Human Health and Ecological Risk Assessment for the Use of Wildlife Damage Management Methods by USDA-APHIS-Wildlife Services

Chapter VIII

The Use of Carbon Monoxide in Wildlife Damage Management

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EXECUTIVE SUMMARY

USDA-APHIS-Wildlife Services (WS) uses five gas cartridge registrations in its wildlife damage management program (WDM). Gas cartridges are pyrotechnic fumigants used to control target animals that live in burrows or dens. All five currently registered gas cartridge products contain the active ingredients sodium nitrate and charcoal, and two inert ingredients. One gas cartridge product also contains the active ingredient sulfur. In addition to the gas cartridges, WS has used a forced gas fumigation system, the PERC® machine, which also produces carbon monoxide.

Sodium nitrate in gas cartridges supports the combustion of the charcoal, which emits carbon monoxide on pyrolysis. The gas cartridge containing sulfur emits carbon monoxide and sulfur oxides on pyrolysis. The PERC machine produces carbon monoxide, forced into burrows from a probe attached to the machine via a hose. Carbon monoxide is poisonous to all animals that use hemoglobin to transport oxygen from the lungs to the cells of the body. Like oxygen, the primary route of entry for carbon monoxide into an animal is through the intake of air. Carbon monoxide attaches to hemoglobin to form carboxyhemoglobin, which causes a decrease in oxygen to cells throughout the body (asphyxiation). Sulfur oxides are lethal to target animals at high enough concentrations.

Based on estimates, WS took an estimated average annual total of 11,358 target rodents and predators representing 16 species with carbon monoxide between FY11 and FY15. WS did not record any nontarget species taken, but burrows were not excavated, so this could not be estimated. Target species take included 29% woodchucks, 17% coyotes, 16% California ground squirrels, and 10% Belding's ground squirrels. WS used an annual average of 4,966 Gas Cartridges for rodents, 1,109 Large Gas Cartridges for canids, 5 The Giant Destroyer cartridges for rodents, and a PERC machine for rodents for FY11-FY15. Gas cartridges and the PERC machine were used in 31 states and the District of Columbia to resolve damage problems with the 16 species.

USDA APHIS evaluated the human health and ecological risks from the use of three registered gas cartridges in WDM and determined the risks to be negligible when following label directions. This includes the U.S. Environmental Protection (USEPA) restrictions where gas cartridges cannot be used to avoid impacts to threatened and endangered species (USEPA 2016a) and per local Section 7 determinations from consultations between U.S. Fish and Wildlife Service and WS. The ignitable cartridges in cardboard tubes minimize potential exposure to the formula and the delivery restricts carbon monoxide (and sulfur oxides if using the cartridge containing sulfur) exposure to only those animals inside a burrow or den. Gas cartridges and forced gas fumigation systems present a low risk to applicators and the public due to the application method, the mode of action of gas cartridges, and label requirements. Similarly, risks are negligible to nonexistent for nontarget fish and wildlife outside of treated burrows, and the environment based on gas cartridge and forced gas fumigation system usage method, chemical fate, and label requirements. Furthermore, label instructions for the gas cartridges reduce risk to nontarget species within burrows by requiring applicators to confirm before treatment that target animals occupy the burrows or dens and nontarget animals are not likely present. The secondary risk to humans and nontarget organisms that may eat animals asphyxiated with carbon monoxide is nil because carbon monoxide adsorption and movement within the target animal presents no risk. The formula and the byproducts of pyrolysis naturally occur in the environment.

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1 INTRODUCTION

The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS) Program conducts wildlife damage management (WDM) to protect public and private landowners from losses to agricultural and natural resources, and to protect human health and safety and property. WS manages burrowing rodents, coyotes[1], red foxes, and striped skunks using the U.S. Environmental Protection Agency (USEPA) registered gas cartridges (Figure 1) and, to a much lesser extent, forced gas fumigation systems (FGFS), which are USEPA-regulated pest control devices; WS has used the PERC® (pressurized exhaust rodent controller) machine (Figure 2), one of two FGFS available. Rodent burrows are highly variable and cause considerable damage depending on species and density (Witmer et al. 2012). This human health and ecological risk assessment is a qualitative evaluation of the risks and hazards to human health, nontarget fish and wildlife, and the environment from the use of gas cartridges by WS, with focus on the lethal byproduct carbon monoxide (CO_1). The American Veterinary Medical Association (AVMA) recommends the use of CO_1 in animal euthanasia because it quickly induces unconsciousness without pain and minimal discernment from the animal, depending on the species, and death occurs quickly (AVMA 2013).

Figure 1. The Gas Cartridge for burrowing rodents.

Figure 2. The PERC® machine used to fumigate burrowing rodents.

Gas cartridges changed design over the last 50 years, with improvements to the formulation and use patterns to enhance safety to applicators and lessen harm to nontarget organisms. FGFS are recent developments and were used for the first time by WS in 2014; the available FGFSs are the Cheetah Rodent Control Machine (Cheetah Industries, Paso Robles, CA, USEPA Establishment No. 90183-CA-1 @ www.cheetahrodentcontrol.com) and the pressurized exhaust rodent controller (PERC) machine (H&M Gopher Control, Tulelake, CA, USEPA Est. No. 83419-CA-1 @ www.hmgophercontrol.com). Both designs introduce exhaust from an internal combustion engine into the burrow. The exhaust is pressurized (e.g., the PERC machine is operated at 110 PSI) and quickly purges burrows of air replacing it with CO_1, which kills the burrowing rodents. Since CO_1 is forcibly introduced into the burrow system, the potential for carbon monoxide to be introduced into farther reaches of the system are greater than that of passively infiltrating gas cartridges.

The methods used to assess human health effects follow standard regulatory guidance and methods (National Research Council 1983, USEPA 2017d), and generally conform to other Federal agencies such as U.S. Environmental Protection Agency (USEPA), Office of Pesticide Programs (OPP). The methods used to assess ecological risk to nontarget fish and wildlife follow USEPA (1998) methodologies regarding eco-risk assessment, with an emphasis on those used by USEPA OPP in the pesticide registration process.

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[1] Scientific names are given in the Risk Assessment Introduction Chapter I

This risk assessment starts with the problem formulation (identify hazard), then performs an exposure assessment (identify potentially exposed populations and exposure pathways for these populations) and a toxicity assessment (the dose-response assessment). Lastly, a combination of the information from the exposure and toxicity assessments characterizes risk (determining whether there are adverse health and ecological risks).

1.1 Use Pattern

WS used two gas cartridge registrations and an FGFS from the beginning of FY11 (Fiscal Year 2011 is Oct. 1, 2010 to Sept. 30, 2011, and so on) through FY15 (Table 1). WS personnel typically record the number of dens or burrows taken, but this was not mandatory to record in the WS MIS[2] until FY14. Therefore, if the number of dens or burrows taken was not recorded (most were), an estimate was made of the number taken based on the number of gas cartridges used for that species (Table 2 – see gas cartridges used per burrow). From the estimate of the den or burrow occupants (Table 2) and the number of burrows taken by WS, the number of occupants in those dens and burrows was estimated (Table 3) using conservative parameters.

Table 1. Pesticide registrations for gas cartridges.

Product and EPA Registration Number	Active Ingredients	Other (Inert) Ingredients	Net Weight[4] per Cartridge	Target Animal
APHIS-Only Gas Cartridge EPA Reg. No. 56228-2[1]	Sodium nitrate 53% Charcoal 28%	Fullers earth and Borax 19%	5.1 ounces (144.6 grams)	Woodchucks, yellow-bellied marmots, ground squirrels, and prairie dogs
Gas Cartridge EPA Reg. No. 56228-61[1]				
APHIS-Only Large Gas Cartridge EPA Reg. No. 56228-21[2]	Sodium nitrate 53% Charcoal 28%	Fullers earth and Borax 19%	10.2 ounces (289.2 grams)	Coyotes, red foxes, and striped skunks
Large Gas Cartridge EPA Reg. No. 56228-62[2]				
The Giant Destroyer Atlas Chemical Corp. EPA Reg. No. 10551-1[3]	Sodium nitrate 50% Charcoal 9% Sulfur 38%	Undisclosed 3%	1.75 ounces (49.6 grams)	Pocket gophers, moles, woodchucks, brown rats, skunks, and ground squirrels

[1] APHIS-Only Gas Cartridge and Gas Cartridge, EPA Registration Numbers 56228-2 and 56228-61. @ https://www3.epa.gov/pesticides/chem_search/ppls/056228-00002-20170131.pdf and https://www3.epa.gov/pesticides/chem_search/ppls/056228-00061-20170131.pdf. Revisions accepted 01/31/2017. *Accessed 8/20/2019.*
[2] APHIS-Only Large Gas Cartridge and Large Gas Cartridge, EPA Registration Number 56228-21 and 56228-62 @ https://www3.epa.gov/pesticides/chem_search/ppls/056228-00021-20170131.pdf and https://www3.epa.gov/pesticides/chem_search/ppls/056228-00062-20170131.pdf. Revisions accepted 01/31/2017. *Accessed 8/20/2019.*
[3] The Giant Destroyer, EPA Registration Number 10551-1 @ https://www3.epa.gov/pesticides/chem_search/ppls/010551-00001-20161019.pdf Revision accepted 10/19/2016. *Accessed 8/20/2019.*
[4] Net weight is the total weight of the contents, but does not include the weight of packaging.

To make an estimate of the number of animals in a burrow or den, assumptions were made. The factors needed to make an estimate of take included the average litter size, standard number of litters per year, the length of time young are with parent(s), the number of burrow systems used by an individual or family group (Gunnison's and white-tailed prairie dogs often use several burrows), timing when gas cartridges are used, and additional WDM actions such as taking the adults with other methods (e.g., calling and shooting which is quite prevalent for coyotes). The same estimates of burrow occupants for rodents were used for the PERC machine. Based on estimates, WS took an estimated average annual total of 11,358 target rodents and predators representing 16 species (Table 2) with CO_1 between FY11 and FY15.

[2] MIS - Computer-based Management Information System used for tracking WDM activities. Throughout the text, data for a year (i.e. FY11 to FY15) will be given and is from the MIS. MIS reports will not be referenced in the text or Literature Cited Section because MIS reports are not kept on file. A database is kept that allows queries to be made to retrieve the information needed.

Table 2. The estimated average number for species taken in burrows or dens treated with gas cartridges (GC) by WS between FY11 and FY15. The formula used was the percentage of GC used during the breeding season multiplied by the average litter size plus one adult per den and one adult in alternate dens (assuming the male was present in alternate dens treated), then divided by average active dens used. This number is added to one multiplied by the percentage of GC not used in the breeding season and divided by the number of active dens. The resulting number was rounded up, and used to calculate the numbers per burrow fumigated.

PARAMETERS FOR DETERMINING THE NUMBER OF ANIMALS TAKEN BY WS IN BURROWS AND DENS							
Species	**GC Used per Burrow/Den**	**Dates When Young in Burrow/Den**	**Avg. # Burrows/Dens Used**	**% GC Used When Young Likely to Be Present**	**Avg. Litter Size**	**Estimated Avg. # Animals per Burrow/Den Treated**	**No. Used for Est.**
Rodents							
Black-tailed Prairie Dog	1.00	3/15-7/14	2 (1-3)	28%	4	0.8	1
Gunnison's Prairie Dog	1.00	3/15-7/14	5 (1-10)	66%	4	0.5	0.67
Woodchuck	1.17	3/15-7/14	2	48%	4	1.0	2
Yellow-bellied Marmot	1.09	3/15-7/14	2	89%	4	1.4	2
California Ground Squirrel	1.10	3/15-7/14	1 (2)	48%	7	2.7	3
Rock Squirrel	1.10	4/15-7/14	1 (2)	0% (*33%*)[1]	4 (2x)[2]	2.3	3
Richardson's Ground Squirrel	1.00	5/1-7/31	1	34%	8	3.0	3
Belding's Ground Squirrel	1.03	4/15-7/14	1	70%	8	3.0	3
Columbian Ground Squirrel	1.18	5/15-8/14	1	49%	4	2.0	3
Thirteen-lined Ground Squirrel	1.00	5/1-7/31	1	33%	8	3.0	3
Mexican Ground Squirrel	1.12	5/1-7/31	1	62%	5	2.3	3
Round-tailed Ground Squirrel	1.00	4/1-6/30	1	46%	5	2.2	3
Predators							
Coyote	1.73	4/1-9/30	1 (2)	96%	6	3.9	4
Red Fox	1.81	4/1-9/30	1 (2)	89%	6	3.7	4
Striped Skunk	1.13	5/1-7/31	1	34%	5	1.9	3

[1] All rock squirrels were taken outside time when young in burrow. We would expect that at least 33% would normally be taken during this time.
[2] Rock squirrels normally have two litters per year.

Of the targeted animals, woodchucks, coyotes, California ground squirrels, and Belding's ground squirrels were the species taken most by WS using CO_1, accounting for 72% of the total take. Gas cartridges were used in 34 states and the District of Columbia with New Mexico, Oregon, and California using the most (Table 3). The APHIS-Only Gas Cartridge was used most of the three labels in 31 States and DC, followed by the APHIS-Only Large Gas Cartridge which was used in 22 States (Table 3). The Giant Destroyer was only used in California and PERC machine was only used in Texas (Table 3).

2 PROBLEM FORMULATION

WS conducts WDM to protect public and private landowners from losses to agricultural and natural resources, and to protect human health and safety and property. Burrowing animals damage resources in these categories and are controlled to reduce or prevent such damages. WS manages several burrowing and den-dwelling animals using EPA-registered gas cartridges, and to a much lesser extent FGFSs.

2.1 Chemical Description and Product Use

The gas cartridge registrations differ in formulation, size, the target species allowed, and directions for use. WS uses the APHIS-Only Gas Cartridge (EPA Reg. No. 56228-2) and Gas Cartridge (EPA Reg. No. 56228-61) in burrows located in open fields, non-crop areas, rangelands, reforested areas, lawns and golf courses to control woodchucks, yellow-bellied marmots, ground squirrels, and prairie dogs (Table 1). WS uses the APHIS-Only Large Gas Cartridge (EPA Reg. No. 56228-21) and Large Gas Cartridge (EPA Reg. No. 56228-

62) in rangelands, crop, and non-crop areas to control coyotes, red foxes, and striped skunks in dens (Table 1). APHIS is the registrant for these four gas cartridge registrations with EPA. These gas cartridges are general use pesticides; anyone (over 16 years old for APHIS labels) can use them. Gas cartridges have been found to be 98% for black-tailed prairie dog control (Hygnstrom and Vercauteren 2000) and 84% for Richardson's ground squirrels with a third smaller gas cartridge compared to the current (Matschke and Fagerstone 1984). WS may periodically use The Giant Destroyer (EPA Reg. No. 10551-1, registered by ATLAS Chemical Corporation) to control pocket gophers, moles, woodchucks, Norway rats, skunks, and ground squirrels in rangelands and non-crop areas including residential lawns, parks, golf courses, re-forested areas, and open fields, which is also a general use pesticide. Finally, WS also uses an FGFS, which under pressure delivers CO_1 to rodent burrows. The FGFSs will be discussed in this risk assessment as they have internal combustion engines that produce CO_1.

Table 3. The estimated annual average number of target burrowing rodents and predators killed with gas cartridges and FGFSs by WS between FY11 and FY15 throughout the United States.

