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Phosphine Exposure to Applicators and Bystanders from Rodent Burrow Treatment with Aluminum Phosphide

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Abstract: An industrial hygiene study was conducted to monitor levels of phosphine gas exposure of applicators and bystander environment during use of aluminum phosphide tablets where used to treat rodent burrows, or when entering treated fields and adjacent buildings. State-of-the-art Draeger Pac III monitoring units and Draeger Phosphine Badges were placed on 33 applicators using Fumitoxin® tablets to treat ground squirrels (*Spermophilus* spp.) and pocket gophers (*Thomomys* spp.). Applicators represented both frequent and infrequent users. Agricultural and urban area applicators and bystander conditions in 9 California counties were monitored. Bystander sites were monitored with the Pac III data logging equipment. Thirty concrete slab or raised foundation buildings and 9 outdoor park and almond or walnut production sites were monitored for phosphine gas.

No applicator phosphine exposures were above either the permissible 8-hour Time Weighted Average (TWA) of 0.3 ppm (Permissible Exposure Limit - PEL), or the 15-minute Short Term Exposure Limit (STEL) of 1.0 ppm. Higher exposures were observed for non-certified infrequent users than for certified or non-certified frequent applicators. The average TWA for applicators was 0.035 ppm, about 10% of the PEL. Label directions are satisfactory to avoid excessive worker exposure and environmental impact. Several work practices were associated with higher exposure potential, and recommendations were made for their mitigation to further reduce exposure. All exposures to PH₃ were related to poor handling procedures that could be avoided by following the label and proper training. Average PH₃ levels at potential bystander sites inside and outside residences were well below the 0.3 ppm TWA. No building registered over 10% of the PEL. In the outside trials, there were only 2 Pac III readings of over 100 that indicated detectable 8-hour TWAs at ground squirrel sites. The sites were very heavily infested, and PH₃ only slightly exceeded 10% of the PEL. No PH₃ was detected above pocket gopher burrows in any field site.

When used according to the current label, the potential PH₃ exposures of applicators and bystanders are low relative to the Low Observed Adverse Effect Level and are within existing occupational standards. Training was associated with lower worker exposures of certified applicators and non-certified frequent users compared to non-certified infrequent users.

Key Words: aluminum phosphide, rodent burrow fumigation, fumigant, worker safety, industrial hygiene, ground squirrel, pocket gopher, phosphine, human phosphine exposure

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INTRODUCTION

Aluminum phosphide tablets (ALP) have been registered for use in controlling certain types of rodents and moles for two decades. During that time, the material has become well recognized as an effective integrated pest management tool, especially in controlling ground squirrels and pocket gophers (Salmon et al. 1982, Baker 1992). According to California Department of Pesticide Regulation (DPR) Pesticide Use Reports, enough of this burrow fumigant is used annually in the state to treat over 1 million burrows in agricultural and non-agricultural areas. Almost equal amounts of fumigant are used in urban and rural areas. Some of the attributes of ALP for burrow fumigation are: 1) it is a highly effective rodenticide, 2) it quickly kills animals following inhalation of a toxic dose, 3) it breaks down to safe, low-toxicity aluminum hydroxide (Pestcon 2000a, Baker 1992), 4) it kills animal parasites in burrows, 5) it can be used in rodent burrows in all outdoor crops, 6) exposure is limited to treated burrows, 7) rodent carcasses pose no risk of secondary hazards to predators or scavengers, and

8) phosphine (PH₃) is not appreciably absorbed dermally or known to cause chronic health effects in humans (Pestcon 1999).

Aluminum phosphide (ALP; CAS 20859-73-8) is a highly toxic rodenticide that requires a "Restricted Material" permit for use. The label also requires that the user be a certified applicator (termed a qualified applicator certificate holder, or "QAC," in California) or be directly supervised by a QAC. All persons applying ALP must be trained in accordance with the product manual (Pestcon 2000a). ALP must not be applied to burrows within 15 feet of any buildings occupied by humans or animals, or into burrows that open under or into such buildings (Pestcon 2000a,b).

Proper applicator training and adherence to label requirements can prevent exposure to unsafe PH₃ levels. Threshold limit values (TLVs) for PH₃ have been published by several organizations including the U.S. Occupational Health and Safety Administration (OSHA), National Institute for Occupational Safety (NIOSH), and the American Conference of Governmental Industrial

Table 1. Threshold Limit Values (TLV) for phosphine gas exposure.

