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K. A. Gano
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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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SUMMARY

The purpose of this paper is to provide a review of the literature and summarize information on factors affecting habitat selection and maximum recorded burrowing depths for representative small mammals that we consider most likely to inhabit waste burial sites in arid and semi-arid regions of the West. The information is intended for waste management designers who need to know what to expect from small mammals that may be present at a particular site. Waste repositories could be designed to exclude the deep burrowing rodents of a region by creating an unattractive habitat over the waste. Summaries are given for habitat requirements of each group along with generalized modifications that could be employed to deter habitation. Representatives from the major groups considered to be deep burrowers are discussed. Further, detailed information about a particular species can be obtained from the references cited.

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INTRODUCTION

The increased concern over radioactive materials in the environment over the past several years has brought about a need to evaluate the methods by which wastes are disposed. Until recently, common practice for disposing of low-level radioactive wastes consisted of digging a hole, depositing the waste material, and backfilling the area with the excavated soil. In some cases, such as uranium mill-tailings, the material was not considered hazardous and was not buried at all. In the case of many buried wastes, it was assumed that once buried, the material would remain in place. The possibilities of biological transport, or transport through soil water or erosion were discounted. Consequently, the importance of these mechanisms became known only after several incidences of waste transport had been reported. In one such incident (O'Farrell and Gilbert 1975), an unknown animal, perhaps a badger, burrowed into a radioactive waste burial site and exposed ^{90}Sr and ^{137}Cs salts. Rickard and Klepper (1976) further outlined the potential for radionuclide transport by animals. Plant roots are well known for transporting radionuclides to the ground surface (Selders 1950, Klepper et al. 1978). In areas of high precipitation, water run-off and erosion play an important role in waste transport (Meyer 1976, Schliager and Apt 1974). This paper will address the potential hazard that burrowing small mammals present at waste burial sites and possible mitigative actions that can be taken to eliminate the threat in arid and semi-arid regions of the West.

Use of shallow waste repositories will continue and no doubt become more widespread, especially in arid regions of the West where water transport is at a minimum. Recent regulations governing the construction of new sites and the remedial action needed for old sites will require new designs to maintain site integrity and safety to the environment. The 95th U.S. Congress enacted Public Law 95-604 in November 1978 to regulate the operation and maintenance of uranium mill tailings sites. Under this law, the Nuclear Regulatory Commission (NRC) set limits of ^{222}Rn emission from U-tailings piles to equal the surrounding native soils. In order to accomplish these standards, U-tailings piles will be covered with a material sufficient to prevent radon diffusion and ultimately restored to resemble the surroundings environs (Federal Register 1980). Such standards will require specific designs for isolating the waste from biological transport mechanisms, i.e. plants and animals. To design economical and effective barriers, it is necessary to know the capabilities and requirements of the potential transport mechanisms. This report demonstrates the capabilities of deep burrowing rodents, a group of animals which constitutes one of the major pathways of biotic intrusion. Badgers are also addressed since they prey almost entirely on burrowing rodents by excavating them from their burrows.

Burrowing rodents can move large amounts of soil to the surface, and initiate other means of waste transport and dispersion in doing so. If unrestructed, these animals pose a serious threat to the integrity of buried waste sites. With a better knowledge of habitat requirements and burrowing potentials, it is possible to design an area that has an unattractive habitat for the endemic rodent species. The following review presents pertinent information on representative species from major groups of deep burrowing mammals.

The groups considered in this work include the following families: Sciuridae, represented by marmots, prairie dogs, ground squirrels, and chipmunks; Geomyidae, pocket gophers; Heteromyidae, pocket mice and kangaroo rats; and Mustelidae, the badger. Other rodent families were not considered here because they are generally not deep burrowers and/or they do not occur in areas typical of shallow waste burial sites.