ANNUAL AVERAGE TARGET SPECIES KILLED WITH GAS CARTRIDGES (GC) AND PERC MACHINE BETWEEN FY11 and FY15				
Species	**Target**	**GC Used**	**Est. # per burrow**	**% of Take**
APHIS-Only GC (Formerly named Gas Cartridge)[1]				
Black-tailed Prairie Dog	434	435	1	5.1%
Gunnison's Prairie Dog	661	1,006	0.67	7.7%
Woodchuck	3,280	1,961	2	38.2%
Yellow-bellied Marmot	246	133	2	2.9%
California Ground Squirrel	1,826	677	3	21.3%
Rock Squirrel	23	9	3	0.3%
Richardson's Ground Squirrel	79	27	3	0.9%
Belding's Ground Squirrel	1,139	406	3	13.3%
Columbian Ground Squirrel	169	67	3	2.0%
Thirteen-Lined Ground Squirrel	2	1	3	0.02%
Mexican Ground Squirrel	58	20	3	0.7%
Round-tailed Ground Squirrel	673	224	3	7.8%
Avg. Ann. No. Animals (12 spp.)	**8,590**	**4,966**		
APHIS-Only Large Gas Cartridge (Formerly named Large Gas Cartridge)[1]				
Coyote	1,926	828	4	73.9%
Red Fox	585	245	4	22.4%
Striped Skunk	95	36	3	3.6%
Avg. Ann. No. Animals (3 spp.)	**2,606**	**1,109**		
The Giant Destroyer[1]				
California Ground Squirrel	15	5	3	100%
Avg. Ann. No. Animals (1 sp.)	**15**	**5**		
PERC (Pressurized Exhaust Rodent Controller) machine (CO_1)[1]				
Mexican Ground Squirrel	51	N/A	3	34.7%
Yellow-faced Pocket Gopher	96	N/A	2	65.3%
Avg. Ann. No. Animals (2 spp.)	**147**	**N/A**		
Grand Total (16 spp.)	**11,358**	**6,080**		

1 The burrows taken were multiplied by the estimated number of rodents in each burrow to get take numbers. Depending on time of year, you could have 0 (often burrowing rodents use more than one burrow system so some have none but look active) to 9 for ground squirrels (several species have the potential for 1 adult and 8 young until July when they disperse). Males are often in their own burrows.

APHIS' gas cartridge products are incendiary fumigants containing the active ingredients sodium nitrate and carbon (charcoal), and two inert ingredients (Fuller's earth and borax). The ATLAS Chemical Corporation's The Giant Destroyer gas cartridge formulation also contains a third active ingredient, sulfur. The gas cartridges are cardboard tubes with cardboard caps that seal the formulation until use. After puncturing one end with a nail in designated areas, applicators insert a fuse into that end. Sodium nitrate ($NaNO_3$), an oxidizer, accelerates the combustion of charcoal, which in turn forms CO_1, sodium carbonate (Na_2CO_3), and nitrogen gas (N_2). Burning of the ingredients may also potentially produce other byproducts, such as nitrogen oxides

(NO_x), sodium oxides (Na_2O), and metal oxides. Burning of The Giant Destroyer gas cartridge also forms sulfur oxides (SO_x). The inert ingredients (Fuller's earth and/or borax) control the rate of burn (Johnston et al. 2001). WS currently uses five different gas cartridge registrations (Table 1). WS previously used the three gas cartridges registrations and a FGFS between FY11 and FY15 to take an annual average of 11,358 animals with 6,080 gas cartridges and an FGFS (Table 3).

Table 4. The estimated annual average number of target burrowing rodents and predators killed with gas cartridges and FGFSs by APHIS-WS in WDM activities between FY11 and FY15 throughout the United States.

ANNUAL AVERAGE GAS CARTRIDGES (GC) AND PERC MACHINE WITH TAKE BY STATE FOR FY11-FY15							
State	**Gas Cartridge[1]**		**Large Gas Cartridge[1]**		**The Giant Destroyer[1]**		**PERC[1]**
	Avg. # Target Animals	**Avg. # GC**	**Avg. # Target Animals**	**Avg. # GC**	**Avg. # Target Animals**	**Avg. # GC**	**Avg. # Target Animals**
Arizona	769	367	7	3	-	-	-
California	1,427	537	16	5	15	5	-
Colorado	168	175	9	4	-	-	-
Connecticut	2	1	-	-	-	-	-
Idaho	6	3	54	21	-	-	-
Indiana	2	1	-	-	-	-	-
Kansas	229	228	5	2	-	-	-
Kentucky	4	2	-	-	-	-	-
Maine	110	57	37	10	-	-	-
Maryland	20	10	-	-	-	-	-
Massachusetts	2	1	-	-	-	-	-
Michigan	6	3	-	-	-	-	-
Minnesota	12	6	6	2	-	-	-
Missouri	16	9	-	-	-	-	-
Montana	24	15	146	79	-	-	-
Nebraska	35	34	354	128	-	-	-
Nevada	24	20	164	57	-	-	-
New Hampshire	478	239	-	-	-	-	-
New Jersey	58	29	5	1	-	-	-
New Mexico	583	860	10	4	-	-	-
New York	89	45	-	-	-	-	-
North Dakota	68	23	218	81	-	-	-
Ohio	936	508	-	-	-	-	-
Oregon	1,663	607	237	90	-	-	-
Pennsylvania	510	494	-	-	-	-	-
South Dakota	-	-	20	7	-	-	-
Tennessee	214	112	25	14	-	-	-
Texas	58	20	62	18	-	-	147
Utah	-	-	266	89	-	-	-
Vermont	51	27	-	-	-	-	-
Virginia	520	286	19	6	-	-	-
Washington	259	116	2	1	-	-	-
West Virginia	235	125	21	7	-	-	-
Wyoming	-	-	923	481	-	-	-
Washington, DC	14	7	-	-	-	-	-
Total[2]	**8,592**	**4,967**	**2,606**	**1,110**	**15**	**5**	**147**
# States	**31 + DC**		**22**		**1**		**1**

1 The burrows taken were multiplied by the estimated number of rodents in each burrow. Depending on time of year, you could have 0 (often burrowing rodents use more than one burrow system so some have none) to 9 for ground squirrels (several species have the potential for 1 adult and 8 young until July when they disperse). Males may be in their own burrows.

2 Rounding to whole numbers sometimes caused differences in the totals reported in Tables 3 and 4.

CO_1 is a clear, odorless, lethal gas and can cause death through asphyxiation. CO_1 is poisonous to all animals that use hemoglobin in their blood to transport oxygen from the lungs to the cells of the body. Like oxygen, the primary route of entry for CO_1 into an animal is through the intake of air. CO_1 crosses the alveolar capillary membrane in the lungs and enters the intravascular space where it binds to hemoglobin, displacing oxygen, and forms carboxyhemoglobin (COHb). This inhibits the delivery of oxygen throughout the body (asphyxia) and causes an insufficient supply of oxygen to the organs and tissues (tissue hypoxia). CO_1 also binds to cardiac myoglobin, causing myocardial depression, hypotension, and arrhythmias. Exposure to sufficient levels of CO_1 causes animals to lose consciousness and lead to death. When gas cartridges were being developed, the criteria for development included humaneness, safety to humans and the environment, availability at low cost, and likelihood of registration through USEPA (Savarie and Connolly 1984).

Before treating active burrows or dens, applicators close open holes except those being treated. A typical pretreatment for rodents, though, usually involves covering all rodent burrow openings a day prior to application; the next day only open burrows are treated. This helps minimize the number of burrows to be treated. Additionally, burrow entrances are covered with paper or debris and dirt to ensure that the CO_1 stays within the burrow and gas does not escape from additional entrances. This allows CO_1, along with SO_x if The Giant Destroyer gas cartridge is used, to reach levels high enough to be lethal to the target animal. The applicator inserts the fuse into one end of the cartridge, lights the fuse, and places the cartridge into the burrow opening fuse-end first. The applicator closes the opening with newspaper or other filler followed by soil before combustion of the cartridge. The filler prevents the soil from smothering the cartridge fuse or closing part of a burrow system. The application rate is typically one to two cartridges per burrow/den, dependent on burrow size. On the label for The Giant Destroyer, use pattern is typically one cartridge per burrow; however, the label suggests more than one cartridge may be used for larger animals or for burrows that have longer or multiple runways. For FGFS, the holes are covered, and a probe is inserted into the burrow system about a foot or so away from the burrow entrance to introduce the gas; the probe easily goes downward when it enters a burrow alerting the applicator that the probe is in the burrow. To ensure that the probe is in the burrow, the entrance is partially closed and if gas is blowing out of the burrow, the burrow is closed; if not, the probe is re-inserted. The FGFS runs for about three minutes per burrow to saturate it with CO_1.

Gas cartridge label instructions require applicators to verify that the burrow or den is active with the target species to increase efficacy and reduce impacts to nontarget animals (Ramey and Schafer 1996); this can be difficult because several species of rodents and predators can have more than one active den, and, thus, empty dens may be treated. It also specifies the time of year treatment can occur in certain areas to protect animals that use burrows created by target animals, such as the burrowing owl.

WS fumigated an annual average of 4,512 burrows of semi-fossorial rodents, including woodchucks, yellow-bellied marmots, prairie dogs, and ground squirrels, and 660 predator dens, including coyotes, red fox, and striped skunks between FY11 and FY15 with gas cartridges. WS did not dig up dens to determine actual take of target and nontarget species, but numbers were estimated from the expected number of target animals per treated burrow or den (Table 2). These were based on the number of young per litter for a species, the timing of cartridges being used, whether a species uses more than one burrow, and the social nature of the species (most predators and rodents are territorial, but males and females can occupy same den during breeding with woodchucks being the most asocial). Tables 3 and 4 provide estimates that are conservative (likely overestimates) so that impacts could be best understood. No known nontarget animals were taken with gas cartridges, but given that dens were not dug up, minimal numbers of nontarget species were likely taken, as discussed in Section 4.2.2.

Ramey and Schafer (1996) summarized efficacy studies published in the scientific literature for the gas cartridge and large gas cartridge formulations. Most of the studies found efficacy levels above 70%. Gas cartridges with 65 grams or more of formulation ($NaNO_3$ 53% and charcoal 28%) were at least 70% effective in controlling wild and domestic (albino) brown (Norway) rats and woodchucks. Gas cartridges with 97 grams of formulation were effective on Richardson's ground squirrels. Large gas cartridges with 240 grams of formulation were at least 70% effective in controlling coyote, striped skunk, and red fox, but not badger. Ramey and Schafer (1996) also summarized reasons for gas cartridge ineffectiveness for controlling certain animals, including tunnel or burrow system design, a tolerance for lower oxygen levels, plugging behavior especially by gophers (Nolte et al. 2000), soil porosity and moisture level, and body weight. In addition, animals may use different parts of the burrow or create burrows for different functions (Kinlaw 1999), indicating the animal's location during treatment may be a factor. For example, brown rats create a burrow for residence, a burrow for storing food, and a burrow for refuge near foraging areas (Kinlaw 1999). The target species or another species may colonize a burrow after treatment. The efficacy of gas cartridges was not incorporated into the take estimates in Table 3, but a 70% efficacy level would reduce the total take (11,211) by 3,363 animals.

In addition to applying gas cartridges for target species, WS also conducts demonstrations of their use (estimated take is included in tables), and make them available to cooperators (the APHIS-Only products are a relabeling of the previous two APHIS products and are no longer sold to the public, but consumer-use gas cartridges are available under separated EPA registrations). Between FY11 and FY15, WS averaged three demonstrations with gas cartridges. In the same time, WS sold or distributed an annual average of 2,070 gas cartridges for prairie dogs in 27 work tasks, 695 for ground squirrels in nine work tasks, and 58 for yellow-bellied marmots and woodchucks in 2 work tasks. Five Large Gas Cartridges for the three predators on the label were distributed in an average of two annual work tasks. WS has no way of determining if the gas cartridges that were distributed or sold were used, or their efficacy.

2.2 Physical and Chemical Properties

The active ingredients in gas cartridges are charcoal (carbon; C) and sodium nitrate ($NaNO_3$). The Giant Destroyer gas cartridge also contains the active ingredient sulfur (S). These ingredients are categorized as active ingredients because when combined, their combustion primarily produces the toxic gas CO_1. Other byproducts include sodium carbonate (Na_2CO_3) and N_2. Additional toxic byproducts from the combustion of The Giant Destroyer are sulfur dioxide (SO_2) and sulfur trioxide (SO_3) (Atlas Chemical Corporation 2010). Appendix 1 provides information on the chemical properties for $NaNO_3$, sulfur, CO_1, Na_2CO_3, N_2, SO_2, and SO_3. Not all gases produced from the combustion of gas cartridges have been identified. For example, for the Large Gas Cartridge, over 40 combustion products were identified, including carbon dioxide (CO_2) (USEPA 2008).

Charcoal (carbon) is an odorless, black solid or powder, created from charring naturally occurring vegetation substances (e.g., peat, wood, etc.) or coal. It is nonhazardous and biodegrades in the environment. It is not soluble in water and has a high melting point (greater than 3500 °C) (National Institutes of Health (NIH) 2016). It is stable unless exposed to ignition sources (e.g., flames, sparks). Combustion of charcoal produces CO_1.

$NaNO_3$ is a colorless transparent crystal or white granule, or powder with a saline slightly bitter taste. It dissolves in moist air, has a high melting point at 308 °C (EPA 1991a), and is very soluble in water (921 grams per liter (g/L)) at 25 °C (OECD 2007, NIH 2016). Nitrates (NO_3^-) are oxidizers and support combustion in an existing fire at temperatures above 1000 °C (USEPA 1991a), but do not cause spontaneous ignition below 1000 °C (OECD 2007). $NaNO_3$ purpose in gas cartridges is to aid in the combustion and oxidation of carbon to produce the byproduct CO_1. Manufacturers use $NaNO_3$ in the production of other chemicals, glass, fertilizer and fireworks (USEPA 1991a). It is also a food additive (OECD 2007).

CO_1 is the primary toxic mechanism of action for gas cartridges and FGFSs. CO_1 is a colorless, odorless, and tasteless gas. Its relative density is 1.25 kg/m^3 at 0 °C with a low solubility in water at 27.6 mg/L at 25 °C. It is flammable and highly toxic. Sources for CO_1 in the environment are anthropogenic sources (e.g., burning of fossil fuels and methane), which account for about 60%of the CO_1, and natural sources accounting for the rest (Raub 1999). Vehicles are the single largest source of CO_1 emissions (Raub 1999). Naturally occurring CO_1 comes from the incomplete combustion of carbon-containing fuels and photochemical reactions in the atmosphere (USEPA 2010). Gas cartridges and FGFSs would add an insignificant amount of CO_1 to the environment compared to other anthropogenic sources.

Na_2CO_3 is a byproduct from the combustion of the gas cartridge. Na_2CO_3, a salt, is a grayish-white powder and naturally occurring in soil and water (USEPA 2006). It is odorless and has an alkaline taste. Na_2CO_3 has a melting point of 851 °C. Its vapor pressure and partition coefficient are negligible as it is an inorganic salt. At 20 °C, its density is 2.532 and water solubility is 215 g/l. At a pH of 10.33 both carbonate and bicarbonate are present in equal amounts (pKa[3] of CO_3^{2-} is 10.33) (OECD 2002). End uses of Na_2CO_3 in industry are glass, soaps, and detergents (OECD 2002).

N_2 is colorless, tasteless, and odorless, and occurs naturally in the environment, comprising 78% of the earth's atmosphere (NIH 2016). N_2 is a byproduct of $NaNO_3$ produced from the combustion of gas cartridges.

Fuller's earth and borax, both inert ingredients, control the rate of burn of the gas cartridge (Johnston et al. 2001). Fuller's earth is a natural clay material. Borax is a salt and a common ingredient in detergents and cosmetics.

Sulfur is part of the formulation in The Giant Destroyer gas cartridge. Sulfur is an odorless, tasteless, yellow solid and naturally occurs in the environment. Sulfur occurs in several insecticides, fungicides, and rodenticides as well as fertilizer (USEPA 1991d). It has a melting point of 115 °C and a vapor pressure of 3.96 x 10^{-6} mmHg[4] at 30.4 °C. It is not soluble in water. Sulfur is flammable.

