci/kg)

PS_i = the soil-to-plant conversion factor specific to radionuclide, i, and chemical form in the soil (Baes et al. 1984; USDOE, 1995),

DW= the conversion from mouse wet weight to dry weight equal to 0.32 (EPA, 1993),

Qv_{mouse} = the ingestion rate of plant by the mouse (dry weight) assumed to be 3.72E-03 kg/day, (Nagy, 1987),

Qs_{mouse} = the ingestion rate of soil by the mouse assumed to be 7.44E-05 kg/day or 2% of plant intake rate, (EPA, 1993),

Qs_{owl} = the ingestion rate of soil by the owl assumed to be 3.46E-04 kg/day or 2% of food intake, (EPA, 1993),

Qm = the ingestion rate of deer mouse (food) by the burrowing owl assumed to be 1.73E-02 kg/day, (Nagy, 1987),

TN = proportionality factor equal to 1 day (normalizes mouse consumption by the owl to the number of mice ingested in 1 day),

FI = the fraction ingested from contaminated source (unitless), given as 1.0 (Assumes consumption of plants and soil from contaminated area only),

EF = the exposure frequency (day/yr), equal to 365,

ED = the exposure duration (years), equal to 1.0,

FR_i = the fraction of the radionuclide retained in the mouse and owl (unitless) which is radioisotope dependent (Baker and Soldat, 1992),

B_i is the burden duration factor for nuclide I (day), which is:

[illegible]

where [illegible] = the [illegible] exposure in days [illegible]

[illegible] = the radiological decay constant (day^{-1}) defined as [illegible] where T is the half-life of the radioisotope in days (Baker and Soldat 1992)

[illegible] = the biological removal constant (day^{-1}) defined as [illegible] where T_b is the biological half-life after ingestion of a radioisotope in days (Baker and Soldat 1992)

[illegible] = the effective decay constant for radioisotope [illegible]

E = the effective energy absorbed constant for radionuclide [illegible] equal to (USDOE 1995)

where

[illegible]

[illegible] = the radionuclide energy for a burrowing owl with an assumed effective radius of 5 cm (MeV/dis) (Baker and Soldat 1992)

BW_{owl} = the body weight (mass) of the owl equal to 0.155 kg (Dunning 1993)

BW_{mouse} = the body weight (mass) of the mouse equal to 0.0039 kg (Silva & Downing 1995)

AT = the averaging time equal to 365 days

3.7.2 External total-body dose rate

The model below is based upon exposure to gamma emitting radioisotopes only (USDOE, 1995). The dose is likely an overestimate of a whole-body dose but less conservative than a skin dose. The dose rate equation presented below for gamma radiation absorbed dose is the same relationship for both the owl and the mouse. This equation is valid for absorbed dose in a receptor's tissue when the receptor resides in an infinite medium uniformly contaminated with the gamma emitter. Since the owl and mouse are assumed to have the same tissue properties, the equation [illegible] both receptors.

The following relationship defines the external dose rate (rad/hr) to a terrestrial receptor exposed to certain radionuclides:

$$D = 2.12 \cdot \sum_{i=1}^{N} \frac{E_i \cdot C_i}{\rho_{soil}}$$

where:

E_i = the average gamma-ray energy emitted by the radioisotope per disintegration (MeV). This value is the sum of probabilities per decay multiplied by the energy of the emitted gamma-ray in MeV.

C_i = the concentration of the radionuclide ($\mu Ci/cm^3$).

ρ_{soil} = the density of the soil ($grams/cm^3$) assumed as 1.5.

D = the external dose rate (rad/h).

3.7.3 Final dose rate calculation

The dose rates for internal and external are summed for each radionuclide and then summed again to derive the total dose, in rad/day, to compare to the IAEA standard of 0.1 rad/day for terrestrial receptors.

3.8 Uncertainty

Uncertainties are associated with the predictive ecological risk assessment. These are related to the exposure concentrations, exposure parameters, and toxicity benchmark values used in the estimation of risk. Because conservative assumptions such as the use of maximum detected concentrations, largest transfer factors reported in the literature for a specific analyte, and NOAELs as benchmarks for wildlife, risk estimates are more likely to over estimate rather than under estimate risk. For each of the ecological risk assessments performed, a qualitative evaluation of uncertainties associated with the risk predictions will be conducted. This discussion will also contain a brief discussion on sensitive parameters within the exposure models as identified through a Monte Carlo analysis.

3.9 Risk Discussion and Summary

Once hazard quotients for the non-radiological and radiological COPECs have been calculated, the evaluation of ecological risk at each site is examined to determine the reasonableness of the predictions. Size of the site, habitat quality, data quality, and background risk (incremental risk) are all incorporated into a risk evaluation which addressed the likelihood of adverse impacts to the ecological receptors examined. This is a qualitative process that results in a risk prediction of none, low, medium, or high and is intended to incorporate uncertainty and site-specific information into a weight-of-evidence approach.

4.0 Preliminary Soil Remediation Goals for SNL/NM ER Sites

Preliminary remediation goals (PRGs) are used to establish concentrations of COPECs for specific media at a specific site that will be protective of receptors potentially exposed to those COPECs at that site. Thus, PRGs set an upper concentration limit for each COPEC such that the mean concentration (estimated by the 95% upper confidence limit of the mean) of the COPEC in that medium must be below its respective PRG to be protective of the receptors of concern for that site. PRGs are, therefore, critical in the determination of the extent of area that will be remediated at the site.

Ecological PRGs (those based on ecological rather than human receptors) for soils at SNL/NM ER sites are determined through the same exposure models used to calculate hazard quotients (HQs) for these sites. However, instead of determining the HQ by inputting site-specific soil concentrations, the PRGs are determined for a particular receptor through the back-calculation of soil concentration after setting the HQ equal to 1.0. This is equivalent to setting the exposure equation equal to the toxicity benchmark and solving the resulting equation for the soil concentration. Because multiple receptors are used in the evaluation of risk for SNL/NM ER sites (deer mice and burrowing owls), this process is repeated for each receptor of concern for the site and the lowest back-calculated soil concentration for a particular COPEC among these receptors is used as the PRG for that COPEC.

Because the underestimation of PRGs can lead to unnecessary habitat disturbance and resource expenditure, the calculation of PRGs incorporates less conservatism than the calculation of HQs used in the predictive level risk assessment process. To this end, Lowest-Observed-Adverse-Effect-Levels (LOAELs) rather than NOAELs are used as the toxicological benchmark for the calculation of PRGs. For wildlife, the procedures for scaling and estimating chronic NOAELs are applied as necessary to the derivation of chronic LOAELs. In cases where only a NOAEL is available (i.e., no effects were observed at any dosage levels in the underlying study), the LOAEL is estimated at 10 times the NOAEL. Chronic LOAELs for the deer mouse and burrowing owl are presented in Appendix B.

In addition to use of LOAELs as the toxicity benchmarks, the values of the parameters used to model exposure in particular receptors are chosen to be more realistic estimates of the mean of these values (based on measured values) rather than conservative estimations of the exposure parameters (as used in the predictive ecological assessment to counter uncertainties). Thus, in the calculation of PRGs for the deer mouse, the proportions of plant and invertebrate food in the diet are 61.5% and 38.5%, respectively, which are values based on year-long measurements of stomach contents from deer mice in the short grass prairie of Colorado (Flake, 1973) as

cited in EPA, 1993). In the predictive assessment, these proportions are both 50%, which represents a generalized omnivorous diet, but which conservatively over-represent invertebrates in the overall diet of this receptor. Also, the fraction of the diet of the deer mouse represented by ingested soil is estimated to be 1.2% for the PRG calculation rather than 2%, as is used in the predictive ecological assessment to calculate HQs. The former is based on mean measured value for white-footed mice from Beyer et al. (1994) while the latter is based on the conservative generalization of these study results ("< 2%") as presented by in USEPA (1993).

Appendix E presents non-site-specific PRGs for the SNL/NM ER program. When the areal extent of a site is smaller than the home range of the receptor, the area use factor (the site area ÷ the home range area) may be applied to the PRGs for that species to derive site-specific PRGs, provided that the off-site or background concentrations of the COPEC are determined or assumed to be at or near zero. Alternatively, the site-specific PRGs are determined such that the weighted average of the PRG (weighted by the area of the site) and the off-site or background concentration (weighted by the home range area minus the area of the site) will equal the non-site-specific PRG for that COPEC (i.e., when the area use factor is 100%). Area use factors for deer mice are nearly always 1.0 due to the small home range of this receptor (0.27 acres). Therefore, site-specific PRGs are typically only applicable to the burrowing owl at sites which are smaller than its home range (34.6 acres).

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Appendix A

Transfer Factors for Inorganic and Organic Constituents of Potential Ecological Concern

Table A.1

Transfer Factors Used in Exposure Models for Inorganic Constituents of Potential Ecological Concern at Environmental Restoration Program Sites, Sandia National Laboratories, New Mexico

Constituent of Potential Ecological Concern	Soil-to-Plant Transfer Factor	Soil-to-Invertebrate Transfer Factor	Food-to-Muscle Transfer Factor
Aluminum	4.00×10^{-4}	1.00×10^{-3}	[illegible]
Antimony	2.00×10^{-4}	1.00×10^{-3}	[illegible]
Arsenic	4.00×10^{-4}	1.00×10^{-3}	[illegible]
Barium	1.50×10^{-3}	1.00×10^{-3}	[illegible]
Beryllium	1.00×10^{-4}	1.00×10^{-3}	[illegible]
Cadmium	5.50×10^{-4}	8.00×10^{-3}	[illegible]
Chromium (total)	4.00×10^{-4}	1.00×10^{-4}	[illegible]
Chromium VI	4.00×10^{-4}	1.00×10^{-4}	[illegible]
Cobalt	4.00×10^{-3}	1.00×10^{-3}	[illegible]
Copper	8.00×10^{-4}	2.50×10^{-3}	[illegible]
Cyanide	---	---	[illegible]
Lead	9.00×10^{-4}	4.00×10^{-3}	[illegible]
Manganese	3.00×10^{-4}	3.00×10^{-4}	[illegible]
Mercury	1.00×10^{-3}	1.00×10^{-3}	[illegible]
Nickel	2.00×10^{-4}	3.50×10^{-4}	[illegible]
Selenium	5.00×10^{-4}	1.00×10^{-3}	[illegible]
Silver	1.00×10^{-3}	2.50×10^{-3}	[illegible]
Thallium	4.00×10^{-4}	1.00×10^{-3}	[illegible]
Titanium	5.50×10^{-4}	1.00×10^{-3}	[illegible]
Uranium	3.00×10^{-4}	1.00×10^{-3}	[illegible]
Vanadium	5.50×10^{-4}	1.00×10^{-3}	[illegible]
Zinc	1.50×10^{-4}	1.00×10^{-3}	[illegible]

[a]From Baes et al. (1984)
[b]Default value
[c]From NCRP (1999)
[d]From Stafford et al. (1991)
[e]From Ma (1992)
[f]From IAEA (1994)
[g]--- designates insufficient data

Table A.2
Transfer Factors Used in Exposure Models for Organic Constituents of Potential Ecological Concern at Environmental Restoration Program Sites, Sandia National Laboratories, New Mexico

