

Fumigating Farm-Stored Grain with Aluminum Phosphide

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Nebraska Extension generally does not recommend that private applicators (farmers) fumigate their own grain because of the potential danger involved. It is best to hire a trained, licensed professional. If you do choose to fumigate your own grain, you must follow all instructions in this publication. Notably, prior to fumigating you must have a valid private pesticide applicator license, the necessary air monitoring equipment, and a Fumigation Management Plan.

Fumigants kill all insect life stages. They control pests by diffusing through the air spaces between grain kernels and into the kernel itself. Fumigants are able to penetrate into places that are inaccessible to insecticide sprays or dusts.

Regardless of formulation, all fumigants are poisonous to humans, other animals, insects, and other pests. Because fumigant chemicals are highly toxic and hazardous to use, they are Restricted Use Pesticides (RUP). Only certified applicators can purchase and use them.

Aluminum phosphide is formulated in tablets, pellets, paper sachets, plates, and blister strips. The tablet or pellet formulation is most suitable for farm applications. Solid aluminum phosphide formulations release hydrogen phosphide (phosphine) gas when exposed to moisture and heat. Warm, humid air *accelerates* the reaction while cool, dry air slows it down. The reaction starts slowly, gradually accelerates, and then tapers off.

Federal regulations require a Fumigation Management Plan (FMP) be developed prior to the application. The basics of an FMP will be discussed in this publication, and a sample fill-in-the-blank fumigation management plan is included as well. Details of requirements for the FMP can be found in the applicator's manual, a supplement included with the fumigation product.

Fumigation Management Plan

All phosphine-type fumigant labels require the development of an FMP for each fumigated storage site. An FMP is a written document, required by the US Environmental Protection Agency (EPA), which describes the grain storage site and details each step of the proposed fumigation. The purpose of the FMP is to ensure the safety of all workers, the community, and the environment. It also is designed to ensure an effective fumigation and to assist in meeting label requirements. **A fill-in-the-blank sample Fumigation Management Plan is provided at the end of this publication.**

The FMP provides a uniformly organized process that will help grain managers at each grain storage site to document their fumigation procedures, and thus "characterize" their fumigation. The FMP should include a facility diagram showing the primary structures and technical features (such as main electrical power, gas, and water shut-off points) of the storage facility, grain storage structures in relation to other buildings, and equipment at the site.

The FMP has a standard data form that is to be completed by the person responsible for the fumigation each time a fumigation application is made. It covers important items like the volume of grain fumigated, the type and dosage level of the fumigant, starting and ending times of the fumigant application, and the overall fumigation time from dosage to structure ventilation. During the fumigation, gas levels must be monitored and documented at specific locations around the storage structure where people work, as well as at specified locations on the property, such as property boundaries downwind from fumigated structures.



Figure 1. Warning placard. Iowa State University Extension and Outreach photo.

The Plan

The FMP must address characterization of the site and include appropriate monitoring and notification requirements consistent with but not limited to the following:

1. Inspect the site to determine its suitability for fumigation.
2. When sealing, consult previous records for any changes to the structure, seal leaks, and monitor any occupied adjacent buildings to ensure safety.
3. Prior to each fumigation, review any existing FMP, safety data sheets (SDS), fumigant label, applicator's manual, and other relevant safety procedures.
4. Develop procedures and appropriate safety measures for all workers in and around the area during the application and subsequent aeration.
5. Develop an appropriate monitoring plan to confirm that nearby workers and bystanders are not exposed to levels above the allowed limits during the application/aeration. This plan also must demonstrate that nearby residents will not be exposed to concentrations above the allowable limits.
6. Develop procedures for local authorities to notify nearby residents in case of an emergency.
7. Confirm the placement of placards (Figure 1) to restrict entrance into any area under fumigation.
8. Confirm that the required safety equipment is in place and the necessary manpower is available to complete a safe, effective fumigation.

These factors must be considered in developing an FMP. It is important to note that some plans will be more comprehensive than others. All plans should reflect the experience and expertise of the applicator and circumstances at and around the site.



Figure 2. Applicator manual for solid phosphine pellets. Iowa State University Extension and Outreach photo.

