Commodity Fumigation A Training Manual for Commercial and Private Pesticide Applicators (Commodity Fumigation Standard)
Michigan State University Extension Service
Revised by Larry Olsen, Pesticide Education Coordinator
June 1995
66 pages

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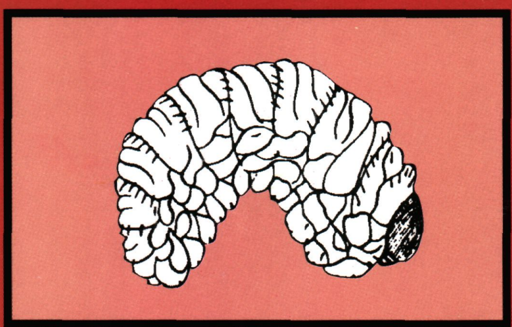

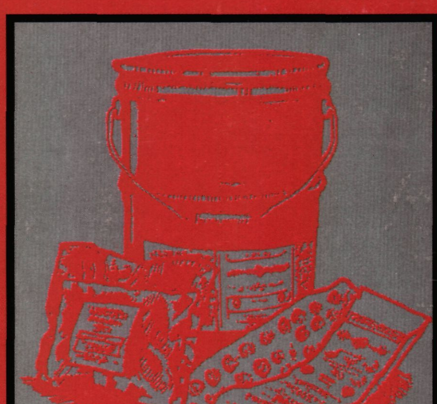

Extension Bulletin E-2579 (Replaces E-2036)
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PESTICIDE EMERGENCY INFORMATION

For any type of an emergency involving a pesticide, immediately contact the following emergency information centers for assistance.

Current as of May 1, 1995

Human Pesticide Poisoning

MICHIGAN POISON CONTROL SYSTEM

From anywhere in Michigan, call

1-800-POISON 1

1-800-764-766 1

Special Pesticide Emergencies

Animal Poisoning

Your veterinarian:

____

Phone No.

or

Animal Health Diagnostic Laboratory (Toxicology) Michigan State University:

(517) 355-0281

Pesticide Fire

Local fire department:

____

Phone No.

and

Fire Marshal Division, Michigan State Police:
M–F: 8–12, 1–5

(517) 322-5847

Traffic Accident

Local police department or sheriff's department:

____

Phone No.

and

Operations Division, Michigan State Police:

****(517) 336-6605***

Environmental Pollution

Pollution Emergency Alerting System (PEAS), Michigan Department of Natural Resources:

____

Phone No.

and

For environmental emergencies:

****1-800-292-4706***

Pesticide disposal information

Michigan Department of Natural Resources. Waste Management Division.
Monday– Friday: 8 a.m.–5 p.m.

(517) 373-2730

** Telephone Number Operated 24 Hours*

National Pesticide Telecommunications Network

Provides advice on recognizing and managing pesticide poisoning, toxicology, general pesticide information and emergency response assistance. Funded by EPA, based at Texas Tech University Health Services Center.
Monday – Friday:
8:00 a.m. – 6:00 p.m. Central Time Zone

1-800-858-7378

Revised by Larry G. Olsen, *Pesticide Education Coordinator, Michigan State University*

COMMODITY FUMIGATION

A Training Manual for Commercial and Private Pesticide Applicators (Commodity Fumigation Standard)

Acknowledgments

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We also incorporated information from the Michigan Department of Agriculture's PPPM Fumigation Procedures Manual from Region 3, Grand Rapids.

TABLE OF CONTENTS

CHAPTER 5: CONTROLLING EXISTING STORED GRAIN INFESTATIONS

CHAPTER 6: FUMIGATION WITH TARPAULINS, TRUCKS AND RAILCARS

CHAPTER 7: SHIPBOARD FUMIGATION

INTRODUCTION

Certification and Application Fumigant

To apply fumigants to commodities, you must be a certified commercial or private pesticide applicator. In addition, you also must be certified in the commodity fumigation standard. This book is the study manual for those preparing to take the commodity fumigation standard exam.