Constituent of Potential Ecological Concern	Log K_{ow}[a]	Soil-to-Plant Transfer Factor[b]	Soil-to-Invertebrate Transfer Factor[c]	Food-to-Muscle Transfer Factor[b]
Acetone	-0.24	5.33×10^{1}	1.28×10^{1}	1.04×10^{-6}
Benzene	2.13	2.27×10^{0}	1.68×10^{1}	2.92×10^{-6}
Benzoic acid	1.87	3.21×10^{0}	1.63×10^{1}	1.57×10^{-6}
Bis(2-ethylhexyl)phthalate	7.30[d]	2.34×10^{-3}	3.05×10^{1}	6.40×10^{-1}
2-Butanone	0.29	2.63×10^{1}	1.36×10^{1}	3.67×10^{-6}
Butyl benzyl phthalate	4.77	6.78×10^{-2}	2.28×10^{1}	1.56×10^{-3}
Carbazole	—[e]	—	—	—
Chlorobenzene	2.51	1.37×10^{0}	1.76×10^{1}	7.21×10^{-6}
Chloroform	1.92[g]	3.01×10^{0}	1.64×10^{1}	1.77×10^{-6}
4-Chloro-3-methylphenol	3.10	6.25×10^{-1}	1.88×10^{1}	2.93×10^{-5}
2-Chlorophenol	2.15	2.21×10^{0}	1.68×10^{1}	3.06×10^{-6}
Dibenzofuran	4.12	1.61×10^{-1}	2.11×10^{1}	3.32×10^{-4}
1,1-Dichloroethylene	2.13[g]	2.27×10^{0}	1.68×10^{1}	2.92×10^{-6}
1,2-Dichloroethylene	1.86[g]	3.26×10^{0}	1.63×10^{1}	1.54×10^{-6}
Dimethylphthalate	2.12	2.30×10^{0}	1.68×10^{1}	2.85×10^{-6}
Di-n-butylphthalate	4.61[g]	8.38×10^{-2}	2.24×10^{1}	1.06×10^{-3}
Di-n-octylphthalate	5.22	3.72×10^{-2}	2.40×10^{1}	4.54×10^{-3}
Methylene chloride	1.25	7.34×10^{0}	1.52×10^{1}	3.60×10^{-7}
Phenol	1.46	5.55×10^{0}	1.56×10^{1}	5.93×10^{-7}
1,1,2,2-Tetrachloroethane	2.39	1.61×10^{0}	1.73×10^{1}	5.42×10^{-6}
Tetrachloroethene	2.67[g]	1.11×10^{0}	1.79×10^{1}	1.05×10^{-5}
Toluene	2.75[g]	9.97×10^{-1}	1.81×10^{1}	1.28×10^{-5}
1,2,4-Trichlorobenzene	4.02	1.84×10^{-1}	2.09×10^{1}	2.62×10^{-4}
1,1,1-Trichloroethane	2.48	1.43×10^{0}	1.75×10^{1}	6.71×10^{-6}
Trichloroethene	2.71[g]	1.05×10^{0}	1.80×10^{1}	1.16×10^{-5}
Xylenes	3.20	5.48×10^{-1}	1.90×10^{1}	3.72×10^{-5}
Explosives				
2-amino-4,6-dinitrotoluene	1.94[i]	2.93×10^{0}	1.64×10^{1}	1.86×10^{-6}
4-amino-2,6-dinitrotoluene	1.94[g]	2.93×10^{0}	1.64×10^{1}	1.86×10^{-6}
2,4-dinitrotoluene	1.98	2.78×10^{0}	1.65×10^{1}	2.04×10^{-6}
2,6-dinitrotoluene	1.72	3.93×10^{0}	1.60×10^{1}	1.10×10^{-6}
HMX	0.26[n]	2.74×10^{1}	1.36×10^{1}	3.42×10^{-8}
m-Dinitrobenzene	1.49[n]	5.33×10^{0}	1.56×10^{1}	6.37×10^{-7}
m-Nitrotoluene	2.45	1.49×10^{0}	1.74×10^{1}	6.25×10^{-6}
Nitrobenzene	1.85	3.30×10^{0}	1.63×10^{1}	1.50×10^{-6}
Nitroglycerin	1.62	4.48×10^{0}	1.59×10^{1}	8.68×10^{-7}
o-Nitrotoluene	2.30	1.81×10^{0}	1.71×10^{1}	4.37×10^{-6}
p-Nitrotoluene	2.37	1.65×10^{0}	1.73×10^{1}	5.17×10^{-6}
PETN	3.71[n]	2.78×10^{-1}	2.02×10^{1}	1.25×10^{-4}
RDX	0.87	1.22×10^{1}	1.45×10^{1}	1.46×10^{-7}
sym-Trinitrobenzene	1.10	8.96×10^{0}	1.49×10^{1}	2.52×10^{-7}
Tetryl	1.65[n]	4.31×10^{0}	1.59×10^{1}	9.32×10^{-7}

Constituent of Potential Ecological Concern	Log K_{ow}[a]	Soil-to-Plant Transfer Factor	Soil-to-Invertebrate Transfer Factor	Food-to-Muscle Transfer Factor
2,4,6-Trinitrotoluene	[illegible]	[illegible]	[illegible]	[illegible]
Polycyclic Aromatic Hydrocarbons (PAHs)				
Acenaphthylene	[illegible]	[illegible]	[illegible]	[illegible]
Anthracene	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(a)anthracene	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(a)pyrene	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(b)fluoranthene	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(g,h,i)perylene	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(k)fluoranthene	[illegible]	[illegible]	[illegible]	[illegible]
Chrysene	[illegible]	[illegible]	[illegible]	[illegible]
Dibenzo(a,h)anthracene	[illegible]	[illegible]	[illegible]	[illegible]
Fluoranthene[b]	[illegible]	[illegible]	[illegible]	[illegible]
Fluorene	[illegible]	[illegible]	[illegible]	[illegible]
Indeno(1,2,3-cd)pyrene	[illegible]	[illegible]	[illegible]	[illegible]
2-Methylnaphthalene	[illegible]	[illegible]	[illegible]	[illegible]
Naphthalene	[illegible]	[illegible]	[illegible]	[illegible]
Phenanthrene	[illegible]	[illegible]	[illegible]	[illegible]
Pyrene	[illegible]	[illegible]	[illegible]	[illegible]
Polychlorinated Biphenyls (PCBs)				
PCB Aroclor-1242	[illegible]	[illegible]	[illegible]	[illegible]
PCB Aroclor-1248	[illegible]	[illegible]	[illegible]	[illegible]
PCB Aroclor-1254	[illegible]	[illegible]	[illegible]	[illegible]
PCB Aroclor-1260	[illegible]	[illegible]	[illegible]	[illegible]

[a]From NLM (1997) except where noted
[b]From equations developed in Travis and Arms (1988)
[c]From equations developed in Connell and Markwell (1990)
[d]From USEPA (1995) as cited in Sample et al. (1996)
[e]"--" designates insufficient toxicity data
[f]From Talmage (1996)
[g]Assumed from 2-amino-4,6-dinitrotoluene
[h]From Rosenblatt et al. (1991)
[i]From Ryan et al. (1988)

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Appendix B

Toxicological Benchmarks for Wildlife and Plant Receptors

Table B.1
No-Observed-Adverse-Effects-Levels (NOAELs) for Inorganic Analytes in the Deer Mouse

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Aluminum	2.04	1.93	Mouse (0.03)	Ondreacka et al. (1966)	As $AlCl_3$. Based on chronic LOAEL of [illegible] mg/kg/d and an uncertainty factor of [illegible]
Antimony	0.13	0.125	Mouse (0.03)	Schroeder et al. (1968)	As antimony potassium tartrate. Based on chronic LOAEL of 1.25 mg/kg/d and an uncertainty factor of [illegible]
Arsenic	0.13	0.126	Mouse (0.03)	Schroeder and Mitchener (1971)	As arsenite (As^{+3}). Based on chronic LOAEL of 1.25 mg/kg/d and an uncertainty factor of [illegible]
Barium	[illegible]	5.1	Rat (0.435)	Perry et al. (1983)	As barium chloride. The NOAEL represents the maximum dose of the study which produced no adverse effect
Beryllium	[illegible]	[illegible]	Rat (0.[illegible])	Schroeder and Mitchener (1975)	As beryllium sulfate. The NOAEL represents the maximum dose of the study which produced no adverse effect
Cadmium	1.85	1.6	Rat (0.303)	Sutou et al. (1980)	As $CdCl_2$
Chromium (total)	5.354	2.737	Rat (0.35)	Ivankovic and Preussmann (1975)	As Cr^{+3} in Cr_2O_3. The NOAEL represents the maximum dose of the study which produced no adverse effect
Chromium VI	6.42	3.28	Rat (0.35)	MacKenzie et al. (1958)	As Cr^{+6} in $K_2Cr_2O_7$. The NOAEL represents the maximum dose of the study which produced no adverse effect
Cobalt					Insufficient data for NOAEL [illegible]
Copper	2[illegible].6	11.7	Mink (1.[illegible])	Aulerich et al. (198[illegible])	As copper sulfate
Cyanide	[illegible]	[illegible]	Rat (0.273)	Howe and Maner (1981)	As potassium cyanide
Lead	[illegible]	8.0	Rat (0.35)	Azar et al. (1973)	As lead acetate
Manganese	[illegible]	38	Rat (0.35)	Laskey et al. (198[illegible])	As Mn_3O_4
Mercury (inorganic)	[illegible]	[illegible]	Mouse (0.0[illegible])	Kreis et al. (1987a)	As mercuric sulfide. The NOAEL represents the maximum dose of the study which produced no adverse effect
Methylmercury	[illegible]	[illegible]	Rat (0.[illegible])	Verschuuren et al. (1976a)	As methylmercury chloride
Nickel	28.[illegible]	[illegible]	Rat (0.35)	Ambrose et al. (1976a)	As nickel sulfate hexahydrate
Selenium	0.39	0.30	Rat (0.35)	Rosenfeld and Beath (1954)	As potassium selenate

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Silver	34.8	17.8	Rat (0.35)	Olcutt (1950)	As silver nitrate. Ventricular hypertrophy observed at 89 mg/kg/d. Because this LOAEL is not considered to be of significance to populations, an uncertainty factor of 0 2 was applied.
Thallium	0 01	0 0074	Rat (0.365)	Formigli et al. (1986)	As thallium sulfate. Based on a subchronic LOAEL of 0.74 mg/kg/d with an uncertainty factor of 0 01.
Titanium	30.9	15.8	Rat (0.35)	RTECS (1997)	Form not specified. Based on LOAEL of 158 mg/kg (assumed to be a daily dosage) and an uncertainty factor of 0.1
Uranium	3 19	3 07	Mouse (0 028)	Paternain et al. (1989)	As uranyl acetate.
Vanadium	0 38	0.21	Rat (0.26)	Domingo et al. (1986)	As sodium metavanadate ($NaVO_3$) Based on chronic LOAEL of 2 1 mg/kg/d
Zinc	313	160	Rat (0.35)	Schlicker and Cox (1968)	As zinc oxide.

[a]In milligrams per kilogram per day (mg/kg/d)
[b]Body weights expressed in kilograms
[c]Lowest-Observed-Adverse-Effect-Level

Table B.2
No-Observed-Adverse-Effects-Levels (NOAELs) for Organic Analytes in the Deer Mouse

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Di-n-butyl phthalate	582	550	Mouse (0.03)	Lamb et al. (1987)	
Di-n-octyl phthalate	84.1	79.4	Mouse (0.03)	(see Comments)	Test species NOAEL based on mouse NOAEL for bis(2-ethylhexyl)phthalate and ratio of LD_{50} values (6,513/1,500) from RTECS (1997).
Methyl ethyl ketone	(see 2-butanone)				
Methylene chloride	11.4	5.85	Rat (0.35)	NCA (1982)	
Phenol	117.37	60	Rat (0.35)	NTP (1983), as cited in USEPA (1997)	
1,1,2,2-tetrachloroethane	27.58	14.1	Rat (0.35)	(see Comments)	Test species NOAEL based on mouse NOAEL for 1,1,1-trichloroethane scaled to a rat (541 mg/kg/d) and ratio of LD_{50} values (250/9,600) from RTECS (1997).
1,1,2,2-Tetrachloroethylene	1.48	1.4	Mouse (0.03)	Buben and O'Flaherty (1985)	Based on a subchronic NOAEL of 20 mg/kg/d (5 out of 7 days), multiplied by 0.07 to convert it to a chronic NOAEL for 7 out of 7 days.
Toluene	27.5	26.0	Mouse (0.03)	Nawrot and Staples (1979)	Based on chronic LOAEL of 260 mg/kg/d and an uncertainty factor of 0.1
1,2,4-Trichlorobenzene	2.90	1.48	Rat (0.35)	Robinson et al. (1981)	Based on a subchronic NOAEL of 14.8 and an uncertainty factor of 0.1.
1,1,1-Trichloroethane	1,100	1,000	Mouse (0.03)	Lane et al. (1982)	The NOAEL represents the maximum dose of the study, which produced no significant adverse effect.
Trichloroethylene	0.74	0.7	Mouse (0.03)	Buben and O'Flaherty (1985)	Based on a subchronic LOAEL of 100 mg/kg/d (5 out of 7 days), multiplied by 0.007 to convert it to a chronic NOAEL for 7 out of 7 days.
Xylenes	2.22	2.1	Mouse (0.03)	Marks et al. (1982)	
Explosives					
2-Amino-4,6-dinitrotoluene	5.50	2.81	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for TNT and ratio of LD_{50} values (1,394/795) from RTECS (1997)
4-Amino-2,6-dinitrotoluene	3.78	1.93	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for TNT and ratio of LD_{50} values (959/795) from RTECS (1997)
m-Dinitrobenzene	0.221	0.113	Rat (0.35)	Cody et al. (1981) as cited in Talmage and Opresko (1996c)	Based on subchronic (16-week) NOAEL of 1.13 mg/kg/d and an uncertainty factor of 0.1
2,4-Dinitrotoluene	1.06	0.54	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
					for TNT and ratio of LD_{50} values [illegible] from RTECS (1997)
2,6-Dinitrotoluene	0.704	0.46	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for TNT and ratio of LD_{50} values [illegible] from RTECS (1997)
HMX	2.97	3.0	Mouse (0.023)	Everett and Maddock (1985) as cited in Maxwell and Opresko (1996)	Based on subchronic NOAEL [illegible] with an uncertainty factor of [illegible]
Nitrobenzene	6.52	6.56	White footed mouse (0.0185)	See Comments	Test species NOAEL [illegible] reference NOAEL for symmetrobenzene [illegible] mg/kg/d) and the ratio of LD_{50} values [illegible] from RTECS (1997)
Nitroglycerin	10.2	6.4	Mouse (0.03)	Ellis et al. (1978, 1984) as cited in Smith (1989)	
m-Nitrotoluene	4.22	2.16	Rat (0.35)	(see Comments)	Test species NOAEL [illegible] for TNT and ratio of LD_{50} values [illegible] from RTECS (1997)
o-Nitrotoluene	1.50	1.21	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for TNT and ratio of LD_{50} values (891.7 [illegible]) from RTECS (1997)
p-Nitrotoluene	7.71	3.94	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for TNT and ratio of LD_{50} values [illegible] from RTECS (1997)
PETN	6,213	5,868	Mouse (0.03)	(see Comments)	Test species NOAEL based on mouse NOAEL for nitroglycerin and ratio of [illegible] values [illegible]
RDX	7.75	7.0	Mouse [illegible]	Lish et al. (1984) as cited in Talmage and Opresko (1998a)	
Tetryl	[illegible]	[illegible]	Rat (0.258)	Reddy et al. (1994) as cited in Talmage et al. (1999)	Based on subchronic NOAEL [illegible] with an uncertainty factor of [illegible]
2,4,6-Trinitrobenzene	[illegible]	6.74	White footed mouse [illegible]	Dalhoeger et al. Associates, Inc. (1984) as cited in Talmage and Opresko (1998b)	[illegible] NOAEL 16.74 [illegible] with an uncertainty factor of [illegible]
2,4,6-Trinitrotoluene	[illegible]	[illegible]	Rat (0.218)	Dilley et al. (1982) as cited in Talmage and Opresko (1995)	Based on a subchronic LOAEL [illegible] mg/kg/d with an uncertainty factor of [illegible]

