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Chapter 1
General Fumigation Information

Learning Objectives
You should learn about:
1. What is fumigation
2. How fumigants work
3. How fumigants are used
4. Safety Rules for fumigators
5. Whether fumigation is necessary

FUMIGATION WHAT IS IT
Fumigation is the distribution of a chemical pesticide as a gas through spaces and materials. This is because gas molecules exist separately and independently. They spread widely into small cracks and crevices. They penetrate into tightly packed materials. The term “space fumigation” designates generally a wide range of treatments in enclosed spaces that either contains infested materials or themselves have residual insect populations. This spreading of individual molecules makes fumigants different from aerosols. Aerosols are discharged as very fine particles that remain suspended in the air long enough to be distributed. Aerosols are unable to penetrate even small distances into materials. For aerosols to be effective, the pest must be exposed or easily reached.

A licensed applicator or a trained serviceperson under the direct supervision of a licensed applicator must perform all fumigations. This applicator or trained serviceperson should know the nature of the chemical being used and its hazards. All effective fumigants are potentially dangerous to plant, animal and human life. They should be handled with due care and judgment.

FUMIGANTS OFFER THE FOLLOWING ADVANTAGES OVER PESTICIDES:
• Fumigants commonly used are toxic to all animal pests, insects, spiders, mites and rodents.
• The use of fumigants is usually the quickest method of controlling pests.
• Fumigants will usually reach pests where sprays, powders or dusts cannot be applied.
• Some fumigants can be used to kill pests in or near food, leaving no harmful residues whereas other pesticides may contaminate or taint food.
• In specific situations, fumigants may be less expensive than repeated treatments with sprays or dusts.

SOME DISADVANTAGES OF FUMIGANTS:
• Most fumigants are very toxic to man.
• Fumigants leave no residual pest control action after fumigation.
• Specialized protective equipment such as self-contained breathing apparatus (SCBA), gas leak detectors, etc. are required.
• The application of fumigants requires a more technical skill set.
• The labor involved may make the labor costs high.
• More application and operational equipment may be needed.
• The use of fumigants may cause inconvenience to people who live or work in the building.
• More than one technician must always be present in any fumigation operation.
• Some fumigants are expensive, corrosive or may leave residues.
• Special permits or licenses are required in many areas.
HOW FUMIGANTS WORK
It has been very difficult to determine exactly how fumigants affect insects. Scientists have explored the question for many years but are not in complete agreement as to just how different fumigants cause death.

In general, fumigants reach the tissues of insects through the respiratory system. The entrance of the fumigant into the cells causes the highest percentage of kill. In most insects, oxygen is taken into the body through the spiracles. Once inside the body, oxygen and the accompanying fumigant are diffused through the thin cell walls. Movement of the insect’s diaphragm, abdomen and thorax acts to assist the flow. The flow has a practical bearing on commodity fumigation.

Insects are most active during periods of optimum temperatures as they breathe normally. Therefore, they absorb more fumigant than they do during cold inactive periods. The fact is that at the lower temperatures the gas is less effective. This is one of the reasons that higher dosages of fumigant must be used as the temperature decreases to compensate for inaction of the insect. A certain amount of gas will enter the cells of inactive insects. Higher concentrations are required to flow into the cells and kill the pests. Some fumigants are nerve poisons. Some fumigants appear to kill insects by preventing the absorption of oxygen in the cells. Others may kill by mechanically preventing oxygen from reaching the insect. Some fumigants appear to kill insects by affecting the enzymes in some way that prevents tissues from uniting with oxygen.

Lethal fumes from the products are released when fumigating within an enclosure. The person applying the fumigation treatment cannot see and in some cases cannot smell the fumes. The pests that he seeks to kill may be hidden away in the heart of a grapefruit or a bale of hay. But the invisible fumes must be capable of killing them regardless of the stage of development or where they are located.

Therefore, fumigators need to know the potential of fumigants and how to apply them properly.

The most important environmental factor influencing the action of fumigants on insects is temperature. In the range of normal fumigating temperatures from 10°C to 35°C (50°F to 95°F), the concentration of a fumigant required to control a given stage of an insect species decreases with the rise in temperature. This is mainly due to the increased rate of metabolism of the insect’s response to the rise in temperature. Also, physical absorption of the fumigant by the material containing the insects is reduced and proportionately more fumigant is available to attack the insects.

HOW FUMIGANTS ARE USED
Fumigants are used in various forms and dosages according to the nature of the commodities and pests involved. Certain generalizations may be made pertaining to killing insect pests in commodities. The state of development and activity of the target pest is important. Active adults are normally easier to kill than inactive or hibernating adults. Immature stages of insects generally require higher dosages or longer exposure for complete death than do active adults.

The amount of free air space compared to the size of the load, how porous the load is, the kind of material and the location of the pests in the load all affect the dosage and exposure period. Finely ground materials such as alfalfa and cottonseed meal have a large surface area. Because of this trait they will absorb more of the fumigant leaving less gas to fumigate insects. At lower temperatures, higher dosages are required to ensure that lethal amounts reach the center of the load or the interior portions of fruits and vegetables.

Tests in recent years indicate that residues resulting from methyl bromide fumigation are lower when temperatures are low. This is true even though the concentration and exposure
are greater at these temperatures. This is probably due to the lower amount of gas that was absorbed at the lower temperatures.

SAFETY RULES FOR FUMIGATORS

- Read and understand the label and all labeling before starting any new job; the label may have changed or even if it hasn’t, it is worth the time to reread the label for review.

- Gain practical training before doing your first fumigation or any new type of fumigation.

- Examine the structure and its components for anything that can be damaged by the fumigation. Use the label to check for things that might be harmed. If in doubt, do test fumigation on a small amount of the material.

- Review all legal fumigants in regard to their contents and required exposure time. Choose the most appropriate one with emphasis on safety.

- Plan the gas release in a manner to avoid human exposure.

- Know symptoms and emergency treatments for exposure to the fumigant to be used.

- Make sure proper respiratory protection and other personal protective equipment are on hand and have all personnel properly trained in its use.

- Before starting fumigation take appropriate instructions to a physician at the nearest medical facility.

- Notify police and fire departments before starting fumigation.

- Rehearse a typical accident ahead of time so all parties will react automatically during an actual incident.

- Be sure you have adequate fumigation insurance before doing any treatment. Normal insurance DOES NOT COVER fumigation.

- Plan for the aeration before releasing gas. Check for adjoining buildings, or buildings connected by common vents.

- Check for weather conditions anticipated during fumigation period and aeration. Know effects of all types of weather on both the fumigation and the aeration.

- Take temperature of the commodities in representative areas. Check these temperatures against the label for prohibitions or necessary changes.

- Take relative humidity (RH) readings, particularly if using hydrogen phosphide. Know when the RH would be too low to release enough gas within the time available. Know when the RH is so high that damage could result to copper and other heavy metals.

- Be sure that you have at least one other trained person with you when doing any fumigation. No alcohol before or during job, or for 24 hours after.

- Properly secure the structure by sealing all openings or by covering structure with gas proof tarps fastened together.

- Equip crew members with appropriate protective clothing. Know what gloves and other clothing is counter-indicated by each fumigant.

- Know all applicable laws including any local ordinances.

- Be sure that the crew can work without undue fear of pesticides. The crew must wear the protective respiratory equipment. There should be respect for the fumigant
but no false bravado that could endanger all.
- Use lifelines if entering tanks or other similar areas.
- Rehearse actual release if first time for the crew.
- Always work in pairs in sight of each other but the “safety man” should be in a relatively safe position. If one man is in a railcar the other should be outside. If one man is in a silo the other should be outside manning the safety line.
- Carefully release the gas with the least possible human exposure. Release compressed gas from the outside if possible. Place slow-release gas such as phosphine tablets quickly enough to ensure exposure below the short-term exposure level (STEL) or wear protective equipment. Place solid phosphine products on paper for easy disposal.
- Seal exit door and secure all doors from accidental entry by use of supplementary locks, guards, warning signs or a combination of these.
- Post proper warning signs on all possible entrance points.
- Check structure for leaks with appropriate detection devices.
- If any fumigant has spilled on clothing, remove clothing and wash. Get medical attention if necessary.
- If any of the crew shows symptoms don’t take chances; get medical attention.
- Monitor gas levels so that the job is terminated only when the proper concentration multiplied by time has been met.
- Start aeration with regard to the amount of gas left and where it might go. Consider the possibility of gas movement to other buildings or gas staying around the building in the event of a temperature inversion with no wind.
- Clear structure according to measured results only. Never trust a set number of hours for clearance. There are too many variables.
- Make final clearance tests with labor and management representatives to avoid undue fears from either group.
- Check products for excessive residue if there is any reason to suspect problems.
- Remove signs when all gas is below established safe exposure limits.
- Notify the authorities that all is clear again.
- Get needed rest after filling out final written reports, but do not drink alcohol for another 24 hours.
Chapter 2
Characteristics of Fumigants

Learning Objectives
You should learn:
1. Characteristics
2. Volatility
3. Molecular Weight
4. Boiling Point
5. Vapor Pressure
6. Specific Gravity
7. Diffusion (Flow) Potential
8. Water Solubility
9. Latent Heat of Evaporation
10. Flammability
11. Chemical Reactivity

CHEMICAL AND PHYSICAL CHARACTERISTICS
Important physical and chemical characteristics of a fumigant include volatility, molecular weight, boiling point, vapor pressure, specific gravity, diffusion potential, water solubility, and latent heat of vaporization, flammability, and chemical reactivity. Read the product information supplied by the manufacturer to be sure that the material you select is appropriate to the commodity, treatment site and target pest. The label must list the commodity and target sites.

VOLATILITY
Volatility is the tendency of a chemical to evaporate and become a gas or vapor. Volatility increases as temperature rises. Some "gaseous-type" fumigants such as methyl bromide are normally a gas at room temperature. Other fumigants exist as a liquid or solid at room temperature. Also, many of the "solid-type" fumigants such as aluminum phosphide are not fumigants themselves but react with moisture to form a fumigant gas (phosphine or hydrogen phosphide).

MOLECULAR WEIGHT
Molecular weight is a measure of the weight of the atoms that form the fumigant molecule. More complex molecules have greater molecular weight because they have more atoms. Larger molecules are often less suitable as fumigants since they are less volatile.

BOILING POINT
The boiling point of the chemical is the temperature at which the liquid stage boils under specific atmospheric conditions to become a gas. Some materials used as fumigants, such as methyl bromide, have low boiling points so they are gases at normal temperatures and atmospheric pressure. These types of fumigants are usually stored as liquids under high pressure.

The boiling point of a fumigant may influence the type of application equipment required. For example, fumigants with low boiling points usually require heaters to warm the gas as it is being released. This is because these materials may freeze on release into the atmosphere, since much heat is lost as fumigants turn from a liquid to a gas. They diffuse more slowly, and it may be important to disperse these types of gases with fans or blowers.

VAPOR PRESSURE WATER
The vapor pressure of the fumigant affects the atmospheric concentration of the gas in the air. When a volatile liquid or solid is confined in an area, equilibrium gradually takes place between molecules in the gas and liquid phases. Once the gas molecules reach a saturation point further volatilization won't increase the number of molecules in the vapor phase. Although volatilization may appear to stop, what actually happens is that a gas molecule condensing back to the liquid form replaces every molecule evaporating from the liquid. Methyl bromide probably cannot revert to a liquid at normal pressure. Since vapor
pressure determines the concentration that can be maintained during fumigation, materials of high vapor pressure will be more concentrated and therefore have better fumigant qualities.

**SPECIFIC GRAVITY**
The specific gravity of a chemical compound is a measure of its weight in a given volume. With fumigants it’s important to know if the gas is lighter or heavier than air. Most commonly used fumigants are heavier than air. A heavy gas in a confined area will tend to concentrate in low areas and mix slowly with the air. These fumigants usually require mechanical mixing with a fan to distribute the molecules evenly through the fumigated area. However, once the fumigant is thoroughly mixed with the air settling takes place very slowly. As a result, the problem of stratification or layering of heavier than air fumigants doesn't have much practical meaning for the exposure periods usually required in fumigation work.

All gases become lighter as they become warmer. This is because warm molecules take up more space, so fewer molecules can be contained in a given space at the same pressure.

**DIFFUSION (FLOW) POTENTIAL**
Diffusion or flow potential is a measure of how fast gas molecules disperse through the atmosphere. After a while the molecules become evenly distributed. The speed with which molecules disperse is affected by the molecular weight of the gas. Gases that are heavier diffuse more slowly and it may be important to disperse these types of gases with fans or blowers.

**WATER SOLUBILITY**
The water solubility of a fumigant becomes an important consideration if items in a fumigated area contain even small amounts of water. The water will tie up water-soluble fumigant molecules, reducing the fumigant concentration in the atmosphere. Toxic molecules also may be incorporated into the water of fumigated materials and may remain as undesirable residues. Suitable fumigants for most applications are those that are insoluble or only slightly soluble in water.

**LATENT HEAT OF EVAPORATION**
Latent heat of evaporation (the extra heat required to change the liquid to a gas) must be considered when using fumigants that have boiling points below room temperature. Unless sustained by warming from an outside source, the temperature of an evaporating liquid constantly drops. This is shown by the cooling effect of evaporating water on the skin.

The factor of latent heat has important practical significance. High-pressure fumigants volatilize and lose heat rapidly on release. Unless the lost heat is restored, the temperature of the fumigant may fall below its boiling point, causing the gas to no longer evolve. Also, as the liquid changing to gas is led through metal pipes and tubes or plastic tubing, the drop in temperature may freeze the fumigant in the lines, preventing further passage.

In many applications, it's wise to apply heat to the fumigant as it passes from the container into the fumigation space. Fumigants that are liquids at normal temperatures and are volatilized from evaporating pans or vaporizing nozzles also lose heat. These applications may require a source of heat, such as a hot plate, so that full concentrations will take place rapidly.

**FLAMMABILITY**
Flammability of a fumigant is another physical characteristic that is very important in its safe use. Fumigants that are flammable gases are usually combined with a non-flammable gas (such as carbon dioxide) to reduce the danger of fire or explosion.

**CHEMICAL REACTIVITY**
Chemical reactivity of some fumigants with other chemicals in the environment may limit some fumigant uses. Phosphine gas reacts with copper, silver and gold (or their alloys
used in electrical wiring, motors and computers) to cause serious corrosion. High temperatures around an open flame may cause some fumigants to form corrosive acids. Certain fumigants may make photographic film and paper unusable because of chemical reaction.

READ AND FOLLOW INSTRUCTIONS ON THE LABEL.
Chapter 3
Types of Fumigants

Learning Objectives
You should learn about:
1. Product Stewardship - What is it?
2. The types of fumigants
3. Their characteristics
4. How fumigants affect insects

PRODUCT STEWARDSHIP - WHAT IS IT?
Most registrants of fumigation products are committed to exercising responsible care for their products in manufacturing and distribution and later in the handling of their products by distributors, dealers and use by its customers.

This means assessing the environmental impact of the products and then taking appropriate steps to protect employee and public health and the environment as a whole. In addition to safe production, stewardship means they have a continuous concern for the proper use and ultimate disposal of their products.

Most registrants will be offering training programs for persons using their products. These training programs will need to be completed by the product users, to purchase many of the fumigants. The staff at the Ohio Department of Agriculture along with the USEPA is in favor of these stewardship programs.

TYPES OF FUMIGANTS
Many of the active ingredients in fumigants used in the early days of fumigation have either been canceled entirely or had their uses restricted. All space-fumigation products and several soil-fumigant products (especially those containing chloropicrin and/or methyl bromide) are now restricted-use pesticides.

The active ingredients that are still legal to use in Ohio include:

METHYL BROMIDE
Methyl bromide is a chemical that has been identified as an ozone depleting substance. According to the USEPA the only uses that are allowed are quarantine and critical use exemptions.

Methyl bromide is a colorless, odorless and tasteless gas. It is heavier than air, so it tends to settle out in low places. It also tends to stratify so fans are needed to assure thorough mixing of the gas with the air. It penetrates most commodities very well, and is effective against all stages of insect life.

As with all other fumigants, methyl bromide is toxic to all forms of animal life. Additionally, repeated exposure to low doses of methyl bromide may accumulate in body tissue. The established threshold limit of methyl bromide daily exposure is 5 parts per million (PPM). (The threshold limit is the maximum permitted daily exposure, eight hours per day, five days per week.)

When handling methyl bromide, you must have respiratory protection. Only SCBA will give adequate protection. READ THE LABEL.

Methyl bromide is supplied in steel cylinders of several sizes. In these pressurized containers, methyl bromide is a liquid. Once the pressure is released, the liquid vaporizes to a gas. The material may be supplied either as 100% methyl bromide or as 98% methyl bromide plus chloropicrin. The chloropicrin (tear gas) serves as a warning agent.

When the cylinder is opened outside, SCBA is not required but eye protection such as a face shield is required. A SCBA should be available and ready for use if the need should arise. Aprons may be worn but loose fitting clothes that can be quickly removed in case of
an accident are preferred. Gloves should not be worn because they could trap gas against the skin causing burns. If methyl bromide should be spilled on shoes, take them off. Methyl bromide trapped in shoes will cause serious blistering.

Once the methyl bromide has been introduced, you should check for leaks. The Halide gas detector has a flame that heats a copper ring. Methyl bromide gas (as well as fluoride, chlorine and the Freon) passing over the heated copper ring will be colored. The depth of color will depend on the gas concentration. A very light green indicates a low concentration. A royal blue color indicates a high gas concentration. New electronic leak detectors are more expensive but have many advantages. All leaks must be repaired when found.

The gas concentration within the fumigation enclosure must also be measured. This is to assure that you have an adequate gas concentration for a long enough time to obtain pest control. There are devices on the market that work well. Two of these devices work on the principals of thermal conductivity. One is the Fumiscope manufactured by Key Chemical and Equipment Co., Clearwater, Florida. The other is the Gow-Mac unit manufactured by the Gow-Mac Instrument Company, Madison, New Jersey. A newer electronic device that can measure small amounts of methyl bromide is the Porta Sens II. This unit will tell the amount of methyl bromide far better than a halide leak detector can. A more complete discussion of monitoring equipment can be found in chapter 7.

CHLOROPICRIN
Chloropicrin fumigant products contain nearly 100 percent chloropicrin and are marketed as liquids. Chloropicrin volatilizes to form a dense gas that is about 5.7 times heavier than air.

Chloropicrin is highly toxic to insects, vertebrates, and many soil microbes, such as fungi. It’s highly irritating to eyes and is a powerful “tear gas.” Concentrations as low as 1.0 part per million (ppm) cause intense eye irritation, and prolonged exposures can cause severe lung injury. Chloropicrin can cause severe injury upon skin contact.

The use of chloropicrin is prohibited on food. It can be used as a warning agent with methyl bromide treatment of houses where all foods have been removed. It can also be used on empty grain bins.

ALUMINUM AND HYDROGEN PHOSPHIDE
Aluminum phosphide is a solid. In the presence of atmospheric moisture and sufficient temperature it breaks down and releases a gas, hydrogen phosphide, otherwise named phosphine. The gas is colorless, but it has a penetrating carbide or garlic odor. Most people will notice the odor at very low concentrations.

Although hydrogen phosphide is slightly heavier than air, it has high molecular activity and does not tend to stratify. Fans, therefore, are not needed to assure even distribution of the gas. If the liberation of hydrogen phosphide occurs too rapidly, a flammable and explosive mixture can occur. Two manufacturers have found a way of controlling the rate of the release of hydrogen phosphide. One formulates the aluminum phosphate with aluminum carbonate, the other with aluminum stearate and calcium oxide. These controlled release formulations preclude any explosion risk when used at normal application rates and there is no accidental exposure to water.

Hydrogen phosphide does not accumulate within body tissues in the same manner as methyl bromide. Any gas entering the body will be completely eliminated within 48 hours. Hydrogen phosphide is very toxic to humans. The threshold limit is only 0.38 PPM. Mathematically, this would indicate that the gas is about 60 times more toxic than methyl bromide. However, because of the manner in which the gas is liberated, because of the ease that the gas is contained in fumigation films, and because of the odor characteristics,
As the formulated aluminum phosphide does not start to break down and liberate hydrogen phosphide for one or two hours after introduction into the fumigation facility, respirators are usually not needed during fumigation introduction. Only monitoring will tell if the gas level is above the TLV. Nevertheless, respiratory protection must be immediately available. The gas below 0.3 PPM does not require respiratory protections. With gas levels from 0.3 to 15 PPM a gas mask can be used. For gas levels over 15 PPM only a SCBA can be used. It should be equipped with yellow canisters having a gray strip around it. Cloth gloves must be worn when handling either the aluminum phosphide, or the residue that remains following fumigation.

Aluminum phosphide registrations are listed on the label and permit fumigation to grain, grain products, nuts, cocoa and coffee beans, seed, bulk animal feeds (including dog food) and stored tobacco. The fumigant is effective against all stages of insect life. Aluminum phosphide tablets or pellets may be fed into the stream as the commodity flows into grain bins. Aluminum phosphide, or its residue, must not be permitted to come into direct contact with any processed food. As noted earlier, aluminum phosphide can be used for the in-transit fumigation of stored product pests. Hydrogen phosphide gas will, in the presence of moisture, react with copper, silver, and several other metals, and may cause severe corrosion, including destruction of motors and electronic equipment.

The aluminum phosphide – ammonium carbonate formulation is supplied in resealable flasks containing 1660 pellets or 500 to 1000 tablets. Each pellet will liberate 0.2 grams of hydrogen phosphide. Each tablet will give 1 gram of hydrogen phosphide. The aluminum phosphide, aluminum stearate, calcium formulation is supplied in vapor permeable bags packed in airtight tins. Each bag will liberate 11 grams of hydrogen phosphide. Once the tins have been opened the entire contents must be used or destroyed.

As indicated, one advantage of aluminum phosphide is that it can be used easily for fumigation. The cube of the space to be fumigated is calculated, and the appropriate number of pellets, tablets, or bags determined. Using cloth gloves, the required number of pellets, tablets or bags is counted out onto a tray or sheet of cardboard. The tray is then slipped under the fumigation tarp. The aluminum phosphide will not start to liberate hydrogen phosphide for one or two hours. This can usually be done without respiratory protection but monitoring is required. If the tarp seals are tight, if all the rips have been repaired and if there is a little air movement in the warehouse or other structure, normal work can continue within the fumigation period, BUT ONLY IF CONSTANT MONITORING IS DONE. Personnel must be evacuated of course, when the traps are removed for aeration. Gas measuring devices are mandatory at this time and are discussed in chapter 7. Fumigation with aluminum phosphide does take time. Normal exposure periods are for 72 hours but research shows that 5 days or more will give a better kill. Buildup of the fumigant concentration is slow. It may take 12 to 48 hours before the desired concentration of gas is reached. If the atmosphere is very dry, the gas build-up may take even longer. In locations where the relative humidity is very low, the gas liberation can be speeded up either by placing a pan of water under the fumigation tarp, or by spraying onto the floor or dirt. UNDER NO CIRCUMSTANCES SHOULD WATER BE PERMITTED TO CONTACT ALUMINUM PHOSPHIDE; A FLAMMABLE OR EXPLOSIVE MATERIAL WILL RESULT.

If dosages are lower than required at the end of the 72-hour period, control can frequently be gained by extending the fumigation period. Aeration after aluminum phosphide is rapid. Open the doors and windows to assure good ventilation. Then with respiratory protection,
remove the sand snakes and lift the tarp at both ends of the stack. Aeration should be complete in one to two hours. If the fumigated commodity is not going to be used for some period of time, there is no objection to leaving the fumigation tarp over the commodity. The tarp will keep dust and bird droppings off the commodity. After fumigation, there will remain a powdery residue from the decomposed pellets, tablets or bags. This residue will contain a very small amount of unreacted aluminum phosphide. This residue must be deactivated. The residue from the pellets or tablets should be stirred into a pail of water to which one-half cupful of detergent has been added. The residue from the bag formulation should be stirred into a bucket containing a 50-50 mixture of water and 70% alcohol (isopropyl, methyl, or ethyl). This deactivation procedure must take place outdoors. After the residue has been deactivated the water may be poured down a sewer or buried without adverse environmental effects.

MAGNESIUM PHOSPHIDE
Magnesium Phosphide is a pesticide that is a solid, dark gray material (granules, or powder) molecular weight of 134.70. The material must be protected from moisture in the atmosphere in airtight containers. The contact of the solid material with moisture in the air, liquids or acids releases phosphine, a highly toxic gas.

Requirements for acute toxicity data have been waived because of the well-known extreme inhalation toxicity of the phosphine gases that it generates. Magnesium phosphide has been placed in the toxicity category I, the highest toxicity category.

Magnesium phosphide is produced as pellets, tablets, and impregnated onto polyethylene plates and strips. As with aluminum phosphide, each magnesium phosphide pellet and tablet releases 0.2 g and 1 g of phosphine, respectively. Each plate (6.75" x 11" x 0.15") releases 33 g of phosphine. A strip is simply 20 plates connected end-to-end. Plates and strips are sealed individually in gastight, foil pouches. The non-resealable pouches are packed in tins, 40 plates or 2 strips per container. Magnesium phosphide is also packaged in small, gas-permeable blister packs for fumigating equipment or small areas.

Aluminum oxide and aluminum hydroxide are by-products of the reaction between aluminum phosphide and atmospheric moisture. These chemicals, along with unreacted aluminum phosphide, remain as a grayish white residue after fumigation. This residue is not permitted to come in direct contact with any processed food or bagged commodity except that aluminum phosphide may be added directly to brewer's rice, malt, and corn grits for use in the manufacture of beer. You can prevent the residue from contacting a commodity by placing the aluminum phosphide on a tray instead of adding it directly to the commodity. The residue must be deactivated and disposed of; instructions can be found on the product label. Magnesium phosphide produces similar residue (consisting of magnesium oxide, magnesium hydroxide, and a small amount of unreacted magnesium phosphide) that has the same restrictions and disposal requirements as the residue from aluminum phosphide.

SULFURYL FLUORIDE
Sulfuryl fluoride is a broad-spectrum post-harvest fumigant. Fumigation is usually the preferred method of post-harvest pest eradication because the pests can be anywhere within the commodity, storage or processing structure, mill or food handling establishment. For many years, methyl bromide has been the fumigant of choice, but its use is being phased out under the Montreal Protocol because of concerns that it depletes the stratospheric ozone layer. The Montreal Protocol is an international agreement ratified by over 160 countries.

Sulfuryl fluoride is a viable alternative to methyl bromide for fumigation of mills, warehouses, storage structures, transportation vehicles, and many commodities and foods within them. Sulfuryl fluoride, because of its unique mode of action, can also be used as a viable rotation tool to manage and help
prevent resistance issues with other fumigants and insecticides.

Sulfuryl fluoride is a colorless and odorless gas, which is a liquid when under pressure. It is heavier than air, so it also tends to settle in low areas. It is non-flammable in all atmospheric concentrations, but it will change to a different, corrosive gas in the presence of open flame or electric heaters. It apparently does not accumulate in body tissue. The threshold limit has been established as 10 PPM. If gas masks are used for respiratory protection, the canisters should be color-coded white with a gray stripe around the top. Sulfuryl fluoride penetrates dry wood products very well, and is registered for the control of dry-wood termites, powder post beetles, and wood boring beetles. It is also registered for the control of bedbugs and clothes moths. The application rates vary considerably, so be sure to read the label. As the gas can get into frost-free refrigerators and freezers, the contents must be removed from the structure or otherwise sealed from the gas. Additionally, items that might trap the gas (such as waterproof mattress covers) must be opened up or removed from the structure. Sulfuryl fluoride does not react with the large number of products to produce odors or damage products, like methyl bromide can. Very few items must be removed from the structure. However, all pilot lights must be turned off and heating devices such as electric heaters must be allowed to cool down. In the presence of open flame or hot surfaces, sulfuryl fluoride will break down to form a very corrosive gas. Sulfuryl fluoride is an excellent fumigant for the control of wood destroying insects. While it is very effective against insect larvae and adults, it is not effective against the egg at normal fumigation concentrations. Sulfuryl fluoride is supplied in compressed gas cylinders of various sizes.