At the end of each chapter in this manual are review questions to help you evaluate your knowledge of the subject. Write the answers to the questions and then check them with the answers printed in the back of the manual. Contact the nearest regional office of the Michigan Department of Agriculture (MDA) when you are prepared to take the exam. You will need to be recertified in this standard in three years. You will be notified then by MDA.

Never Fumigate Alone

Many fumigant labels require that two trained persons work together during the application. Even if the label does not require a team of two people, we urge you never to fumigate by yourself because fumigants are highly toxic gases. Another person who is equipped with safety gear and understands how fumigants work should be present in case you need emergency assistance.

Use of Methyl Bromide Scheduled to End

At the time this manual is being written, methyl bromide is a commonly used fumigant. Applicators should be aware that the registration of pesticide products containing methyl bromide is being phased out. Proponents for ending the use of methyl bromide believe that the chemical damages the earth's ozone layer.

- The 1991 United Nations Environment Programme issued a scientific document entitled *Environmental Effects of Ozone Depletion: 1991 Update.* The document implicated methyl bromide as a potential ozone-depleting substance. It rated its ozone depletion potential (ODP) between 0.44 and 0.69, compared with Freon, which was assigned an ODP of 1.0.
- The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to list as a Class 1 ozone depleter any substance with an ODP of 0.2 or greater and to phase out all production by the year 2000. Methyl bromide appears to meet this criterion. For this reason, the EPA has developed a schedule for phaseout of methyl bromide production and consumption.
- Several environmental organizations have petitioned the EPA to accelerate the phaseout schedule .
- The EPA proposed the following actions regarding methyl bromide production its use in the United States in March 1993:

  1. Freeze production of methyl bromide at 1991 levels on January 1, 1994.
  2. Allow the use of methyl bromide at 1991 levels until December 31, 1999.
  3. Stop methyl bromide production and import into the United States on January 1, 2001.

Fumigants and Integrated Pest Management

In Michigan, we encourage those who work with pest management to use an IPM (integrated pest management) approach. Some plant pest quarantines will require fumigation for certifying that commodities are free from certain pests. However, in most cases, fumigation should be the last resort of an IPM program.

IPM uses all available tactics or strategies to manage pests to achieve acceptable yield and quality economically and with the least disruption to the environment. IPM is a systematic approach that considers and uses all reasonable methods to avoid pest problems. It combines the control or suppression procedures that best suit the particular situation. It is a holistic approach that removes causes rather than just treating symptoms.

Your efforts will achieve lasting success when you control the reasons for the infestation. Several types of interventions are usually more effective than only one type when they are coordinated well. Cost effectiveness is another major consideration that knits together an IPM program. It must be considered over the long term as well as the short term.

IPM decides if intervention is needed and:

- When it is needed.
- Where it is needed.
- What intervention is needed.

Fumigation is but one highly specialized procedure of IPM. Fumigants kill most pests. Rodents, bats, birds, insects and other related arthropods will be killed during a fumigation job if they are on the site. You should have an IPM program that:

- Identifies the pest accurately.
- Identifies ways to prevent pest entry.
- Denies access to food, water and harborage.
- Monitors all areas of the facility regularly.
- Then assesses the best options to control the pest.

This approach enhances your ability to provide effective service to your client or your own operation.

CHAPTER 1

CHARACTERISTICS OF FUMIGANTS

A fumigant is a pesticide chemical that, at the proper temperature and humidity, forms a gas. When the fumigant gas is at a high enough concentration for a long enough exposure period, it can kill pest organisms. Fumigants can penetrate most materials and are toxic to a wide spectrum of pests.

It is important to remember that fumigants are gases. Gases are tiny molecules that can move into very small gaps, such as between the particles of a concrete block or the fibers of wood, through small openings in equipment or between kernels of grain. This is the only form of pesticide that can penetrate hollow block or brick walls or other protected areas. It is because fumigant gas molecules penetrate so well that they must be confined in an enclosed space to be effective. As soon as the fumigant escapes from the enclosure and its concentration decreases, reinfestation can occur.

We can predict where fumigants will move by understanding a few laws of physics. For example, gases move from an area of higher concentration to an area of lower concentration until there is equilibrium. Temperature affects the speed of gas movement: slower when cold, faster when warm.

