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DEVELOPMENT OF A SIMPLE TWO-INGREDIENT PYROTECHNIC FUMIGANT

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ABSTRACT: In laboratory tests with adult coyotes (Canis latrans) a pyrotechnic fumigant containing two active ingredients, sodium nitrate and charcoal, was found to be just as effective as the U.S. Fish and Wildlife Service Gas Cartridge that contains six active and two inactive ingredients. The two-ingredient cartridge produces high concentrations of carbon monoxide. Field tests with cartridges containing 240 g of 65% sodium nitrate and 35% charcoal produced a 96% mortality rate in coyote pups. A cartridge containing 65 g of 65% sodium nitrate and 35% charcoal was effective in both laboratory and field tests on wild Norway rats (Rattus norvegicus). In field tests conducted at a rat-infested cattle feedlot, there was a 77% average (35% to 95% range) reduction in numbers of reopened burrows after fumigation as compared to pretreatment figures.

Sodium nitrate and charcoal are not dangerous chemicals. The acute oral LD_{50} for both sodium nitrate and charcoal is greater than 3,000 mg/kg in rats, and there was no potentiation when given in combination at 3,000 mg/kg.

No signs of secondary toxicity were observed in bobcats (Lynx rufus) fed rats killed by fumes from burning sodium nitrate and charcoal.

Since gas cartridges are used underground, potential hazards to humans and the environment are nil. When the cartridges are used properly they are effective devices for controlling vertebrate pests such as coyotes and rats.

INTRODUCTION

A pyrotechnic fumigant is a device containing ingredients that emit toxic gases when burned. For over 30 years, the U.S. Fish and Wildlife Service (FWS) has used a pyrotechnic fumigant known as the Gas Cartridge (Environmental Protection Agency Registration Number 6704-4). It is registered for control of burrowing rodents, specifically woodchucks, prairie dogs, gophers, and ground squirrels. In 1976 this fumigant was considered for re-registration for burrowing rodents. Interest was also expressed in registering it for use in coyote dens. However, the re-registration issue was complicated because of a paucity of information about its efficacy under laboratory and field conditions, and because of its numerous ingredients (sulfur, charcoal, red phosphorus, black summer oil, sodium nitrate, sawdust, borax, and Fuller's earth). Data for each are required for registration, but the cost and manpower necessary to obtain this information may not be justified on a cost:benefit basis. Our purpose was to develop a fumigant cartridge containing fewer ingredients with equal or better efficacy.

During the latter half of the 1940's, the U.S. Army Chemical Warfare Service at the Army Chemical Center in Maryland studied and compared various types of pyrotechnic fumigant devices (Magram, no date). They found that a cartridge with two ingredients, sodium nitrate and charcoal, produced more carbon monoxide than the FWS cartridge containing eight ingredients. Although these tests implied that the FWS cartridge could be improved, no animal test data were presented to support this hypothesis.

The objectives of our studies were to: (1) compare the biological effectiveness of the FWS Gas Cartridge and the "Army" cartridge on adult coyotes under laboratory conditions; (2) demonstrate the effectiveness of the two-ingredient cartridge on coyote pups and Norway rats under laboratory conditions; and (3) demonstrate the effectiveness of the two-ingredient cartridge in coyote dens and Norway rat burrows in the field.

GENERAL METHODS

1. Acute oral toxicity tests with charcoal and sodium nitrate (rats)

Sprague-Dawley adult, male, albino rats (190-250 g) from Simonsen Laboratories, Gilroy, California, were individually caged in the laboratory for 7 days before testing. Purina Lab Chow and water were available ad libitum. Animals were fasted 4 to 6 hours before testing, then gavaged with 3,000 mg/kg charcoal, 3,000 mg/kg sodium nitrate, or a combination of the two chemicals at 3,000 mg/kg each. Deionized water was the carrier. Thirty animals (10 per treatment) received the chemicals and 10 control animals received equivalent volumes of deionized water only. They were observed for 14 days after dosing.