BADGERS

Badgers are the largest and most powerful animals posing a potential threat to hazardous waste disposal sites, chiefly through their feeding habits. These animals capture ground squirrels and other burrowing rodents by lying in wait in burrows dug adjacent to prey burrows or by digging out prey burrows. Their excavations, recorded to depths of 1.5 m (Anderson and Johns 1977) are largely directed at prey burrows containing litters of young (Knopf and Balph 1969). Though more friable soil is preferred, badgers will also excavate hard-baked earth in the middle of unpaved roads (Ingels 1974).

Badger activity over secured waste burial sites could be severely detrimental by causing a widening of prey burrows to a diameter of 8 inches (20 cm) or more (Ingles, 1974 p. 377). Thus the depth of prey burrowing is potentially the depth of badger burrowing. Fortunately, protective measures taken to exclude prey would also effectively deter badgers by removal of their burrowing incentive.

MARMOTS

The yellow-bellied marmot (Marmota flaviventris) is the largest, of the burrowing rodents likely to be encountered at a waste disposal site. The species tendency to form social groups (Merriam 1971) with burrow clusters indicates that marmot colonization of disposal sites could result in extensive damage. As many as 78 burrows in a 0.85 ha area (Svendsen 1976) have been observed, although about 6 per ha is a more average figure for large areas containing several clusters (Henderson and Gilbert 1978). Henderson and Gilbert (1978) showed that burrow density ranged from 1.8/ha in newly seeded pastures to 16.8/ha in undisturbed fence rows. Each burrow was 1 m or more deep and 6 to 8 m long with several entrances and lateral passageways.

Available literature suggests, however, that even though marmots may occur in many waste disposal localities, their habitat requirements may mitigate their impacts at most sites. There appears to be a strong preference for well drained slopes (Merriam 1971) that are open grassy or herb-covered and facing in a north-easterly or southwesterly direction at a 15^{o} to 40^{o} angle of incline (Svendsen 1976). Moreover, entrances and even burrow structure may be closely associated with numerous large rocks and boulders. Rocky outcrops and talus slopes are also preferred habitats for yellow-bellied marmot (Burt and Grossenheider 1976; Ingles 1974). However, talus slopes composed of flat sedimentary rocks averaging 50-10 cm thick and 40 cm in diameter are not normally inhabited because the animals cannot burrow through the tightly packed rocks to the underlying soil (Svendsen 1974). Where similar sized rocks are mixed with soil, marmots can burrow and use the rocks for burrow support.

Disposal sites for hazardous wastes could be structured to avoid one or more of these conditions, thereby reducing the likelihood of marmot intrusion. For example, waste sites could be constructed level with the ground surface, avoiding the sloped terrain apparently preferred by this marmot. Existing sites with sloped boundaries, such as uranium mill tailings piles, could be modified using a compacted clayrock mixture or some other impenetrable surface to discourage colonization by marmots. The need for such action should be determined at each site by the presence of these animals. Further research is needed to develop appropriate barriers against these rodents for areas where they may present a problem.

PRAIRIE DOGS

Prairie dogs, genus Cynomys, typically inhabit the short grass plains but will also colonize other areas with low vegetation such as overgrazed pasture land (Bond 1945; Osborn 1942). Osborn and Allan (1949) reported that after cattle grazing was discontinued on a tall grass prairie in Oklahoma, the secondary plant succession of tall species forced blacktailed prairie dogs (C. ludovicianus) to abandoned their town. Blacktailed prairie dogs form tight-knit colonies with continual displays of social interaction. A short grass community is very conducive to this behavior and has been described as the preferred habitat of the blacktailed prairie dog (Tileston and Lechleitner 1966). White-tailed prairie dogs (C. leucurus) and Gunnison's prairie dogs (C. gunnisoni) on the other hand, are less social and inhabit less open habitats in valleys and parks of the more mountainous areas (Kelso 1939; Fitzgerald and Lechleitner 1974).

Soils that prairie dogs occur in are generally fine textured. Sheets et al. (1971) excavated 18 black-tailed prairie dog burrows in well drained stream deposited soil made up of clay, silt loams, and sandy loam. In these soil conditions burrows were very extensive (Table 1). Clark (1971) excavated two white-tailed prairie dog burrows in soil that contained 40% clay. He noted they were able to penetrate a solid clay layer at 46 cm deep and continue on deeper (Table 1).