Some fumigators seal the structure with tape or laminated paper, but better gas retention is obtained if the entire structure is covered with a tarp. As with all structural fumigation, interior doors, closets and interior vents should be left open to help with circulation. Sulfuryl fluoride is nearly odorless, so it is recommended that an odorizer be introduced prior to the introduction of the fumigant. To do this, place a handful of cotton in a shallow pan. Locate the pan in front of a fan. Pour one ounce of chloropicrin per 15,000 cubic feet onto the cotton complete the seal of the structure and turn on the fan. Allow five to ten minutes for chloropicrin circulation, and then introduce the fumigant.

The sulfuryl fluoride should be introduced to the building from outside the structure. The introduction tubing should be ⅛” to ¼” in diameter and made of polyethylene, polypropylene, or nylon tubing. The rate of fumigant release through larger tubing would be too great for good gas distribution. The tubing should be at least 62 mils thick to withstand the gas pressure. Do not heat the gas. As sulfuryl fluoride is heavier than air, it is necessary to use fans to help circulate the gas. The fans should be so placed to ensure good gas distribution, and they should be left running during the fumigation operation.

The manufacturers of sulfuryl fluoride have developed special slide rules, called FUMIGUIDES. These devices consider several factors: the cube of the structure, adequacy of the ground seal, wind temperature, and exposure time. Based on these factors, the FUMIGUIDE calculates the application rate to be used. Then, based on subsequent gas concentration readings, the FUMIGUIDE tells you how much gas must be added to achieve pest control. Gas concentrations are measured with a thermal conductivity unit (similar to the units used to measure methyl bromide or carboxide fumigants) specially calibrated to read sulfuryl fluoride. Tubing should be run from various parts of the structure to one or more points outside the structure so that the gas concentration readings may be obtained. There is no good device to detect sulfuryl fluoride leaks. The odor from the chloropicrin is the best guide to leak determination.
Aeration following fumigation is quite rapid. The gas desorbs rapidly. Once the gas has been removed, or the windows and doors opened, the gas concentration should drop below 10 ppm in an hour or less. At very high final gas concentrations, the aeration period may last an hour and 45 minutes. There is a small electric furnace together with a sampling tube that can be used to determine that the gas concentration is below the 10 ppm threshold limit.

**THE PRE-DEATH BEHAVIOR OF FUMIGATED INSECTS**

Insect death with fumigants occurs more quickly at higher temperatures than at lower temperatures. Temperature determines the molecular rate of activity of the chemical or chemicals. At higher temperatures the chemical diffuses more rapidly, thereby getting to the pest more quickly.

Treated insects may be unable to walk or fly in a normal manner. They usually come to rest on their backs and eventually are unable to recover from that position; however, they may move their head, legs, or antennae for several days before death finally occurs. Insect activity, when observed shortly after exposure to slow-killing fumigants, may be disappointing to inexperienced persons. The effect on insects that have been exposed to lethal dosages of these gases is accumulative and regardless of how long it takes to kill them they never recover.
Chapter 4
The Label and Applicators Manual

Learning Objectives
You should learn about:
1. How to read and use the label
2. How to use the applicator’s manual

THE LABEL AND APPLICATOR’S MANUAL
You might have heard this statement before, “THE LABEL IS THE LAW.” The label is a very important part of the pesticide application. The label and any documentation should be completely read before proceeding. The label has very important information on it such as active ingredients, statements of practical use and registrant’s information, etc.

Most fumigant information is different from herbicides and insecticides. Most fumigants have a label and an applicator’s manual that is supplied with the product. The Applicator’s Manual contains information such as how to use the product, pest controlled by the product and what to wear when using the product. This manual is considered to be a part of the label, which is the law. The applicator’s manual, like the label, should be completely read before performing any fumigation.

Most fumigants are “restricted use” pesticides, which means that only a licensed pesticide applicator may purchase or use these chemicals. The only exception is a trained serviceman who is not licensed, but working under direct supervision of a licensed applicator, may use these chemicals.

Fumigants are very toxic chemicals that turn into a gas. Fumigants are not selective like some herbicides and insecticides; Fumigants are very, very toxic to almost everything that the gas contacts, including you! So read the label and the applicator’s manual and be safe.

DISCLAIMER
The label and applicator’s manual contained in this publication are to be used for education and information purposes ONLY. These are not recommendations for use of these products. These products were chosen because of the many uses and pests that were covered on the label and manual.

RESTRICTED USE PESTICIDE DUE TO INHALATION TOXICITY
For sale to and use only by Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicator's certification.

Precautionary Statements
Hazards to Humans and Domestic Animals

SPECIMEN LABEL
(Dow AgroSciences)

Specialty Gas Fumigant
*Trademark of Dow AgroSciences LLC

For control of: Existing infestations of insects and related pests such as (or including) drywood termites, Formosan termites, powder post beetles, death watch beetles, old house borers, bedbugs, cockroaches, clothes moths, rodents (rats, mice), and the larvae and adults of carpet beetles (except egg stage), oriental, American, and brown-banded cockroaches.

For use in: Dwellings (including mobile homes), Buildings, Construction Materials, Furnishings (household effects), and Vehicles including automobiles, buses, surface ships, rail cars, and recreational vehicles (but not including aircraft).

When fumigating, observe local, state, and federal rules and regulations including such things as use of chloropicrin, clearing devices, positive-pressure self-contained breathing apparatus, security requirements, and placement of warning signs.

Active Ingredient
sulfuryl fluoride ................................99.8%
Inert Ingredients ..................................2%
DANGER POISON PELIGRO
Precaucion al usuario: Si usted no lee ingles, no use este producto hasta que la etiqueta le haya sido explicada ampliamente.

Extremely Hazardous Liquid and Vapor Under Pressure
• Inhalation of Vapors May Be Fatal • Liquid May Cause Freeze Burns of Exposed Skin

Do not get in eyes, on skin, or on clothing. Vikane® gas fumigant is odorless. Exposure to toxic levels may occur without warning or detection by the user.

Directions for Use
It is a violation of Federal law to use this product in a manner inconsistent with its labeling. Read all Directions for Use carefully before applying.

First Aid
In all cases of overexposure, such as nausea, difficulty in breathing, abdominal pain, slowing of movements and speech, numbness in extremities, get medical attention immediately. Take person to a doctor or emergency treatment facility.

If Inhaled: Get exposed person to fresh air. Keep warm and at rest. Make sure person can breathe freely. If breathing has stopped, give artificial respiration. Do not put anything in the mouth of an unconscious person.

If Liquid Is On Skin: Immediately apply water to contaminated area of clothing before removing. Once area has thawed, remove contaminated clothing, shoes, and other items covering skin. Wash contaminated skin area thoroughly or shower.

If Liquid Is In Eyes: Flush with plenty of water for at least 5 minutes. Get medical attention.

Note to Physician: Vikane is a gas, which has no warning properties such as odor or eye irritation. (However, chloropicrin is used as a warning agent and is a known lachrymator). Early symptoms of exposure to Vikane are respiratory irritation and central nervous system depression. Excitation may follow. Slowed movement, reduced awareness, and slow or garbled speech may be noted. Prolonged exposure can produce lung irritation, pulmonary edema, nausea, and abdominal pain. Repeated exposure to high concentrations can result in significant lung and kidney damage. Single exposures at high concentrations have resulted in death. Treat symptomatically.

Liquid Vikane in the eye may cause damage due to refrigeration or freezing.

Notice: Read the entire label. Use only according to label directions. Before buying or using this product, read "Warranty Disclaimer" and "Limitation of Remedies" elsewhere on this label.

In case of emergency endangering health or the environment involving this product, call 1-800-992-5994. If you wish to obtain additional product information, visit our web site at www.dowagro.com.

General Information

Agricultural Chemical: Do not ship or store with food, feeds, drugs or clothing.

Before using, read and follow all label precautions and directions. Prior to the parties entering into a fumigation agreement, the Fact Sheet for Vikane must be provided to an adult occupant of the structure to be fumigated.

Storage and Handling
Store in dry, cool, well-ventilated area under lock and key. Post as a pesticide storage area. Do not contaminate water, food, or feed by storage.

Store cylinders upright; secured to a rack or wall to prevent tipping. Cylinders should not be subjected to rough handling or mechanical shock such as dropping, bumping, dragging, or sliding. Do not use rope slings, hooks, toms, or similar devices to unload cylinders. Transport cylinders using hand truck or fork truck to which the cylinder can be firmly secured. Do not transport any cylinders in closed vehicles where they occupy the same common airspace as personnel. Transport securely only in an upright position.

Do not remove valve protection bonnet and safety cap until immediately before use. Replace safety cap and valve protection bonnet when cylinder is not in use.

When cylinder is empty, close valve, screw safety cap onto valve outlet, and replace protection bonnet before returning to supplier. Only the registrant is authorized to refill cylinders. Do not use cylinder for any other purpose. Follow registrant’s instructions for return of empty or partially empty cylinders.

Leaks Procedures: Evacuate immediate area of leak. Use a NIOSH or MSHA approved positive pressure self-contained breathing apparatus (SCBA, not SCUBA) or combination air-supplied/SCBA respirator, such as manufactured by Ranger, Survivair, Scott, or MSA, for entry into affected areas to correct problem. Move leaking or damaged cylinder outdoors or to an isolated location, observing strict safety precautions. Work upwind if possible. Do not permit entry into leakage area by unprotected persons until concentration of fumigant is determined to be 5 parts per million (ppm) or less, as determined by a detection device with sufficient sensitivity such as an INTERSCAN or MIRAN gas analyzer. For more detailed information on the source and use of air monitoring devices or respirators, consult the Vikane Gas Fumigant Structural Fumigation Manual.

Cylinder and Product Disposal: Promptly return all empty cylinders to your distributor of Vikane. Follow proper cylinder handling directions above.

Pesticide wastes are toxic. Improper disposal of excess pesticide is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, consult your State Pesticide or Environmental Control Agency, or the Hazardous Waste Representative at the nearest EPA Regional Office for guidance.

Vikane is a highly hazardous material and should be used only by individuals knowledgeable of the hazards of this chemical and trained in the use of required respiratory equipment, detector devices, emergency procedures, and in the proper use of this fumigant.

When used for fumigation of enclosed spaces, such as houses and other structures, warehouses, vaults, chambers, trucks, vans, boxcars, ships, and other transport vehicles, 2 persons trained in the use of this product, at least one being an applicator that is licensed/certified by the state, must be present at all times during introduction of fumigant, reentry prior to aeration, and during the initiation of the initial aeration procedure when exposure exceeds 5 ppm. Two persons need not be present if monitoring is conducted remotely (outside the area being fumigated). If fumigating for insect pests, do not apply when temperature at site of pest activity is below 40°F. This temperature may be measured at the slab foundation, sub-floor soil, or wherever the coolest part of the structure may be. This restriction does not apply when fumigating for rodents.

When fumigating a single unit/room within or connected to a larger structure (such as town houses, apartments, condominiums) all units of the entire structure must be vacated during the fumigation and aeration periods.

Remove edible items from the structure before the fumigation if they cannot be adequately sealed to prevent exposure to Vikane. Chloropicrin must be used as described on the label to warn of an ongoing fumigation.
Preparation for Fumigation

Structural Fumigation
Remove from the structure to be fumigated all persons, domestic animals, pets, including fish, and desirable growing plants. Remove mattresses (except waterbeds) and pillows completely enveloped in water proof covers or remove covers. Food, feed, drugs, and medicinal (including those items in refrigerators and freezers) can remain in the structure if they are in plastic, glass, or metal bottles, cans, or jars with the original manufacturer's air-tight seal intact. Food, feed, drugs, and medicinals (including those items in refrigerators and freezers) not in plastic, glass, or metal bottles, cans, or jars with the original manufacturer's air-tight seal intact, need to be removed from the fumigation site, or double bagged in Nylofume° packs, which are available from distributors of Vikane gas fumigant.

Note: Extinguish all flames, including pilot lights of water heaters, gas refrigerators, ranges, ovens, broilers, etc. Turn off or unplug all electrical heating elements such as those in heaters, pianos, organs, etc. Shut off automatic switch controls for appliances and lighting systems, which will be included in the space to be fumigated.

Open operable internal doors, internal openings to attics and sub areas, storage chests, cabinets, drawers, closets, and appliances (such as washers, dishwashers, dryers, microwave or conventional ovens, etc.). Using electric fan(s) will help provide for forced distribution and aeration of basements and other dead air spaces to facilitate rapid dispersion of gas. Refrigerator and freezer doors may be left open if the units are turned off or disconnected and all food items have been removed. If the applicator chooses to leave sealed food items in closed refrigerators and freezers during the fumigation, the appliances should be opened when clearing the structure until the concentration of Vikane in them is 5 ppm or less.

Tarpaulin Fumigation
Open operable windows. When taping, use a highly resistant material such as a vinyl coated nylon, or polyethylene sheeting of at least 4 mil thickness. Seal all seams. Seal all live edges of the cover (such as with soil, sand, or weighted "snakes"). This will minimize escape of gas through the soil and to avoid injury to nearby water bodies. Use a method that will remain in place throughout the fumigation.

Taped Fumigation
For fumigation sites that can be sealed with plastic, paper, or tape, seal adequately around doors, windows, vents, and other openings.

Chamber Fumigation
For chamber fumigation use as a gas-tight chamber with adequate circulation.

Construction Materials, Furnishings (Household effects), and Vehicles
Follow preparations as appropriate in above paragraphs for chamber, taped fumigation, or tarpaulin fumigation to assure good confinement of the gas for the recommended period of exposure.

Fumigation of Surface Ships in Port
Surface ships in size up to and including large ocean-going ships may be fumigated with Vikane to control the various pests listed. The professional fumigator and the ship's captain (or owner) shall follow all applicable regulations including those listed in the Department of Transportation, Chapter 1, Parts 147A-1-147A-43. Except for those persons involved in fumigation, no people, plants, or pets mayspan onboard during fumigation.

The person responsible for the fumigation must notify the master of the vessel, or his representative, of the requirements relating to personal protection equipment and detection equipment. Emergency procedures, cargo ventilation, periodic monitoring and inspections, and first aid measures must be discussed with and understood by the master of the vessel or his representative.

If leakage of the fumigant is detected, the person in charge of the fumigation shall take action to correct the leakage, or shall inform the master of the vessel, or his representative, of the leakage so that corrective action can be taken.

Edible commodities shall not be exposed to the chemical. If not removed from the vessel they shall be protected from exposure. The vessel must not be moved during the fumigation and aeration periods. If reentry is necessary before aeration is completed, positive pressure self-contained respiratory protection must be worn.

Warning Agent
Chloropicrin is a warning agent introduced into the structure during fumigation. In order to avoid direct exposure to the fumigant being released, chloropicrin must be released within the structure at least 5 to 10 minutes prior to introduction of the fumigant. Place a handful of wicking agent, (e.g., cotton) in a shallow chloropicrin evaporation container. Do not use chloropicrin evaporation containers or application equipment made of magnesium, aluminum, or their alloys, as chloropicrin may be severely corrosive to such metals. To enhance the distribution of chloropicrin throughout the structure, place the shallow chloropicrin evaporation container in the air stream of a fan. Pour chloropicrin over the wicking agent. When adding chloropicrin to evaporation containers, disperse no more than 3 fluid ounces per container. Use 1 fluid oz/10,000 to 15,000 cubic feet (-30 ml/283 to 425 cubic meters) of space to be fumigated. Establish at least one chloropicrin introduction site for each 45,000 cubic feet of space to be fumigated. Removal of all chloropicrin evaporation containers from the fumigated space during Step 1 of the "Aeration Procedure 1" will aid in the dissipation of the warning agent from the structure.

Chloropicrin must not be used when fumigating railcars; however, a thorough walk-through inspection must be performed of each railcar with doors being immediately locked upon leaving each car, and a guard must be posted during fumigant introduction, exposure period, and aeration.

Chloropicrin is a warning agent, which causes smarting of the eyes, tears, and discomfort, and has a very disagreeable pungent odor at very low concentrations. Chloropicrin must be used by a person certified to apply Vikane or under their supervision. Fumigators must observe the precautionary statements and safety recommendations appearing on the label of this product.

Protective Clothing
Wear goggles or full-face shield for eye protection during introduction of the fumigant. Do not wear gloves or rubber boots. Do not re-use clothing or shoes that have become contaminated with liquid Vikane until thoroughly aerated and cleaned.

Respiratory Protection
If the concentration of Vikane in the fumigated area (as measured by a detector device with sufficient sensitivity such as an INTERSCAN or MiRAN gas analyzer) does not exceed 5 ppm (20 mg/cubic meter), no respiratory protection is required.

When this concentration is exceeded, all persons in the exposed area must wear a NIOSH or MSHA approved positive pressure self-contained breathing apparatus (SCBA, not SCUBA) or combination air-supplied/SCBA respirator as manufactured by Ranger, Survivor, Scott, or MSA. Before using any make or brand of SCBA, learn how to use it correctly. Determine that it has an adequate air supply for the job at hand that it fits properly, providing an adequate seal around the face, and that it is in good working order. For more detailed information on the source and use of air monitoring devices and respirators, consult the Vikane Gas Fumigant Structural Fumigation Manual.

Pre-fumigation Check: Check for potential leaks.

Securing Structure Entrances
All exterior entrances to the fumigated structure shall be locked during the fumigation exposure period and Step 2 of the aeration period, using existing locking mechanisms, if present. In addition, all structures shall have a secondary lock on all exterior doors during the fumigation period and Step 2 of the Aeration Procedure 2. A secondary lock shall consist of a device or barricade that is demonstratively effective in preventing an exterior door or entrance from being opened by normal means by anyone other than the ship's licensed/certified applicator in charge of the fumigation or persons under his/her on-site direct supervision. Consult state and local regulations for any supplementary instructions and restrictions on secondary locks.

Dosage and Exposure Time
For fumigation to control drywood termites and non-egg stages of other insect and related structural and household pests, the Fumiguide® calculator(s) to be used for the coordination of fumigant rates with soil or slab temperature, exposure period, and fumigant loss rate measured as half-loss-time (HLT). When control of the egg stage is desired or when fumigating for Formosan termites, use the indicated multiple factor of the drywood termite dosage (as determined by Fumiguide calculator(s) for pests listed below in the following table).

<table>
<thead>
<tr>
<th>Pest</th>
<th>Dosage Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rodents</td>
<td>1/XX</td>
</tr>
<tr>
<td>Carpet Beetles and Cockroaches</td>
<td>1 X</td>
</tr>
</tbody>
</table>

Table: Dosage and Exposure Time

Dosage and Exposure Time
Furniture Carpet Beetles and Bedbugs 3X
Old House Borers and Formosan Termites 4X
Clothes Moths 6X
Powder Post Beetles and Death Watch Beetles 10X

These dosages apply to dwellings, buildings, construction materials, furnishings, and vehicles.

To determine the proper dose for rodent control, use 80°F as the calculating temperature. Unlike insects, rodents are warm blooded and do not require increased dosages at lower temperatures.

More than one fumigation may be needed to control the infestation after egg hatch.

For fumigation to control rodents, use sufficient gas to accumulate at least 36 ounce-hours following equilibrium, regardless of ambient air temperature. Refer to the Vikane Gas Fumigant Structural Fumigation Manual.

The Fumiguide B Calculator is to be used for unmonitored structures to coordinate fumigant rates with temperatures, a 20 to 24 hour exposure period, and an estimated HLT.

The Fumiguide Y Calculator is used in conjunction with Fumiguide B when fumigant concentrations are monitored and/or there are measured variations in exposure time.

The Fumiguide Calculator is a hand held microprocessor, which performs the functions of both the Fumiguide B and Y calculators and includes relative humidity as a calculating factor.

These calculators, Directions For Use, and referenced literature may be obtained from Dow AgroSciences.

Introducing the Fumigant

Release the fumigant from outside the structure, tent, or vehicle. The release point(s) should be into a large open space(s) in the fumigation site(s). Release the fumigant through a suitable leak-proof tube with a minimum burst pressure of 500 pounds per square inch (psi). Direct the fumigant into the blast of air from a fan(s) having a capacity of at least 1,000 cubic feet per minute (cfm) for each pound of Vikane released per minute. Damage to household materials can occur if insufficient fan capacity is used for the rate of Vikane released. It is recommended that protective sheeting, such as polyethylene plastic under the shooting stand, shooting hose, and shooting fan can be used to further protect floors during application.

To Prevent Damage, Do Not Apply Fumigant Directly To Any Surface.

Posting of Fumigated Areas

The applicator must post all entrances to the fumigated areas with signs bearing, in English and Spanish:

1. The signal word DANGER/PELIGRO and the SKULL and CROSSBONES symbol.
2. The statement, "Area under fumigation, DO NOT ENTER/NO ENTRE.
3. The date of fumigation.
4. Name of fumigant used.
5. Name, address, and telephone number of the applicator.

Only a certified applicator may authorize removal of placards, and only when the concentration of Vikane in the treated site is 5 ppm or less.

Aeration and Reentry

No one should be in treated areas if the level of Vikane is above 5 ppm unless provided with a NIOSH or MSHA approved positive pressure self-contained breathing apparatus (SCBA, not SCUBA) or combination air supplied SCBA respirator, such as manufactured by Ranger, Survivair, Scott, or MSA. Since the INTERSCAN and MIRAN gas analyzers give immediate readings, respiratory protection is not required when clearing with these instruments after having completed the initial 1-hour aeration procedure. If a reading indicates levels in excess of 5 ppm, leave the affected area immediately.

Only an approved detection device of sufficient sensitivity, such as the INTERSCAN or MIRAN, can be used to confirm a concentration of Vikane of 5 ppm or less. The concentration of Vikane must be monitored in breathing zones. Structure must remain posted for fumigation until cleared for reentry.

Select the appropriate procedure based on the fumigation rate:

All structures fumigated at 16 oz/MCF or less may be aerated using procedures 1 or 2.
All structures fumigated at concentrations greater than 16 oz/MCF must be aerated using procedure 2.

Aeration Procedure 1

Step (1): Aerate structure with all operable windows and doors open, aided by the use of 1 or more fans, for a minimum of 1 hour. Each fan shall be capable of displacing a total of 5,000 cfm.

Step (2): Secure the structure and do not allow reentry for a minimum of 6 hours from the start of aeration (first opening of the seal). During this time structures must remain posted.

Step (3): After the minimum 6 hour waiting period, measure the concentration of Vikane in breathing zones. If the concentration of Vikane is greater than 5 ppm, ventilate structure with operable doors and windows open for at least 10 minutes. Structure may be reoccupied when concentration is 5 ppm or less.

Aeration Procedure 2

Step (1): Aerate structure with all operable windows and doors open, aided by the use of 1 or more fans, for a minimum of 1 hour. Each fan shall be capable of displacing a total of 5,000 cfm.

Step (2): Secure the structure and do not allow reentry for a minimum of 8 hours from the start of aeration (first opening of the seal). During this time the structure must remain posted.

Step (3): After the minimum 8-hour waiting period, measures the concentrations of Vikane in breathing zones. If the concentration of Vikane is greater than 5 ppm, ventilate structure with operable doors and window open for at least 10 minutes. Structure may be reoccupied when the concentration Vikane is 5 ppm or less.

For more detailed information on the source and use of air monitoring devices or respirators, consult the Vikane Gas Fumigant Structural Fumigation Manual. Do not reoccupy fumigation site, i.e. building, ship, vehicle or chamber, or move vehicle until aeration is complete. Warning signs must remain posted until aeration is determined to be complete.

Warranty Disclaimer

Dow AgroSciences warrants that this product conforms to the chemical description on the label and is reasonably fit for the purposes stated on the label when used in strict accordance with the directions, subject to the inherent risks set forth below. Dow AgroSciences MAKES NO OTHER EXPRESS OR IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR ANY OTHER EXPRESS OR IMPLIED WARRANTY.

Inherent Risks of Use

It is impossible to eliminate all risks associated with use of this product. Plant injury, lack of performance, or other unintended consequences may result because of such factors as use of the product contrary to label instructions (including conditions noted on the label, such as unfavorable temperature, soil conditions, etc.), abnormal conditions (such as excessive rainfall, drought, tornadoes, hurricanes), presence of other materials, the manner of application, or other factors, all of which are beyond the control of Dow AgroSciences or the seller. All such risks shall be assumed by buyer.

Dow AgroSciences shall not be liable for losses or damages resulting from handling or use of this product unless Dow AgroSciences is promptly notified of such loss or damage in writing. In no case shall Dow AgroSciences be liable for consequential or incidental damages or losses.

The terms of the "Warranty Disclaimer" above and this "Limitation of Remedies" cannot be varied by any written or verbal statements or agreements. No employee or sales agent of Dow AgroSciences or the seller is authorized to vary or exceed the terms of the "Warranty Disclaimer" or this "Limitation of Remedies" in any manner.

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Dow AgroSciences LLC • Indianapolis, IN 46268 U.S.A.
EPA-Accepted 10/28/96
Label Code: D02-069-011 Replaces Label: D02-069-010
Revisions:
Changes by Notification 01-06-00 and 03-03-00
22
THE APPLICATOR’S MANUAL
RESTRICTED USE PESTICIDE
DUE TO ACUTE INHALATION TOXICITY OF HIGHLY TOXIC HYDROGEN PHOSPHIDE
(PHOSPHINE, PH₃) GAS For retail sale to and use only by certified applicators for those uses
covered by the Applicator's certification or persons trained in accordance with the Applicator's Manual working under the direct supervision and in the physical presence of the certified applicator. Physical presence means on site or on the premises. Read and follow the label and the DEGESCH, America, Inc. Applicator's Manual, which contains complete instructions for the safe use of this pesticide.

APPLICATOR’S MANUAL
FOR
DEGESCH PH0ST0XIN® PELLETS AND TABLETS-R
EPA Reg. No. 40285-3     EPA Reg. No. 40285-1

FOR USE AGAINST INSECTS WHICH INFEST STORED COMMODITIES AND CONTROL OF BURROWING PESTS

Active Ingredient: Aluminum Phosphide ........................................55%
Other Ingredients ........................................................................45%

KEEP OUT OF REACH OF CHILDREN

PRECAUCION AL USUARIO: Si usted no lee ingles, no use este productor hasta que la etiqueta se le haya sido explicado ampliamente. (TO THE USER: If you cannot read English, do not use this product until the label has been fully explained to you.) STATEMENT OF PRACTICAL TREATMENT Symptoms of overexposure are headaches, dizziness, nausea, difficulty breathing, vomiting, and diarrhea. In all cases of overexposure get medical attention immediately. Take victim to a doctor or emergency treatment facility.

If the gas or dust from aluminum phosphide is inhaled:
Get exposed person to fresh air. Keep warm and make sure person can breathe freely. If breathing has stopped, give artificial respiration by mouth-to-mouth or other means of resuscitation. Do not give anything by mouth to an unconscious person.

If aluminum phosphide pellets, tablets or powder are swallowed:
Drink or administer one or two glasses of water and induce vomiting by touching back of throat with finger, or if available, syrup of ipecac. Do not give anything by mouth if victim is unconscious or not alert.

If powder or granules of aluminum phosphide get on skin or clothing:
Brush or shake material off clothes and shoes in a well-ventilated area. Allow clothes to aerate in a ventilated area prior to laundering. Do not leave contaminated clothing in occupied and/or confined areas such as automobiles, vans, motel rooms, etc. Wash contaminated skin thoroughly with soap and water.

If dust from pellets or tablets gets in eyes:
Flush with plenty of water. Seek medical attention.
D & D HOLDINGS, INC.
Weyers Cave, Virginia 24486 - USA - Telephone (540) 234-9281 / (800) 330-2525 - Fax (540) 234-8225
EPA Est. No. 40285-VA-01
EPA Reg. No. 72959-4 and 72959-5

Form 17828 (R2/99)

AN APPROVED LABEL AND APPLICATOR’S MANUAL ACCOMPANY THIS PRODUCT. READ AND UNDERSTAND THE ENTIRE LABELING. ALL PARTS OF THE LABELING ARE EQUALLY IMPORTANT FOR SAFE AND EFFECTIVE USE OF THIS PRODUCT. CALL DEGESCH AMERICA, INC., OR EPA IF YOU HAVE ANY QUESTIONS OR DO NOT UNDERSTAND ANY PART OF THIS LABELING.