Combustion of gas cartridges containing sulfur forms the byproducts SO_2 and SO_3, as well as CO_1. SO_2 is a colorless, nonflammable gas with a strong odor. SO_2 has a high vapor pressure (3,000 mmHg at 20 °C) and, thus is typically present in a gaseous phase (USEPA 2007b). It has a density of 2.927 g/L and a melting and boiling point of 72.7 °C and -10 °C, respectively. SO_2 is very soluble in water, with its solubility varying from 5.88% at 40 °C to 22.9% at 0 °C (Agency for Toxic Substances and Disease Registry (ATSDR) 1998a). In moist air, it combines with water to form sulfurous acid (H_2SO_3), very slowly oxidizing into sulfuric acid. Other sources of SO_2 in the environment include the combustion of fossil fuels, smelting of sulfide ores, and volcanic emissions (USEPA 2007b). The U.S. Food and Drug Administration classifies SO_2 as "*generally recognized as safe*" for a preservative in certain foods (USEPA 2007b). SO_3 is generally a colorless liquid or gas. It exists in the environment for short periods, reacting with water in the air to form sulfuric acid (ATSDR 1998b). Sulfuric acid is a colorless, odorless, nonflammable liquid with a melting and boiling point of 10.36 °C and 350 °C, respectively (ATSDR 1998b). Sulfuric acid has a vapor pressure of 1 mmHg at 145.8 °C (ATSDR 1998b). Sources of sulfuric acid include industries producing detergents, fertilizers, and batteries, as well the release of SO_2 from burning coal, oil, and gas (ATSDR 1998b). Food processing and dairy facilities use sulfuric acid as a sanitizer (USEPA 1993).

[3] pKa is the acid dissociation constant, Ka, logarithm (to the base 10) which is a quantitative indicator of the strength of an acid in a solution. Ka is such a large number, pKa makes it easier to use.

[4] mmHg is millimeters of mercury (Hg) which is a manometric unit of pressure.

2.3 Environmental Fate

The cardboard tube of the gas cartridge separates the formulation content from the applicator and the surrounding environment. Applicators place gas cartridges inside burrow or dens, which confines the release of the formulation or combustion byproducts and minimizes the off-site transport through the atmosphere and water. Cartridges that fail to burn release the formulation into the environment as the cartridge container disintegrates over time. The formulation ingredients enter their respective elemental cycles or undergo degradation by soil microorganisms (Ramey and Schafer 1996).

$NaNO_3$ is not volatile and remains as a particulate in the soil. However, $NaNO_3$ is highly soluble in water so its mobility in soil and water is high. Its persistence is low because $NaNO_3$ undergoes degradation in soil through microbial activity. Microbes in soil and water transform nitrate to N_2, a process known as denitrification, which enters the nitrogen cycle (OECD 2007). Some nitrous oxide (N_2O), a greenhouse gas, may also form (OECD 2007). Under poor drainage and aeration, nitrate may reduce to NO_x gases and escape. Excess nitrate can promote excessive algal growth in water, which can reduce available oxygen to other organisms (OECD 2007). The pyrolysis of $NaNO_3$ results in simple organic and inorganic compounds, mostly in the form of gases, which diffuse through burrow openings or into the soil.

Sulfur is a component of The Giant Destroyer gas cartridge. Sulfur occurs naturally in soil and water and enters the sulfur cycle (USEPA 1991d). Sulfur released in the environment oxidizes to sulfate, which plants and microorganisms utilize (Komarnisky et al. 2003).

After combustion of the gas cartridge, the byproducts are Na_2CO_3 (a solid), CO_1, and N_2 (Ramey and Schafer 1996). SO_2 and SO_3 are also byproducts from the combustion of The Giant Destroyer gas cartridge.

Na_2CO_3 dissociates in water to sodium and carbonate ions (pKa 10.33) (OECD 2002). The ions do not adsorb on particulate matter and do not bioaccumulate in living tissues (OECD 2002).

Diffusion of CO_1 into the atmosphere from the combustion of the gas cartridge is minimal because applicators place the cartridge inside burrows underground. The fate of CO_1 inside burrows is inhalation by target animals, uptake by soil microorganisms, or entry into one of the several carbon cycles such as conversion to carbon dioxide or fixation by bacteria (Conrad 1996, Ramey and Schafer 1996, King 1999, ATSDR 2012). Nolte et al. (2000) tested the levels and spread of CO_1 in artificial pocket gopher burrows using sensors that could measure 5,000 parts per million (ppm) CO_1. A sensor 4.5 m from the artificial burrow entrance measured 5,000 ppm after deployment of a rodent gas cartridge, but at 7.5 m from the burrow entrance levels were below detectible levels by sensors. Placement of two gas cartridges resulted in a measurement of 5,000 ppm at both the 4.5 m and 7.5 m distances from the artificial burrow entrance, with levels dropping below detectable levels further away from the entrance.

The N_2 produced as a byproduct of combustion spreads into the surrounding air and does not produce a biological hazard. N_2 accounts for around 78% of the earth's atmosphere by volume. In soil or water, it becomes part of the various nitrogen cycles.

In the environment, elemental sulfur enters into the natural sulfur cycle (USEPA 1991d) and is not an environmental concern. Soil and water can absorb SO_2, a byproduct from the combustion of sulfur (USEPA 2007b). Plants can also absorb SO_2 from the air (USEPA 2007b). SO_2 in air can oxidize to sulfate and form *acid rain*. SO_2 may photochemically transform or oxidize to sodium trioxide in the air (USEPA 2007b). Both

SO_2 and SO_3 rapidly react with water vapor in the air to form sulfuric and sulfurous acids, respectively (ATSDR 1998b). Sulfuric acid rapidly degrades in the environment to sulfate salts which are of no toxicological concern and considered "*generally recognized as safe*" by the U.S. Food and Drug Administration (USEPA 1993). Sulfuric acid dissolves in atmospheric water and separates to form hydrogen ions and sulfate, and can also leach into surface water and groundwater (ATSDR 1998b). Soil particles adsorb ions from sulfuric acid and plants can uptake sulfates (ATSDR 1998b).

USEPA (1991a, 1991d, 2006, 2008) waived the environmental fate studies and data requirements for carbon, sulfur, $NaNO_3$, and the byproducts of the gas cartridges. The basis for these waivers was with ecological effects since these chemicals are widespread or natural occurring in the environment (USEPA 1991a, USEPA 2008). USEPA (1991a) stated, "*The pyrolysis of these products results in simple organic and inorganic compounds, mostly in the form of gases, which diffuse through burrow openings or into the soil. Exposure of the environment is limited and localized, however, and environmental fate studies are not required.*"

2.4 Hazard Identification

The pyrolysis of charcoal and in the gas cartridge forms CO_1, Na_2CO_3, and N_2. The pyrolysis of The Giant Destroyer gas cartridge, which contains sulfur in its formulation, also produces SO_2 and SO_3. The toxicity of gas cartridge chemicals and byproducts that result from pyrolysis are available. Toxicity for CO1 (Table 5), NaNO3 (Table 6), sulfur compounds (Table 7), and Na2CO3 (Table 8) are summarized below for mammals, birds, and fish.

FGFS disperses CO_1 into a burrow system, which the machines produce. Since no pyrolysis occurs, the FSGS produces no byproducts. The machines use fuel, so the FSGS produces a minimal amount of gases associated with burning fossil fuels.

In addition to toxicity of the chemicals created, it is feasible that the burning of gas cartridges could ignite dry grass, leaves, or other combustible materials, which may expose the applicator to harm. Product labels warn of this risk and specify not to use $NaNO_3$ gas cartridges near vegetation or structures likely to catch fire.

2.4.1 Carbon Monoxide (CO_1) Hazard Identification

CO_1 is a lethal gas when inhaled in enough quantities. CO_1 binds to hemoglobin in the blood, displacing oxygen, forming COHb. This inhibits the delivery of oxygen throughout the body (asphyxia) and causes an inadequate supply of oxygen to the organs and tissues (tissue hypoxia). In humans, 1-hour exposure to 0.32% CO_1 will cause unconsciousness and 0.45% CO_1 will cause death (Bloom 1972, AVMA 2013). The Immediately Dangerous to Life or Health Concentration (IDLH) for CO_1 in humans is 1,200 ppm based on acute inhalation toxicity data in humans, including nonlethal symptoms at 1-hour exposure to 1,000 to 1,200 ppm CO_1 and potential lethal reaction at 1-hour exposure to 1,500 to 2,000 ppm CO_1 (Centers for Disease Control and Prevention (CDC) 1994) (Table 5).

In humans, the most common symptoms of CO_1 poisoning are headache, nausea, vomiting, confusion, and flu-like illness (Piantadosi 2004). Additional neurological signs include visual disturbance and seizures (Blumenthal 2001). Exposure to CO_1 can result in long term or permanent symptoms which may develop weeks or years after exposure (Weaver 2009). Cardiac injuries and neurological abnormalities, including memory impairment and changes to personality, developed in survivors of CO_1 poisoning (Smith and Brandon 1973, Raub 1999). Symptoms of CO_1 poisoning generally appear when COHb levels reach about 15%

(Piantadosi 2004). For reference points, people living in areas with clean air have COHb of 1 to 2% from endogenous CO_1 production while people living in large cities typically have COHb levels of 2% (Piantadosi 2004). The amount of COHb formed in response to CO_1 exposure is dependent on the CO_1 concentration and duration of exposure, ambient pressure, as well as the age, size, and health status (e.g., cardiovascular- and pulmonary-related diseases) of the person (USEPA 2010).

Table 5. Toxicity data for carbon monoxide on mammals and birds.

TOXICITY DATA FOR CARBON MONOXIDE				
Test species	**Test**	**Results**	**Time**	**Reference**
Mammals				
Brown Rat	LC_{50}[1]	8,636 ppm	15 min.	Hartzell et al. 1985[4]
		5,207 ppm	30 min.	Hartzell et al. 1985[4]
		4,600-5,000 ppm	30 min	NIH 2016[5]
		1,784 ppm	4 hr.	Rose et al. 1970[4]
		1,807 ppm	4 hr.	NIH 2016[5]
House Mouse		2,414 ppm	4 hr.	Rose et al. 1970[4]
		2,444 ppm	4 hr.	NIH 2016[5]
Guinea Pig (*Cavia porcellus*)		5,647 ppm	4 hr.	Rose et al. 1970[4]
		5,818 ppm	4 hr.	NIH 2016[5]
Human	LC_{LO}[2]	5,000 ppm	5 min.	Tab Biol Per 1933[4]
		4,000 ppm	30 min.	Lefaux 1968[4]
Birds				
Japanese Quail (*Coturnix japonica*)	LD_{50}	2,103 mg/kg	Oral	Schafer and Bowles 2004
	LC_{50}	1,938 ppm	Inhalation	USDA 2016
European Starling	LC_{50}	LC_{50} 2,213 ppm	Inhalation	USDA 2016
Red-winged Blackbird	LC_{50}	LC_{50} 1,334 ppm	Inhalation	USDA 2016

[1] LC_{50} is the lethal concentration of a material in air/water that will kill 50% of the test subjects when administered as a single exposure.
[2] LC_{LO} is the lowest concentration of a material in air/water reported to have caused the death of animals or humans.
[3] LD_{50} is the lethal dose of a material given orally to test animals that will kill 50% of the population, administered as a single exposure.
[4] CDC (1994) cited the study.
[5] NIH 2016 is a database of values queried September 10, 2014.

The American Veterinary Medical Association (AVMA 2013) reviewed several studies on CO_1 exposure to animals. On exposure to a concentration of 8% CO_1, guinea pigs collapsed in 40 seconds to two minutes, and death occurred within six minutes. CO_1 exposure of mink and chinchillas (*Chinchilla lanigera*) caused collapse in one minute, cessation of breathing in two minutes, and cardiac arrest in 5–7 minutes. CO_1 LC_{50} is 1,807 ppm in rat, 2,445 ppm in mouse, and 5,720 ppm in guinea pig (Rose et al. 1970, CDC 1994). CDC (1994) summarized lethal concentration data for CO_1 (Table 8). The AVMA (2013) considers the use of CO_1 as an acceptable form of euthanasia as it produces fatal hypoxemia because it readily combines with hemoglobin and blocks uptake of O_2 by erythrocytes by forming carboxyhemoglobin, but under particular settings; field use was not specifically addressed for CO_1, though. Advantages of CO_1 include loss of consciousness without pain and minimal discernable discomfort, the hypoxemia produced is insidious (gradual and cumulative), and death is rapid at concentrations of 4-6%; disadvantages include that it is an aversive agent for laboratory rodents, need to ensure employees are safeguarded, and electrical equipment should not be in the vicinity since especially at concentrations greater than 12% it is combustible and explosive (AVMA 2013).

2.4.2 Charcoal (Carbon) Hazard Identification

Charcoal (carbon) is common in the environment and is a basic part of all living organisms. Charcoal is used in various food processes and as a fuel for outdoor cooking (USEPA 1991b). Its absorptive properties remove toxins from water and its oral administration removes poisons in humans and animals. An oral charcoal toxicity study showed no oral toxicity to albino lab rats given up to 3,000 mg charcoal per kg of body weight (mg/kg) (Ramey and Schafer 1996). Toxicity to humans can occur at very high dosages, but this would be an unusual circumstance.

2.4.3 Sodium Nitrate ($NaNO_3$) Hazard Identification

Acute toxicity studies for sodium and potassium nitrates indicate that it may cause eye irritation (Toxicity Category II[5]). However, sodium and potassium nitrates pose a relatively low acute oral toxicity hazard (Toxicity Category III), produces some low-level acute dermal effects (Toxicity Category III) and slight dermal irritation (Toxicity Category IV) (USEPA 1991a).

The sodium nitrate oral LD_{50} values (dose at which 50%of the test population dies) for rats and domestic rabbits was 1,267 mg/kg and 2,480 mg/kg, respectively (OECD 2007) (Table 6). Rats given drinking water with $NaNO_3$ (0 and 4,000 mg/L) resulted in the lowest-observed-adverse-effect level (LOAEL) of 4,000 mg/L based on a decrease of vitamin E levels as well as an increase in pulmonary lesions (Table 6). This study did not set a no-observed-adverse-effect level (NOAEL) (OECD 2007). The human health drinking water tolerance level is 10 mg/L, a relatively high level (USEPA 2017c).

In a six-week study, rats fed doses of $NaNO_3$ at 5,000 or 10,000 mg/kg/day had slight or moderate decline in weight gain. At necropsy, the abnormal color of the blood and spleen indicated methemoglobinemia, a blood disorder where an abnormal amount of methemoglobin, a form of hemoglobin, forms (OECD 2007). The USEPA (2007a) oral reference dose for nitrate is 1.6 mg/kg/day, based on clinical signs of methemoglobinemia in infants (excess of 10%) 0 to 3 months of age exposed to nitrate in infant formula.

Table 6. Toxicity data for sodium nitrate for mammals, fish, amphibians, and invertebrates.

SODIUM NITRATE TOXICITY DATA				
Test species	**Test**	**Results**	**Time**	**Reference**
Mammals				
Brown Rat	LD_{50}[1]	1,267 mg/kg	Oral	NIH 2016[4]
House Mouse		175 mg/kg	Intravenous	
		2,480 mg/kg	Oral	
European Rabbit		1,600 mg/kg – 2,680 mg/kg	Oral	
Fish				
Bluegill	LC_{50}[2]	9,000-12,000 mg/L	96 hr.	OECD 2007
Rainbow Trout		1,685-8,226 mg/L	96 hr.	
Chinook Salmon		5,800 mg/L	96 hr.	
Western Mosquitofish (*Gambusia affinis*)		6,650 mg/L	96 hr.	
Amphibians/Invertebrates				
African Clawed Frog	EC_{50}[3]	1,655 mg/L	96 hr.	OECD 2007
Daphnia magna		490 mg/L	48 hr.	
Eastern Oyster (*Crassostrea virginica*)		15,810 mg/L (adult)	96 hr.	
		23,040 mg/L (juvenile)	96 hr.	