Whitehead (1927) reported on a prairie dog colony living in a salt-grass pasture near Barstow, Texas. The water table was only 127 cm below the surface, forcing the animals to make very shallow burrow systems. His excavations showed that burrowing depth ranged from 61 to 107 cm. One system was only 37 cm below the surface of adobe soil and was 14.6 meters long. This demonstrates that prairie dogs do not, in all cases, require deep tunneling conditions to inhabit an area. Deep tunnels in this area are probably not necessary to avoid winter frosts as is likely the case in more northern climates.

Prefered habitats of prairie dogs are generally open grasslands which may or may not include shrubs but never include tall dense grasses. The soil must have relatively fine texture and be loose enough to allow the animals to excavate tunnels. It must also be deep enough to construct burrows that afford

TABLE 1. Reported Burrowing Depths of Two Species of Prairie Dogs

Species	Depth (cm)	Length (m)	Reference
Black-tailed prairie dog Cynomys ludovicianus	30-427	4-33	Sheets et al. 1971; Whitehead 1927
White-tailed prairie dog Cynomys leucurus	112-183	3.7- 6.1	Clark 1971

protection from climatic factors and from predators. The depth of the average frost in an area is presumably the minimum depth requirement of soil for prairie dogs to inhabit an area.

Prairie dogs can be excluded from areas such as hazardous waste repositories by designing in features that are unattractive to the animals. For prairie dogs, such factors should include tall grass forming a continuous sword, shallow soil which covers a layer of impenetrable rock, or possibly highly compacted soil and rock which would make burrowing extremely difficult.

GROUND SQUIRRELS

Ground squirrels, like prairie dogs, are vigorous burrowers. Various species of the genus Spermophilus are represented in every western state. In most cases they are found in fairly open habitat (Michener 1979; Rongstad 1965; and Scheffer 1941; Grinnel and Dixon 1918; Shaw 1918; Howell 1938; Bailey 1936). They are often observed sitting in their typical "picket pin" posture surveying their surroundings. Low vegetation and perches such as large rocks and stumps accommodate their need for unobstructed vision. Owings and Borchert (1975) stated that California squirrels (Spermophilus beecheyi) used numerous promontories for visual surveillance in areas of tall grass. Linsdale (1946) suggested that a favorable habitat for this squirrel would contain scattered trees and bushes, sparse low grass and loose soil. He also described an unfavorable habitat as one containing tall dense grass with hard or wet soil. The Columbian ground squirrel (S. columbianus) inhabits the open bunchgrass communities and edges of open forests in northern Idaho and parts of the surrounding states (Howell 1938; Burt and Grossenheider 1976).

In nearly all cases, ground squirrels prefer soils of fine texture for constructing their burrows. Some species, such as the California ground squirrel, occassionally burrow among large rocks and stumps, taking advantage of the protection they offer (Owings and Borchert 1975). Grinnell and Dixon (1918) showed that burrows of the golden-mantled ground squirrel (Spermophilus lateralis) were nearly always located among big roots, logs, and rocks. They reasoned that these objects provided safety from enemies and precluded the need for deep, extensive burrow systems. Townsend ground squirrels (S. townsendi) occur in dry light soils of the arid west. Davis (1939) described the soils in which this species occurred in southern Idaho as "volcanic ash of flour-like consistency."

Most ground squirrels are somewhat colonial, though some species are more solitary and occupy a burrow as a single individual. These efficient burrowers are capable of excavating relatively deep tunnels. Burrows of the thirteen-lined ground squirrel (S.tridecemlineatus) have been recorded in Manitoba, Canada as deep as 183 cm (Table 2). The California ground squirrel is one of the largest of this genus and is capable of burrowing very deep (Table 2). It is probably better known for having very extensive tunnel systems with as many as 10-50 entrances and occupying areas as large as 15.3 meters square (Fitch 1948).

