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The Evolution Of Aphis Two Gas Cartridges

Craig A. Ramey
U.S. Department of Agriculture

Edward W. Schafer Jr
U.S. Department of Agriculture

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CRAIG A. RAMEY, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, National Wildlife Research Center, 1716 Heath Parkway, Ft. Collins, Colorado 80524-2719.

EDWARD W. SCHAFER, JR., U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Denver Wildlife Research Center, Denver, Colorado 80225-0266.

ABSTRACT: The U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) has two federal (Section 3) vertebrate pesticide registrations with the U.S. Environmental Protection Agency (EPA) for gas cartridges to control damage to American agricultural resources and reduce threats to public health and safety. The gas cartridges are pyro-fumigant devices that produce primarily carbon monoxide when ignited. In sealed burrows or dens, carbon monoxide is highly toxic when inhaled, leading to tissue hypoxia. Carbon monoxide is recommended by the American Veterinary Medicine Association's panel for euthanatizing animals because it quickly induces unconsciousness without pain and with minimal discernible discomfort. APHIS's gas cartridges for rodent and predator control have been developed and maintained primarily by research conducted at the Denver Wildlife Research Center (DWRC). APHIS's Gas Cartridge (EPA Reg. No. 56228-2) for burrowing rodent control has evolved through various formulations and sizes. Formerly, the Gas Cartridge was formulated with six-active ingredients; however, in April 1996, an amendment to use only two-active ingredients [sodium nitrate and charcoal (carbon)] and two-inert ingredients (fuller's earth and borax) was approved by EPA. These two-active ingredients produce carbon monoxide, and the inerts increase the burn time. DWRC field studies have shown the gas cartridge to be effective for the control of rats, woodchucks and Richardson's ground squirrels, but not for Northern pocket gophers. The Large Gas Cartridge (EPA Reg. No. 56228-21) was originally developed using only two ingredients (sodium nitrate and charcoal) as a predacide to control coyotes in dens. Recent efficacy data led to the addition of the fox and skunk to the label; however, the Large Gas Cartridge was not effective in controlling badgers. This paper discusses the evolution of APHIS's gas cartridges and includes: 1) an introduction to APHIS's gas cartridges; 2) a synopsis of gas cartridge research conducted by personnel of the Denver Wildlife Research Center; and 3) a discussion of the management implications associated with the current status and future of APHIS's gas cartridges.

KEY WORDS: carbon monoxide, fumigant, predacide, rodenticide, vertebrate pesticide

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INTRODUCTION

The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) has maintained, as required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), two federal (Section 3) vertebrate pesticide registrations for gas cartridges used by APHIS's Animal Damage Control (ADC) program (Ramey et al. 1992). ADC provides federal leadership authorized by the Animal Damage Control Act of 1931 (USDA 1990) in managing wildlife conflicts with human activities that may result in damage to agricultural and industrial resources, pose risks to public health and safety, or impact other natural resources including wildlife species (Acord 1991). ADC has developed and/or maintains several low volume minor use vertebrate pesticides, including the gas cartridges, for these purposes (USDA 1994). Although the types and status of APHIS's pesticides and their active ingredients (AIs) have been summarized elsewhere (Ward 1962; Ramey et al. 1992 and 1994b; USDA 1994), a comprehensive history and status of APHIS's gas cartridges is presented in this manuscript.

The Denver Wildlife Research Center (DWRC) is the only major federal research facility in the U.S. conducting research related to wildlife damage management (Reidinger 1990). Among its many activities, DWRC generates data according to Good Laboratory Practice guidelines (U.S. EPA 1991a) for submission to EPA. Many of these studies support current APHIS vertebrate pesticide registrations and the reregistration of their AIs (Ramey et al. 1994b). However, to meet the challenges of the next century, DWRC scientists are also investigating nonlethal repellents and new technology-based alternatives such as immunocontraception to provide more alternatives for use by ADC in its Integrated Pest Management (IPM) program (Ramey et al. 1994a). The search for new and/or improved IPM tools and techniques should require wildlife managers to develop selection criteria about ideal products. For vertebrate pesticides, Savarie and Connolly (1984) have suggested several criteria including: humaneness to the species of concern, efficacy under practical working conditions, safety to humans and the environment, availability at low cost, and the likelihood of registration with EPA or Food and Drug Administration. These criteria are similar to several suggested for an ideal fumigant by Fiedler et al. (1990), but they also recommended a preference for a solid

fumigant that is easy to handle, transport, apply, and store. One vertebrate pesticide that meets most of the criteria mentioned above is APHIS's gas cartridge.