REFER TO THE APPLICATOR’S MANUAL FOR DETAILED PRECAUTIONS, RECOMMENDATIONS AND DIRECTIONS FOR USE.

Seller warrants that the product conforms to its chemical description and when used according to label directions under normal conditions of use, it is reasonably fit for the purposes stated on the label. Seller makes no other warranty, either express or implied, and buyer assumes all risk should the product be used contrary to label instructions.

CLASSIFIED BY UNDERWRITERS LABORATORIES, INC., AS TO FIRE HAZARD ONLY WHEN USED SPECIFICALLY AS DIRECTED IN THE MANUFACTURER’S INSTRUCTIONS. DEGESCH PHOSTOXIN TABLETS AND PELLETS ARE NON-COMBUSTIBLE, BUT EXPOSURE TO MOIST AIR OR WATER RELEASES FLAMMABLE AND TOXIC PHOSPHINE (HYDROGEN PHOSPHIDE) GAS. SPONTANEOUS IGNITION MAY RESULT IF CONTACTED BY WATER, ACIDS, OR CHEMICALS. 4387

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1. INTRODUCTION

**Phostoxin** fumigants are used to protect stored commodities from damage by insects and for the control of burrowing pests. Fumigation of stored products with **Phostoxin** in the manner prescribed in the labeling does not contaminate the marketed commodity.

**Phostoxin** and other DEGESCH metal phosphide fumigants are acted upon by atmospheric moisture to produce hydrogen phosphide (phosphine, PH3) gas. **Phostoxin** tablets and pellets contain aluminum phosphide (AIP) as their active ingredient and will liberate hydrogen phosphide via the following chemical reaction:

\[
AIP + 3H2O \rightarrow Al(OH)3 + PH3
\]

Hydrogen phosphide gas is highly toxic to insects, burrowing pests, humans, and other forms of animal life. In addition to its toxic properties, the gas will corrode certain metals and may ignite spontaneously in air at concentrations above its lower flammable limit of 1.8% (v/v). These hazards will be described in greater detail later on in this Applicator's Manual for DEGESCH **Phostoxin** Pellets and Tablets-R.

**Phostoxin** also contains ammonium carbamate, which liberates ammonia and carbon dioxide as follows:

\[
NH2COONH4 \rightarrow 2NH3 + CO2
\]
These gases are essentially nonflammable and act as inerting agents to reduce fire hazards. The ammonia gas also serves as a warning agent.

**Phostoxin** is prepared in two spherical shapes. The rounded tablets weigh approximately 3 grams and release 1 gram of hydrogen phosphide gas. They are about 16mm in diameter and are bulk packaged in resealable aluminum flasks containing 100 or 500 tablets each. The pellets weigh approximately 0.6 gram and release 0.2 gram of hydrogen phosphide gas. They are about 10mm in diameter and are also packaged in resealable flasks containing about 1660 pellets.

Upon exposure to air **Phostoxin** pellets and tablets begin to react with atmospheric moisture to produce small quantities of hydrogen phosphide gas. This reaction starts slowly, gradually accelerates and then tapers off again as the aluminum phosphide is spent. **Phostoxin** pellets react somewhat faster than do the tablets. The rates of decomposition of the tablets and pellets will vary depending upon moisture and temperature conditions. For example, when moisture and temperature of the fumigated commodity are high, decomposition of **Phostoxin** may be complete in less than 3 days. However, at lower ambient temperatures and relative humidity levels, decomposition of **Phostoxin** may require 5 days or more. After decomposition, **Phostoxin** leaves a gray-white powder composed almost entirely of aluminum hydroxide and other approved inert ingredients. This will cause no problems if the fumigant has been added directly to a commodity such as grain or bulk animal feed. However, the spent powder must usually be retrieved for disposal after space fumigations. If properly exposed, the spent **Phostoxin** will normally contain only a small amount of unreacted aluminum phosphide and may be disposed of without hazard. While not considered a hazardous waste, partially spent residual from incompletely exposed **Phostoxin** will require special care. Precautions and instructions for further deactivation and disposal will be given later in this Manual.

**Phostoxin** tablets and pellets are supplied in gas-tight containers and their shelf life is unlimited as long as the packaging remains intact. Once opened for fumigation, the aluminum flasks of tablets or pellets may be tightly resealed and stored for future use. Storage and handling instructions will be given in detail later in the Applicators Manual. A summary of safety recommendations is outlined below:

**SAFETY RECOMMENDATIONS SUMMARY**

1. Carefully read the labeling and follow instructions explicitly.
2. Never fumigate alone from inside the storage structure.
3. Person supervising must be a certified fumigator and personnel assisting must be trained in the use of **Phostoxin**. Never allow uninstructed personnel to handle **Phostoxin**.
4. Approved respiratory protection must be available for the fumigation of structures from within.
5. Wear **dry** gloves of cotton or other material if contact with **Phostoxin** tablets, pellets or dust is likely. Aerate used gloves and other contaminated clothing in a well-ventilated area prior to laundering. Wash hands thoroughly after using **Phostoxin**.
6. Never open fumigant containers in a flammable atmosphere. It is preferable to open them in open air, near a fan or other appropriate ventilation which will rapidly exhaust
contaminated air. Containers may be opened inside the structure to be fumigated provided worker’s exposure to hydrogen phosphide gas does not exceed allowable limits.

7. Do not allow Phostoxin to contact liquid water or to pile up.

8. Dispose of empty containers and spent residual dust in a proper manner consistent with the label instructions.

9. Post warning placards on fumigated areas.

10. Prior to fumigation, notify appropriate company employees. Provide to local officials (fire department, rescue squad, police, etc.) on an annual basis relevant safety information for use in the event of an emergency.

11. Hydrogen phosphide fumigants are not to be used for vacuum fumigations.

12. Exposure to hydrogen phosphide must not exceed the eight-hour TWA of 0.3 ppm during application, or a ceiling concentration of 0.3 ppm after application is completed.

13. Fumigated areas must be aerated to 0.3 ppm hydrogen phosphide or less prior to reentry by unprotected workers.

14. Finished foods and feeds which have been fumigated with Phostoxin must be aerated for 48 hours prior to offering to the end consumer.

15. Transfer of a treated commodity to another site without complete aeration is permissible provided that the new storage site is placarded if its concentration is above 0.3 ppm.


17. Protect materials containing metals such as copper, silver, gold and their alloys and salts from corrosive exposure to hydrogen phosphide.

18. Tablets, pellets and/or their reacted residues must not come into contact with any processed food except that they may be added directly to processed brewer's rice, malt and corn grits used in the manufacture of beer.

19. Do not use aluminum phosphide containers for any purpose other than recycling or reconditioning. OSHA recommends pre-exposure screening of employees to detect impaired pulmonary function. They recommend that any employees developing this condition be referred for medical examination.

2. PRECAUTIONARY STATEMENTS

2.1 Hazards to Humans and Domestic Animals

DANGER: Aluminum phosphide from DEGESCH Phostoxin tablets, pellets or dust may be fatal if swallowed. Do not get in eyes, on skin or on clothing. Do not eat, drink or smoke while handling aluminum phosphide fumigants. If a sealed container is opened, or if the material comes into contact with moisture, water or acids, these products will release hydrogen phosphide (phosphine, PH3) which is an extremely toxic gas. If a garlic odor is detected, refer to the Industrial Hygiene Monitoring Section 8.6 on Page of the Applicator’s Manual for appropriate monitoring procedures. Pure hydrogen phosphide gas is odorless; the garlic odor is due to a contaminant. Since the odor of hydrogen phosphide may not be detected under some circumstances, the absence of a garlic odor does not mean that dangerous levels of hydrogen phosphide gas are absent. Observe proper reentry procedures specified elsewhere in the labeling to prevent overexposure.
2.2 **Statement of Practical Treatment**
Symptoms of overexposure are headache, dizziness, nausea, difficult breathing, vomiting, and diarrhea. In all cases of overexposure get medical attention immediately. Take victim to a doctor or emergency treatment facility.

If the gas or dust from aluminum phosphide is inhaled: Get exposed person to fresh air. Keep warm and make sure person can breathe freely. If breathing has stopped, give artificial respiration by mouth-to-mouth or other means of resuscitation. Do not give anything by mouth to an unconscious person.

If aluminum phosphide pellets, tablets or powder are swallowed:
Drink or administer one or two glasses of water and induce vomiting by touching back of throat with finger, or if available, syrup of ipecac. Do not give anything by mouth if victim is unconscious or not alert.

If powder or granules of aluminum phosphide get on skin or clothing:
Brush or shake material off clothes and shoes in a well ventilated area. Allow clothes to aerate in a ventilated area prior to laundering. Do not leave contaminated clothing in occupied and/or confined areas such as automobiles, vans, motel rooms, etc. Wash contaminated skin thoroughly with soap and water. If dust from pellets or tablets gets in eyes: flush with plenty of water. Seek medical attention.

2.3 **Note to Physician (we recommend that this section be given to the attending physician)**
Aluminum phosphide tablets, pellets or dust reacts with moisture from the air, acids and many other liquids to release hydrogen phosphide (phosphine, PH3) gas. Mild exposure by inhalation causes malaise (indefinite feeling of sickness), ringing in the ears, fatigue, nausea and pressure in the chest which is relieved by removal to fresh air. Moderate poisoning may cause weakness, vomiting, pain just above the stomach, chest pain, diarrhea and dyspnea (difficulty in breathing). Symptoms of severe poisoning may occur within a few hours to several days resulting in pulmonary edema (fluid in lungs) and may lead to dizziness, cyanosis (blue or purple skin color), unconsciousness, and death. In sufficient quantity, phosphine affects the liver, kidneys, lungs, nervous system and circulatory system. Inhalation can cause lung edema (fluid in lungs) and hyperemia (excess of blood in a body part), small perivascular brain hemorrhages and brain edema (fluid in brain). Ingestion can cause lung and brain symptoms but damage to the viscera (body cavity organs) is more common. Phosphine poisoning may result in (1) pulmonary edema, (2) liver elevated serum GOT,LDH and alkaline phosphatase, reduced prothrombin, hemorrhage and jaundice (yellow skin color) and (3) kidney hematuria (blood in urine) and anuria (abnormal or lack of urination). Pathology is characteristic of hypoxia (oxygen deficiency in body tissue). Frequent exposure to concentrations above permissible levels over a period of days or weeks may cause poisoning. Treatment is symptomatic. The following measures are suggested for use by the physician in accordance with his own judgment In its milder forms, symptoms of poisoning may take some time (up to 24 hours) to make their appearance, and the following is suggested:

1. Give complete rest for 1-2 days, during which the patient must be kept quiet and warm.
2. Should patient suffer from vomiting or increased blood sugar, appropriate solutions should be administered. Treatment with oxygen breathing equipment is recommended as is the administration of cardiac and circulatory stimulants.
In cases of severe poisoning (Intensive Care Unit recommended):
1. Where pulmonary edema is observed, steroid therapy should be considered and close medical supervision is recommended. Blood transfusions may be necessary.
2. In case of manifest pulmonary edema, venesection should be performed under vein pressure control. Heart glycosides (I.V.) (in case of hemoconcentration, venesection may result in shock). On progressive edema of the lungs: immediate intubation with a constant removal of edema fluid and oxygen over-pressure respiration, as well as any measures required for shock treatment. In case of kidney failure, extracorporeal hemodialysis is necessary. There is no specific antidote known for this poisoning.
3. Mention should be made here of suicidal attempts by taking solid phosphide by mouth. After swallowing, emptying of the stomach by vomiting, flushing of the stomach with diluted potassium permanganate solution or a solution of magnesium peroxide until flushing liquid ceases to smell of carbide. Thereafter, apply medicinal charcoal.

2.4 Physical and Chemical Hazards
Aluminum phosphide in tablets, pellets and partially spent dust will release hydrogen phosphide if exposed to moisture from the air or if it comes into contact with water, acids and many other liquids. Since hydrogen phosphide may ignite spontaneously at levels above its lower flammable limit of 1.8% v/v, it is important not to exceed this concentration. Ignition of high concentrations of hydrogen phosphide can produce a very energetic reaction. Explosion can occur under these conditions and may cause severe personal injury. Never allow the buildup of hydrogen phosphide to exceed explosive concentrations. Do not confine spent or partially spent metal phosphide fumigants as the slow release of hydrogen phosphide from this material may result in formation of an explosive atmosphere. Aluminum phosphide fumigants should not be stacked or piled up or contacted with liquid water. This may cause a temperature increase, increase the rate of gas production and confine the gas so that ignition could occur.

It is preferable to open containers of aluminum phosphide products in open air as under certain conditions, they may flash upon opening. Containers may also be opened near a fan or other appropriate ventilation which will rapidly exhaust contaminated air. When opening, point the container away from the face and body and slowly loosen the cap. Although the chances for a flash are very remote, never open these containers in a flammable atmosphere. These precautions will also reduce the fumigator's exposure to hydrogen phosphide gas. Containers may be opened inside the structure to be fumigated provided worker's exposure to hydrogen phosphide gas does not exceed allowable limits.

Pure phosphine (hydrogen phosphide) gas is practically insoluble in water, fats and oils, and is stable at normal fumigation temperatures. However, it may react with certain metals and cause corrosion, especially at higher temperatures and relative humidities. Metals such as copper, brass and other copper alloys, and precious metals such as gold and silver are susceptible to corrosion by phosphine. Thus, small electric motors, smoke detectors, brass sprinkler heads, batteries and battery chargers, fork lifts, temperature monitoring systems, switching gears, communication devices, computers, calculators and other electrical equipment should be protected or removed before fumigation. Hydrogen phosphide will also react with certain metallic salts and, therefore, sensitive items such as photographic film, some inorganic pigments, etc., should not be exposed.
3. DIRECTIONS FOR USE

3.1 General
It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

3.1.1 DEGESCH Phostoxin tablets and pellets are Restricted Use Pesticides due to the acute inhalation toxicity of hydrogen phosphide (phosphine, PI-13) gas. These products are for retail sale to and use only by certified applicators for those uses covered by the applicator's certification or persons trained in accordance with the Applicator's Manual working under the direct supervision and in the physical presence of the certified applicator. Physical presence means on site or on the premises. Read and follow the label and the DEGESCH America, Inc., Applicator's Manual which contains complete instructions for the safe use of this pesticide.

3.1.2 Phostoxin is a highly hazardous material and should be used only by individuals trained in its proper use. Before using, read and follow all label precautions and directions. Additional copies of this Manual are available from:
DEGESCH America, Inc.
P. O. Box 116
Weyers Cave, VA 24486
(540) 234-9281
Fax:(540)234-8225
Internet address: http://www.degeschamerica.com

Persons working with Phostoxin should be knowledgeable of the hazards of this chemical and trained in the use of required respiratory equipment and detector devices, emergency procedures, and use of the fumigant.

3.1.3 At least two persons trained in the use of Phostoxin must be present during fumigation of structures if entry into the structure is required for application of the fumigant. Two trained persons must also be present during reentry into fumigated or partially aerated structures. Only one trained person is required to be present when Phostoxin is applied from outside the area to be treated.

3.1.4 Shipholds, barges, containers on ships, railroad cars and containers shipped piggyback by rail may be fumigated in transit. However, trucks, vans, trailers and similar transport vehicles cannot be moved over public roads or highways until they are aerated and the warning placards removed.

3.1.5 Do not fumigate commodities with Phostoxin when commodity temperature is below 40°F (5°C).

3.1.6 The site to be fumigated must first be inspected to determine if it can be made sufficiently gas tight. Then a plan should be developed to provide for safe and efficient application of the fumigant to include emergency procedures, etc., where required, and to decide how monitoring should be conducted to prevent excessive exposures.

3.1.7 Wear dry gloves of cotton or other material while handling Phostoxin tablets and pellets. Wash hands thoroughly after use.

3.1.8 Hydrogen phosphide gas may flash at concentrations above its flammable limit. Therefore, never open Phostoxin containers in a flammable atmosphere. It is preferable to open them in open air, near a fan or other appropriate ventilation which will rapidly exhaust contaminated air. These precautions will also reduce the applicator's exposure to hydrogen phosphide gas. Containers may be opened inside the structure to be fumigated provided worker's exposure to hydrogen phosphide gas does not exceed allowable limits.
3.1.9 Piling of tablets, pellets, dust from their fragmentation or addition of liquid water to Phostoxin may speed up the reaction, cause a temperature increase and confine the gas so that ignition could occur.

3.1.10 As much as is possible, protect unused Phostoxin from excessive exposure to atmospheric moisture during application and tightly reseal the aluminum flask prior to returning tablets or pellets to storage.

3.1.11 Hydrogen phosphide gas may react with certain metals and their salts to produce corrosion. This gas is corrosive to copper, copper alloys and precious metals such as silver and gold. Sensitive equipment and items containing these elements should be removed or protected prior to fumigation with Phostoxin.

3.1.12 Do not allow Phostoxin or its residual dust to come in contact with processed foods or commodity packages intended for retailers except that Phostoxin tablets and pellets may be added directly to processed brewer's rice, malt and corn grits used in the manufacture of beer.

3.1.13 Respiratory protection approved for the concentration to which the fumigator will be exposed must be available if Phostoxin is to be applied from within the structure to be fumigated. Respiratory protection need not be available for uses such as outdoor application, addition of tablets or pellets to automatic dispensing devices, etc., if exposures above the allowable limits will not be encountered.

A NIOSH/MSHA approved, full-face gas mask - hydrogen phosphide canister combination may be used at levels up to 15 ppm. Above this level or in situations where the hydrogen phosphide concentration is unknown, a NIOSH/MSHA approved, self-contained breathing apparatus (SCBA) or its equivalent must be used.

3.1.14 Notify appropriate company employees prior to fumigation. Provide to local officials (fire department, rescue squad, police, etc.) on an annual basis relevant safety information for use in the event of an emergency.

3.2 Efficacy
Phostoxin has been found effective against the following insects and their pre-adult stages - that is, eggs, larvae and pupae:

- almond moth
- Angoumois grain moth
- bean weevil
- cadelle
- cereal leaf beetle
- cigarette beetle
- confused flour beetle
- dermestid beetles
- dried fruit beetle
- dried fruit moth
- European grain moth
- flat grain beetle
- fruit flies
- granary weevil
- greater wax moth
- hairy fungus beetle
- Hessian fly
- Indian meal moth
- Khapra beetle
- lesser grain borer
- maize weevil
- Mediterranean flour moth
- pink bollworm
- raisin moth
- red flour beetle
- rice weevil
- rusty grain beetle
- saw-toothed grain beetle
- spider beetles
- tobacco moth
- yellow meal worm

Although it is possible to achieve total control of the listed insect pests, this is frequently not realized in actual practice. Factors contributing to less than 100% control are leaks, poor gas distribution, unfavorable exposure conditions, etc. In addition, some insects are less susceptible to hydrogen phosphide than others. If maximum control is to be attained, extreme care must be taken in sealing, the higher dosages must be used, exposure periods
lengthened, proper application procedures followed and temperature and humidity conditions must be favorable.

3.3 Exposure Conditions
The following table may be used as a guide in determining the minimum length of the exposure period at the indicated temperatures:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Minimum Exposure Periods for Phostoxin</th>
</tr>
</thead>
<tbody>
<tr>
<td>below 40°F (5°C)</td>
<td>Do not fumigate</td>
</tr>
<tr>
<td>40°-53°F (5-12°C)</td>
<td>8 days (192 hours) Do not fumigate</td>
</tr>
<tr>
<td>54°-59°F (12-15°C)</td>
<td>4 days (96 hours) 5 days (120 hours)</td>
</tr>
<tr>
<td>60°-68°F (16-20°C)</td>
<td>3 days (72 hours) 4 days (96 hours)</td>
</tr>
<tr>
<td>above 68°F (20°C)</td>
<td>2 days (48 hours) 3 days (72 hours)</td>
</tr>
</tbody>
</table>

The length of the fumigation must be great enough so as to provide for adequate control of the insect pests which infest the commodity being treated. Additionally, the fumigation period should be long enough to allow for more or less complete reaction of Phostoxin with moisture so that little or no unreacted aluminum phosphide remains. This will minimize worker exposures during further storage and/or processing of the treated bulk commodity as well as reduce hazards in the disposal of partially spent aluminum phosphide products remaining after space fumigations. The proper length of the fumigation period will vary with exposure conditions since, in general, insects are more difficult to control at lower temperatures, and the rate of hydrogen phosphide gas production by Phostoxin is lower at lower temperatures and humidities.

It should be noted that there is little to be gained by extending the exposure period if the structure to be fumigated has not been carefully sealed or if the distribution of gas is poor and insects are not subjected to lethal concentrations of hydrogen phosphide. Careful sealing is required to ensure that adequate gas levels are retained and proper application procedures must be followed to provide satisfactory distribution of hydrogen phosphide gas. Some structures can only be treated when completely tarped while others cannot be properly sealed by any means and should not be fumigated. Exposure times must be lengthened to allow for penetration of gas throughout the commodity when surface application or shallow probing does not uniformly add fumigant to the commodity mass, for example. This is particularly important in the fumigation of bulk commodity contained in large storages.

Remember, exposure periods recommended in the table are minimum periods and may not be adequate to control all stored products pests under all conditions nor will they always provide for total reaction of Phostoxin, particularly if temperatures and commodity moisture levels or humidity are low during the fumigation.

3.4 Commodities Which May be Fumigated with Phostoxin
Phostoxin may be used for the fumigation of listed raw agricultural commodities, animal feed and feed ingredients, processed foods, tobacco and certain other nonfood items.

3.4.1 Raw Agricultural Commodities, Animal Feed and Feed Ingredients
Phostoxin tablets and pellets may be added directly to animal feed, feed ingredients and raw agricultural commodities stored in bulk. For these commodities not stored in bulk, Phostoxin may be placed in moisture permeable envelopes, on trays, etc., and fumigated as with processed foods.
Raw Agricultural Commodities and Animal Feed and Feed Ingredients
Which May Be Fumigated with Phostoxin

- almonds
- animal feed & feed ingredients
- barley
- Brazil nuts
- cashews
- cocoa beans
- coffee beans
- corn
- cottonseed
- dates
- filberts
- flower seed
- grass seed
- millet
- oats
- peanuts
- pecans
- pistachio nuts
- popcorn
- rice
- rye
- safflower seed
- sesame seed
- seed & pod vegetables
- sorghum
- sunflower seeds
- triticale
- vegetable seed
- walnuts
- wheat

3.4.2 Processed Foods
The listed processed foods may be fumigated with Phostoxin. Under no condition shall any processed food or bagged commodity come in contact with Phostoxin tablets, pellets or residual dust except that Phostoxin may be added directly to processed brewer's rice, malt and corn grits for use in the manufacture of beer.

Processed Foods Which May Be Fumigated With Phostoxin
- Processed Candy and Sugar
- Cereal Flours and Bakery Mixes
- Cereal Foods (including cookies, crackers, macaroni, noodles, pasta, pretzels, snack foods and spaghetti)
- Processed Cereals (including milled fractions and packaged cereals)
- Cheese and Cheese Byproducts
- Chocolate and Chocolate Products (such as assorted chocolate, chocolate liquor, cocoa, cocoa powder, dark chocolate coating and milk chocolate)
- Processed Coffee
- Corn Grits
- Cured, Dried and Processed Meat Products and Dried Fish
- Dates and Figs
- Dried Eggs and Egg Yolk Solids
- Dried Milk, Dried Powdered Milk, Nondairy Creamers, and Nonfat Dried Milk
- Dried or Dehydrated Fruits (such as apples, dates, figs, peaches, pears, prunes, raisins, citrus and sultanas)
- Processed Herbs, Spices, Seasonings and Condiments
- Malt
- Processed Nuts (such as almonds, apricot kernels, Brazil nuts, cashews, filberts, macadamia nuts, peanuts, pecans, pistachio nuts, walnuts and other processed nuts)
- Processed Oats (including oatmeal)
- Rice (brewer's rice grits, enriched and polished, wild rice)
- Soybean Flour and Milled Fractions
- Processed Tea
- Dried and Dehydrated Vegetables (such as beans, carrots, lentils, peas, potato flour, potato products and spinach)
- Yeast (including primary yeast)
- Other processed foods.

3.4.3 Nonfood Commodities, Including Tobacco
The listed nonfood items may be fumigated with Phostoxin. Tobacco and certain other of the nonfood commodities should not be contacted by tablets, pellets or residual dust.

**Nonfood Commodities Which May Be Fumigated With Phostoxin**
- Processed or Unprocessed Cotton, Wool and Other Natural Fibers or Cloth, Clothing
- Straw and Hay
- Feathers
- Human Hair, Rubberized Hair, Vulcanized Hair, Mohair
- Leather Products, Animal Hides and Furs
- Tobacco
- Wood, Cut Trees, Wood Chips, Wood and Bamboo Products
- Paper and Paper Products
- Dried Plants and Flowers
- Seeds (grass seed, ornamental herbaceous plant seed and vegetable seed)
- Other nonfood commodities

### 3.5 Recommended Dosages

Hydrogen phosphide is a mobile gas and will penetrate to all parts of the storage structure. Therefore, dosage must be based upon the total volume of the space being treated and not on the amount of commodity it contains. The same amount of Phostoxin is required to treat a 30,000 bushel silo whether it is empty or full of grain unless, of course, the surface of the commodity is sealed off by a tarpaulin. The following dosage ranges are recommended for bulk and space fumigations:

**Dosage Guidelines for Fumigations with Phostoxin**

<table>
<thead>
<tr>
<th>Product</th>
<th>per 1000 cu.ft.*</th>
<th>per 1000 bu.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pellets</td>
<td>100 - 725</td>
<td>120 - 900</td>
</tr>
<tr>
<td>Tablets</td>
<td>20 - 145</td>
<td>25 - 180</td>
</tr>
</tbody>
</table>

*Dosage range for dates, nuts & dried fruits is 100-200 pellets, 20-40 tablets/1000 cu. ft.; 125-250 pellets, 25-50 tablets/1000 bu.*

These dosages are not to be exceeded. It is important to be aware that a shortened exposure period cannot be fully compensated for with an increased dosage of hydrogen phosphide. The wide range of dosages listed above is required to handle the variety of fumigation situations encountered in practice. Somewhat higher dosages are usually recommended under cooler, drier conditions or where exposure periods are relatively short. However, the major factor in selection of dosage is the ability of the structure to hold hydrogen phosphide gas during the fumigation. A good illustration of this point is comparison of the low dosages required to treat modern, well-sealed warehouses with the higher range used for poorly constructed buildings that cannot be sealed adequately. In certain other fumigations, proper distribution of lethal concentrations of gas to reach all parts of the structure becomes a very important factor in dose selection. An example where this may occur is in the treatment of grain stored in tall silos. Poor gas distribution frequently results when the fumigant cannot be uniformly added to the grain and it must be treated by surface application. Although it is permissible to choose from the full range of dosages listed above, the following dosage ranges are recommended for the various types of fumigations:
# Recommended Phostoxin Dosages for Various Types of Fumigations

<table>
<thead>
<tr>
<th>Type of Fumigation</th>
<th>Dosage Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pellets</td>
</tr>
<tr>
<td>1. Space</td>
<td></td>
</tr>
<tr>
<td>mills, warehouses, etc.</td>
<td>100-300/1000 cu. ft.</td>
</tr>
<tr>
<td>bagged commodities</td>
<td>150-300/1000 cu. ft.</td>
</tr>
<tr>
<td>processed dried fruits and nuts</td>
<td>100-200/1000 cu. ft.</td>
</tr>
<tr>
<td>stored tobacco</td>
<td>100-200/1000 cu. ft.</td>
</tr>
<tr>
<td>2. Bulk Stored Commodities</td>
<td></td>
</tr>
<tr>
<td>vertical storages</td>
<td>150-300/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>200-375/1000 cu. ft.</td>
</tr>
<tr>
<td>tanks</td>
<td>150-350/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>200-450/1000 cu. ft.</td>
</tr>
<tr>
<td>flat storages (loose construction)</td>
<td>250-725/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>300-900/1000 cu. ft.</td>
</tr>
<tr>
<td>farm bins</td>
<td>350-725/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>450-900/1000 cu. ft.</td>
</tr>
<tr>
<td>bunkers &amp; tarped ground storages</td>
<td>150-400/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>200-500/1000 cu. ft.</td>
</tr>
<tr>
<td>railcars</td>
<td>150-325/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>200-400/1000 cu. ft.</td>
</tr>
<tr>
<td>barges</td>
<td>250-725/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>300-900/1000 cu. ft.</td>
</tr>
<tr>
<td>shipholds</td>
<td>150-330/1000 cu. ft.</td>
</tr>
<tr>
<td></td>
<td>200-375/1000 cu. ft.</td>
</tr>
</tbody>
</table>

Higher dosages are recommended in structures that are of loose construction and in the fumigation of bulk stored commodities in which diffusion will be slowed and result in poor distribution of hydrogen phosphide gas.