Other ground squirrels such as the Mohave ground squirrel (S. mohavensis) and the whitetail antelope squirrel, Ammospermophilus leucurus are found in the arid climate and sandy soils of the southwest deserts. The Mohave ground squirrel is restricted to the Mohave desert, while the antelope squirrel is more widely distributed.

The depths of ground squirrel burrows may be influenced by the depth of the average frost line in an area (Wade 1930; Criddle 1939). This is almost certainly a factor influencing all species in areas of deep frost. Under such

TABLE 2. Reported Burrowing Depths of Some Representative Ground Squirrels

Species	Recorded Burrowing depths (cm)	Reference
Ammospermophilus leucurus Whitetail antelope squirrel	∿30	Bartholomew and Hudson 1961;
Spermophilus townsendi Townsend ground squirrel	31-147	Alcorn 1940
Spermophilus tridecemlineatus Thirteen-lined ground squirrel	10-183	Criddle 1939; Desha 1966; Johnson 1917; Rongstad 1965; Wade 1930
Spermophilus columbianus Columbian ground squirrel	46-152	Shaw 1918; Shaw 1926; Bailey 1936; Howell 1938
Spermophilus beecheyi California ground squirrel	46-168	Fitch 1948; Grinnel and and Dixon 1918
Spermophilus mohavensis Mohave ground squirrel	∿91	Bartholomew and Hudson 1961

circumstances, areas with shallow soil (above frost line) laid over an impenetrable subsoil of rock or hard clay would be unsuitable habitat for burrowing rodents that hibernate. Colonization of waste burial sites could be prevented by applying a layer of impenetrable material (e.g. coarse rock) and then covering it with a layer of topsoil shallower than the frost line. This technique could be especially useful in reclamation of burial sites containing hazardous materials, such as uranium mill-tailings, low level radioactive waste, and chemical wastes.

POCKET GOPHERS

Of all the burrowing mammals investigated, pocket gophers are one of the most thoroughly studied. These animals spend a high percentage of time below ground. As common inhabitants of grasslands and meadows, they are vigorous burrowers, constantly remodeling their burrow systems, opening new tunnels and filling old ones. Their burrows serve primarily as a means of protection from predators and from extremes of temperature. Representative of the group, the northern pocket gopher (*Thomomys talpoides*) is not very heat tolerant, becoming hyperthermic at ambient temperatures above 32°C (Gettinger 1975). The daily range of burrow temperature may vary only 5°C, while above-ground temperatures range 23°C. Gettinger (1975) suggests that thermal stress to pocket gophers is probably insignificant since the animals can presumably move to deeper burrows if more shallow burrows become too warm or too cold.

A primary factor affecting pocket gopher species distribution appears to be soil type (Best 1973). It has been shown that the cost of burrowing increases with the effort required to shear the soil loose and push it around and with density of soil. Thus the energy cost to construct a given burrow segment may be an order of magnitude greater in clay as compared to sandy soils (Vleck 1979). Other factors limiting pocket gopher activity may be impervious strata limiting gas diffusion, saturated soil, water table, and frozen soils (Davis et al. 1938; Ingles 1949; Kennerly 1964; Miller 1957). Best (1973) compared soils occupied by three species of pocket gophers (*Pappogeomys castonops*, *T. bottae*, and *Geomys bursarius*) from 62 localities. He showed that *T. bottae* and *P. castanops* primarily occurred in loamy-clay-loam surface soils of slow to very slow permeability. *G. bursarius*, on the other hand, occurred in deeper, sandier soils with moderate permeability.

Another important factor in species distribution and abundance appears to be the composition of available vegetation. Although pocket gophers appear generally to select forbs (Ward and Keith 1962), gopher genera display differences in their ability to utilize grasses as a significant part of the diet (Myers and Vaughan 1964). At waste burial sites where *Thomomys talpoides* may become a problem, revegetating with grasses may discourage use since their diet consists largely of forbs.

