# Illnesses and Injuries Associated with Exposures to Phosphine and Phosphine Decomposition Products

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**Abstract**

For 1982 - 1992, records from the California Pesticide Illness Surveillance Program (PISP) showed 210 cases associated with exposure to phosphine gas and solid formulations of aluminum and zinc phosphide and 205 cases had sufficient information to retain in the data analysis. Of the cases with sufficient information, 179 (87.3%) cases involved isolated exposure to aluminum phosphide and 3 involved isolated exposure to zinc phosphide. The remaining 23 cases involved exposures to multiple compounds including chlorophacinone and methyl bromide. Fumigation of agricultural commodities (grains, nuts, and fruit) accounted for 142 (69.3%) of the cases, rodent control applications accounted for 52 (25.4%), fumigation of non-agricultural products accounted for 6 cases (2.9%), and in 5 (2.0%) the fumigated product was not specified. Fifty-one (24.9%) of the cases involved fumigant handlers and 154 (74.1%) involved incidental exposures to non-handlers. Twenty-six incidents (involving from 2 to 18 individuals) accounted for 139 (67.8%) of the total cases, including 16 (31.4%) of the 51 fumigant handler cases and 123 (79.9%) of the 154 non-handler cases. Among the handler cases, 2 (3.9%) were associated with accidental direct exposure, 32 (62.7%) with applications for which no violation of proper handling procedure was reported, 13 (25.5%) with documented violations of proper handling procedures, and 4 (7.8%) with phosphine fires or explosions. The latter included 2 cases of serious traumatic injury. Among the 154 non-handler cases, there was one inadvertent case of direct exposure to partially spent aluminum phosphide residue. Four cases (2.6%) were associated with drift exposures short distances off of the sites of application, 70 (45.5%) with reportedly proper fumigation and aeration of treated commodities, and 14 (9.0%) with documented failure to follow appropriate application and aeration procedures. Fifty-six cases (36.4%) were associated with phosphine fires or explosions, illegal fumigation in transit with 3 (1.9%), and 6 (3.9%) with inadvertent contact with fumigant containers. Of the non-handler cases, 123 (79.9%) were related to 22 separate illness clusters. Notable episodes included 4 large clusters occurring in spite of reported compliance with appropriate fumigation and aeration requirements; and 6 cluster episodes involved phosphine fires or explosions. The cases described demonstrate the potential for safety problems associated with handling phosphide fumigants. In addition to the risk of systemic phosphine poisoning, mishandling of phosphide fumigants may cause fires and explosions, leading to serious injuries in both handlers and non-handlers. Minimizing risk may be achieved by careful attention to handling procedures and monitoring of air levels associated with its use. The recurrent illness clusters occurring among packing/processing workers illustrate the importance of frequent work place monitoring and rapid response to safety concerns of employees working in the vicinity of phosphide fumigants.

## Introduction

During commodity fumigations and rodent control operations, agricultural laborers handling or working in the vicinity of compounds that generate phosphine gas may develop serious respiratory problems and systemic illness. Phosphine-generating fumigants also present unique safety hazards in both handling and disposal because of the gas's tendency to spontaneous oxidation. This report reviews cases involving exposure to phosphine fumigants reported to the California Pesticide Illness Surveillance Program (PISP) from 1982 to 1992.

## Background

Phosphide fumigants liberate phosphine ($PH_3$) gas on contact with either moisture in the environment or acid in the intestinal tract. Aluminum phosphide (AlP - Phostoxin®, Fumitoxin®, et al) is used for commodity fumigation and occasionally for rodent control.

Aluminum phosphide reacts with water to form phosphine gas:

$$AlP + 3H_20 \rightarrow Al(OH)_3 + PH_3$$

Some formulations also contain ammonium carbamate which releases ammonia gas and $CO_2$, compounds that help stabilize the inherently reactive phosphine:

$$NH_4COONH_4 \rightarrow 2NH_3 + C0_2$$

Zinc phosphide ($Zn_3P_2$ - ZP Rodent Bait®, Dexol Gopher Killer®, et al) is more stable chemically than aluminum phosphide. It is used as a rodenticide and less frequently for commodity fumigations. Magnesium phosphide ($Mg_3P_2$ - Magtoxin®) is comparatively less stable than aluminum phosphide. It is used for commodity applications when short fumigation times are required, and very occasionally for rodent control. [a] The phosphine gas liberated from all three products has the following chemical and physical properties (Hayes, 1990; International Progamme on Chemical Safety, WHO, 1988; Weast et al, 1978).

*Phosphine physical/chemical properties*

**Molecular weight**: 34.04 grams/mole
**CAS #:** 7803-51-2
**Melting point:** -134°C
**Boiling point:** -87.7°C
**Solubility in water:** 0.26 cc in 100 cc
**Formula:** $PH_3$

**Appearance and odor:** Phosphine is a colorless gas with a characteristic fish/garlic odor. It is reported to be detectable at threshold concentrations ranging between 0.02 ppm and 3 ppm.

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[a] 1993 California Use Data showed 6,274 applications/171,522.0 pounds used for aluminum phosphide; 191 applications/956.1 pounds used for magnesium phosphide; 1,618 applications/3,298.7 pounds used for zinc phosphide

Phosphine is odorless in its pure state, but the technical product usually has a foul odor associated with impurities, including substituted phosphines, diphosphine, methane, arsine, hydrogen and nitrogen. The presence of an odor cannot be relied on for warning of toxic concentrations.

**Exposure standards:** The current 0.3 ppm threshold limit value (TLV), calculated as an 8-hour time-weighted average, is intended to prevent systemic phosphine poisoning (American Conference of Governmental Industrial Hygienists, 1986). The short-term exposure limit is 1 ppm. These standards are based primarily upon the study reported by Jones (1964) of phosphine exposures to Australian grain terminal workers.

*Significant chemical reactions*

On contact with oxygen, phosphine has a tendency to decompose to more stable forms of phosphorous - ultimately to phosphoric acid.[b] This may occur rather explosively at concentrations above 1.8%, especially when trace amounts of diphosphine are present to catalyze the reaction (Cotton and Wilkinson, 1972). It also reacts violently with halide compounds. According to information supplied by the manufacturer[c] it can react with a variety of metals including copper, brass, gold, and silver.