2. Laboratory tests (coyotes)

A simulated coyote den (SCD) was used to evaluate pyrotechnic fumigants in the laboratory. The SCD was constructed of 1/2-inch plywood with inside dimensions of 14 by 14 inches. It was composed of seven individual sections, ranging in length from 2 to 7 feet. The sections acted as a burrow and could be bolted together to obtain the desired length. A detachable box (18 by 22 by 36 inches, internal dimensions) at the end of the sections served as a holding "den" for coyotes. Coyotes were confined to the box by a screen door. Tests were conducted in a heated (14° to 17°C) garage which could be easily ventilated by fans.

Two sizes of SCD's were used. Ten tests were conducted with individual adult coyotes and two tests with coyote pups in an SCD configuration in the shape of a "U". It was 22-1/2 feet long and the total volume was 34 cubic feet. Two tests were conducted with coyote pups in a straight SCD, 10-1/2 feet long and 18 cubic feet in volume. Captive adult coyotes (8.2 to 13.2 kg) of either sex were maintained in the laboratory for a minimum of 30 days before testing. Two litters of coyote pups were obtained from dens in the field and maintained in the laboratory for 1 to 2 days before testing. Two litters were born in captivity.

Carbon monoxide concentrations in the SCD during tests with coyote pups were measured with a Draeger gas sampling apparatus (National Draeger, Inc., 401 Parkway View Drive, Pittsburgh, PA 15205). The carbon monoxide situation of hemoglobin (carboxyhemoglobin) in blood from the pups was analyzed by a commercial laboratory (Poisonlab, 1469 South Holly Street, Denver, Colorado 80222) using the spectrophotometric method of Tietz (1970). Control carboxyhemoglobin content was determined from two pups killed with sodium pentobarbital.

3. Field evaluation of the gas cartridge (coyotes)

Based on laboratory tests with coyotes, a cartridge containing 240 g of 65% sodium nitrate and 35% charcoal was evaluated in the field. The cartridge was 12-1/2 inches long and 1-1/2 inches inside diameter (i.d.). This cartridge is shown in Figure 1.