## 3.6 Application Procedures

### 3.6.1 General Statement

Regardless of the type of storage or structure to be treated, there are several important factors common to all application procedures. A number of these points have been covered in other sections of the Applicator's Manual but are listed again in the following for completeness.

1. A plan should be devised for application, aeration and disposal of the fumigant so as to keep to a minimum any exposures to hydrogen phosphide. See the requirements for Industrial Hygiene Monitoring under the Applicator and Worker Exposure section of this Applicator's Manual.

2. **Phostoxin** tablets or pellets should be applied so as to provide effective gas concentrations throughout the storage. When tablets or pellets are not applied uniformly to a bulk commodity (surface application in a tall silo or ship's hold, for example), exposure times should be lengthened to allow for penetration of gas throughout the storage.

3. The storage structure should be sealed so as to maintain a suitable gas concentration over the time period required for control of insect pests.

4. Ideally, exposure periods should be long enough to provide for adequate control of insect pests and also more or less completely react the fumigant.
5. Piling of large numbers of tablets or pellets, whether applied to a bulk commodity or for space fumigation, may prevent complete breakdown of the product by limiting its access to moist air. This can result in decreased efficacy as a result of poor gas release and may leave an active residual for disposal which contains considerable amounts of not reacted aluminum phosphide. Piling of product may also result in increased hazard of fire if water should come into contact with the mass of aluminum phosphide.

6. Contact with liquid water should be carefully avoided when applying Phostoxin for treatment of bulk commodities or space.

7. Aluminum phosphide fumigants should not be applied to confined spaces where the concentration of hydrogen phosphide may build up to exceed its lower flammable limit.

8. Observe the precautionary and safety statements mentioned elsewhere in this manual.

The following instructions are intended to provide general guidelines for typical fumigations. These instructions are not intended to cover every type of situation nor are they meant to be restrictive. Other procedures may be used if they are safe, effective and consistent with the properties of aluminum phosphide products.

3.6.2 Fumigation of Farm Bins
Leakage is the single most important cause of failures in the treatment of farm storages. Since these storages are often small, they usually have a higher leakage area in proportion to their capacity. Most wooden storage structures are so porous that they cannot be successfully fumigated unless they are completely tarped. Do not fumigate storages, which will be entered by humans or animals prior to aeration.

Do not fumigate areas which house sensitive equipment containing copper or other metals likely to be corroded by hydrogen phosphide gas.

Seal the bin as tightly as possible. It is recommended that the surface of the grain be covered with poly after Phostoxin has been applied. Tarping the grain surface will greatly reduce the leak rate of the gas as well as reduce the amount of Phostoxin required. Only the volume below the tarp must be dosed. If not tarped, the entire volume of the storage must be treated, whether full or empty.

Phostoxin tablets or pellets may be scattered over the surface or probed into the grain using a rigid PVC pipe about 5 to 7 feet in length and having a diameter of 1-1/4 inches. Use about 20-50 tablets or 100-250 pellets per probe. Spread the dose uniformly over the surface. Immediately cover the surface of the grain with a plastic tarpaulin. Place no more than 25 percent of the total dose at the bottom if the bin is equipped with aeration fans. Caution: Make sure that the aeration duct is dry before adding Phostoxin. Addition of Phostoxin to water in an aeration duct may result in a fire. Seal the aeration fan with 4 mil plastic sheeting.

Place fumigation warning signs on entrances to the bin and near the ladder.

Following aeration of the bin, the surface of the grain may be sprayed with an approved protectant to discourage reinfestation.

3.6.3 Fumigation of Flat Storages
1. Establish a plan for application of fumigant to the structure. Treatment of these types of storages may require considerable effort; therefore, sufficient manpower should be available to complete the work rapidly enough to prevent excessive exposure to hydrogen phosphide gas. Vent flasks outside the storage, conduct fumigations during cooler periods and employ other work practices to minimize exposures. It is often advisable to wear respiratory protection during application of fumigant to flat storages. Refer to the sections on Applicator and Worker Exposure and Respiratory Protection.

2. Seal any vents, cracks and other sources of leaks.

3. Apply tablets or pellets by surface application, shallow probing, deep probing or uniform addition as the bin is filled.

   Storages requiring more than 24 hours to fill should not be treated by addition of fumigant to the commodity stream as large quantities of hydrogen phosphide may escape before the bin is completely sealed.

   Probes should be inserted vertically at intervals along the length and width of the flat storage. Pellets or tablets may be dropped into the probe at intervals as it is withdrawn. Surface application may be used if the bin can be made sufficiently gas tight to contain the fumigant gas long enough for it to penetrate the commodity. In this instance, it is advisable to place about 25 percent of the dosage in the floor level aeration ducts. Check the ducts prior to addition of Phostoxin to make sure that they contain no liquid water.

4. Tarping the surface of the commodity is often advisable, particularly if the overhead of the storage cannot be well sealed.

5. Lock all entrances to the storage and post fumigation warning placards.

3.6.4 Fumigation of Vertical Storages (concrete upright bins and other silos in which grain can be rapidly transferred)

   1. Close all openings and seal all cracks to make the structure as airtight as possible. Prior to the fumigation, seal the vents near the bin top, which connect to adjacent bins.

   2. Pellets or tablets may be applied continuously by hand or by an automatic dispenser on the head house/gallery belt or into the fill opening as the commodity is loaded into the bin. An automatic dispenser may also be used to add Phostoxin into the commodity stream in the up leg of the elevator.

   3. Seal the bin deck openings after the fumigation has been completed.

   4. Bins requiring more than 24 hours to fill should not be fumigated by continuous addition into the commodity stream. These bins must be fumigated by probing, surface application, or other appropriate means. Exposure periods should be lengthened to allow for diffusion of gas to all parts of the bin if Phostoxin has not been applied uniformly throughout the commodity mass.

   5. Place warning placards on the discharge gate and on all entrances.

3.6.5 Fumigation of Mills, Food Processing Plants and Warehouses

   1. Using the label, calculate the length of the fumigation and the dosage of tablets or pellets to be applied based upon volume of the building, air and/or commodity temperature and the general tightness of the structure.

   2. Carefully seal and placard the space to be fumigated.
3. Place trays or sheets of Kraft paper or foil, up to 12 sq. ft. (1.1 sq. M) in area, on the floor throughout the structure to hold Phostoxin tablets or pellets.

4. Spread Phostoxin on the sheets at a density no greater than 30 tablets per sq. ft. or 75 pellets per sq. ft. This corresponds slightly more than one-half flask of tablets or one-half flask of pellets per 3'x4' sheet. Check to see that Phostoxin has not piled up and that it is spread out evenly to minimize contact between the individual tablets or pellets.

5. Doors leading to the fumigated space should be closed, sealed, locked and placarded with warning signs.

6. The fumigation period usually lasts from 2 to 5 days, depending upon the temperature. Upon completion of the exposure period, windows, doors, vents, etc., should be opened and the fumigated structure allowed to aerate for at least two hours before entering. When required, gas concentration readings may be taken using low level detector tubes or similar devices to ensure safety of personnel who reenter the treated area. Refer to the section on Applicator and Worker Exposure.

7. Collect the spent Phostoxin dust and dispose of it, with or without further deactivation, following recommendations given under Disposal.

8. Remove fumigation warning placards from the aerated structure.

3.6.6 Fumigation of Railcars, Containers, Trucks, Vans, and Other Transport Vehicles

Railcars and containers, trucks, vans and other transport vehicles shipped piggyback by rail may be fumigated in transit. However, it is not legal to move trucks, trailers, containers, vans, etc., over public roads or highways until they have been aerated.

Transport vehicles loaded with bulk commodities to which Phostoxin tablets or pellets may be added directly are treated in essentially the same way as any other flat storage facility. Phostoxin may be added as the vehicle is being filled, the dose may be scattered over the surface after loading has been completed or the tablets or pellets may be probed below the surface. Carefully seal any vents, cracks or other leaks, particularly if the fumigation is to be carried out in transit. See Section 6 of this Applicator's Manual for recommendations on placarding. Notify the consignee if the commodity is to be shipped under fumigation with Phostoxin.

Phostoxin Prepacs or Fumi-Cel© plates (not classified by UL) are recommended for the treatment of transport vehicles or similar storages containing processed foods for which no direct contact is allowed with tablets or pellets.

Proper handling of treated railcars at their destination is the responsibility of the consignee. The consignee must be familiar with the properties of hydrogen phosphide fumigants, worker exposure limits and symptoms and first aid treatment for hydrogen phosphide poisoning and must know how to make gas concentration measurements. The consignee must:

1. aerate the railcar and verify that it contains no more than 0.3 ppm hydrogen phosphide,
2. remove the fumigation warning placards,
3. ensure that Worker safety limits have not been exceeded,
4. transfer the fumigated commodity from the railcar, with or without prior aeration and
5. placard the new storage if it contains more than 0.3 ppm hydrogen phosphide.
3.6.7 Tarpaulin and Bunker Fumigations

Use of plastic sheeting or tarpaulins to cover commodities is one of the easiest and least expensive means for providing relatively gas tight enclosures, which are very well suited for fumigation. Poly tarps are penetrated only very slowly by hydrogen phosphide gas, and tight coverings are readily formed from the sheets. The volume of these enclosures may vary widely from a few cubic feet, for example, a fumigation tarpaulin placed over a small stack of bagged commodity, to a plastic bunker storage capable of holding 600,000 bushels of grain or more.

An enclosure suitable for fumigation may be formed by covering bulk or packaged commodity with poly sheeting. The sheets may be taped together to provide a sufficient width of material to ensure that adequate sealing is obtained. If the flooring upon which the commodity rests is of wood or other porous material, it should be repositioned onto poly prior to covering for fumigation. The plastic covering of the pile may be sealed to the floor using sand or water snakes, by shoveling soil or sand onto the ends of the plastic covering or by other suitable procedures. The poly covering should be reinforced by tape or other means around any sharp corners or edges in the stack so as to reduce the risk of tearing. Thinner poly, about 2 mil, is suitable for most indoor tarp fumigations and for sealing of windows, doors and other openings in structures. However, 4 mil poly or thicker is more suitable for outdoor applications where wind or other mechanical stresses are likely to be encountered. Tablets or pellets may be applied to the tarped stack or bunker storage of bulk commodity through slits in the poly covering. Probing or other means of dosing may be used. Avoid application of large amounts of Phostoxin at any one point. The Phostoxin should be added below the surface of the commodity if condensation or other source of moisture is likely to form beneath the poly. The slits in the covering should be carefully taped to prevent loss of gas once the dose has been applied. Phostoxin Prepacs (not classified by UL) are recommended for the treatment of bagged commodities and processed foods although tablets and pellets on trays or sheets of Kraft paper may be used. Care should be taken to see that the poly is not allowed to cover the Phostoxin and prevent contact with moist air or confine the gas. Distribution of hydrogen phosphide gas is generally not a problem in the treatment of bagged commodities and processed foods. However, fumigation of larger bunker storages containing bulk commodity will require proper application procedures to obtain adequate results. Place warning placards at conspicuous points on the enclosure.

3.6.8 Fumigation of Ships 3.6.8.1

3.6.8.1 General Information

1. Important - shipboard, in transit ship or shiphold fumigation is also governed by U.S. Coast Guard Regulation 46 CFR 147A. Interim regulations for shipboard fumigation. Refer to this regulation prior to fumigation. For further information contact:

Commandant
U.S. Coast Guard
Hazardous Materials Standards
Division
GMSO-3
Washington, DC 20593-0001

2. DEGESCH Phostoxin tablets and pellets are classified by EPA as restricted use pesticides due to the acute inhalation toxicity of hydrogen phosphide (phosphine, PI-13) gas. These products are for retail sale to and use only by certified applicators for
those uses covered by the applicator's certification or persons trained in accordance with the Applicator's Manual working under the direct supervision and in the physical presence of the certified applicator. Physical presence means on site or on the premises. Read and follow the label and the DEGESCH America, Inc. Applicator's Manual which contains complete instructions for the safe use of this pesticide.

3.6.8.2 Pre-Voyage Fumigation Procedures

1. Prior to fumigating a vessel for in transit cargo fumigation, the master of the vessel, or his representative, and the fumigator must determine whether the vessel is suitably designed and configured so as to allow for safe occupancy by the ship’s crew throughout the duration of the fumigation. If it is determined that the design and configuration of the vessel does not allow for safe occupancy by the ship’s crew throughout the duration of the fumigation, then the vessel will not be fumigated unless all crew members are removed from the vessel. The crew members will not be allowed to reoccupy the vessel until the vessel has been properly aerated and a determination has been made by the master of the vessel and the fumigator that the vessel is safe for occupancy.

2. The person responsible for the fumigation must notify the master of the vessel, or his representative, of the requirements relating to personal protection equipment*, detection equipment and that a person qualified in the use of this equipment must accompany the vessel with cargo under fumigation. Emergency procedures, cargo ventilation, periodic monitoring and inspections, and first aid measures must be discussed with and understood by the master of the vessel or his representative.

*Personal protection equipment means a NIOSH/MSHA approved respirator or gas mask fitted with an approved canister for phosphine. The canister is approved for use up to 15 ppm. SCBA or its equivalent must be used above 15 ppm or at unknown concentrations.

3. Seal all openings to the cargo hold or tank and lock or otherwise secure all openings, manways, etc., which might be used to enter the hold. The overspace pressure relief system of each tank aboard tankers must be sealed by closing the appropriate valves and sealing the openings into the overspace with gas-tight materials.

4. Placard all entrances to the treated spaces with fumigation warning signs.

5. If the fumigation is not completed and the vessel aerated before the manned vessel leaves port, the person in charge of the vessel shall ensure that at least two units of personal protection equipment and one gas or vapor detection device, and a person qualified in their operation be on board the vessel during the voyage.

6. During the fumigation or until a manned vessel leaves port or the cargo is aerated, the person in charge of the fumigation shall ensure that a qualified person using gas or vapor detection equipment tests spaces adjacent to spaces containing fumigated cargo and all regularly occupied spaces for fumigant leakage. If leakage of the fumigant is detected, the person in charge of the fumigation shall take action to correct the leakage, or shall inform the master of the vessel, or his representative, of the leakage so that corrective action can be taken.

7. Review with the master, or his representative, the precautions and procedures to follow during the voyage.

3.6.8.3 Application Procedures for Bulk Dry Cargo Vessels and Tankers

1. Apply tablets or pellets by scattering uniformly over the commodity surface or they may be shallow or deep probed into the commodity mass.
2. Immediately after application of the fumigant, close and secure all hatch covers, tank
tops, butterworth valves, manways, etc.

3.6.8.4.1 Intransit Fumigation of Transport Units (Containers) Aboard Ships
In transit fumigation of transport units on ships is also governed by D.O.T. RSPA 49 CFR
176.76(i) transport vehicles, freight containers, and portable tanks containing hazardous
materials and International Maritime Dangerous Goods Code P9025-1 Arndt. 27-94.
Application procedures for fumigation of raw commodities or processed foods in transport
units (containers) are described in Section 3.6.6.

3.6.8.5 Precautions and Procedures During Voyage
1. Using appropriate gas detection equipment, monitor spaces adjacent to areas
containing fumigated cargo and all regularly occupied areas for fumigant leakage. If
leakage is detected, the area should be evacuated of all personnel, ventilated, and
action taken to correct the leakage before allowing the area to be occupied.
2. Do not enter fumigated areas except under emergency conditions. If necessary to
enter a fumigated area, appropriate personal protection equipment must be used.
Never enter fumigated areas alone. At least one other person, wearing personal
protection equipment, should be available to assist in case of an emergency.

3.6.8.6 Precautions and Procedures During Discharge
1. If necessary to enter holds prior to discharge, test spaces directly above grain surface
for fumigant concentration, using appropriate gas detection and personal safety
equipment. Do not allow entry to fumigated areas without personal safety equipment,
unless fumigant concentrations are at safe levels, as indicated by a suitable detector.

3.6.9 Fumigation of Barges
Barge fumigations are also regulated by U. S. Coast Guard Regulation 46 CFR 147A as
modified by U. S. Coast Guard Special Permit 2-75. This permit which must be obtained
prior to the fumigation is available from:

Commandant
U. S. Coast Guard
Hazardous Materials Standards Div.
GMSO-3
Washington, DC 20593-0001

Leaks are a common cause of failures in the treatment of commodities aboard barges.
Carefully inspect all hatch covers prior to application of Phostoxin and seal, if necessary.
Notify consignee if the barge is to be fumigated in transit.

3.6.10 Fumigations in Small Sealable Enclosures
Excellent results may be attained in the treatment of small enclosures since it is often
possible to control the temperature during fumigation and also to make the enclosure
virtually gas tight. Take care not to overdose during these fumigations. A single pellet will
treat a space of from 1.4 to 10 cubic feet. From 6.9 to 50 cubic feet may be fumigated
with a single Phostoxin tablet.

3.6.11 Treatment of Beehives, Supers and Other Beekeeping Equipment
Phostoxin tablets and pellets may be used for the control of the greater wax moth in
stored beehives, supers and other beekeeping equipment and for the destruction of bees,
Africanized bees, and diseased bees including those infested with tracheal mites and
foulbrood. The recommended dosage for this use is 30-45 tablets or 150-225 pellets per
1000 cu. ft. Fumigations may be performed in chambers at atmospheric pressure, under tarpaulins, etc., by placing the tablets or pellets on trays or in moisture permeable envelopes. Do not add more than 2 tablets or 10 pellets to each envelope. Honey from treated hives or supers may only be used for bee food.

3.6.12 Burrowing Pest Control

3.6.12.1 List of Burrowing Pests

Phostoxin tablets and pellets may be used out of doors only for the control of the following burrowing rodents and moles: Marmot sp. - Woodchucks and Yellow-Belly Marmots (Rockchucks), Prairie Dogs (except Utah Prairie Dogs), Norway and Roof Rats, Mice, Ground Squirrels, Moles, Voles, Gophers and Chipmunks.

3.6.12.2 Directions for Use

Add from 1 to 4 Phostoxin tablets or 5 to 20 pellets to each burrow opening. Then seal tightly by shoveling soil over the entrance after first packing the opening with crumpled newspaper or something similar so as to prevent soil from covering the Phostoxin and slowing its action. Subsurface tunnels or runways should be treated every 5 to 10 feet with a dose of 2 to 4 tablets or 10 to 20 pellets. Use lower rates in smaller burrows in tight soils under moist soil conditions and higher rates in larger burrows in porous soils when soil moisture is low. Addition of several cups of water to the burrow prior to dosing with Phostoxin may improve efficacy in some porous soils. Treat reopened burrows and fresh runways a second time 1 to 3 days after the initial treatment. Phostoxin may be used outside only for control of burrowing pests. Do not use within 15 feet (5 meters) of inhabited structures. Do not apply to burrows which may open under or into occupied buildings. For use on all agricultural and non-cropland areas.

3.6.12.3 Environmental Hazards

This product is very highly toxic to wildlife. Non-target organisms exposed to phosphine gas in burrows will be killed. Do not apply directly to water or wetlands (swamps, bogs, marshes, and potholes). Do not contaminate water by cleaning of equipment or disposal of wastes.

3.6.12.4 Endangered Species Restrictions

The use of Phostoxin in a manner that may kill or otherwise harm an endangered or threatened species or adversely modify their habitat is a violation of Federal laws. Before using this pesticide on range and/or pastureland in the counties listed below, you must obtain the PESTICIDE USE BULLETIN FOR PROTECTION OF ENDANGERED SPECIES for the county in which the product is to be used. The bulletin is available from your Ohio State University Extension Agent, State Fish and Game Office, or your pesticide dealer. Use of this product in a manner inconsistent with the PESTICIDE USE BULLETIN FOR PROTECTION OF ENDANGERED SPECIES is a violation of Federal laws. Even if applicable county bulletins do not prohibit the use of this product at the intended site of application, you may not use this product for control of prairie dogs in the states of Arizona, Colorado, Kansas, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah or Wyoming unless a pre-control survey has been conducted. Contact the nearest U. S. Fish and Wildlife Service Endangered Species Specialist to determine survey requirements in your area. This survey must be in compliance with the Black-Footed Ferret Survey Guidelines, developed by the U.S. Fish and Wildlife Service, and a determination must be made in accordance with the guidelines that black-footed ferrets are not present in the treatment area.
3.6.12.5 Special Local Restrictions

1. **NORTH CAROLINA** - Phostoxin tablets and pellets may only be used for control of rats and mice in the state of North Carolina. Use against other pests is not permitted.

2. **OKLAHOMA** - A special permit for black-tailed prairie dog control by poisoning is required in Oklahoma. Contact the Oklahoma State Department of Wildlife Conservation to obtain this permit.

3. **WISCONSIN** - A state permit is required for use of pesticides in Wisconsin to control small mammals, except rats or mice. Please contact your local Department of Natural Resources office for information.

4. **INDIANA** - Use of Phostoxin tablets or pellets for mole control is not legal in the state of Indiana.

5. **MISSOURI** - A state permit is required for use of pesticides in Missouri to control small mammals, except rats and mice. Please contact the Missouri Department of Conservation office for information.

6. **KANSAS** - A special permit for black-tailed prairie dog control by poisoning is required in Kansas. Contact the Kansas Fish and Game Commission to obtain this permit.

7. **CALIFORNIA** - Use of Phostoxin tablets and pellets for chipmunk control is not legal in the state of California.

4. **PROTECTIVE CLOTHING**

Wear dry gloves of cotton or other material if contact with Phostoxin tablets, pellets or dust is likely. Wash hands thoroughly after handling aluminum phosphide products. Aerate used gloves and other contaminated clothing in a well ventilated area prior to laundering.

5. **RESPIRATORY PROTECTION**
5.1 **When Respiratory Protection Must Be Worn**
NIOSH/MSHA approved respiratory protection must be worn if worker exposure limits cannot be met through engineering controls (such as forced air ventilation) and/or appropriate worker practices. Respiratory protection is required if exposure is likely to exceed the eight hour TWA of 0.3 ppm during application, or a 0.3 ppm ceiling at any time afterwards. For example, respiratory protection is required to be worn upon reentry into a partially aerated structure if the hydrogen phosphide concentration is above 0.3 ppm. When required, gas concentration measurements for safety purposes may be made using low level detector tubes. See the section on Applicator and Worker Exposure for monitoring requirements. Information on hydrogen phosphide (phosphine, PH3) detector tubes may be obtained from DEGESCH America, Inc., or your DEGESCH distributor.

5.2 **Permissible Gas Concentration Ranges for Respiratory Protection Devices**
A NIOSH/MSHA approved, full-face gas mask - hydrogen phosphide canister combination may be used at levels up to 15 ppm or to escape from levels up to 1500 ppm. Above this level or in situations where the hydrogen phosphide concentration is unknown, a NIOSH/MSHA approved, self-contained breathing apparatus (SCBA) or its equivalent must be used. The NIOSH/OSHA Pocket Guide, 8-85, DHEW/NIOSH 78-210, lists these and other types of approved respirators and the concentration limits at which they may be used.

5.3 **Requirements for Availability of Respiratory Protection**
If Phostoxin is to be applied from within the structure to be fumigated, an approved full-face gas mask – phosphine canister combination or self-contained breathing apparatus (SCBA) or its equivalent must be available at the site of application in case it is needed. In addition, SCBA or its equivalent must be available locally, for example, at fire station or rescue squad if it is not available at the fumigation site.

Respiratory protection need not be available for applications from outside the area to be fumigated such as addition of tablets or pellets to automatic dispensing devices, outdoor applications, etc., if exposures above the permitted exposure limits will not be encountered.

If monitoring equipment is not available on a farm and application of fumigant cannot be made from outside the structure, an approved canister respirator must be worn during application from within the structure being treated.

6. **PLACARDING OF FUMIGATED AREAS**
The applicator must placard or post all entrances to the structures under fumigation with signs bearing, in English and Spanish:

1. The signal word DANGER/PELIGRO and the SKULL AND CROSSBONES symbol in red.
2. The statement "Area and/or commodity under fumigation, "DO NOT ENTER/NO ENTRE."
3. The statement, "This sign may only be removed after the commodity is completely aerated (contains 0.3 ppm or less of hydrogen phosphide gas). If incompletely aerated commodity is transferred to a new site, the new site must also be placarded if it
contains more than 0.3 ppm. Workers must not be exposed to more than 0.3 ppm hydrogen phosphide."

4. The date and time fumigation begins and is completed.
5. Name of fumigant used.
6. Name, address and telephone number of the applicator.

All entrances to a fumigated area must be placarded. Where possible, placards should be placed in advance of the fumigation to keep unauthorized persons away. For railroad hopper cars, placards must be placed on both sides of the car near the ladders and next to the top hatches into which the fumigant is introduced.

Do not remove placards until the treated commodity is aerated down to 0.3 ppm hydrogen phosphide or less. To determine whether aeration is complete, each fumigated site or vehicle must be monitored and shown to contain 0.3 ppm or less hydrogen phosphide gas in the air space around and, if feasible, in the mass of the commodity. Transfer of incompletely aerated commodity to a new site is permissible. However, the new storage must be placarded if it contains more than 0.3 ppm hydrogen phosphide. No placarding is required if aeration occurs during transfer. Workers who handle incompletely aerated commodity must be informed and appropriate measures taken (i.e., ventilation or respiratory protection) to prevent exposures from exceeding 0.3 ppm hydrogen phosphide.

It is recommended that the persons responsible for removing placards be familiar with the physical, chemical and toxicological properties of hydrogen phosphide. They should also be knowledgeable in making gas concentration measurements, exposure limits and symptoms and first aid treatment for hydrogen phosphide poisoning.

7. AERATION OF FUMIGATED COMMODITIES

7.1 Foods and Feeds
Tolerances for hydrogen phosphide residues have been established at 0.1 ppm for animal feeds and 0.01 ppm for finished foods. To guarantee compliance with these tolerances, it is necessary to aerate these commodities for 48 hours prior to offering them to the end consumer. As an alternative to this aeration period, each container of the treated commodity may be analyzed for residues using accepted analytical methods.

7.2 Tobacco
Tobacco must be aerated for at least three days (72 hours) when fumigated in hogsheads and for at least two days (48 hours) when fumigated in other containers. Tobacco fumigated in containers with plastic liners will probably require longer aeration periods to reach 0.3 ppm.

8. APPLICATOR AND WORKER EXPOSURE

8.1 Hydrogen Phosphide Exposure Limits
Exposure to hydrogen phosphide gas may not exceed 0.3 ppm, measured as an eight hour time-weighted average (TWA), for applicators and workers during application. Application is defined as the time period covering the opening of the first container, applying the appropriate dosage of fumigant and closing up the site to be fumigated. All persons in the treated site and in adjacent indoor areas are covered by this exposure standard.
After application, exposure for any person may not exceed a 0.3 ppm ceiling for hydrogen phosphide. Such exposures may occur if the commodity or space under fumigation leaks, when treated commodity is transferred or handled, if an unaerated or partially aerated space is entered, etc.