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Polycyclic Aromatic Hydrocarbons (PAHs)					
Acenaphthylene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Anthracene	105.85	100	Mouse (0.03)	USEPA (1989a)	NOAEL based on the highest dose (1,000 mg/kg/d, subchronic) and an uncertainty factor of 0.1.
Benzo(a)anthracene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Benzo(b)flouranthene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Benzo(k)fluoranthene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Benzo(g,h,i)perylene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Benzo(a)pyrene	1.06	1.0	Mouse (0.03)	Mackenzie and Angevine (1981)	Considered the most toxic PAH to wildlife, therefore, used as the default for PAHs with insufficient toxicity information for NOAEL determination.
Chrysene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Dibenzo(a,h)anthracene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
Fluoranthene	13.23	12.5	Mouse (0.03)	USEPA (1988)	Based on subchronic NOAEL of 125 mg/kg/d and an uncertainty factor of 0.1.
Fluorene	13.23	12.5	Mouse (0.03)	USEPA (1989b)	Based on subchronic NOAEL of 125 mg/kg/d and an uncertainty factor of 0.1.
Indeno(1,2,3-cd)pyrene	1.06	1.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The NOAEL for benzo(a)pyrene is used as default.
2-Methylnaphthalene	4.79	2.45	Rat (0.35)	(see Comments)	Test species NOAEL based on rat NOAEL for pyrene (4.06 mg/kg/d, scaled from mouse NOAEL of 7.5 mg/kg/d) and ratio of LD_{50} values (1,630/2,700) from RTECS (1997).
Naphthalene	5.29	5.00	Mouse (0.03)	(see Comments)	Test species NOAEL based on mouse NOAEL for pyrene (7.5 mg/kg/d) and ratio of

Chemical Name	Deer Mouse NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Phenanthrene	1.06	1.0	Mouse (0.03)	(see Comments)	[illegible] values [illegible] from RTI [illegible] insufficient toxicity data available for compound. The NOAEL for benzo(a)pyrene is used as default
Pyrene	7.94	7.5	Mouse (0.03)	USEPA (1989)	Based on subchronic NOAEL of [illegible] and an uncertainty factor of [illegible]
Polychlorinated Biphenyls (PCBs)					
Aroclor 1254	0.18	0.060	Mink (1.0)	Bleavins et al. (1980)	Based on chronic [illegible] and an uncertainty [illegible]
Aroclor 1248	0.04	[illegible]	Rhesus monkey (5.0)	[illegible]	Based on chronic LOAEL [illegible] and an uncertainty factor of [illegible]
[illegible]	[illegible]	0.028	Outbred mouse (0.014)	Mc[illegible] et al. (1979)	Based on chronic LOAEL [illegible] and an uncertainty factor of [illegible]
Aroclor [illegible]	0.08	0.040	Rat (0.35)	[illegible]	[illegible] species [illegible] Aroclor 1254 [illegible] from NOAEL for [illegible] values [illegible]

[a] Milligrams per kilogram per day (mg/kg/d)
[b] Body weights expressed in kilograms
LOAEL Lowest Observed Adverse Effect Level

Table B.3
Lowest-Observed-Adverse-Effects-Levels (LOAELs) for Inorganic Analytes in the Deer Mouse

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Aluminum	20.4	19.3	Mouse (0.03)	Ondreicka et al. (1966)	As $AlCl_3$.
Antimony	1.32	1.25	Mouse (0.03)	Schroeder et al. (1968)	As antimony potassium tartrate.
Arsenic	1.33	1.26	Mouse (0.03)	Schroeder and Mitchener (1971)	As arsenite (As^{+3}).
Banum	38.7	19.8	Rat (0.35)	Borzelleca et al.(1988)	As barium chloride. Based on a subchronic LOAEL of 198 mg/kg/d and an uncertainty factor of 0.1.
Beryllium	12.9	6.6	Rat (0.35)	Schroeder and Mitchener (1975)	As beryllium sulfate. The LOAEL represents 10 x the maximum dose of the study, which produced no adverse effect.
Cadmium	18.9	10	Rat (0.303)	Sutou et al. (1980)	As $CdCl_2$.
Chromium (total)	53,540	27,370	Rat (0.35)	Ivankovic and Preussmann (1975)	As Cr^{+3} in Cr_2O_3. The LOAEL represents 10 x the maximum dose of the study, which produced no adverse effect.
Chromium VI	25.7	13.14	Rat (0.35)	Steven et al. (1976)	As Cr^{+6}. Based on a subchronic LOAEL of 131.4 mg/kg/d and an uncertainty factor of 0.1
Cobalt	---	---	---	---	Insufficient data for NOAEL determination
Copper	38.5	15.14	Mink (1.0)	Aulerich et al. (1982)	As copper sulfate.
Cyanide	1,260	687	Rat (0.273)	Tewe and Maner (1981)	As potassium cyanide. The LOAEL represents 10 x the maximum dose of the study, which produced no adverse effect.
Lead	156	80	Rat (0.35)	Azar et al. (1973)	As lead acetate.
Manganese	556	284	Rat (0.35)	Laskey et al. (1982)	As Mn_3O_4.
Mercury (inorganic)	140	132	Mouse (0.03)	Revis et al. (1989)	As mercuric sulfide. The LOAEL represents 10 x the maximum dose of the study, which produced no adverse effect
Mercury (organic)	0.31	0.16	Rat (0.35)	Verschuuren et al. (1976)	As methyl mercury chloride
Nickel	156	80	Rat (0.35)	Ambrose et al. (1976)	As nickel sulfate hexahydrate
Selenium	0.65	0.33	Rat (0.35)	Rosenfeld and Beath (1954)	As potassium selenate
Silver	174	89	Rat (0.35)	Olcott (1950)	As silver nitrate.

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Thallium	0.15	0.074	Rat (0.365)	Formigli et al. (1986)	As thallium sulfate. Based on a sub-chronic LOAEL of 0.74 mg/kg/d with an uncertainty factor of 0.1
Titanium	369	158	Rat (0.35)	RTI CS (1997)	Form not specified
Uranium	6.38	6.13	Mouse (0.028)	Paternain et al. (1989)	As uranyl acetate
Vanadium	3.81	2.10	Rat (0.26)	Domingo et al. (1986)	As sodium metavanadate (NaVO3)
Zinc	626	320	Rat (0.35)	Schlicker and Cox (1968)	As zinc oxide

[a] milligrams per kilogram per day (mg/kg/d)
[b] Body weights expressed in kilograms

Table B.4
Lowest-Observed-Adverse-Effects-Levels (LOAELs) for Organic Analytes in the Deer Mouse

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Acetone	97.8	50	Rat (0.35)	USEPA (1986)	Based on a subchronic LOAEL of 500 mg/kg/d with an uncertainty factor of 0.1
Benzene	279	264	Mouse (0.03)	Nawrot and Staples (1979)	
Benzoic acid	42.3	40	Mouse (0.03)	Shtenberg and Ignat'ev (1970)	
Bis(2-ethylhexyl)phthalate	194	183	Mouse (0.03)	Lamb et al. (1987)	
2-Butanone	8,940	4,571	Rat (0.35)	Cox et al. (1975)	Synonymous with methyl ethyl ketone.
Butyl benzyl phthalate	91.9	47.0	Rat (0.35)	NTP (1985a), as cited in USEPA (1997)	
Carbazole	---	---	---	---	Insufficient data for LOAEL determination.
Chlorobenzene	127	120	Mouse (0.03)	NTP (1985b), as cited in USEPA (1997)	
Chloroform	80.2	41	Rat (0.35)	Palmer et al. (1979)	Based on a subchronic LOAEL of 410 mg/kg/d with an uncertainty factor of 0.1
2-Chlorophenol	9.78	5.0	Rat (0.35)	Exon and Koller (1982)	Based on a subchronic LOAEL of 50 mg/kg/d and an uncertainty factor of 0.1.
4-Chloro-3-methylphenol	26.7	13.6	Rat (0.35)	(see Comments)	Test species LOAEL based on rat LOAEL for 2-chlorophenol and ratio of LD_{50} values (1,830/670) from RTECS (1997).
Dibenzofuran	---	---	---	---	Insufficient data for LOAEL determination.
1,1-Dichloroethylene	587	300	Rat (0.35)	Quast et al. (1983)	The LOAEL represents 10 x the maximum dose of the study, which produced no significant adverse effect.
1,2-Dichloroethylene	478	452	Mouse (0.03)	Palmer et al. (1979)	The LOAEL derived from 10 x the maximum dose of the study, which produced no significant adverse effect. This dose was converted from subchronic to chronic by an uncertainty factor of 0.1.
Dimethyl phthalate	878	830	Mouse (0.03)	(see Comments)	Test species LOAEL based on mouse LOAEL for bis(2-ethylhexyl)phthalate and ratio of LD_{50} values (6,800/1,500) from RTECS (1997).