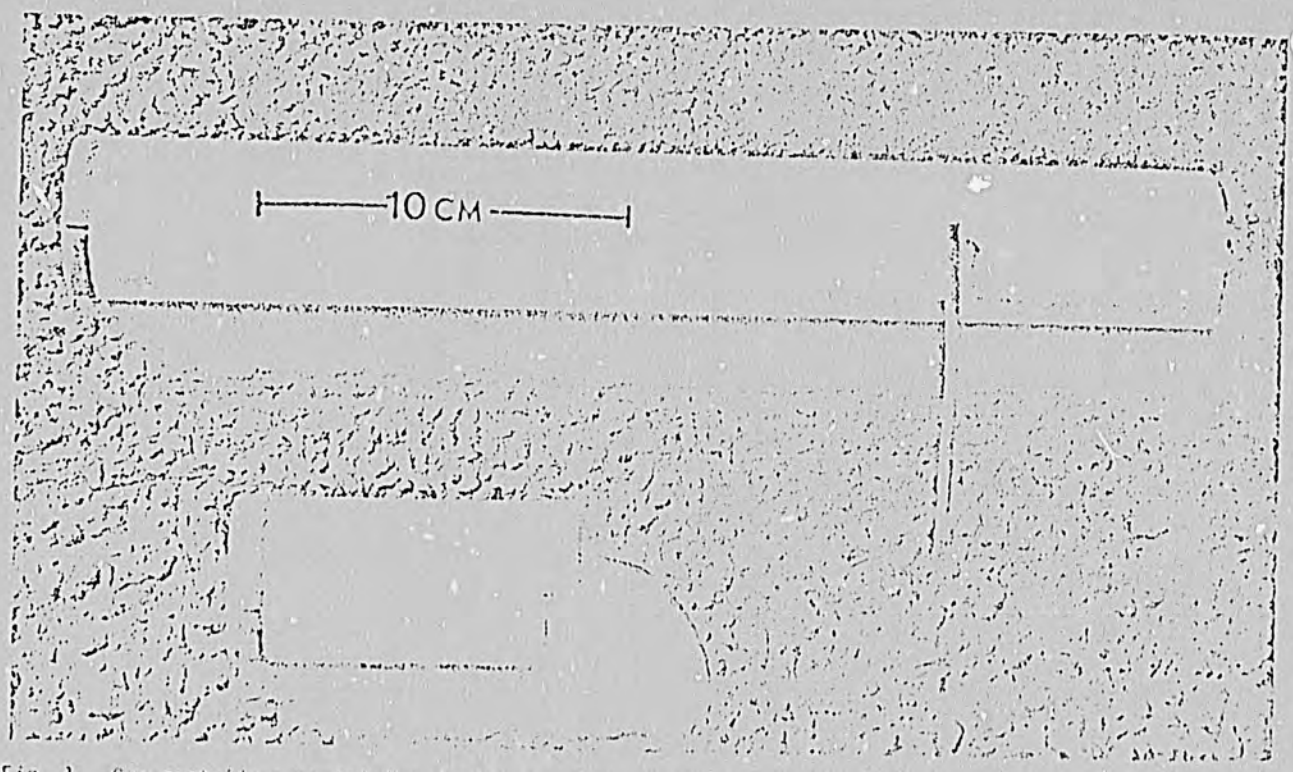

Fig. 1. Gas cartridges containing a mixture of 65% sodium nitrate and 35% charcoal with fuse. Top: Coyote gas cartridge that contains 240g. Bottom: Rodent gas cartridge that contains 65g.

Since this cartridge produces a toxic material, testing was prohibited on public lands by Executive Order 11643. Therefore it was tested on private land in cooperation with FWS Animal Damage Control (ADC) personnel who worked with or were instructed by Denver Wildlife Research Center personnel in the use of the device and data collection. Tests were conducted during the spring of 1973 in California, Oregon, Wyoming, Texas, and Nebraska.

When a den was located and determined to contain pups, all but one exit hole was plugged if more than one existed. A cartridge was attached to a 6-foot metal rod, ignited, inserted as far as possible into the den, and the hole was plugged. After one half to 1 hour the den was opened to recover animals.

4. Laboratory tests (rats)

Only the two-ingredient cartridge was evaluated in a simulated rodent burrow (SRB). This cartridge contained 65 g of 65% sodium nitrate and 35% charcoal and was 3-1/2 inches long and 1-1/2 inches i.d. (see Fig. 1). Figure 2 shows a diagram of the SRB. The SRB was constructed primarily of 3-inch (i.d.) plastic pipe. It had 12 branches, a total length of 65 feet, and a volume of 3.32 cubic feet. Three Norway rats were exposed during each trial at positions 1, 2, and 3 on Figure 2.

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[1] Use of trade names does not imply endorsement by the federal government.