In addition to the plan, the applicator must read the entire label and supplemental applicator manual (Figure 2), then follow the directions carefully. If the applicator has any questions about the development of an FMP, contact the product registrant for further assistance.

The FMP and related documentation, including monitoring records, must be maintained for a minimum of three years for fumigations made in Nebraska.

Application and Distribution of Aluminum Phosphide

Aluminum phosphide tablets and pellets (Figure 2) may be applied to the grain mass by probing them below the grain surface, adding them as the grain is turned, or placing them in the aeration ducts below the grain mass. Treatment during turning of the grain generally is not feasible in on-farm storage; often alternative methods must be used to treat the grain in place. In shallow bins, tablets may be probed into the grain using a 5- to 7-foot-long hollow tube designed for this purpose. These tubes can be made from 1.5-inch PVC pipe or other material.

In metal farm bins, air currents form within the grain mass even if visible leaks have been sealed. When cold grain is fumigated during warm weather, the dominant currents will carry the fumigant downward, so most of the fumigant should be probed into the top 5 to 8 feet of the grain mass. When warm grain is fumigated during cool weather, chimney-effect air currents carry fumigant toward the surface. Therefore, much of the fumigant should be applied beneath the grain mass, in the aeration ducts. Consult the label for instructions about the maximum portion that can

be applied in the aeration ducts or drying floor. Never apply the fumigant to a wet floor or duct as dangerous fumes are released when exposed to moisture.

The following is a step-by-step description of a typical probe application of aluminum phosphide to grain in a circular steel bin.

Equipment Needed

- *Man-in-Bin* sign placed near the control panel or auger power control.
- 2- or 3-inch tape, spray adhesive, and adhesive for polyethylene sheets.
- Applicator's manual and current label.
- Sufficient fumigant for the volume of the bin.
- Tape measure to calculate volume of grain to be treated.
- 2- to 6-mils polyethylene film large enough to cover the grain surface. Attach a rope to the polyethylene film for easy removal after fumigation.
- Cotton gloves for handling phosphine-type fumigant—do not handle tablets with bare hands or wet gloves.
- All fumigations should be done by at least two people, each equipped with a full set of safety equipment, including chemical-resistant gloves, protective clothing, etc. If entrance into the structure is required for fumigating the grain, two licensed people **MUST** be present.
- Proper respiratory protection for all personnel involved in the fumigation. Check the fumigant label for specific requirements.
- Probes for applying aluminum phosphide tablets.
- Safety rope to attach to anyone climbing into a bin, and long enough to extend through the bin access point and strong enough so rescue personnel can drag a victim to the exit if necessary.
- Shovels to level grain mass prior to treatment.
- Grain thermometer to measure grain temperature prior to treatment at locations throughout the grain mass.
- Fumigation placards.
- A lock to keep unauthorized personnel out of the building. Be sure everyone is out before attaching the lock.
- Monitoring equipment to check gas concentration available from the vendors listed at the end of this guide.

Level the Grain

Level the grain surface and break up any crusted areas prior to fumigant application.

Seal the Bin

Sealing the bin is the single most important step in achieving good fumigation results. The bin must be made as airtight as possible to achieve and maintain the proper gas concentration and exposure time necessary to kill grain pests.

Metal storage bins are not gas-tight. Many were originally designed to hold and aerate grain, but can be used for fumigation with proper sealing. It is important to recognize that bins will vary in tightness depending upon how well they were built. If the corrugated sections were caulked when put together, and then bolted, they will be more gas-tight. Loosely constructed wooden bins may have to be totally covered with a gas-tight plastic sheet or coated tarpaulin to retain enough fumigant to be effective.

Grain in flat storage buildings must be covered with a tarpaulin for maximum effectiveness. Remember, the goal is to confine the gas in the grain mass long enough at the proper concentration to be lethal to the target pests. *Sealing is extremely important* and demands study and work. There are several places in a bin where gas can escape. The roof-wall junction may look tight from the outside, but most grain bins have a gap between the roof and wall so water that may condense on the underside of the roof can run down and drip outside the bin. This gap is difficult to seal because it is usually dusty and may be damp. Cracks wider than 1 inch are even harder to seal.

