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The Use of Forced Gas Rodent Burrow Fumigation Systems and the Potential Risk to Humans

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ABSTRACT: The use of fumigants has been commonly practiced for decades to manage burrowing rodent populations in both agricultural and urban habitats. Stories abound about farmers and ranchers illegally fumigating rodent burrows by inserting toxic gas-producing road flares into burrow openings or by simply piping automotive exhaust into burrows systems. Legal fumigant technology includes incendiary devices such as gas cartridges that produce carbon monoxide, and highly reactive magnesium and aluminum phosphide pellets that produce toxic gasses by reaction with the atmosphere. These devices rely on passive diffusion of the toxic gasses through the burrow system. Recently, products have been introduced to the market that force toxic gasses into burrow systems by using blowers or pressurized gas systems. The effectiveness of fumigation systems where toxic gasses, such as carbon monoxide, are allowed to passively infiltrate burrow systems are limited in their geographical range, and as a result are limited in the potential risk to humans or other organisms. Regardless, these products have traditionally had use restrictions based on the proximity to structures and other inhabited areas. The use of systems where toxic gasses are forcefully blown into burrow systems present a greater hazard potential. This manuscript examines the potential risk, in terms of US EPA Standards, for carbon monoxide exposure; published data on carbon monoxide levels in burrow systems; burrow morphology of various burrowing species; and suggests safe distance standards for burrow fumigation activities conducted around structures and other human-occupied habitats.

KEY WORDS: burrow, carbon monoxide, exhaust, fumigation, rodent control

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INTRODUCTION

Rodents comprise the largest taxonomic group of mammals in the world (Nowak 1991). In North America alone, there are over 400 species of rodents (Hall 1981). The vast majority of rodents don't cause significant damage to humans and their resources (Witmer and Singleton 2012). In fact, rodents provide a number of important functions in ecosystems, including seed and spore dispersal, pollination, energy and nutrient cycling, soil mixing and aeration, and a food source for many predatory species. However, some rodent species have adapted to and taken advantage of human modified environments. In these settings, rodents that create extensive burrow systems can cause various problems for humans, including undermining building, road, and levee foundations (Witmer et al. 2012). A variety of methods are being used to reduce rodent populations and/or the damage they cause (Witmer and Singleton 2012). Rodent toxicants are an important part of the rodent control toolbox and these comprise oral toxicants and burrow fumigants (Witmer and Eisemann 2007). Rodenticides and fumigants are regulated by federal and state agencies to assure their proper, safe, and effective use. Risk assessments are also done to help assure safe use of rodenticides (Rattner et al. 2012). Additionally, rodent research continues to reduce risks of current control tools and to provide new or improved rodent damage reduction methods (Witmer and Moulton 2014). In this paper, we examine 1) the potential risk, in terms of U.S. Environmental Protection Agency (US EPA) and Occupational Safety and Health Administration (OSHA) standards, for carbon monoxide (CO) exposure, 2) the published data and literature on carbon monoxide levels in rodent burrow systems, 3) burrow morphology of various burrowing rodent species, and 4) suggest safe distance standards for burrow fumigation activities conducted around structures and other human-occupied settings. This assessment is limited to burrows of prairie dogs, pocket gophers, ground squirrels, field mice, and moles.

CARBON MONOXIDE BURROW FUMIGATION SYSTEMS

There are numerous devices on the market for introducing carbon monoxide into burrow systems. The oldest and most common is the gas cartridge. The gas cartridge is an incendiary device, commonly containing a source of carbon such as charcoal, sodium nitrate and sometimes sulfur. These devices are place in the mouth of a rodent burrow and ignited. The burrow opening is then plugged. The ignited devices produce carbon monoxide gas, which passively infiltrates the burrow system. Common gas cartridges include the Small Gas Cartridge (US Department of Agriculture, EPA Reg. No. 56228-2), the Giant Destroyer Smoke Bombs (Atlas Chemical Corp., Cedar Rapids, IA, EPA Reg. No. 10551-1) and Revenge Rodent Smoke Bombs (Bonide Products Co. Inc., Oriskany, NY, EPA Reg. No. 61110-12).