[1] LD_{50} is the lethal dose of a material given orally to test animals that will kill 50% of the population, administered as a single exposure.
[2] LC_{50} is the lethal concentration of a material in air/water that will kill 50% of the test subjects when administered as a single exposure.
[3] EC_{50} is the effective concentration of a material in air that induces a response halfway between baseline and maximum.
[4]NIH 2016 is a database of values queried September 10, 2014.
[5] OECD 2007 summarizes $NaNO_3$ toxicity data for more species than presented in this table.

Inhalation of technical grade (100%) $NaNO_3$ may cause irritation to the respiratory tract, and lead to methemoglobinemia, cyanosis, tachycardia, labored breathing, and death (Fisher Scientific 2001). Chronic

[5] For a discussion of USEPA toxicity categories, please see Chapter 7 of USEPA (2016c).

(prolonged) exposure may cause anemia and methemoglobinemia, expressed as dizziness, drowsiness, headache, labored breathing, and elevated heart rate (Fisher Scientific 2001).

Studies showed technical grade $NaNO_3$ is not a carcinogen or a teratogen (OECD 2007). $NaNO_3$ is not genotoxic *in vitro*, confirmed through the Ames test and micronucleus and chromosome aberration tests with mammalian human lymphocyte cells (OECD 2007).

Studies showed nitrates are not reproductive or developmental toxicants. In a two-generation rabbit study, $NaNO_3$ at dose levels up to 500 mg/L in drinking water had no effect on the number of pregnancies, litter sizes, or pup weights (OECD 2007). In another study, nitrate had no effect on maternal or fetal survival when given by gavage during gestation at doses up to 400 mg/kg for groups of mice and hamsters and up to 250 mg/kg for groups of rats and rabbits. Mice treated for 14 days with $NaNO_3$ did not have statistically significant reductions in fertility or liter size (OECD 2007).

2.4.4 Sulfur (S) and Sulfur Oxides (SO_x) Hazard Identification

Sulfur is an ingredient in the formulation of The Giant Destroyer gas cartridge. Byproducts from pyrolysis of The Giant Destroyer gas cartridge include SO_2 and SO_3 (Atlas Chemical Corporation 2010). SO_3 is a gas and is an intermediate in the formation of sulfuric acid from SO_2 exposed to water in the air. Other substances in the air, such as ammonia, can neutralize sulfuric acid and determine whether exposure to sulfuric acid will occur (ATSDR 1998a).

Sulfur has very low acute oral toxicity and does not irritate skin in humans and was placed in Toxicity Category IV[5] (USEPA 1991d) (Table 7). However, sulfur can cause eye irritation and has low dermal toxicity and inhalation hazards putting it into Toxicity Category III (USEPA 1991d) (Table 7). Sulfur, 98%, has very low acute oral toxicity in rats with an acute oral LD_{50} > 5,000 mg/kg and an acute inhalation in rats >2.56 mg/L (USEPA 1991c). Chronic exposure to sulfur dust and SO_2, as occurs for mineworkers, showed ocular disturbances, chronic bronchitis, and respiratory and sinus effects (USEPA 1991d). Sulfur has no known risks of oncogenic, teratogenic, or reproductive effects and is non-mutagenic in microorganisms.

Table 7. Toxicity data for sulfur dioxide and sulfuric acid in mammals and birds.

SULFUR TOXICITY DATA				
Test species	**Test**	**Results**	**Time**	**Reference**
Sulfur Dioxide				
Brown Rat	LC_{50}[1]	2,520 ppm TC[3] III	1 hr.	USEPA 2007b
		20 mg/m^3 TC III	5 hr.	
House Mouse		3,000 ppm (7.0 mg/L) TC IV	30 min	
		1,000 ppm (2.6 mg/L) TC IV	4 hr.	
		150 ppm TC IV	847 hr.	
Guinea Pig		1,000 ppm (2.7 mg/L) TC IV	20 hr.	
		1,039 ppm (2.7 mg/L) TC IV (lowest)	24 hr.	
		130 ppm TC IV	154 hr.	
No Data	Acute Oral and Dermal Toxicity, and Dermal Sensitization			
Sulfuric Acid				
Unknown	LD_{50}[2]	350 mg/kg TC II	Oral	USEPA 1993
		>2,000 mg/kg TC III	Dermal	
Guinea Pig	LC_{50}[1]	18 mg/m^3 TC I	Inhalation	
No Data	Dermal Sensitization[4], and Dermal and Eye Irritation (TC I)			

[1] LC_{50} is the lethal concentration of a material in air/water that will kill 50% of the test subjects when administered as a single exposure.
[2] LD_{50} is the lethal dose of a material given orally to test animals that will kill 50% of the population, administered as a single exposure.
[3] TC = Toxic Category (see USEPA 2016c for description of toxic categories)
[4] Dermal sensitization was not required by USEPA based on TC.

SO_2 is a byproduct from the combustion of The Giant Destroyer gas cartridge. SO_2 has low toxicity (Toxicity Category IV), unless exposure to high concentrations occurs. The U.S. Food and Drug Administration classifies SO_2 as "*generally recognized as safe*" for a preservative in certain food products (USEPA 2007b). Exposure to 100 ppm of SO_2 can be harmful to humans (ATSDR 1998a, Komarnisky et al. 2003). For comparison, typical outdoor concentrations of SO_2 may range from zero to 1 ppm (ATSDR 1998a). Incidents of human exposure to SO_2 report symptoms such as chest pains, dizziness, numb hands, teary eyes, blurred vision, itching, and rashes (USEPA 2007b). These exposure cases did not involve vertebrate gas cartridges. A natural source of SO_2 is volcanic eruptions, and is a dominant source of sulfuric acid (formed when SO_2 reacts with water) in the atmosphere (ATSDR 1998a). Reproductive effects did not occur in inhalation studies with rats (5-30 ppm SO_2 for a period from 9 days prior to mating until 12-14 days of pregnancy), mice (25 ppm SO_2 7 hours/day on gestation days 6-15), and rabbits (70 ppm SO_2 7 hours/day on gestation days 6-18) (ATSDR 1998a). Carcinogenicity in humans exposed to SO_2 is not known (USEPA 2007b). Female mice exposed to SO_2 developed lung tumors; however, the concentration of SO_2 evaluated in these inhalation studies was not reported (USEPA 2007b).

SO_3 is a byproduct from the combustion of The Giant Destroyer gas cartridge. SO_3 reacts with water, including water vapor in the air and forms sulfuric acid. SO_3 rapidly converts to sulfuric acid in the respiratory tract. Several industries use sulfuric acid in their processes, including the manufacture of fertilizers, explosives, glue, and batteries, and some home cleaners contain compounds that release sulfuric acid (ATSDR 1998b). Sulfuric acid is corrosive and can be irritating to the respiratory tract, eyes, and skin (ATSDR 1998b). Due to these affects, sulfuric acid has a Toxicity Category I for eye and dermal irritations, and acute toxicity inhalation routes and Toxicity Category II for acute oral toxicity (USEPA 1993). Workers chronically exposed to sulfuric acid have experienced irritation and damage to the lungs (ATSDR 1998b). The lowest concentrations and exposure durations causing changes in pulmonary function in people with asthma were 40-minute exposure to 0.07 mg/m^3 and 50-minute exposure to 0.1 mg/m^3 (ATSDR 1998b). Persons exposed to sulfuric acid for one hour or more, including exposure of asthmatic volunteers to 0.999 mg/m^3 sulfuric acid aerosol for one hour, reported feeling dizziness, fatigue, and headaches (ATSDR 1998b). Prolonged exposure can also cause erosion of the teeth (ATSDR 1998b). Ocular exposure can result in severe damage and loss of sight (ATSDR 1998b). Sulfuric acid can also cause burns. Sulfuric acid is not likely to cause reproductive, developmental, immunological or neurological (other than subjective symptoms and reflex response) effects in humans. The USEPA has not classified SO_3 or sulfuric acid as carcinogenic.

In a summary of acute toxicity studies, The LD_{50} was 2,140 mg/kg in rats fed sulfuric acid in water at a concentration of 0.25 g/ml. No deaths occurred in chicks fed sulfuric acid in the diet at 11,117 mg/kg/day for 14 days or mallard ducklings at 12,393 mg/kg/day for 15 days (ATSDR 1998b). In 1996, the Occupational Safety and Health Administration (OSHA) set a permissible exposure limit of 1 mg/m^3 for sulfuric acid aerosols. No inhalation or oral minimal risk levels (MRL) are set for SO_3 or sulfuric acid exposure. Death is unlikely to occur at concentrations of sulfuric acid normally found in the environment or at hazardous waste sites (ATSDR 1998b). Sulfuric acid rapidly degrades in the environment to sulfate salts which are of no toxicological concern and considered "*generally recognized as safe*" by the U.S. Food and Drug Administration (USEPA 1993).

2.4.5 Sodium Carbonate ($NaCO_3$) Hazard Identification

Na_2CO_3 is a byproduct from combustion of $NaNO_3$ and charcoal. It has low toxicity to humans and the primary hazard in the environment is its alkalinity. $NaCO_3$ has low oral toxicity, confirmed through oral toxicity studies in animals, and no cases of acute oral poisoning in humans (OECD 2002). $NaCO_3$ has an oral LD_{50} of 4,000 mg/kg in rats and an acute oral LD_{50} in rats is 2,800 mg/kg (OECD 2002) (Table 8).

$NaCO_3$ has no or low skin irritation potential based on animal and human studies (OECD 2002) (Table 8). The dermal LD_{50} in rats is greater than 2,000 mg/kg (OECD 2002) (Table 8). However, $NaCO_3$ is an eye irritant (OECD 2002) (Table 8). The LC_{50} for inhalation are 800, 1,200, and 2,300 mg/m^3 for guinea pigs, mice, and rats, respectively (OECD 2002) (Table 8). Genetic toxicity tests indicate $NaCO_3$ has no genotoxic effects and reproduction toxicity is not expected (OECD 2002).

Table 8. Toxicity data for sodium carbonate for mammals, fish, amphibians, and invertebrates.

TOXICITY VALUES FOR SODIUM CARBONATE				
Test species	**Test**	**Results**	**Comment**	**Reference**
Mammals				
Brown Rat	LD_{50}[1]	2,800 mg/kg	Oral	OECD 2002[7]
	LC_{50}[2]	2,300 mg/m^3 (800-4,600 mg/m^3)[5]	2 hr.	
House Mouse		1,200 mg/m^3 (600-3,000 mg/m^3)	2 hr.	
Guinea Pig		800 mg/m^3 (500-3,000 mg/m^3)	2 hr.	
European Rabbit	Skin	Not irritating (OECD Test # 404)	EPA 16 CFR 1500.3	
	Eye	Irritating (EPA CFR 1500.42)	Irritation	
		Highly irritating (OECD Test # 405)[6]	Corrosion	
Brown Rat	Inhalation 5 µm particles	70 ± 2.9 mg/m^3 (histopathological changes resp. tract); 10-20 mg/m^3 (no effects)	4h/day, 5 days/week repeated 3.5 mo.**	
Brown Rat	Developmental Toxicity – Oral Intubation	3.4-340 mg/kg	No effects on implant., dam/fetus survival, or tissue anomalies	
House Mouse		2.45-245 mg/kg		
European Rabbit		1.79-179 mg/kg		
No Data	Sensitization, and Reproduction and Genetic (*in vivo*) Toxicity			
Fish				
Bluegill	LC_{50}[2]	300 mg/L (3 size classes)	96 hr. TLm (tolerance limit median)	OECD 2002[7]
W. Mosquitofish		740 mg/L		
Emerald Shiner (*Notropis atherinoides*)	LC_{LO}[3]	250 mg/L	120 hrs.	
Spotfin Shiner (*Notropis spilopterus*)		250 mg/L	120 hrs.	
Invertebrates				
Ceriodaphnia cf. dubia	EC_{50}[4]	200-227 mg/L	48 hr. immobile. test	OECD 2002[7]
Escherichia coli	Chromotest–S9	0.11-11000 µg/ml (triplicate)	No induction DNA dam.	

[1] LD_{50} is the lethal dose of a material given orally to test animals that will kill 50% of the population, administered as a single exposure.
[2] LC_{50} is the lethal concentration of a material in air that will kill 50% of the test subjects when administered as a single exposure.
[3] LC_{Lo} is the lowest concentration of a material in air reported to have caused the death of animals or humans.
[4] EC_{50} is the effective concentration of a material in air that induces a response halfway between baseline and maximum.
[5] Whole-body exposure to aerosol
[6] Conjunctival redness/chemosis
[7] OECD 2002 database of values from many studies

Developmental toxicity test on gestation days 6 to 15 in rats, mice, and rabbits at levels of 3.4 to 340 mg/kg caused no effects on embryo implant in the lining of uteruses or survival of fetuses (USEPA 2006). An *in vitro* mutagenicity test with bacteria was negative (OECD 2002). $NaCO_3$ is an ingredient in many household cleaning products and skin exposure is common. Na_2CO_3 is a food additive (OECD 2002).

3 DOSE-RESPONSE ASSESSMENT

3.1 Human Health Dose-Response Assessment

A dose-response assessment evaluates the dose levels (toxicity criteria) for human health effects including acute and chronic toxicities. The summary of hazards and toxicity studies for the formulation ingredients and byproducts in Section 2.4 and ecological effects in Section 3.2, include lethal dose and lethal concentration studies in animals, which provides information on the toxicity potential to humans.

For gas cartridges, an applicator places one cartridge, and possibly two, into burrows or dens for fumigation. The applicator lights the cartridge's fuse, places the cartridge inside the burrow opening, and seals the burrow with soil before pyrolysis occurs. For FGFS, the applicator inserts a probe into the burrow about a foot from the entrance and covers the entrance once it is inside.

The formulation in gas cartridges contains $NaNO_3$, charcoal, and two inert ingredients. The Giant Destroyer also contains sulfur. Charcoal and sulfur in the gas cartridges both have low toxicity to humans (USEPA 1991b). In one oral toxicity study, albino rats showed no toxicity to 3,000 mg/kg of charcoal (study cited in Ramey and Schafer 1996). Toxicity to humans could occur at very high dosages of charcoal, but this would be an unusual circumstance. Sulfur has very low acute oral toxicity, with an LD_{50} of more than 5 g/kg for 98% sulfur in rat. Similarly, sulfur is not a skin irritant or skin sensitizer, with an LD_{50} of more than 2 g/kg for 98% sulfur from an acute dermal rabbit (USEPA 1991c). Sulfur can cause eye irritation, dermal toxicity, and inhalation hazards (USEPA 1991d).

$NaNO_3$ has low acute oral toxicity hazard (USEPA 1991a). The USEPA developed an oral reference dose of 10 mg/L (1.6 mg/kg/day) for nitrate-nitrogen (OECD 2007, USEPA 2016b) based on the development of methemoglobinemia in infants who ingested water containing concentrations greater than 10 mg nitrate-nitrogen/L, but not at concentrations below this level.

The pyrolysis of carbon through the aid of $NaNO_3$ combustion produces CO_1, a lethal gas. The sulfur in The Giant Destroyer gas cartridge is easily ignitable and forms SO_2, a noxious gas, upon combustion.