To begin the sealing process, clean the dust from the surfaces before applying tape or other sealing material. Professionals often clean the surface first and then spray it with an adhesive dispensed from a pressurized can. The gap is then sealed with tape. Use at least 2-inch and preferably 3-inch wide tape when sealing these cracks.

A pressurized can of spray adhesive is a useful tool. It is available from the fumigant distributor or sometimes from hardware or hobby stores. This adhesive can help attach plastic sheets and make the tape's sticky surface stickier and improve the holding quality.

Polyurethane foams can be used to seal gaps, but they are expensive and difficult to remove. **Any roof vents that are covered during fumigation must later be uncovered, as roof vents must not be obstructed during grain aeration.**

Another key area to seal is the gap between the bottom of the wall and the concrete floor. Some manufacturers design the wall base to accept a special sealant that can give a long-term seal. Various sealing materials have been used, includ-

ing one made with polyurethane impregnated with asphalt. Roofing asphalt also has been used on the outside as a sealant but does not have as much elasticity.

Roof ventilators must be covered with plastic at least 3 mils thick. The plastic is less likely to tear against sharp edges if a burlap bag is placed over the ventilator first. The plastic must be taped in place and removed before aeration.

Bin doors are not gas-tight. Seal them with plastic and tape.

Aeration ducts must be sealed to avoid gas loss. Remove the fan and heater, and seal the opening with plastic 3 mils thick, and tape.

Determine Dosage

Determine the number of tablets required to treat the volume of grain in the bin and the head space.

Since hydrogen phosphide is a gas and will penetrate to all parts of the storage structure, dosage must be based upon the total volume of the space being fumigated and not on just the amount of grain, unless the grain surface is covered with a plastic tarpaulin.

Follow label instructions for dosage determinations.

Calculate Dosage

All fumigant labels provide information on the recommended dosages required to effectively treat stored grain. Using less fumigant than recommended can result in a concentration of gas too low to be effective. Using more fumigant than recommended is illegal, adds unnecessary cost, and may not increase efficacy.

Dosages recommended for the various phosphine-producing fumigant formulations are fairly similar. However, the actual amount of phosphine involved in specific fumigations will vary depending on the type of structure to be treated. Because phosphine distribution is not affected by the presence of grain, application rates are based primarily on the gas tightness of the structure, the size and shape of the structure, and the method of application.

Dosages for aluminum phosphide formulations are expressed in terms of tablets per 1,000 bushels storage capacity or 1,000 cubic feet of space.

Calculating Total Bin Volume—Cubic Feet

To calculate the total volume in a bin, follow the steps outlined here. The total volume is determined by combining the volume of the bin from the floor, typically a concrete pad, to the eave with the volume of the bin above the eave.

Step 1: Volume of space from concrete pad to the eave (ft^3) = $0.785 \times \text{diameter}^2 \times \text{height to eave}$

Example: A bin has a diameter of 30 feet and is 18 feet from the concrete pad to the eave.

The volume (ft^3) = $0.785 \times 30 \text{ ft} \times 30 \text{ ft} \times 18 \text{ ft} = 12,723 \text{ ft}^3$

Step 2: Volume of the head space under the roof (ft^3) = $0.2618 \times \text{diameter}^2 \times \text{height (from eave to peak)}$

Example: The head space in the bin is 5 feet higher at the peak than at the eave.

The head space volume (ft^3) = $0.2618 \times 30 \text{ ft} \times 30 \text{ ft} \times 5 \text{ ft} = 1,178 \text{ ft}^3$

Step 3: Total volume of the bin = volume to eave + volume above the eave = $12,723 \text{ ft}^3 + 1,178 \text{ ft}^3 = 13,901 \text{ ft}^3$

Post warning placards

The applicator must post warning signs at all entrances to the fumigated area. These signs must contain:

1. The words "DANGER/PELIGRO." The SKULL AND CROSSBONES symbol in red.
2. The words "Area and/or commodity under fumigation, DO NOT ENTER/NO ENTRE."
3. The words "This sign may only be removed after the commodity is completely aerated (contains 0.3 ppm or less phosphine gas)." If incompletely aerated commodity is transferred to a new site, the new site must also be placarded and workers must not be exposed to more than 0.3 ppm phosphine.
4. The date and time fumigation begins and is completed, name of fumigant used, and the name, address, and telephone number of the applicator.