Recent introductions to the fumigation market include forced or pressurized gas systems. Examples of these products include the Pressurized Exhaust Rodent Controller (PERC, H&M Gopher Control, Tulelake, CA, EPA Est. No. 83414-CA-001, U.S. Patent No. 7,581,349) and the Cheetah Rodent Control Machine (Paso Robles,

Table 1. Published standards for exposure to carbon monoxide.

Standard	Recommended Exposure Limit		Citation
	1 Hour	8 Hour	
OSHA Permissible Exposure Limit	-	50 ppm TWA*	OSHA 2006
NIOSH Recommended Exposure Limit	-	35 ppm TWA	NIOSH 1992
ACGIH Threshold Limit Value	-	25 ppm TWA	ACGIA 1994
USEPA National Air Quality Standards	35 ppm	9 ppm	USEPA 2011

* TWS – Time Weighted Average

CA). The two systems operate in similar manner by forcing exhaust from an internal combustion engine into the burrow. Since the exhaust is pressurized, it is forced through the burrow system and the burrow is quickly purged of air. The rodents quickly succumb to the effects of carbon monoxide. Since carbon monoxide it forcibly introduced into the burrow system, the potential for carbon monoxide to be introduced into farther reaches of the system are much greater than that of passively-infiltrating gas cartridges.

EXPOSURE STANDARDS FOR CARBON MONOXIDE

For purposes of this assessment, we are relying on carbon monoxide exposure standards set by the United States Occupational Safety and Health Administration (OSHA), the National Institute of Safety and Health (NIOSH), American Conference of Governmental Industrial Hygienists (ACGIH), and the US EPA. Table 1 provides Time Weighted Average for exposure limits as recommended by these organizations. For purposes of this assessment, we are basing our threshold for concern on the US EPA National Air Quality Standards of 35 ppm for one hour. We are assuming that rodent fumigation will be less than one hour in duration for any single burrow system and that burrow systems will be mostly free of carbon monoxide within eight hours.

CARBON MONOXIDE LEVELS IN RODENT BURROW SYSTEMS

Nolte et al. (2000) reported CO concentrations in artificial and natural burrow systems following ignition of gas cartridges. In this series of studies, the researchers constructed a multi-level burrow system from PVC pipe and monitored CO concentrations in the system at four different sampling ports located 14.7, 18, 24.5, and 42.5 feet from the gas cartridge ignition box. Tests were conducted with and without the aid of a blower system to circulate fumes throughout the burrow system. The burn time of the gas cartridge was approximately six minutes. Results of tests conducted with the blower system most closely represent the proposed PERC system. In these tests, Nolte et al. reported that when a low blower speed was used, CO concentrations at all sensor locations had reached the maximum detection limit of 5,000 ppm between 1.5 minutes (14.7 feet from ignition box) and seven minutes (42.5 feet from ignition box) after igniting a single gas cartridge. This concentration was maintained until the test ended at nine minutes. The blower was turned off when the gas cartridge burned out, approximately six minutes after ignition. When two gas cartridges were lit simultaneously, under the same test conditions, CO levels at all sensors reached the 5,000 ppm sensor limit between 4.75 minutes and 5.5 minutes after ignition and these levels were maintained for the 20-minute test period.

In the second test, Nolte et al. (2000) monitored CO concentrations in natural pocket gopher burrows. In this test, two gas cartridges were simultaneously lit and a low speed blower was used for the first six minutes to circulate gases around the burrow system. CO levels in a nest chamber (distance from ignition box was not stated) rapidly rose to a peak of 2,500 ppm (exact time not reported) and steadily declined to a level of 800 ppm where it remained until the end of the 40-minute test period.

In the third test, Nolte et al. (2000) reported the results of a field study testing the efficacy of a system using two simultaneously-ignited gas cartridges in a pocket gopher burrow and a low speed blower, run for six minutes after ignition, to facilitate the circulation of gases into the burrow system. Besides being effective, the most pertinent report from this study was the comment that “on several occasions, smoke was seen emerging from the system up to 20 meters (65 feet) from the injection point within a few minutes after starting the blower.”