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Di-n-butyl phthalate	1,940	1,833	Mouse (0.03)	Lamb et al. (1987)	[illegible]
Di-n-octyl phthalate	840	794	Mouse (0.03)	(see Comments)	Test species LOAEL [illegible] LOAEL for bis(2-ethylhexyl)phthalate and ratio of LD_{50} values [illegible] both RTECS (1992)
Methyl ethyl ketone	[illegible]	[illegible]	(see 2-butanone)		
Methylene chloride	[illegible]	50	Rat (0.35)	NCA (1982)	[illegible]
Phenol	235	120	Rat (0.35)	NTP (1983), as cited in [illegible]	
1,1,2,2-Tetrachloroethane	149	141	Rat (0.35)	(see Comments)	Test species LOAEL [illegible] LOAEL for [illegible] ratio of [illegible] values [illegible] from RTECS [illegible]
1,1,2,2-Tetrachloroethylene	[illegible]	[illegible]	Mouse (0.03)	Buben and O'Flaherty (1985)	Based [illegible] mg/kg/d, [illegible] Days
Toluene	[illegible]	[illegible]	Mouse (0.03)	Hewitt and Staples (1979)	[illegible]
1,2,4-Trichlorobenzene	11.0	[illegible]	Rat (0.35)	Robinson et al. (1981)	Based on a sub-lethal LOAEL [illegible]
1,1,1-Trichloroethane	11,000	10,000	Mouse (0.03)	Lane et al. (1982)	The LOAEL represents [illegible] dose of the study which [illegible] adverse effect
Trichloroethylene	141	[illegible]	Mouse (0.03)	Buben and O'Flaherty (1985)	Based on a sub-lethal LOAEL [illegible] mg/kg/d, [illegible] Days
[illegible]	[illegible]	[illegible]	Mouse (0.03)	Maxwell et al. (1986)	
			Explosives		
[illegible]	[illegible]	[illegible]	Rat (0.35)	[illegible]	[illegible]
[illegible]		[illegible]	Rat (0.35)	[illegible]	Test species NOAEL [illegible] from RTECS [illegible]
[illegible]	[illegible]	[illegible]	Rat (0.35)	[illegible] et al. (1981) as cited in Talmage and [illegible] (1994)	Based on sub-lethal 10-week LOAEL [illegible] mg/kg/d and [illegible]
[illegible]	[illegible]	[illegible]	Rat (0.35)	(see Comments)	Test species NOAEL [illegible]

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
					for TNT and ratio of LD_{50} values (268/795) from RTECS (1997).
2,6-Dinitrotoluene	6.96	3.56	Rat (0.35)	(see Comments)	Test species NOAEL based on rat LOAEL for TNT and ratio of LD_{50} values (177/795) from RTECS (1997).
HMX	7.43	7.5	Mouse (0.023)	Everett and Maddock (1985) as cited in Maxwell and Opresko (1996)	Based on subchronic LOAEL of 75 mg/kg/d with an uncertainty factor of 0.1.
Nitrobenzene	11.0	11.7	White-footed mouse (0.0185)	(see Comments)	Test species LOAEL based on white-footed mouse LOAEL for sym-dinitrobenzene (11.35 mg/kg/d) and the ratio of LD_{50} values (590/572) from RTECS (1997).
Nitroglycerin	1,080	1,022	Mouse (0.03)	Ellis et al. (1978, 1984) as cited in Smith (1989)	
m-Nitrotoluene	42.2	21.6	Rat (0.35)	(see Comments)	Test species NOAEL based on rat LOAEL for TNT and ratio of LD_{50} values (1,072/795) from RTECS (1997).
o-Nitrotoluene	35.0	17.9	Rat (0.35)	(see Comments)	Test species NOAEL based on rat LOAEL for TNT and ratio of LD_{50} values (891/795) from RTECS (1997).
p-Nitrotoluene	77.1	39.4	Rat (0.35)	(see Comments)	Test species NOAEL based on rat LOAEL for TNT and ratio of LD_{50} values (1,960/795) from RTECS (1997).
PETN	65,800	62,200	Mouse (0.03)	(see Comments)	Test species LOAEL based on mouse LOAEL for nitroglycerin and ratio of LD_{50} values (7,000/115) from RTECS (1997).
RDX	38.8	35	Mouse (0.036)	Lish et al. (1984) as cited in Talmage and Opresko (1996a)	
Tetryl	11.2	6.2	Rat (0.258)	Reddy et al. (1994) as cited in Talmage et al. (1996)	Based on subchronic LOAEL of 62 mg/kg/d with an uncertainty factor of 0.1.
sym-Trinitrobenzene	10.6	11.35	White-footed mouse (0.0185)	Pathological Associates, Inc (1994) as cited in Talmage and Opresko (1996b)	Based on subchronic LOAEL of 113.5 mg/kg/d with an uncertainty factor of 0.1
2,4,6-Trinitrotoluene	30.6	16.0	Rat (0.318)	Dilley et al. (1982) as cited in Talmage and Opresko (1995)	Based on a subchronic LOAEL of 160 mg/kg/d with an uncertainty factor of 0.1

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Polycyclic Aromatic Hydrocarbons (PAHs)					
Acenaphthylene	100	100	Mouse (0.03)	(see Comments)	[illegible]
Anthracene	1,000	1,000	Mouse (0.03)	EPA (1986a)	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	Mouse (0.03)	Mackenzie and Angevine (1981)	[illegible]
[illegible]	[illegible]	[illegible]	Mouse (0.03)	(see Comments)	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Chemical Name	Deer Mouse LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
					of LD_{50} values (533/800) from RTECS (1997).
Phenanthrene	10.6	10.0	Mouse (0.03)	(see Comments)	Insufficient toxicity data available for this compound. The LOAEL for benzo(a)pyrene is used as default.
Pyrene	13.2	12.5	Mouse (0.03)	EPA (1989c)	Based on subchronic LOAEL of 125 mg/kg/d and an uncertainty factor of 0.1.
Polychlorinated Biphenyls (PCBs)					
Aroclor-1242	1.8	0.60	Mink (1.0)	Bleavins et al. (1980)	
Aroclor-1248	0.4	0.1	Rhesus monkey (5.0)	Barsotti et al. (1976)	
Aroclor-1254	0.59	0.68	Oldfield mouse (0.014)	McCoy et al. (1995)	
Aroclor-1260	0.77	0.40	Rat (0.35)	(see Comments)	Test species LOAEL based on rat LOAEL for aroclor-1254 (0.304 mg/kg/d, scaled from LOAEL for oldfield mouse) and ratio of LD_{50} values (1,315/1,010) from RTECS (1997).

[a]In milligrams per kilogram per day (mg/kg/d).
[b]Body weights expressed in kilograms.
[c]Lowest-Observed-Adverse-Effect-Level.

Table B.5
No-Observed-Adverse-Effects-Levels (NOAELs) for Inorganic Analytes in the Burrowing Owl

Chemical Name	Burrowing Owl NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Aluminum	109.7	109.7	Ringed Dove (0.156)	[illegible]	[illegible]
Antimony	[illegible]	[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	Mallard [illegible]	[illegible]	[illegible]
Barium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Beryllium					
[illegible]	[illegible]	[illegible]	Mallard [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chromium VI					Insufficient data for NOAEL [illegible]
Cobalt					Insufficient data for NOAEL [illegible]
Copper	47	47	Chicks (0.534)	Mehrle et al. (1988)	[illegible]
Cyanide					Insufficient data for NOAEL [illegible]
Lead	[illegible]	[illegible]	American Kestrel [illegible]	Pattee (1984)	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] (1985)	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Single dose [illegible]
[illegible]	[illegible]	[illegible]	Mallard [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] and Hoffman (1986)	[illegible]
[illegible]					Insufficient data for NOAEL [illegible]
[illegible]					Insufficient data for NOAEL [illegible]

Chemical Name	Burrowing Owl NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Titanium	---	---	---	---	Insufficient data for NOAEL determination.
Uranium	16	16	Black Duck (1.25)	Haseltine and Sileo (1983)	As depleted metallic uranium. The NOAEL is based on highest dose (160 mg/kg/d, subchronic) and an uncertainty factor of 0.1.
Vanadium	11.4	11.4	Mallard (1.17)	White and Dieter (1978)	As vanadyl sulfate. NOAEL based on the maximum dose, which produced no significant adverse effect.
Zinc	14.5	14.5	Chicken (1.935)	Stahl et al. (1990)	As zinc sulfate.

[a]In milligrams per kilogram per day (mg/kg/d).
[b]Body weights expressed in kilograms.
[c]Lowest-Observed-Adverse-Effect-Level.

Table B.6
No-Observed-Adverse-Effects-Levels (NOAELs) for Organic Analytes in the Burrowing Owl

Chemical Name	Burrowing Owl NOAEL*	Test Species NOAEL*	Test Species (Body Weight)[a]	Reference	Comments
Acetone	---	---	---		Insufficient data for NOAEL determination
Benzene	---	---	---		Insufficient data for NOAEL determination
Benzoic acid	---	---	---		Insufficient data for NOAEL determination
Bis(2-ethylhexyl)phthalate	1.1	1.1	Ringed Dove (0.155)	Peakall (1974)	NOAEL based on single dose wh[illegible] produced no significant adverse effe[illegible]
2-Butanone					Insufficient data for NOAEL determination
Butylbenzyl phthalate					Insufficient data for NOAEL determination
Carbazole					Insufficient data for NOAEL determination
Chlorobenzene					Insufficient data for NOAEL determination
Chloroform					Insufficient data for NOAEL determination
2-Chlorophenol					Insufficient data for NOAEL determination
4-Chloro-3-methylphenol					Insufficient data for NOAEL determination
Dibenzofuran	---	---	---		Insufficient data for NOAEL determination
1,1-Dichloroethylene					Insufficient data for NOAEL determination
1,2-Dichloroethylene	---	---	---		Insufficient data for NOAEL determination
Dimethyl phthalate					Insufficient data for NOAEL determination
Di-n-butyl phthalate	0.11	0.11	Ringed Dove (0.155)	Peakall (1974)	NOAEL based on a single dose that was considered to be a chronic LOAEL and an uncertainty factor of 0.1
Di-n-octyl phthalate					Insufficient data for NOAEL determination
Methyl ethyl ketone					Insufficient data for NOAEL determination
Methylene chloride					Insufficient data for NOAEL determination
Phenol	---	---	---		Insufficient data for NOAEL determination
1,1,2,2-Tetrachloroethane					Insufficient data for NOAEL determination
1,1,2,2-Tetrachloroethylene					Insufficient data for NOAEL determination
Toluene					Insufficient data for NOAEL determination
1,2,4-Trichlorobenzene					Insufficient data for NOAEL determination

Chemical Name	Burrowing Owl NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
1,1,1-Trichloroethane	---	---	---	---	Insufficient data for NOAEL determination.
Trichloroethylene	---	---	---	---	Insufficient data for NOAEL determination.
Xylenes	---	---	---	---	Insufficient data for NOAEL determination.
Explosives					
2-Amino-4,6-dinitrotoluene	---	---	---	---	Insufficient data for NOAEL determination
4-Amino-2,6-dinitrotoluene	---	---	---	---	Insufficient data for NOAEL determination
m-Dinitrobenzene	---	---	---	---	Insufficient data for NOAEL determination
2,4-Dinitrotoluene	---	---	---	---	Insufficient data for NOAEL determination.
2,6-Dinitrotoluene	---	---	---	---	Insufficient data for NOAEL determination
HMX	---	---	---	---	Insufficient data for NOAEL determination
Nitrobenzene	---	---	---	---	Insufficient data for NOAEL determination.
Nitroglycerin	---	---	---	---	Insufficient data for NOAEL determination
m-Nitrotoluene	---	---	---	---	Insufficient data for NOAEL determination.
o-Nitrotoluene	---	---	---	---	Insufficient data for NOAEL determination
p-Nitrotoluene	---	---	---	---	Insufficient data for NOAEL determination.
PETN	---	---	---	---	Insufficient data for NOAEL determination.
RDX	---	---	---	---	Insufficient data for NOAEL determination
Tetryl	---	---	---	---	Insufficient data for NOAEL determination
sym-Trinitrobenzene	---	---	---	---	Insufficient data for NOAEL determination
2,4,6-Trinitrotoluene	---	---	---	---	Insufficient data for NOAEL determination.
Polycyclic Aromatic Hydrocarbons (PAHs)					
Acenaphthylene	---	---	---	---	Insufficient data for NOAEL determination.
Anthracene	---	---	---	---	Insufficient data for NOAEL determination.
Benzo(a)anthracene	---	---	---	---	Insufficient data for NOAEL determination
Benzo(b)flouranthene	---	---	---	---	Insufficient data for NOAEL determination
Benzo(k)fluoranthene	---	---	---	---	Insufficient data for NOAEL determination
Benzo(g,h,i)perylene	---	---	---	---	Insufficient data for NOAEL determination
Benzo(a)pyrene	---	---	---	---	Insufficient data for NOAEL determination
Chrysene	---	---	---	---	Insufficient data for NOAEL determination
Dibenzo(a,h)anthracene	---	---	---	---	Insufficient data for NOAEL determination
Fluoranthene	---	---	---	---	Insufficient data for NOAEL determination
Fluorene	---	---	---	---	Insufficient data for NOAEL determination

Chemical Name	Burrowing Owl NOAEL[a]	Test Species NOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
[illegible]					[illegible]
[illegible] Methylnaphthalene					Insufficient data for NOAEL determination
Naphthalene					Insufficient data for NOAEL determination
Phenanthrene					Insufficient data for NOAEL determination
Pyrene					Insufficient data for NOAEL determination
Polychlorinated Biphenyls (PCBs)					
Aroclor 1254[c]	0.43	0.43	[illegible] (0.181)	[illegible]	[illegible]
Aroclor 1248					Insufficient data [illegible]
Aroclor [illegible]	[illegible]	[illegible]	Intact Mallard Duck (1.1)	[illegible]	[illegible]
[illegible]					

[a] [illegible]
[b] [illegible]
Lowest Observed Adverse Effect Level

Table B.7
Lowest-Observed-Adverse-Effects-Levels (LOAELs) for Inorganic Analytes in the Burrowing Owl