In contrast, smokes, fogs and aerosols are dispersions made of very fine particles or droplets and are not considered gases. Sometimes smokes, fogs and aerosols are mistakenly called fumigants, but they are not true fumigants because they are not gases.

You need to know the nature and effects of fumigants as well as the legal requirements before you can apply this type of pesticide safely and effectively.

Toxicity and Hazards

Fumigants are usually highly toxic. They act fast and may be odorless and cannot be seen. Some fumigants are flammable and under the wrong conditions can be explosive. For example, hydrogen phosphide should never be allowed to contact water. A spontaneous combustion or explosion may result from the chemical reaction that occurs.

Fumigants are potentially dangerous materials. No one should use them without thorough training and adequate precautionary measures to protect life and property. A trained applicator who takes precautions reduces the hazards and should get more effective results.

Advantages of Fumigants

Fumigants have several advantages:

- They can be toxic to insects, rats, birds, mammals, weed seeds, nematodes and fungi.
- Some are fast-acting and can be the quickest way of controlling pests.
- Fumigants can provide 100 percent control (eradication) of all stages of insect activity.
- They can be applied by several methods.
- They can penetrate into cracks, crevices, burrows, partitions, soil, commodities and equipment that cannot be reached by other methods.
- Sometimes they can be applied without disturbing the commodity.
- They are usually readily available, though some are restricted use pesticides.

- Some may be used in or near food without leaving harmful residues, tastes or odors.
- Some are more economical to use than other pesticides.

Disadvantages of Fumigants

Some disadvantages of using fumigants are:

- They can be toxic to humans, animals and plants.
- They require specialized protective equipment, such as self-contained breathing apparatus, gas masks and gas monitoring equipment.
- They have no residual effectiveness after aeration.
- They require the complete and tight enclosure of the commodity or area to be treated.
- Some may injure seed, reducing germination, or leave toxic residues, tastes or odors.
- Because they are fast-acting, problems and emergencies can develop very quickly and require fast response.
- Some are expensive or corrosive or may leave residues. Phosphine, for example, can be very corrosive to precious metals.
- You may need to obtain special licenses or permits to use them.
- They require highly trained applicators.
- Temperature and humidity requirements may be hard to meet, especially in northern climates.

Factors Affecting Use

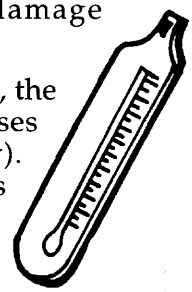
Many factors affect the use and effectiveness of fumigants:

- The stage of development and activity of the target pest. Active adult insects, for example, are easier to kill than inactive or hibernating adults. Immature insects (eggs and pupae) generally require higher dosages or longer exposure than adults.
- The amount of free or open space in the area to be fumigated.
- The temperature.
- The porosity (having pores that permit liquids or gas to pass through) of the product being fumigated.
- The kind of product being fumigated.
- The location of the pest within the product.
- The type of structure to be fumigated.
- Other sorbitive materials in the fumigated area.

Each of these factors must be studied to select an effective dosage and exposure periods.

Temperature

The most important factor influencing the action of a fumigant is temperature. As temperature increases, the rate of an insect's metabolism increases and the amount of fumigant required to kill the pest decreases. Fumigants may not kill the insects if temperatures in the space are below 40 degrees F. Fumigants such as methyl bromide may condense at cold temperatures (40 degrees F) and damage plants.



Also, as temperature increases, the volatility of the fumigant increases (it turns into a gas more quickly). This means the fumigant releases more rapidly and spreads and penetrates more quickly. Sorption (binding of the fumigant to the commodity being treated) is reduced. Thus, dosage and exposure periods for most fumigants vary with the temperature.

Air Movement or Diffusion

For a fumigation to be completely effective, the gas must reach toxic levels in all areas of the confined space for the required exposure period. The fumigant, when released in a closed space, naturally seeks to become equally distributed throughout. This state is called equilibrium. The ability of fumigants to spread varies among gases, depending on their weight and penetrating characteristics.

Some fumigants need air circulation to reach equilibrium quickly. For example, many fumigants (such as methyl bromide) are heavier than air and settle to the bottom of the fumigation area. This creates an overdose at the bottom and an underdose at the top.