*Toxidrome*

Acute illness produced by exposure to phosphine produces symptoms resembling those associated with common upper respiratory and gastrointestinal illnesses. Serious cases may develop pulmonary edema and severe neurologic symptoms including dizziness, headache, staggering gait, tremor, and diplopia (Feldstein et al, 1991; Harger, 1958; Hayes, 1990; Heyndrickx 1976; Hryhorczuk 1992; Jones, 1964; Morgan, 1989; Schoonbroodt et al, 1992; Wilson et al, 1980). In cases of deliberate ingestion, patients have been observed to excrete phosphine in the breath for several days following the ingestion. These cases also demonstrate phosphine's capacity to affect almost every organ system in the body. Significant clinical syndromes associated with ingestion of phosphide fumigants have included ventricular and atrial arrhythmias, S-T segment changes, heart block, pericarditis, renal failure, adrenal injury, liver necrosis and failure, pulmonary edema, and severe CNS disturbances (Chugh, Ram, Chugh, et al 1989; Chugh, Singhat et al 1989; Chugh, Ram, Mehra, et al 1989; Chugh, Ram, Sharma et al 1989; Misra, Bhargava et al 1988, Misra, Tripathi et al 1988, Gupta and Ahlawat 1995; Rodenberg et al 1989; Singh et al, 1989). Phosphine is rapidly oxidized in the body to inorganic phosphate. No laboratory tests are therefore available to aid in diagnosis of poisoning except in cases of ingestion where blood

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[b] $PH_3$ has a high heat of formation (2.21 kilocalories/g-mole) relative to oxidized phosphorous compounds: $HP0_2$ (-228.2 kilocalories/g-mole), $H_3PO_2$ (-145.5 kilocalories/g-mole), $H_3PO_3$ (-232.2 kilocalories/g-mole), and $H_3PO_4$ (-306.2 kilocalories/g-mole). Reference: Weast, 1978.

[c] Degesch America, Inc. (Weyer's Cave, Virginia 24486) Degesch Phostoxin® Pellets and Tablets; EPA registration number 40285-1

aluminum can be measured (Garry, 1993) or phosphine measured in expired air (Chugh, Ram, Chugh et al, 1989).

**Methods**

California law requires physicians to report suspected pesticide related-illnesses. Jurisdiction for illness surveillance has been assigned to the pesticide regulatory agency in California since 1974 (Mehler, 1992). The current program is called the Pesticide Illness Surveillance Program (*PISP*). The PISP source files contained 29,863 total reports of illness for the eleven years from 1982 through 1992. These were reviewed for cases associated with formulations of aluminum, zinc, and magnesium phosphide. Cases were labeled with a tag in the exposure category field (*expoclass*) according to the circumstances of exposure: direct accidental exposure (**Expoclass=1**), offsite exposure [drift] (**Expoclass=2**), handling of commodity after reported normal fumigation and aeration (**Expoclass=5**), fumigation reentry violation or failure to properly aerate fumigated commodity (**Expoclass=6.0**), routine application (**Expoclass=7**) (included cases for which required industrial hygiene monitoring was not conducted, but no violation of application technique occurred), violation of proper application or disposal procedure [over application and failure to provide and document appropriate training] (**Expoclass=8**), ingestion (**Expoclass=9**), incidental exposure to non-fumigation workers associated with phosphine fires or explosions (**Expoclass=10**), fumigation in transit (**Expoclass=11**), and handling of used containers (**Expoclass=12**). These exposure classifications were compared to the activity classifications in the source file. The **Expoclass** category was re-evaluated where it appeared incompatible with the activity classification. The original activity designation was not generally altered, but modifications were made where the activity classification was inconsistent with the case description. The fumigant handler activity designation was applied to workers placing fumigant tablets, untarping fumigated commodity, and disposing of partially spent tablets (activity code 131-133, and also to a single case involving an illegal non-occupational application (activity code=220). The exposure categories related to application work included direct exposure (**Expoclass=1**), applications without reported violations (**Expoclass=7**), documented violation of proper application or aeration technique (**Expoclass=8**), and exposures resulting from phosphine fires or explosions (**Expoclass=10**).

Non-handlers included workers packing/processing agricultural commodities (activity code 171), workers handling fumigant containers for storage or transport (activity code 182), emergency response personnel (activity code 183), and miscellaneous workers exposed to fumigant by-products following application or disposal accidents. The exposure categories corresponding to the non-handler activities work included offsite exposure (drift [**Expoclass=2**]), handling properly treated/aerated commodity (**Expoclass=5**), handling incompletely aerated commodity (**Expoclass=6**), exposures resulting from phosphine fires or explosions (**Expoclass=10**), fumigation in transit (**Expoclass=11**), and handling containers (**Expoclass=12**).

The relationship between exposure and illness was evaluated by comparing the reported symptoms with the phosphine toxidrome described above. Cases were classified as definite,

probable, possible, or unlikely based upon degree of exposure and presence or absence of compatible symptoms. Cases with symptoms limited to topical irritation of the eye, skin or upper respiratory tract were categorized separately from those with systemic or lower respiratory symptoms. Cases with definite evidence of a condition not associated with phosphine exposure (e.g., a non-occupational medical problem such as a urinary tract infection) were classified as unrelated. Where no information on symptoms was available, cases were classified as having inadequate information. Skeletal and other traumatic injuries resulting directly from phosphine fires or explosion of phosphine gas were classified as definitely related, but not included in the tabulations for systemic illness. Non-cluster cases judged to have inadequate information about either the symptoms or the nature of the exposure were excluded from the analysis. All cases that formed part of cluster illness episodes were retained in the file, but some were judged as having inadequate information because they lacked information on the nature of the symptoms.

Hospitalization and disability status were recorded in the PISP investigation files by the CAC staff performing the field investigation. Disability status was descriptively termed as “prolonged” if there were more than 4 days of lost work time.