Finally, in an unpublished study (Webster and Nguyen 2012), the registrant of the PERC system reported CO concentrations from a site located in the Lompoc Valley, CA test site with “normal compact soil.” This study reported that the CO concentration coming out of the engine was 200 ppm. Within one minute of the start of fumigation, 37 feet from the injection probe, CO concentrations ranged from 30 to 80 ppm. One measurement at the same distance was shown to be >1,000 ppm; however, in this instance, a burrow entrance was left open, allowing unobstructed flow of gasses within that burrow. Five minutes after beginning fumigation, the CO concentration 37 feet from the probe was 30 ppm. Within 10 minutes of shutting the system off, CO levels in the burrow dropped to 5 ppm at a distance of 37 feet from the site of injection. Clearly, CO concentrations in the burrow system had the potential to reach lethal concentrations but dissipated quickly after turning the system off. It should be noted, however, that there was no replication in this brief study.

MORPHOLOGY OF RODENT BURROWS OF SPECIES LISTED ON THE PERC SYSTEM

The literature available that describes the burrows of rodents does not include the maximum straight-line length burrows can obtain. Instead, because the burrows of these species are branched and sometimes multi-level, the length of burrows is given as a total length. This makes it difficult to determine how far an individual burrow may extend in any single direction when considering how large a buffer should be required for fumigating around structures. An extensive database was compiled on published sources for burrow morphology for select fossorial rodents. In Table 2, we compiled reported burrow lengths of those species listed on the PERC label and we summarized that information by organism group below.

Table 2. Total burrow lengths (including side tunnels) of select species.

Species	Common Name(s)	Length
PRAIRIE DOGS		
Cynomys	prairie dogs	5 m (16.4 ft) [a] 50 ft [b] 5-35 m (16.4–114.5 ft) [c] average of 13 m (42.5 ft) [d] 4-34 m (13.1-111.2 ft) [e] tunnels 15.5-86.0 ft [f] usually 5-10 m (16.4-32.8 ft) total, up to 33 m (107.9 ft) [g]
Cynomys leucurus	white-tailed prairie dog	29.3 m (95.8 ft) [c] 3.6-3.7 m (11.8-12.0 ft) total [h] 16.5 m (54 ft) [i]
Cynomys ludovicianus	black-tailed prairie dog	usually 5-10 m (16.4-32.8 ft), up to 33 m (107.9 ft) [j, k] 14.12 ± 6.41 m (46.2 ± 21 ft) [l] 14.37 ± 8.83 m (47 ± 28.9 ft) [m] one burrow was 6.4 m (20.9 ft) [n]
POCKET GOPHERS		
Geomyidae	pocket gophers	up to 183 m (598.6 ft) of tunnels per burrow [o] main tunnels 73 m (238.8 ft) on average, up to 150 m (490 ft) [p]
Geomys bursarius	plains pocket gopher	61-155 m (199.5-507 ft) [q]
Geomys personatus marittimus	marittimepocketgopher	24.9 m (81.7ft) [pp]
Thomomys bottae	Botta's pocket gopher	1.33 m (4.4 ft) per segment [r] tunnels 31-275 ft, 107 ft on average; one burrow was 226 ft total [s] average length 103-206 feet [t]
Thomomys talpoides	northern pocket gopher	45-60 m (147.2-196.3 ft) total [u] 24-240 m (78.5-785 ft) total; burrows of reproductive males are longer [v]
Cratogeomys castanops	yellow-faced pocket gopher	42-104 m (137.4-340.2 ft) total [w]
VOLES		
Microtus montanus	montane vole	100-133 cm (3.3-4.4 ft) [x] 133 cm (4.4 ft) on average, up to nearly 11 m (36 ft) [y] 1.0 m (3.3 ft) on average [x]
Microtus ochrogaster	prairie vole	1.9-3.4 m (6.2-11.1 ft) on average [aa] up to 110 m (359.8 ft) [bb] 912 cm (2.9 ft) on average [cc]
MICE		
Mus musculus	house mouse	segments 5-200 cm (2 in-6.6 ft) [dd] some burrows about 30 cm (0.9 ft) with one or more bends [ee] total length 10-835 cm (4 in-27.4 ft), 137.9 cm (4.5 ft) on average [ff]
Peromyscus maniculatus	deer mouse	132 cm (4.3 ft) on average [y] 0.7 m (2.3 ft) [z] entrance tunnel 20 cm (7.8 in) or less, 12.8 cm (5 in) on average [gg]
GROUND SQUIRRELS		
Spermophilus	ground squirrels	hibernation burrows more than 2 m (6.5 ft) [hh]
Spermophilus franklinii	Franklin ground squirrel	main tunnels 0.9-1.8 m (2.9-5.9 ft) [ii]
Spermophilus tridecemlineatus	thirteen-lined ground squirrel	5-6 m (16.4-19.6 ft) [jj] nest burrows >1.8 m (>5.9 ft); hiding burrows <0.6 m (2 ft) [kk] nest burrows average 1.6 m 5.2 ft); hiding burrows 0.95 m (3.1 ft) [ll] nest burrows 1.2-6.1 m (3.9-20 ft); hiding burrows 0.6 m (2 ft) [mm]
Spermophilus variegatus	rock ground squirrel	1.5-5.8 m (4.9-19 ft); usually short [nn] up to 16 m (52.3 ft) [oo]