8.2 Application of Fumigant
Depending upon temperature and humidity, DEGESCH Phostoxin tablets and pellets release hydrogen phosphide gas slowly upon exposure to moisture from the air. In most cases, this release is slow enough to permit applicators to deposit fumigant in the desired areas and then vacate the premises without significant exposure to the gas. If the fumigator’s exposure exceeds the eight hour TWA of 0.3 ppm, approved respiratory protection must be worn. When required, gas concentration measurements for safety purposes may be made using low level detector tubes. See the writeup below on Industrial Hygiene Monitoring. Information on (hydrogen phosphide phosphine, PH3) detector tubes may be obtained from DEGESCH America, Inc., or your DEGESCH distributor. It is often advisable to wear respiratory protection during application of fumigant under hot and humid conditions, particularly when considerable time must be spent inside the structure being treated.

8.3 Leakage from Fumigated Sites
Hydrogen phosphide is highly mobile and given enough time may penetrate seemingly gas-tight materials such as concrete and cinder block. Therefore, adjacent, enclosed areas likely to be occupied should be examined to ensure that significant leakage has not occurred. Sealing of the fumigated site and/or air flow in the occupied areas must be sufficient to meet exposure standards.

8.4 Aeration and Reentry
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. The area or site must be monitored to ensure that liberation of gas from the treated commodity does not result in the development of unacceptable levels of hydrogen phosphide. Do not allow reentry into treated areas by any person before this time unless protected by an approved respirator.

8.5 Handling Unaerated Commodities
Workers must not be exposed to hydrogen phosphide in excess of 0.3 ppm during moving, storage or processing of incompletely aerated commodities.

8.6 Industrial Hygiene Monitoring
It is recommended that hydrogen phosphide exposures be documented in an operations log or manual for each site and operation where exposures may occur. The purpose of this monitoring is to prevent excessive exposures and to determine when and where respiratory protection is required. This monitoring is mandatory although, once exposures have been adequately characterized, subsequent monitoring is not required. However, spot checks should be made occasionally, especially if conditions change significantly or if an unexpected garlic odor is detected. Gas measurements should be made in the worker’s breathing zone. Monitoring is not required for outdoor operations.

If monitoring shows that workers are exposed to concentrations in excess of the permitted limits, then engineering controls (such as forced air ventilation) and/or appropriate work practices should be used, where possible, to reduce exposure to within permitted limits.
There are a number of devices on the market for the measurement of hydrogen phosphide gas levels for industrial hygiene purposes. One of these is the hydrogen phosphide detector tube used in conjunction with the appropriate hand-operated air sampling pump. These devices are reliable, portable, simple to use, do not require extensive training and are relatively rapid, inexpensive and accurate. Low level detector tubes are available which can detect 0.1 ppm and are suitable for industrial hygiene monitoring.

9. STORAGE INSTRUCTIONS

1. Store Phostoxin in a dry, well ventilated area away from heat, under lock and key. Post as a pesticide storage area. Do not contaminate water, food or feed by storing pesticides in the same areas used to store these commodities.

2. Do not store in buildings where humans or domestic animals reside. Keep out of reach of children.

3. DEGESCH Phostoxin tablets and pellets are supplied in gas-tight, resealable aluminum flasks. Do not expose the product to atmospheric moisture any longer than is necessary and seal tightly before returning opened flasks to storage.

4. The shelf life of Phostoxin is virtually unlimited as long as the containers are tightly sealed.

10. DISPOSAL INSTRUCTIONS

10.1 General

10.1.1 Do not contaminate water, food or feed by storage or disposal.

10.1.2 Unreacted or partially reacted Phostoxin is acutely hazardous. Improper disposal of excess pesticide is a violation of Federal Law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance. For specific instructions, see Section 11 of this manual, Spill and Leak Procedures.

10.1.3 Some local and state waste disposal regulations may vary from the following recommendations. Disposal procedures should be reviewed with appropriate authorities to ensure compliance with local regulations. Contact your state Pesticide or Environmental Control Agency or Hazardous Waste Specialist at the nearest EPA Regional Office for guidance.

10.1.4 Triple rinse flasks and stoppers with water. Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by other procedures approved by state and local authorities. Rinsate may be disposed of in a sanitary landfill by pouring it out onto the ground or by other approved procedures. Or, it is permissible to remove lids and expose empty flasks to atmospheric conditions until residue in the flasks is reacted. Then puncture and dispose of in a sanitary landfill or other approved site, or by other procedures approved by state and local authorities.

10.1.5 If properly exposed, the residual dust remaining after a fumigation with Phostoxin will be a grayish-white powder. This will be a non-hazardous waste and contain only a small amount of unreacted aluminum phosphide. However, residual dust from incompletely exposed Phostoxin, so called "green dust," will require special care.

10.2 Directions for Disposal of Residual Dust from Phostoxin
10.2.1 Confinement of partially spent residual dust, as in a closed container, or collection and storage of large quantities of dust may result in a fire hazard. Small amounts of hydrogen phosphide may be given off from unreacted aluminum phosphide, and confinement of the gas may result in a flash.

10.2.2 In open areas, small amounts of residual dust, up to about 5 to 8 kg, may be disposed of on site by burial or by spreading over the land surface away from inhabited buildings.

10.2.3 Spent residual dust from Phostoxin may also be collected and disposed of at a sanitary landfill, incinerator or other approved sites or by other procedures approved by Federal, State or Local authorities. "Green dust" must be further deactivated before disposal at a landfill.

10.2.4 From 2 to 3 kg (4 to 7 lbs.) of spent dust from 2 to 3 flasks of Phostoxin may be collected for disposal in a 1-gallon bucket. Larger amounts, up to about one-half case, may be collected in burlap, cotton or other types of porous cloth bags for transportation in an open vehicle to the disposal site. Do not collect dust from more than 7 flasks of tablets or 10 flasks of pellets (about 11 kg or 25 lbs.) in a single bag. Do not pile cloth bags together. Do not use this method for partially spent or "green dust." Caution: Do not collect dust in large drums, dumpsters, plastic bags or other containers where confinement may occur.

10.3 Directions for Deactivation of Partially Spent Residual Dust from Phostoxin

10.3.1 Partially spent dust must be deactivated further prior to ultimate disposal. This is especially true in cases of incomplete exposure, which has resulted in so-called "green dust" or following a fumigation, which has produced large quantities of partially spent material.

10.3.2 Residual dust from Phostoxin may be deactivated as follows using the "Wet Method."

10.3.2.1 Deactivating solution is prepared by adding the appropriate amount of low sudsing detergent or surface active agent to water in a drum or other suitable container. A 2% solution of detergent is suggested. The container should be filled with deactivating solution to within a few inches of the top.

10.3.2.2 Residual dust is poured slowly into the deactivating solution and stirred so as to thoroughly wet all of the particles. This should be done in the open air and not in the fumigated structure. Dust from Phostoxin tablets or pellets should be mixed into no less than about 10 gallons of water-detergent solution for each case of material used. Wear appropriate respiratory protection during wet deactivation of partially spent dust.

10.3.2.3 Dispose of the deactivated dust-water suspension, with or without preliminary decanting, at a sanitary landfill or other suitable site approved by local authorities. Where permissible, the slurry may be poured out onto the ground. If the slurry has been held for 36 hours or more, it may be poured into a storm sewer.

10.3.2.4 Caution: Wear appropriate respiratory protection during wet deactivation of partially spent material. Do not cover the container being used for wet deactivation. Do not dispose of Phostoxin dust in a toilet.

10.3.3 Residual dust from Phostoxin may also be deactivated as follows using the "Dry Method."

10.3.3.1 Extension of the fumigation period is the simplest method for further deactivation of "green" or partially spent dust prior to ultimate disposal.
10.3.3.2 Small amounts of partially spent dust, from 2 to 3 kg (4 to 7 lbs.) may be further deactivated by storage in a 1-gallon bucket. Larger amounts of dust (about 11 kg or 25 lbs.) may be held for deactivation in porous cloth bags (burlap, cotton, etc.). Caution: Transport these bags in open vehicles. Do not pile up the bags. Do not store "green dust" in bags.

FOR ASSISTANCE, CONTACT: DEGESCH America, Inc., P. O. Box 116 Weyers Cave, Virginia 24486 USA - Telephone: (540) 234-9281 Fax: (540) 234-8225 or CHEMTREC (800) 424-9300.

11. SPILL AND LEAK PROCEDURES

11.1 General Precautions and Directions
A spill, other than incidental to application or normal handling, may produce high levels of gas and, therefore, attending personnel must wear SCBA or its equivalent when the concentration of hydrogen phosphide gas is unknown. Other NIOSH/MSHA approved respiratory protection may be worn if the concentration is known. Do not use water at any time to clean up a spill of Phostoxin. Water in contact with unreacted tablets or pellets will greatly accelerate the production of hydrogen phosphide gas, which could result in a toxic and/or fire hazard. Wear dry gloves of cotton or other material when handling aluminum phosphide.

Return all intact aluminum flasks to fiberboard cases or other packaging, which has been suitably constructed and marked according to DOT regulations. Notify consignee and shipper of damaged cases.

If aluminum flasks have been punctured or damaged so as to leak, the container may be temporarily repaired with aluminum tape or the Phostoxin may be transferred from the damaged flask to a sound metal container, which should be sealed and properly labeled as aluminum phosphide. Transport the damaged containers to an area suitable for pesticide storage for inspection. Further instructions and recommendations may be obtained, if required, from DEGESCH America, Inc.

If a spill has occurred which is only a few minutes old, collect the tablets and pellets and place them back into the original flasks, if they are intact, and stopper tightly. Place the collected tablets and pellets in a sound metal container if the original flasks are damaged. Caution, these flasks may flash upon opening at some later time.

If the age of the spill is unknown or if the tablets and pellets have been contaminated with soil, debris, water, etc., gather up the spillage and place it into small open buckets having a capacity no larger than about 1 gallon. Do not add more than about one flask of spilled material, 1 to 1.5 kg (2 to 3 lbs.), to the bucket. If on-site, wet deactivation is not feasible, these open containers should be transported in open vehicles to a suitable area. Wet deactivation may then be carried out as described in 11.2. Alternatively, small amounts of spillage from 4 to 5 flasks (4 to 8 kg, 9 to 18 lbs.) may be spread out in an open area away from inhabited buildings to be deactivated by atmospheric moisture.

11.2 Directions for Deactivation by the Wet Method
If the contaminated material is not to be held until completely reacted by exposure to atmospheric moisture, deactivate the product by the "Wet Method" as follows:
11.2.1 Deactivating solution is prepared by adding the appropriate amount of low sudsing detergent or surface active agent to water in a drum or other suitable container. A 2% solution or 4 cups in 30 gallons is suggested. The container should be filled with deactivating solution to within a few inches of the top.

11.2.2 The tablets or pellets are poured slowly into the deactivating solution and stirred so as to thoroughly wet all of the Phostoxin. This should be done in the open air. Phostoxin tablets or pellets should be mixed into no less than about 15 gallons of water-detergent solution for each case of material. Wear appropriate respiratory protection during wet deactivation.

11.2.3 Allow the mixture to stand, with occasional stirring, for about 36 hours. The resultant slurry will then be safe for disposal.

11.2.4 Dispose of the slurry of deactivated material, with or without preliminary decanting, at a sanitary landfill or other suitable site approved by local authorities. Where permissible, this slurry may be poured into a storm sewer or out onto the ground.

11.2.5 Caution: Wear appropriate respiratory protection during wet deactivation of unexposed or incompletely exposed Phostoxin. Never place pellets, tablets, or dust in a closed container such as a dumpster, sealed drum, plastic bag, etc., as flammable concentrations and a flash of hydrogen phosphide gas are likely to develop.

11.2.6 The EPA has determined that proper disposal of aluminum phosphide will cause no unreasonable adverse effects to the environment.
Chapter 5
Determining the Need for Fumigation

Learning Objectives
You should learn about:
1. Determining a need for fumigation
2. Choosing a fumigant
3. Target pest
4. Habits of pest

DETERMINING A NEED FOR FUMIGATION
Several criteria should be considered in determining the need and suitability of fumigation for pest control. These include:

1. Characteristics and habits of the pest
2. Life stages of the pest
3. Hazards located in the treatment area
4. Available pest-management alternative
5. Established pesticide-residue tolerances

CHOOSING A FUMIGANT
If the need for fumigation has been proven, the right fumigant must be chosen. To decide on an effective fumigant, it’s important for the applicator to know the habits of the pest, the limitations and characteristics of the fumigation site, and environmental conditions that may influence the fumigation process. He or she also needs to understand the chemical and physical characteristics of the fumigant.

When choosing a fumigant, consider such factors as these:

- Toxicity to the target pest
- Volatility and ability to penetrate
- Corrosive effect, flammability, and potential for explosion
- Warning properties and detection methods
- Effect on seed germination and finished-product quality
- Residue tolerances
- Availability
- Ease of application
- Cost

TARGET PEST SITUATIONS
Fumigants used in pest control tend to affect all forms of life. Almost any pest in an enclosed area can be destroyed when exposed to an adequate concentration of a fumigant. Fumigations are most often used to eradicate pests that infest harvested commodities such as bulk grain, greenhouse insects, etc. Inaccessible pests, such as wood-boring beetles and drywood termites, are also targets for fumigation.

Fumigation may sometimes be the best choice for controlling heavy infestations of insects such as cockroaches, especially when it’s hard to gain access to all of the pest’s hiding places. Fumigation is also useful to avoid toxic residues associated with application of other pesticide formulations to food, clothing, and similar materials.

HABITS OF THE PEST
Pests that are reclusive or hard to locate can often be treated successfully with fumigation. However, it’s important to understand the habits of the pest before choosing fumigation. For example, colonies of drywood termites, very uncommon in Ohio, nest in structural wood above ground and are good targets for fumigation. The far-more-common subterranean termites nest underground and are not killed by fumigation. Situations where large reservoirs of the pest will remain outside the treated area can allow quick re-infestation, wiping out the benefits of fumigation.

LIFE STAGES OF THE PEST
An applicator should also consider how various life stages of the pest respond to fumigation. For instance, many insects are relatively non-susceptible to fumigants or other insecticides during their egg and pupal stages. Insects may also be dormant during certain periods and not be susceptible. Be
sure to check the fumigant label to see what stages of the target pests the manufacturer claims the product will control.
Chapter 6  
Fumigation Types and Processes

Learning Objectives
You should learn about:
1. Structural Fumigation
2. Chamber Fumigation
3. Tarpaulin Fumigation
4. Rail car and Truck Fumigation
5. Stored Grain Fumigation
6. Soil Fumigation

TYPES OF FUMIGATION
Sites should be thoroughly surveyed to identify and protect items that may react with, or be damaged by, the fumigant. Fumigation may be used in several types of situations, including structures, bulk-storage facilities, and specially designed chambers, rail cars and under certain conditions, trucks.

However, fumigants should only be used in enclosed areas, because the molecules of the fumigant penetrate throughout the area and escape through openings. Fumigants can NOT be used in localized areas of a building unless the entire building is vacated or it is possible to completely seal and control access to the treated area throughout the fumigation and aeration period with the properly designed fumigation chamber. Fumigants should never be used in any areas that can't be fully secured to prevent entry or contact by unauthorized people or animals. The fumigation site also must have the proper environmental conditions to allow successful use of the fumigants. This includes correct temperature, humidity, and air circulation conditions required for effective pest control.

Sites should also be thoroughly surveyed to identify and protect items that may react with or be damaged by the fumigant. This may include such items as furnishings, floor coverings, foodstuffs, wall hangings, finishes, plumbing and electrical devices, and moisture sources. Check the label and do a test fumigation on a small sample if there is any question.

STRUCTURAL FUMIGATION
Fumigation may be used to control certain pests within existing buildings such as grain storage and homes. Since typical construction is not sufficiently airtight, these require sealing. In relatively airtight structures, tarping may be sufficient. However, many buildings require tarping the entire structure.

Fumigants used in grain storage are very useful for control of stored-product insects such as weevils and various “bran bugs.” Household fumigations can help control pests such as drywood termites, powder-post beetles and other wood-boring beetles that are hard to control with other methods.

CHAMBER FUMIGATION
Since environmental conditions can be carefully controlled and monitored, chamber fumigation is a superior method for fumigating many materials. Using a chamber will allow only small amounts of a commodity to be fumigated at a time because of the limited size of the chamber. However, the limited space can be an advantage, because the fumigant is confined, saving the time it takes to seal and saving the amount of fumigant used. The ability to carefully control environmental conditions in a chamber also allows fumigation to be used to control pests on fragile commodities such as fresh fruits or vegetables without damage.

Chamber fumigation can also be used to disinfect fresh produce, packaged foods, bagged or baled agricultural products,
museum specimens, furniture, high-value garments, and similar items.

Chambers used for fumigation may be either the atmospheric or vacuum type. Vacuum chambers provide the quickest and most thorough fumigation and are best for finely divided items such as flour. Applying a vacuum increases the penetration of a fumigant and shortens fumigation time. However, some materials may be damaged by vacuum and require special precautions. Atmospheric chambers are useful for fumigating materials that might be damaged in a vacuum chamber. Fumigation in a well-sealed railcar or truck trailer is a type of chamber fumigation. Obtaining a good seal is not always easy. Monitoring the fumigation is the only way to know if the seal is good.

**TARPAULIN FUMIGATION**

Tarpaulin fumigation involves placing a gas-tight material over the commodity or structure to be fumigated. The tarps must be specially made for fumigation, such as impregnated nylon or sheet polyethylene. (Waterproof canvas tarpaulins ARE NOT satisfactory.) Polyethylene tarps can be used in thickness from two to six mils. Use gas-impervious adhesive tape to join various sections of polyethylene film.

The tarpaulin method provides thorough protection from insect damage at practical cost. Done in place, it permits fumigation without the expense of moving huge stores of commodities. Tarpaulin fumigation can effectively and economically free material such as bagged grain, dried fruit, stacked lumber, and other commodities from insects.

Tarpaulin fumigation may be done in the open, on loading docks, or in areas of buildings that allow safe aeration when the tarpaulin is removed. However, sites must also be checked for possible hazards in securing the fumigated area from humans and animals as well as for adequate sealing.

Workers should not be allowed into areas containing taped fumigated materials unless there is adequate ventilation and regular monitoring. Even under these conditions, such as may occur at ship docking areas, tarps are often torn accidentally causing failure of the fumigation and potentially dangerous levels of gas for workers to inhale.

**RAIL AND TRUCK FUMIGATION**

Items shipped in rail cars or in large truck trailers are often fumigated after they are loaded into the vehicle. This prevents pests from being transported to other locations and protects shipped products from pest damage during transport. Most vehicles, depending on their condition and on the type of commodity being fumigated, require tarping or other sealing to confine the fumigant.

Pests controlled by rail car and truck fumigation include beetles and moths that infest flour, grains, nuts, dried fruits, and other agricultural products. Some insect pests may hide in empty vehicles, feeding on residues from previous cargoes. Unless controlled by fumigation or removed by thorough cleaning, these pests can infest future loads.

Fumigations of rail car and truck trailers must comply with the regulations of the state and local highway departments and departments of transportation as well as the departments of agriculture and the label instructions. In some cases, loaded rail cars can be fumigated in transit. However, regulations prohibit truck trailers from being moved until fumigation and aeration have been completed. When performing a truck or rail car fumigation, the pesticide applicator must post warning signs on all entrances to warn of the hazards.

Because fumigated rail cars or trailers may contain residues of a fumigant after aeration, the vehicles need to be monitored with appropriate detection equipment once they reach their destination and before they are unloaded. The person opening and monitoring fumigated loads must wear
respiratory protection and any other protective equipment required by the fumigant label.

STORED GRAIN FUMIGATION
Understanding how fumigants react in grain and what influences their behavior is an essential step in developing the “know-how” to effectively and safely use grain fumigants.

Sorption - When a fumigant gas attaches itself to the surface of a grain kernel or penetrates into the kernel, it slows diffusion and disrupts penetration of the fumigant through the grain mass. However, some sorption must occur if the fumigant is to reach all stages of pest insects, especially those that develop within the kernel.

The degree of sorption of individual components is the basis for selection of many fumigants. Some fumigants react with materials in the grain to form other chemical compounds that may be permanent, thus forming residues. Methyl bromide fumigants are particularly subject to this type of chemical reaction that has necessitated the establishment of residue limits or tolerances for the amount of bromide permitted in grain.

Temperature - Temperature influences the distribution of fumigants in grain and affects their ability to kill insects. At temperatures below 60°F, volatility of a fumigant is reduced significantly, sorption of fumigant vapors into the grain is increased, and distribution is less uniform throughout the grain mass. At colder temperatures gases move more slowly and insects breathe less. It takes longer for the fumigant vapors to reach insects in the grain and less gas is actually available for controlling the pests. And since the insects are less active, less gas enters their bodies. Desorption may take longer at cold temperatures because grain retains more fumigants longer at low temperatures, requiring prolonged ventilation periods.

Grain Moisture - The moisture content of grain also influences the penetration of fumigant gases by altering the rate of sorption. In general, moist grain requires an increase in dosage or an extended exposure to compensate for the reduced penetration and increased sorption. However, as previously mentioned, moisture is necessary for the generation of phosphine from solid formulations. Although most grain that will support insect development will also contain sufficient moisture to start the chemical reaction, grain below 10 percent moisture will slow solid fumigant decomposition.

Grain Type and Condition - Various grains have different characteristics that can affect fumigations. The surface area of individual grain kernels is an influencing factor in the dosage required to treat various commodities. For example, sorghum, because of its smaller size and more spherical shape, has higher total surface area than wheat. Increased surface means greater sorption loss, which reduces the amount of fumigants left in the space between the grain kernels and further reduces the amount of fumigant available to penetrate throughout the grain. To compensate for this increased sorptive loss, higher dosage rates are required in sorghum than in wheat, particularly with the high sorption fumigants.

The type and amount of dockage in grain has a pronounced effect on the sorption and distribution of fumigants. When the grain mass contains large amounts of dockage such as chaff or broken kernels, the fumigant vapors are rapidly sorbed by this material and further penetration into the grain is impaired. Unfortunately, such areas are frequently sites that attract the greatest number of insects. When isolated "pockets" of dockage occur within a grain mass, such as below grain spouts, fumigant vapors may pass around such pockets and follow the path of least resistance down through the intergranular area of the grain. Similar changes in fumigant distribution patterns may be obtained in grain that has settled or compacted unevenly during long storage periods or in storage vibrated by nearby traffic such as a railroad.
**Insects** - Grain insect pests and their various developmental stages (egg, larva, pupa and adult) vary in their susceptibility and resistance to fumigants. Beetles and other insects that develop outside grain kernels are usually more susceptible to fumigants than certain moth and beetle species that develop inside grain kernels. The pupae and eggs are the hardest developmental stages to kill while the young larvae are relatively susceptible. Heavy infestations in which large amounts of dust, damaged grain, webbing and cast skins have accumulated are more difficult to control because of the effect these materials have on the penetration and diffusion of grain fumigants.

**Storage Facility** - A fumigant whether applied initially as a gas, liquid or solid, penetrates the grain and enters the insect in the form of a gas. The "gas tightness" of the storage bin, therefore, greatly influences the retention of the fumigant. Metal bins with caulked or welded seams or concrete bins will lose some gas but are generally better suited for fumigation than wooden bins.

Although there are often label recommendations for fumigation of grain in wooden bins, the high dosages and poor control usually achieved normally make this type of fumigation uneconomical.

The size and shape of the storage structure affect both distribution and retention of fumigants. The height of a storage bin often determines the type of fumigant used and its method of application. Solid fumigants may be more effective if mixed with the grain during transfer into the bins. Commercial applicators may use special techniques to achieve control that would be difficult for a farmer to apply.

Winds and thermal or heat expansion are major factors influencing gas loss. Winds around a grain storage structure create pressure gradients across its surface resulting in rapid loss of fumigant concentrations at the grain surface and on the downwind side of the storage. The expansion of head space air due to solar heating of roofs and walls followed by nighttime cooling can result in a "pumping" of the fumigant from the bin. Large flat storages that contain more grain surface than grain depth are particularly susceptible to gas loss due to wind and heat expansion. The greatest gas loss frequently occurs at the grain surface, a location that often contains the highest insect populations. Furthermore, when the grain surface is uneven with large peaks and valleys, the distribution of fumigants through the grain will also be uneven.

**Air Movement** - Successful fumigation of stored grain requires an understanding of air movement within the grain mass. It is easy to think that the air in between the kernels of grain in a bin is as immobile as the grain itself. This is not true and is one of the reasons that fumigation sometimes fails even when done by professional fumigators.

Air moves along the path of least resistance, with warm air moving upward and cold air moving downward. In a bin, there is usually air movement both up and down because of temperature difference between the well-insulated middle and the grain near the perimeter that is affected by the outside temperature. Air movement upward can carry moisture (moisture migration) that can condense on the surface and cause crusting. The resulting crust can also interfere with air and gas movement.

Air will move more easily through a grain mass composed of larger kernels, such as corn, and more slowly through those composed of smaller grains, such as grain sorghum. Air may move around a hot spot and carry a fumigant gas away from the critical area. Fumigant gases can penetrate these areas better than normal air but the air movement can affect how much gas reaches and stays at these critical areas. Gas movement in a grain mass is affected by other forces such as gravity, sorption, temperature and moisture content, but an
understanding of the air movement is the first step in understanding the many forces that determine gas dispersion.

**Dosage and time of exposure** - Because fumigants act in the gaseous state, the dosage necessary to kill an insect is related to the concentration of gas surrounding the insect, the insect's respiration rate (which is related partially to temperature), and the time of exposure of the insect to the specific concentration of fumigant. For most fumigants there is a general relationship between concentration and time: high concentrations require shorter exposure time and low concentrations require longer exposure to achieve comparable kill. In phosphine fumigations, time of exposure is often more important than the concentration of gas. This situation is partly due to the increased time necessary for release of the gas from the solid material and also because the rate of uptake of phosphine by insects is somewhat time dependent.

Variations in recommended dosages are generally based on sorption differences of commodities and the relative gas tightness of different storage structures. For example, dosage requirements for sorghum are generally higher than for less sorptive commodities such as wheat, and dosages in wooden bins are higher than in steel or concrete bins. Application rates for phosphine-producing fumigants are based primarily on the type of storage structure being treated and its gas tightness. Because phosphine is less affected by sorption loss in grain, the rates of application for most commodities are virtually the same.

Dosage rates for methyl bromide are on the labeling and are based on the amount of total space within a storage vehicle rather than the amount of grain present. Grain should not be fumigated with methyl bromide unless the gas is recirculated.
Chapter 7
Equipment

Learning Objectives
You should learn about:
1. Personal Protective Equipment (PPE) for Applicators
2. Fumigant Detection Equipment

PERSONAL PROTECTIVE EQUIPMENT (PPE)
Applicators should wear loose fitting clothing and gloves of cotton if handling phosphine and no gloves if using methyl bromide. The objective with methyl bromide is, do not hold the fumigant next to skin, this will cause injury.

The fumigant label will have all the information on personal protective equipment required to perform the fumigations. PLEASE READ THE LABEL.

There are several masks available to be used for fumigation. They are:

Canister Type Gas Mask – Are often ineffective when breathable oxygen is too low. They do not prevent sorption through skin. They require different types of canisters for different toxic gases. They cannot be used with methyl bromide or sulfuryl fluoride (Vikane® and ProFume®).

Self-Contained Breathing Apparatus (SCBA) - The wearer carries his own breathing air with SCBA. Its use is required in atmospheres immediately dangerous to life or health, for the rescue of personnel, or escape. The SCBA should be properly fitted and used according to instructions.

Air Supplied Respirator – The Air Supplied Respirator has the advantage of a continuous supply of air, however, freedom of movement is somewhat restricted due to the connecting hose. Care should be taken to avoid cutting or damaging the hose.

Only the SCBA and the air-supplied respirator can be used with methyl bromide, sulfuryl fluoride or phosphine at levels above 15 ppm or unknown concentrations of phosphine.

FUMIGANT DETECTION DEVICES
It is becoming increasingly important to be able to determine the amount of fumigant gas in an air/gas mixture. During the fumigation, the concentration should be monitored to determine the loss due to sorption or leakage so that adjustments can be made if possible. It may be necessary to reseal an area, add more gas or lengthen the exposure period to give the proper concentration X time ratio. If we do not know the concentration at various points, we cannot know to make the adjustments.