Gas Cartridge

The gas cartridge is a pyrotechnic device and is composed of two parts: 1) the tube—a cardboard cylinder closed by cardboard caps at both ends containing the formulated product, predominantly sodium nitrate and charcoal; and 2) the fuse—a fireworks fuse inserted through one end cap into the combustible mixture. After the fuse is lit, it burns into the mixture and causes it to ignite. When the burning gas cartridge is used in a confined space with a limited air supply, such as a burrow or den, it can produce lethal concentrations of carbon monoxide.

Using the gas cartridge for the control of vertebrate pests, the applicator carefully selects the den or burrow of the specific animal of concern and ensures that the cartridge will freely enter the burrow or den. Next, the applicator obtains material to plug the burrow entrance after ignition and plugs all other openings to the burrow/den system. The gas cartridge is prepared for use by puncturing one end of the cartridge, with a 1/8" diameter nail at one of the two central points marked, and the supplied fuse is inserted into the hole leaving a minimum of 3 inches of fuse exposed. After all secondary burrow openings are closed, the fuse is safely lit and the cartridge is placed, fuse-end first, into the burrow entrance as far as possible and this opening is immediately closed with dirt and/or rock(s). In burrows with steep entrances, the contents of the cartridge may flow out of the lighted end; therefore, in these instances the cartridge should be placed as deep into the burrow as possible with the fuse-end up before lighting and closing the burrow. During combustion, the applicator should prevent the escape of any generated gases using more soil/rocks as appropriate to plug any areas where gases are observed escaping from the burrow. Gases produced by the burning cartridge are mostly simple organic and inorganic compounds with carbon monoxide the primary toxic gas (Savarie et al. 1980; U.S. EPA 1991b).

Cartridge Mode of Action

Charcoal (carbon) and sodium nitrate are common chemicals, and they are widely accepted as safe. Human toxicity to carbon could occur only under very unusual or overwhelming dosage conditions (USDI 1981). Toxicity reports from DWRC research for albino rats show no signs of toxicity or mortality to oral doses of 3,000 mg/kg of either charcoal or sodium nitrate (DWRC 1979). Charcoal is used as a fuel for barbecuing foods and in the human food industry to process sugar and alcoholic beverages (USDI 1981). The adsorptive properties of charcoal have been utilized in removing toxic chemicals from water (Dawson et al. 1976) and as "activated charcoal" for the emergency treatment of some cases of poisoning (Picchioni et al. 1966). Similarly, sodium nitrate is considered safe and is used in the manufacture of various products including glass, explosives, ceramics, detergents, pulpwood and paper, charcoal briquettes, and fertilizer (USDI 1981). In the metallurgy industry, sodium nitrate is used as a flux or oxidizing agent, and its use as a color fixing agent for meat is accepted by USDA (Olin Corp. 1978).

However, combustion of these safe chemicals produces carbon monoxide (CO) according to the following formula (Magram, no date).

$$4C + 2\ NaNO_3 \rightarrow 3\ CO + Na_2CO_3 + N_2$$

Summary: Carbon + sodium nitrate → carbon monoxide + sodium carbonate + nitrogen gas

Carbon monoxide is a colorless, odorless, tasteless, and highly poisonous gas (Windholz and Budavari 1983). It is highly toxic 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 of CO into the animal is through inspired air. Because CO has a much higher affinity than oxygen to combine with hemoglobin in the lungs, it displaces oxygen and forms a complex molecule (carboxyhemoglobin) which circulates through the body and quickly produces tissue hypoxia (Swinyard 1975). Secondary toxicity does not occur with CO poisoning (Savarie et al. 1980).

The acute inhalation toxicity of carbon monoxide to humans can be explained by two factors—concentration and duration of exposure. Symptoms of CO poisoning can occur after exposure to 0.05% (500 ppm) concentration for 1 hour or 0.10% (1,000 ppm) for 30 minutes. If the concentration reaches 0.15%, exposure for 1 hour may cause mortality, and higher concentrations produce death very quickly (American Industrial Hygiene Assoc. 1965). The signs and symptoms of carbon monoxide poisoning are directly correlated with the carboxyhemoglobin content of the blood (Swinyard 1975; USDI 1981). The American Veterinary Medicine Association's (AVMA) Panel on Euthanasia recommends CO for euthanatizing animals, because it quickly induces unconsciousness without pain, produces minimal discernible discomfort, and results in rapid death at concentrations of 4-6% (AVMA 1993).