[a] Hygnstrom and Virchow 1994
[b] Long 2002
[c] Slobodchikoff et al. 2009
[d] King 1984
[e] Nowak 1999a
[f] Costello 1970
[g] Hoogland 1995
[h] Clark 1971
[i] Burns et al. 1989
[j] Hoogland 1996
[k] Hoogland 2003
[l] Sheets et al. 1971
[m] Verdolin et al. 2008
[n] Scheffer et al. 1937
[o] Case and Jasch 1994
[p] Baker et al. 2003
[q] Downhower and Hall 1966
[r] Vleck 1981
[s] Miller 1957
[t] Reichman et al. 1982
[u] Verts and Carraway 1999
[v] Bonar 1995
[w] Hickman 1977
[x] Sera and Early 2003
[y] Reynolds and Wakkinen 1987
[z] Laundre and Reynolds 1993
[aa] Mankin and Getz 1994
[bb] Nowak 1999b
[cc] Davis and Kalisz 1992
[dd] Avenant and Smith 2003
[ee] Berry 1968
[ff] Schmid-Holmes et al. 2001
[gg] Dawson et al. 1988
[hh] Yensen and Sherman 2003
[ii] Haberman and Fleharty 1971
[jj] Nowak 1999c
[kk] Rongstad 1965
[ll] Desha 1966
[mm] Fitzpatrick 1925
[nn] Oaks et al. 1987
[oo] Grinnell and Dixon 1918
[pp] Cortez et al. 2013

Prairie Dogs

Fifteen published sources were found for information on prairie dog burrow morphology. A great majority of those studies reported total burrow lengths of less than 50 feet (Figure 1, Table 2). Three reports were made of burrows that exceeded 100 feet.

Pocket Gophers

Nine published sources were found for information on pocket gopher burrow morphology. All but one those studies reported total burrow length reaching distances of greater than 150 feet (Figure 2, Table 2). The single study that reported burrow lengths of 4.4 feet was referring to segments of burrow systems. As with all the species listed on the PERC label, a pocket gopher burrow is a circuitous complex of multiple side tunnels and chambers branching off multiple main tunnels. In addition, they can have multiple levels. Therefore, the reported length of a burrow can be deceptive.

As an example of burrow morphology, Reichman et al. (1982) reported on the burrow systems of Botta's pocket gophers (*Thomomys bottae*) in two geographically distinct sites in northern Arizona. Seventeen burrows were measured at the 'Museum' site and 27 were measured at the 'Tuzitoot' site. The average burrow system length (which included all main, branch and terminal tunnels) was 206 feet and 103 feet, respectively. Further examination of this paper shows that all of the burrows at each site were concentrated in an area approximately 140 feet in diameter, and the longest straight-line distance of a single burrow was approximately 75 feet.