Organization	Type of Limit	Phosphine Level (ppm)
OSHA	Personal Exposure Limit (PEL)	0.3
	As an 8-hour time weighted average (TWA)	0.3
NIOSH	Recommended Exposure Limit (PEL) as a TWA for up to 10 hours/day	0.3
	Short term exposure limit (STEL*) as a 15-minute period that should not be exceeded at anytime in a work day.	1.0
	Immediately dangerous to life and Health (IDLH)	50.0
ACGIH	Threshold limit value (TLV) as an 8-hour TWA	0.3
	STEL*	1.0

*15-minute period, may not occur more frequently than once during a 60-minute interval, and no more than 4 times daily (ACGIH 1998, NIOSH 1999).

Hygienists (ACGIH) (Table 1).

In late 1998 there was great concern in agriculture and the pest control industry that Risk Mitigation Measures (RMMs) proposed as part of EPA's Re-Registration Eligibility Decision would too severely restrict, limit, or even eliminate the use of ALP for burrowing rodent control. Some of the proposed measures included the following:

- Extend the minimum distance from treated burrows to residences from 15 feet to 100 feet
- Require applicators to wear respiratory protection, regardless of PH₃ concentrations
- Reduce the PEL from 0.3 ppm to 0.03 ppm, 1/10 of the existing workplace standard (EPA 1998).

These measures evolved due, in part, to EPA review of a California summary document "Case Reports Received by California Pesticide Illness Surveillance Program in Which Health Effects Were Attributed to Exposure to Phosphine, 1982-1994" (DPR 1998). The 15 cases occurred during a 13-year period when pesticide use reports indicated that there had been more than 10 million applications of ALP to rodent burrows. Review of these cases revealed that few involved labeled uses of ALP. Most involved poor handling practices, lack of training, and negligent acts such as sprinkling tablets on the ground around and under a house, and applying many times the label rate to burrows that opened under a house. Others resulted from carrying ALP in an open flask for the entire application period, and failure to wear gloves. Other cases involved persons who wore excessive personal protective equipment (PPE) including chemical resistant suits, rubber gloves, and respirators in warm weather. Their illness may have been attributable to heat stress or heat exhaustion rather than PH₃ exposure (Baker 1999). These cases reinforce the need for applicator training and adherence to label use conditions.

The present monitoring study examined potential PH₃ exposures of certified and non-certified applicators

and bystanders under normal field conditions, to document handling practices, and to identify possible training needs.

ALP TECHNICAL INFORMATION

There are several brands of ALP, but the two most often used for rodent control in California are Fumitoxin[®], produced by Pestcon Systems, Inc., Wilson, NC, and Phostoxin[®], produced by Degesch, Weyers Cave, VA. Tablets and pellets are composed of 55% to 60% finely-ground ALP, ammonium carbonate, and sometimes a binder or coating of paraffin. The products are classified as "Water Reactive" and "Flammable Solids" due to their reactivity with water. When exposed to moisture in the atmosphere, the tablets or pellets liberate highly toxic phosphine (PH₃) gas. Water should not be added to burrows, and piling of tablets or dust may cause spontaneous combustion. Ammonium carbonate liberates ammonia and carbon dioxide to reduce the fire hazard of the PH₃. PH₃ is colorless and odorless; the smell of ammonia serves as a warning agent. The odor threshold generated from ALP tablets was reported to be 0.01 to 0.02 ppm (Fluck 1976). Gibbons (1988) attributed the odor to impurities that impart a carbide, fish, or garlic-like odor to PH₃ (Pestcon 1999, Science International Inc. 2000). However, the odor is not sufficient to be relied upon as a warning agent in all situations (Zaebst et al. 1988, NIOSH 1999).

Tablets are preferred over pellets for rodent burrow treatment due to lower labor costs. The tablets are shipped and stored in aluminum flasks that contain either 100 or 500 tablets. The flasks have a screw cap with a heavy rubber gasket for re-sealing. Burrowing rodents with open burrows are controlled by placing 2 to 4 tablets into each burrow opening to be treated, then packing a wad of newspaper into the burrow, followed by covering the newspaper with soil. The paper prevents soil from covering the tablets. All the untreated openings to the burrow system are then tightly packed with soil. Lower ALP rates are used for smaller burrow systems and when

soil moisture is high, and higher label rates are used for larger systems and when soil moisture is relatively low (Pestcon 2000a).

For rodents and moles with closed burrow systems, the label recommends use of a probe to create a hole large enough to allow placement of the tablets or pellets into the main burrow. Two to 4 tablets are dropped through the probe hole before it is sealed with a clod, sod plug, or other suitable material.

Ground squirrels (*Spermophilus* spp.) and pocket gophers (*Thomomys* spp.) in California are commonly treated rodent pests. When pocket gophers are treated, usually 2 or 3 tablets are placed into each of 2 probed holes, rather than 2 to 4 tablets in one probed hole. This is due to the difficulty of identifying separate burrow systems, as they often overlap. Ground squirrels are often treated by placing 3 to 4 tablets into each burrow opening unless the openings clearly belong to the same system. Ground squirrels may have from one to many openings in the same system depending on the type of system (male, breeding, or colonial).