The environmental fate of CO from natural and manmade sources has been studied extensively. Eventually, CO: 1) disperses harmlessly into the atmosphere in an insignificant amount (Seiler et al. 1978); 2) is entrapped in the soil where it is metabolized by soil microorganisms such as fungi (Inman and Ingersoll 1971) and bacteria (Heichel 1973); or 3) enters one of several carbon cycles (USDA 1994), such as conversion to carbon dioxide or fixation by bacteria.

Besides CO, sodium carbonate (Na_2CO_3) and nitrogen gas (N_2) are also formed when the gas cartridge is used. The oral LD_{50} for sodium carbonate in rats is about 4,000 mg/kg (Frank 1948), and its toxicity to humans depends upon its ingestion in large quantities producing corrosion of the gastrointestinal tract, collapse and death (Windholz and Budavari 1983). The nitrogen gas produced does not pose any biological hazard, because it either dissipates into the air where it already constitutes about 78% of the earth's atmosphere by volume (Windholz and Budavari 1983) or it becomes incorporated into various nitrogen cycles when exposed to soil or water. In summary, the use of gas cartridges does not produce a negative impact on the environment, and the

CO produced is well established as a humane euthanatizing agent.

HISTORY OF GAS CARTRIDGES

The gas cartridge was developed during the 1940s by the Bureau of Biological Survey for the control of burrowing rodents. By 1945, the U.S. Fish and Wildlife Service (USFWS) recognized a need for a fumigant for controlling coyotes in dens. Arrangements were made with the U.S. Army Chemical Warfare Service to develop a better cartridge than the six-active ingredient gas cartridge being produced by the Pocatello Supply Depot (PSD) (238 E. Dillon Street, Pocatello, ID) (USDI 1981). Magram (no date) studied and compared various types of pyrotechnic fumigants and found that a cartridge with only two-active ingredients, sodium nitrate and charcoal, produced more CO than the six-active ingredient cartridge, and he implied that the former might, therefore, be more efficacious, although he provided no animal efficacy data. APHIS currently maintains two gas cartridge registrations for underground use to control burrowing rodents (Gas Cartridge) and coyotes (Large Gas Cartridge).

Gas Cartridge (EPA Reg. No. 56228-2)

The Gas Cartridge was originally registered by the U.S. Department of Interior (USDI), U.S. Fish and Wildlife Service (USFWS) (Reg. No. 6704-4) in 1960. It contained six-active ingredients (sodium nitrate, charcoal, sulfur, red phosphorus, black summer oil, and sawdust) and two-inert ingredients (borax and fuller's earth) (W. Jacobs, EPA, pers. commun.). It was registered for control of burrowing rodent pests, specifically woodchucks, prairie dogs, gophers, and ground squirrels (Savarie et al. 1980). This registration was transferred to USDA/APHIS in 1986, during the transfer of the ADC program from USDI to USDA, as EPA Reg. No. 56228-2 (Ramey et al. 1992).

Using a simulated rodent burrow (SRB), efficacy tests for a two-active ingredient rodent gas cartridge (65 g) were begun in the late 1970s. SRB laboratory studies using Norway rats (*Rattus norvegicus*) (Savarie et al. 1980), indicated the two-active ingredient gas cartridge formulation was as effective as the original six-active ingredient cartridge. In field studies, Savarie et al. (1980) reported the two-active ingredient gas cartridge was 77% effective with Norway rats in burrows (Table 1). Later the SRB was improved using polyvinyl chloride (PVC) plastic pipe (Elias et al. 1983), which allowed for the measurement of oxygen or toxic gases anywhere along the system. Using this system, Elias et al. (1983) reported 100% efficacy using six albino rats (Table 1).

Because of an accidental fatality from cartridge misuse in 1980, the EPA began to look at use warnings, fuse characteristics, and burn time attributes to increase cartridge safety. Citing other cases of gas cartridge injuries such as burns, the EPA sent USDI a notice of intent to cancel both of APHIS's gas cartridge registrations if revised labeling, warning notices, longer fuses, and minimum standards for fuse burn time were not made. In response, DWRC researchers made label changes that were approved by EPA, developed a formulation accepted by EPA with minimum fuse and cartridge burn time characteristics (Savarie et al. 1991, 1993) (Table 1), and addressed endangered species considerations.