Chemical Name	Burrowing Owl LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Aluminum	1,097	1,097	Ringed Dove (0.155)	Carriere et al. (1986)	As $Al_2(SO_4)_3$. LOAEL based on 10 x a single test dose that produced no adverse effect.
Antimony	---	---	---	---	Insufficient data for LOAEL determination.
Arsenic	12.84	12.84	Mallard (1.0)	USFWS (1964)	As sodium arsenite (As^{+3}).
Barium	41.6	41.6	Chicks (0.121)	Johnson et al.(1960)	As barium hydroxide. Based on a subchronic LOAEL of 416 mg/kg/d and an uncertainty factor of 0.1.
Beryllium	---	---	---	---	Insufficient data for LOAEL determination
Cadmium	20.0	20.0	Mallard (1.153)	White and Finley (1978)	As $CdCl_2$.
Chromium (total)	5.0	5.0	Black Duck (1.25)	Haseline et al. (1985) (unpublished), as cited in Sample et al. (1996)	As Cr^{+3} in $CrK(SO_4)_2$.
Chromium VI	---	---	---	---	Insufficient data for LOAEL determination
Cobalt	---	---	---	---	Insufficient data for LOAEL determination
Copper	61.7	61.7	Chicks (0.534)	Mehring et al. (1960)	As copper oxide.
Cyanide	---	---	---	---	Insufficient data for LOAEL determination.
Lead	38.5	38.5	American Kestrel (0.13)	Pattee (1984)	As metallic lead. The LOAEL is based on 10 x the maximum dose, which produced no significant adverse effects.
Manganese	9,770	9,770	Japanese Quail (0.072)	Laskey and Edens (1985)	As Mn_3O_4. LOAEL based on 10 x a single test dose that produced no observed adverse effect.
Mercury (inorganic)	0.90	0.90	Japanese Quail (0.15)	Hill and Schaffner (1976)	As mercuric chloride.
Mercury (organic)	0.064	0.064	Mallard (1.0)	Heinz (1979)	As methyl mercury dicyandiamide. Based on a single dose which was considered to be a chronic LOAEL.
Nickel	107	107	Mallard (0.782)	Cain and Pafford (1981)	As nickel sulfate.
Selenium	1.5	1.5	Screech Owl (0.2)	Wiemeyer and Hoffman (1996)	As selenomethionine.
Silver	---	---	---	---	Insufficient data for LOAEL determination
Thallium	---	---	---	---	Insufficient data for LOAEL determination

Chemical Name	Burrowing Owl LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Titanium					Insufficient data to derive LOAEL determination
Uranium	160	166	Black Duck (1.25)	Haseltine and Sileo (1983)	As depleted metal [illegible] based on highest dose (1000 mg/kg/d) subfraction which produced no significant adverse effect and at [illegible]
Vanadium	114	114	Mallard (1.17)	White and Dieter (1978)	As vanadyl sulfate. No AEL [illegible] maximum dose which produced no significant adverse effect
Zinc	131	131	Chicken (1.935)	Stahl et al. (1989)	As zinc sulfate

[a] [illegible] mg/kg/day (dry weight)
[b] Body weight [illegible] in kilograms.

Table B.8
Lowest-Observed-Adverse-Effects-Levels (LOAELs) for Organic Analytes in the Burrowing Owl

Chemical Name	Burrowing Owl LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Acetone	---	---	---	---	Insufficient data for LOAEL determination.
Benzene	---	---	---	---	Insufficient data for LOAEL determination.
Benzoic acid	---	---	---	---	Insufficient data for LOAEL determination.
Bis(2-ethylhexyl)phthalate	11.0	11.0	Ringed Dove (0.155)	Peakall (1974)	LOAEL based on 10 x a single test dose that produced no significant adverse effect
2-Butanone	---	---	---	---	Insufficient data for LOAEL determination.
Butyl benzyl phthalate	---	---	---	---	Insufficient data for LOAEL determination.
Carbazole	---	---	---	---	Insufficient data for LOAEL determination
Chlorobenzene	---	---	---	---	Insufficient data for LOAEL determination
Chloroform	---	---	---	---	Insufficient data for LOAEL determination.
2-Chlorophenol	---	---	---	---	Insufficient data for LOAEL determination
4-Chloro-3-methylphenol	---	---	---	---	Insufficient data for LOAEL determination
Dibenzofuran	---	---	---	---	Insufficient data for LOAEL determination
1,1-Dichloroethylene	---	---	---	---	Insufficient data for LOAEL determination.
1,2-Dichloroethylene	---	---	---	---	Insufficient data for LOAEL determination.
Dimethyl phthalate	---	---	---	---	Insufficient data for LOAEL determination.
Di-n-butyl phthalate	1.1	1.1	Ringed Dove (0.155)	Peakall (1974)	LOAEL based on a single dose that was considered to be a chronic LOAEL.
Di-n-octyl phthalate	---	---	---	---	Insufficient data for LOAEL determination.
Methyl ethyl ketone	---	---	---	---	Insufficient data for LOAEL determination
Methylene chloride	---	---	---	---	Insufficient data for LOAEL determination.
Phenol	---	---	---	---	Insufficient data for LOAEL determination
1,1,2,2-tetrachloroethane	---	---	---	---	Insufficient data for LOAEL determination
1,1,2,2-Tetrachloroethylene	---	---	---	---	Insufficient data for LOAEL determination
Toluene	---	---	---	---	Insufficient data for LOAEL determination
1,2,4-Trichlorobenzene	---	---	---	---	Insufficient data for LOAEL determination

Chemical Name	Burrowing Owl LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
Trichloroethylene	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
Xylenes	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
Explosives					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
4-Amino-2,6-dinitrotoluene	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
2-Amino-4,6-dinitrotoluene	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
m-Dinitrobenzene	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
HMX	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
PETN	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
PETX	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
Tetryl	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
1,3,5-Trinitrobenzene	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
Polycyclic Aromatic Hydrocarbons (PAHs)					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Insufficient data for LOAEL determination

Chemical Name	Burrowing Owl LOAEL[a]	Test Species LOAEL[a]	Test Species (Body Weight)[b]	Reference	Comments
Indeno(1,2,3-cd)pyrene	---	---	---	---	Insufficient data for LOAEL determination.
2-Methylnaphthalene	---	---	---	---	Insufficient data for LOAEL determination.
Naphthalene	---	---	---	---	Insufficient data for LOAEL determination.
Phenanthrene	---	---	---	---	Insufficient data for LOAEL determination.
Pyrene	---	---	---	---	Insufficient data for LOAEL determination.
Polychlorinated Biphenyls (PCBs)					
Aroclor-1242	4.1	4.1	Screech Owl (0.181)	McLane and Hughes (1980)	LOAEL based on 10 x a single dose that produced no significant adverse effect
Aroclor-1248	---	---	---	---	Insufficient data for LOAEL determination.
Aroclor-1254	1.8	1.8	Ring-Necked Pheasant (1.0)	Dahlgren et al. (1972)	Based on the lowest dose, which was considered to be a chronic LOAEL.
Aroclor-1260	---	---	---	---	Insufficient data for LOAEL determination

[a]In milligrams per kilogram per day (mg/kg/d).
[b]Body weights expressed in kilograms.

Table B.9
Plant Benchmarks for Soil Concentrations of Inorganic Analytes

Chemical Name	Plant Benchmark*	Form of Chemical Tested	Test Species	Reference	Comments
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Not specified	Not specified	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Barley	Barley	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Various crops affected	[illegible]	[illegible]
[illegible]	[illegible]	Not specified	Not specified	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Chemical Name	Plant Benchmark[a]	Form of Chemical Tested	Test Species	Reference	Comments
Titanium	—	—	—	—	Insufficient data to determine benchmark
Uranium	5.0	Uranyl nitrate	Swiss chard	Sheppard et al. (1983)	Lowest concentration tested.
Vanadium	2.0	Not specified	Not specified	USEPA (1980)	Based on secondary source information with no experimental details.
Zinc	50.0	Various	Various	Will and Suter (1995)	Benchmark estimated as the 10th percentile from 14 reported LOAEL values for plants

[a]In milligrams per kilogram soil.
[b]No-Observed-Adverse-Effect-Level.
[c]Lowest-Observed-Adverse-Effect-Level.

Table B.10
Plant Benchmarks for Soil Concentration of Organic Analytes

Chemical Name	Plant Benchmark[a]	Test Species	Reference	Comments
Acetone	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Benzene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Benzoic acid	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Bis(2-ethylhexyl)phthalate	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
2-Butanone	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Butyl benzyl phthalate	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Carbazole	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Chlorobenzene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Chloroform	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
2-Chlorophenol	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
4-Chloro-3-methylphenol	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Dibenzofuran	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
1,1-Dichloroethylene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
1,2-Dichloroethylene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Dimethyl phthalate	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Di-n-butyl phthalate	200	Corn and soybeans	Overcash et al. (1982)	Benchmark based on LOAELs' lowest concentration tested [illegible] species had NOAELs of 2,000 mg/kg in other soils tested
Di-n-octyl phthalate	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Methyl ethyl ketone	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Methylene chloride	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Phenol	70	Lettuce	Hulzebos et al. (1993)	Benchmark based on an EC_{50} value from a loam soil. [illegible] second loam soil with lower clay content was [illegible]
1,1,2,2-Tetrachloroethane	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
1,1,2-Trichloroethylene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
Toluene	200	Corn and soybean	Overcash et al. (1982)	Benchmark based on LOAELs lowest concentration tested [illegible] species had NOAELs of 2,000 mg/kg in other soils tested
1,2,4-Trichlorobenzene	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark
1,1,1-Trichloroethane	[illegible]	[illegible]	[illegible]	Insufficient data to determine benchmark

Chemical Name	Plant Benchmark*	Test Species	Reference	Comments
Trichloroethylene	---	---	---	Insufficient data to determine benchmark.
Xylenes	---	---	---	Insufficient data to determine benchmark.
Explosives				
2-Amino-4,6-dinitrotoluene	80.0	Yellow nutsedge	Pennington (1988)	The benchmark value is a NOAEL.
4-Amino-2,6-dinitrotoluene	---	---	---	Insufficient data to determine benchmark.
m-Dinitrobenzene	---	---	---	Insufficient data to determine benchmark.
2,4-Dinitrotoluene	---	---	---	Insufficient data to determine benchmark.
2,6-Dinitrotoluene	---	---	---	Insufficient data to determine benchmark.
HMX	---	---	---	Insufficient data to determine benchmark.
Nitrobenzene	---	---	---	Insufficient data to determine benchmark.
Nitroglycerin	---	---	---	Insufficient data to determine benchmark.
m-Nitrotoluene	---	---	---	Insufficient data to determine benchmark.
o-Nitrotoluene	---	---	---	Insufficient data to determine benchmark.
p-Nitrotoluene	---	---	---	Insufficient data to determine benchmark.
PETN	---	---	---	Insufficient data to determine benchmark.
RDX	100	Cucumber	Simini et al. (1992)	
Tetryl	25.0	Wheat	Fellows et al. (1992)	
sym-Trinitrobenzene	---	---	---	Insufficient data to determine benchmark.
2,4,6-Trinitrotoluene	30.0	Blando brome grass	Cataldo et al. (1989)	
Polycyclic Aromatic Hydrocarbons (PAHs)				
Acenaphthylene	---	---	---	Insufficient data to determine benchmark.
Anthracene	---	---	---	Insufficient data to determine benchmark.
Benzo(a)anthracene	18	Wheat and barley	Sims and Overcash (1983)	Benchmark based on a NOAEL.
Benzo(b)flouranthene	18	Wheat and barley	Sims and Overcash (1983)	Benchmark based on a NOAEL.
Benzo(k)fluoranthene	---	---	---	Insufficient data to determine benchmark.
Benzo(g,h,i)perylene	---	---	---	Insufficient data to determine benchmark.
Benzo(a)pyrene	---	---	---	Insufficient data to determine benchmark.
Chrysene	---	---	---	Insufficient data to determine benchmark.
Dibenzo(a,h)anthracene	---	---	---	Insufficient data to determine benchmark.