GOALS AND OBJECTIVES

This study involved measurement of human PH_3 exposure resulting from use of ALP tablets, according to label conditions at maximum label rates, in the integrated pest management of ground squirrels and pocket gophers. The primary objective was to determine potential PH_3 exposures of applicators and bystander environments under normal field conditions in both agriculture and urban pest control. Persons monitored were classed as follows:

1. Applicators
 - a. QACs - Frequent and infrequent users
 - b. Non-QACs - Frequent and infrequent users
2. Bystander Environments
 - a. Treated out door urban and crop areas
 - b. Buildings adjacent to treated areas

A secondary objective was to observe normal application procedures, to identify potential hazardous work practices, and to collect information important to safe handling of ALP that might guide training and modification of application equipment.

A third objective was to evaluate the performance, precision, and dependability of the Draeger Pac III Hygiene Model Data Logger and Draeger PH_3 Badges. These were evaluated under normal field conditions and under controlled conditions at very low PH_3 concentrations.

METHODS AND MATERIALS

Monitoring Equipment and Procedures

According to the protocol developed in consultation with experts and USEPA personnel, each applicator simultaneously wore a Draeger PH_3 Badge and a Draeger Pac III Hygiene Model Data Logger. The badges, in a Draeger diversion housing, were normally placed on the

collar, in the vest pocket, or suspended from a Pac III safety neck strap, from the start to the end of the workday. The Draeger badge in the diversion housing is designed to quantitatively measure PH_3 in air for durations of 30 minutes to 8 hours. The detectable level of PH_3 ranges from 0.01 to 0.3 ppm for an 8-hour period (TWA). The badge color is compared to that of a printed color standard in order to establish workplace PH_3 . Color was read and verified by 2 persons including a project employee.

Pac III Hygiene data logging gas detectors were used for personal breathing zone and bystander site monitoring. Applicators carried Pac IIIs in their shirt pockets and secured them with a neck strap. Monitors were equipped with XSEC hydride sensors. The PH_3 detection range was 0.01 ppm to 20 ppm. The specified reproducibility of measurements was ± 0.02 ppm. PH_3 concentrations were logged at 1- and 15-minute intervals. The 15-minute time interval was used in early trials. A 1-minute interval was used later, based upon battery life under field conditions. PH_3 levels, average TWA short term exposure limit (STEL), maximum PH_3 exposures, and any alarm activations were recorded on field data forms at the end of each day. These data were also downloaded to the Gas Vision 4.0 program on a Hewlett Packard Pavilion Notebook PC hard drive and backed by floppy discs. The Pac III had both sound and flashing light alarms to warn applicators of high PH_3 levels. The alarms were set at 19 ppm for short high peaks and 1 ppm for STEL periods. A STEL alarm triggered immediate investigation of application practices by study staff. Observations were recorded on field data sheets and in logbooks.

All Pac III units were initially calibrated at Draeger labs and were re-calibrated at least every 6 months with certified 0.5 ppm PH_3 gas. Before use, the Pac IIIs were warmed up for about 15 minutes and a zero calibration was performed. The certified calibration gas was also used as a "bump gas" prior to each trial.

ALP Application

When separate burrow systems could be easily defined, ALP applications to rodent burrows were made using the maximum label rate of 4 tablets per burrow system. Every opening was treated unless it was obviously connected to an adjacent one. Usually 8 to 12 tablets were used in each ground squirrel system. Four to 6 tablets were used for each pocket gopher burrow. Three tablets were usually applied in each of 2 probed holes when one specific system could not be easily separated.

Over 41,000 tablets of Pestcon's Fumitoxin[®] brand ALP were applied during the monitoring period. The number of tablets used by each applicator was recorded daily. When 2 or 3 applicators worked together, the total applied was the reference point for each team member. This convention was used because team members rotated between work tasks. All employees were exposed to

some degree whether they were shoveling soil, stuffing paper into burrows, or applying the tablets. The total amount used (41,000 tablets) was the actual amount used during the study and was not inflated by the convention used to record the work of applicator teams.

Analysis and Review

All PH₃ data logged was analyzed using the Draeger Gas Vision 4.0 program that allowed establishment of average application exposure levels (representing the period of application only). The descriptive charts and graphs in the program assisted in reviewing notes and logs to help identify important work practices. The results are presented as written narrative, illustrative tables, and descriptive statistics (i.e., percentages, means, and ranges).