After the fumigation is over, it is equally important to be able to know that the gas has been reduced to a level below the Permeable Exposure Level (PEL) or the Threshold Limit Value (TLV) of the gas to assure worker safety upon re-entry.

DETECTOR TUBES
Gas detector tubes for determining low levels of several gases are available on the market. These are sealed glass tubes filled with an appropriate indicator chemical to react with a particular gas and give a color reaction. To make a determination, the seals are broken at each end of the tube and a definite volume of the atmosphere being sampled is drawn through by a hand operated or mechanical pump. The tubes are marked off in scale divisions. The concentration is determined by the length of discoloration of the indicator for a given volume of atmosphere.

Detector tubes are simple, easy to use devices that can provide reasonably reliable,
on-the-spot measurement of gas concentrations. Their accuracy may be in the range of 70 to 90 percent of the mean value if sampling is done carefully according to manufacturers' directions. For taking gas samples from difficult locations, extension tubes are available from manufacturers so that the detector tubes can be placed at the desired site.

In addition to these tubes, which give an immediate reaction, long duration tubes for monitoring various toxic gases throughout the normal workday are available. These tubes can be carried anywhere on a worker's clothing in a special holder, while a lightweight pump continuously draws a measured volume of air through the tube. At the end of the shift, the tube can be evaluated to give a time-weighted average (TWA) of exposure for the working day.

Handbooks that describe in detail the characteristics and capabilities of a wide range of detector tubes are available from some manufacturers (Leichnitz, 1979).

In making use of detector tubes some precautions should be noted:

- Tubes will deteriorate with age - some have a shelf life of two years when stored at room temperature. Temperatures above 30°C increase the rate of deterioration.

- Direct sunlight can affect the properties of the tubes.

- At low temperatures (around freezing or below) tubes may not give reliable readings; they should be warmed to room temperature for best performance. Tubes may have cross-sensitivity to gases other than those for which they are designed.

Colorimetric detectors include devices such as glass detection tubes and personal indicator badges. Glass detection tubes manufactured by Draeger Safety, MSA, and others are among the oldest and simplest types of gas detection devices to use. Tubes are available for hundreds of different gasses and ranges of sensitivity. For fumigation work, tubes are available to detect methyl bromide, phosphine, and sulfuryl fluoride. Detection tubes contain chemicals that react and change color as a specific volume of air is drawn through the tube by a simple pump. The amount of color change is correlated to a scale on the tube reading gas concentration in the sample. Detection tubes are most often used today to clear fumigations, checking for leaks, or environmental monitoring areas near a fumigation.

Personal indicator badges, such as a phosphine badge, are variations on the design of glass detector tubes. Workers with a potential to be exposed can be warned of phosphine by color changes on the badge.

Halide detectors were popular years ago for clearing fumigations and detecting leaks. These devices utilize a specialized nozzle and an open flame from a small propane cylinder. Halogenated compounds, including methyl bromide can be detected by observing the color of the flame. Halide detectors are not used very much anymore because they do not provide precise readings, their sensitivity is not good enough, and open flames are not acceptable at most fumigation sites.

Electronic devices are most popular for fumigant monitoring and safety. A number of different detection technologies are employed in these instruments. Like all types of electronics, products are becoming more affordable and features are improving at a rapid pace.

Fumigations are often monitored with instruments to ensure that time and concentration requirements of the fumigation gas are met. Some of the common instruments for this type of monitoring include the Fumiscope, Riken Optical Gas Indicator,
and others. These instruments are usually positioned in fresh air and connected by sampling hoses to the fumigated space. The Fumiscope instrument is often configured with the capability to measure either methyl bromide or sulfuryl fluoride. A number of detection technologies are employed by the sensors in this type of equipment including thermal conductivity, infrared, flame ionization, electron capture, and others.

A wide array of small, portable, battery-powered instruments are available for monitoring personal breathing zone air and to test air in confined spaces prior to entry. The greatest demand for gas detection safety equipment is for workers in the underground utility, industrial maintenance, and firefighting occupations. Dozens of companies and hundreds of instruments compete for this business. A significantly smaller number feature sensors for fumigation gasses such as phosphine or methyl bromide. Phosphine detection usually employs electrochemical sensors in instruments that can monitor from one to five or more gasses. Electrochemical sensors function by measuring the resistance of a gas as it passes through a chemical gel medium. A single gas phosphine instrument may be adequate for fumigation work. Popular examples include the Draeger MicroPac Plus, Draeger PAC III, Lumidor UniMax, and Analytical Technology’s PortaSens. Since gas detection equipment is often used for checking confined spaces prior to entry, versatile equipment with remote sampling capability and sensors for multiple gasses is often desirable. Common sensors in these instruments include oxygen, carbon monoxide, explosive gasses, and sensors for toxic gasses. Popular examples of multi-gas instruments include the Draeger MiniWarn, Draeger MultiWarn, MSA Passport, and the Lumidor MicroMax Series.

Electrochemical sensors and instruments are rapidly becoming more affordable and easier to use. Users should never forget the need for regular calibration and alarm testing. Instrument calibration may be required as often as monthly, while alarm testing is usually recommended at the beginning of each day’s work.

Not all gasses can be detected with electrochemical sensors. Volatile organic chemicals (VOC’s), including methyl bromide, require a different type of sensor, especially photo ionization detectors (PID’s) for small portable instruments. An example is the ToxiRAE PID. PID’s do not detect a specific gas, but rather all VOC’s. The programming of an instrument and knowledge of the environment where it will be used allow for accurate detection of a single target gas. Some PID’s have the sensitivity to detect gasses in the parts per billion ranges. Some instruments combine a PID sensor with electrochemical sensors for the broadest possible versatility.
Chapter 8
Calculation for Fumigation

Learning Objectives
You should learn about:
1. Formulas for Application
2. Types of Structures
3. Measuring an Area
4. Calculating the Amount of Fumigant to Use

FORMULAS
Here are a few formulas you will need to calculate areas:

THE RECTANGLE (4 sides)

Formula: Length X width = square feet

Example 1: If the length of the rectangle is 20 ft. and the width is 10 ft. the equation should look like this: 
\[20' \times 10' = 200 \text{ square feet}\]

Example 2: If the length of the rectangle is 20 ft. and the width is 10 ft. and the height is 14 ft. the equation should look like this: 
\[20' \times 10' = 200 \text{ sq. feet} \times 14' = 2800 \text{ cubic feet} \]

The same logic would apply to a square.

THE TRIANGLE (3 sides)

Formula: \(\frac{1}{2} \times \text{base} \times \text{height}\)

Example: If the height is 10’ and the base is 20’ the equation should look like this: \(\frac{1}{2} \times \text{20' X 10'} = 100 \text{ cubic ft.}\)

THE CYLINDER – A CONTINUOUS CIRCULAR STRUCTURE (USE 3.14 PI)

Formula: \(3.14 \times \text{radius}^2 \times \text{height} = \text{Volume}\)

If the radius is 5’ and the height is 40’ the equation should look like this: 
\[3.14 \times (5' \times 5') \times 40' = 3.14 \times 25' \times 40' = 3140 \text{ cubic feet}\]

THE CONE

Formula: \(\frac{1}{3} \times \text{radius}^2 \times \text{height} = \text{Volume}\)

If the radius is 6’ and the height is 10’ the equation should look like this: 
\[\frac{1}{3} \times 3.14 \times (6' \times 6') \times 10' = 376.8 \text{ cubic feet}\]

THE HEMISPHERE

Formula – \(\frac{2}{3} \times \text{Ab} \times \text{height}\)

If the average base is 12’ and the height is 8’ the equation should look like this: 
\[\frac{2}{3} \times [12' \times 8'] = 64 \text{ cubic feet}\]
TYPES OF STRUCTURES
There are a variety of structures that could be fumigated. These structures are made up of various shapes, buildings with the shapes of squares, rectangles, and triangles. Some are storage places with the shapes of circles and cones. The formulas above will help you to find the volume of these different structures.

MEASURING AREAS
First determine how large the structure is and then calculate the volume of the structure to properly fumigate it. You have to determine the length, width and height of the structure and use the correct formula to calculate the area. If the structure has a roof or cover you have to determine the radius and height and use the correct formula to calculate the area. Once you have the area of the building and the roof area then you add the two figures together to get the total area.

AMOUNT OF FUMIGANT
The product label is the law and also where you would get the figures for the amount of fumigant to use. Most fumigants will have a very detailed label and an applicator’s manual that should be read before you use any fumigant. These will provide any information needed for the application.

GRAIN STORAGE MATH
Dry Measure
1 bushel – 1.2445 cubic ft.
1 cubic ft. – 0.8035 bushels

Liquid Measure
1 pint = 16 fl. oz.
1 gal = 128 fl. oz.

CALCULATING SURFACE AREA
Surface area of a circular surface (e.g., metal bin)
Circular Bin Surface Area = 0.7854 X Bin Diameter Squared

For example, a bin having a diameter of 21 feet would have a circular surface area of:
(0.7854 X 21 X 21) = 346.4 square feet.

Surface area of rectangular surface (e.g., flat storage)
Rectangular Surface Area = Length X Width

For example, flat storage 50 feet long and 30 feet wide would have a surface area of (50 x 30) or 1,500 square feet.

Because flat storage is generally peaked, assuming a 28-degree angle of repose, the rectangular surface area should be increased 10 percent to obtain a more accurate measure of surface area to be treated. Thus, a more accurate estimate of flat-storage surface area would be (50 X 30) X 1.1 = 1,650 square feet.

CALCULATING GRAIN SURFACE TREATMENTS
Assuming treatment of 3 fluid ounces of protectant in 2 gallons of water per 1,000 square feet of surface area, the amount of protectant required for surface area of a bin 21 feet in diameter would be calculated as follows:
Surface area = (0.7854 X 21 ft. X 21 ft.) = 346.4 sq. ft.
The formula is: (Dosage / 1,000 sq. ft.) X (surface area / 1,000)
3 fl. oz. / 2 gal) X (364.4 / 1,000) = 1 fl. oz. / 0.7 gal
Thus, apply 1 fl. oz. of protectant on 0.7 gal of water to the grain surface area of a bin 21 ft. in diameter.

CALCULATING GRAIN VOLUME
VOLUME OF CIRCULAR STORAGE FACILITY
Circular Volume = 0.7854 X Diameter Squared X Height

For example, a bin with a diameter of 21 feet and a fill height of 24 feet would have a volume of:
(0.7854 x 21 x 21) = 8,312.7 cu. ft.
or 6,679 bu. (8,312.7 cu. ft. x 0.8035 bu./cu. ft. = 6,679 bu.)
VOLUME OF FLAT STORAGE
Assuming that flat-storage grain is peaked with an angle of repose of about 28 degrees, calculation of the volume of flat storage must include the volume of a rectangular shape plus the volume of the peaked grain.
Estimate of such a shape would include:
  
  Rectangular volume = Width X Length X Grain height on wall
  Peaked volume = Width square X 0.125 X (Length – ½ Width)

For example, a grain store 40 feet wide and 60 feet long with a grain height along the wall of 8 feet and the grain peaked down the center would have a volume as follows:

  Rectangular volume = [(40 ft. X 40 ft. X 0.125) X (60 ft. – 20 ft.)] = 8,000 cu. ft.
  Total vol. = (Rectangular vol. + Peaked vol.) = 27,200 cu. ft.
  or (27,200 cu. ft. X 0.8035 bu./cu. ft.) = 21,855 bu.

CALCULATING PROTECTANT REQUIREMENTS

Assuming the above example of flat storage of 21,855 bu. how many fluid ounces of protectant and water carrier are required if broad spectrum pesticide is applied at a rate of 10 fluid oz. in 5 gallons of water per 1,000 bushels (ca. 60,000 lbs.)?

  Protectant required = 10 fl. oz. X (21,855 bu./1,000 bu.) = 219 fl. oz. or 1.71 gal
  Water carrier required = 5 gal X (21,855 bu./1,000) = 109 gal water

Thus, 1.7 gal broad spectrum insecticide in 109 gal water / 21,855 bu. corn

CALCULATING PROTECTANT FLOW RATE
Assuming application of 2 gallons of protectant mixture (protectant plus water carrier) to 1,000 bushels of grain, how many fluid ounces of mixture should flow per minute during a calibration test if grain flows through an auger or leg at the rate of 500 bushels per hour?

  Mixture Rate = 2 gal mixture per 1,000 bu. grain
  Grain Flow = 500 bu./1 hour
  Mixture/hour = 2 gal X (500 bu./hr. / 1,000 bu.) = 1 gal mixture/hour
  Mixture/min test = 1 gal X (1 min / 60 min) = 1/60 gal = 0.0167 gal
  or = 0.0167 gal X (128 fl. oz./gal.) = 2.14 fl. oz.

CALCULATING FUMIGANT REQUIREMENT

Assuming a circular bin of 8,300 cubic feet had to be fumigated using aluminum phosphide pellets at the rate of 400 pellets per 1,000 cubic feet, how many flasks are required if 1,660 pellets are in a flask?

  Pellets required = 8,300 cu. ft. X (400 pellets / 1,000 cu. ft.) = 3,320 pellets
  Flasks required = 3,320 pellets / 1,660 pellets per flask = 2.0 flasks
Learning Objectives
You will learn about:
1. Insect growth and development
2. Adult Insect anatomy - external

Biologists have divided all living things into two major classifications referred to as "Kingdoms." These kingdoms are the plant kingdom and the animal kingdom. In general, the plant kingdom consists of all living organisms that are incapable of moving from place to place and use inorganic materials as foods. Animals, on the other hand, are more or less mobile and use organic materials as foods.

Each of the kingdoms is further subdivided into the Phylum, Class, Order, Family, Genus and Species.

GROWTH AND DEVELOPMENT
All insects begin as eggs, but from there the development may take place in several different forms. Eggs may also vary greatly in appearance from the oval small single white egg of a flour beetle to a cockroach's cluster of eggs within a divided egg case. In addition to size and shape, numbers, texture, etc., insects vary greatly in where they will deposit or lay their egg or eggs. Some just drop their eggs in a suitable place. Others may attach them firmly to a food source or surface, or they may bury them to protect their eggs from predators or the environment.

Once insects hatch, they grow in a series of definite stages. As will be explained later in this guide, insects have an external skeleton as opposed to an internal skeleton, and their growth is limited to the size of the skeleton. As an insect develops or grows, it develops a new skeleton within the old. After a period of time, the insect splits and sheds its old skeleton and expands to a larger size before the new skeleton hardens. This process is known as molting and may be repeated from four to eight times for the average insect. The stage of the insect's growth between molts is known as an instar. When referring to the immature form of an insect, they are referred to as first, second, third, fourth, etc., instar, depending on the number of molts that have taken place.

Many insects change not only in size but also in form. This change in form or “metamorphosis” varies within insect groups. Other than size, some insects, like the cockroach, show little difference between an early instar and an adult. However, in other insects, such as beetles and moths, four distinct changes take place in form: egg, larva, pupa, and adult. The four general methods of development among insects are described below.

Without Metamorphosis – Some insects, such as silverfish and firebrats, develop without metamorphosis. The size is the only difference between an early instar and an adult. Food, habits, and environmental requirements are the same. The only major differences between the young and adult are the size and the sexual maturity.

Gradual Metamorphosis - Some insects, such as the cockroach, grasshopper, and termite, develop in three distinct stages: egg, nymph (with several instars), and adult. Again, the young nymphs resemble adults in form and environmental requirements, with the differences being in wing development, size, and sexual maturity.

Incomplete Metamorphosis – Insects within this group, such as dragonflies, damselflies
and mayflies are rarely considered pests. The young are known as naiads and are of a completely different body structure than adults. They are adapted to living in the water. Adults mature with wings and live out of the water. Developmental changes within the body are greater than those with gradual metamorphosis, but less than those with complete metamorphosis.

**Complete Metamorphosis** – The majority of pest insects, including beetles, moths, flies, and ants, are within this classification of development. There are four clearly defined stages of development that exist within this classification of insects. They are the egg, larva, pupa and adult. Each of these stages differs generally in its habits, choice of foods, and appearance.

*Insect development without metamorphosis*
Insect development gradual metamorphosis

Insect development incomplete metamorphosis
Insect development with complete metamorphosis

Generally, the larval stage of development is considered the most destructive to foodstuffs. The majority of all feeding, growth (insect fragments), packaging destruction, and webbing are done in this stage. Normally, the larva is found within a completely different environment than the adult. Because of its destructiveness in this form, it is important that we be able to recognize various insect larval stages and understand their biology and habits.

Larvae vary in form. Beetle larvae have six legs on the thoracic area while moth larvae have six legs on the thorax and legs on the abdomen, known as prolegs. Fly larvae, also known as maggots, are commonly encountered in many areas. Moth and butterfly larvae are often referred to as caterpillars.

After undergoing several molts or instars, the larva develops into the pupa. The pupa, which is often called a resting stage, is when development from the larva into the sexually mature adult (beetle, moth, fly) takes place. During this stage, little movement occurs, with no nourishment or eating taking place.

While some pupae are protected within a silken cocoon, as in moths, others are completely unprotected during this stage. It should be noted that the time required for the pupa stage varies, depending on the insect, environment, and seasonal changes.

After full development of the pupa, the adult insect emerges from the pupal, case, or cocoon. Within this stage, no further growth or development occurs. While several adult forms are responsible for serious damage to foodstuffs and packaging, generally the adult's main function and role is sexual reproduction.

ADULT INSECT ANATOMY – EXTERNAL

An easy method of understanding the insect body is to visualize an elongated tube with appendages arranged along each side of the body (bilateral symmetry). Along this tube, the body is segmented or jointed into three distinct regions: the head, thorax, and abdomen.

Human skeletons are called endoskeletons because they are inside the body. The insect skeleton differs from that of humans in that it supports the body from the outside with an exoskeleton.

The body wall or exoskeleton serves three basic functions: prevention of moisture loss, protection of soft body tissues and vital organs, and provision for muscle attachment.
Basically, this body wall or exoskeleton is composed of three principal layers: the cuticula, which is composed of the epicuticle, exocuticle, and endocuticle; the hypoderma or epidermis; and the basement membrane. The body wall is always one continuous piece, with variations for various functions. Joints may be flexible for movement, and other portions are hard with protective plates or support structures. Other characteristics found on the exoskeleton that are often used in insect identification include sclerites, which are support rings around the body; sutures, which are used as support between sclerites; and setae, which are receptors for the nervous system.

The Head – The antennae, the appendages of the head, are sense organs having the functions of touch, smell, and in a few cases, hearing. Antennae traits (their shape, number of segments, and relative size) are often used to identify various insects. There are several different kinds of antennae, a few of which are listed: Capitate - having a head Clavate - clubbed Filiform - thread-like Lamellate - Leaf-like Moniliform - bead-like Pectinate - comb-like Serrate - saw-like Setaceous - tapering

Insect

<table>
<thead>
<tr>
<th>The Head</th>
<th>The Thorax</th>
<th>The Abdomen</th>
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<tbody>
<tr>
<td>Antennae traits are used to identify various insects.</td>
<td>One set of legs is attached to each segment of the thorax.</td>
<td>The abdomen is made of eleven segments.</td>
</tr>
<tr>
<td>Insects have compound eyes that are sensitive to motion.</td>
<td>Variations in leg size and shape is used in identification.</td>
<td>If appendages are on the abdomen, they're usually related to the reproductive process.</td>
</tr>
<tr>
<td>Mouthparts indicate habits and food preferences.</td>
<td>The forewings on several insects are hard and leathery for protection.</td>
<td>The respiratory system consists of small openings along the abdomen called spiracles.</td>
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Insect eyes differ from those of humans in that they are made up of several separate small lenses, which compose a large compound eye. Instead of a clear image of an object as that received by a human eye, a mosaic pattern is received. While its ability to distinguish form is poor, it is extremely sensitive to motion. The mouth and mouthparts are also commonly used in insect identification. Variations often serve to indicate the habits and food preferences of a particular insect in question. There are six principle types of mouth variations that include: Chewing - beetles, cockroaches, and termites Raspining-sucking - thrips Piercing-sucking - mosquitoes and fleas Sponging - horseflies and fruit flies
Siphoning - moths and butterflies
Chewing-lapping - bees and wasps

The mouthparts of immature insects are often the same as those found in the adult, but in the case of moths and butterflies, the immature larval forms have the typical chewing-type and represent the destructive form.

The Thorax - The middle region of the insect's body is known as the thorax. It is made up of three segments, the prothorax, mesothorax, and metathorax. One set of legs is attached to each segment, and whenever wings are present, the forewing is attached to the mesothorax, with the hind wing attached to the metathorax.

The insect's leg is always jointed and consists of six parts: coxa, trochanter, femur, tibia, tarsus, and pretarsus. The variations in size and shape of these legs are often used in identification, and they can tell much of the insect's habits. Legs are greatly modified between species for running, jumping, grasping, and digging.

Most adult insects have two pairs of wings. While most wings are thin and flexible for flight, the forewings on several are often hard and leathery and are used more for protection than flight. The variations in wing number, size, development, shape, texture, and arrangement are characteristics used in identification.

The Abdomen - The insect abdomen is made up of eleven segments, but because they are often fused together, or because the last segment is reduced in size, it often appears to be less. Appendages found on the abdomen are generally present only on the last segment and are related to sensory functions, which are primarily present for the reproductive process.

Although every insect has the same essential form, minor variations help to identify specific species. See the pictorial guide to cockroaches for an example.

ADULT INSECT ANATOMY – INTERNAL
While insects are very minute animals, their body is designed to perform all the essential functions of life and reproduction as those of higher forms of animal life.

Digestive System - An insect's digestive system consists of a tube that runs the length of the body and contains glands, pouches, and grinding organs structured to aid in digestion. These parts are modified depending on the food and insect. Essentially, insects have the same nutritional requirements as other animals.

Insects that require a high moisture diet, such as flies and cockroaches, usually excrete a moist waste material, whereas a confused flour beetle, which receives its moisture from cereal products that are low in moisture content, uses an organ called the Malpighian tubules to assist in recycling its body liquids.

Circulatory System - The circulatory system for insects is not enclosed with a series of tubes (arteries, capillaries, and veins) as in humans. The blood simply flows through open cavities to various parts of the body. The heart is basically a pulsating tube, equipped with valves to prevent backflow, which picks up blood from the hind portion of the insect, forcing it towards the head.

Respiratory System - Basically, the respiratory system of non-aquatic forms of insects consists of small openings along the body wall called spiracles, which connect to a series of tubes called tracheae. These tracheae carry oxygen directly to the body tissues and cells. Normally, insects draw and expel air by expanding and contracting their abdomens. Several insecticides, particularly fumigants, penetrate the body through the respiratory system.

Nervous System - The nervous system of an insect is made up of a brain located in the head, with a ventral nerve cord made up of
pairs of nerve centers called ganglia spaced throughout the thorax and abdomen. Nerve endings are generally concentrated around the mouthparts, antennae, and tarsi.

Several insecticides are taken into the insect's body through these nerve endings, particularly those sprayed on the walking surface that are picked up through the tarsi of the legs and taken into the body.

**Muscular System** - Muscles within the insect differ from those of humans in that they are attached internally to the exoskeleton. They provide the same basic functions as in other animals: movement, digestion, circulation, and respiration. More than 2,000 different muscles are found in some insects providing an extremely effective, rapid, and powerful system.

**INSECT BEHAVIOR**
Insects vary in their responses to various forms of stimulation, environmental conditions, and chemicals. Understanding these responses for insects needing to be controlled is very important. The responses are not a result of intelligence, but rather reactions, and they result largely from inherited traits. Therefore, each insect within a species will react in the same manner.

Examples of these stimuli, such as light, temperature, moisture, chemicals, touch, gravity, or air currents, could be tested for various species, with no species reacting exactly as another. Some might be attracted to ultraviolet light (insect traps), and others might be repelled, such as a cockroach. Understanding these various behavioral characteristics will assist the sanitarian or pest control operator in controlling insect pests.
Chapter 10
Stored Product Pests

Learning Objectives
You will learn about
1. Stored Product pests and their life cycles
2. Grain Weevils
3. Grain Borers
4. Grain and Flour Moths
5. Grain and Flour Beetles

Insects generally referred to as stored product insects, are those usually found infesting whole grains, such as wheat, corn, nutmeats, etc., and milled or processed foodstuffs. Based on their behavior patterns, stored product insects are divided into two major groups - internal and external feeding insects.

Mealworm - is the common name for the yellowish larva of an insect pest that is widely distributed by commerce and infests cereals and flour in mills and granaries. The larvae are used as fish bait and as pet food for birds and fish. The black adult mealworm is about 1.9 cm (about 0.7 in) long, the larva about 1.2 cm (about 0.5 in) long.

Scientific classification - The mealworm belongs to the family Tenebrionidae, order Coleoptera. It is classified as (Tenebrio molitor).

In addition, the external group is further defined by their feeding habits as scavengers or secondary external feeding pests as outlined below. Stored product insects are divided into four groups, based on their behavior, life cycle and feeding habits.

- Internal Feeding Insects: The eggs of these insects are laid within the grain. The larvae feed entirely inside the kernel of grain (Granary weevil).
- External Feeding Insects: The larva feeds outside the kernel inwards (Indian meal moth).
- External Scavengers: These feed on grain only after it has been broken or has been damaged by other insects (Confused flour beetle).
- Secondary External Feeding Insects: These feed on materials in poor condition that usually have mold growth and are damp (Flat grain beetle).

INTERNAL FEEDING INSECTS
Weevils, lesser grain borers, and Angoumois grain moths are all internal infesting insects. Their larvae infest whole and damaged grain and develop within the grain kernel, emerging as adults. Included below are descriptions of their life cycles and habits.

Figure 10.1 Granary Weevil

Granary Weevil – (Sitophilus granarius) (L)

The egg, larva, and pupa are found within the grain kernel, so they are rarely seen. The larva is legless, with a small, capsules, and tan-colored head. Adults are 1/8-1/4 inch (3-4.8 mm) in length. They may often be the smaller size. The adult is uniform in color, blackish or chestnut-brown, with oval or elongated pits on its thorax (area between the head and wing covers). Its wings are poorly developed, and it cannot fly. The adult insect
has a long, downward curved rostrum or beak that is readily distinguishable.

**Life History** - Adults prefer a temperate climate and are more commonly found in the northern states, but they are cosmopolitan in their distribution. Adult insects may hibernate during the cold winter months and revive and resume egg laying when it gets warm. Both adults and larvae are voracious feeders on wide varieties of grains. Adults generally live an average of seven to eight months, with the females laying from 50 to 250 eggs during their lifetime. There are four instars that require 19-34 days for development. Females, using their mandibles, bore small holes into the grain kernels, lay one egg in each hole, and then cover the hole with a gelatinous seal. Since the larvae are cannibalistic, only one egg is deposited per kernel. The life cycle is defined as complete metamorphosis and can be completed in 1-5 months depending on conditions and temperatures.

**Figure 10.2 Rice Weevil**

**Rice Weevil** – *Sitophilus oryzae* (L)

As with the granary weevil, the egg, larva, and pupa are rarely seen since they develop entirely within the grain kernel. The larvae are legless, thickened in the middle (humpbacked) and have a tan colored head. Adults are smaller than the granary weevil, with the average size being around 1/8 inch (2.5-3.5 mm) in length. The adults vary in color from a reddish-brown to nearly black, with four light-colored (reddish or yellowish) paler marks on the wing covers. The thorax is covered uniformly with round or irregularly shaped pits, differing from the oval pits found on the granary weevil. The wings are fully developed, and the rice weevil can fly and is attracted to light. The rice weevil also has a downward curved rostrum or beak.

**Life History** - The rice weevil is found worldwide and is considered one of the worst pests of stored grains, particularly in warmer climates. The adult lives between 3-6 months, and each female will lay from 300 to 400 eggs during its life. Their early life stages are almost identical to the granary weevil, but it is reported that their life cycles can be as short as 32 days under ideal conditions.