**Results**

For 1982 - 1992, PISP records showed 210 cases associated with exposure to phosphine gas and solid formulations of aluminum and zinc phosphide. Five were excluded from the analysis because of incomplete information on either the nature of the symptoms or the circumstances of exposure. There was one additional case with incomplete information about the nature of reported symptoms that was retained as part of an illness cluster. Of the 205 retained cases, 179 (87.3%) cases involved isolated exposure to aluminum phosphide and 3 involved isolated exposure to zinc phosphide. The remaining 23 cases involved exposures to multiple compounds. These included 18 from a single incident - the combustion of zinc phosphide, mixed as rodent bait with the anticoagulant chlorophacinone, accidentally contaminated with moisture.

Fumigation of agricultural commodities (grain, nuts, and fruit) accounted for 142 (69.3%) of the cases, rodent control applications for 52 (25.4%), fumigation of non-agricultural commercial products accounted for 6 cases (2.9%), and in 5 (2.4%) the fumigated product was not specified. In one case the exposure resulted from transportation of fumigant containers and was not associated with any application.

Fifty-one (24.9%) of the cases involved fumigant handlers and 154 (74.1%) involved incidental exposures to non-handlers. Twenty six incidents (involving 2 - 18 individuals and 9 priority illness investigations) accounted for 139 (67.8%) of the total cases, including 16 (31.4%) of the fumigant handler cases and 123 (79.9%) of the non-handler cases. Twenty-five (12.2%) of the cases were hospitalized for either one or two days. These included 2 (3.9%) of the fumigant handler and 23 (14.9%) of the non-handler cases. Hospitalization status was unknown in 2 cases (1.0%), and 178 cases (86.8%) did not require hospitalization. Seventy-five (36.6%) of the cases lost between 1 and 14 days of work and the worker in 1 case lost an unspecified period of time from work. Ninety-seven cases (47.3%) lost no work time and in 32 (15.6%) cases the disability

status was not reported. The disability cases included 15 (29.4%) of the 154 handlers and 61 (39.6%) of the non-handler cases (including 1 case of disability of indeterminate length).

Table 1 shows the distribution of illness classifications. There was one definite illness case, involving a fatal exposure of a transient who broke into a rail car being fumigated in transit (described below). Thirteen cases (6.3%) were classified as probable illness, based upon either documented exposures exceeding the 0.3 ppm TLV for $PH_3$ (12 cases) or upon direct accidental exposure to partially spent aluminum phosphide residue (1 case). There were 108 (52.7%) of the cases of possible illness. These involved reported exposures without Dräger measurements (101 cases) or measurements taken too long after the reported exposure occurred (7 cases); all had non-specific symptoms compatible with phosphine toxidrome. Twelve (6.3%) were classified as unlikely/unrelated, because of symptoms incompatible with the phosphine toxidrome (1 case), or long delay between exposure and onset of reported symptoms (1 case), negative Dräger samples (8 cases), or a long delay between the reported date of fumigation and date of exposure (2 cases). Fifty-two (25.4%) had only topical irritation symptoms, 2 (1.0%) had traumatic injuries but no poisoning symptoms, and 16 (7.8%) were asymptomatic. One case could not be classified because of inadequate information about the nature of the reported illness but was retained in the file as part of a cluster illness episode.

*Fumigant handler cases*

Among the 51 handler cases, 2 (3.9%) were associated with **direct accidental exposure**, 32 (62.7%) with reported **routine applications**, and 13 (28.6%) with **documented violations of application procedure**, and 4 (7.8%) with **phosphine fires or explosions**. Details of selected application cases are shown by exposure category in Table 2.

*Direct exposure cases*

The two direct exposure cases occurring among fumigant handlers resulted in topical irritation. One occurred because of a spill of partially-spent residue during a disposal operation (**83-2209**), and the other as a result of inadvertent hand-to-eye contamination during a rodent control operation (**82-1968**). Neither case involved hospitalization or prolonged disability.

*Applications without reported violations*

There were 32 cases involving fumigant handlers involved in applications for which no violation of application procedure was reported. Five cases (15.6%) case involved time lost from work. One case **(88-1254**) lost 11 days of work and 4 others lost either 1 (**90-237**) or 2 days **(85–2397**, **91-290**, and **91-953**) from work. None of the cases required hospitalization. By illness category, 25 cases (78.1%) had possible systemic illness, 3 (9.4%) had symptoms of topical irritation, and 1 (3.1%) had no symptoms. Three cases (9.4%) were classified as unlikely to be related to phosphine exposure.

The non-violation handler cases included 13 cluster illnesses, associated with four distinct episodes. Two incidents involving crews of rodent control workers accounted for 10 (76.9%) of the cases. Although all 3 workers (**index 84-163 and 2 related cases**) involved in the first cluster reported adhering to normal application procedure and use of respiratory protection, 2 reported mild, non-specific systemic illness symptoms. (The remaining worker was asymptomatic). The second episode (**index 85-437 and 6 related cases**) involved applications of aluminum phosphide to rodent burrows in a field of tall, wet grass by employees of a California state agency. No Dräger samples were taken, but an internal investigation by the agency concluded that application conditions had caused the aluminum phosphide pellets to evolve phosphine gas more rapidly than expected. Additional fumigant handler cluster illnesses included two workers exposed to residual phosphine as they removed a tarp from a truckload of fumigated animal feed (IDs **82-2204, 2205**). An additional small cluster (**index 84-2184** and the accompanying case in a non-handler [**84-2185**]) involved topical symptoms (dermatitis) whose cause could not be determined from the investigation report. The observed rash was not related to any direct accidental exposure to phosphine gas or partially spent dust.

*Violations of application procedure*

Violations of proper application procedure accounted for 13 (25.5%) of the fumigant handler cases and of these, 4 (30.7%) involved either hospitalization or prolonged disability. Case **92-1323** involved a silo worker fumigating a large volume of wheat without appropriate respiratory protection. He had a car accident after passing out on the way home from work. Although he did not require hospitalization, he lost fourteen days from work. Other cases of prolonged disability included workers applying aluminum phosphide for rodent control (**92-2526**) and to agricultural commodities (**91-621**, **86-1830**).