Applicator Exposure Field Trials

A total of 33 ALP applicators who worked for more than 800 hours in central and southern California were monitored for PH₃ exposure. Participants were classified as either frequent or infrequent applicators of ALP, in both urban and agricultural crop environments, to ground squirrel and pocket gopher burrows. Monitoring occurred in both hot and mild weather. There were 2 primary groups of applicators:

1. Qualified Applicators – 12 QACs from southern California urban areas, including Los Angeles, Orange, Riverside, and San Diego counties, were monitored. Sites treated included school grounds parks, golf courses, residential yards, rights-of-way, and industrial parks. The QACs included 10 persons who frequently applied ALP (more than 10 days/year and at least 80 hours/year and who received annual Pesticide Worker Safety Training-PWST) and 2 persons with lesser experience who made applications infrequently.

2. Non-qualified Applicators – 21 applicators were monitored, 18 from 4 counties in the central valley of California (Fresno, Madera, Merced, and Tulare) who worked on farm sites, and 3 from southern counties (San Diego and Los Angeles) who worked in urban areas. Nine persons were experienced frequent applicators who applied 2 to 3 times a year (and received annual PWST training) for more than 10 total days and at least 80 hours/year, and 12 were applicators who applied infrequently (and only occasional, or one time, received PWST) or were employees who had been trained but never had actually applied ALP. Data representing infrequent and newly trained workers were combined for analysis. Nine of 18 applicators from farms worked in teams of 2 or 3, and 9 applicators worked alone.

All applicators were trained by project personnel in the use of the monitoring equipment and were informed about the purpose and importance of the tests relative to their safety. Three groups of farm applicators were given instruction in Spanish by a bilingual research assistant.

Applicator training for ALP handling and understanding of PWST was evaluated prior to burrow treatments by reviewing pesticide training records and interviewing personnel to confirm their understanding of ALP application procedures.

A pre-application (control) monitoring period of 4 hours to 2 days was used to detect for “cross gases” (gases other than PH₃ that cause a false positive reading) prior to the monitoring of ALP treatments. The length of the control period varied according to PAC III responses. Sometimes interferences could be avoided during the applications and not compromise data evaluation. Treatment periods lasted 3 to 4 days, except in one case when a participant had to leave the area for other work after one day. Most employees were monitored for 8 hours each day, but due to work requirements a few days were cut to 2 to 5 hours.

Applicator Activities

Usually applicators worked at the crop production sites within sight of at least one of the project personnel. The Certified Applicators in urban environments were more difficult to observe because they moved through the area in utility trucks. Regardless, their work was frequently observed during the study period. Observations regarding unsafe practices, needs for training, STEL alarms, and potential sources of cross gases were recorded in a logbook and on field data sheets.

Breathing zone air was sampled with PH₃ detection tubes if a STEL alarm was activated or if an unexpectedly high reading was displayed on the Pac III. A concentrated effort was also made to detect PH₃ levels in the breathing zone when particular application practices seemed to have a higher-than-normal exposure potential. Special emphasis was also given to times when new and when previously-used flasks were first opened.

Potential Bystander Exposure Persons Entering Treated Fields

Nine sites that ranged from 1.5 acres to 40 acres were monitored to represent potential bystander PH₃ exposure after treatment of the adjacent acreage with ALP for pocket gophers and/or ground squirrels. Three sites were treated for pocket gophers only, 3 for ground squirrels only, and 3 for both species. All sites harbored moderate to heavy pest populations, and 2 (Visalia and Fresno Lara farms) had the heaviest ground squirrel infestations observed for many years by the Principal Investigator.

All bystander potential exposure sites were monitored using sets of 3 Draeger Pac III data loggers for 1 to 2 days prior to treatment and for 2 to 3 days post-application. The monitors were attached to stakes or strapped to trees. Two data loggers were 3½ to 4 feet above the ground in the heart of the most heavily treated area (usually directly over treated burrows). The third data logger was downwind about 1 foot above ground and within 25 to 100 feet of the nearest treated burrow.

Table 2. Bystander exposure sites in buildings.