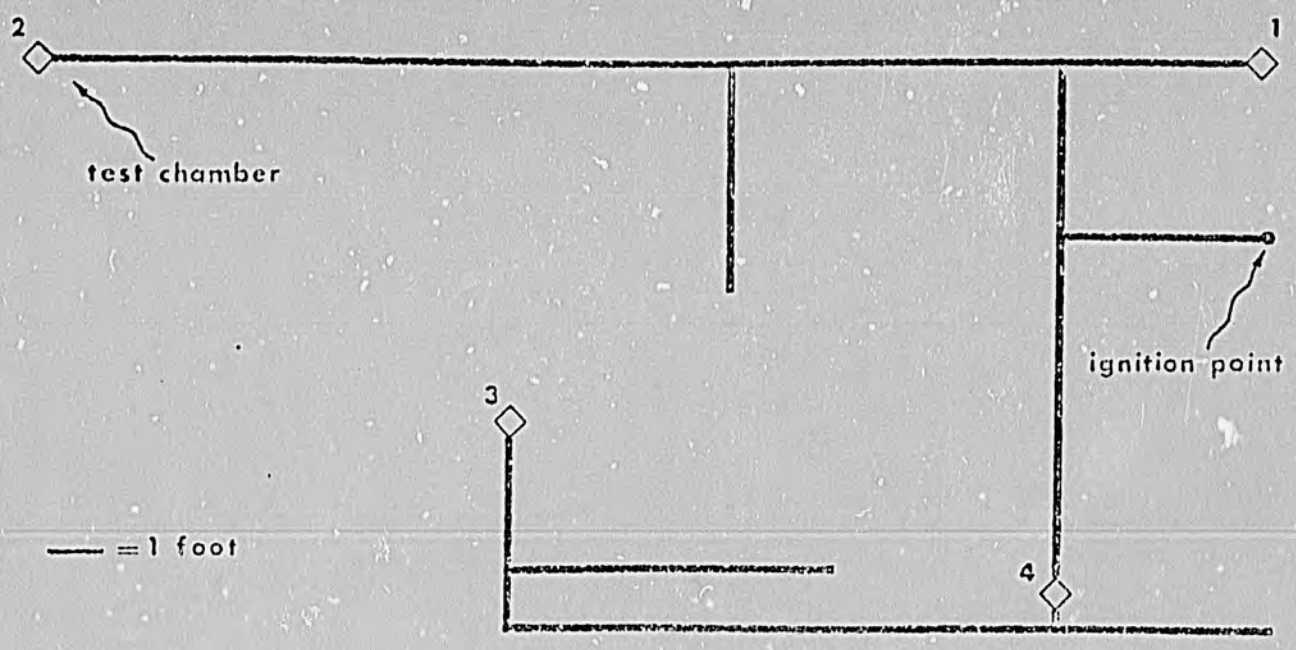

Fig. 2. Diagram of simulated rodent burrow (SRB).

5. Field evaluation of the gas cartridge (rats)

Field testing of the cartridge evaluated in the SRB was conducted in January 1980 at a Norway rat infested cattle feedlot near Commerce City, Colorado. Ten test sites were selected at different points within the feedlot. A test site is defined as a cluster of burrows at least 25 yards from any other cluster or group of burrows. Each burrow opening was plugged initially. Then, reopened burrows were counted and replugged for 3 consecutive days to determine which were active. A minimum of five active (reopened) burrows per day was necessary for a test site to be included in the evaluation. Following the count of active burrows on the third day, the test sites were fumigated by inserting lighted fumigant cartridges into the active burrows and replugging them. If it was obvious that some burrow openings were directly connected to those in which cartridges were placed (e.g., as evidenced by large amounts of smoke escaping) then these openings were counted and plugged, but additional cartridges were not inserted. An attempt was made to kill all rats flushed out of burrows by fumes. The procedure of counting and plugging reopened burrows was repeated for 3 more consecutive days after fumigation.

The test sites or burrow clusters were considered the experimental units with data consisting of the pre- and post-treatment average numbers of active burrows. Data analysis was done by a one-tailed, paired T-test, and the nonparametric Wilcoxon signed rank test (Snedecor and Cochran 1967).

6. Secondary hazard tests (bobcats)

Adult male albino rats were maintained as previously described. Groups of six rats each were euthanized in a box chamber with carbon monoxide generated by burning 20 g of 65% sodium nitrate and 35% charcoal in a 1-1/2 inch i.d. x 1 inch long cardboard cylinder. Carbon monoxide concentrations were measured with DRÄGER gas sampling tubes.

Five days before receiving treated rats, three bobcats (1 male and 2 females, 5.4-6.4 kg) were each prebaited with two rats killed by cervical dislocation. Each bobcat was then offered two rats killed by fumes from the gas cartridge for 7 consecutive days. They were subsequently fed control rats and observed for an additional 14 days.

RESULTS AND DISCUSSION

1. Acute oral toxicity tests with charcoal and sodium nitrate (rats)

No signs of toxicity or mortalities were observed in rats orally dosed with 3,000 mg/kg charcoal or sodium nitrate. Windholz (1976) reported the minimum oral lethal dose of sodium nitrate in rats to be 200 mg/kg. Wanntorp and Swahn (1955) reported the acute oral LD_{50} of sodium nitrate to be about 5,000 mg/kg in female albino rats.

Two of 10 rats died following administration of an oral dose of 3,000 mg/kg charcoal and 3,000 mg/kg sodium nitrate. Statistical analysis of these test results by a comparison of the proportions revealed no significant differences, indicating that charcoal and sodium nitrate do not potentiate each other.