**Figure 10.3 Lesser Grain Borer**

**Lesser Grain Borer** – *Rhizopertha dominica* (F)

Related to the woodborer family of insects, the lesser grain borer lives off and destroys a variety of whole grains and milled products. The head is tucked under the thorax and is not visible from above. Their wings are well developed, and they are excellent flyers. Adults are about 1/8 inch (3 mm) long and shiny dark brown to black in color. Antennae have the shape of a club with three large segments on the end.

**Life History** - Lesser grain borers are cosmopolitan in distribution and are particularly damaging pests during warmer seasons. The larva appears as a whitish grub and crawls actively. Both the adult and larva are destructive, damaging not only grains and milled products, but also packaging materials. Females lay 200 to 500 eggs during their life,
depositing singly or in clusters on finely milled or damaged kernels. Larvae will either bore into grain kernels or develop in damaged or milled particles. Eggs hatch in a few days. There are 2-5 larval instars that require about 17 days for completion. Development time (egg to adult) averages 58 days which can be shortened to as short as 3-4 weeks during warmer weather (93° F/34° C).

Angoumois Grain Moth – (Sitotroga cerealella Olivier spp.)

The Angoumois grain moth is a small buff or yellowish-brown moth, with a wing expanse of about 1/2 to 5/8 inch (12-17 mm). They are often found infesting grain fields. The hind wings are gray, with long hairs along the edge. A notch on the hind wing gives a pointed appearance (accusing finger), which makes it easy to differentiate this moth from other moths.

Life History - The Angoumois grain moth is cosmopolitan in distribution. Under normal conditions, the female lays about 40 eggs singly or in small groups on the grain kernel. The eggs turn red and larvae hatch in four to eight days. After the first instar, they bore into the grain kernels and pass through three instars in about three weeks. Pupal period lasts 10-14 days. In warm climates, a complete life cycle (egg to egg) can take 5 to 7 weeks but in cooler conditions may require 6 months. There are 2-5 generations per year generally but there may be 10-12 in heated structures. The larva feeds on the endosperm and germ, developing through the instar stages. Prior to pupation, the larva channels to the outside of the seed and constructs a weakly fastened flap through which it exits after developing into an adult.

EXTERNAL FEEDING INSECTS

These insects include those most commonly found feeding on ingredients and finished products in food plants and warehouses. The following describes the life cycles and habits of the selected insect species.

Indian Meal Moth – (Plodia interpunctella)(Huh)

The mature larvae are about 1/2 inch (9-19 mm) long when fully grown. Their colors vary from a dirty white to tinted green to pink depending on its food. Like all moths, they can be easily identified from beetle larva by their prolegs (legs found on the abdomen). When found in large numbers, the larvae can cause severe damage by the webbing they deposit as they move along the surface of ingredients and equipment.

The larvae will normally form a silken cocoon in the corner or wall junction or within a tight crevice, such as a cardboard corrugation, and pupate until they emerge as adults.

The adults are approximately 3/8 inch (9 mm) long, with a wingspread of about 5/8 to 3/4 inch (16-20 mm). They are easily recognized
by the coloration on the wing, a reddish-brown (copper luster) band on the last 2/3 of the front wings. Indian meal moths are excellent flyers and are easily recognized from a distance when at rest on a light-colored surface.

**Life History** - Females will lay from 100 to 400 eggs, either singly or in clusters on food materials during a 1-18 day period. Larvae hatch after only a few days, crawling throughout their foodstuffs, leaving a silken web as they go. Heavily infested foods will often be seriously damaged as a result of this matting. Indian meal moths feed only during their larval stage, with the adult only living for one to two weeks, functioning in reproduction. Larval stages can last 13-288 days dependent on conditions.

The larvae prefer course-milled products, such as whole-wheat flour and cornmeal, but they will attack all grains and grain products, nutmeats (almonds, peanuts, pecans, walnuts), dried fruits (raisins, figs, prunes, currants), beans, candies, spices, garden seeds, and dry pet foods.

There are usually 4-6 generations per year with a life cycle (egg to egg) typically requiring 25-135 days. Larvae are reported to be very resistant to low temperatures, spending long periods during cold weather in their larval stages and then developing into adults quickly.

**Cigarette Beetles** - *(Lasioderma serricorne)* *(F)*

**Drugstore Beetles** *(Stegobium paniceum)* *(L)*

Both species are similar in appearance and are closely related. Larvae are grub-like in appearance and about 1/16 to 1/8 inch (2-3 mm) in length when fully grown. Pupae are difficult to see because they are concealed within cells of cemented food particles.

The adults vary in size, but they are usually about 1/16 to 1/8 inch (2-3.5 mm) in length and reddish-brown in appearance. The cigarette beetle and drugstore beetle differ in appearance in that the cigarette beetle appears very smooth and silky, while the drugstore beetle has distinctly striated wing covers. In addition, the cigarette beetle appears humpbacked in appearance, while the drugstore beetle is more cylindrical in shape. Both insects are excellent flyers.

**Life History** - Cigarette beetle females lay 30-40 oval eggs (in or around food materials) that hatch in 6 to 20 days. There are 4 to 6 instar periods. The complete life cycle (egg to egg) requires 30 to 90 days with 3 to 6 overlapping generations per year. Adults may live from 23 to 28 days.

Found throughout the world, both insects are very general feeders, attacking a great variety of foods and other materials. It has been said that they will eat anything, except cast iron. Feeding on almost anything organic, they have been found in drugs, tobacco, grain and
grain products, beans, powdered milk, dried flowers, seeds, spices, nutmeats, yeast, leather, wool, bamboo, furniture stuffing, paste, hair, and straw. The cigarette beetle is particularly good at finding small amounts of product residue left in equipment and establishing a breeding location.

EXTERNAL SCAVENGERS

Figure 10.8 Red Flour Beetle

Red Flour Beetles – \(Tribolium\ castaneum\) (Hbst)

Confused Flour Beetles – \(Tribolium\ con, fusum\) (DuV)

Both the red and confused flour beetles are very similar in appearance and are very closely related. The adults can be distinguished with the use of a magnifying glass by looking at the antennae segments, which show a gradual increase in size of segments from the base on the confused flour beetle to an abrupt increase (club like) in the last three segments on the red flour beetle. The distance between the eyes also differs between these species. The eyes of the confused flour beetle are twice as far apart as the eyes of the red. The larval stages of the two insects are so similar that it is very difficult to distinguish between them.

The larvae reach a length of about 1/8-1/4 inch (4-5 mm) and are a cream to yellowish color. They are slender in appearance, with two pointed projections at their tails. Adults are shiny reddish brown, with a flattened appearance about 1/8 inch (3-4 mm) in length. The red flour beetle has fully developed wings and is a good flyer, while the confused flour beetle cannot fly and has poorly developed hind or flight wings. Both species are attracted to light and may appear in light traps being used in a food plant.

Life History - Females lay approximately 300-500 clear/white sticky eggs on or among food items, normally within the first three months of adulthood. Eggs are laid loosely in flour or other food material in which the adults live. Females lay 2-3 eggs per day. Eggs hatch in 5 to 12 days. After hatching these beetles go through 5 to 18 instars (usually 7-8) and reach maturity in 30 days under optimum conditions. Life cycles (egg to egg) can be completed in as little as 7 weeks or may require up to three months depending on conditions and temperature. Life spans have been reported in excess of three years, but on the average, the adults live for about one year.

Both red and confused flour beetles are found throughout the world, but confused flour beetles are more commonly found in cooler climates, while red flour beetles predominate in warmer climates. Flour beetles may be found deep within the food material or along the surface. In fact, often these insects are found infesting a bag of flour and are never seen from the outside.

Flour beetles are found infesting all cereal products, including flour, oats, rice, rye, bran, breakfast cereals, etc. They are common pest insects in processing plants, warehouses, distribution vehicles, retail stores, homes, etc.; anywhere that foods are processed,
stored, or handled. Although they are not harmful to humans, they do impart a disagreeable odor and taste to the flour they infest.

Figure 10.10 Saw-toothed Grain Beetle

Saw-toothed Grain Beetles – (Oryzaephilus surinamensis)(L)

Figure 10.11 Merchant Grain Beetle

Merchant Grain Beetles – (Oryzaephilus mercator) (Fauv)

Both the saw-toothed and the merchant grain beetles are closely related and are similar in appearance and habits. The egg, larva, and pupa of both species are similar. Adults both have similar characteristics, including six saw-toothed projections on each side of their thorax. The diagnostic characteristic used in identification is the location of the eye. The eye on a merchant grain beetle appears to be larger than that of a saw-toothed grain beetle, and it is set back on the head, with the eye of the saw-toothed located about a third of the way up from the back of the head.

The adults are about 1/8 inch (2.5-3 mm) in length and brown, with a flattened body. Adults are often not easy to see. They become very inactive after being disturbed, then move rapidly along flat surfaces when left alone for a short period of time.

Life History - Female saw-toothed grain beetles lay approximately 45-285 white shiny eggs in small clusters during a 2 to 5 month period, with merchant grain beetles laying about 22-150 eggs over several months. Adults live an average of six to ten months. Both saw-toothed and merchant grain beetles are found throughout the world, with the merchant grain beetle preferring warmer climates. Their life cycles are both similar. Under ideal conditions, it can be as short as four weeks but under poor conditions a life cycle can take over a year.

Both species are found infesting a wide variety of foodstuffs, from ingredients to finished products, with the merchant beetle more commonly found in cereals including rolled oats, rice flour, cake mixes, macaroni and cookies. Saw-toothed grain beetles are commonly found in cereals, bread, breakfast foods, macaroni, dried fruits, nuts, sugar, chocolate, dried meats, candy bars, drugs, tobacco, and snuff.

SECONDARY EXTERNAL FEEDING PESTS

Flat Grain Beetles – (Cryptolestes pusillus) (Sch)

Figure 10.12 Flat Grain Beetle
The flat grain beetle and the rusty grain beetle are the smallest beetles commonly found in stored food products. They are small, flattened, oblong, reddish-brown beetles about 1/16 inch (2 mm) long. The male flat grain beetle can be distinguished easily from the rusty grain beetle in that the flat grain beetle's antennae are about 2/3 as long as the body, whereas the rusty grain beetle's antennae are not more than 1/2 the body length. Female beetles and larval stages are so similar in appearance and habits that distinguishing between rusty and flat is very difficult.

**Life History** - Females will lay approximately 200 eggs during their life span. They lay small white eggs in crevices in the grain or loosely in particles of foodstuffs. Larvae are found particularly in wheat germ and are commonly found feeding on dead insects.

When fully grown, the larvae form cocoons of gelatinous substance to which food particles adhere. They transform into the pupal stages in these cocoons and later emerge as adults. Under ideal conditions, their life cycles can be as short as five weeks.

Both insects are cosmopolitan in their distribution, but the rusty grain beetle is more resistant to cold weather and is more commonly found in the northern states and Canada.

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**Cadelle Beetles** – *(Tenebroides mouritonicus)* (L)

Adult is an elongated, oblong, flattened, black or blackish beetle about 1/3 inch (8 mm) in length. The cadelle is easily identified by the visible gap between the rear of the prothorax and the front edge of the wing covers that creates an hourglass shape. Cadelle larvae are the largest of the grain-infesting insects and are easily recognized by the two dark, horny points at the end of their abdomens. About 3/4 inch (20 mm) long, the larva is very fleshy and a dirty to chalky white, with a black thoracic shield and two horny points.

**Life History** - The cadelle beetle is one of the longest-lived of all the stored product insects, living between one and two years. The female lays eggs for most of her life, depositing about 1000 eggs under favorable conditions, usually in batches of 60-100. Eggs are laid in clusters in food materials, with the larvae hatching within two weeks.

Both the larvae and adults can live for long periods without food and often remain hidden in cracks and crevices or bore into woodwork until more favorable conditions exist. Cosmopolitan in their distribution, these insects are commonly found infesting mills, granaries, and storehouses, where they infest flour, meal, and grain.
Life cycles are dependent on the environment and can extend from 48-414 days. Larva may molt three to seven times with the average being four.

**DERMESTIDS OF THE GENUS TROGODERMA**

Within the Dermestid beetle family there are a few members of the *Trogoderma* genus that are considered important pests of stored food products, the Khapra beetle *T. granarium*, and the warehouse beetle, *T. variable*. Accurate identification of Trogoderma species is very difficult at best and will need to be conducted by an entomologist familiar with the morphological characteristics of this group of beetles. In suspected cases of Khapra beetle infestations a positive identification becomes very important to aid in eradication/quarantine efforts within the United States.

![Figure 10.15 Khapra Beetle](image)

**The Khapra Beetle (*Trogoderma granarium*)**

The Khapra beetle, considered to be one of the world's most destructive pests of grain products and seeds, probably originated from regions now including India and Bangladesh, but has since spread to other areas including northern and eastern Africa, southern Europe and the Mediterranean region, the Mideast, and east into Asia. The Khapra beetle is under Federal quarantine and requires instances of this pest to be reported to APHIS as soon as possible. This pest thrives in warm, dry climates. Populations build rapidly in a short time under hot, dry conditions, but can survive in colder climates in heated situations such as warehouses, food plants and grain storages. The beetle cannot fly, and is therefore spread mainly by commerce and trade. The problem of preventing the beetle's spread is compounded by its ability to survive for several years with little food, and its habit of hiding in cracks, crevices and even behind paint scales or rust flakes. The Khapra beetle, if left uncontrolled, can make the surface of a grain in storage appear alive with crawling larvae. This species is considered to be a dirty feeder, breaking or powdering more kernels than it consumes. They not only consume the grain, but may also contaminate it with body parts and setae that are known to cause adult, and especially infant, gastrointestinal irritation.

Hosts-In addition to the obvious grain and stored product hosts, the beetle has been found in many locations that would not be obvious food sources, unless one realizes that the insect is by nature an omnivorous protein scavenger. It has been found in the seams and ears of burlap bags and wrappers, in baled crepe rubber, automobiles, steel wire, books, corrugated boxes (glue), bags of bolts, and even soiled linen and priceless oil paintings. It is frequently intercepted on obvious food products such as rice, peanuts, dried animal skins, as well as its preferred natural foods such as wheat and malted barley. Such infestations may result from the storage of the product in infested warehouses, by transportation in infested conveyances, or from re-use of sacks or packaging previously used to hold material infested by Khapra beetle.

Detection may be accomplished by trapping or visual inspection. A Khapra beetle trap developed by the USDA is commercially available. See previously released trapping guidelines (FACTS-34) for more information. When using traps, be aware that a trap will only indicate that the species is present if trapped, but that negative trapping results shall never be used as absolute proof that the insect is not present. Inspecting for Khapra beetle is difficult and meticulous due to the small size of the insect, its habits, and the difficulty of identifying small or damaged specimens.
High-risk areas that should be checked first include:

- cracks in walls and floors
- behind loose paint or rust
- along pallet, and the end-grain of pallet wood
- seams and ears of burlap bags
- low light areas
- trash from cleaning equipment, and the equipment itself.

Low risk areas for inspection include:

- well-lighted areas
- areas of dampness, moisture, or where debris is moldy
- areas that are oily, such as floors.

To assist the inspector in drawing cast skins or dead adults out of cracks and crevices, and to pick up debris, vacuum cleaners can be used. Vacuum cleaner filters must be changed between inspection locations.

Life cycle and description - The classic telltale sign of a Khapra beetle infestation is the presence of cast skins and larvae. The larvae are yellowish to golden brown. They are clothed with fine setae, and there are tufts of barbed setae on each side of the terminal abdominal segments. Adults are oval shaped, brown to blackish, and with indistinct lighter brown patterns on the elytra. They may appear slightly hairy on top under a microscope. These hairs may trap dust, giving a dirty appearance. In older adult specimens the hairs may be rubbed off. Mature larvae are about one-quarter inch long, and adult females are about one-eighth inch long with males somewhat smaller. They pass through 4-7 molts during the larval stage, resulting in numerous cast skins. Adults are short-lived, persisting only for one to two weeks, but only for a few days at temperatures over 100 degrees F. Adult activity is seldom noticed. They are more active during mid-day if the light is subdued, and prefer to avoid the light until they are of older age. Dead adults are not often found since larvae may cannibalize them, leaving only fragmentary remains for identification.

Mating occurs almost immediately after adult emergence, with oviposition for one to six days following. Eggs hatch in five to seven days. Larval development may occur in four weeks, but under cooler temperatures, crowding, poor food quality, or frass buildup, the larvae may enter a quiescent condition. They may persist for months, even as long as one to three years with little or no food in this diapause-like condition. Quiescent larvae may aggregate in large numbers in cracks or other hiding places. They may periodically wander in search of food, but then return to hiding for extended periods.

The Warehouse beetle adult is brownish black, 1/8 inch (3.2 mm) long with a molted pattern of brown against a dark background on the wing covers. The larva is about 1/4 inch (6.3 mm) long and will vary in color from a yellow white to dark brown. Females lay up to 94 eggs over several days. The eggs can reach adulthood in 32-43 days depending on the temperature. “The male larvae undergo five molts and the female six prior to pupation. Adult warehouse beetles are capable of flight.” (PCT Field Guide, p. 104, Stoy Hedge & Dr. Mark Lacey)

As with other Dermestids, the hairs or hastisetae from the larval molt skins can cause moderate to severe irritation of the intestines if ingested by humans. Infants are especially susceptible. The eyes can become irritated through airborne contamination while cleaning areas where large numbers of larval
cast skins are present such as electrical boxes or insect light traps. When insect light traps are utilized, they should be maintained on a regular cleaning schedule so that they do not become an infestation source of dermestid beetles.
Chapter 11
Structural Pests

Learning Objectives
You will learn about:
1. Insect pests and their life cycles
2. Drywood termites and their life cycles
3. Rodents and their life cycles

COCKROACHES
In general, their shape is flat, with long spiny legs, and they are capable of quick movement. They can easily squeeze into small cracks and crevices, hiding in voids and below equipment bases. As described earlier, cockroaches develop through gradual metamorphosis (egg-nymph-adult). The adults are sexually mature, with fully developed wings. The nymphs resemble the adult, except for the absence of wings and size.

Their wide range, mobility and association with food processing, warehouses, restaurants, and hospitals make them dangerous potential pathogen carriers. Included below are descriptions and life cycles of the four most common cockroaches found in North America.

Figure 11.1 German Cockroach
German cockroach – (Blattella germanica) (L)

Adults are approximately 1/2 to 5/8 inch (13-16 mm) in length and are light tan to light brown in color. As mature adults, their wings cover the rear of their bodies. Two dark stripes (lengthwise) on the side (top) of each pronotum clearly distinguish them from other species. Immature German cockroaches resemble adults, except they are wingless and generally darker in color, often appearing black.

Life History - The female German cockroach differs from most species in that she carries the egg capsule protruding from her abdomen until the eggs are ready to hatch. Often females will drop their egg cases earlier, as a result of contact with an insecticide or other stress. The premature dropping of eggs normally increases the mortality rate of the cockroaches in the egg capsule.

Both nymphs and adults prefer dark crevices or hidden areas during daylight or lighted periods and become very active at night. German cockroaches are generally found in moist areas and near their food source. As a general rule, German cockroach nesting sites will be within a fifteen-foot sphere of where the sighting occurs. They are excellent climbers and are often found along overheads and upper false wall panels or cabinets. Every void space, crack or crevice 3/8 inch (10 mm) or less should be thoroughly investigated as part of the survey for activity.

The German cockroach is considered a general feeder, eating varieties of starch foods, syrups, glues, etc. When stressed, this cockroach will eat just about everything including their young and their fecal material. While the German cockroach has fully developed wings, it rarely flies. It gains easy entry into most areas, packages, and equipment through its ability to climb and enter small cracks and openings.

The most common cockroach found in food processing facilities, the German cockroach is often harbored in a wide variety of buildings, equipment, transport vehicles, and packaging. Its complete life cycle is 54-215 days with an average of 103 days. The female produces 4-8 ootheca each averaging 30-40 cockroaches in each. Adults live an
average of 100-200 days depending on conditions. A typical German cockroach population consists of about 75% nymphs or immature cockroaches.

Recent studies indicate that the gravid or pregnant female will remain deep in a harborage area and not eat for up to six weeks during the gestation period. Once the egg has been dropped, the female resumes feeding to replace body fats and may again become pregnant. This behavior by the female must be taken into account when treating for this species. The offspring of the sequestered females may become the population that re-infests your facility in a very short time.

Brown-banded cockroach – (*Supela longipalpis*)

Adults are approximately 1/2 inch (13-14 mm) long and are light tan to dark brown in color. Both immature and adult females are broad in appearance from the top. Adult males appear slender, with wings covering the abdomen and can fly where females of this species cannot. In comparison to the German cockroach, the brown-banded cockroach has two light-colored (cream) bands running across its back. The bands are generally more pronounced on the immatures and adult females.

**Life History** - Females cement their purse-shaped egg capsules in place along the sides or under surfaces of infested areas. Adult and immature brown-banded cockroaches are generally found inhabiting the same areas, preferring temperatures of 80°F (23° C) or higher. They do not require as much moisture as the German cockroach does, and they are often found infesting areas away from wet or damp environments. Brown-banded cockroaches are similar to other cockroaches in that they prefer dark, unlighted areas and are rarely seen during the day.

Brown-banded cockroaches are excellent climbers and are often found in similar areas as the German cockroach along overheads, upper walls, and throughout equipment.

More common in the southern regions of North America, brown-banded cockroaches are found throughout Midwest and northeast temperate areas, thriving in heated buildings and areas.

Brown-banded cockroaches prefer starchy foods, but are considered general feeders. Moisture requirements are lower than most other roaches, allowing them a wider environment. The adults are considered fair flyers.

American cockroach – (*Periplahceta americana*)

Adults are reddish brown in color, except for a light tan border around the pronotum. The adults are approximately 1 3/8 to 2 1/8 inches (3453 mm) in length, with both males and females having fully developed wings. The immatures resemble adults, except they are wingless.
**Life History** - Females deposit their egg cases (from a few hours up to 4 days from when the case is formed) near food sources or along unkept areas where they may be covered with debris or attached and hidden. In warmer climates, the females often deposit their eggs along outside areas in decaying materials. Depending on climate, the life cycle from egg to adult averages seven to twelve months.

Both adults and nymphs prefer dark, moist areas near wet processing areas, below equipment, around sewers, and along basement walls, floors, and ceilings. They are also commonly found along steam-heated pipes where the insulation is poor. Throughout the southern U.S., American roaches are commonly found surviving outside in areas where there is decay close to garbage and unkept areas.

They are considered general feeders, but they prefer decayed organic matter, along with glues, bookbinding, syrups, etc. Infestations are generally found near their food supply.

Adults, while having well-developed wings, seldom fly; they gain easy entry into buildings, equipment, and sewers through crawling and their ability to climb. At 84°F/29°C females live an average of 225 days as adults. Males live about 200 days as adults. At average room temperatures the adult female may live 440 days.

Both nymphs and adults have similar habits. They are found in dark, decayed areas along moist areas of basements, sewers, drains, etc. Oriental cockroaches are rarely found very high off the floor or in walls. They are slower in movement than most cockroaches and are usually found along the floor and basement areas of buildings and equipment bases.

They are considered general feeders, preferring dirty, unkept areas of decaying organic materials. The life cycles are approximately 1½ years.

**TERMITES**

**DRYWOOD TERMITES** (*Incisitermes minor*)

Unlike the Subterranean termite, they do not require any contact with the soil. They live in undecayed wood with low moisture content. Although the drywood termite is not native to this region they can be transported in wood products from other regions.

**Description** - Individuals are in distinct forms or castes - reproductives, workers, and soldiers. Each performs a separate biological function. Only the reproductives are winged (4 wings).

There are no workers in the drywood termite group - instead the young reproductives and...
soldiers serve as workers until they mature. The vast majority in the colony is the worker caste and the workers and the reproductives have chewing mouthparts especially adapted for chewing wood. It is the workers who do the widespread destruction. The soldiers have powerful mandibles to attack their enemies (usually ants).

Male and Female reproductive are up to 1/2 inch long. Bodies soft and cylindrical in shape, usually pale brown in color; six legged; they have compound eyes and chewing type mouthparts. During the winged stage there are 4 equal size wings that extend longer than the body by 1/8-1/4 inch.

Diet - Wood and occasionally other cellulose materials. They eat wood in houses, utility poles, furniture and dying trees. They cannot digest the cellulose directly. They have other microorganisms (protozoans and bacteria) in their stomachs that help break down the cellulose that then can be digested by their own metabolism.

Habitat - They live in small social colonies in dry wood. They mate and fly to new dry wood areas enter a small hole in the wood and start to form a colony. In the first year, colony size may be only around 50. After 4 years, there may be as many as 700 individuals in one colony. At this time, the colony may swarm to start the cycle over again. After 15 years, the colony will have grown to approximately 3,000 individuals. They do not need a source of water and live off of the water that is produced from the digestion of the cellulose.

They infest dry, undecayed wood, including structural lumber as well as dead limbs of native trees and shade and orchard trees, utility poles, posts, and lumber in storage.

The Drywood variety has a low moisture requirement and can tolerate dry conditions for prolonged periods. They remain entirely above ground and do not connect their nests to the soil. Piles of their fecal pellets, which are distinctive in appearance, may be a clue to their presence.

From these areas, winged reproductives seasonally migrate to nearby buildings and other structures usually on sunny days during fall months.

This type is usually found in the humid coastal and subtropical regions (i.e. California, Hawaii, Florida, Arizona, South and North Carolina, New Mexico, Texas, Alabama, Mississippi, Louisiana and Puerto Rico). They usually infest attic spaces or exterior wood members exposed to them when they swarm in early spring or summer.

POWDER POST BEETLES

Powderpost Beetle – (Lyctus planicollis) (LeC.)

Powderpost beetles can be found in dead wood as well as dried and cured lumber. Damage occurs to many wood products such as rafters, joists, flooring, molding, paneling, crating, furniture, antiques, tool handles, gunstocks, fishing poles and baskets. Sometimes homeowners hear rasping or ticking in the wood at night, notice a blistering appearance on the wood, see powdery frass piled below holes in the wood, find numerous round or oval exit holes at the wood surface, and even collect powderpost beetles around windows or lights. Mistakes are sometimes made determining if the infestation is active or non-active.
Identification – the powderpost beetle is a term used to describe several species of wood-boring insects. Adult Lyctids are flattened, slender, reddish-brown to black, varying from 1/32 to 1/8 inch long. The basal abdominal segment is long, and the antenna bears a club of only two segments. The head is visible from above. Mature larvae are C-shaped, slightly hairy with three pairs of spine-like legs, and yellowish-white with a brown head. The frass is fine flour or talc-like and loosely packed in tunnels. Large quantities often fall out at exit holes and cracks.

Figure 11.7 Powderpost beetle wood damage
(exit holes and frass)
Wood Damage by Powderpost beetles

Adult anobiid beetles have slender, cylindrical bodies, are reddish-brown to nearly black and range from 1/16 to 1/8 inch long. In most species, the head is bent downward. The widest point of the thorax is slightly forward of the base, tapering backward and appearing as a rough, diamond-shaped outline. Larvae are C-shaped and nearly white except for a dark head. The frass is fine to coarse, pellet-shaped, usually a gritty quality and packed loosely in tunnels. There also is a small amount of frass around the exit holes.

Figure 11.8 Bostrichid Beetle

Adult bostrichid beetles, 1/32 to 3/8 inch long, are cylindrical in most species, dark brown or black, with a roughened thorax. Antennae bear a club of three distinct segments. The head is usually not visible when viewed from above. Larvae are C-shaped; the body segments immediately behind the head capsule are much wider than the body segments at the rear. The frass is fine to coarse, tightly packed and tends to stick together.

Life cycle and habits – Lyctid beetles attack only large-pored hardwoods such as oak, ash, hickory and mahogany. They attack "seasoned hardwood" and sapwood timbers found in woodwork molding, window and door frames, plywood, flooring, structural wood, furniture, tool handles and firewood. Pine and soft woods are not normally attacked. Adult beetles can emerge from wood stored in the home and infest structural wood or furniture. Lyctids rarely infest wood older than five years. Infestations usually result from wood that contained eggs or larvae when placed in the home. The wood could have been improperly dried or stored. Adult exit holes are round and 1/32 to 1/16 inch in diameter. Larvae cause the damage.