Gases spread more easily when there are higher temperatures, lower air pressure, shorter penetration distances and higher initial concentration. Applicators often use air circulation equipment to speed circulation.

Given enough time, fumigant gases will naturally seek equilibrium. But, in some fumigations it is best to help the gas along by installing a mechanical system to pump or recirculate the fumigant to achieve equilibrium. Grain storage fumigation is a good example of a situation in which a mechanical system is sometimes necessary. Grain can pack to form a dense mass that is difficult for the fumigant to penetrate.

It is essential that the equipment selected fit the job. Fans are sufficient to stir up the air in relatively open areas. Confined areas with tightly packed commodities will require blowers or ducts and pipes to move the air from one place to another.

Labels List a Range of Dosages

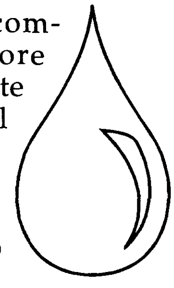
Many fumigant labels list a wide range of dosages. The range is necessary to accommodate the variety of fumigation situations that might occur. The most important factor in selecting a dosage is the tightness of the structure and its ability to hold the fumigant during the exposure period. The upper dosages listed are recommended for structures that are of loose construction. For example, flat grain storage buildings tend to be of less tightly constructed than rail cars and thus may require a higher dosage of the fumigant.

Sorption

Sorption of a fumigant is the binding of the fumigant to the commodity being treated. When sorption occurs, part of the fumigant is removed from the vapor state. Sorption includes binding of the fumigant within the material when it penetrates beyond the surface of the material (absorption) and binding of the fumigant on the surface (adsorption). Some fumigants are much more subject to sorption than others. Commodities also vary greatly in their sorptive capacity. Finely ground products such as flour have a large surface and are more sorptive than whole grain or inert physical items such as machinery.

When sorption is high, you will need to use a much higher dosage of fumigant. Because diffusion will be slower, long treatment times will be required, and the fumigant will release more slowly from the treated commodity. Besides requiring longer aeration, slower release of the fumigant from the commodity may cause problems of toxic residues, off-flavors or odors, poor germination, etc.

Moisture



As the moisture content of a commodity increases, it becomes more difficult for the fumigant to penetrate it. This also increases the potential for residues exceeding legal tolerances. On the other hand, some fumigants require some moisture, and moisture can reduce injury to living plants.

Seal

A tight seal around the fumigated structure or commodity is necessary to ensure an effective fumigation and to protect the safety of those in nearby areas. The quality of the seal affects the amount of fumigant needed and the length of time necessary for complete kill of the target pest.

A fumigation chamber is an example of an excellent seal. Little gas loss occurs from a well constructed fumigation chamber. Placing a gas-tight tarpaulin over commodities or structures can provide a poor to excellent seal, depending on the condition of the tarp (new vs. old and worn), the tightness of the seams and the type of ground seal. Structures in sandy soils or with dirt crawl spaces can lose fumigant gas through the soil. Tarping commodities over a cement floor is less effective than first placing commodities on a bottom layer of tarpaulin. Some structures may be too large to tarp, such as food processing plants or warehouses.

The applicator can improve the seal of the treatment area by taping or otherwise sealing all doors, windows and vents with an airtight material. In this case, more fumigant gas will probably be needed to account for greater loss through the walls of the structure. The condition of the structure and the type of construction must be considered. A wooden structure or unpainted cinder blocks, even when sealed well, will not hold fumigants long enough for safe, effective fumigation. Such structures should be sealed by being tarped, not taped.

Applicator Knowledge and Skill

Applicator knowledge and skill in handling fumigants is a factor affecting fumigant use. Proper application technique controls the previously mentioned factors — temperature, air movement, sorption, moisture and seal. All of these factors must be controlled for the fumigant to be applied effectively and safely. In the long run, the most important variable in fumigation is the applicator. The applicator's best source for information is the fumigant label and any additional labeling.