The Immediately Dangerous to Life or Health Concentration (IDLH) for CO_1 in humans is 1,200 ppm (CDC 1994). The IDLH is based on acute inhalation toxicity data in humans, including nonlethal symptoms (e.g., headache, nausea, vomiting, confusion, flu-like illness, visual disturbance, and seizures) at 1-hour exposure to 1,000 to 1,200 ppm CO_1 and potential lethal reaction at 1-hour exposure to 1,500 to 2,000 ppm CO_1 (CDC 1994). The multi-hour ambient air-quality standard for CO_1 is 9 ppm (10 mg/m^3), set to protect susceptible population groups from adverse exposure effects in the environment (USEPA 2017b). The occupational exposure limits range from 25 to 50 ppm (30-60 mg/m^3) during a typical 8-hour workday (Raub 1999).

For humans, OSHA set threshold limit values for SO_2 in atmospheric air at 2 ppm for a normal 8-hour workday or 40-hour workweek. Repeat exposure to this amount will not have adverse effects. A maximum concentration of SO_2 that should not be exceeded at any time during a 15-minute exposure period is 5 ppm (CDC 1974).

3.2 Ecological Effects Analysis

This section of the risk assessment discusses ecological effects data for terrestrial and aquatic biota. The characterization of risk for gas cartridges and FGFS to nontarget wildlife and domestic animals integrates the available acute and chronic toxicity data for all major taxa in this section with the exposure analysis section (Section 4). Tables 5-8 summarize several ecotoxicity studies.

The gas cartridge formulation contains charcoal and $NaNO_3$; The Giant Destroyer gas cartridge also contains sulfur. The byproducts from the pyrolysis of gas cartridges include CO_1, Na_2CO_3, and N_2. In addition to these byproducts, the pyrolysis of The Giant Destroyer gas cartridge produces SO_2 and SO_3.

USEPA requires ecological toxicity studies to determine active ingredient(s) hazards for pesticide registrations. USEPA (2008) waived these requirements for gas cartridges due to the limited environmental release from the proposed use pattern. The belowground use of gas cartridges and their environmental fate precludes significant exposure to nontarget terrestrial species that do not use burrows and aquatic species. Of most concern are threats to threatened and endangered (T&E) species. However, the label requires users to access an endangered species website that identifies areas of the United States where gas cartridges cannot be used due to T&E species concerns (USEPA 2016a). This website is partially populated with restrictions for some T&E species and updated as additional EPA requested Section 7 consultations are completed. WS also requests local consultations with U.S. Fish and Wildlife Service. Together, the USEPA (2016a) and WS consultations should mitigate risk of gas cartridges use for specific T&E species. Similarly, WS would not use FGFS where T&E species could be affected.

3.2.1 Aquatic Effects Analysis

The toxicity of charcoal is low to aquatic species. The N_2 byproduct does not produce a biological hazard. N_2 is slightly soluble in water and becomes part of the various nitrogen cycles. CO_1 is a gas and is not soluble in water. The chemical and physical properties of CO_1 are not an aquatic concern, with no potential to cause aquatic effects.

3.2.1.1 Fish and Amphibians

Studies suggest $NaNO_3$ is not toxic to fish. For $NaNO_3$, the 96-hour LC_{50} values for the bluegill and rainbow trout as well as other fish species, were greater than 100 mg/L, a very high level (OECD 2007). Symptoms in rainbow trout exposed to levels above 1,600 mg/L $NaNO_3$ included mobility problems and labored respiration (OECD 2007).

Studies indicate low toxicity of $NaNO_3$ to amphibian embryos. The 10-day LC_{50} for the Pacific treefrog (*Pseudacris regilla*) embryos was 578 mg/L $NaNO_3$. The sodium nitrate LC_{50} for the African clawed frog (*Xenopus laevis*) embryos ranged from 438.4 to 871.6 mg/L (Schuytema and Nebeker 1999). After 2-3 days exposure to 1000 mg/L $NaNO_3$, embryos from both frog species remained motionless. LOAEL based on length and weight was 110 mg/L $NaNO_3$ for the treefrog (Schuytema and Nebeker 1999). The LOAEL for the clawed frog was 111 mg/L and 56.7 mg/L $NaNO_3$ based on length and weight, respectively (Schuytema and Nebeker 1999). Exposure of European common toad (*Bufo bufo*) and Australian green tree frog (*Litoria caerula*) tadpoles to 40 and 100 mg/L of $NaNO_3$ under laboratory conditions reduced feeding and caused weight loss (Baker and Waights 1993, 1994). Table 6 and Section 2.4 provide a summary of several $NaNO_3$ toxicity studies. In a 96-hour-chronic exposure study, the ammonium nitrate fertilizer (not $NaNO_3$) LC_{50} for tadpoles of several amphibian species was between 13.6 and 39.3 mg/L (Hecnar 1995), suggesting moderate toxicity of tadpoles to nitrate (ammonium nitrate fertilizer produces both the ammonium cation and nitrate anion in solution). Behavioral and physical effects, particularly at high concentrations of ammonium nitrate fertilizer, include reduced feeding, weight loss, eye deformities, loss of pigment, bent tails, less vigorous swimming, and reduced response to stimuli (Hecnar 1995).

Sulfur is practically nontoxic to aquatic species. A study using 99.5% sulfur dust found that LC_{50} values for two fish species, bluegill and rainbow trout were greater than 180 ppm (Extension Toxicology Network 1996). A study using 90% sulfur found that the 48-hour LC_{50} for daphnia (*Daphnia* spp.) was greater than 5,000 ppm and the 96-hour LC_{50} for mysid shrimp (Order Mysida) was greater than 736 ppm (Extension Toxicology Network 1996).

SO_2 is soluble in water, forming sulfuric acid (USEPA 2007b). Dissolved SO_2 could be toxic to aquatic life (USEPA 2007b). Studies on the toxicity levels of SO_2 lethal to fish species report concentrations of 16 to 19 ppm lethal to sunfish (*Lepomis* spp.) in 1 hour exposure; 10 minutes of exposure at 10 ppm in tap water was lethal to trout; and 1 hour of exposure at 5 ppm killed trout (NIH 2016).

SO_3 also forms from the pyrolysis of The Giant Destroyer gas cartridge, but rapidly reacts with water to form sulfuric acid (ATSDR 1998b). Sulfuric acid rapidly degrades in the environment to sulfate salts (USEPA 1993). The dissociation of sulfuric acid releases hydrogen ions in the environment, increasing the pH of water (USEPA 1993), which can cause a loss of fish.

Na_2CO_3 can affect the pH of aquatic and terrestrial ecosystems. Its effect on ecosystems and its acute toxicity to aquatic organisms depends on the buffering capacity of the ecosystems. Mortality for amphipods (Order Amphipoda) occurs at concentrations higher than 100 mg/L (OECD 2002). In one study, the LC_{50} for amphipods was 360 mg/L over a 24-hour period (Dowden and Bennett 1965). Bluegill had an LC_{50} value of 385 mg/L exposure over 24-hour period (Dowden and Bennett 1965). Lethal effects for salmon and trout *(Onchorhynchus* and *Salmo* spp.) occurred at 67-80 mg/L, but these studies had low reliability (OECD 2002) (Table 7).

3.2.1.2 Aquatic Invertebrates and Plants

$NaNO_3$ is relatively nontoxic to *Daphnia magna* with a 48-hour EC_{50} value of 490 mg/L (OECD 2007). Net-spinning caddisflies (*Cheumatopsyche pettiti* and *Hydropsyche occidentalis*) are freshwater invertebrates common in rivers and streams in North America. In short-term toxicity studies for $NaNO_3$, the 72, 96, and 120-hour LC_{50} values were 148.5, 97.3, and 65.5 ppm NO3-N, respectively, for the early instar of *H. occidentalis* and 183.5, 109.0, and 77.2 ppm NO3-N for the last instar of *H. occidentalis* (Camargo and Ward 1992). For *C. pettiti* the 72, 96, and 120-hour LC_{50} values were respectively 191.0, 113.5, and 106.5 ppm NO3-N for the early instar and 210.0, 165.5, and 119.0 ppm NO3-N for the last instar (Camargo and Ward 1992). Both species retreated from their capture nets and their anal papillae protruded as $NaNO_3$ concentrations increased (Camargo and Ward 1992).

Sulfur is practically nontoxic to *Daphnia* spp. and mysid shrimp (USEPA 1991d).

Na_2CO_3 was not acutely toxic to mosquito (*Culex* sp.) larvae exposed to 1,820 mg/L over a 24-hour period (Dowden and Bennett 1965). Similarly, $NaCO_3$ is relatively nontoxic to *D. magna* and eggs of freshwater snail *(Lymnaea* sp.), with LC_{50} values of 347 mg/L and 403 mg/L, respectively, when exposed to $NaCO_3$ over a 24-

hour period (Dowden and Bennett 1965). $NaCO_3$ can increase the alkalinity of the water, which can cause a decline in aquatic plant health.

Emissions of SO_2 contribute to the deposition of sulfuric acid, which can acidify water bodies. This in turn can decrease the abundance of aquatic invertebrates (Driscoll et al. 2003). Green plants can be sensitive to atmospheric SO_2. In exposure studies of non-aquatic, terrestrial plants, alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), cotton (*Gossypium* spp.), and wheat (*Triticum* spp.) are potentially injured at levels between 0.15 and 0.20 ppm of atmospheric SO_2, while potatoes (*Solanum tuberosum*), common onions (*Allium cepa*), and corn (*Zea mays*) are much more resistant (NIH 2016). The dissociation of sulfuric acid releases hydrogen ions in the environment, increasing the pH of water and soil potentially causing a decline in plant health (USEPA 1993).

3.2.2 Terrestrial Effects Analysis

Charcoal, $NaNO_3$, SO_2, SO_3, N_2, $NaCO_3$, and CO_1 that are available in open terrestrial environments are generally nontoxic to most wildlife species, but toxicity depends on concentrations, wildlife characteristics, and the physical and chemical qualities of the air and soil (e.g., temperature, moisture).

3.2.2.1 Mammals

CO_1 is a lethal gas to all mammals and exposure can lead to death, depending on the concentration of the gas and length of exposure. In acute oral inhalation tests over a 4-hour period, LC_{50} values for rat, mouse, and guinea pig were 1,807 ppm, 2,444 ppm, 5,818 ppm, respectively (NIH 2016) (Table 5). Exposure of rats to high levels of CO_1 (1500-2500 ppm) for 90 minutes caused hypertension, hypothermia, unconsciousness, and behavioral changes indicating central nervous system damage (Penny et al. 1993 cited in Raub, 1999, p. 81). Continual exposure of rats to 200 ppm CO_1 during the last 18 days of gestation caused a decrease in litter size and birth weights (Raub, 1999). Weanling domestic pigs exposed to 300 ppm CO_1 (a nonlethal level for pig) decreased their food intake and had reduced body weight gain compared to the control by day 10 and 21 (Morris et al. 1985).

$NaNO_3$ generally has low toxicity to mammals (NIH 2016). Section 2.4 and Table 6 summarizes several toxicity studies for mammals. The lowest acute oral LD_{50} values were 1267mg/kg in rats, 2,480 mg/kg in mice, and 1,600 mg/kg in rabbits (NIH 2016). Ruminants have a lower toxicity level due to the microbial conversion of nitrate to nitrite, particularly if a high dose was administered within a short time period. Cows had an LD_{50} of 450 mg $NaNO_3$/kg following a single oral dose whereas the LD_{50} was 970-1,360 mg/kg when the total dose was administered over a 24 h period (IPCS 1996).

Sulfur has low toxicity to mammals (Extension Toxicology Network 1996), and some studies are summarized in Table 7. In separate studies, sulfur had oral LD_{50}s of greater than 5,000 mg/kg and 8,437 mg/kg for rats. In studies of single oral doses of 98% sulfur, no deaths occurred for rats given 5,000 mg/kg and rabbits 2,000 mg/kg. The dermal LD_{50} for rats was greater than 5,000 mg/kg. The acute inhalation LC_{50} for 98% sulfur in rats is greater than 2.56 mg/L and greater than 5.74 mg/L for 80% sulfur. The acute dermal LD_{50} in rabbits was greater than 2,000 mg/kg at 98% sulfur. Irritation to rabbit eyes after applying 98% sulfur cleared six days after treatment. The decline in vertebrate populations near industrial sites that emit high concentrations of SO_2 indicates that high concentrations of SO_2 may affect vertebrates (Paoletti et al. 1996).

Na_2CO_3 has low to negligible toxicity to mammals (OECD 2002). Toxicity studies are summarized in Table 8 and Section 2.4. The alkalinity of Na_2CO_3 can be an irritant to eyes (Table 8).

3.2.2.2 Birds

In adult male white leghorn chickens, CO_1 at 0.1% for 60 minutes caused an increase in tidal and minute volumes and a decrease in blood pressure (COHb concentration of 39%) (Tschorn and Fedde 1974). An increase to 0.5% CO_1 was lethal after an average of 20.5 minutes (COHb concentrations of 52% in 15 minutes) (Tschorn and Fedde 1974).

Acute and chronic toxicity studies for $NaNO_3$ in birds are limited. Dietary exposure of 15 male chickens to 4.2 g/kg $NaNO_3$ reduced weight gain, adversely effected growth and immunological status, and impaired liver and kidney functions (Atef et al. 1991). Exposure of young (between one and 30-day old) Japanese quail (*Coturnix japonica*) to 5,280 ppm or more $NaNO_3$ in drinking water caused death of all birds by day four in two of three experiments (Adams 1974). Exposure of quail to 3,960 ppm or less did not affect cumulative mortality by day seven or affect weight gain and egg production (Adams 1974).

Sulfur is nontoxic to birds. In an 8-day dietary study, northern bobwhite had an LC_{50} greater than 5,620 ppm for a 95% sulfur wettable powder formulation (Extension Toxicology Network 1996).

Exposure of 17 male white leghorn chickens to 100 ppm SO_2 for 1-hour did not cause death, but did alter the heart rate, blood pressure, tidal volume, respiratory frequency, or arterial blood gases and pH (Fedde and Kuhlmann 1979). Exposure to 1,000 ppm caused death for two out of 13 birds while exposure to 5,000 ppm caused death in all but one bird. A SO_2 concentration of 100 ppm is a very high; for comparison, typical outdoor concentrations of SO_2 may range from zero to 1 ppm (ATSDR 1998a).

Na_2CO_3 has low toxicity to birds. Environmental fate studies of Na_2CO_3 focus on the water phase of amphibians, fish, and aquatic invertebrates and not birds because it readily adsorbs to sediment and dissociates into sodium and carbonate ions in water.

3.2.2.3 Reptiles and Amphibians (*Terrestrial Phase*)

Several reptile and amphibian species spend time underground in tunnels built by other animals, and may even change the existing burrow for their purpose (Halliday and Adler 1986 cited in Kinlaw 1999). Toxicity data for birds serves as a surrogate for toxicity data for reptiles. Similarly, toxicity data for fish and aquatic phase amphibians is a surrogate for terrestrial phase amphibians.

3.2.2.4 Terrestrial Invertebrates and Microorganisms

Insects are generally resistant to CO_1. CO_1 at 100 ppm had negligible effects on the behavior, health, and biological functions of annelid worms (*Enchytraeus* spp.), orange-banded arion (land slug) (*Arion fasciatus*), common woodlouse (*Tracheoniscus rathkei*), millipede (*Diploiulus* sp.), harvestmen spiders (*Liobunum calcar*), and several other invertebrates of forest litter (NIH 2016). Exposure of ladybirds (*Coccinella septempunctata*) and stick insects (*Carausis morosus*) to high levels of CO_1 (80% CO_1, 20% oxygen) for 20 days resulted in the death of all insects. By day two of the study, both insect types exposed to 80% CO_1 consumed less food than the controls. The ladybirds were less active by the first day. Exposure to 20% CO_1 caused death of all insects within 37 days compared with 36% of the control insects, which may be partly from starvation as the insects displayed a lack of energy at this CO_1 exposure level (Baker and Wright 1977). Exposure of stick insects to 20% CO_1 arrested the insect's growth and regeneration of lost limbs, whereas the control group had normal growth and limb regeneration. In these experiments, between 7% and 41% of the ladybirds and stick insect in the control group died.