Site Name	County	Foundation Type		Number of Units	Type Use	Pest Treated*	Infestation Level**
		Raised	Slab				
El Toro-1	Orange	√		10	Residence 1,350-1,400 sq ft	P.G.	Mod - Heavy
El Toro-2	Orange		√	10	Residence 1,700-1,900 sq ft	P.G.	Mod -Heavy
CP – 1	Los Angeles		√	2	Offices, and Lg. Commons Area 1,000-4,000 sq ft	G.S.	Lt - Mod
CP – 2	Los Angeles	√		3	Apartments 3,000 sq ft	G S.	Lt - Mod
Corona	Riverside	√		1	Residence 2,500 sq ft	G.S.	Mod - Heavy
Corona	Riverside	√		1	Attached Study 500 sq ft	G.S.	Mod-Heavy
Spadra 1	Los Angeles		√	1	Storage Shed 3,000 sq ft	G.S.	Mod - Heavy
Spadra 2	Los Angeles		√	1	Residence (Small) 510 sq ft	G.S.	Mod - Heavy
Spadra 3	Los Angeles		√	1	Same Unit, Winter	G.S.	Mod - Heavy
<i>Totals</i>		15	15	30			

* P.G. = pocket gopher
G.S. = ground squirrel

** Infestation levels were evaluated according to the following criteria:

	Burrow systems per residential yard	Burrow systems per acre of turf	Burrow openings per residential yard	Burrow openings per acre of turf
Pocket Gophers				
Light	1 - 2	4 - 5	NA	NA
Moderate	3 - 4	6 - 7	NA	NA
Heavy	≥5	≥8	NA	NA
Ground Squirrels				
Light	1	1	1 - 8	≤12
Moderate	2	2 - 3	9 -14	13 - 19
Heavy	≥3	≥4	≥15	≥20

Persons Occupying or Entering Buildings Adjacent to Treated Areas

Thirty residences or other structures were monitored for PH₃ following treatment of adjacent areas for burrowing rodents (Table 2). Ten residences on raised foundations and 10 on slab foundations were monitored after treatment for pocket gophers. Most treatments were made in spring and summer. Five slab and 5 raised-foundation units were monitored after treatment of ground squirrel burrows in adjacent areas. A larger number of buildings would have been desirable, but ground squirrels occur much less commonly than pocket gophers near residences. All available secure sites were utilized. All ALP treatments were made according to label directions, including use of 15-foot buffer areas. All

buildings or residential units were monitored where there was good air movement, using a Pac III data logger placed inside the building near the wall adjacent to the most heavily treated area. (Air movement allowed the PH₃ to enter the structure. In this study and in pilot trials, no PH₃ could be detected in areas not exposed to air flow from outside.) All buildings were monitored for 1 to 2 days prior to treatment to detect PH₃ or possible cross gas interference. If PH₃ was detected during the control period, it was commonly traceable to empty sewer traps or uncovered sewer clean-out caps. All sink and bathroom drain traps were filled with clean water to block entry of the gases prior to the last control day (or first post treatment day) to further insulate the site.

Most treated sites had moist sandy loam or sandy

clay loam soils that contributed to effective burrow treatments. The heavy clay loam at Pomona and Spadra also contained moist soil in the burrows, but surface cracks on the soil were visible in areas exposed to direct sunlight.

RESULTS

Results of both applicator and bystander exposure monitoring using the Draeger Pac III were more predictive and accurate than using the Draeger badges. All of the results in this section are based upon Pac III data supported by Draeger PH₃ detection tube readings and limited badge results. The badges were not reliable PH₃ indicators.¹

Potential Applicator PH₃ Exposure

Primarily because of varying periods of actual ALP handling, we calculated average application PH₃ exposure levels for the actual application time using the Gas Vision 4.0 data program, in order to assist in identifying factors that might contribute to PH₃ exposures. Most workers applied for 8 hours. Other applicators who traveled or had other duties may have actually applied ALP for 1 to 4 hours per day. To identify characteristic exposures, average TWAs and the number of STEL periods were compiled by ALP use patterns, worker qualifications and experience, training, and amounts of ALP applied.

Neither the TLV-TWA of 0.3 ppm PH₃ nor the TLV-STEL of 1 ppm (>4 times per day) was exceeded by any QAC or non-QAC applicator. The 1 ppm STEL level was reached by several applicators, but none exceeded the level more than 2 times per day. The 8-hour TWA mean average for all applicators was 0.035 ppm. The highest 8-hour TWA level recorded was 0.22 ppm.

Level of Exposure Grouped by Qualification, Training, and Experience

The QACs had a mean 8-hour TWA of 0.02 ppm PH₃, while the mean TWA for non-QACs was 0.044 ppm. The highest individual TWA was 0.12 ppm for QACs and 0.22 ppm for non-QACs. Twelve certified applicators registered only one STEL, whereas 21 non-certified applicators had 13 STEL events (Table 3).

Frequent user QACs and non-QACs (n=19) also had lower exposure levels and fewer STEL periods than infrequent users (n=14). The QAC infrequent user group was too small to represent a statistically significant sample. The non-QAC frequent user group had a mean TWA of 0.028 ppm PH₃, one-half that of the infrequent / new user group (0.056 ppm) (Table 3). Frequent users recorded 4 STEL events while the infrequent users had 10, more than twice as many. Training and experience

were associated with low potential PH₃ exposure, although specific determinants of exposure were not identified.