Pocket gophers pose potential problems to hazardous waste disposal practice in two ways. Their burrows may penetrate biobarriers and radically increase the rates of water penetration to greater depth, possibly leading to increased leaching of contaminants into ground-water aquifers. Or, animals may bring contaminated materials to the surface where they are more readily available to plant roots (food chain contamination) or subject to dispersal by wind and water.

The degree to which gophers affect disposal is a function of population density, depth and extent of burrowing, and volumes of material transported to the surface. In one study, estimates of 22 gophers per acre were considered average (Ward and Keith 1962). The tunnel system of each gopher may vary widely, depending upon soil type, species and climate. In a study in the Pine

Ridge formation of western Nebraska, most tunnel systems were located within 1 m of the ground surface, but two were observed to extend to a depth of about 2 m (Axthelm and Lee 1976). From a study at Rocky Flats in northern Colorado, it was suggested that most (perhaps 54%) burrow systems are between 10 and 30 cm of the surface (Winsor and Whicker 1980). These shallow tunnels are usually feeding tunnels that provide access to underground parts of food plants and to surface feeding areas (Vleck 1979). Table 3 shows recorded burrowing depths and lengths of some representative pocket gophers.

In a study of potential plutonium redistribution by pocket gophers, Winsor and Whicker (1980) estimated that six to ten animals living on a 2.6 ha study plot accounted for 155 kg/ha of upcast subsurface soil covering 6.5 m^2/ha during March to October. They estimated that 0.5% of the soil plutonium inventory at Rocky Flats may be transported to the surface, subject to dispersal by wind and water, in a decade. They cite estimates of soil movement from other studies ranging from 818 kg/ha annually to 195,000 kg of soil brought to each surface ha in one month.

Pocket gophers generally tend to be shallow burrowers compared to the other groups considered here, but on occasion are capable of exceeding 1 m in depth. The more important aspect of their burrowing habits is that they continually construct new tunnels and push soil to the surface. On waste disposal sites that have been constructed with a protective animal barrier between the waste and the covering top-soil, there will be very little danger of penetration and transport of waste to the surface. Their tunnels, however, may provide channels for water erosion in areas of high run-off.

If pocket gophers are present in areas surrounding prospective waste repositories or existing sites, mitigative action should include using a top-soil (texture) cover not attractive to the particular species present. Also, revegetation of the site should include a high percentage of species not common or preferred in the gophers diet.

TABLE 3. Recorded Burrowing Depths and Lengths of Four Species of Pocket Gophers

Species	Depth cm	Length (m)	Reference
Thomomys bottae Valley pocket gopher	5-35	45	Vleck 1979; Best 1973
Thomomys talpoides Northern Pocket gopher	10-30	30	Winsor and Whicker 1980; Gettinger 1975
Geomys bursarius Plains pocket gopher	15-23		Best 1973; Gettinger 1975
Pappogeomys castanops Mexican pocket gopher	10-132	104	Hickman 1977; Best 1973

HETERMYID RODENTS

KANGAROO RATS

The family Heteromyidae consists of a group of very efficient burrowers ranging in size from the smallest pocket mice, Perognathus fasciatus, P. flavescens, P. merriami, P. flavus, and P. longimembris (7-9g) to the largest kangaroo rat, Dipodomys ingens, weighing 127-179 g (Burt and Grossenheider 1976). This family is adapted to arid and semi-arid habitats. They are nocturnal, never require free water, and are nearly always associated with sandy or easily worked soil (Hall and Kelson 1959).