Apply the Aluminum Phosphide Tablets

Divide the total number of tablets needed by four so they may be placed in each pie-shaped quarter of the bin. Typically, the number would then be divided by five (the number of tablets per probe) to determine the number of probes needed per quarter. For example, if the total number of tablets required for the bin is 280, the number for each quarter is 280 divided by four, which equals 70 tablets per quarter section. Each section would be probed 70 divided by 5, or 14 times with five tablets in each probe.

When placing the tablets in the probe, place the first one



Figure 3. Full-face canister respirator. Iowa State University Extension and Outreach photo.

when the probe is down 5 feet, then raise the probe 1 foot, and place the next tablet in the probe. Continue until five tablets are placed. The last tablet should be placed about 6 inches from the surface.

Applicators must work in *pairs*, be properly fitted with respiratory devices and other personal protective equipment required by the label, and must monitor the atmosphere.

Provide Respiratory Protection

If the fumigator needs to enter the fumigated structure for any reason, such as to apply the fumigant or reopen the structure, she or he must do so with the proper equipment, and very carefully. The gas level must be monitored, and workers must not be exposed to more than 0.3 ppm on a time-weighted average basis, unless wearing gas masks.

When entering the fumigated structure, a National Institute for Occupational Safety and Health (NIOSH)-approved gas mask or other equipment **must** be used. The NIOSH-approved full-face gas mask consists of a full-face mask, canisters, and filters. (Figure 3). Before using this respirator, ensure that the canisters and cartridges aren't damaged, soiled, or expired. Air should be monitored to know the level of fumigant concentration, to ensure the gas concentration is 15 ppm or less.

If monitoring equipment is not available and the application cannot be done from outside the structure, the NIOSH-approved canister respirator **must** be worn during application within the enclosed indoor area.

A NIOSH-approved, self-contained breathing apparatus (SCBA) also must be available if needed (Figure 4). SCBA



Figure 4. Self-contained breathing apparatus (SCBA) with facemask. HoneywellSafety.com photos.

gear consists of a full facepiece and independent air supply. Typically this is compressed air in a tank and carried by the wearer. The gas continually feeds into the facepiece each time you breathe.

SCBA may be present at a nearby emergency responder, but the applicator must have written proof of availability. SCBA gear is used only if it were necessary to enter a fumigated structure containing an unknown concentration or a phosphine concentration greater than 15 ppm.

If monitoring equipment is not available and the gas concentration is unknown, you must use the SCBA apparatus. The following graphic shows permissible gas concentration ranges (based on eight hours, time-weighted average) for these protective devices:

Gas Concentration	Respiratory Protection
Less than 0.3 ppm	None required
0.3–15 ppm	NIOSH/MSHA-approved full face gas mask-hydrogen phosphide canister combination
More than 15 ppm	NIOSH/MSHA-approved self-contained breathing apparatus (SCBA)

Both the full-face and self-contained types of respirators must form a tight seal around the face and eyes. Before wearing these respirators, you must be medically evaluated to ensure your health and lung capacity allow respirator use. After being cleared to wear a respirator, you must have a fit test to determine whether your respirator provides an acceptable fit. See EC3027, *Fit Testing a Respirator for Pesticide Applications* (<http://extensionpubs.unl.edu/publication/9000019652386/fit-testing-a-respirator-for-pesticide-applications-ec3027/>).

Seal the Doors

After all sections of the bin have been probed, close the bin and seal the access point with tape or plastic glued into place. This seal prevents fumigant vapors from venting to the outside and prevents the wind from drawing the fumigant out of the grain.

Determine Length of Fumigation

The exposure time of the phosphine gas in the grain must be long enough to provide for adequate control. Lengthen the time at lower temperatures because insects are more difficult to kill under these conditions (*Table 1*).