2. Laboratory tests (coyotes)

Both the two-ingredient and eight-ingredient cartridges were tested on adult coyotes in the "U" shaped SCD. Under these conditions the two-ingredient cartridge containing only sodium nitrate and charcoal was equally effective as the eight-ingredient cartridge (Table 1). These results show that time to death is similar when equal weights of ingredients for the cartridges are used. Based on these results, tests with the eight-ingredient cartridge were discontinued.

Table 1. Laboratory testing of fumigants in adult coyotes

Fumigant	Amount of ingredients	Number of coyotes	Time to death
Two ingredients[a]	120 g	3	33, 35, 48 min
Two ingredients	240 g	3	17, 19, 20 min
Eight ingredients[b]	120 g	2	35, 45 min
Eight ingredients	240 g	2	less than 20 min[c]

[a]Contains 65% sodium nitrate and 35% charcoal.

[b]Contains 10.84% sulphur, 17.34% charcoal, 3.25% red phosphorus, 14.09% mineral oil, 43.36% sodium nitrate, 3.52% sawdust, and 7.60% inert ingredients (borax and Fuller's earth).

[c]Box rapidly filled with dense smoke and exact time of death could not be determined.

Results from laboratory tests on coyote pups with the two-ingredient cartridge containing 240 g of 65% sodium nitrate and 35% charcoal are shown in Table 2. All pups for a given test were from the same litter. Pups in Tests 1 and 2 were obtained from the field and pups in Tests 3 and 4 were born in captivity. Pups in Test 1 were estimated to be 6 weeks old and weighed from 1,035 g to 1,250 g. Pups in Test 2 were approximately 4 weeks old and weighed from 801 g to 873 g. Pups in Tests 3 and 4 were 3 weeks old (538 to 644 g) and 10 days old (232 to 339 g), respectively.

Table 2. Laboratory testing of the two-ingredient cartridge on coyote pups.[a]

Size of SCD	Test number	Number of pups	% carbon monoxide after ignition	% carboxy-hemoglobin[d]	Time to death (min)
"U" shape, 34 cu ft	1	4	0.7[b]	85 (-)[e]	12 to 14
	2	5	0.7[b]	87 (85-90)	12 to 14
Straight, 18 cu ft	3	5	3.0[c]	79 (70-85)	4 to 6
	4	5	3.5[c]	83 (75-85)	4 to 7

(Control % carboxyhemoglobin in each of two pups less than 5%)

[a]Cartridge contains 240 g of 65% sodium nitrate and 35% charcoal.

[b]15 min after ignition.

[c]10 min after ignition.

[d]Mean (range).

[e]Each of the four values was 85%.

As shown in Table 2, lethal quantities of carbon monoxide were generated in only a few minutes. The high percentage of carboxyhemoglobin in blood from the pups is indicative of the acute toxicity of carbon monoxide. In a review of euthanizing agents for the veterinary profession, the AVMA (1978) Panel on Euthanasia stated that the advantages of carbon monoxide (CO) were: (1) rapid and painless death; (2) insidious hypoxemia so that the animal is completely unaware of it; and (3) unconsciousness without pain or appreciable discomfort.

3. Field evaluation of the gas cartridge (coyotes)

Field tests of the two-ingredient cartridge were 96% successful (Table 3). In some instances death of all the pups could not be confirmed. Sometimes the den was very large and all pups could not be retrieved. Some dens may have been so extensive that there was insufficient carbon monoxide produced by a single cartridge. In one den, a culvert in Oregon, a cartridge failed to kill the three pups, and

the only logical explanation was that there was an undetected air leak in the culvert which supplied oxygen to the animals.

Table 3. Coyote dens fumigated with the two-ingredient cartridge.[a]

State	Number of dens	Number of pups in den[b]	Number of pups killed	Percent killed
Nebraska	2	9	9	100
California	10	49	46	94
Wyoming	26	169	154	91
Oregon	30	170	167	98
Texas	30	124	124	100
Totals	98	521	500	$\bar{x}$ = 96

[a]Cartridge contains 240 g of 65% sodium nitrate and 35% charcoal.

[b]Based on pups seen, taken, or number of placental scars when a female coyote was killed at or near the den.

In addition to pups, six adult females were also killed in the dens. Based on the number of dead pups recovered and good estimates of the numbers present, the 96% mortality rate indicates a high level of efficacy for the two-ingredient cartridge.