Exposure Levels by Amounts of Material Applied and Pests Treated

Mean TWAs were not indicative of amounts of ALP applied, except for the very heavy users whose mean average TWA was 0.07 ppm. This highest ALP use group (over 1,100 tablets per day) also had 6 STELs associated with the opening of flasks. Opening and working with new flasks was more closely linked to higher exposures and STEL events than was other applicator work.

Potential PH₃ exposures of both certified and non-certified applicators were reviewed to determine the relationship between treatment of the burrows of the 2 rodent species and PH₃ exposure. In this sample, there were 9 applicators monitored for each species exclusively, with the remaining 13 applicators treating both species. Field applicators who treated ground squirrel burrows, commonly in moderate to dense populations, had more STEL alarms and more than double the PH₃ mean 8-hour TWA (0.051 ppm) of workers who treated pocket gophers (0.022 ppm). Applicators who treated ground squirrel burrows handled 2 to 3 times as much ALP, and they often had the container open for much longer periods than workers who treated pocket gophers. These factors were likely linked to the higher potential PH₃ exposures of these applicators. However, analysis of PH₃ application exposure “during burrow treatment only” showed that the workers who treated ground squirrel burrows actually only had a 36% higher potential exposure (0.053 ppm) than those treating pocket gopher burrows (0.039) (Table 4). Three employees who treated pocket gopher burrows under very low, dense almond tree canopies behind a very effective windbreak had higher exposures than those who worked in open areas or on turfgrass. Ventilation is a likely determinant of relative potential PH₃ exposure.

Application Exposure for Teams

All of the applicators who worked in teams treated ground squirrels in crop production areas and all were non-certified applicators. The levels of exposure for the teams were slightly higher (TWA, 0.051 ppm) than the exposure of the non-certified applicators in this study (TWA, 0.044 ppm). It is likely that the higher levels resulted from exposure to the increased levels of PH₃ associated with treatment of ground squirrels (see above). The more important fact about team exposure is that when tasks on the teams are rotated between team members, all are going to have about the same PH₃ exposure. Team tasks included application, shoveling, and stuffing paper in burrows. On 2-man teams, the shoveler usually also stuffs newspaper into the burrow so that dirt does not cover the tablets. When work tasks

¹ The greatest problem was that freshly opened, unexposed badges had a base color that matched the first or second colors of the six-stage standard indicating an apparent low level of PH₃. Other unused replacement batches also registered an apparent 0.2 ppm PH₃. The origin of this problem is unknown.

Table 3. Applicator exposure levels by training and experience.

	<i>Number</i>	<i>8-Hour TWA* Range ppm</i>	<i>Mean 8-Hour TWA ppm</i>	<i>Occurrences STEL ** Exceeded (number)</i>
Certified Applicators (QACs)***	12		0.02	
Frequent Users	10	0-0.12	0.019	1
Infrequent Users	2	0.01-0.06	0.03	0
Non-Certified Applicators	21		0.44	
Frequent Users	9	0-0.09	0.028	3
Infrequent Users	12	0-0.22	0.056	10

* TWA = time-weighted average

** STEL = short-term exposure limit

***QACs = qualified applicator certificate-holders

Table 4. Applicator exposure levels by rodent species controlled.

<i>Rodent Pest</i>	<i>Application Numbers</i>	<i>Average Application Exposure* ppm</i>	<i>Mean 8-hour TWA** ppm</i>	<i>Occurrences STEL *** exceeded (number)</i>
Pocket Gophers	9	0.039	0.022	1
Open Areas	6	0.028	0.015	
Crop w/ windbreak & heavy canopy	3	0.062	0.035	1
Ground Squirrels	9	0.053	0.051	8

* Treatment Period Only

** TWA = time-weighted average

*** STEL = short-term exposure limit

Table 5. Bystander potential exposure in field plots.

<i>Pest Treated & Site Name</i>	<i>Acres</i>	<i>Amount ALP Applied (tablets)</i>	<i>Maximum 8 Hour TWA Period (ppm)</i>			
			<i>Control</i>	<i>Day 1</i>	<i>Day 2</i>	<i>Day 3</i>
Pocket Gopher						
El Toro 1	3	123	0	0	0	0
El Toro 2	1.5	72	0	0	0	0
LA	10	800	0	0	0	0
Ground Squirrel						
Merced	20	750	0	0	0	0
FrL	20	1,500	0	0	0	0
Visalia	8	5,000	*	0.05	0.02	
Both Pests						
Pomona	20	1,700	0	<0.01	** 0.06	0.03
Porterville	12	750	0	0	0	0
El Toro 3	2.5	111	0	0	0	0.01

* no control

** accidentally treated again on Day 2

were not rotated, the applicator had the highest potential PH₃ exposure and the shoveler the lowest.