Sulfur is practically nontoxic to honey bees (USEPA 1991d).

Toxicity studies on the effects of $NaNO_3$, Na_2CO_3, sulfur and SO_x to terrestrial invertebrates and microorganisms are lacking.

3.2.2.5 Terrestrial Plants

Terrestrial plant toxicity data is limited. The use pattern and environmental fate of the formulation and byproducts of the gas cartridges suggest low toxicity to plants. Several degradates of gas cartridges are important for plant growth. However, concentrations of SO_2 as low as 1-2 ppm have caused severe stress to green plants (USEPA 2007b).

4 EXPOSURE ASSESSMENT

The exposure assessment begins with the use and application method of the gas cartridge and FGFS. For gas cartridges, the WS applicator locates an active burrow of the target species and insures that a gas cartridge will fit inside. Holes are poked with a nail into one end of the gas cartridge at predesignated sites, which are illustrated on the cap. A fuse is placed in the center hole. The applicator lights the fuse, with the fuse pointing away and inserts the cartridge fuse-end first inside the burrow. Once the cartridge is in place, the applicator covers the burrow with paper or debris (e.g., moss, twigs, or leaf litter) to prevent smothering the cartridge with dirt or closing a burrow. Next, they pour dirt on top (usually from a bucket) to seal the hole. The applicator waits for the cartridge to ignite. The pyrolysis of the cartridge is audible even with the dirt on top. Adjacent holes and the area around the burrow treated are monitored for gas release, which with gas cartridges is a bright yellowish color gas, and cover these holes with dirt to minimize gas loss. The exposure pathway for gas cartridge includes (1) gas release from the gas cartridge, (2) an exposure point where contact can occur, and (3) an exposure route such as ingestion or inhalation by which contact can occur (USEPA 1989).

For FGFS, the applicator finds an active burrow of the target species. About a foot away, in the direction of the burrow, the applicator inserts a probe into the ground until the burrow is found (the probe slides easily when it enters a burrow). The active opening is mostly covered with dirt, except for a small opening. The gas is pumped into the burrow system. When it is obvious that the probe is in the burrow (gas escaping from the burrow blows dirt), the burrow opening is completely covered with dirt from a bucket. The area and adjacent openings are monitored for gas release. The burrow is fumigated for about three minutes, but several hoses can be operated together.

4.1 Human Health Exposure Assessment

The human health exposure assessment estimates the potential exposure of humans to the formulation ingredients and byproducts of the gas cartridge. WS personnel who handle gas cartridges and FGFS are the most likely population at risk of exposure to CO_1, the formulations, and byproducts. The public, such as residents, are not a potentially exposed population given the WS use pattern, especially because an applicators are present when gas cartridges and FMGS machines are used and these products are not used near occupied structures.

Human exposure to the formulation for gas cartridges and the byproduct CO_1, and SO_x from The Giant Destroyer is minimized in three ways following label instructions. First, the labels prohibit use in or under buildings. Second, pre-packaged gas cartridges remove dermal contact with the formulation since cardboard surrounds the product. Last, combustion occurs below ground in an enclosed burrow or den, removing the applicator's exposure to CO_1 and SO_2. Thus, WS personnel are unlikely to make dermal contact with the formulation or inhale CO_1 (or SO_x from The Giant Destroyer gas cartridge) during its intended use.

Human exposure to CO_1 from FGFS is low to negligible. The big difference between FGFS and gas cartridges is that the FMGS delivers CO_1 under pressure and has a higher likelihood of affecting structures close to burrow systems (Eisemann et al. 2016). Various distances from a PERC machine to an occupied structure have been suggested for moles (150 feet), gophers and prairie dogs (100 feet), and ground squirrels and field mice (50 feet) (Eisemann et al. 2016). Other than potential exposure in a structure adjacent to a burrow system, the PERC machine meets California EPA standards and is safe to use around children, pets, and gardens.

Accidental exposure of WS personnel to the formulation may occur if the cartridge opens and some of the contents spill on to the skin or close to the applicator's face, exposing airways or eyes to the formulation. The particulates of $NaNO_3$, borax, and fuller's earth, as well as sulfur in The Giant Destroyer, could irritate airway passages and eyes. Exposure to the entire contents of the gas cartridge at one time is unlikely; rather, the applicator would likely meet only a portion of the formulation.

Exposure to CO_1 after combustion of the gas cartridge may occur; however, exposure is unlikely since pyrolysis occurs below ground and these cannot be. Exposure to CO_1 from the PERC machine is also unlikely since the burrow entrance is covered as soon as gas can be seen escaping. CO_1 remains in the burrow for the most part. Exposure of WS applicators to CO_1 could occur when they cover other holes where gas is escaping. However, WS applicators stay upwind and the gas rapidly dissipates in the open air. Pyrolysis that occurs before the applicator covers the burrow or den opening with soil may cause an escape of CO_1, but the applicator will move away from the opening where CO_1 concentrations are greatest. The fuse for gas cartridges has a minimum 5-second burn time until pyrolysis, which allows plenty of time to cover the burrow. As with CO_1, exposure to SO_x from the burning of The Giant Destroyer's cartridge is unlikely because of the use pattern; however, burning before covering the burrow or den opening may cause an escape of SO_x.

In WS WDM, accidental exposure to $NaNO_3$ would be of low frequency and short duration. WS did not report any spillage of gas cartridge formulation from FY06 to FY15. USEPA (2015) summarized incident data kept by the Association of American Poison Control Center. Between 1993 and 2005, 958 incidents involved sulfur, of which 167 involved The Giant Destroyer, with none involving WS (USEPA 2015). WS is an infrequent user and is not the only user of The Giant Destroyer gas cartridge. Home and garden shops sell the product to the public. Other pesticide applicators such as state wildlife personnel and commercial extermination companies also use the product. Thus, the total number of The Giant Destroyer gas cartridges used during these any year is unknown and, therefore, the frequency of incidents cannot be estimated. Between FY11 to FY15, WS used an annual average of five Giant Destroyer gas cartridges compared to 4,967 Gas Cartridges and 1,110 Large Gas Cartridges (Table 4).

The WS use pattern makes dietary exposure to the formulation or byproducts unlikely. Consumption of target animals taken with gas cartridges is unlikely since people typically do not harvest these animals for consumption. However, should this occur, the CO_1 levels inside the animal would dissipate quickly, and consumption of animals recently taken by exposure to CO_1 would not be a risk to humans. In rats with a pre-exposure COHb level of 3%, COHb levels measured 9% 45-60 minutes after a 2-hour exposure to 200 ppm CO_1 (Penn et al. 1992). In male chickens, after a 2-hour inhalation exposure to 200 ppm CO_1, the clearance half time was only 13.8 minutes; after 60 minutes, serum COHb levels were back to baseline levels (Penn et al. 1992).

As described in the environmental fate section (Section 2.3), the formulation and byproducts occur naturally in the environment and assimilate into natural processes. The gas cartridge formulation and byproducts are unlikely to accumulate in vegetation growing nearby a burrow or den. Chemical residue on aboveground plant parts is also unlikely since pyrolysis occurs below ground. Thus, there is no exposure pathway for dietary plant consumption or dermal contact to plants. The labels for the Gas Cartridge and The Giant Destroyer specify use in non-crop areas, indicating no risk of exposure to the formulation and byproducts through agricultural crops. The label for the Large Gas Cartridge indicates use on crop and non-crop areas.

The fuse in a gas cartridge burns for a minimum of five seconds before pyrolysis occurs (3" of fuse are to be exposed at a minimum per label directions). Gas cartridges that fail to combust after placement would eventually break down. In turn, the formulation would break down and enter natural elemental cycles. If pyrolysis does not occur, which is typically audible, an employee may dig up the cartridge. It is unlikely that the fuse would fall out of the cartridge during placement. In one study, 100% of the 524 gas cartridges set in northern pocket gopher burrows burned after lighting the fuse (Matschke et al. 1995). It is unlikely that a person other than the applicator would dig up an unignited gas cartridge; thus, it is unlikely that direct contact with the gas cartridge and subsequent exposure would occur.

The proper use and function of gas cartridges remove the exposure pathway for groundwater or surface water. The environmental fate for the formulation ingredients and byproducts indicate assimilation into the natural chemical cycles. Although $NaNO_3$ is soluble and can leach from soil to groundwater (see Section 2.3), the release of $NaNO_3$ into the environment is unlikely given the pyrolysis success rate of gas cartridges (Matschke et al. 1995). CO_1 is not soluble in water. SO_x are soluble in water, and form sulfurous acid and sulfuric acid. Sulfuric acid rapidly degrades to sulfates in the environment. Groundwater and surface waters contain SO_x, sulfate, and other forms of sulfur naturally or from anthropogenic sources such from the burning of fossil fuels. The byproduct from Na_2CO_3 is also soluble in water.

Gas cartridges have a fuse time of 5 seconds. An accidental exposure may occur for applicators if their skin or clothing touches the burning fuse or if the cartridge ignites before they place it in the burrow or den. The discussion of uncertainties in Section 6 further evaluates the accidental exposure scenario.

4.2 Ecological Exposure Assessment

The ecological exposure assessment estimates the exposure of nontarget species to the formulation ingredients and byproducts of the gas cartridge. The most likely population at risk of exposure to gas cartridge formulation and byproducts according to WS use in WDM are species within a few meters of a burrow system treated with a gas cartridge or FGFS (Nolte et al. 2000). Burrow systems vary in width and length and, thus, volume. The higher the volume, the more likely the possibility of needing to use more than one gas cartridge in a burrow.

Following label instructions minimizes exposure of nontarget species to the formulation and CO_1, as well as SO_x from The Giant Destroyer, in several ways. First, pre-packaged gas cartridges remove dermal contact with the formulation. Second, combustion occurs at least five seconds after placement of the cartridge, reducing the likelihood that an animal would dig up and eat the formulation. Third, combustion occurs below ground in an enclosed burrow or den, eliminating exposure to CO_1 and SO_x to species not inside the burrow or den. Finally, label instructions reduce exposure risk to nontarget species by limiting application to certain times of year to avoid burrow cohabitation periods or locations where T&E species occur (USEPA 2016a). Following these same basic guidelines for use of the PERC machine or other FGFS, also reduces risk to nontarget species. Several T&E species (USEPA 2013a, 2016a) burrow and could be impacted by gas cartridges and CO_1 from an FGFS. Species such as the Utah prairie dog (*Cynomys parvidens*), Columbia Basin pygmy rabbit (*Brachylagus idahoensis*), black-footed ferret, New Mexico ridge-nosed rattlesnake (*Crotalus willardi obscurus*), desert tortoise (*Gopherus agassizii*), Wyoming (*Anaxyrus baxteri*) and Houston (*A. houstonensis*) toads, and California (*Ambystoma californiense*) and Sonoran tiger salamanders (*A. mavortium stebbinsi*) use burrows and, therefore, burrows are not treated in their potential range unless WS has mitigation measures from the U.S. Fish and Wildlife Service in a Section 7 consultation that allow use under certain conditions.

4.2.1 Aquatic Exposure Assessment

Aquatic ecosystems at risk include water bodies adjacent to, or downstream from, the treated burrow or den. The anticipated use of gas cartridge and FGFSs in WS WDM reduces the possibility of significant exposure in aquatic environments. The design and use of gas cartridges mitigates offsite transport of $NaNO_3$ from drift and reduce the potential for any run-off to aquatic systems. Applicators place cartridges inside burrows or dens, and the soil around the treatment area serves as a buffer. Few burrows or dens of target species are close to water bodies because they would become flooded from groundwater near the water body. Some runoff could occur if gas cartridges break open and the formulation spills on the soil surface or into a nearby water source. The runoff from this scenario would be minimal at most, resulting in negligible estimated residues. Most gas cartridges remain intact and burn after placement. One study showed an efficacy of 100% burn rate for gas cartridges inside burrows (Matschke et al. 1995), indicating a high probability that the formulation would remain inside the burrow. The byproducts CO_1 and N_2 enter their respective cycles. The byproduct Na_2CO_3 has low toxicity and its greatest impact is its alkalinity. In the environment, the alkalinity of Na_2CO_3 can change the pH of water depending on its concentration, affecting aquatic animals (OECD 2002). Na_2CO_3 occurs naturally in soil and water, and is unlikely to adversely affect wildlife, nontarget organisms or water resources (USEPA 2006). CO_1 from an FGFS will not affect aquatic ecosystems.

SO_x are soluble in water and already occur in water bodies, originating from natural and anthropogenic (e.g., burning of fossil fuels) sources.

4.2.2 Terrestrial Exposure Assessment

The primary exposure pathway for CO_1 to terrestrial wildlife and domestic animals is through inhalation. Exposure to CO_1 may occur for those animals that are near a gas cartridge or FGFS deployment site. In a sampling study, 82 species of invertebrates occupied black-tailed prairie dog burrows in Oklahoma (Wilcomb 1954 cited in Kinlaw 1999). Researchers identified 14 species of reptiles, 22 families of insects, and six orders of non-insect arthropods using banner-tailed kangaroo rat (*Dipodomys spectabilis*) burrows in New Mexico (Hawkins and Nicoletto 1992). Researchers found 66% of burrowing owls surveyed in Oklahoma were found in prairie dog burrows despite the small area (0.16%) occupied by these burrows in the study area (Butts and

Lewis 1982). Potential nontarget mammals known to occupy burrows of woodchucks, prairie dogs, ground squirrels, or pocket gophers include eastern chipmunks, other chipmunks (*Neotamias* spp.), kangaroo rats (*Dipodomys* spp.), pocket mice (*Perognathus* spp.), deermice (*Peromyscus* spp.), jumping mice (*Zapus* spp.), voles, other ground squirrels, cottontails, shrews, moles, raccoons, foxes, weasels, skunks, opossums, and nine-banded armadillos (Grizzell 1955, Vaughan 1961, Schmeltz and Whitaker 1977). Other species found in pocket gopher burrows in Colorado included several species of toads (*Anaxyrus* spp.), lizards, snakes, and ornate box turtles (Vaughan 1961). If any of these species are cohabitating with the target species, they could become a nontarget species killed since CO_1 in the burrow system will likely kill them too. Many nontarget vertebrate species are likely living in unoccupied rodent burrows, which WS avoids during treatment.

In a study to determine the efficacy of camera probes and retrieval hooks for exploring California ground squirrel burrows following a treatment with toxicants and retrieving their carcasses, Vercauteren et al. (2002) found that this system could be used. The study was most interested in determining whether animals would be found within 2 meters of the burrow entrance, which coincides with the area the researchers believed would have the highest opportunity for secondary poisoning from the toxicants used. Two days after treatment, the researchers probed 654 burrows; 104 burrows could only be probed to less than one meter due to obstructions and 550 to greater than or equal to one meter. They found 45 California ground squirrels: 31 dead, 9 dying, and 5 healthy. Of interest though, they also found one dead western harvest mouse (*Reithrodontomys megalotis*), a clutch of burrowing owls, three side-blotched lizards (*Uta stansburiana*), three western diamondback rattlesnakes, and one gopher snake. Of the burrows they surveyed, it was likely that additional ground squirrels and nontarget species were further in the burrow system (Vercauteren et al. 2002). The camera were much easier than using hand shovels or backhoes to dig up the burrow system, but they had difficulties getting the camera into some burrows and going beyond two meters in any burrows because the camera was difficult to maneuver. However, for a relative frequency of nontarget species in the California ground squirrel burrows, they found one for every five ground squirrels found, or a nontarget vertebrate for 1.4% of the burrows probed.