4. Laboratory tests (rats)

Results of testing the two-ingredient cartridge under laboratory conditions on wild Norway rats are shown in Table 4. Applying Duncan's multiple range procedure to these data indicates that animals at Position 1 located 11 feet and two branches from the cartridge ignition point died sooner than animals at Positions 2 and 3, ($p < 0.01$), each of which is 26 feet from the ignition point (Fig. 2). The time to death at Positions 2 and 3 is not significantly different, indicating that diffusion of the fumes from the ignition point to these positions is comparable.

Table 4. Results of the two-ingredient cartridge in a simulated rodent burrow with wild Norway rats.[a]

Trial #	Sex, weight, and time to death of test animals at: Position 1	Position 2	Position 3
1	M, 510 g, 35 min	M, 515 g, 300 min[b]	M, 425 g, 170 min
2	F, 322 g, 25 min	F, 350 g, 352 min	F, 375 g, 230 min
3	F, 325 g, 37 min	F, 285 g, 420 min[b]	F, 287 g, 420 min[b]
4	M, 295 g, 27 min	F, 267 g, 390 min[b]	M, 251 g, 195 min
5	M, 339 g, 4 min	M, 442 g, 213 min	M, 351 g, 209 min

[a]Cartridge was 3-1/2 inches long x 1-1/2 inches inside diameter and contained 65 g of 65% sodium nitrate and 35% charcoal.

[b]Estimated; exact time to death not determined.

5. Field evaluation of the gas cartridge (rats)

The overall percent reduction in number of reopened burrows after fumigation as compared with pretreatment figures is 77% with a range from 35% at site 6 to 95% at site 1 (Table 5). Analysis of these data by both the paired T-test and the Wilcoxon signed rank nonparametric test indicates that this reduction is significant ($p = .016$ and $p < .005$, respectively).

Rats were flushed from burrows in 5 of the 10 test sites (4, 5, 8, 9, 10). Three rats each were killed at sites 4 and 5; 25 at site 8, 17 at site 9, and 2 at site 10. Some rats flushed from site 5 escaped. Several of the burrows were under either concrete or wooden feed bunkers. In one instance, under a wood bunker at site 9, fumes were emitted from a hole 30 feet from point of ignition, indicating a very extensive burrow system.

6. Secondary hazard tests (bobcats)

All rats killed by fumes from the sodium nitrate and charcoal died within 15 minutes and the carbon monoxide concentration in the air exceeded 1.2%.

No symptoms of intoxication were observed in the three bobcats during 7 days of feeding on two rats per day. There was never any rejection of rat carcasses and, in most instances, the entire carcass, including feet and tail, was consumed.

Table 5. Field evaluation in wild Norway rat burrows. Number of burrows opened before and after fumigation with two-ingredient cartridge.[a]

Test site	Day 1	Day 2	Day 3	Total	$\bar{x}$	No. cartridges used	Day 4	Day 5	Day 6	Total	$\bar{x}$	Percent reduction
1	26	34	22	82	27	18	0	2	2	4	1	95
2	8	14	24	46	15	23	1	2	2	5	2	89
3	18	13	24	55	18	14	1	1	2	4	1	93
4	53	51	57	161	54	43	11	21	21	53	18	67
5	44	24	33	101	34	25	8	10	7	25	8	75
6	5	8	7	20	7	5	4	5	4	13	4	35
7	38	29	15	82	27	10	3	6	8	17	6	79
8	20	18	24	62	21	22	2	4	3	9	3	89
9	86	59	64	209	67	60	26	19	15	60	20	71
10	182	206	249	637	212	149	52	41	46	139	46	78
	480	456	519	1,455	482	360	108	111	110	329	109	77

[a]Cartridge was 3-1/2 inches long x 1-1/2 inches inside diameter and contained 65 g of 65% sodium nitrate and 35% charcoal.