Aeration and Re-Entry

If the area is to be entered after fumigation, it must be aerated until the level of hydrogen phosphide gas is 0.3 ppm or below. Remove the plastic that covers the grain surface immediately after fumigation even if the bin is not to be aerated. The area or site must be monitored to ensure that liberation of gas from the treated grain does not develop into unacceptable levels of hydrogen phosphide. Do not allow anyone to enter treated areas before this time unless protected by an approved respirator.

Table 1. Guide to determine the minimum length of exposure¹ for aluminum phosphide.

Temperature to which fumigant and/or insects are exposed	Pellets	Tablets
Below 40°F	Do not fumigate	Do not fumigate
40°F–53°F	8 days	10 days
54°F–59°F	4 days	5 days
60°F–68°F	3 days	4 days
Above 68°F	2 days	3 days

¹ As a rule of thumb, add at least one day—preferably two—to the exposure time listed above for each 10 feet the gas must penetrate downward.

After the bin is aired out, treat the grain surface with an approved grain protectant to reduce insect reinfestation and to kill any flying insects in the space above the grain.

At the end of a phosphine fumigation, the powdery residue of tablets or pellets will still contain a small amount of aluminum phosphide for several days. Under normal circumstances of grain handling, these residues do not present a hazard, but do avoid inhaling the powder.

Determining concentrations. After the fumigation is over, it is important to determine that the gas has been reduced to a level below the eight-hour time-weighted average (0.3 ppm) to ensure worker safety upon re-entry.

There is no single device that can economically and efficiently measure all fumigants at all normal levels.

Various devices can be used depending on the gas being measured and whether a high reading during the fumigation or a low-range reading for compliance with the time-weighted average after the fumigation is needed. Follow instructions for the particular device you use.

Detection tubes (*Figure 5*) are probably the most versatile tools available for measuring gas concentrations. They are available for many industrial gases as well as for phosphine. The matching pumps (*Figure 6*) used with the tubes are well built, durable, and manufactured by a number of suppliers. The initial equipment cost for the pumps is moderate and can be amortized over hundreds of uses and many years. For most gases, they are sufficiently accurate.

The disadvantage to using the detection tubes is that they are designed for a single use on a single type of fumigant. Their cost can be burdensome when many readings are needed. And, they are not available for both high and low readings, so separate tubes of different capacities must be used. The tubes have a limited shelf life and are not reliable after the expiration date. In addition, they have limited accuracy on some gases.



Figure 5. Gas detection tubes.



Figure 6. Gas detection pump with a detector tube attached.

Cautions

- All fumigants are dangerous if improperly used. Follow the cautions listed on the container label and use only in strict accordance with label directions.
- **Never place aluminum phosphide on a wet surface or in standing water since it would evolve the gas too fast and could possibly ignite or explode.**
- Wear respiratory protection approved by NIOSH/ MSHA (Mine Safety and Health Administration) for the level of hydrogen phosphide gas to which you will be exposed.
- The effective life of a gas mask canister is limited. Keep an accurate record of the time that a canister is used and replace it when it has reached its hours-of-time limit, if you smell fumigant, or the canister is outdated.
- A self-contained breathing apparatus requires a refilling source. Your local fire station or rescue squad may be a refill source.
- **Never fumigate a bin by yourself.** Have one or more people on site to help if you get into trouble. The helper(s) must be properly fitted with approved respiratory protective devices. Devise a code so that you can communicate with one another. Make sure gas and electrical connections are turned off. Have the telephone numbers of the police and fire departments, hospital, physician, and rescue squad.
- Do not drink alcoholic beverages for a day before, during, or after exposure to grain fumigants.
- Perhaps you did not take precautions during past fumigations and had no problems or emergencies. Ignoring safety procedures may have serious consequences. Fumigants demand respect if you want to avoid injury or death, so protect yourself and others when working with these products.
- **If there are differences between information provided here and on the aluminum phosphide label, follow the label instructions.**

Fumigation Supply, Safety, and Gas Detection Vendors

AFC International, Inc.

P.O. Box 894
715C S.W. Almond St.
DeMotte, IN 46310
1-800-952-3293
<http://www.afcintl.com>
Email: sales@afcintl.com

Draeger Safety Inc.