Ground Squirrels

Nineteen published sources were found for information on ground squirrel burrow morphology. A great majority of the studies reported total burrow lengths of less than 50 feet (Figure 3, Table 2). Only one report was made for a burrow exceeding 100 feet (199 feet).

Field Mice

This category is reported as 'Field Mice' on the proposed label. It is assumed that this category includes mice and voles (*Microtus* spp.). It was recommended that the Colorado Department of Agriculture modify the label to identify what rodents are considered 'Field Mice."

Six published sources were found for information on mouse burrow lengths. All but one author reported burrow lengths shorter than 8 feet (Table 2). One author reported a burrow length of 27.4 feet, but the average length in this paper was 4.5 feet.

Six published sources were found for information on vole burrow lengths. Voles will make subsurface burrows, but the majority of their 'burrowing' activity is in the creation of above ground runway systems. All but one author reported burrow lengths shorter than 11 feet (Table 2). One author reported a burrow length of 359 feet.

Moles

While moles are insectivores (and not rodents), their burrow systems can cause damage that is similar in many ways to that of several types of rodents. One paper was found that reported on the home range (consequently burrow length) of eastern moles (Harvey 1976). In this study, seven moles were followed for periods of 11 months to two years. The average home range was 1.8 acres with an average burrow length of 600 feet. However, this ranged from 0.9 acres (total burrow length of 343 feet) to 4.4 acres (total burrow length of 1,151 feet). Further examination of the burrow diagrams reveals the maximum straight-line length of a burrow was 330 feet and the shortest was approximately 70 feet.

RISK ANALYSIS AND DISCUSSION

As stated above, this assessment does not consider the exposure of workers conducting the fumigation operations. It only considers the risk presented from fumigating burrows with CO near routinely or periodically inhabited structures. When considering the risk to people inhabiting subgrade portions of structures, the distance the CO source is from a structure is critical. The closer the CO source is to a structure, the higher the potential risk of deleterious exposure. In addition, the risk increases if rodent burrows, which serve as a conduit for CO gasses, are close to or up against building foundations. In these situations, buildings with cracked foundations or poorly sealed below-grade windows and doors could be infiltrated by CO gasses during rodent burrow fumigation operations. Additional areas of potential risk are dirt-floored shops, garages, and barns where rodents have burrowed directly into the interior spaces of the structure.

For the purposes of this assessment, the baseline data used for acceptable levels of exposure are based on the US EPA National Air Quality Standards (NAQS). It is acknowledged that these standards are more conservative than other standards listed in Table 1. However, they are the only standards that provide one-hour exposure recommendations. This assessment assumes burrow fumigation operations are more likely to result in exposures closer to one hour exposure rather than eight hours. As indicated by the data presented above, the concentration of CO in rodent burrows can easily exceed the US EPA NAQS of 35 ppm.

The first consideration in assessing risk is the concentration of CO in rodent burrows during and after fumigation. In the Nolte et al. (2000) study employing the artificial PVC burrow system, CO concentrations peaked at the instrument detection limit of 5,000 ppm and remained at that concentration until the end of the test after the blower was turned off (three additional minutes). It is unknown how long it took for CO to dissipate to safe levels within the burrow system. Subsequent tests by Nolte et al. (2000) indicated that CO concentrations in a natural burrow did not fall below 800 ppm within 40 minutes after turning off the blower. The data provided by the registrant showed that CO concentrations in the burrow (37 feet from the injector) peaked at concentrations greater than 1,000 ppm, but declined to 5 ppm within ten minutes of turning off the PERC system. It is clear from this data that CO concentrations in burrows during and after fumigation activities exceed the NAQS, and concentrations exceeding the standard have been shown to exist for at least 40 minutes.