*Phosphine fires and explosions*

Four fumigant handler cases involved phosphine fires or explosions. A small explosion occurred when trays of partially spent aluminum phosphide tablets were enclosed in a plastic bag following fumigation of a Bakersfield seed business. The handler (**83-1351**) carrying the trays was not injured in the explosion, but afterwards developed dizziness and shortness of breath, and was hospitalized briefly for observation. The hospitalization data on two cases involved in an explosion during a disposal accident was not recorded but both workers (**90-3004, 3005**) involved appeared to have significant injuries. The remaining case involved a small fire in a Sacramento rice mill that occurred during an unsuccessful attempt at wet disposal of unspent residue (**87-165**). The affected worker missed one day of work, but was not hospitalized. Other fire and explosion incidents principally affected non-handlers and are described in the text below and in Table 3.

*Non-handler cases by exposure category*

Of 154 non-handler cases, there was one accidental **direct exposure** (case **90-2428**, involving a packing/processing worker moving a bin of almonds treated a month earlier with aluminum phosphide). Four (2.6%) of the cases involved reported **offsite (drift)** exposure (Expoclass=2) and 70 cases (45.5%) involved **handling of commodity reported to have been properly treated and aerated** (Expoclass=5). Fourteen cases (6.8%) either involved **documented re-entry violations** (7 cases) or exposures (7 cases) to levels of phosphine exceeding the 0.3 ppm TLV (Expoclass=6). An additional 56 (36.4%) involved exposure to byproducts of phosphine fires or explosions, 3 (1.9%) involved illegal fumigation of motor vehicles in transit, and 6 (3.9%) involved inadvertent handling of fumigant containers in transportation or in warehouse operations, or following inappropriate container disposal. Twenty-three episodes of cluster illnesses accounted for 123 (80.4%) of the non-handler cases, with the 9 episodes involving 5 or more cases accounting for 95 (62.1%) of the total. Details of non-handler illness clusters and selected non-cluster cases are shown in Table 3 and discussed below by exposure category.

*Offsite exposures (Expoclass=2)*

In a building adjacent to a fumigation conducted in 1984, 2 workers complained of non-specific systemic symptoms (headache, nausea, etc), but frequent air monitoring in the workers' vicinity during the fumigation did not detect any phosphine (cases **84-2567 & 2610**). In 1987, an elderly couple living approximately 600 feet from a phosphine application site noticed an odor and developed symptoms suggestive of hyperventilation: dizziness, shortness of breath, tingling sensations of the lips, and dry mouth during a fumigation. No air monitoring was performed during the investigation (cases **87-2209 & 2210**).

*Handling of properly treated commodity after reportedly normal fumigation and aeration (Expoclass=5.0)*

There were 70 illnesses involving non-handlers working in the vicinity of fumigations reportedly carried out according to label requirements followed by adequate aeration. Of these, 8 illness clusters accounted for 56 cases (80%), with 4 large clusters (**index numbers 87-2451, 88-2334, 88-2574, 88-2911**) accounting for 48 (68.6%) of the total (Table 3). Three of the episodes occurred in a single Kern County almond processing operation and have been discussed in a previous publication by Ames (1991). In one episode (**88-2334**), the mild systemic illnesses reported were associated with an ammonia-like odor in the processing line. Two conjunctivitis episodes (**88-2574 and 88-2911**) occurred in a single work-place a few months apart. There was no documented exposure to phosphine in the 3 episodes for which air monitoring was conducted. The remaining large cluster episode (**88-2334**) occurred in Tulare County. No air monitoring was performed, but the circumstances were otherwise similar to the three Kern County episodes. In one of the small cluster episodes (**91-2796**), 3 workers unloading rattan furniture that had been fumigated in transit with aluminum phosphide developed non-specific symptoms compatible

with phosphine exposure, but Dräger samples taken were reported as negative. The remaining 4 small cluster episodes (**91-2416, 91-2796, 84-2184, 82-2696**) accounted for an additional 8 cases.

Fourteen non-cluster illnesses included 4 cases of possible systemic symptoms related to phosphine exposure with no Dräger samples taken (**85-2641**, **89-161**, **89-753**, **90-578**). There were also 3 cases unlikely to have been related to phosphine because of negative air samples taken at the time of exposure (**92- 618, 91-2397, 85-2072** ). In an additional case, it seemed unlikely that there was un-reacted fumigant or phosphine gas present because of the 4 month interval between the application and the reported date of illness (**82-2453**) and in one case (83-1924) the reported symptoms were not compatible with the phosphine toxidrome. In the remaining 5 cases (**85-2183**, **87-44**, **88-2579**, **88-2808**, and **90-56**) only topical symptoms were reported.

*Fumigation re-entry violation and failure to properly aerate commodity (Expoclass=6.0)*

The 14 cases of early reentry or documented aeration failure included 3 small clusters. Index number **87-89** involved 3 warehouse workers possibly exposed to phosphine from a leaking fumigation chamber (demonstrated to contain a 10 ppm residual level of phosphine by inspectors from the county department of agriculture after it had been aerated, but not tested by the handler). The affected workers complained of dizziness, blurry vision, muscular weakness, headache and nausea. Another multiple illness episode involved 2 grain elevator employees taking barley samples from grain treated 8 days earlier. After one of the workers noted an odor in the basement, an air sample taken there proved to have 25 ppm of phosphine gas (**83-2159 and 83-2160**). In the other episode, 2 US Depart of Agriculture employees (**87-2206** and **87-2207**) had probable excess exposure to phosphine as they inspected bins of incompletely aerated almonds.

Other noteworthy cases included a federal grain inspector (**92-814**) evaluating incompletely aerated commodity who developed both topical and systemic symptoms following exposure to 0.35 ppm phosphine. A port worker (**87-2924**) unloading rice noted an odor and complained of headache and nausea. Air samples taken in his work area showed 2.0 ppm of phosphine. A similar brief exposure to 2.0 ppm did not result in symptoms in case **90-2114**. A reentry violation (**89-474**), resulted in the fatal poisoning of an unemployed man who stowed away in a rail car fumigated in transit between Houston, Texas and Maxwell, California. Details of this case have been reported previously by Perotta et al (1994). Less severe poisoning followed the brief reentry violations described in **91-621 and 89-395**. A misapplication by an un-licensed handler (see case **91-118**, above) led to his own illness and secondary poisoning of a friend (**91-119**). In case **89-327,** an employee of an animal feed manufacturer was exposed to phosphine while opening a shipment of grain from a supplier that had been treated with Fumitoxin® the evening before, but not labeled.

