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## ZINC PHOSPHIDE RESIDUES IN VOLES: SCENARIOS SHOWING LOW RISKS TO DOMESTIC CATS AND DOGS

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ABSTRACT: Zinc phosphide  $(Zn_3P_2, CAS \#1314-84-7)$  is an acute rodenticide having numerous agricultural applications. This paper estimates the risk of mortality posed to domestic cats (*Felis domesticus*) and dogs (*Canis familiaris*) from ingestion of voles (*Microtus* spp.) that succumb to 2.0%  $Zn_3P_2$  baits. Following a brief review of direct/indirect studies and incident reports relevant to nontarget- $Zn_3P_2$  effects and vole control, four scenarios of vole-carcass ingestions needed for light and heavy cat and dog predators/scavengers to receive approximate lethal doses (ALDs = 40 mg/kg) of undigested rodenticide are described. Scenarios were derived using values reported by Sterner and Mauldin (1995) as the maximum 8.2 mg  $Zn_3P_2$  ingested (ad libitum) and average 1.7 mg  $Zn_3P_2$  whole-carcass residue. Extrapolating these "worst-case" loads to 2 and 6 kg cats and 1 and 36 kg dogs showed that between 5 and 847  $Zn_3P_2$ -baited vole carcasses must be consumed in fairly rapid succession for these nontargets to ingest cumulative ALDs. The likelihood that even light ( $\leq 1-2$  kg) cats and dogs will find and rapidly ( $\leq 24$  h) ingest multiple ( $\geq 5$ )  $Zn_3P_2$ -dosed vole carcasses under registered applications seems remote.

KEY WORDS: hazards, rodenticides, residual effects, toxicity, zinc phosphide, pesticides, field rodents, voles

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#### INTRODUCTION

Zinc phosphide is an acute rodenticide that has numerous applications in agriculture and public health (Gratz 1973, Marsh 1988, Sterner 1994). For example, current Animal and Plant Health Inspection Service (APHIS) registrations include: 1.82% and 2.0% on wheat and steam-rolled oats for mouse control (*Microtus* spp. and *Peromyscus* spp.) in orchards/groves (non-bearing phase), rangelands, etc. (EPA Reg. Nos. 56228-3, -5 or -6) and 2.0% on steam-rolled oats for prairie dog control (*Cynomys* spp.) on rangelands (Reg. No. 56228-14).

That Zn<sub>3</sub>P<sub>2</sub> affords high acceptance and efficacy for numerous rodent species is well documented (e.g., Marsh 1988, Sterner et al. in press, Tietjen 1976); however, bait shyness (Marsh 1988, Sterner 1994) and broad-spectrum toxicity (Johnson and Fagerstone 1994, Marsh 1988) are recognized deficiencies. Mitigation of bait shyness usually involves pre-baiting to increase initial bait ingestion and reduce the frequency of sub-lethal dosings (Marsh 1988). Nontarget rodents are at risk, but selective use of baits reduces foraging by nontarget mammals and birds (Johnson and Fagerstone 1994, Marsh 1988). Additionally, residue hazards of Zn<sub>3</sub>P<sub>2</sub> to nontarget mammalian predators and avian scavengers/raptors remain a concern-loads of undigested rodenticide in the gastrointestinal (GI) tracts of target animals can be fatal to predators/scavengers (Bell and Dimmick 1975, Sterner and Mauldin 1995, Tkadlec and Rychnovsky 1990).

This paper reviews selected literature on nontarget hazards posed by the use of  $Zn_3P_2$  baits to control voles in agriculture. Scenarios of hazards that vole carcasses containing low  $(\bar{x} = 1.7 \text{ mg})$  and high "worst-case" (maximum ingested = 8.2 mg)  $Zn_3P_2$  loads pose to relatively light and heavy domestic cats and dogs are discussed.