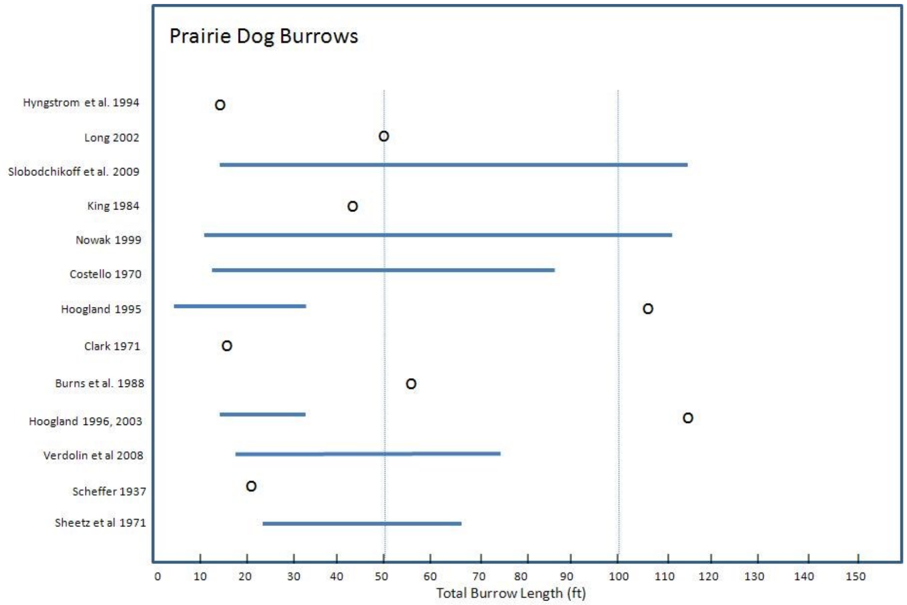

Figure 1. Prairie dog burrow lengths reported in the open literature. Burrow lengths are most often reported as total length, including side tunnels. (Bars indicate a range of data was reported. Circles indicate single values were reported.)

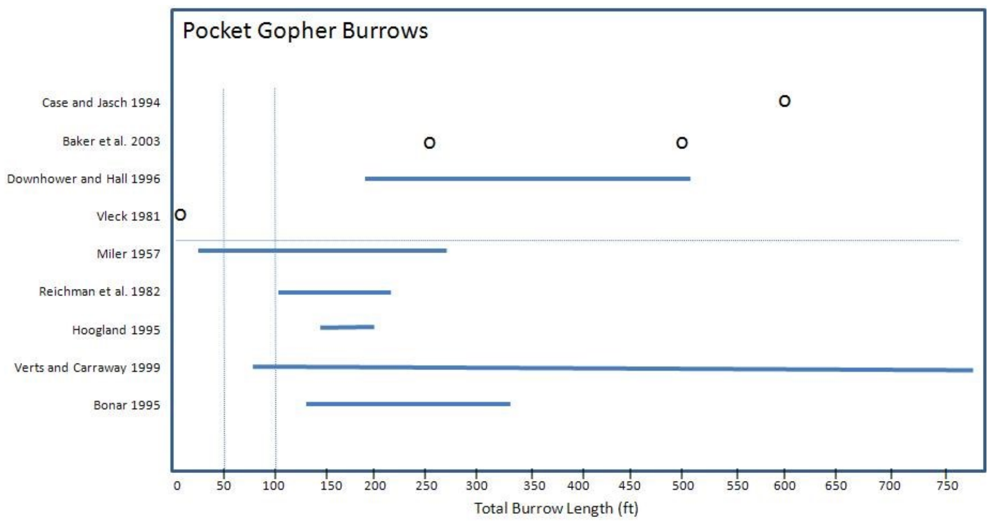

Figure 2. Pocket gopher burrow lengths reported in the open literature. Burrow lengths are most often reported as total length, including side tunnels.