*Exposure to non-handlers in phosphine fires and explosions (Expoclass=10)*

Improper disposal of unspent phosphide fumigants or phosphine fires accounted for 56 non-handler illnesses as well as the 4 fumigation illnesses described above. Seven cluster illness episodes (Table 3) accounted for 53 (94.6%) of these 56 cases. The largest episode (index **90-534**) involved 18 workers exposed to phosphine combustion products when water from a broken pipe saturated a stored mixture of zinc phosphide and the anticoagulant rodenticide chlorophacinone. In another incident, partially spent residue from a rice mill fumigation spontaneously ignited after it was discarded in a dumpster located in a Butte County business park. The fumes and combustion products from the fire resulted in the illness of several firemen and business park tenants **(index 90-2429**). A small illness cluster (**index 83-2653**) also resulted from an illegal disposal in a dumpster in Santa Maria. Several illnesses were reported in firemen and 1 in a television reporter covering the fire. An additional case involved two sanitation workers **(91-330 and 91-331)** whose truck started emitting smoke after they unknowingly picked up a dumpster containing illegally discarded Fumitoxin® tablets. Two other episodes involved single individuals (**89-783, 89-2664**) who discovered or attempted to extinguish dumpster fires resulting from illegal disposal of aluminum phosphide tablets. In **84-2571** a mechanic was exposed to byproducts of a phosphine fire 200 feet from his work area.

Rain leaking under a tarp covering cotton debris under fumigation at a power generation plant led to an additional phosphine fire and asymptomatic exposures to 4 firemen and 1 generation plant worker (index **90-842**). Air samples taken at the fire did not show any detectable levels of phosphine gas. Seven firemen were exposed in a fire resulting from an illegal home application of aluminum phosphide for rodent control and were hospitalized for overnight observation (index **86-861)**. The homeowner who made the application did not report developing any symptoms.

Difficulties in handling partially spent fumigant also accounted for several phosphine fires. The largest was a fire in a Los Angeles tomato processing plant following an attempt at wet disposal of unspent aluminum phosphide. Following the fire, 4 neighborhood residents and 4 firefighters were hospitalized briefly for observation (**83-2253**). A similar problem arose following attempted deactivation in a Yolo County rice mill, the worker involved suffering minor traumatic injuries and a brief systemic illness (**87-165**). Two workers were seriously injured in a fire and explosion in a Kern County almond processing operation that occurred after partially spent aluminum phosphide pellets were dumped in an empty bin and covered with a tarp. The index case (**90-3004**) suffered facial burns, hair loss, broken left leg and a perforated ear drum. A coworker (**90-3005**) suffered facial burns and lacerations.

*Illegal fumigation in transit (Expoclass=11)*

In addition to the fatal poisoning described above involving a legal in-transit fumigation of a railcar, there were three cases reported involving illegal application of aluminum phosphide to vehicles transported on public highways. A truck driver and a warehouse worker were unknowingly exposed to phosphine gas following the application of aluminum phosphide to a

truck load of raisins (Cases **87-1793** and **87-1794**). The truck driver suffered only minor systemic illness, but the warehouse worker lost consciousness and was hospitalized for 2 days following the exposure. In the remaining case (**86-1978**), a trucker became ill (chest pain, irregular heart beat, weakness, nausea, shortness of breath) transporting a load of rice illegally fumigated in transit with aluminum phosphide.

*Handling containers (Expoclass=12)*

Six cases involved exposures to non-handlers handling or coming into accidental contact with fumigant containers. Case **91-147** involved a commodity packing/processing worker who came into inadvertent contact with a reportedly empty fumigant container. Three additional cases involved a store clerk (**90-1611**), a secretary (**89-1425**), and feed-bin employee (**89-2469**) casually handling full containers of fumigant. The two remaining cases involved workers accidentally exposed to containers of leaking fumigant (**85-2216**, **89-68**).

**Discussion**

The cases described above demonstrate the potential for both serious illness and serious injury associated with handling phosphide fumigants. Injury may occur through lack of proper handling during application, failure to monitor air levels associated with applications, or improper disposal of unspent product. Fires associated with mishandling of unspent product have particularly disastrous consequences, producing illnesses associated with phosphine, phosphine decomposition products, and occasional severe injuries. Although some cases have been reported in the absence of documented violations of proper fumigant handling procedures, these did not frequently produce prolonged disability or illness that required hospitalization, but did produce several large illness clusters. The clusters illustrate the importance of frequent work place monitoring and rapid response to safety concerns of employees working in the vicinity of phosphide fumigants.

Minimizing risk may be achieved by careful attention to handling procedures and monitoring of air levels associated with its use. Air monitoring may be conducted by relatively unskilled personnel with colorimetric tubes (Dräger®, Sensidyne®) and a hand held pump, or with direct reading monitors (Sensidyne®, Beckman®, GasTech®). Monitoring should be conducted periodically to evaluate air levels associated with routine applications and in response to complaints of odor or symptoms possibly related to phosphine gas generated by phosphide fumigants. Disposal procedures should be carried out by properly trained personnel with special attention to the reactive nature of unspent aluminum phosphide in confined spaces and on mixture with water.

Physicians should be aware of the non-specific nature of the symptoms associated with exposure to phosphine gas and the variable relationship between the presence of detectable odor and the amount of phosphine gas present in a given environment. Severe respiratory symptoms should suggest the presence of delayed onset pulmonary edema. Workers with systemic symptoms should be cautioned against driving or performing other complex tasks.