The kangaroo rats (genus Dipodomys) are represented in nearly all the western states. D. ordi is the most widely distributed, found in arid habitats from Canada to Mexico. Other species are restricted to more localized habitats ranging from grassland to desert, to chaparrel covered slopes (Burt and Grossenheider 1976). Most species prefer an open habitat. The banner-tailed kangaroo rat, D. spectabilis, occurs in open grasslands of the lower to upper Sonoran life zones (Vorhies and Taylor 1922; Holdenried 1957). The distribution of Merriam's kangaroo rat (D. merriami) in Arizona closely coincides with open habitat dominated by creosote-bush (Reynolds 1958). Other studies have shown that relative density of D. merriami decreases in areas dominated by thick cover (Monson and Kessler 1940; Rosenzweig 1973). Reynolds (1950) suggested that perenial grass interfered with ease of travel and escape from predators. The Ord kangaroo rat, D. ordi, is also found in open habitats such as pinyon/juniper (Hatch et. al. 1971) sagebrush/juniper (Rogers and Hedlund 1980) as well as open areas of desert grassland (Lemen and Rosenzweig 1978; Schroder and Rosenzweig 1975).

Heteromyids are generally associated with loose soil in which they construct deep, complex burrow systems (Kay and Whitford 1978). Soil textures selected for can range from coarse gravel for P. intermedius (Hoover et al. 1977) to sandy soil for D. merriami (Hardy 1945) to loamy soil for P. parvus (Kritzman 1970). Tunnels are often numerous and form a labyrinth maze, possibly a diversionary tactic to confuse snakes and allow time for the occupant to escape through alternate tunnels (Rosenzweig 1973) . D. spectabilis constructs some of the most complex burrow systems of all kangaroo rats encompasing an area from 152 cm to 457 cm in diameter (Vorhies and Taylor 1922). D. merriami, on the other hand, constructs less complex burrows, often among the roots of shrubs (Monson and Kessler 1940) but of similer depth (Table 4).

POCKET MICE

Pocket mice (genus Perognathus) are also common to most western states and occur in habitats very similar to kangaroo rats. Lemen and Rosenzweig (1978) studied microhabitat selection of P. flavus and D. ordi. Their study showed that the two species coexisted in the same area, with P. flavus selecting the

TABLE 4. Recorded Burrowing Depths of Some Kangaroo Rats

Species	Depths cm	Reference
Dipodomys microps Chisel-toothed kangaroo rat	24-61	Anderson and Allred 1964
Dipodomys venustus Narrow-faced kangaroo rat	5-51	Hawbecker 1940
Dipodomys heermanni Heermann's kangaroo rat	30-76	Tappe 1941; Fitch 1948
Dipodomys ingens Giant kangaroo rat	∿46	Grinnell 1932
Dipodomys spectabilis Banner-tailed kangaroo rat	15-122	Vorhies and Taylor 1922
Dipodomys merriami Merriam's kangaroo rat	26-175	Bienek and Grundmann 1971; Kenagy 1973
Dipodomys nitratoides Fresno kangaroo rat	61	Culbertson 1946

grassy habitats. They suggested that Perognathus is more adept in dense vegetation since members of this genus are smaller and more quadrupedal. Kenagy (1973) compared ecological differences of D. merriami, D. microps and P. longimembris and concluded that P. longimembris coexisted by making different spatial and temporal use of the habitat. Comparisons of habitat selected by P. penicillatus and P. intermedius showed that the former preferred a sand-gravel area dominated by creosote bush (Larrea tridentata) and forbs, while the latter was found in a coarse gravel area dominated by forbs and grasses (Hoover et al. 1977). Others who have studied pocket mice in similar open and semi-open habitats are Arnold 1942; O'Farrell et al. 1975; Rosenzweig and Winakur 1969; and Schreiber 1978.

Pocket mice, though much smaller than kangaroo rats, are also capable of constructing deep and complex burrows. Scheffer (1938) reported P. parvus burrows as deep as 193 cm (Table 5). Burrow depths are most likely influenced by soil texture and depth (Anderson and Allred 1964; Tappe 1941). Depth of frost line is another probable influence on burrow depths of hibernating heteromyid rodents. French (1976) experimented with temperature selection by hibernating P. longimembris. He found they would select the warmest environment available (hence, the deepest parts of their burrow) for winter hibernation.