In a similar study of black-tailed prairie dog burrows, Witmer et al. (2006) probed 777 burrows, 460 active and 317 inactive, to a depth of three meters using similar cameras in natural grasslands and urban/suburban areas. Black-tailed prairie dog burrows are typically 12 meters in length, two to three meters in depth, 10-15 cm in diameter, and average two openings; many have enlarged nest areas and sometimes plugged areas (Sheets et al. 1971). Witmer et al. (2006) and Sheets et al. (1971) found little vertebrate usage of burrow systems, other than prairie dogs, but that invertebrates were common consisting of beetles and crickets mostly, and to a lesser extent sow bugs, spiders, and fleas. Thus, it is believed that nontarget species could be killed by gas cartridges, but numbers should be minimal.

The exposure pathways for $NaNO_3$ from gas cartridges is most likely through the oral, dermal, and, possibly, inhalation routes from spilled formulation and its dust or from intake of contaminated drinking water; however, these pathways are minor since aquatic residues would be below concentrations that could result in adverse effects. However, oral or dermal exposure to $NaNO_3$ is unlikely as the compound is sealed inside the cartridge and only broken when an end is opened with a nail; at that time, a fuse is inserted and then it is lit and placed into a burrow. However, $NaNO_3$ degrades in the environment and is not volatile unless burned.

Terrestrial exposure to Na_2CO_3 at lethal doses is not expected. Na_2CO_3 resulting from pyrolysis of the gas cartridge will settle in the soil inside the burrow likely at the place of the gas cartridge. As described in the environmental fate Section 2.3, Na_2CO_3 dissociates in water to sodium and carbonate ions (OECD 2002). The ions do not adsorb on particulate matter or accumulate in living tissues (not bioaccumulable) (OECD 2002).

Species passing through the burrow or den after treatment may come in dermal contact with Na_2CO_3. Na_2CO_3 occurs naturally in soil and water and is unlikely to affect adversely wildlife, nontarget organisms or water resources (USEPA 2006).

The labels for the gas cartridges require applicators to watch for target animal activity through direct observation or evidence such as tracks, scat, and spider webs before treating a burrow or den. The labels also require applicators to check all burrows and dens for signs of nontarget vertebrate species, and not to treat if present.

In areas with T&E species considerations, the label limits the use of gas cartridges to qualified individuals (e.g., wildlife biologists, certified applicators, representatives from State or Federal agencies, etc.) trained to distinguish dens and burrows of target species from those of nontarget species. The label or website provides restrictions on the treatment of burrows and dens in areas inhabited by federally listed T&E species (USEPA 2016a)[6]. For example, Gas Cartridge (EPA Reg. No. 56228-2 and 56228-61) labels restrict the use of the gas cartridges in several California counties between October 1 and April 15 to protect the federally listed blunt-nosed leopard lizard (*Gambelia silus*). In addition, use of cartridges from April 15 through September 30 is limited to daylight hours when air temperatures are between 77-95 °F. The current gas cartridge label lists 17 federal T&E species to avoid. The T&E species and restrictions will be listed at USEPA (2016a) when the consultation is completed. These lists and guidance are followed when a FGFS apparatus is used.

The exposure risk to nontarget animals from using gas cartridges to control coyote, red fox, and striped skunk dens is lower since these species usually do not tolerate other species in their burrows and are not likely to be found in active dens. In addition, most applications occur during the spring when pups are present, limiting the exposure period to one time of the year. In addition, dens are larger and may be easier to check for nontarget animals than rodent burrows.

Take of nontarget species occurs with CO_1 fumigation (Dolbeer et al. 1991), but was not documented by WS between FY11 and FY15. Without excavating the burrows, WS would not know the nontarget species taken. In one study that did excavate burrows treated with gas cartridges, the treatment of 97 woodchuck burrows took 4 nontarget animals - one juvenile eastern cottontail rabbit in a burrow and three deermice in two other burrows (Dolbeer et al. 1991). Following the Dolbeer et al. (1991) study, it would be expected that if 4 nontargets were taken for every hundred burrows treated, WS could have taken an average of about 180 nontarget animals in the 4,512 rodent burrows treated each year (about 2% of total estimated take). It is expected that predator burrows would have fewer nontargets, because most would be eaten if captured by the target species. However, if nontarget take was similar for predator dens as with rodent burrows, the average 660 dens treated would have had 26 nontarget species taken each year (about 1% of total estimated take). Considering the potential nontarget species that could be present at sites where WS personnel used gas cartridges and the PERC machine, it is assumed that nontarget take was minimal. A factor that reduces nontarget species take includes examination of dens and burrows treated for the presence of the target species and no nontarget species. Additionally, gas cartridges and FGFSs are not used in the range of burrowing T&E species unless mitigation measures are in place; thus, since nontarget take during WS' use is likely minimal, it would be insignificant to any species' populations.

[6] USEPA (2016a) is being updated; the USEPA plans to initiate Section 7 consultations for additional species with U.S. Fish and Wildlife Service, and to update the restrictions as consultations are completed.

Dietary exposure to scavengers that consume animals that have received a lethal dose of CO_1 is unlikely, because most animals die inside the burrows or dens and are not accessible to aboveground scavengers. Where a target animal dies above ground or is scavenged underground by animals that will go into burrows such as badgers and invertebrates, no risks are expected. Species that consume the flesh of species killed with CO_1 will not be affected because CO_1 dissipates from the carcasses rapidly. In addition, CO_1 does not bioaccumulate or persist in the target organism.

5 RISK CHARACTERIZATION

Risk characterization combines information from the dose-response (Section 3) and exposure (Section 4) assessments.

5.1 Human Health Risk Characterization

This section provides a qualitative characterization of the risks of gas cartridges to human health. The WS use pattern for gas cartridges should pose minimal risks to human health.

The exposure assessment identifies WS personnel as the population at risk of exposure to gas cartridges and FGFSs. Exposure of WS personnel to the formulation within gas cartridges or to the byproducts from pyrolysis would be minimal, especially following the label and usage instructions. Exposure to CO_1 from gas cartridges or an FGFS will be negligible.

An accidental break of the gas cartridge during handling would release formulation. Should this occur, it is unlikely that entire contents would spill on the applicator's skin or contact the eyes and airway passages. Acute toxicity studies for $NaNO_3$ indicated it is an eye irritant , causes slight dermal irritation, and has some low-level acute dermal effects; however, $NaNO_3$ poses relatively low acute oral toxicity hazards (Toxicity Category III) (USEPA 1991a). Inhalation of technical grade (100%) $NaNO_3$ may cause irritation to the respiratory tract, which could lead to methemoglobinemia, cyanosis, tachycardia, labored breathing, and death (Fisher Scientific 2001). However, applicators are unlikely to inhale quantities sufficient to evoke these symptoms should a cartridge break open. Chronic (prolonged) exposure to $NaNO_3$, which is highly unlikely to occur with gas cartridges, may cause anemia and methomoglobinemia, and are expressed by dizziness, drowsiness, headache, labored breathing, and increased heart rate (Fisher Scientific 2001). Charcoal is of low or no toxicity to humans (USEPA 1991b). Sulfur, part of the formulation in The Giant Destroyer gas cartridge, has minimal acute or chronic toxicity to humans based on several mammalian toxicity studies (see Section 2.4). APHIS does not expect the formulation to contact applicators because the cartridge is unlikely to break open. Should a cartridge break open, a small amount of formulation would spill and the duration of exposure would be short and the contents are unlikely to harm the user. The labels do not require the user to wear Personal Protective Equipment (PPE) to use gas cartridges, but most WS personnel wear long pants and closed shoes in the field, and often wear gloves. The use of these would further reduce the potential for exposure, which is already minimal.

Exposure to CO_1 during pyrolysis of the gas cartridge or its production in an FGFS apparatus may cause harm to applicators; however, exposure is unlikely since pyrolysis occurs below ground for gas cartridges and a hose with a probe attached from the PERC machine is inserted into burrows before CO_1 is allowed to flow. Pyrolysis that occurs before the applicator covers the burrow or den with soil may cause an escape of small quantities of CO_1, but applicators will move away from the opening where CO_1 concentrations are greatest. In humans, exposure to 0.32% CO_1 and 0.45% CO_1 for 1 hour will induce unconsciousness and death, respectively (Bloom 1972, AVMA 2013). The IDLH for CO_1 in humans is 1,200 ppm based on acute inhalation toxicity data in humans, including nonlethal symptoms at 1-hour exposure to 1,000 to 1,200 ppm CO_1 and potentially lethal reaction at 1-hour exposure to 1,500 to 2,000 ppm CO_1 (CDC 1994). In humans, the most common symptoms of CO_1 poisoning are headache, nausea, vomiting, confusion, and flu-like illness (Piantadosi 2004). Although CO_1 is an inhalation hazard to humans, the low potential for exposure to CO_1 from gas cartridges suggests that a risk to applicators is negligible. The concentration and exposure time would be insufficient to cause harm to the applicator.

The exposure scenario for SO_x is similar to the scenario for CO_1 (see above). SO_x concentrations and exposure time would be insufficient to cause harm to the applicator, as they will move away from the burrow or den opening. OSHA sets threshold limit values for SO_2 in atmospheric air as 2 ppm for a normal 8-hour workday or 40-hour workweek; repeat exposure to this amount will not have adverse effects. Five parts per million of SO_2 is a maximum concentration that should not be exceeded at any time during a 15-minute exposure period (CDC 1974). Exposure to SO_2 from the pyrolysis of The Giant Destroyer gas cartridge may cause temporary irritation to mucus membranes, but the applicator will move away from the concentrated product. Sulfuric acid can be irritating to the respiratory tract, eyes, and skin (ATSDR 1998b). People exposed to sulfuric acid for one hour or more reported feeling dizziness, fatigue, and headaches. This study included the exposure of asthmatic volunteers to 0.999 mg/m^3 sulfuric acid aerosol for one hour (ATSDR 1998b). The applicator exposed to SO_x from gas cartridges may temporarily experience irritation to the eyes and skin.

Based on toxicity studies, Na_2CO_3 and N_2 formed from the pyrolysis of one gas cartridge is unlikely to be harmful to the applicator.

Injury to applicators may occur if gas cartridges start to burn in their hand or near them, with the potential to cause severe burns. The label warns users to hold cartridges away from face, hands, and clothing because it burns vigorously and can cause severe burns. The fuse time of 5 seconds gives the applicator time to place the gas cartridge inside the burrow and cover the hole with soil.

APHIS received no reports of accidental exposures of WS personnel or the public to the formulation or byproducts of gas cartridges and PERC machines between FY05 to FY14.

5.2 Ecological Risk Characterization

This section integrates the dose-response assessment with the potential for exposure to evaluate whether direct or indirect risks would occur for nontarget organisms and domestic animals from WS use of gas cartridges and FGFSs. Direct risk refers to those risks that could occur from direct exposure to the formulation ingredients ($NaNO_3$) in the gas cartridge or to the byproducts (CO_1 or SO_x) after combustion. Indirect risks refer to impacts that could occur to prey or habitat that nontarget organisms rely on for food and shelter.

The proposed use of gas cartridges and FGFS apparatuses suggest minimal risk for aquatic species including vertebrates, invertebrates, and plants. This includes direct risk from exposure to the formulation as well as any indirect risk to available food items and habitat. The labels provide use restrictions in areas where T&E species occur.

Exposure of nontarget terrestrial animals (e.g., mammals, birds, invertebrates, etc.) to harmful or lethal levels of CO_1, as well as SO_x if using The Giant Destroyer gas cartridge, could occur if the animals occupy the treated burrow or den. Terrestrial invertebrates in burrows, dens, or surrounding soil during treatments are at risk of exposure to the noxious gases. Gas cartridges are unlikely to affect most bird species given the subterranean use pattern. Bird species that use underground burrows or dens, such as the burrowing owl, are at risk of exposure to harmful or lethal levels of CO_1 as well as SO_x if using The Giant Destroyer gas cartridges. However, label instructions require applicators to monitor the burrow or den for nontarget animal activity and to avoid treatment if nontarget animals are present. In addition, the label instructs applicators to avoid treatment of rodent burrows if evidence of burrowing owls is found from May through July.

The risks to terrestrial animals are limited to the area within and adjacent to the treated burrow or den and would not result in impacts to populations over a large area. Impacts would also be short term since CO_1 and SO_x would dissipate or degrade rapidly after treatment. Nolte et al. (2000) tested the CO_1 spread and levels in artificial pocket gopher burrows using sensors that could measure up to 5,000 ppm CO_1. A sensor 4.5 m from the artificial burrow entrance measured 5,000 ppm after use of one gas cartridge (for rodents) with levels dropping to low (7.5 m) or no detectible levels by sensors placed further away from the entrance. Placement of two gas cartridges resulted in a measurement of 5,000 ppm at both the 4.5 m and 7.5 m distances from the artificial burrow entrance, with levels dropping the further away from the entrance.

Terrestrial exposure to Na_2CO_3 at lethal doses is not expected. Na_2CO_3 occurs naturally in soil and water and is unlikely to affect adversely wildlife, nontarget organisms or water resources (USEPA 2006).

The take of target and nontarget species during treatment will not likely impact species that prey on them as a food source since treatment does not affect all potential prey in the area. An exception is the black-footed ferret, which relies on prairie dogs as its primary food source. WS will not use gas cartridges in areas where T&E species, including the ferret, could potentially be present and, therefore, will have no effect on them.

The risk to terrestrial plants that have roots extending into the areas around treated burrows and dens is negligible. CO_1 and SO_x exposure would be short term to plants and the risks, if any, would be to individual plants and not expected to result in any mortality. Other ingredients and byproducts of gas cartridges pose negligible risk to plants and terrestrial invertebrates since they are natural components of environment. Any increase in residues would remain localized and is unlikely to cause an increase significantly above ambient levels.

6 UNCERTAINTIES AND CUMULATIVE IMPACTS

Failure of gas cartridges to combust would leave untransformed $NaNO_3$ in the soil, which can leach into water. The $NaNO_3$ in a cartridge is about 76 g for Gas Cartridges for Rodents, 153 g for Giant Gas Cartridge, and 0.88 g for The Giant Destroyer gas cartridge. Typically, burrow and dens have multiple holes, which mean applicators may use more than one gas cartridge in a treatment area. The average number of gas cartridges used for the different target species is given in Table 2, therefore, is not possible to calculate the total number of grams of $NaNO_3$ used in the area (or total average of pyrolysis byproducts in an area). However, the success rate of gas cartridges combusting after lighting the fuse is high. For example, in one study, 100% of the 524 gas cartridges set in northern pocket gopher burrows combusted after lighting the fuse (Matschke et al. 1995). In the environment, non-combusted $NaNO_3$ would undergo microbial breakdown and enter the nitrogen cycle.

As discussed in Section 2.4, other sources to $NaNO_3$ exist. Fertilizers contain nitrate, and nitrate is a coloring and food preservative (OECD 2007). Several industrial processes use nitrate to manufacture nitrites, nitrous oxide, explosives, and pyrotechnics (OECD 2007). The major dietary source of nitrate is from vegetables containing high amounts of nitrate such as spinach (500 to 1,900 ppm), radishes (1,500 to 1,800 ppm), and lettuce (600 to 1,700 ppm) (Keeton et al. 2009). The addition of nitrate to the environment and in particular aquatic resources may be of concern due to nutrient contamination, which includes various forms of nitrogen that can result in eutrophication and degraded water quality. Recent data for rivers and streams in the United States show that excess nitrogen occurs throughout various ecoregions of the country. Greater than 60% of the river and stream miles in the Upper Plains have excess nitrogen compared to only 7% of the river and stream miles in the Coastal Plains (USEPA 2013b). Sources of nitrogen pollution include fertilizers, manure from livestock, leaking septic tanks, and various other industries. Cumulative impacts to water quality that could affect human health or the environment would be incrementally negligible when considering the WS use of gas cartridges in relation to other manufactured and natural inputs. For example, 50 lbs. of $NaNO_3$ fertilizer is a suggested application rate at the low end; it would take 298 unignited Gas Cartridges/acre to equal 50 lbs. N/acre. A high-end application may be 50 gas cartridges per acre (30 is likely the high). The high application rate for gas cartridges, assuming all of these did not ignite, would not rise to the application rate of fertilizer. Thus, WS believes that it will not have any effects and that the use of gas cartridges is unlikely to contribute $NaNO_3$ in quantities that would cause water supplies to exceed the human health drinking water standard of 10 mg NO_3-N/L (= 44.3 mg NO_3^-/L) (Matschke et al. 1995, OECD 2007).