#### Zn<sub>2</sub>P<sub>2</sub> VOLE, CAT AND DOG TOXICITY

The mode of action of  $Zn_3P_2$  involves hydrolysis to phosphine (PH<sub>3</sub>) upon reaction with stomach acids; circulating PH<sub>3</sub> decreases electron transport and cellular respiration (Chefurka et al. 1976, Hazardous Substance Databank 1994, Murphy 1986). Acute-oral, medianlethal-dose (LD<sub>50</sub>) values for  $Zn_3P_2$  in diverse vole species are between 15 to 20 mg/kg; the LD<sub>50</sub> for prairie and meadow voles are 16.2 and 15.7-18.0 mg/kg, respectively (see Bell 1972, Hood 1972). Hudson et al. (1984) reported  $Zn_3P_2$  ALDs for both domestic cats and dogs of 40 mg/kg; to the author's knowledge, no LD<sub>50</sub>s for these nontargets are available.

### $\mathbf{Zn_3P_2}$ FOR VOLE CONTROL: KEY NONTARGET LITERATURE

Johnson and Fagerstone (1994) provided a comprehensive review of the literature concerning primary and secondary hazards of Zn<sub>3</sub>P<sub>2</sub> to nontarget wildlife. These authors identified 61 acute oral toxicity studies of Zn<sub>3</sub>P<sub>2</sub> involving 28 mammalian and 16 avian species, plus 16 hazards studies involving 12 mammalian predators/scavengers, 6 raptor, 2 reptilian, and 1 amphibian species. Hazards of Zn<sub>3</sub>P<sub>2</sub> to nontarget predators/scavengers are not strictly secondary; undigested rodenticide within target animals (a primarytype hazard) pose the danger. Because the objective focuses on nontarget risks posed by the use of Zn<sub>2</sub>P<sub>2</sub> for vole control, a brief update of the literature relevant to voles as the source of Zn<sub>3</sub>P<sub>2</sub> for felids and canids is provided here.

Information of Zn<sub>3</sub>P<sub>2</sub>-residue effects in voles and potential consequences for nontarget species can be categorized under three headings: direct-effect studies, indirect-effect studies, and nontarget-incident reports.

"Direct-effect" studies refer to those in which carcasses of voles that died following ingestion of  $Zn_3P_2$  baits are fed to nontarget predators/scavengers. "Indirect-effect" studies refer to residue estimates of vole carcass  $Zn_3P_2/PH_3$  extrapolated to nontarget predator/scavenger doses based upon published  $LD_{50}$  or ALD doses. Nontarget-incident reports refer to documented or anecdotal cases where sub-lethal signs or nontarget deaths were associated with  $Zn_3P_2$  applications.

#### **Direct-Effect Studies**

Bell and Dimmick (1975) conducted the most often cited direct-effect study of Zn<sub>3</sub>P<sub>2</sub>. These authors force fed prairie voles fatal doses of Zn<sub>3</sub>P<sub>3</sub> pellets (86.94 mg/kg) 5 h prior to use of the carcasses. A three-day period to condition nontarget experimental and control animals/ raptors to eating voles was used. Control nontargets were included to monitor food habits/behaviors of animals fed non-Zn<sub>3</sub>P<sub>2</sub>-dosed voles. Results showed that two red foxes (Vulpes vulpes), two gray foxes (Urocyon cinereoargenteus) and two great horned owls (Bubo virginianus) ate an average 11.5, 11.7, and 8.5 non-dosed vole carcasses, respectively, during this conditioning period. No deaths in these animals were observed during the experimental period after ingestion of 4 to 12 vole carcasses containing mean doses of 10.64, 8.60, and 22.31 mg/kg Zn<sub>3</sub>P<sub>2</sub> for these species, respectively; however, some lethargy and altered behaviors occurred. For example, one red fox (9) would neither eat nor cache a vole after the first test day; whereas, the owls roosted on the ground (beneath rain shelters), rather than on the rain shelters as observed prior to the first day's dosings.