Chemical Name	Plant Benchmark[a]	Test Species	Reference	Comments
Fluoranthene	---	---	---	Insufficient data to determine benchmark
Fluorene	---	---	---	Insufficient data to determine benchmark
Indeno(1,2,3-cd)pyrene	---	---	---	Insufficient data to determine benchmark
2-Methylnaphthalene	---	---	---	Insufficient data to determine benchmark
Naphthalene	---	---	---	Insufficient data to determine benchmark
Phenanthrene	---	---	---	Insufficient data to determine benchmark
Pyrene	---	---	---	Insufficient data to determine benchmark
Polychlorinated Biphenyls (PCBs)				
Aroclor 1242	---	---	---	Insufficient data to determine benchmark
Aroclor 1248	---	---	---	Insufficient data to determine benchmark
Aroclor 1254	40.0	Pigweed	Strek and Weber (1980)	
Aroclor 1260	---	---	---	Insufficient data to determine benchmark

[a]In milligrams per kilogram soil
[b]Lowest Observed Adverse Effect Level
[c]No-Observed-Adverse-Effect Level
[d]Effective concentration to 50% of the exposed population

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Appendix C

Radiological Properties for Selected Radionuclides

Table C.1
Radiological Properties for Selected Radionuclides
Sandia National Laboratories, New Mexico

Radionuclide	Radioactive Half-life (days)[a]	Effective Absorbed Energy for Deer Mouse (MeV)[a]	Effective Absorbed Energy for Burrowing Owl (MeV)[a]	Biological Half-life (day)[a]	Fraction of Radionuclide Retained By Receptor (unitless)[a]	Average Gamma Energy Per Decay (MeV)[b]
Am-241	1.580E+05	5.510E+00	5.200E+00	20000	0.001	[illegible]
Co-60	1.920E+03	2.370E-01	1.370E-01	9.5	0.5	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H-3	4.510E+03	5.800E-03	5.800E-03	10	1	[illegible]
Na-22	3.500E+04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pu-238	3.200E+04	5.510E+00	5.510E+00	65000	0.001	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	65000	0.001	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	65000	0.001	[illegible]
Ra-226	5.830E+07	1.100E+01	1.100E+01	8100	0	[illegible]
Ra-228	2.100E+03	6.000E+00	6.000E+00	8100	0.2	[illegible]
Sr-90	1.060E+04	1.100E+00	1.100E+00	1000	0.3	0.000E+00
Th-228	6.980E+03	5.600E+00	5.600E+00	5000	2.00E-04	3.03E-03
Th-230	2.810E+07	4.800E+00	4.800E+00	5000	[illegible]	[illegible]
[illegible]	[illegible]	1.000E+00	1.000E+00	5000	2.00E-04	[illegible]
U-234	8.900E+07	[illegible]	[illegible]	500	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.300E+00	1.300E+00	500	0.05	[illegible]

[a] Baker, D.A. and J.K. Soldat. 1992. Methods for Estimating Doses to Biota from Radioactive Materials. Report of Pacific Northwest Laboratory, Richland, Washington. [illegible]

[b] Source: Department of [illegible] Sandia National Laboratories Facility Worker [illegible] Sandia Laboratory, Manzano Facility, 13 December 1989.

Appendix D

Radiological Ecological Risk Assessment Methodology
Environmental Restoration Program
Sandia National Laboratories, New Mexico

Radiological Ecological Risk Assessment Methodology
Environmental Restoration Program
Sandia National Laboratories, New Mexico

The following information summarizes the radiological eco-risk assessment methodology applied to the deer mouse and to the burrowing owl exposed to radionuclides in the environment in which they reside. The first section provides a mathematical derivation of the internal dose rate "basic" equation that is applied to both the deer mouse and the burrowing owl internal dose rate models. The second and third sections outline how the basic internal dose rate equation derived in section one, is applied to the internal dose rate models for the deer mouse and the burrowing owl. The fourth section introduces the external dose rate model that is applied to both receptors and the fifth section defines the concept of the total dose rate.

1. Mathematical Derivation of the General Internal Total-body Dose Rate Equation

This section will outline a mathematical derivation of a general form of the internal dose rate equation that is applied to both the deer mouse and the burrowing owl exposed to radionuclides in the environment in which they reside.

The Hanford Site Risk Assessment Methodology (HSRAM) (DOE, 1995) defines a term called the "body burden" (dose rate) that is the negative effect that radionuclides have in the body of a receptor after ingestion. The change in the body burden or dose rate, b, per unit time is expressed as the following first-order, linear differential equation:

$$\frac{db}{dt} = \frac{P}{M} - \lambda b$$

where
- b = body burden or dose rate of a receptor for a single radionuclide (Ci/kg).
- P = rate of uptake of the radionuclide by the body of the receptor (Ci/day).
- M = mass of the receptor (kg).
- λ = effective removal constant of the radionuclide from the body of the receptor (1/day). This term considers both radiological and biological removal processes.

Integrating the differential equation results in the following function:

$$b(t) = e^{-\lambda t}\left(\frac{P}{\lambda M} + C\right)$$

where
- C = constant of integration.

All terms have been previously defined.

Multiplying the exponential term, $e^{-\lambda T}$, through the term in the brackets results in the following:

$$b(T) = \left(e^{-\lambda \cdot T}\right)\left(\frac{P}{\lambda \cdot M}\right)\left(e^{\lambda \cdot T}\right) + C \cdot \left(e^{-\lambda \cdot T}\right)$$

where: All terms have been previously defined.

Simplifying this equation results in the following equation with which we can introduce the initial conditions.

$$b(T) = \frac{P}{\lambda \cdot M} + Ce^{-\lambda \cdot T}$$

where: All terms have been previously defined.

Applying the initial condition, b(T=0) = 0 (the body burden of the receptor is zero at time zero, which means the receptor has yet to ingest radionuclides into its body), results in the final solution shown below.

$$b(T) = \frac{P}{M} \cdot \frac{\left[1 - e^{-\lambda \cdot T}\right]}{\lambda}$$

This equation is the basic form of the internal dose rate models for both the burrowing owl and the deer mouse. This equation, derived by USDOE (1995) describes the dose obtained by considering intake of radionuclides and the energy inparted due to radioactive decay by the term P. The $(1-\exp(-\lambda T))/\lambda$ term describes the effective time that a radionuclide can cause damage to the internal body of the receptor. The larger the biological and radiological removal processes take, the larger the dose will become due to this term. Since imparted energy from the radionuclides depends upon the mass of the receptor, the term M must be in the dose rate equation. The b(T) dose rate relationship is divided by an averaging period to obtain the dose rate on a daily basis.

This mathematical derivation is presented to provide a background to the origin of the internal total-body dose rate equations that are used for the deer mouse and the burrowing owl.

2. Derivation of the Internal Total-body Dose Rate for the Deer Mouse

This section will show a step-by-step derivation of the internal total-body dose rate equation for the deer mouse. The dose rate equations for internal radiation dose appear to be very complex due to the large number of terms it contains. The following equation defines the total-body dose rate for the deer mouse in rad per day for *N* radionuclides:

[illegible]

This equation will be assembled [illegible] that the purpose [illegible] can be explained more clearly.

The first step in the derivation of the internal deer mouse dose rate equation is to define how the receptor transfers radionuclides from the environment into its body to contribute to dose rate. The deer mouse is assumed to intake radionuclides into its body via ingestion of soil and plants on a daily basis. It is assumed that the deer mouse diet consists of 100% plants. Insect intake is not considered in the radiological dose rate model since soil-to-insect transfer data [illegible] radionuclides are not available. Soil ingestion is assumed to be 2% of its plant intake rate (EPA, 1993). The plant intake rate of the deer mouse is estimated from the allometric equations presented in Nagy (1987) and are the same intake values as used in the non-radiological ecorisk models.

The intake of radionuclides via plant ingestion by the deer mouse is represented by the following:

$$[illegible] = CS \times PS \times Qv \quad (Ci/day)$$

where: CS = concentration of the radionuclide in the soil (Ci/kg)
PS = soil-to-plant transfer factor which is radionuclide specific (unitless) (Baes et al., 1984, USDOE, 1995)
Qv = plant ingestion rate equal to 3.72×10^{-1} (kg/day) (Nagy, 1987)

The concentration of the radionuclide in the soil is assumed to be taken up by the plants as reflected by the soil-to-plant transfer factor, PS, based on plant dry weight. Ingestion of the radionuclides present in the plants is considered by the plant ingestion rate term, Qv. The combined product of these terms represents the total radioactivity per day ingested by the deer mouse via ingestion of plants only.

The intake of radionuclides via soil ingestion by the deer mouse is represented by the following expression:

$$[illegible] = CS \times Qs \quad (Ci/day)$$

where: CS = concentration of the radionuclide in the soil (Ci/kg)
Qs = soil ingestion rate equal to $7.44 \times 10^{-[illegible]}$ (kg/day) (2% of the deer mouse plant intake) (EPA, 1993)

This term reflects the uptake of radionuclides through soil ingestion as it lives in the contaminated location. The combined product of these two terms represents the total radioactivity per day ingested by the deer mouse via soil ingestion.

The sum of the plant and soil ingestion provides the total intake of radioactivity into the body of the deer mouse per day assuming only a diet of plants and ingestion of soil. The total intake of the radioactivity by the deer mouse is provided by the following:

$$(CS \cdot PS \cdot Qv + CS \cdot Qs) \text{ (Ci/day)}$$

where: All terms previously defined.

The deer mouse is assumed to ingest plants and soil from a variety of locations in the environment in which it resides. Obviously, the distribution of radionuclides throughout this environment is not homogeneous and this must be reflected by the dose rate model. The deer mouse may ingest plants and soils from the contaminated locations part of the time and from uncontaminated locations other times. The previous equation can be modified to the following:

$$(CS \cdot PS \cdot Qv + CS \cdot Qs) \cdot FI \text{ (Ci/day)}$$

where: CS, PS, Qv, and Qs are previously defined,
FI = Fraction ingested from contaminated source which is assumed to be the 100% (unitless).

The dose rate model presented here assumes that the deer mouse resides and ingests plants and soils from only the contaminated source. This is a worst-case, conservative assumption that considers maximum intake of radionuclides.

The next term to introduce considers what fraction of the total radionuclides taken into the body via ingestion of plants and soils is absorbed by the internal tissues of the deer mouse. This fraction is a function of the absorption characteristics of the chemical element. Introducing this term into the previous equation results in the following:

$$(CS \cdot PS \cdot Qv + CS \cdot Qs) \cdot FI \cdot FR \text{ (Ci/day)}$$

where: CS, PS, Qv, and Qs are previously defined,
FR = fraction of the radionuclide retained by the body of the deer mouse which is specific to the chemical element (unitless) (Baker & Soldat, 1992).

This equation represents the fraction of the radionuclide concentration in the soil that actually concentrates in the internal body tissues of the deer mouse.

The next step in deriving the [illegible] equation [illegible] radioactivity intake rate [illegible] condition can be reached for the [illegible] the radi[illegible] environment in which it resides [illegible] amount of radioactivity ingested [illegible] over a 1 year period.

[illegible]

where: [illegible]

	fraction of the radionuclide concentrated in the [illegible] concentrates in the body tissues of the deer mouse
EF	Exposure frequency equal to 365 days/yr
ED	Exposure duration equal to 1 yr

This equation represents the total amount of radioactivity that is actually present in the body tissues of the deer mouse over a one year exposure duration, assuming that removal mechanisms have not yet taken place.

The next step in the derivation is to introduce a term called the "burden duration factor" for the radionuclide present in the body of the deer mouse. The burden duration factor, B, describes how long a radionuclide deposited inside the body of the deer mouse can contribute to a dose rate considering the effects of biological and radiological removal. The longer it takes to remove the radionuclide from the body via radiological and biological means, the larger the total body dose. Typically, radionuclides are removed from the body much faster by biological means than by radiological means. Therefore, B is driven by the biological removal term more than the radiological removal term in most cases. The burden duration factor is provided by the HSRAM (DOE, 1995) as

$$B = \frac{1 - e^{-\lambda t}}{\lambda}$$

where

B	=	burden duration factor (days)
t	=	duration of exposure equal to 365 days
λ	=	effective removal constant equal to the sum of the biological and radiological removal constants given as $\lambda = \lambda_b + \lambda_r$ where
		λ_r = $\ln(2)/T_r$ where T_r is the radiological half-life for the radionuclide (days)
		λ_b = $\ln(2)/T_b$ where T_b is the biological half-life for the radionuclide in the body of the deer mouse (days)

The radiological and biological half lives are defined as the time required for a given amount of radioactive material to be reduced by half either by radioactive decay or biological elimination processes, respectively.

Introducing the burden duration factor into the dose equation provides the following:

$$(CS \cdot PS \cdot Qv + CS \cdot Qs) \cdot FI \cdot FR \cdot EF \cdot ED \cdot B \text{ (Ci-day)}$$

where: $(CS \cdot PS \cdot Qv + CS \cdot Qs)FI \cdot FR \cdot EF \cdot ED$ = the total radioactivity in Curies that has been absorbed by the deer mouse (All terms defined previously),

B = the burden duration term which is a function of the radionuclide (day).

The dose rate equation in this form describes the total radioactivity present in the deer mouse and the time that the radionuclide resides in the body to contribute to the dose rate.