Applicator Observations

Field observations proved invaluable in identifying the contributing causes for higher readings, especially the STEL periods. They also proved helpful in identifying good application practices and in identifying training needs and the benefits of various training methods.

Following is a list of poor application practices observed:

- Holding open flask too close to head and body
- Holding open flask pointed toward head and body
- Opening and/or holding open container up wind
- Leaving flask open too long
- Applying with no air movement
- Wiping sweat off face with contaminated gloves
- Applying up wind and close to other persons
- Combining partial flasks
- Applying tablets with tongs (flask open much too long to grab and apply product before replacing cap)
- Using rags or other homemade tops to close flask throughout the day
- Use of excessive personal protective clothing on hot days
- Pouring tablets into gloves
- Applying to open pocket gopher burrows
- Using improperly-trained applicators
- Putting contaminated gloves in truck cabs
- Storing ALP in open baskets in front of or behind ATV drivers (leads to dusty and broken tablets and loose tops)
- Crouching under trees with open container near face
- Applying in area while sprinklers were on
- Not airing out dirty gloves

When poor application practices occurred, it was a result of inadequate training, especially a lack of field demonstrations. We found that field demonstrations of sound applicator work practices improved application technique.

Bystander Exposure to PH₃

Persons Entering Treated Fields

All bystander field plots were found to be well below the TLV-PEL of 0.3 ppm PH₃. Pocket gopher plots of 1.5 to 10 acres treated with 72 to 800 tablets produced no PH₃ levels high enough to register detectable TWAs over a 72-hour post-treatment monitoring period (Table 5). The sites were chosen to simulate parks and school grounds with moderate to heavy pest populations in irrigated turf.

Sites treated for ground squirrels ranged from 8 to 20 acres, were all nut tree orchards, and had moderate to very heavy pest populations. Such a heavy population

would present a worst-case scenario for potential PH₃ exposure. The Visalia (V) and Fresno County Lara Farms (FrL) sites were much more heavily infested than a likely park setting. This is especially true for the 8-acre Visalia plot, where more than 1,250 burrows were treated with 5,000 tablets. This site, located in an urban area, included a flood control ditch with extensive burrows running as deep as 50 feet into the ditch banks of the orchard, landscaped parkways, and burrows under the street and extending into adjacent yards. It must be noted that only the site with the heaviest ground squirrel treatment registered 8-hour TWAs on more than one of the 3 Pac IIIs (range 0.01 to 0.05 ppm); and only one of the down-wind Pac IIIs, the one at this same location, had any TWA readings (0.01 to 0.02 ppm). This down-wind Pac III was placed within 10 feet of treated burrows due to lack of a nearby secure area across an adjacent road. All of the positive readings (with the one exception) occurred immediately over treated ground squirrel burrows, since nearly every tree had a burrow opening and the PAC IIIs were fastened to the tree trunks for security.

The sites treated for both pocket gophers and ground squirrels ranged in size from 2.5 to 20 acres and were treated with 111 to 1,700 tablets. One of these sites, the most heavily treated, produced an 8-hour maximum TWA of 0.06 ppm PH₃ (Table 5).

In all sites, the highest levels of PH₃ were detected from about sunset to sunrise, after the wind had died down. In all but one case, the highest PH₃ readings were recorded the night of the ALP application.

Persons Entering Adjacent Buildings

Of the 20 buildings on raised and slab foundations monitored adjacent to treated pocket gopher burrows, a detectable PH₃ 8-hour TWA level occurred in only one of each type (Table 6). The highest of these readings was only 10% of the current 0.3 ppm TLV-TWA for PH₃. Several yards had very heavy pocket gopher infestations. The number of tablets applied varied from 12 to 48 per yard; yards ranged from 1,500 to 10,000 ft² including treated common areas.

Each ground squirrel site had a moderate to high number of systems in adjacent yards and gardens. The smallest site had 6 burrows and the largest site had 35 burrows, requiring 32 and 140 tablets, respectively. The closest system was 15 feet away from the foundation, while the farthest was about 150 to 200 feet uphill from the residence. All sites had some systems within 20 feet of the buildings. No 8-hour PH₃ TWAs could be detected in any of the buildings.

DISCUSSION

Potential Applicator PH₃ Exposure

Each worker was questioned about his condition at the beginning and end of each day. It is important to note that no applicators reported experiencing any symptoms while working with ALP in this trial, and none of the

Table 6. Bystander potential exposure in adjacent buildings.