Tkadlec and Rychnovsky (1990) studied both direct and indirect effects of 5.0% Zn<sub>3</sub>P<sub>2</sub> baits in common voles (*M. arvalis*)—5.0% Zn<sub>3</sub>P<sub>2</sub> baits are used for vole control in Czechoslovakia. In the direct-effects study, one cat died within a day after ingesting five vole carcasses that succumbed from eating 5.0% Zn<sub>3</sub>P<sub>2</sub> baits. This amounted to a maximum 103.5 mg dose for the cat (37 mg/kg Zn<sub>3</sub>P<sub>2</sub>)—a dose near the reported 40 mg/kg ALD cited for this species (Hudson, et al. 1984). A second cat, two weasels (*Mustela nivalis*), and three kestrels (*Falco tinnunculus*) did not die following ingestion of multiple vole carcasses containing maximum 60, 160 to 182, and 77 to 88 mg/kg Zn<sub>3</sub>P<sub>2</sub> doses, respectively.

#### Indirect-Effect Studies

In an indirect study, Tabata (1986) measured the dissipation and acid decomposition of  $Zn_3P_2/PH_3$  in redbacked wood mice (*Apodemus speciosus*) dosed orally with 10 mg  $Zn_3P_2$  (1.8 mg ALD). The mice exhaled a maximum 379  $\mu$ g of  $Zn_3P_2$  as  $PH_3$ ; this is equal to about 1.4 mg of  $Zn_3P_2$  or 14.4% of the total dose. Considerable undigested  $Zn_3P_2$  was detected in GI contents.

As mentioned, Tkadlec and Rychnovsky (1990) also provided analytical data on  $Zn_3P_2$  residues in common voles. Using a colorimetric method of  $PH_3$  absorption, they reported that ~58% (±25%) of total ingested  $Zn_3P_2$  was found in the GI tracts of  $Zn_3P_2$ -killed voles; only 0.3% (±0.3%) of ingested  $Zn_3P_2$  was found in the remainder of carcasses.

More recently, Sterner and Mauldin (1995) attempted to develop improved cryogenic-preservation and gaschromatographic techniques for estimating whole-carcass  $Zn_3P_2/PH_3$  residues in a mixed sample of meadow (M. pennsylvanicus) and prairie voles (M. orthogaster). Voles ingested fatal doses of 2% Zn<sub>3</sub>P<sub>2</sub>/SRO-groats fed ad libitum. Cryogenic procedures did not enhance Zn<sub>3</sub>P<sub>2</sub> recovery; the main difficulty with analyses seemed to result from inadequate homogenization and hydrolyzation of Zn<sub>3</sub>P<sub>2</sub> trapped in the voles' pelts. Results showed that: 1) whole-carcass Zn<sub>3</sub>P<sub>2</sub> residues averaged 1.73 mg (minmax: 0.31-4.95) — ~ 25-50% of the calculated  $Zn_3P_2$ intake—and PH<sub>3</sub> residues averaged 10.6  $\mu$ g (min-max: 0.5-21.0); and 2) significant (positive) linear regressions were found between: 1) bait consumption/Zn<sub>3</sub>P<sub>2</sub> intake \* body weight ( $r^2 = 0.64$ , p  $\leq 0.001$ ); 2) carcass  $Zn_3P_2$ \* bait consumption/ $Zn_3P_2$  intake ( $r^2 = 0.32$ ,  $p \le 0.043$ ); and 3) carcass  $Zn_3P_2^{-*}$  body weight ( $r^2 = 0.60$ , p Minimum and maximum Zn<sub>3</sub>P<sub>2</sub> intakes  $\leq 0.002$ ). observed for specific voles were 2.0 and 8.2 mg, respectively; whereas, calculated doses of Zn<sub>3</sub>P<sub>2</sub> ingested by the voles averaged  $\geq 134.2$  mg/kg (min-max 79.2 to 243.2 mg/kg).