The next term to introduce deals with the amount of energy imparted to the deer mouse tissues, internally, due to radioactive decay. The energy imparted to body tissues is a function to the size of the receptor. This model assumes that a deer mouse has a body radius of approximately 2 cm. Absorbed energy data in Baker & Soldat (1992) is provided as a function of radionuclide and body radius. When applicable, the data provided by Baker & Soldat (1992) include the contributions to absorbed energy from radioactive daughters. The following term is defined by the HSRAM (DOE, 1995) as the effective absorbed energy by the body tissues:

$$E = 5.12x10^4 \cdot \varepsilon \text{ (kg-rad/Ci-day)}$$

where:

E = effective absorbed energy for a particular radionuclide and an assumed radius for the body size of the mouse (kg-rad/Ci-day),

ε = absorbed energy of the radionuclide for a deer mouse with a radius assumed to be 2 cm (MeV/decay),

$5.12x10^4$ = conversion factor from MeV/decay to kg-rad/Ci-day.

This equation was determined using the following conversion from MeV per decay to kg-rad/Ci-day (all values referenced from USDOE (1995):

$$E = \varepsilon\left(\frac{MeV}{decay}\right) \times 3.70x10^{10}\left(\frac{decay/\sec}{Ci}\right) \times 8.64x10^4\left(\frac{\sec}{day}\right) \times 1.60x10^{-11}\left(\frac{kg-rad}{MeV}\right) = 5.12x10^4 \cdot \varepsilon\left(\frac{kg-rad}{Ci-day}\right).$$

The effective absorbed energy is based upon the size of the deer mouse. Assuming that a gamma-emitting nuclide is present, the size or radius of the deer mouse is small enough that only

a fraction of the gamma rays will [illegible] remainder of the gamma rays will [illegible] tissues. Alpha and beta-emitter [illegible] tissues. Data for the absorbed energy [illegible] in Baker & Soldat [illegible] radionuclides as a function of body radius. The methodology used to [illegible] the absorbed energy values as a function of [illegible] assumes a spherical body [illegible] It is also assumed that all of the radionuclide activity is present at the center of the [illegible] uniformly irradiating all locations within the spherical body. These assumptions are made so that the maximum amount of radionuclide energy can be absorbed by the body tissues of the organism.

Introducing the deer mouse body weight and the effective absorbed energy into the dose rate equation results in the following

$$[illegible] \quad (1)$$

where [illegible]

the product of the total radioactivity present in the deer mouse and the time that the radionuclide resides in the body [illegible] contribute to the dose rate (Ci-day)

F effective absorbed energy due to decay of the radionuclide in the deer mouse body (kg-rad/Ci-day)

BW body weight of the deer mouse assumed to be [illegible] (Silva & Downing, 1995)

This equation provides the total radiological absorbed dose over a one year exposure duration due to the presence of radionuclides internally in the deer mouse.

The final step in the derivation is to average the radiological absorbed dose to provide a daily dose rate estimate. So, introducing the averaging time, AT, into the previous equation provides the following

$$[illegible] \quad \text{rad/day} \quad (2)$$

where [illegible]

total radiological absorbed dose over one year (terms previously defined)

AT averaging time for the calculation, equal to [illegible]

This equation provides a dose rate due to a deer mouse ingesting plants and soils on an average daily basis for one radionuclide only. If there are multiple radionuclides present, the following equation can be used to examine the combined dose rate due to all of the radionuclides present in the body of the deer mouse.

$$R_{mouse} = \sum_{i}^{N} \frac{(CS_i \cdot PS_i \cdot Qv + CS_i \cdot Qs) \cdot FI \cdot FR_i \cdot EF \cdot ED \cdot B_i \cdot E_i}{BW \cdot AT} \text{ rad/day.}$$

This equation defines the total dose rate to the deer mouse exposed to N radionuclides in rad per day. The result can then be compared to the dose rate benchmark of 0.1 rad/day.

3. Derivation of the Internal Total-body Dose Rate for the Burrowing Owl

This section will show a step-by-step derivation of the internal total-body dose rate equation for the burrowing owl. The dose rate equations for internal radiation dose appear to be complex due to the large number of terms it contains. The following equation defines the total-body dose rate for the burrowing owl in rad per day:

$$R_{owl} = \sum_{i=1}^{N} \frac{FR_i \cdot FI \cdot EF \cdot ED \cdot B_i \cdot E_i \cdot \left(Cs_i \cdot Qs_{owl} + \left[\frac{Qm \cdot TN}{BW_{mouse} \cdot DW}\right]\left\{FR_i \cdot Cs_i \cdot Ps_i \cdot Qv_{mouse} + FR_i \cdot Cs_i \cdot Qs_{mouse}\right\}\right)}{BW_{owl} \cdot AT}$$

This equation assumes that the burrowing owl ingests contaminated soil and deer mice that contain radionuclides through its ingestion of deer mice and soil. This equation is similar to that of the deer mouse; however, the intake portion of the equation requires modification to consider the diet of the burrowing owl. This equation will be assembled piece-by-piece so that the purpose of the terms in the equation can be explained more clearly. A dose rate model will be derived for an exposure to only one radionuclide initially and will evolve to the general relationship shown above.

The first step in the derivation of the internal burrowing owl dose rate equation is to define how the receptor receives radionuclides from the environment into its body to contribute to a dose rate. The burrowing owl is assumed to intake radionuclides into its body via ingestion of soil and deer mice on a daily basis.

The first term reflects the ingestion of radionuclides through soil ingestion as it lives in the contaminated location. The burrowing owl diet consists of 100% deer mice . Insect intake is not considered in the radiological dose rate model since soil-to-insect transfer data for radionuclides are not available. Soil ingestion by the burrowing owl is assumed to be 2% of its food intake rate (EPA, 1993). The food intake rate of the burrowing owl is estimated from the allometric equations presented in Nagy (1987) and are the same intake values as used in the non-radiological eco-risk models. The combined product of these two terms represents the total radioactivity per day ingested by the burrowing owl via ingestion of soil only. The intake of radionuclides via soil ingestion by the burrowing owl is represented by the following:

where CS [illegible] radionuclide [illegible]

Qs [illegible] the owl assumed [illegible] day or 2[illegible] the [illegible] intake rate [illegible]

The next term in the intake portion of the internal dose rate equation is [illegible] the burrowing owl's diet of deer mice. This model assumes that the deer mouse is [illegible] environment and has been exposed to a radionuclide for a one year period when it [illegible] by the burrowing owl. At that time, the deer mouse has a certain amount of absorbed radioactivity deposited internally due to the ingestion of soil and its diet of plants. [illegible] consumption of the deer mouse, the burrowing owl will have ingested the radioactivity absorbed by the deer mouse. To account for this amount of radioactivity, it is necessary to derive the plant and soil ingestion rates for the deer mouse and apply it to the burrowing owl to [illegible] intake. The following expression defines the intake rate [illegible] by the deer mouse:

[illegible] (Ci/day)

where CS = concentration of the radionuclide in the soil (Ci/kg)

PS = soil-to-plant transfer factor which is radionuclide specific (unitless)

Qv [illegible] = plant ingestion rate by the mouse equal to [illegible] kg/day

FR = fraction of the radionuclide retained by the body tissues of the deer mouse which is radionuclide specific (unitless)

The deer mouse ingests radionuclides via soil ingestion as it lives in the contaminated location. There is no transfer factor necessary for this term since the radionuclides present in the soil are not diluted before ingestion. The intake of radionuclides via soil ingestion by the deer mouse is represented by the following expression:

[illegible] (Ci/day)

where CS = concentration of the radionuclide in the soil (Ci/kg)

Qs [illegible] = soil ingestion rate by the mouse equal to [illegible] kg/day

FR = fraction of the radionuclide retained by the body tissues of the deer mouse which is radionuclide specific (unitless)

The sum of the plant and soil ingestion terms provides the total intake of radioactivity into the body of the deer mouse per day. This equation does not yet consider internal absorption into body tissues of the burrowing owl. The total intake of the radioactivity by the deer mouse is provided by the following:

$$(CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR) \text{ (Ci/day)}$$

where: All terms previously defined.

This is the amount of radioactivity ingested for each deer mouse consumed by the burrowing owl. The number of deer mice consumed per day needs to be considered to quantify the total radionuclide intake for the burrowing owl. The number of deer mice consumed per day can be determined by the following expression.

$$\frac{Qm \cdot TN}{BW_{mouse} \cdot DW} \text{ (unitless)}$$

where:

Qm	=	food (deer mouse) ingestion rate by the burrowing owl equal to 0.0173 kg dry weight per day (kg_{dw}/day) (Nagy, 1987),
TN	=	proportionality factor equal to 1 day that looks at the mouse consumption per day,
BW_{mouse}	=	the body weight of the deer mouse equal to 0.0239 (kg) (Silva & Downing, 1995),
DW	=	conversion from mouse wet weight to dry weight equal to 0.32 (unitless) (EPA, 1993).

The expression for the number of deer mice consumed per day can be combined to the total radioactivity absorbed by the deer mouse to provide an expression that considers the total radioactivity ingested through the burrowing owl's diet of deer mice as shown below:

$$\frac{Qm \cdot TN}{BW_{mouse} \cdot DW}\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR\} \text{ (Ci/day)}$$

where: All terms previously defined.

The previous equation can now be combined with the burrowing owl's ingestion of soil to arrive at an expression that defines the total intake of radionuclides into the body of the burrowing owl.

$$(CS \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR\}) \text{ (Ci/day)}$$

The burrowing owl is assumed to ingest deer mice and soil from a variety of locations in the environment in which it resides. Obviously, the distribution of radionuclides throughout this environment is not homogeneous and this must be reflected by the dose rate model. The burrowing owl may ingest deer mice and soils from the contaminated locations part of the time and from uncontaminated locations other times. The dose rate model presented here assumes that the burrowing owl resides and ingests food and soils from only the contaminated source. This is a worst-case, conservative assumption that considers maximum intake of radionuclides. The previous equation can be modified to the following:

The next step in deriving the internal burrowing owl dose rate equation is converting the daily radioactivity intake rate to a yearly intake rate. This step is performed so that an equilibrium condition can be reached for the burrowing owl exposure to the radionuclides in the contaminated environment in which it resides. The previous equation can be modified to consider the total amount of radioactivity ingested via deer mice and soil over a 1-year period

$$[illegible]$$

where $[illegible]$

[illegible] = fraction of the radionuclide concentration in the soil that concentrates in the body tissues of the burrowing owl [illegible] day⁻¹

EF = Exposure frequency equal to 365 day/yr.

ED = Exposure duration equal to 1 yr

This equation provides the dose rate model with the total amount of radioactivity that is actually present in the body tissues of the burrowing owl assuming that removal mechanisms have not yet taken place.

The next term to introduce [illegible] energy imparted [illegible] internally due to radioactive [illegible] of the receptor. The model [illegible] cm. Absorbed energy data in Baker & Soldat [illegible] is provided [illegible] and body radius. When applicable the data [illegible] by Baker & Soldat [illegible] the contributions to absorbed energy [illegible] daughters. [illegible] the HSRAM/DOE [illegible] as the effective absorbed energy by the body [illegible]

[illegible]

where [illegible] effective absorbed energy [illegible] and assumed radius for the body [illegible] kg rad/day

[illegible] absorbed energy of the for a 5 cm radius burrowing owl for the radionuclide MeV decay [illegible] Baker & Soldat 1992

5.12x10[illegible] conversion factor from MeV decay [illegible] rad/day

This equation was determined using the following conversion from MeV per decay [illegible] rad/day (all values referenced from HSDOE (1995))

[illegible]

The effective absorbed energy is based upon the size of the burrowing owl. Assuming that a gamma-emitting nuclide is present, the size or radius of the burrowing owl is small enough that only a fraction of the gamma rays will be absorbed by the body as it passes through tissues. The remainder of the gamma rays will pass through the mouse without interacting at all in the body tissues. Alpha and beta-emitters impart 100% of their energy into the mouse tissues. Data for the absorbed energies are available in Baker & Soldat (1992) for a variety of radionuclides as a function of body radius. The methodology used for compute the absorbed energy values as a function of radionuclide and radius assumes a spherical body shape. It is also assumed that all of the radionuclide activity is present at the center of the organism and is uniformly distributed throughout all locations within the spherical body. These assumptions are made so that the maximum amount of radionuclide energy can be absorbed by the body tissues of the organism.

The next expression provides the total radiological absorbed dose over a [illegible] exposure duration due to the presence of radionuclides internally in the burrowing owl. Incorporating the burrowing owl body weight and the effective absorbed energy into the dose rate equation results in the following

$$\frac{(CS \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR\}) \cdot FI \cdot FR \cdot EF \cdot ED \cdot B \cdot E}{BW_{owl}} \quad \text{(rad)}$$

where:

$$(CS \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR\}) \cdot FI \cdot FR \cdot EF \cdot ED \cdot B$$

= the product of the total radioactivity present in the burrowing owl and the time that the radionuclide resides in the body to contribute to the dose rate (Ci-day),

E = effective absorbed energy due to decay of the radionuclide in the burrowing owl body (kg-rad/Ci-day),

BW_{owl} = body weight of the burrowing owl equal to 0.155 (kg) (Dunning, 1993).