Hazard Assessment of Two-Ingredient Cartridge

Neither charcoal nor sodium nitrate is considered to be dangerous chemicals. The toxicity hazard of carbon to humans ranges from "none" to "slight" (Sax 1975). The relative innocuous nature of charcoal can be appreciated by the fact that its adsorptive capacity is used for emergency treatment of some types of chemical poisonings (Swinyard 1975a). The dose of activated charcoal used as an antidote is 10 g administered orally as a thick slurry in water. Activated charcoal is used in the food industry for processing foods such as sugar and alcoholic beverages. Charcoal is a popular fuel for barbecuing and in 1978 about 700,000 tons were used for that purpose (Seeds, personal communication).

Sodium nitrate is used in the manufacture of numerous products including glass, explosives, pyrotechnics, ceramics, detergents and soaps, porcelain enamel, pulpwood and paper, charcoal briquettes, and fertilizers. In metallurgical industries it is used as a flux, as a component in baths for heat treatment of metals, and as an oxidizing agent. Food grade sodium nitrate is acceptable to the United States Department of Agriculture Meat Inspection Division as a color fixing agent in curing meats (Olin Corporation 1978).

When carbon and sodium nitrate are burned, large amounts of carbon monoxide (CO) are generated according to the following formula (Magram, no date).

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

carbon + sodium nitrate → carbon monoxide + sodium carbonate + nitrogen

Two other products, sodium carbonate (Na_2CO_3) and nitrogen (N_2), are also formed. The acute oral LD_{50} of sodium carbonate (soda ash) in rats is about 4,000 mg/kg (Frank 1946). The toxicity of sodium carbonate to humans depends on the extent of exposure (Windholz 1976). Repeated topical use may produce sensitivity reactions and ingestion of large quantities may irritate the gastrointestinal tract and induce vomiting, diarrhea, circulatory collapse, and death. Since gas cartridges are used underground, it is highly unlikely that people would be exposed to the sodium carbonate that is formed. The nitrogen produced by the cartridges is insignificant and would not pose any biological hazard. In the normal atmosphere nitrogen constitutes about 75% by weight or 78% by volume of the air (Windholz 1976). Carbon monoxide is the most hazardous product formed.

Carbon monoxide is highly toxic by the inhalation route of administration. The toxicity of carbon monoxide is due to its ability to combine with hemoglobin to form carboxyhemoglobin. Carboxyhemoglobin is not able to carry oxygen. The affinity of hemoglobin for carbon monoxide is about 240 times greater than for oxygen and when carbon monoxide is inhaled, it is rapidly removed from the plasma and combines with hemoglobin in the red blood cell (Swinyard 1975b). Toxic reactions following inhalation of carbon monoxide are the result of tissue hypoxia since the blood cannot carry sufficient oxygen for normal metabolic processes.

The two-ingredient cartridge will be used underground and the likelihood of it contaminating the environment is nil. Carbon monoxide is the most hazardous product of this cartridge, but the environment is well equipped to take care of it. Soil microorganisms absorb and metabolize carbon monoxide as an energy source (Inman and Ingersoll 1971). It has been estimated that "the capacity of the total soil surface (to absorb carbon monoxide) of the continental United States can be calculated

to be over 500 million metric tons per year, which is over twice the estimated annual worldwide production of carbon monoxide by man" from technological sources such as fossil fuel burnings in cars and factories. Green plants produce more carbon monoxide than they assimilate. Loewus and Delwiche (1963) calculated that a field of 100 hectares of alfalfa could produce about 2,000 liters of carbon monoxide in a 10-hour period. It is estimated that total carbon monoxide production by plants is 0.5 to 1.0 x 10^{14} g/year (Seiler et al. 1978). This figure represents about 110 to 220 trillion pounds of carbon monoxide. The estimated amount of carbon monoxide generated from 1,000 cartridges (12-1/2 x 1-1/2 inches) containing 240 g of 65% sodium nitrate and 35% charcoal is about 185 pounds.

In conclusion, we believe that the two-ingredient cartridge would be an effective pyrotechnic fumigant for vertebrate pests that live in burrows or dens. Its effectiveness was evident in both laboratory and field tests on coyotes and rats. It could probably be used on other burrowing rodents by slight adjustments in the amounts of ingredients. The lack of secondary toxicity to bobcats implies that carcasses killed by fumes from the cartridge would not be toxic to scavengers. The cartridge is safe to humans and the environment because it is used underground and contamination is minimal.

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