The use pattern of gas cartridges indicates a low risk of repeat exposure of WS personnel to the formulation and pyrolysis products. An accidental exposure is unlikely to lead to substantial risk or accumulation in the body (see Section 3.1). APHIS received no reports of accidental exposures of WS personnel to the formulation or byproducts of gas cartridges from FY05 to FY15, and is not aware of any ever occurring.

The dominant sources for CO_1 in the environment are anthropogenic sources (e.g., burning of fossil fuels and methane production) which account for about 60% of the CO_1 with natural sources accounting for the rest (Raub 1999). Vehicles are the single largest source of CO_1 emissions (USEPA 2017a). Naturally occurring CO_1 forms mostly through the incomplete combustion of carbon-containing fuels and photochemical reactions in the atmosphere (USEPA 2010). The CO_1 from gas cartridges and FGFS apparatuses may contribute a negligible amount to the atmospheric CO_1 levels, but this would be negligible compared to other sources. In addition, the subterranean use pattern indicates some CO_1 uptake by microorganisms in the soil.

Similar to CO_1, sources of SO_x are mostly from anthropogenic sources such as power plants and industrial facilities accounting for 73% and 20%, respectively, of SO_2 emissions (USEPA 2017e). The SO_x formed after the pyrolysis of The Giant Destroyer gas cartridges used by WS would contribute a negligible amount of SO_x to the atmosphere. In addition, the subterranean use pattern and rapid degradation of SO_x to sulfate show some uptake by plants and microorganisms. Thus, WS believes that it would not add to current sulfur levels in the atmosphere.

7 SUMMARY

WS uses three gas cartridge products and an FGFS, the PERC machine, to control target rodents and predators that live in burrows or dens. All three gas cartridges contain $NaNO_3$, charcoal, and inert ingredients. One product also contains sulfur. The PERC machine delivers only pressurized CO_1 (110 psi) into burrows.

An analysis of human health and ecological effects from gas cartridges and FMGS apparatuses pose low risk to human health, nontarget fish and wildlife, and the environment because of the WS use pattern and the environmental fate of the cartridge formulation and byproducts. In addition, label instructions further reduce risk to nontarget species by requiring applicators to confirm target animals actively inhabit the burrows or dens before treatment and that nontarget animals are not present.

The conclusion is that gas cartridges and FMGS apparatuses are low risk WDM methods of fumigating.

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9.0 PREPARERS

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9.2 Internal Reviewers

Michael Green - Editor
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9.3 Peer Reviewers

The Office of Management and Budget requires agencies to have peer review guidelines for scientific documents. The APHIS guidelines were followed to have "Use of Carbon Monoxide from Gas Cartridges and Forced Gas Fumigation Systems in Wildlife Damage Management" peer reviewed. WS worked with the Association of Fish and Wildlife Agencies to have experts review the documents.

9.3.1 Peer Reviewer Agencies Selected by the Association of Fish and Wildlife Agencies

Arizona Game and Fish Department
Association of Fish and Wildlife Agencies
California Department of Fish and Wildlife
Missouri Department of Conservation
South Dakota Game, Fish and Parks
Tennessee Wildlife Resources Agency
Wyoming Game and Fish Department

9.3.2 Comments

Comments regarding concerns with the risk assessment and a response:

1. **Comments:** WS did not dig up the majority of dens to determine actual take of target and nontarget species, but target numbers were estimated from the expected number of animals per treated burrow or den (Table 2); thus, the risk assessment should incorporate some nontarget take as this mostly occurred at some rate. Had concerns that the impact on nontarget species is underestimated. Without data regarding the effectiveness of measures to avoid nontarget wildlife, it is not possible to make conclusions as to the extent of nontarget exposure. There are very limited data regarding exposure of nontarget wildlife in burrows at the time of treatment.
   Response: The sheer number of underground dwelling wildlife in the United States (Section 4.2.2) would make it difficult to have any meaningful analysis of nontarget wildlife take at the species level. Section 2 was revised to refer to Section 4.2.2 where nontarget annual take by WS was roughly estimated based on the one study available where burrows were excavated to determine nontarget take. WS cannot use gas cartridges and FGFS where T&E species occur and could be affected without conservation measures in place, so these species would not be impacted. WS believes that nontarget take was minimal, no species' population would be impacted by use of gas cartridges, and FGFS since most species that may be taken are, at least, fairly abundant in areas where gas cartridges are used. In fact, from FY96 to FY15, the only known nontarget take was a raccoon in FY09 for a project protecting federally threatened piping plovers (*Charadrius melodus*) from red fox and raccoons, a WS employee found a den that he thought was an active red fox den. After applying a gas cartridge, he dug up the den and found a raccoon occupied it. Even though the raccoon was targeted, it was a nontarget because the method used was not registered for it.

2. **Comments:** Mitigation to avoid nontarget take is dependent upon the diligence of the operator. While the labels for gas cartridges require applicators to take measures to avoid burrows containing nontarget wildlife, data

regarding the effectiveness of such measures is lacking. A monitoring plan would include excavation of treated burrows, which were believed to lack nontarget wildlife before fumigation to determine the accuracy of the assumptions.

Response: WS personnel that apply gas cartridges or use FGFS are required to abide by labels and WS Directives. We believe that WS personnel follow these guidelines, which includes WS personnel monitoring application sites for nontarget species and not applying gas cartridges where nontarget species could be killed. With that said, the only known incident that took place in the last 25 years with gas cartridges was in FY09; when an employee used a gas cartridge to take what he thought was a targeted red fox, but when he opened the den he found a targeted raccoon for the project, but is not on the label. Other than that incident, no mishaps with gas cartridges have been known to occur, nor nontarget species taken. WS personnel recognize active burrows of the target species either by inspection for fresh fecal material of the target animal and their tracks with no nontarget fecal material, regurgitated pellets or castings, tracks, and no cobwebs, or by covering holes with dirt to determine active burrows and dens to treat. We believe that, as a result, nontarget take is minimal, but likely occurs, especially for species cohabitating with the target species. We believe nontarget species are taken periodically, but cannot verify efficacy and nontarget take due to the lack of studies. Possibly this could be taken up by the WS National Wildlife Research Center as a study, but WS does not require field personnel to dig up burrows because the time required to undertake such endeavors, the possibility of acquiring a disease, and the potential for a den to cave in. Coyote and red fox dens for many years were often dug up to verify the take number, prior to FY04 (WS Directive 2.425) when it became policy to avoid digging up dens. No known nontarget species take was reported from FY96 through FY15 even with dens commonly dug up prior to FY05. Additionally, several more species have been taken with denning (digging up a den to take the target animal including mostly coyotes and red fox, but also periodic arctic and gray fox, bobcats, feral dogs, badgers, beavers, and a swift fox from FY96 to FY15. No known nontarget species was taken during these endeavors either. The one incident that took place with gas cartridges was in FY09. Other than that incident, no mishaps with gas cartridges have been known to occur, nor nontarget species recorded as taken.

3. **Comment:** I have animal welfare concerns in that the slow rate of CO_1 generation and dispersal through a burrow system may lead to prolonged hypoxia while the animals are conscious.

   Response: WS is also concerned with animal welfare as discussed in Chapter 1 Section 5 of the Introduction. Humaneness was one of the primary factors when determining methods to register for fumigation (Savarie and Connolly 1984). We are unsure of any studies regarding gas dispersal speed of CO_1 in a burrow for species targeted with gas cartridges, but know that gas from gas cartridges moves rapidly throughout a burrow system (smoke is seen within seconds at unplugged holes 30 feet or more away from the source). Gas cartridges may not have enough CO_1 to fill a burrow and kill the target animal (Nolte et al. 2000). The concentration levels of CO_1 at different distances from the source gas cartridge was measured in artificial gopher burrows in Nolte et al. (2000). Blowers were used to enhance the spread of CO_1 in gopher burrow systems, but the results indicated that the blower did not improve efficacy of gas cartridges for gophers so it is likely that the CO_1 did not disperse evenly. The use of two gas cartridges in the same burrow did raise CO_1 levels enough to be lethal in longer burrows (Nolte et al. 2000). However, ground squirrels, prairie dogs, marmots, coyotes, skunks and red fox are the primary targets of APHIS gas cartridges. With the current gas cartridges containing 145 g and 290 g, we believe that prolonged hypoxia would not occur in the typical treated burrow, especially for ground squirrels that do not have extensive burrow systems. In extensive burrow systems and dens, WS personnel often use more than one gas cartridge to ensure that enough gas is produced to fill the area. However, as discussed in Section 2.1, the efficacy of gas cartridges is high for ground squirrels and prairie dogs activity at greater than 70-90% for most species (Ramey and Schafer 1996). Since not all targeted rodents get a lethal dose, it is possible that a few target animals suffer from hypoxia as a result.

4. **Comments:** The FGFS apparatus generates greenhouse gases through the combustion of fossil fuels in addition to the CO_1 generated by gas cartridges.

   Response: CO_1 is the primary gas produced by gas cartridges and FGFS, but the combustion engines to run FGFS also produces the primary greenhouse gas, carbon dioxide (CO_2). The FGFS use by WS has been minimal and would not add to greenhouse gas emissions to any significant degree. It takes about 30 seconds to treat a burrow system, but for the sake of being conservative, we will say a minute. WS treated an average of 65 burrows or 65 minutes running the machine per year. A typical mid-sized riding lawn mower has a two-gallon tank and uses about 1-2 gallons per hour. We could not find how much gasoline was used in a PERC, but imagine this would be similar. The burning of two gallons of gas would be about the maximum amount of fuel used in a PERC each year, which would equate to a negligible amount of greenhouse gases produced annually.

CO_1 is the primary gas produced by gas cartridges, but is not a primary gas in greenhouse gases. With that said, it can be a potent indirect source of greenhouse gas emissions because it reacts with other molecules in the air such as hydroxyl (OH) to create CO_2, a primary greenhouse gas. WS used an average of 4,967 gas cartridges and 1,110 large gas cartridges annually. Each gas cartridge and large gas cartridge weighs 5.1 and 10.2 ounces. The total amount of charcoal and sodium nitrate, the ingredients that combine to make CO_1 and other gases, in each is 81% of the ingredients. Multiplying these factors gives a conservative estimate of 1,856 pounds for the CO_1 produced from WS' gas cartridge use each year, assuming the ingredients make only CO_1. The molecular weights of CO_1 = 28.10 g/mol, OH = 17.01 g/mol, and CO_2 = 44.01 g/mol. Thus, CO_1 reacts with hydroxyl and increases 160% in weight (about equal to the weight of OH). Again, multiplying 1,856 by 1.6 would equal making 2,970 pounds of CO_2 produced or 1.35 metric tons. The average car produces 4.75 metric tons of CO_2 annually (@https://www.reference.com/science/much-pollution-average-car-produce-7f2a3d41ed9d2689). Thus, the gas cartridges used by WS would produce, at a maximum, the amount a typical car in the United States produces in 4 months. For context, vehicles in the United States produce 1,559 million metric tons per year (@https://www.eia.gov/tools/faqs/faq.php?id=307&t=11). Thus, we believe this to be a minimal addition of CO_2 gases to the greenhouse gases produced in the U.S. annually by vehicles alone (less than a billionth of the total).

Comments received not requiring a response.

1. **Comment:** The risk management plan provides a good overview of potential risks and hazards associated with the use of carbon monoxide in wildlife damage management, adequately synthesizing the available literature and data on deployment of this chemical for purposes of wildlife damage management.

2. **Comment:** The qualitative risk assessment for the use of CO_1 gas cartridges and FGFS apparatuses accurately describes the potential risks to humans and nontarget species and methods for mitigating those risks.

3. **Comment:** Assumptions and uncertainties have been accurately described.

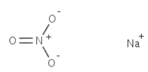
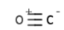
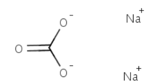
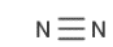
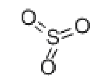
4. **Comments:** We have thoroughly reviewed the risk assessment and believe the methods described were comprehensive, adequate, and safe.

5. **Comments:** Thank you for the opportunity to participate in this review.

6. **Comment:** I had no comments except to say that this is well done

7. **Comment:** Although highly toxic to vertebrate animals and some invertebrates, carbon monoxide deployed using the technologies described in this assessment for purposes of wildlife damage management presents relatively little risk to humans or non-target organisms and, therefore, concur with the findings of this assessment.

APPENDIX 1. Chemical and physical properties for sodium nitrate, sulfur, carbon monoxide, sodium carbonate, nitrogen gas, sulfur dioxide, and sulfur trioxide (OECD 2002, 2007, Chemical Book 2016, NIH 2016).

Property	Sodium Nitrate	Sulfur	Carbon Monoxide	Sodium Carbonate	Nitrogen Gas	Sulfur Dioxide	Sulfur Trioxide
Physical state	Solid, white granules or powder, odorless	Solid, yellow, oily or rotten egg odor	Gas, colorless, odorless	Solid, grayish-white powder, odorless	Gas, colorless, odorless	Gas or liquid, colorless, strong odor	Colorless to white crystalline solid which fumes in air
Chemical structure		S					
Molecular formula	H-N-O3.Na	S	C-O	C-Na2-O3	N2	O2S	O3S
Molecular weight	84.99	32.06	28.01	105.99	28.013	64.064	80.06
Melting point	307-308 ºC	115 °C	-199 ºC	856 ºC	-210.01 ºC	-75.5 ºC	16.8 ºC
Boiling point	380 ºC at 1 atm (decomposes)	445 °C	-191.5 ºC	decomposes	-195.79 ºC	-10.05 ºC	44.8 ºC
Density	2.26 g/ml at 20 °C	2.07 g/cu cm	1.250 g/L at 0 ºC /4 ºC	2.54 g/cu cm	1.251 g/L at 0 ºC and 1 atm; 0.804 (liquid), and 1.0265 (solid)	2.619 g/L	1.97 g/mL at 25 °C (lit.)
Vapor pressure	ca. 2.1E-17 hPa	3.95X10-6 mmHg at 30.4 ºC	1.55X10+8 mmHg at 25 ºC	negligible	1 atm @ 77.347 ºK	3X10+3 mmHg at 25 ºC	280 mmHg (25 °C)
Water solubility	921 (g/l) at 25°C	Insoluble in water	Sparingly soluble in water: 3.3 ml/100 ml at 0 ºC, 2.3 ml/100 ml at 20 ºC	215 g/l at 20 ºC	Slightly soluble in water and ethanol; 100 vol water absorbs 2.4 vol nitrogen at 0 ºC; 100 vol water absorbs 1.6 vol nitrogen at 20 ºC	Soluble in water (17.7% at 0 ºC; 11.9% at 15 ºC; 8.5% at 25 ºC; 6.4% at 35 ºC)	Reacts violently
pH	7 at 25 °C			Aqueous solutions are strongly alkaline. At 25 ºC	7		
Acid dissociation constant (pKa)	Sodium: 14.8; Nitric acid: -1.4						
Partition coefficient n-octanol/water (log value)	-0.79						
Oxidation/reduction potential	NFPA Class I oxidizer						
Explosive properties	Not explosive/ detonable	Easily ignitable solid				Noncombustible	May ignite other combustible materials (wood, paper, oil, etc.)