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**Table 1 - Phosphine cases by exposure class**

| *Exposure Class* | *Definite* | *Probable* | *Possible* | *Unlikely/ Unrelated* | *Topical* | *Trauma* | *Asymp-tomatic* | *Inadequate* | *Total* |
|---|---|---|---|---|---|---|---|---|---|
| **Direct accidental exposure (Expoclass=1)** | | 1 | | | 2 | | | | 3 |
| **Offsite exposure [drift] (Expoclass=2)** | | | 2 | 2 | | | | | 4 |
| **Handling commodity after reported normal fumigation and aeration (Expoclass=5.0)** | | | 22 | 7 | 41 | | | | 70 |
| **Fumigation reentry violation or failure to properly aerate commodity or documented exposure exceeding threshold limit value (TLV) for $PH_3$ (Expoclass=6.0, 6.1)** | 1 | 9 | 3 | | | | 1 | | 14 |
| **Routine application work: no reported violation (Expoclass=7.0)** | | | 25 | 3 | 3 | | 1 | | 32 |
| **Application work: documented violation (Expoclass=8.0)** | | 3 | 8 | | 2 | | | | 13 |
| **Disposal problem, fire or explosion (Expoclass=10.0)** | | | 40 | | 4 | 2 | 13 | 1 | 60 |
| **Fumigation in transit (Expoclass=11.0)** | | | 3 | | | | | | 3 |
| **Handling concentrate/used container (Expoclass=12.0)** | | | 5 | | | | 1 | | 6 |
| **Total** | **1** | **13** | **108** | **12** | **52** | **2** | **16** | **1** | **205** |

| Table 2 Illness in fumigant handlers | | |
|---|---|---|
| **ID** | **Illness Date** | **Comment** |
| **Accidental direct exposure** | | |
| 83-2209 | 08/09/83 | A worker developed conjunctivitis after Phostoxin® residue blew into his face during a disposal operation. He lost one day of work, but was not hospitalized. |
| 82-1968 | 08/17/82 | Applying Phostoxin® pellets, a worker wiped her eye with a gloved hand, then she developed burning in the eye. She lost no work time and was not hospitalized. |
| **Application without reported violations** | | |
| 91-290 | 2/6/91 | After fumigation of the vans with phostoxin prepacks, a rice mill worker developed headache, diarrhea, and dizziness and missed 2 days of work. The company maintained logs of Dräger test results, but test information was not included in the investigation. |
| 90-237 | 1/26/90 | A city employee applying aluminum phosphide for rodent control inhaled fumes from canister of fumigant. Symptoms included nausea, vomiting, and vertigo. He missed one day from work, but was not hospitalized. |
| 88-1254 | 6/15/88 | A rodent control worker applying aluminum phosphide tablets (wearing coveralls, rubber gloves, goggles) noticed an onion/garlic odor and developed tightness in chest. He was not hospitalized but missed 11 days from work. |
| 84-163, 164, 410 | 02/02/84 | A crew of 3 trained workers fumigating rodent holes with Phostoxin® reportedly wore respirator and gloves, but 2 developed non-specific illness symptoms. 84-164 reported mild abdominal cramps; 84-410 reported mild dizziness, headache and stomach cramps. 84-163 was asymptomatic. None of the workers was hospitalized and none lost time from work. |
| 85-2397 | 10/13/85 | A pest control worker developed a rash while helping with a fumigation; the rash may have been due to "straw itch mite". |
| 85-437, 1514-1519 | 3/12/85 | A crew of 7 workers employed by a state agency became ill after applying Phostoxin® to squirrel holes in an area that had tall, wet grass. They did not wear respiratory protective equipment, but the product label did not clearly state that it was required. Each of the affected workers reported non-specific symptoms - including headache, nausea, dizziness, stomach pain, vision problems - initially thought to be caused by influenza. None were hospitalized or lost time from work. |
| 84-2184, 2185 | 9/6/84 | A worker (84-2184) reported a rash on his torso after application of Phostoxin® to rice under a tarp in warehouse. The other worker affected (84-2185) also had a rash, but his exposure was limited to handling treated rice. There was no hospitalization or lost work time. |
| 82-2204, 2205 | 9/24/82 | While removing tarp from truck load of animal feed fumigated with Phostoxin® 48 hours earlier, two workers developed symptoms that included nausea, abdominal cramps and vomiting. Neither worker missed time from work. |
| **Violation of application procedure** | | |
| 92-2526 | 10/20/92 | Worker was applying aluminum phosphide pellets to gopher holes when he developed headache, dizziness, nausea, vomiting, burning and swelling of esophagus, chest pain with deep breathing, and a burning rash on shoulders and armpits. He missed 7 days of work, but did not require hospitalization. His employer was cited for lack of employee training and the employees failure to use appropriate safety equipment. |
| 92-1323 | 7/24/92 | A worker fumigated 1,000 short tons of wheat in a silo. Exposures occurred during fumigation/aeration. He wore a 16-inch beard, but did not wear a respirator despite the intermittent presence of a garlic odor, characteristic of phosphine gas in his work area. No industrial hygiene measurements were made. He had a car accident after passing out while driving home from work. Although he was not hospitalized, he missed 14 days from work. |

| Table 2 Illness in fumigant handlers | | |
|---|---|---|
| **ID** | **Illness Date** | **Comment** |
| 91- 621 | 4/30/91 | After 15 seconds in a walnut fumigation chamber previously reported to be cleared of phosphine (Dräger test taken through sample port of fumigation chamber reported negative), a worker complained of smelling foul odor "like sewer water". He developed abdominal cramps, diarrhea, chest tightness, dizziness, tachycardia, headache, shortness of breath, and metallic taste in mouth. Repeat sampling by county department of agriculture later showed 20 ppm of phosphine inside the chamber. He was admitted to a hospital for evaluation, then released after 10 hours. |
| 91-118 | 1/27/91 | A man found a container of aluminum phosphide left by a previous owner of his recently purchased home that he applied under and around the house for gopher control. He later developed dehydration, nausea, vomiting, diarrhea, arm spasms, and mild shortness of breath. His girlfriend also became ill (see 91-119, described below), but did not handle the fumigant. |
| 90-1810 | 7/17/90 | A rice mill employee opened a container to get Phostoxin® packets and was exposed to phosphine gas. Dräger samples taken afterwards showed "off scale" (>0.5 ppm) levels of phosphine. |
| 86-1830 | 9/29/86 | Worker wore cloth and leather gloves while placing Phostoxin® tablets (exceeding label rate) into bins of walnuts, then securing plastic liner on top. He developed headache, dizziness, faintness, incoherence, and shortness of breath 1 hour later. He lost 5 days from work. |
| 89-1665 | 7/19/89 | During fumigation of railcars at a rice mill, aluminum phosphide strips began reacting and giving off phosphine gas. 89-1665 felt nauseated and chilled, but did not lose time from work. The employer was cited for employee's failure to use respiratory protection. |
| 87-2464 | 10/7/87 | A fumigant handler opened an un-placarded container of almonds to apply Phostoxin®. The container had actually been treated 2 days earlier. Two hours after the incident the concentration in the container was 100 ppm. The affected worker developed a headache, but did not seek treatment. |
| **Phosphine fires and explosions** | | |
| 90-3004, 3005 | 2/21/90 | Unspent Phostoxin® pellets left from a fumigation were put in a 4x4x4 wooden bin and tarped until spent. The bin exploded on two men checking the bin. Case **90-3004** suffered facial burns, hair loss, broken left leg and perforated ear drum. **90-3005** suffered facial lacerations and burns. Hospitalization and lost-work-time information was not recorded for either case. |
| 87-165 | 3/12/87 | As an employee of a Sacramento-area rice mill stirred partially spent aluminum phosphide residue into a barrel 3/4 filled with water, the residue ignited, shooting flames up to the ceiling, and burned for 20 minutes. The room filled with smoke and the worker developed chest tightness and mild dizziness. Dräger tube samples were routinely taken at the mill during fumigation and disposal operations, but none were taken during the fire. |
| 83-1351 | 7/29/83 | A worker put fumigation tarps and packed trays of partially spent dust into a truck for removal from an application site (a Bakersfield seed company). During the process, a tray of partially spent Phostoxin® pellets wrapped in a plastic bag exploded. Shortly afterwards, the worker developed breathing/talking difficulty and dizziness. He was observed in the hospital for 24 hours and lost 2 days from work. |