#### **Incident Reports**

Johnson and Fagerstone (1994) cited 12 published or unpublished accounts of Zn<sub>3</sub>P<sub>2</sub> baitings and nontarget incidents involving 14 species/genus. Of the nontarget species/genus involved in these accounts, seven bird [i.e., Canada goose (*Branta candensis*), Snow goose (*Chen caerulescens*), ducks (e.g., *Anas* spp.), wild turkey (*Meleagris gallopavo*), partridges (e.g., *Perdix* spp., *Callipepla* spp., *Colinus* spp.), corvidae (*Corvus* spp.), chickens (*Gallus* spp.)] and seven mammal species/genus [i.e., red fox, domestic cat, domestic dog, gray squirrel (*Sciurus carolinensis*), cottontail rabbit (*Sylvilagus floridanus*), horse (*Equus caballus*)] were listed. With the exception of the data for corvidae and chickens, all nontarget avian effects occurred due to foraging on

Only four references (not provided here) cited by Johnson and Fagerstone (1994) deal with predator/scavenger consumption of  $Zn_3P_2$ -dosed rodents. Specifically, two red foxes allegedly died after eating mice that consumed  $Zn_3P_2$ -treated grain bait, unspecified numbers of dogs died after eating ground squirrels poisoned with  $Zn_3P_2$ , two cat carcasses were recovered near a no-till corn field in Illinois treated with 2.0%  $Zn_3P_2$  grain baits, and one cat death was noted in another poorly documented account.

#### Zn<sub>3</sub>P<sub>2</sub>-HAZARDS SCENARIOS: CATS AND DOGS

To provide some perspective concerning  $Zn_3P_2$  residues in voles, the author prepared four "mortality-hazards scenarios" for two nontarget species—domestic cat and domestic dog. Mean (1.7 mg) and maximum (8.2 mg)  $Zn_3P_2$  residues (100% retention) observed in fatally-dosed voles by Sterner and Mauldin (1995), plus representative light and heavy predators/scavengers, were varied to produce four scenarios of risk. These residues were then used to calculate total carcasses needed to dose light/heavy cats and dogs with 40 mg/kg (ALD) of  $Zn_3P_2$ 

(Table 1). Tacit assumptions include: vole carcasses are consumed during continuous feeding and entire carcasses are ingested.

As shown, Scenario I reflects the hypothetical "worst case" situation—the least numbers of vole carcasses projected to deliver ALD doses to the nontargets. This scenario assumes that the maximum consumption of Zn<sub>3</sub>P<sub>2</sub> by a vole (8.2 mg) noted by Sterner and Mauldin (1995) would be retained by voles and that light cats (e.g., kitten) and dogs (e.g., puppy, Chihuahua) would ingest these voles during relatively continuous feeding. Interestingly, the "worst case" intake of 8.2 mg Zn<sub>3</sub>P<sub>2</sub> (assumed 100% retention and 2.0% bait) observed for a ole would equate to ingestion of ~12 to 13 voles for the cat reported by Tkadlec and Rychnovsky (1990).

Scenario II was developed using the same assumptions regarding  $Zn_3P_2$ , but hypothetical large cats (e.g., adult) and dogs (e.g., adult Labrador retriever) were substituted. As shown, the number of vole carcasses projected to cause mortality increased dramatically in this case to ~29 and ~176 for cats and dogs, respectively.

Scenarios III and IV are based on an assumption of the mean 1.7 mg  $Zn_3P_2$  residue detected in voles by Sterner and Mauldin (1995). Using this value, ~5-fold increases in the Scenario I and II carcass ingestions would be needed to attain the ALD cumulative doses for light and heavy cats and dogs, respectively. Even lightweight cats and dogs would have to consume  $\geq$ 24 vole carcasses in Amount of  $Zn_3P_2$  in Vole(s) (mg) relatively continuous feeding bouts to ingest ALDs under Scenarios III and IV.

Table 1. Hypothetical hazards scenarios showing the numbers of vole carcasses that must be consumed (in relatively rapid succession) for domestic cats and dogs of different weight classes to ingest an ALD (Note: ALD for cat and dog =  $40 \text{ mg/kg Zn}_3P_2$ ; Hudson et al. 1984).