The final step in the derivation is to average the radiological absorbed dose to provide a daily dose rate estimate. So, introducing the averaging time, AT, into the previous equation provides the following:

$$\frac{(CS \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + CS \cdot Qs_{mouse} \cdot FR\}) \cdot FI \cdot FR \cdot EF \cdot ED \cdot B \cdot E}{BW_{owl} \cdot AT} \quad \text{(rad/day)}$$

where: $\frac{(CS \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{CS \cdot PS \cdot Qv_{mouse} \cdot FR + FR \cdot CS \cdot Qs_{mouse} \cdot FR\}) \cdot FI \cdot FR \cdot EF \cdot ED \cdot B \cdot E}{BW_{owl}}$

= total radiological absorbed dose over one year (rad) (terms previously defined),

AT = averaging time for the calculation, equal to 365 days.

This equation provides a dose rate due to a burrowing owl ingesting plants and soils on an average daily basis for one radionuclide only. If there are multiple radionuclides present, the following equation can be used to examine the combined dose rate due to all of the radionuclides present in the body of the burrowing owl with units of rad per day.

$$R_{owl} = \sum_{i=1}^{N} \frac{FR_i \cdot FI \cdot EF \cdot ED \cdot B_i \cdot E_i \cdot (Cs_i \cdot Qs_{owl} + (\frac{Qm \cdot TN}{BW_{mouse} \cdot DW})\{Cs_i \cdot Ps_i \cdot Qv_{mouse} \cdot FR_i + Cs_i \cdot Qs_{mouse} \cdot FR_i\})}{BW_{owl} \cdot AT} \quad \text{(rad/day)}$$

This equation defines the total dose rate to the burrowing owl exposed to N radionuclides in rad per day. The result can then be compared to the dose rate benchmark of 0.1 rad/day.

4. External Total-body Dose Rate Model for the Burrowing Owl and Deer Mouse

Both the deer mouse and the burrowing owl [illegible] the same total-body [illegible] for external exposure to radionuclides since they are similar in size and [illegible] The model considers a total-body dose rate to [illegible] from gamma-emitting radionuclides only. This model assumes that there is no external dose rate contribution [illegible] alpha and beta emitters present in the soil. The relationship presented below is valid for the [illegible] internal body tissues due to gamma-emitting radionuclides that are uniformly distributed throughout an infinite medium. Those radionuclides that have significant daughter [illegible] are considered as well. This equation is particularly specific to ecological receptors that reside in the soil for significant periods of time and are exposed to a uniform gamma radiation field.

The external dose rate equation for the deer mouse and the burrowing owl is provided by the following:

$$R = \sum_i 2.12 \, E_i \, C_{S,i} \, \rho_s \quad \text{(rad/hr)}$$

where:

R	=	external dose rate (rad/hr)
2.12	=	proportionality factor (g-rad/MeV-µCi-hr)
E_i	=	average gamma energy per disintegration for radionuclide i (MeV)
$C_{S,i}$	=	concentration of radionuclide, i, in the soil (µCi/cm³)
ρ_s	=	density of the soil assumed to be 1.5 g/cm³

The proportionality factor, 2.12 g-rad/MeV-µCi-hr, is determined using the following conversion:

$$1 \frac{MeV}{disin} \times 1.70 \times 10^{-13} \frac{disin}{\mu Ci} \times 3600 \frac{sec}{hr} \times 1.60 \times 10^{-6} \frac{g-rad}{MeV} = 2.12 \frac{g-rad}{\mu Ci-hr}$$

This equation can be multiplied by 24 hours/day to provide an average daily dose rate in rad/day.

The external dose rate equation presented above is valid for only one gamma emitter only. The equation can be modified slightly to consider the external dose rate due to [illegible] radionuclides as follows (shown with the conversion from rad per hour to rad per day):

$$R = \sum_i 2.12 \, E_i \, C_{S,i} \, \rho_s \times 24 \quad \text{(rad/day)}$$

5. Total Dose Rate for the Burrowing Owl and Deer Mouse

The internal and external dose rates are summed for each radionuclide and then summed again to derive the total dose, in rad/day, to compare to the International Atomic Energy Agency (IAEA) standard of 0.1 rad/day for terrestrial receptors.

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USDOE, see United States Department of Energy.

USEPA, see United States Environmental Protection Agency.

Appendix E

Preliminary Remediation Goals

Table E.1
Preliminary Remediation Goals (PRGs) for
Inorganic Constituents of Potential Ecological Concern in Soil
Environmental Restoration Program
Sandia National Laboratories, New Mexico

Constituent of Potential Ecological Concern	Deer Mouse PRG[a]	Burrowing Owl PRG[a]	Final PRG[a]
Aluminum	3.28 x 10[illegible]	4.50 x 10[illegible]	[illegible]
Antimony	1.63 x 10[illegible]	---[b]	[illegible]
Arsenic	2.23 x 10[illegible]	5.35 x 10[illegible]	[illegible]
Barium	5.39 x 10[illegible]	1.34 x 10[illegible]	[illegible]
Beryllium	2.38 x 10[illegible]	---	[illegible]
Cadmium	2.39 x 10[illegible]	9.54 x 10[illegible]	[illegible]
Chromium total	3.97 x 10[illegible]	1.59 x 10[illegible]	[illegible]
Chromium VI	1.91 x 10[illegible]	---	[illegible]
Cobalt	---	---	[illegible]
Copper	4.12 x 10[illegible]	1.43 x 10[illegible]	[illegible]
Cyanide	---	---	[illegible]
Lead	[illegible]	[illegible]	[illegible]
Manganese	[illegible]	3.35 x 10[illegible]	[illegible]
Mercury	8.87 x 10[illegible]	9.98 x 10[illegible]	[illegible]
Nickel	3.57 x 10[illegible]	3.80 x 10[illegible]	[illegible]
Selenium	5.89 x 10[illegible]	5.80 x 10[illegible]	[illegible]
Silver	1.55 x 10[illegible]	---	[illegible]
Thallium	2.35 x 10[illegible]	---	[illegible]
Titanium	4.95 x 10[illegible]	---	[illegible]
Uranium	1.32 x 10[illegible]	4.40 x 10[illegible]	[illegible]
Vanadium	6.12 x 10[illegible]	4.42 x 10[illegible]	[illegible]
Zinc	3.63 x 10[illegible]	3.38 x 10[illegible]	[illegible]

[a]Preliminary Remediation Goals in mg/kg soil
[b]"---" indicates insufficient toxicity data was found to determine a PRG based on LOAELs for inorganic mercury.

Table E.2
Preliminary Remediation Goals (PRGs) for Organic Constituents of Potential Ecological Concern in Soil
Environmental Restoration Program
Sandia National Laboratories, New Mexico

Constituent of Potential Ecological Concern	Deer Mouse PRG[a]	Burrowing Owl PRG[a]	Final PRG[a]
Acetone	1.67×10^{1}	—[b]	1.67×10^{1}
Benzene	2.27×10^{2}	—	2.27×10^{2}
Benzoic acid	3.29×10^{1}	—	3.29×10^{1}
Bis(2-ethylhexyl)phthalate	1.06×10^{2}	4.20×10^{0}	4.20×10^{0}
2-Butanone	2.68×10^{3}	—	2.68×10^{3}
Butyl benzyl phthalate	6.70×10^{1}	—	6.70×10^{1}
Carbazole	—	—	—
Chlorobenzene	1.07×10^{2}	—	1.07×10^{2}
Chloroform	6.30×10^{1}	—	6.30×10^{1}
2-Chlorophenol	8.00×10^{0}	—	8.00×10^{0}
4-Chloro-3-methyl phenol	2.24×10^{1}	—	2.24×10^{1}
Debenzofuran	—	—	—
1,1-Dichloroethene (1,1-DCE)	4.78×10^{2}	—	4.78×10^{2}
1,2-Dichloroethene (1,2-DCE)	3.71×10^{2}	—	3.71×10^{2}
Dimethyl phthalate	7.15×10^{2}	—	7.15×10^{2}
Di-n-butyl phthalate	1.44×10^{3}	2.02×10^{2}	2.02×10^{2}
Di-n-octyl phthalate	5.82×10^{2}	—	5.82×10^{2}
Methylene chloride	6.06×10^{1}	—	6.06×10^{1}
Phenol	1.60×10^{2}	—	1.60×10^{2}
1,1,2,2-Tetrachloroethane	2.31×10^{2}	—	2.31×10^{2}
1,1,2,2-Tetrachloroethene (PCE)	6.28×10^{0}	—	6.28×10^{0}
Toluene	2.33×10^{2}	—	2.33×10^{2}
1,1,1-Trichloroethane (1,1,1-TCA)	9.27×10^{3}	—	9.27×10^{3}
1,2,4-Trichlorobenzene	8.25×10^{0}	—	8.25×10^{0}
Trichloroethylene (TCE)	6.28×10^{0}	—	6.28×10^{0}
Xylenes	2.31×10^{0}	—	2.31×10^{0}
Explosives			
2-amino-4,6-Dinitrotoluene	4.34×10^{1}	—	4.34×10^{1}
4-amino-2,6-Dinitrotoluene	2.98×10^{1}	—	2.98×10^{1}
m-Dinitrobenzene	2.22×10^{-1}	—	2.22×10^{-1}
2,4-Dinitrotoluene	8.38×10^{0}	—	8.38×10^{0}
2,6-Dinitrotoluene	5.20×10^{0}	—	5.20×10^{0}
HMX	2.16×10^{0}	—	2.16×10^{0}
Nitrobenzene	8.49×10^{0}	—	8.49×10^{0}
Nitroglycerin	7.83×10^{2}	—	7.83×10^{2}
m-Nitrotoluene	3.55×10^{1}	—	3.55×10^{1}
o-Nitrotoluene	2.91×10^{1}	—	2.91×10^{1}
p-Nitrotoluene	6.45×10^{1}	—	6.45×10^{1}
PETN	5.32×10^{4}	—	5.32×10^{4}
RDX	1.90×10^{1}	—	1.90×10^{1}
Tetryl	8.22×10^{0}	—	8.22×10^{0}
sym-Trinitrobenzene	6.07×10^{0}	—	6.07×10^{0}

Constituent of Potential Ecological Concern	Deer Mouse PRG[a]	Burrowing Owl PRG[a]	Final PRG[a]
2,4,6-Trinitrotoluene	2.20 x 10[illegible]	---	[illegible]
Polycyclic Aromatic Hydrocarbons (PAHs)			
Acenaphthylene	8.28 x 10[illegible]	---	8.28 x 10[illegible]
Anthracene	7.97 x 10[illegible]	---	7.97 x 10[illegible]
Benzo(a)anthracene	7.02 x 10[illegible]	---	7.02 x 10[illegible]
Benzo(a)pyrene	6.63 x 10[illegible]	---	6.63 x 10[illegible]
Benzo(b)fluoranthene	6.29 x 10[illegible]	---	6.29 x 10[illegible]
Benzo(g,h,i)perylene	5.84 x 10[illegible]	---	5.84 x 10[illegible]
Benzo(k)fluoranthene	6.10 x 10[illegible]	---	6.10 x 10[illegible]
Chrysene	6.79 x 10[illegible]	---	6.79 x 10[illegible]
Dibenzo(a,h)anthracene	6.34 x 10[illegible]	---	6.34 x 10[illegible]
Fluoranthene	1.81 x 10[illegible]	---	1.81 x 10[illegible]
Fluorene	2.05 x 10[illegible]	---	2.05 x 10[illegible]
Indeno(1,2,3-cd)pyrene	5.55 x 10[illegible]	---	5.55 x 10[illegible]
2-Methylnaphthalene	3.45 x 10[illegible]	---	3.45 x 10[illegible]
Naphthalene	7.35 x 10[illegible]	---	7.35 x 10[illegible]
Phenanthrene	7.87 x 10[illegible]	---	7.87 x 10[illegible]
Pyrene	9.07 x 10[illegible]	---	9.07 x 10[illegible]
Polychlorinated Biphenyls (PCBs)			
PCBs (aroclor-1242)	1.37 x 10[illegible]	1.30 x 10[illegible]	1.37 x 10[illegible]
PCBs (aroclor-1248)	2.53 x 10[illegible]	---	2.53 x 10[illegible]
PCBs (aroclor-1254)	3.76 x 10[illegible]	1.56 x 10[illegible]	3.76 x 10[illegible]
PCBs (aroclor-1260)	4.90 x 10[illegible]	---	4.90 x 10[illegible]

[a]Preliminary Remediation Goals in mg/kg soil

[b]"---" indicates insufficient toxicity data was found to determine a PRG

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