The family Heteromyidae is a fairly diverse group with representatives taking advantage of nearly all xerophytic communities in the western United

TABLE 5. Burrow Depths For Three Species of Pocket Mice

Species	Depth (cm)	Reference
Perognathus faciatus Olive-backed pocket mouse	∿200	Criddle 1915
Perognathus longimembris Little pocket mouse	52-62	Kenagy 1973
Perognathus parvus Great Basin pocket mouse	35-193	Scheffer 1938; Schreiber 1978

States. A feature all of these species have in common that waste repository designers can take advantage of is their preference for fairly open habitats. Although habitat selection by the family varies from creosote-bush communities with sparse understory (inhabited by D. merriami) to more grassy habitats (inhabited by P. flavus), all species select semi-open to open habitats. Another similarity they have in common is their seeming enthusiam for constructing complex and in many cases, deep burrow systems. This is predicated by the texture and depth of soil in their habitat.

Several design options can be used to exclude these rodents from waste areas. First, an effective barrier should be placed over the hazardous waste materials. The topsoil covering should be of a texture that is unattractive to the local heteromyid species (generally a gravelly or coarse texture). Revegetation of the area should contain grasses which form a dense sward. An example might be the persistant annual cheatgrass, Bromus tectorum. Studies have shown that cheatgrass communities support very low populations of pocket mice, P. parvus (Gano and Rickard 1982; Hedlund et al. 1975).

CHIPMUNKS

Western chipmunks (genus Eutamias) are found from sagebrush communities to transition zones of oak-ponderosa pine and to ponderosa-lodgepole pine forests. Johnson (1943) identified the availability of refuge and nesting places as probably the most important factor limiting the distribution of chipmunks in California. Most of the more than 10 species there depend on decaying logs of softwood trees, especially pines and firs, digging tunnels and chambers in the soft, rotten wood. Some species also nest in rock crevices or may utilize the burrows of other mammals. The burrows of mantled ground squirrels at the base of trees and stumps are commonly used (Larrison 1947). Johnson maintains that Californian chipmunks seldom or never dig extensive burrows in the ground. The best summary of known information on western chipmunks indicates that soil burrows are often found on open ground with little or no cover (Broadbooks 1958). Burrows generally consist of a short entrance tunnel to depths of 31 cm or more and lengths of up to 122 cm, with a terminal nest chamber and very short laterals. No soil is deposited at the hole entrances, which are often located under the edge of a tree or rock. All nests described were from areas where winter snow cover might restrict frostline penetration to a few decemeters.

Information on the eastern chipmunk, genus Tamias, indicates the possibility of both simple and extensive burrow systems (Panuska and Wade 1956). One system extended 29 feet and reached a final depth of 36 cm. Burrow depth tended to be greater in northern (Panuska and Wade 1956) than in southern climates (Thomas 1974).

The extent of burrowing by these animals tends to be small and habitat requirements are unlike the usual hazardous waste disposal site. It is unlikely chipmunks would pose any serious treat to the integrity of a site. Since chipmunks tend to seek the refuge provided by large boulders, trees, and shrubs, burial sites designed and maintained free of these shelters will have very low chances of attracting these animals.

SUMMARIES OF BURROWING POTENTIAL AND POSSIBLE MITIGATIVE ACTION

Badgers

Badgers are extremely powerful burrowers and capable of moving large amounts of soil to the surface. Their main incentive for burrowing is to capture burrowing rodents, their food source. Removal of these prey species will remove the incentive for badgers at a site.

Marmots

Yellow-bellied marmots naturally occur on sloped terrain and construct their burrows among large rocks and outcropings. They are powerful burrowers, capable of excavating long tunnels. Waste burial sites could easily be designed to repel this species by avoiding burial designs with sloped sides. Existing sites with sloping borders, such as Uranium tailings piles, could be recontoured to reduce slope and an impenatrable barrier placed beneath a shallow soil surface.