Scenario		Assumptions		
	Amount of $Zn_3P_2 \text{ in}$ $vole(s)^1$ $(mg)$	Nontarget predator or scavenger	Nontarget weight (kg)	Estimated carcasses to ALD (#)2
<ul><li>I. High Zn<sub>3</sub>P<sub>2</sub> load</li><li>&amp; light nontarget</li></ul>	8.2	Cat Dog	2	~ 10 ~ 5
II. High Zn <sub>3</sub> P <sub>2</sub> load & heavy nontarget	8.2	Cat Dog	6 36	~ 29 ~176
III. Mean (low) Zn <sub>3</sub> P <sub>2</sub> load & light nontarget	1.7	Cat Dog	2 1	~ 47 ~ 24
V. Mean (low) Zn <sub>3</sub> P <sub>2</sub> load & heavy nontarget	1.7	Cat Dog	6 36	~ 141 ~ 847

<sup>&</sup>lt;sup>1</sup> From Sterner and Mauldin (1995).

<sup>&</sup>lt;sup>2</sup> Carcasses =  $\frac{\text{ALD Dose (mg/kg) x Nontarget Weight (kg)}}{\text{Amount of Zn}_{3}P_{2} \text{ in Vole(s) (mg)}}$ 

#### **CONCLUSIONS**

Prior direct- and indirect-hazards studies, coupled with several incident reports, confirm that: 1) ingestion of multiple, Zn<sub>2</sub>P<sub>2</sub>-laden-vole carcasses can prove fatal to domestic cats in single-choice feeding situations (Bell and Dimmick 1975, Tkadlec and Rychnovsky 1990); 2) although toxic signs have been noted for nontarget wildlife species in direct-hazards studies (see Bell and Dimmick 1975), the procedures used have involved conditioning of nontargets to carcass-feeding regimen and single-choice tests; 3) while only about half ( $\leq 69\%$  or 2.2 mg) of ingested  $Zn_3P_2$ , and negligible amounts of PH<sub>3</sub> ( $\leq 21 \mu g$ ), have been recovered from carcasses using current analytical techniques (Sterner and Mauldin 1995, Tabata 1986, Tkadlec and Rychnovsky 1990), data suggest that undigested Zn<sub>3</sub>P<sub>2</sub> in the GI tracts (~95% of the ingested amount) of target rodents pose the main potential hazard nontarget predators/scavengers (Tkadlec Rychnovsky 1990). Together, these results, and the lack of much unequivocal incident data, suggest that multiple dead or dying Zn<sub>3</sub>P<sub>2</sub>-baited voles must be consumed for representative predators/scavengers to ingest a cumulative lethal dose of Zn<sub>3</sub>P<sub>2</sub>/PH<sub>3</sub>.

Scenario I is supported as a conservative estimate of hazards posed to cats and dogs by ingestion of Zn<sub>2</sub>P<sub>2</sub>killed voles. Still, the likelihood of even lightweight cats and dogs ( $\leq 1$  kg) finding and rapidly (< 24 h) ingesting multiple (≥5) Zn<sub>3</sub>P<sub>2</sub>-dosed vole carcasses under field conditions seems remote. In a recent 14-day efficacy study involving a single 11.2 kg/ha broadcast application of 2.0% Zn<sub>2</sub>P<sub>2</sub> oat groats within 7, 0.2-ha enclosures planted in alfalfa, Sterner et al. (in press) found only 25 exposed vole carcasses during daily post-baiting searches (51 to 76 h total) over a 14-day period. Moreover, expected onset of hydrolysis-induced illness in nontargets, <100% retention of Zn<sub>2</sub>P<sub>2</sub> in carcasses, and selective avoidance of GI tracts containing undigested Zn<sub>3</sub>P<sub>2</sub> by certain nontarget species should preclude many predators/scavengers from ingesting fatal doses.

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