| Table 3 - Illness in Non-handlers | | |
|---|---|---|
| **ID** | **Illness Date** | **Comments** |
| **Cluster Illness after reported normal fumigation and aeration** | | |
| 91-2416, 2417 | 10/14/91 | Two almond sorters developed an itchy rash on their arms and upper chest, handling commodity that was fumigated then aerated at least 4 days previously. The work area was hot, humid and dusty. |
| 91-2796, 3016, 3208 | 10/18/91 | 3 workers entered shipping containers to unload rattan furniture. Some had residual powders from fumigation-in-transit and some had been fumigated locally. Dräger samples taken were reported as negative. Symptoms included headache, dizziness, burning eyes, blurred vision, chest congestion, difficulty breathing, coughing, rash, and sore throat. |
| 88-2334-2345, 3136-3139 | 9/26/88 | Sixteen workers became ill and sought medical attention. The almond sorting building was fumigated the day before. Despite aeration, a distinct ammonia odor was present when the workers arrived at the building. No Dräger sample was taken. Fifteen workers had non-specific symptoms compatible with the phosphine toxidrome, but one experienced only nasal irritation. |
| 88-2574-2578, 2856-2864 | 8/10/88 | Fourteen workers complained of eye irritation after a fumigation of commodity bins at an almond processing plant was made the previous weekend. Eight had some symptoms of mild systemic illness. Dräger samples were reported to have been taken routinely prior to untarping the bins to ensure complete dissipation of phosphine. The plant was affected in two other episodes (87-2451, and 88-2911). |
| 88-2911-2921 | 11/2/88 | Eleven workers involved in episode 88-2574 experienced a re-occurrence of eye irritations while working in an almond/pistachio processing plant. Two also had non-specific systemic symptoms. (See also 87-2451). |
| 87-2451-2456, 2944 | 9/21/87 | Seven warehouse workers experienced eye irritation and headaches while working around Phostoxin® fumigation bins. Company policy stated that no tarps are removed until Dräger sampling is conducted and detector tubes show no detectable phosphine is present, but no specific sampling results were reported in the investigation (see also 88-2911 and 88-2574). |
| 84-2185 | 9/6/84 | A rice mill employee developed hives after handling rice treated with aluminum phosphide sometime previously. A related case was reported in a fumigant handler (84-2184). |
| 82-2696, 2734 | 11/30/82 | A forklift driver (82-2696) and a co-worker (82-2734) worked in a warehouse near bins of prunes treated 12 days earlier with aluminum phosphide. The driver could smell a garlic odor, but Dräger tube readings samples taken prior were negative. The reported symptoms the following day included fatigue, aches and pains, weakness, headache, sore throat, congestion, wheezing, cough, and shortness of breath. |
| **Fumigation reentry violation or failure to use proper aeration procedure** | | |
| 92- 814 | 3/24/92 | A federal grain inspector was evaluating wheat that had been previously treated with aluminum phosphide and developed headache, bloody nose, sneezing, and difficulty breathing. A Dräger sample was reported to exceed 0.35 ppm. |
| 91-119 | 1/27/91 | A woman had secondary exposure to phosphine after a friend illegally applied aluminum phosphide to control rodents around his new home (see case 91-118, described above). She developed nausea, vomiting, and coughing. |
| 90-2114 | 4/18/90 | A worker unloading rail cars containing rice fumigated with aluminum phosphide in transit from Arkansas noticed a strong odor, but did not develop illness symptoms. A Dräger sample taken under the hatch of one car showed a 2.0 ppm of phosphine. Similar samples taken from the two other cars contained 0.1 and 0.2 ppm. |
| 89- 474 | 3/22/89 | An unemployed male stowed away in rice filled railcar that was undergoing fumigation in transit between Texas and California. He was found dead several days later when the car was opened. An autopsy showed the body was badly decomposed. |
| 89-395 | 2/28/89 | A forklift operator was exposed to fumes after he accidentally ruptured a tarp covering a pallet of rice under fumigation with aluminum phosphide. His symptoms included dizziness, vomiting, nausea, diarrhea, abdominal pain, disorientation, ineffective motor skills and sleepiness. His employer was fined for not doing air monitoring. |
| 89-327 | 12/16/88 | While removing the tarp on a load of raw grain mix received from a supplier, a worker at a dog food manufacturing plant in Stockton noticed an odor he recognized from prior experience as phosphine. The load proved to have been treated the evening before with Fumitoxin® but was not labeled. He felt nauseous and dizzy, and was taken for medical evaluation. He did not lose time from work. |