7256 S. Sam Houston W, Ste. 100
Houston, TX 77085
1-800-437-2437
https://www.draeger.com/en-us_us/Applications/Productselector

DEGESCH America, Inc.

P.O. Box 116
153 Triangle Drive
Weyers Cave, VA 24486
1-540-234-9281
<http://degeschamerica.com>
Email: info@degeschamerica.com

Fumigation Service and Supply, Inc.

16950 Westfield Park Road
Westfield, IN 46074
1-317-896-9300 or 1-800-992-1991
<http://www.fumigationzone.com/>
Email: info@fumigationzone.com

Grainger

9345 J St.
Omaha, NE 68127
1-800-472-4643
<http://www.grainger.com/>

Matheson Gas, Inc.

6901 Cornhusker Hwy
Lincoln, NE 68529
1-402-434-6010 or 1-888-288-8749
<http://www.mathesongas.com/>
Email: info@mathesongas.com

Mine Safety Appliances Company

P.O. Box 426

Pittsburgh, PA 15230

1-800-672-2222

<http://us.msasafety.com>

Email: infor-us@msasafety.com

Pest Fog Sales

3049 Cabaniss Parkway

P.O. Box 270959

Corpus Christi, TX 78427

1-800-395-2345

<http://www.pestfogsales.com/>

Email: pestfog@aol.com

Sensidyne, Inc.

1000 112th Circle North, Suite 100

St. Petersburg, FL 33716

1-800-451-9444

<http://www.sensidyne.com/>

Email: info@Sensidyne.com

SKC, Inc.

863 Valley View Rd.

Eighty Four, PA 15330

1-800-752-8472 or 1-724-941-9701

<http://www.skcsopping.com/>

Email: skcorder@skcinc.com



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Sample Fumigation Management Plan

The purpose of this sample Fumigation Management Plan is to assist (Your name or Enterprise name) in (City), Nebraska, to ensure the safety of the workers, the community, and the environment. It is also designed to ensure an effective fumigation and to assist in meeting phosphine label requirements.

Owner/Manager

Name:

Address:

Day Telephone Number:

Night Telephone Number:

Email:

Certified Applicator(s) in Charge

Name:

Address:

Day Telephone Number(s):

Night Telephone Number(s):

Email(s):

Certification Number(s):

Year of Expiration(s):

Emergency Telephone Numbers

Local Police:

Local Fire Department:

Local Hospital:

Sheriff's Office:

Poison Control: 1-800-222-1222

Fumigant Company:

Date of site inspection: _____

or previous FMP date: _____

Date of developing FMP & worker safety plan: _____

Date of developing a monitoring plan: _____

Date of developing procedures for notifying local authorities and to notify nearby residents in the event of an emergency: _____

Date of confirming the placement of placards: _____

Date of confirming the presence of the required safety equipment: _____

Target pest(s): _____

Commodity fumigated: _____

Date of application: _____ Start time: _____

Fumigant trade name: _____ EPA registration number: _____

Location of nearest telephone: _____
(May refer to facility diagram with telephone marked)

Emergency electrical, gas, and water shut-off stations:
(May refer to facility diagram with telephone marked)

Reason for Fumigation — pest(s), buyer requirements, etc.

Type of Fumigation: steel bin, corrugated steel, etc.

Previous fumigation history:

Site(s) to be fumigated: (Indicate below or refer to attached diagram of facility)	Treated Area Volume	Commodity Temperature	Commodity Moisture	Dosage	Fumigation Time

Sites to placard:
(List below or indicate on attached diagram)

Sites to be monitored:
(List below or indicate on attached diagram)

Site	Date	Phosphine reading

Site, wind speed and direction, date, and reading for samples taken at property line.

Site	Wind speed	Wind direction	Date	Phosphine reading

Site(s) and date cleared of phosphine:
(List below or indicate on attached diagram)

Site	Date cleared	Phosphine reading

Method of disposal of unused pesticide: _____

Names of Fumigators:
Example:

Person fumigating	License number
Abraham Lincoln	NEB 000000
Jefferson Davy	NEB 000000

Attach a facility diagram showing structures to be fumigated in relation to other structures; electrical, gas, and water shut-off controls; telephones, equipment; etc.