Prairie Dogs

Prairie dogs generally occur in open to semi-open areas which provide them with unobstructed vision of predators and allow social interaction within the colony. They are capable of excavating very deep tunnels (427 cm or 14 ft). Along with an effective barrier, the planting of tall dense grasses would make an area unattractive to these deep burrowers.

Ground Squirrels

Ground squirrels, like prairie dogs, are most often found in open to semi-open habitats. They construct deep burrows (Table 2) in fine textured soil. This widely distributed group contains many diverse species, several of which utilize promontories to survey their surroundings. These animals could be discouraged from colonizing an area by establishing a dense stand of vegetation free of shrubs and debris. An impenatrable barrier would prevent deep burrowing and excavation of buried wastes.

Pocket Gophers

Pocket gophers, though not generally considered deep burrowers, are capable of displacing enormous quantities of soil to the surface. Because distribution of the various species appears to be related to soil type and texture, the endemic species of a site should be considered before an appropriate soil cover is selected. The diet of many pocket gophers is high in forbs; consequently, a stand of dense grass may be a suitable deterrent. An effective subsoil barrier would prevent penetration of the buried waste.

Kangaroo Rats and Pocket Mice

These animals occur in arid climates and select open to semi-open habitats. Soil texture and depth appear to be important for this group. Vegetation structure is also very important. To deter colonization by these animals, a coarse textured soil covering a barrier may be effective. Also dense grasses are effective for providing an unattractive habitat.

Chipmunks

Chipmunks occur mostly in areas with trees and shrubs. Burrows are usually shallow and constructed under the protection of large rocks or roots. Chipmunks are not anticipated as inhabitants of waste burial sites. However, as they may occur in adjacent habitats, shrubs and large objects (boulders, stored equipment etc.) should not be allowed on waste burial sites.

CONCLUSIONS

Hazardous waste repositories are subject to constant environmental pressures that must be accounted for in designing disposal sites. Every effort should be made to identify and evaluate these pressures. This review has identified the potential hazard that deep burrowing rodents may pose if allowed to inhabit a waste burial site. Prime habitats common to the various species have also been identified in order to document habitat conditions that would attract a deep burrowing rodent. This information will be useful in designing waste burial sites that will not attract burrowing rodents. There are three variables that can be manipulated to control habitation of a site by deep burrowing rodents. They are vegetation type, soil texture and depth, and subsurface barriers.

Wise selection of plantrspecies for revegetation is an essential component of waste site design. If this component is not addressed in a burial design, natural revegetation will take place and likely provide an attractive habitat to burrowing rodents. In areas where it is feasible, a dense sward of tall grass would provide the most discouraging vegetation structure to deep burrowing rodents. As stated previously in the text, most of these animals seem to require open to semi-open habitats. Some ground squirrels occur in more closed habitats but only where trees, shrubs, or large objects provide promontories for observing their surroundings. If these features are not available ground squirrels will not be attracted to a tall dense grass habitat.

Soil texture is another very important factor in habitat selection. By covering a waste burial site with a soil texture unattractive to the endemic burrowing rodents, colonization may be discouraged.

An impenetrable barrier can be placed below the soil surface to insure site integrity (Cline et al. 1980). The material used for such a barrier and the depth of overlying topsoil will vary with each site, depending on the burrowing rodents present. For example, a barrier to exclude prairie dogs will have to be much stronger than one to exclude pocket mice or kangaroo rats. If absolute exclusion of an area is required, a barrier capable of deterring the most powerful burrower of the surrounding environs should be applied.

Burrowing depth of many hibernating rodents may be influenced by the average depth of frost. In areas of deep frost, a barrier could be placed above the average frost line, thus freezing out animals attempting to overwinter on the site.

When all features that are attractive to burrowing rodents are removed or omitted from an area, the incentive to take up residence is also removed. However, absolute exclusion of these animals from an area cannot be achieved simply by omitting habitat requirements. There will always be a few individuals attempting to take up residence. Therefore an impenetrable barrier should also be implemented as an ultimate insurance against deep burrowing rodents at sites where total isolation of waste is required.

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