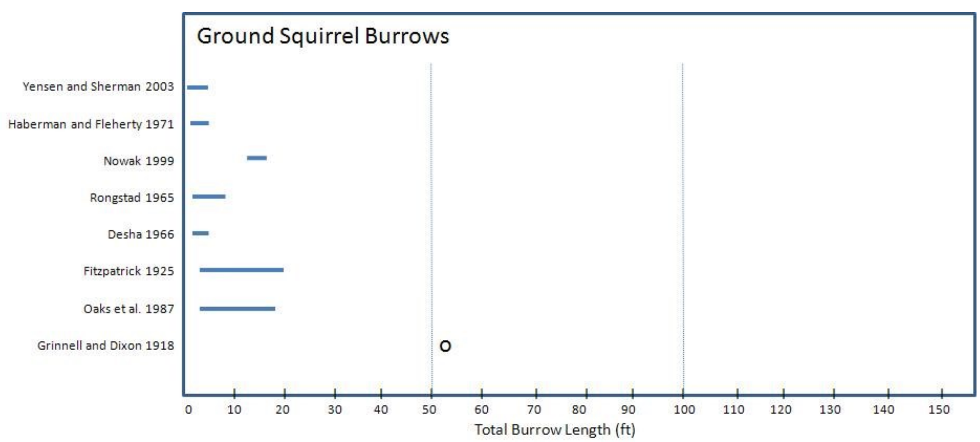

Figure 3. Ground squirrel burrow lengths reported in the open literature. Burrow lengths are most often reported as total length, including side tunnels.

Table 3. Potential risk of burrow fumigation with CO when the point of origin is 65 feet from structure.

Organism		Burrow Length (ft) (Ave. and Range)	Maximum Known Distance of CO Fumes (ft) (Nolte et al. 2000)	Risk Potential
Prairie Dog		<90 (13 – 114.58)	65	Medium
Pocket Gopher*		<150 (<31 – 785)	65	Medium
Ground Squirrel		<20 (<1 – 27.4)	65	Low
Field Mice	Mice	<8 (<1 – 27.4)	65	Low
	Voles	<11 (4 – 359)	65	Low
Mole		<300	65	High

*See Reichman et al. 1982 for description of typical burrow morphology.

The next consideration in assessing risk is the likelihood that CO will enter inhabited structures. The primary consideration for assessing risk is the length of burrow systems and their proximity to structures. It can be seen from the information presented in Table 2 and in Figures 1-Figure 3, that the burrow lengths of the species proposed on the PERC label can range widely. Comparing the average and maximum burrow lengths of these species to the distances CO has been proven to move from the point of origin would provide an estimate of what might be considered a safe distance to allow fumigation activities around structures. Nolte et al. (2000) reported observing smoke rising from burrow openings 65 feet (20 meters) from the point of origin, and in a separate test they reported that CO concentration in burrows maintained a relatively stable level of 800 ppm in a burrow for at least 40 minutes after the CO source had been removed. Therefore, we considered this to be the minimum distance from structures at which burrow fumigation should be allowed. When estimating burrow length from those studies listed in Table 2, the reported lengths were loosely categorized into three basic categories; 0-50 feet, 51-100 feet and >100 feet long and generalizations were made as to typical burrow length and maximum reported length for each species. Table 3 provides an estimate of the risk associated with burrow fumigation under this paradigm.

When making accurate estimates of safe distances around structures for burrow fumigation, one must consider other factors besides burrow length. These factors include:

- Permeability of the soil
- Potential for CO entry points in building foundations
- Maximum total CO output during fumigation operations in relation to the total volume on the potentially impacted space in a building
- Temporal nature of people ‘inhabiting’ the building

Because of the site specific nature of these types of data, none of these factors are considered in the above assessment. Therefore, until those data are available, a risk assessment should be conservative in that it provides adequate protection to those potentially exposed. Given these considerations, we recommend considering the following recommendations for placing restrictions on use of the PERC system around structures for the protection of human health and safety.

- Prohibit burrow fumigation within 50 feet of structures when fumigating for ground squirrels and ‘field mice’.
- Prohibit burrow fumigation within 100 feet of structures when fumigating for prairie dogs and pocket gophers.
- Prohibit burrow fumigation within 150 feet of structures when fumigating for moles. In addition, applicators should attempt to ensure that no portion of the mole burrow system is within 50 feet of a structure.

Recently, ground-penetrating radar has been used to assess rodent burrow systems (Cortez et al. 2013). Perhaps this technology could be used in the future to help identify the nearest distance of a burrow to an inhabited structure.

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