While DWRC personnel were adjusting the formulation to produce a safer and equally or more effective rodent gas cartridge, other DWRC scientists were field testing sizes of the two-active ingredient Gas Cartridge. Fagerstone et al. (1981) reported 67% efficacy using a 65 g cartridge to control Richardson's ground squirrels (*Spermophilus richardsonii*); radiotelemetry was used for carcass retrieval (Table 1). Because this cartridge did not attain the 70% efficacy arbitrarily established by EPA for rodenticide registration, the efficacy of a larger and heavier cartridge (97 g) was tested by Matschke and Fagerstone (1984) a few years later; they reported 84% control with the same species (Table 1). Later, Dolbeer et al. (1991) conducted a comparison efficacy study using both the PSD Gas Cartridge with six-active ingredients and a 117 g, two-active ingredient gas cartridge for controlling woodchucks (*Marmota monax*) in their burrows. Efficacy, determined by excavating 97 burrows and retrieving the carcasses, was similar for both gas cartridges and was 80% for the latter (Table 1). In addition, they found that careful use of gas cartridges led to low mortality (4%) of co-habitating nontarget species (Dolbeer et al. 1991). Recently, a 145 g formulation was used to control Northern pocket gophers (*Thomomys talpoides*) (Matschke et al. 1995); however, it was not effective (Table 1). These investigations demonstrated that gas cartridge efficacy was not compromised by using the new two-active ingredient formulation and that other sizes this gas cartridge was effective in the control of several rodent species.

On August 16, 1991 APHIS applied for a new gas cartridge registration for rodent control (Gas Cartridge II), including only carbon (charcoal) and sodium nitrate as AIs; however, small amounts (< 15%) of three-inert ingredients (borax, fuller's earth, and mineral oil) were added to the formulation to slow the burn time and to reduce the hazard to personnel placing these cartridges in burrows or dens (Savarie et al. 1991; Savarie and Blom 1993). This change in registrations was sought by APHIS to avoid the potentially extensive data requirements and expensive reregistration costs to support the continued use of primarily sulfur and phosphorus in the registered six-active ingredient rodent gas cartridge produced by the Pocatello Supply Depot. Reregistration Eligibility Documents for carbon and sodium nitrate were issued in 1992 by EPA, but they did not acknowledge the requested reduction in APHIS's Gas Cartridge from 6 AI to 2 (U.S. EPA 1991b). After extensive discussions with EPA about continuing to pursue both the registration and reregistration activities on two separate tracks, APHIS withdrew the application for the Gas Cartridge II in 1993. This allowed APHIS to reduce the number of active ingredients in the Gas Cartridge (i.e., for rodent control) through a formulation amendment rather than a new registration application. Eventually the new Gas Cartridge was reformulated, eliminating the mineral oil, and the final two-active ingredient (sodium nitrate and charcoal) and two-inert ingredient (fuller's earth and borax) Gas Cartridge formulation was submitted to EPA

Table 1. Efficacy results from DWRC studies supporting APHIS's two gas cartridges with two-active ingredients for control of selective vertebrate pests in burrows/dens.

EPA Reg. No.	Study Citation	Species Common Name	Cartridge Weight	Percent Efficacy
FUSE and CARTRIDGE BURN TIME				
56228-2	Savarie et al. 1991	NA	145 g	70%, n=30*
56228-2	Savarie et al. 1993	NA	145 g	93%, n=30*
GAS CARTRIDGE				
56228-2	Savarie et al. 1980	Norway Rats	65 g	77%, n~500
56228-2	Fagerstone et al. 1981	Richardson's GS	65 g	67%, n=43
56228-2	Elias et al. 1983	Albino Rats	65 g	100%, n=6
56228-2	Matschke & Fagerstone 1984	Richardson's GS	97 g	84%, n=50
56228-2	Dolbeer et al. 1991	Woodchuck	117 g	80%, n=41
56228-2	Matschke et al. 1995	Northern PG	145 g	17%, n=42
LARGE GAS CARTRIDGE				
56228-21	Savarie et al. 1980	Coyote	240 g	95%, n>500
56228-21	Ramey 1992a	Striped Skunk	240 g	100%, n=10
56228-21	Ramey 1992b	Red Fox	240 g	100%, n=10
56228-21	Ramey 1993	Badger	240 g	33%, n=6

*Appearance of side scorch burn time characteristic ≥25 seconds.

in 1993 to replace its six-active ingredient predecessor. In April 1996, APHIS's new Gas Cartridge for rodent control was approved by EPA. APHIS now has 18 months to phase out production of the six-active ingredient Gas Cartridge and to phase in the production of the new Gas Cartridge.