Pest Treated/ Site I.D.	Am't ALP Applied (tablets)	Number of Units	Foundation Type	Maximum 8 Hr TWA Period (ppm)			No. of 8 Hr. TWA Readings/No. Possible
				Day 1	Day 2	Day 3	
Pocket Gopher							
El Toro – 1	273	10	Raised	0.03	0.01	0	2/90
El Toro – 2	251	10	Slab	0.02*	0		1/60
Ground Squirrel							
CP Pom – 1	136	2	Slab	0	0	0	0/9
CP Pom – 2	80	3	Raised	0	0	0	0/9
Spadra – 1	140	1	Slab	0	0	0	0/9
Spadra – 3	100	1	Slab	0	0		0/6
Corona – 1	32	2	Raised	0	0		0/6
Corona – 1	32	1	Slab	0	0		0/6

* cross gas indicated

exposures were associated with illness or other complaints.

The results of these tests re-affirm that applicators and bystanders have little risk of exceeding TLVs for PH₃ when label instructions and good application practices are followed. There is no indication of a need for additional personal protective equipment (PPE). Increased exposures were recorded when applicators did not follow label directions and/or were not adequately trained regarding the importance of air movement and ALP handling practices.

While the mean TWA of non-QACs was double that of QACs, factors other than certification probably better represent the determinants of exposure. When the infrequent and newly-trained (lowest level of training) applicators are removed from the non-QAC group, the mean TWA decreases from 0.044 ppm to 0.028 ppm, which is only 40% higher than the QACs' mean TWA (0.02 ppm). Additionally, when the use patterns discussed below are considered, there may be little if any difference. QACs primarily treated pocket gophers in open areas, and none treated moderate or heavy ground squirrel infestations (only one used more than one flask per day of ALP). This compares to the non-QAC frequent users, where 56% treated moderate-to-heavy ground squirrel sites 100% of the time they were monitored, and the non-QAC applicators with the highest TWAs handled 4 or more flasks of ALP per day. While certification is a determining factor for reducing potential exposure, the level of training seems to be equally important.

Highest potential PH₃ exposures occurred during the opening or handling of new ALP flasks. Care to avoid PH₃ while opening new flasks should be emphasized during applicator training. New or partially full flasks that have been stored for long periods should be aired for a few minutes prior to starting ALP application. This practice was field tested during these trials, and it reduced

PH₃ exposure. Other effective common-sense measures to reduce exposure potential include holding the mouth of the flask away from the breathing zone, and opening flasks and applying ALP with good airflow.

Deficient handling practices observed during this study could easily be avoided by careful adherence to label directions. Use of field demonstrations and close supervision of non-QAC personnel by QACs, especially when first working with ALP, can contribute to establishment of sound work practices. Field demonstrations were especially effective with agricultural applicators who had little formal education and with those who were unable to read or write English.

Wearing smooth leather gloves when applying ALP tablets or pellets to rodent burrows should be emphasized on the label. Persons who used vinyl or other elastomeric gloves had trouble avoiding accumulation of moisture from perspiration. Gloves also ripped when workers used the probes and shovels. Baker (1992) found that cotton gloves retained high PH₃ residue levels for longer periods of time than leather gloves.

A training module, including a video or slides, would be a helpful supplement to product labels. The training module should emphasize handling techniques such as:

1. Apply when there is constant air movement (wind) so fumes blow away from your breathing zone
2. Use smooth leather gloves
3. Do not pour the product directly into or onto gloves; rather use the cap, funnel, or other device or pour ALP directly into burrows
4. The use of the smaller flasks (e.g., 100 tablets) reduces the risk of applicator exposure
5. Always point and hold the flask out and away from the breathing area when the cap is not tightly in place

6. When opening a new flasks, vent them for 1-2 minutes prior to use, less time if air is moist
7. Never apply during any rainfall, or when in areas being irrigated with sprinklers
8. Do not mix the contents of partially-used flasks
9. Use a leverage device to open new containers to avoid placing it against your waist or knee for leverage
10. Close the flask as quickly as possible using the manufacture's cap
11. When applying for pocket gopher control, always use a probed hole, or open the system with a shovel, spade, or similar device and cover the hole properly; never apply into already open pocket gopher burrows
12. Be careful not to wipe your face with your gloves
13. Always air out your gloves overnight and between applications
14. Air out any contaminated clothing.

Potential Bystander PH₃ Exposure

The current label wording regarding use near occupied buildings is sufficient to protect the environment and bystanders. When ALP is used according to the label, little PH₃ gas escapes the closed burrows. There is also no need to restrict entry to treated areas, with the possible exception of prohibiting tent camping over treated burrows for an appropriate period of time. This potential source of direct exposure must be forbidden until it is evaluated under simulated conditions of ALP use in campgrounds.

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