Anobiid beetles may attack both hardwoods and softwoods, which means that infestations may be found in all the same places as Lyctid beetles as well as in structural timbers (beams, sills, joists, studs, subflooring, etc.). Maple, beech, poplar and pine are especially susceptible to attack. Anobiid beetles prefer to infest wood that is damp; therefore, infestations usually begin in moist, poorly
ventilated areas such as crawl spaces, basements, garages and utility sheds. Under favorable conditions of moisture and temperature, infestations may spread upwards into walls and upper levels of the structure, including furniture. Infestations may occur as a result of using infested lumber, or from beetles flying in from outdoors or being carried in on firewood. Infestations develop slowly, but wood can be re-infested year after year. Anobiid beetles are called deathwatch beetles because in the past superstitious people believed the ticking one species makes foretold impending death in the household. Adult beetles make the sound during the mating season by tapping their heads on a hard surface. They attack seasoned softwood, hardwood, sapwood and heartwood found in woodwork, flooring, structural wood, furniture, tool handles and sometimes firewood. Exit holes are round and 1/16 to 1/8 inch in diameter.

Bostrichid beetles are more abundant in the tropics. The bamboo powderpost beetle is found in baskets, picture frames, furniture and other imported bamboo material. These insects attack unseasoned and seasoned softwood, hardwood and sapwood, and are often found in dying trees or recently felled logs as well as seasoned lumber and wood products. Adults rarely re-infest wood. Adult exit holes are round and 3/32 to 9/32 inch in diameter. Both larvae and adults cause the damage.

Adult females lay eggs on or in the pores of bare, unfinished wood. Eggs hatch into tiny larvae that tunnel through the wood. Adults emerge one to five years later, usually April-July through holes cut to the wood surface by the larvae. Adults are short lived, active at night and may return to the same wood or go elsewhere, lay eggs and start a new life cycle. It is the damage that homeowners are more likely to see.

The length of the life cycle for Lyciptis is three months to one year, for Anobiid beetles one to three years and for Bostrichid beetles about one year. Some wood-boring beetles complete the life cycle in a few months, while others live in wood 30 years before emerging.

Detecting Infestations - The key to avoiding serious problems from powderpost beetles is early detection. Homeowners are much more likely to see damage than the beetles themselves. Since tunneling and development of the larvae takes place entirely below the wood surface, the only signs of infestation are the emergence holes made by the adults and the powder-like frass sifting from the holes.

Lycipt or Anobiid beetles - Knowing how to differentiate lyctid from anobiid beetle damage is more than academic since Anobiid beetle have a broader range of woods that they can potentially infest. Both lyctid and anobiid beetles chew small, circular emergence holes in the surface of wood. Holes made by Lyctid beetles are about the diameter of a pinhead whereas exit holes made by anobiid beetles are slightly larger. One way to differentiate holes of the two species is to insert a "click-type" (refillable) ballpoint pen into the exit-hole; only the tip of the ball will fit through lyctid beetles emergence holes. If an anobiid beetle made the hole, the tip of the pen will enter part way up the angled face of the point.

Another way to differentiate powderpost beetles is from the consistency of the powder (frass) that sifts out of the exit holes. Lyctid frass is extremely fine and feels like talc when rubbed between the fingers. Anobiid frass is also powder-like, but feels gritty.

Active or inactive infestations - Infestations sometimes die out on their own accord. Therefore, it is important to be able to determine whether the infestation is active or inactive. Active infestations will usually have powder the color of fresh-cut wood sifting from the exit holes. In contrast to old, abandoned holes, new holes will not have taken on the weathered appearance of the surrounding wood. Powder streaming from
recently opened holes may accumulate in small piles beneath the exit holes. If these piles of powder are covered with a film of dust or debris, the damage is old. Careful observation may be required to distinguish new powder from frass that has been dislodged from old larval galleries by vibrations.

One final means of confirming that an infestation is active is to mark or seal any existing exit holes. Use crayon or tape over the holes to see if more holes appear. Sweep up all powder, and recheck the wood for new holes and powder at a later date. Since most emergences occur from April-July, it might be worthwhile to wait until the following spring to determine if new holes and fresh powder are present. This is especially true when attempting to make a determination during the fall or winter months.

Control - Homeowners should know that there are various options for control. Selecting which is best depends on a number of factors including the severity of infestation, area being attacked, potential for reinfection and treatment expense the customer is willing to bear. POWDERPOST BEETLES DAMAGE WOOD SLOWLY; thus, homeowners should not feel as though they must act immediately in order to preserve the structural integrity of their home. A "wait and see" approach is often desirable, especially when there is still doubt as to whether the infestation is active.

Prevention - Most powderpost beetles are introduced into homes in lumber or finished wood products (e.g., furniture, paneling or flooring). Lumber that has been improperly stored or dried should not be used, particularly if beetle exit holes are present. Many of the most serious infestations arise from clients who used old lumber from a barn or woodpile behind their house to panel a room or build an addition.

Powderpost beetles will only lay their eggs on bare, unfinished wood. Wood that is painted, varnished, waxed or similarly sealed is generally safe from attack provided no unfinished surfaces are exposed. Bare wood can be protected from attack by painting or finishing exposed surfaces. Beetles emerging from finished articles such as furniture were usually in the wood before the finish was applied. (Note: beetles emerging from finished wood can, however, re-infest by laying eggs in their own exit holes; sealing the holes prevents this possibility.)

Moisture control - Powderpost beetles, especially anobiid beetles, have specific moisture requirements for survival. Since wood moisture levels below 13 percent (during spring and summer) are generally unsuitable for anobiid development or reinfection, it’s advisable to install a moisture barrier in the crawl space of infested buildings. Covering the soil with four to six mil polyethylene reduces movement of moisture into the substructure and reduces the threat of an infestation spreading upwards into walls and upper portions of the building. Most beetles do not develop in wood with moisture content below 10 to 15 percent.

Another way to lower moisture content in damp crawl spaces is to increase ventilation. This can be accomplished by installing foundation vents (one square foot of vent area per 150 square feet of crawl space). Moisture meters, used by some pest control operators, are useful tools for predicting the potential reinfection in wood.

Wood replacement - If the infestation appears to be localized (e.g., only a few holes in a board or sheet of paneling), simply replacing the board or sheet of paneling may solve the problem. If additional holes begin to appear in adjacent areas, additional action can then be taken.

Kiln dried lumber - For new construction, use kiln-dried lumber (dried a minimum of eight hours at 130 to 140 degrees F and 80 percent relative humidity). Treated wood has a slightly green cast and is often sold for use
as landscape timbers and for fencing and deck construction.

**Fumigation** - Is an expensive means of ridding a structure of powderpost beetles and should be considered a last resort. However, in the case of severe, widespread infestations, it may be the only option. Instances warranting structural fumigations are when infestations have spread into walls, between floors, and other areas where access or wood removal is impractical. The best way to avoid such problems is through early detection and implementation of one or more of the corrective actions mentioned above. Fumigation of a home will typically run upwards of $3,000 or more. After fumigating, there is no residual chemical left to prevent subsequent infestations.

Fumigation of infested furniture, antiques and other manufactured articles can be done at a substantially lower cost by placing the items under tarps, in trailers, or in vaults that maintain gas concentrations at high levels. Some pest control companies offer this service. Only a properly certified, licensed and trained applicator can apply fumigants.

**Rodents and human welfare** - Rats and mice have accompanied man to most of the areas of the world that he has settled. Historically, they have been responsible for more human illnesses and deaths than any other group of mammals. Man’s indifference and carelessness in handling food and refuse have fostered populations of rats and mice in such proximity to his home and work that they are commonly called “domestic” rodents.

**Economic importance** - Rats in the human environment cause enormous economic loss. They consume or contaminate vast quantities of food and animal feed. They destroy other property as, for example, when they cause fires by gnawing the insulation from electrical wires. It is estimated that rats cause 5 to 25 percent of fires of unknown origin on farms.

No reliable estimate of the rat population of the United States is available as a basis for calculating these losses, although the ratio of one rat for every person has frequently been quoted in the literature. If, in consideration of recent improvements in environmental sanitation and rodent control, this rough estimate used in the past is reduced by one half (that is, one rat for each two people), then the United States has approximately 137,500,000 rats. Each rat damages between $1 and $10 worth of food and other materials per year by gnawing and feeding, and contaminates 5 to 10 times more. Thus, rats may cost the United States between $500,000,000 and $1,000,000,000 annually in terms of direct economic losses.

**Rat bites** - In addition to the annual dollar losses due to rats, there is also the intangible cost of rat-associated injury and illness. Rat bites create a serious health problem and are far more common than most people realize. In some of the larger cities, hundreds of rat bites are reported each year. Many cases are never reported.

Based upon available records, large metropolitan areas of the United States experience rat-bite at a rate as high as 10 per 100,000 persons per year. Prior to the initiation of the Federal Urban Rat Control Program in 1969, this amounted to 3,000 to 4,000 cases annually in the large cities alone, and the cases unreported from them and from the smaller cities and towns undoubtedly totaled several thousand more. Based on a rate of 10 cases of rat bite per 100,000 persons, in an urban population of 140 million, it was estimated that there were 14,000 victims of domestic rat-bite in this country annually. Even higher estimates have been published

Helpless infants and defenseless adults (invalids, unconscious, and elderly persons) are particularly subject to attack by rats. Occasionally rat-bite wounds cause death. All rodent bites should be promptly and carefully cleaned and disinfected. Tetanus
immunization or a booster shot is often recommended. However, since 1969, the Public Health Service has advised that bites of rats and mice seldom, if ever, call for rabies prophylaxis. “This recommendation, based on the low rate of infection in wild rodents, is supported by the fact that there has never been a case of human rabies in this country attributed to rodent exposure, even though rodent bites are common. An estimated 24,000 rodent bites (from domestic and wild rodents) per year are severe enough to require medical consultation.

**BIOLOGICAL FACTORS**
The term “domestic rodents” includes Norway rats, roof rats, and house mice – members of the order *Rodentia*, family *Muridae*. Some authorities believe the term “domestic” implies that man willingly raises these rodents as he does livestock. These persons prefer the term “commensal” rodents, which refers to the fact that “these animals live at man’s expense, eating his foods, living in his house, and sharing with man their diseases, without contributing anything beneficial to the relationship.”

All rodents are best characterized by their single pair of incisor teeth on each jaw and by the absence of canine teeth. Domestic rodents in the Old World family *Muridae*, often called “murine rodents”, have tails with fine scales and few hairs, whereas many of the American rodents such as the field mice, wood rats, squirrels and chipmunks, have hairy or bushy tails.

The Norway Rat (*Rattus norvegicus*), predominantly a burrowing rodent, is the most common and the largest of the domestic rats. It is distributed throughout the temperate regions of the world, including the United States. Common names for the species are brown rat, house rat, barn rat, sewer rat, and wharf rat.

**Figure 11.9 Norway Rat**

The Norway Rat (*Rattus norvegicus*), predominantly a burrowing rodent, is the most common and the largest of the domestic rats. It is distributed throughout the temperate regions of the world, including the United States. Common names for the species are brown rat, house rat, barn rat, sewer rat, and wharf rat.

**Body:** Heavy, stocky.

**Body weight:** 7 to 18 ounces (200 to 500 grams), adults average about a pound (450 grams).

**Length of head & body:** 7 to 10 inches (180 to 255mm)

**Tail:** to 8½ inches (150 to 215mm); shorter than head plus body, bi-colored, dark above pale below.

**Total length:** 13 to 18½ inches (325 to 460 mm).

**Fur:** coarse, usually brownish correddish-gray above, whitish on belly with gray under fur. Entirely black individuals occur in the United States.

**Nose:** blunt.

**Ear:** small, close-set, with fine hairs, appears half buried in fur, does not reach eyes. Rarely over ¾ inch (20mm) long.

**Eye:** small.
Teats in female: 12: 3 anterior (pectoral) and 3 posterior (pelvic) pairs.
Droppings: large, up to ¾ inch (20mm) long, capsule-shaped, often with blunt ends.
Sexual maturity: reaches in 3 to 5 months after birth.
Gestation period: averages 22 days.
Young: often 8 to 12 per litter.
Number of litters: about 4 to 7 per year.
Number weaned: about 20 per female.
Length of life: maximum about 1 year.
Harborage: outdoors – in burrows in the ground and under foundations of buildings, particularly barns, chicken houses, and animal quarters, in rubbish and garbage dumps, and in sewers. Indoors – between floor and ceilings and in walls, on enclosed spaces of cabinets, shelving, and appliances, in piles of rubbish and in other spaces concealed from view.
Range: 100 to 150 feet (30 to 50 meters).
Food: garbage, meat, fish, vegetable, fruit, and cereal baits are well accepted: Daily requirement, ¾ to 1 ounce (22 to 30 grams) of dry food, more of moist food.
Water: Daily requirement, ½ to 1 ounce (15 to 30 ml).

**HOUSE MOUSE**
The house mouse (*Mus musculus*) is abundant throughout the United States. It is found throughout the world.

![Figure 11.10 House Mouse](image)

Body: slender, graceful.
Body weight: ½ to ¾ ounce (14 to 21 grams).
Length of head & body: 2½ to 3½ inches (65 to 90mm).
Tail: 3 to 4 inches (75 to 100mm). Equal to, or a little longer than head plus body, uniformly grayish.
Total length: 5½ to 7½ inches (140 to 190 mm).
Fur: fine, brownish-gray on back, gray on belly.
Nose: pointed.
Ear: large, prominent, with some hairs, stands out from fur, can be pulled over eye. Generally more than ¾ inch (20mm) long.
Eye: large.
Teats in female: 10: 3 anterior (pectoral) and 2 posterior (pelvic) pairs.
Droppings: small, up to ¼ inch (7mm) long, rod or spindle-shaped.
Sexual maturity: reached in 1½ to 2 months after birth.
Gestation period: averages 19 days.
Young: often 5 to 6 per litter.
Number of litters: as many as 8 per year.
Number weaned: about 30 to 35 per female.
Harborage: indoors, in any convenient space between walls, in cabinets, in other furniture or in stored goods;
outdoors, in weeds, rubbish, or grasslands.

**Range:**
10 to 30 feet (3 to 10 meters).

**Food:**
cereal grains preferred, but most types of edible materials; the mouse is a nibbler. Daily requirement:
1/10 ounce (3 grams) of dry food, more of moist food.

**Water:**
Daily requirement, 3/10 ounce (9 ml); however the mouse can live and grow in a dry habitat, as a sack of grain in a warehouse without free water, and utilize the metabolic water in food.

**Length of Life:**
maximum less than 1 year.

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**SENSES, AGILITY, AND REACTIONS OF RODENTS**

**Touch** - Well-developed highly sensitive whiskers or vibrissae, and in certain guard (tactile) hairs. Rats and mice prefer to run along sidewalls, between things, or in runways where they can keep their whiskers in contact with vertical or side surfaces.

**Vision** - Not as well developed as in man. Rodents are color blind, so distinctive coloring of poison baits does not reduce their acceptance by rats and mice. Their vision is adapted to dim light. They can distinguish between shapes of objects and discern movement at distances up to 30, sometimes 45 feet.

**Smell keen** - Rodents apparently like the odors of most foods eaten by man. They are used to the odor of man; his odor on baits and traps does not repel them.

**Taste well developed** - Rats and mice will eat most foods that man will eat and prefer fresh food to spoiled food. Norway rats often eat bitter poison baits containing red squill which roof rats and mice refuse. Mice eat strychnine-poisoned grain that rats usually refuse. Rats associate sickness caused by poison bait with the bait and not with the poison. Norway rats can detect minute amounts of warfarin contaminants (250 parts per billion) in poison baits.

**Hearing keen** - They can locate the source of a noise within 6 inches. Loud noises cause rodents to attempt escape from a building. Many attempts have been made to produce ultrasonic devices that would drive rodents from buildings. Brooks has summarized much of the research in this field as follows: “Ultrasound will not drive rodents from buildings or areas, will not keep them from their usual food supplies, and cannot be generated intensely enough to kill rodents in their colonies. Ultrasound has several disadvantages: it is expensive, it is directional and produces ‘sound shadows’ where rodents are not affected, and its intensity is rapidly diminished by air and thus of limited range.”

**Balance excellent** - A falling rodent always lands on its feet. The roof rat maintains its balance while walking on suspended wires.

**Reaction to strange objects** - Rats may avoid a new sound or a strange object in their environment for 3 or 4 days, particularly if their associates are alarmed by it. Other objects are readily accepted by them (examples: food, garbage). As rodent
population pressures build, the rats frequently exhibit “chain-fright reaction” to disturbances.

**Climbing** - Roof rats and house mice are good climbers, and the Norway rat can climb quite well when necessary.

**Jumping & Reaching** - Rats can jump nearly 2 feet vertically, 3 feet with a running start. They can jump 4 feet horizontally, 8 feet horizontally from an elevation that is 15 feet above the finishing point. Rats can reach about 13 inches.

**Swimming** - Rodents are good swimmers. They are able to swim up through floor drains and toilet bowl traps.

**RECOGNIZING RAT AND MOUSE SIGNS**

Rats and mice are usually nocturnal and secretive and are rarely seen during the day except when infestations are heavy. Therefore it is necessary to properly interpret signs that indicate their presence to plan control work. These signs are found along walls, under piles of rubbish, and behind or under boxes, boards and thick vegetation. From the rodent signs, one can tell the species present, and whether there is a current or old, heavy or light, infestation.

**Droppings** - Fresh droppings of feces are usually moist, soft, shiny and dark, but in a few days they become dry and hard. Old droppings are dull and grayish, crumble when pressed with a stick, and are often moldy or covered with fungi. When examined under magnification, hairs are usually visible in rodent droppings. Cockroach droppings never contain hairs.

**Runways** - Rats habitually use the same runways between food, water and harborage. Because of the keenly developed sense of touch in their vibrissae (whiskers) and in specialized hairs along the body, rats prefer continual body contact with at least one vertical surface, such as a fence or wall. Outdoors these runways are narrow pathways of beaten earth swept clear of debris. Indoors, greasy runways are found along walls, steps, and rafters. Undisturbed cobwebs and dust in a runway indicate that it is not in use.

**Rub marks** - Along regularly traveled runways, a dark, greasy mark forms from contact by the rodent’s body. Fresh marks are soft and will smear if rubbed. As the grease ages, it dries and gathers dust and will flake off when scratched with a fingernail. The rub marks of the Norway rat are most commonly found along runways near ground or floor level, while those made by the roof rat commonly sees most overhead as swing marks beneath beams of rafters at the point where they connect to the walls. Mice do not leave detectable rub marks unless an infestation is heavy.

**Burrows** - The Norway rat prefers burrows for nesting and harborage: the roof rat burrows only occasionally. Burrows are found in earth banks, along walls, under rubbish or concrete slabs, and in similar places. If a burrow is in use, its entrance will be free of cobwebs and dust. Fresh rub marks on hard packed soil at the opening indicate a well-established and presently used burrow. The presence of fresh fragments of food or freshly dug earth at the burrow entrances also indicates current use by rats. Burrows are seldom far from a source of food and water.

**Gnawing** - The incisor teeth of rats grow at a rate of 4 to 6 inches per year. So these rodents must do some gnawing each day to keep their teeth short enough to use. Rats gnaw to gain entrance and to obtain food. When gnawings in wood are fresh, they are light colored and show distinct tooth marks. Small chips of wood or other materials indicate recent gnawing. With age, wood gnawings become dark and smooth from weathering and from frequent contact with the rodent’s body.

**Tracks** - Fresh tracks are sharp and distinct, whereas old tracks are covered with dust and are therefore less distinct. The tracks of the 5-toed rear paws are more commonly observed...
than are those of the 4-toed front paws, but both may be present. Smooth tracking patches of any material, such as talc, placed along runways are of value in checking for rodent activity. To see tracks in the dust, the inspector should hold a flashlight at an acute angle that causes the tracks to cast distant shadows. Tail marks, too, are often visible in dust or tracking patches.

CONTROL OF RODENT POPULATIONS
Basic principles - Controlling rat populations, not individual rats, is the key to a successful rodent-control program in a community. Examples of populations are the rats within a city block, those in a sewer, the rats infesting a farm, or those living in and around a feed mill. At any given time, each city block has a certain capacity to support rats. This capacity is related to the availability of food, harborage, living space, and other vital rodent requirements. The rat population in a block cannot be greater than this capacity. Permanent reduction of one or more vital factors (food, water, or harborage) in the block will result in a permanent reduction in the rodent population.

Population forces - Forces that determine the size of a rodent population at a given time are reproduction, mortality, and movements in and out of an area. Reproduction increases a population, mortality decreases it, and movement can do either. Rats breed during the entire year, with peaks in spring and fall. Winter is the best time to conduct a poisoning campaign, since breeding is then at a minimum. The next best time is summer, then fall. In field tests, populations reduced by poisoning in the winter took 12 months to return to their former levels; those poisoned in summer took only 6 months.

Population changes - As rat and mouse populations increase in size, the mortality rate also increases until state of equilibrium is reached. Increased competition due to population pressure increases the mortality and movements of rodents. Movements into or out of an area are less important in determining the size of rat populations than either reproduction or mortality. Rodents often migrate much greater distances than the limits of their normal home range (rats – 100 to 150 feet, mice – 10 to 30 feet) as, for example, their annual movement from fields to buildings in the fall and then back to the fields in the spring; and their migrations when their usual sources of food are cut off, or when they are flooded out or burned out.

Limiting factors - The factors that establish a balance among reproduction mortality and movement of rodents are the physical environment, predation and parasitism, and competition.

The physical environment is comprised of three main elements: food and water, harborage, and climate. Improperly handled foods, garbage and field crops, are the major sources of rodent food. Climate directly affects the number of rodents that survive outdoors but has little or no effect on those living in heated buildings. A given environment can support only a certain number of animals. Generally speaking, areas with warm, moist climates support more, while those with dry, cold climates support fewer. Man can reduce rodent populations and keep them low by permanently eliminating their food, water, or harborage.

The effect of predators and parasites in reducing rodent populations appears to be temporary. This includes the predatory activities of man, dogs, cats, foxes, rats, birds, snakes and other foes, and the parasitic activities of bacteria, rickettsia, spirochetes, protozoa, viruses and worms.

Competition, whether between members of the same species or between two or more species, is one of the most important factors limiting rat populations. Norway rats compete
intensely with roof rats and have replaced them over large areas, particularly in many cities where both once were found. Competition among members of the same species is very closely associated with the social organization of a population. Definite social orders or hierarchies exist among mice. These social orders are determined largely by fighting, and the most aggressive animals in a population are dominant. Others are killed or are forced to move, and those that move may suffer even higher mortality from predators and resident rodents in the new areas. The strife caused by increased population pressure lowers the rate of reproduction, increases the mortality rate, and decreases the population.

In summary, the most lasting control can be achieved by permanent alterations of the physical environments of rats and mice. Man should so change the environment as to cause increased competition and predation, therefore lowering the capacity of the environment to support rats and mice. Environmental sanitation is thus the first and foremost requirement for permanent rodent control.
Glossary

Abdomen - The hind part of the insect's body. The part of the rodent's body containing the stomach, intestines and other organs.
Anatomy - The structure of a body.
Appendages - An external organ or part, such as leg.
Application - The act of applying the chemical.
Boiling Point - The temperature at which the liquid stage boils under specific atmospheric conditions to become a gas.
Certification - A document that sets forth standards of competency by which the Ohio Department of Agriculture abides.
Chamber - A compartment of limited size for fumigation of certain items.
Chemical Reactivity - An undesirable reaction of one chemical with another.
Circulatory System - The blood flow through open cavities to various parts of the body.
Cocoon - A case in which some pupae are protected.
Commodities – Agricultural products such as grain. In this manual, the items to be fumigated.
Cone - A solid with a circle for its base; a curved surface tapering evenly to an apex.
Development - A step or stage in growth.
Diaphragm - A muscle that assists in breathing.
Diffusion – (Flow potential) - Measure of how fast gas molecules disperse through the atmosphere.
Digestive System - A tube that runs the length of the body and contains glands, pouches and grinding organs structured to aid in digestion.
Dry Measure - A system of measuring the volume of dry things, such as grain.
Endoskeleton - Skeleton inside the body.
Enzymes - Protein-like substances in cells that act as organic catalysts in initiating or speeding up specific chemical reactions.
Equipment - Items to release the pesticides, and protective items such as gas masks, detection devices.
Exoskeleton - Skeleton outside the body.
FIFRA - Federal Insecticide, Fungicide, Rodenticide Act - The federal law that regulates the use of pesticides.
Flammability - The ability of the fumigant to catch fire or explode.
Fumigant - Materials registered for control of pests contained within structures, stored products and various enclosed spaces.
Fumigation - The application of fumigants to structures, or to commodities or equipment which are enclosed within structures or other specially confined areas including areas temporarily confined expressly for the purpose of fumigation, such as bins, rooms, cargo spaces, and boxcars.
Gas - Vapor; form that is neither liquid nor solid.
Gas Chromatographs - Used for analysis of fumigants in field projects.
Growth - The process of growing or developing.
Halide Leak Detector - An instrument used for indicating the presence and approximate concentration of fumigants in the air.
Halogen Leak Detector - Indicates the presence of the gas by an audible ticking sound.
Hemisphere - Half of a sphere or a globe.
Hibernating - Dormant, not moving.
Immature - Not completely grown or developed.
Inactive - Not moving.
Infrared Analyzers - An instrument that can measure concentrations of gases by the absorbing effect the gases have on a beam of infrared radiation.
Ingredients - The things or parts that a chemical is made of.
Instars - The stage of the insect's growth between molts.
Invertebrate - A pest that is without a spinal column.
Label - The paper attached to the chemical indicating what it is made of and giving directions for its use.
Larva - The early form of some insects that is the most destructive to foodstuffs.
Latent Heat of Evaporation - The extra heat required to change liquid to a gas.
Lethal fumes – Gases that cannot be seen, but are capable of killing.
Licensed Applicator - A person who is licensed by the Ohio Department of Agriculture to perform fumigations.
Liquid Measure - A system of measuring liquids.
Mealworm - Common name for the yellowish larva of an insect pest that infests cereals and flour in mills and granaries.

Metamorphosis - A change in form, structure or function as a result of development

Molecular Weight - A measure of the weight of the atoms that form the fumigant molecule.

Molt - The insect develops a new skeleton within the old and splits and sheds its old skeleton.

Muscular System - Muscles within the insect are attached internally to the exoskeleton and provide movement, digestion, circulation and respiration.

Nervous System - The nervous system of an insect is made up of a brain located in the head, with a ventral nerve cord made up of pairs of nerve centers called ganglia spaced throughout the thorax and abdomen. Nerve endings are generally concentrated around the mouthparts, antennae and tarsi.

Ohio Revised Code - The state law that regulates the use of pesticides.

Other Detectors - Devices for estimating exposure of individuals to toxic gases.

Phosphine Badge - A color indicator badge worn by persons likely to be exposed.

Rail Car - A car transported by train.

Rectangle - A four-sided plane figure with four right angles.

Residual - Remaining chemical.

Respiratory System - Small openings along the body wall called spiracles, which connect to a series of tubes called tracheae.

Specific Gravity - The specific gravity of a chemical compound is a measure of its weight in a given volume.

Spiracles - Openings through which the insect breathes.

Stored Grain - Grain that is kept in a storage area.

Structural - Associated with the structure of a building.

Surface - The outer face or exterior of an object.

Tarpaulin - A gas-tight material to place over the commodity or building to be fumigated.

Thorax - The middle one of the three main segments of an insect's body. The chest of a rodent.

Toxic - Acts as a poison.

Trained Serviceman - A person who is under the direct supervision of a licensed applicator.

Triangle - A three-sided figure.

Truck - A trailer transported by a semi-truck.

Vapor Pressure Water - Gas molecules condensing back to the liquid form.

Vertebrate - A pest that has a spinal column and a brain enclosed in a brainpan or cranium.

Volatility - The tendency of a chemical to evaporate and become a gas or vapor.

Volume - Cubic contents.

Water Solubility - Water will tie up water-soluble fumigant molecules, reducing the fumigant concentration in the atmosphere.
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