Large Gas Cartridge (EPA Reg. No. 56228-21)

The Large Gas Cartridge was developed by the DWRC and was registered in 1981 (Savarie et al. 1980; EPA Reg. No. 6704-84) to control coyotes (*Canis latrans*) in dens. Savarie et al. (1980) described its development using a formulation containing only two ingredients (sodium nitrate and charcoal), based on earlier work conducted by the U.S. Army. In laboratory tests with adult coyotes, using the simulated coyote dens (SCD) developed at DWRC, Savarie et al. (1980) found that a 240 g gas cartridge produced 100% mortality (n=19) in young coyotes and similar efficacy (96%) in field studies with coyote pups (Savarie et al. 1980) (Table 1). In 1986, this registration was transferred with the ADC program and DWRC to USDA/APHIS; it was renumbered as EPA Reg. No. 56228-21 (Ramey et al. 1992).

Results of additional field efficacy tests to determine mortality for other large carnivores with the Large Gas Cartridge have recently been completed. This cartridge produced 100% mortality with skunks (*Mephitis mephitis*) (Ramey 1992a) and red fox (*Vulpes vulpes*) (Ramey 1992b), but only 33% with badgers (*Taxidea taxus*) (Ramey 1993) (Table 1). Based on these data, the EPA approved the addition of fox and skunk to the Large Gas Cartridge registration.

The current Large Gas Cartridge formulation utilizes a loose mixture of sodium nitrate and charcoal. Because the formulation is not physically stabilized in the cartridge, some applications can result in incomplete combustion or the release of its contents without igniting. Although these problems might be avoided by carefully following the Use Directions on the label, the lack of formulation stabilization may result in reduced efficacy. APHIS will shortly reformulate the Large Gas Cartridge so that its contents will be exactly the same as the newly approved Gas Cartridge for rodent control.

DISCUSSION AND MANAGEMENT IMPLICATIONS

The history of pesticide regulations (Fagerstone et al. 1990) and their effect on APHIS's vertebrate pesticide registrations have been previously presented (Ramey et al. 1992). Since these manuscripts were published, all required data submissions were completed for the gas cartridges in November 1994, including data for the recently approved reformulated Gas Cartridge. The reregistration process is complete for both of APHIS's gas cartridge products and we expect EPA approval in the near future.

As part of these efforts, DWRC has addressed concerns expressed by EPA and others (Schmeltz and Whitaker 1977) about the nontarget hazards posed by the use of gas cartridges. Although APHIS's gas cartridges have stated that they were to be used only in the underground burrows or dens of target animals, DWRC scientists observed the need for further clarifications for use. Dolbeer et al. (1991) emphasized that in the use of gas cartridges, nontarget mortality could be minimized by treating only burrows with signs of "active use" by the species of concern rather than indiscriminately treating all target species burrows in an area. Consequently, use instructions on the APHIS gas cartridge labels were recently modified to incorporate descriptive information on how to identify burrows with signs of active use by the target species (Palmateer 1993) and excluding use during the burrowing owl's nesting season.

In summary, APHIS's gas cartridges when carefully used have been shown to be effective in the selective control of several rodents (Norway rats, Richardson's ground squirrels, and woodchucks, but not Northern pocket gophers) and a few predators (coyotes, striped skunk, red fox, but not badgers). Undoubtedly, increased efficacy could result from a better understanding by applicators of all the factors affecting CO poisoning survival by target species in burrows or dens. Possible factors allowing mammal survival in the DWRC studies discussed above include: 1) intricate tunnel/burrow design (Savarie et al. 1980; Dolbeer et al. 1991; Matschke et al. 1995); 2) a tolerance for lowered oxygen levels (Kennerly 1964; Studier and Procter 1971; Ramey 1993); 3) burrow plugging behavior during burrow entrance disturbance (Minta and Marsh 1988; Ramey 1993); 4) soil porosity and moisture content (Fagerstone et al. 1981; McClean 1981); and; 5) body weight (Fagerstone et al. 1981; Matschke and Fagerstone 1984). Applicator experiential learning about these possible variables may enhance the effectiveness of APHIS's gas cartridges. Wildlife damage managers should be sure that such information is reported to APHIS/DWRC so its gas cartridges may be improved and continue to be an effective, safe, humane, and low cost tool in ADC's Integrated Pest Management program.

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