| Table 3 - Illness in Non-handlers | | |
|---|---|---|
| **ID** | **Illness Date** | **Comments** |
| 87-2206, 2207 | 9/21/87 | Two federal department of agriculture employees inspecting unlabeled bins of aluminum phosphide treated almonds experienced symptoms that included headache, popping in the ears, bad taste in the mouth, accelerated heart beat, nausea, and diarrhea. Monitoring with a Gastech® direct reading instrument and detector tubes the following day encountered levels 0.35 ppm of phosphine above a fumigant residue bucket in the inspectors work area, indicating that the concentrations around the inspectors' work area may have been elevated the previous day. Transient concentrations of phosphine above 0.3 ppm were also noted during untarping of several almond bins. |
| 87-89, 564, 565 | 1/28/87 | Three county department of agriculture employees inspecting grain noticed an odor in their work area. Subsequent investigation showed a high $PH_3$ level in an adjacent fumigation chamber that happened to have its ventilation fan shut off. A worker who entered the fumigation chamber wearing a respirator to turn on the fan noticed a break through odor. Symptoms reported by the three workers included headache, dizziness, poor vision/focusing ability, upset stomach, and weak limbs. |
| 87-2924 | 12/17/87 | A port worker, unloading rice treated with aluminum phosphide from the bottom of a truck trailer, developed nausea and a headache. Dräger tube readings taken in his work area were positive for phosphine at 0.1, 1.5, and 2.0 ppm. |
| 83-2159 83-2160 | 8/10/83 | Two employees of a Tehama County grain company were collecting samples of grain treated 8 days earlier with aluminum phosphide when they noted an odor of phosphine in the basement of a grain elevator. The Dräger samples taken showed a level of 25 ppm phosphine in the area. Symptoms developed by the two employees included headache, nausea, tightness in the chest, and stomach cramps. |
| **Fumigation in Transit** | | |
| 87-1793, 1794 | 7/24/87 | A truck driver opened a trailer that was fumigated in transit with aluminum phosphide; he developed a headache and nausea, but had no disability. The other worker blacked out, and also reported a choking sensation, and a headache. He was hospitalized for 2 days, but did not miss additional days of work. The employer was fined for violation of label prohibition against fumigation in transit for trucks, vans and trailers. |
| 86-1798 | 8/11/86 | A truck driver, transporting rice treated with aluminum phosphide, developed chest pain, irregular heart beat, weakness, nausea, and shortness of breath. He was not hospitalized; his disability status was not recorded. |
| **Dumpster fires** | | |
| 91- 330, 331 | 03/06/91 | Two trash men picked up a dumpster at a packing house. The dumpster contained Fumitoxin® tablets which produced a chemical reaction and the truck started smoking. Thinking the truck was on fire, they dumped the refuse in an empty lot and called the fire department. Case 91-330 developed a burning sensation in the nose and chest; his coworker developed conjunctivitis. Both lost 2 days from work. |
| 90-2429 | 10/08/90 | After fumigating a rice mill, employees of a Butte County pest control business disposed of the unspent residue in a dumpster behind their office in an industrial business park. Four firemen and 1 employee of an adjoining business developed headache and non-specific gastrointestinal (nausea, stomach cramps, gas, and diarrhea), and constitutional symptoms (aching muscles, weakness, and fatigue). Three of the firemen were hospitalized over night and 4 lost 2 days from work. Four additional firefighters received medical evaluation, but had no symptoms. |
| 89- 783 | 03/28/89 | A dumpster containing illegally discarded aluminum phosphide caught fire at a county facility in Los Angeles. A state agricultural biologist who attempted to extinguish it, reported a sore throat and tightness in the chest and lost 1 day from work. |
| 89-2664 | 12/01/89 | An electrician used a fire extinguisher to help put out a fire in a dumpster. They later found spent aluminum phosphide in the dumpster. Symptoms included dizziness and labored breathing from inhaling the smoke. Disability status was not reported. |
| 83-2653 83-2671 83-2675 | 11/28/83 | Phostoxin® pellets were improperly discarded in a dumpster. The worker who discovered the subsequent fire (83-2371) developed weakness, nausea, dizziness, chest burning, headache, shortness of breath, and a flushing of the face. He was hospitalized for 1 day and lost 5 days from work. A policeman evacuating the surrounding neighborhood (83-2653) experienced throat irritation, coughing nausea, and a bad taste in the mouth (disability status not reported). A TV reporter covering the story developed shortness of breath and nausea, but did not lose time from work. |

| Table 3 - Illness in Non-handlers | | |
|---|---|---|
| **ID** | **Illness Date** | **Comments** |
| **Combustion during attempted disposal** | | |
| 83-2253 | 10/02/83 | A Phostoxin® fire occurred at a spaghetti sauce factory in North Hollywood following two attempts to dispose of unspent material from 62 trays of aluminum phosphide. Initially 20 trays were placed in a barrel with liquid and a detergent; this resulted in a small explosion; a second explosion occurred when 42 trays were placed in a dry barrel. Four firefighters responding to the call developed nausea and were hospitalized for 40 hours. Plant employees were treated and released at a nearby emergency room. Four neighborhood residents were briefly admitted to the hospital for observation. |
| **Spontaneous combustion during fumigation or storage** | | |
| 90-842 | 04/23/90 | Five workers involved in putting out fire in Phostoxin® treated cotton debris piles that spontaneously caught fire after a heavy rain seeped underneath the fumigation tarp. Dräger tube sampling showed no detectable levels of phosphine in the vicinity of the fire. No symptoms were reported, although all 5 workers had precautionary medical evaluations. |
| 90-534 | 02/22/90 | Eighteen bank employees were exposed to phosphine combustion products when water from a broken pipe saturated a stored mixture of zinc phosphide and chlorophacinone, apparently stored on the premises by an unknown person for use as rodent bait. The symptoms included nausea, headaches, weakness, dizziness, slurred speech, and sore throat. None lost time from work. |
| 86-861 | 05/22/86 | Grower/homeowner over applied Phostoxin® tablets to a squirrel hole next to his house and ignited a fire. Smoke from the burrow entered into the basement of his house. Seven firemen, exposed to Phostoxin® gas responding to the call, were hospitalized for 1 day, but did not lose additional work time. The homeowner (86-861) had no symptoms, but did have a precautionary medical evaluation. |
| 84-2571 | 11/07/84 | A mechanic, working in a shop area 200 feet from burning phosphine, reported shortness of breath, cough, and nausea. No Dräger measurements were recorded. |