Fumigation Failures

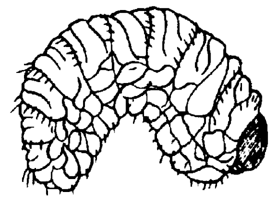
In summary, the following factors are the most frequent causes of failure in fumigation.

Temperature. Fumigants are most effective when used at temperatures between 65 F and 95 degrees F. Fumigations done when temperatures are under 60 degrees F may be unsuccessful. Never fumigate when temperatures are 40 degrees F or lower.

Poor distribution. Many applicators do not adequately distribute the fumigant throughout the product mass. To improve chances of success, distribute the fumigant as much as possible.

Improper sealing. Fumigators will often attempt to fumigate enclosures and containers without properly sealing vents, exhaust ducts, minor tarpaulin holes and other possible leakage areas. There are always enough wind currents to suck the fumigant out of these openings and cause inadequate penetration into the target area.

Insect populations. Know the target pest that is causing the problem and its life stage. Is the insect a larva, pupa or adult? Calculate insect population densities to decide the proper pesticide and dosage for the product. Know the severity of the problem and the alternatives to fumigation that could be used.



Concentration plus time. Fumigation is effective only if the target pest is exposed to the fumigant at the required concentration for the required exposure period. Gas monitoring is required for effective and safe fumigation.

REVIEW QUESTIONS

Write the answers to the following questions **(based on the introduction and Chapter 1)**, and then check them with the answers in the back of this manual.

1. What are the certification requirements for applicators who want to apply fumigants to commodities in Michigan?

2. Explain the role of the person who remains outside the treatment area while the fumigator applies the fumigant.

3. Methyl bromide, a commonly used fumigant, is scheduled to be phased out of use by the year 2000. True or false?

4. Your efforts as a pest manager will be most effective when you take precautions to avoid infestations — fumigation should be a last resort. True or false?

5. Describe the components of a successful commodity IPM program.

6. A fumigant is a pesticide that at the proper temperature forms a ______________ that can penetrate most materials.

7. Smokes, fogs and aerosols are fumigants. True or false?

8. Which of the following characteristics are true about fumigants:

   a. They are usually highly toxic.
   b. They cannot be seen and may be odorless.
   c. Some are flammable and under certain conditions can explode.
   d. All of the above
   e. a and c only

9. List some of the advantages and disadvantages of fumigants.

10. Immature insects (eggs and pupae) generally require higher dosages or longer exposure than adults. True or false?

11. Why does it take less fumigant to kill a pest when temperatures are warmer?

12. As temperatures increase, fumigants turn into a gas less easily. True or false?

13. Dosage and exposure periods for most fumigants vary with the temperature. True or false?

14. Explain what equilibrium is and what it means for fumigant distribution.

15. Describe how mechanical systems or fans can be used to help fumigants be effective.

16. What is sorption and how does it affect fumigant dosages?

17. For maximum efficiency, fumigate at temperatures between _______ and ________.

CHAPTER 2

PRECAUTIONS AND HANDLING FUMIGANTS

Fumigants as a class are the most toxic pesticides. Because they are highly volatile, penetrating and extremely toxic, they can seriously injure or kill people if not used with proper precautions. **It is extremely important that you always use fumigants with the proper precautions, procedures and protective equipment.**

Specific precautions necessary for a particular fumigant or method of fumigation are included in other chapters of this manual. General precautions and the care and use of safety equipment are discussed here.

Besides the regulations administered by the Environmental Protection Agency (EPA) and the Michigan Department of Agriculture about handling pesticides and certification, the Occupational Safety and Health Act (OSHA) also has responsibility related to pesticide use. OSHA regulations say that protective equipment — including personal protective equipment for eyes, face, head and extremities; protective clothing; respiratory devices; and protective shields and barriers — must be provided, used and maintained in a sanitary and reliable condition. Applicators must be given personal protective equipment wherever chemical hazards may cause injury or impairment in the function of any part of the body through absorption, inhalation or physical contact (Subpart I, Paragraph 6950.1, Section 1910.32, General Requirements). **The pesticide label will specify the needed protective equipment for the particular fumigant.**

You may be cited by the EPA, the Michigan Department of Agriculture or OSHA for failing to follow instructions for using or caring for protective equipment, or for misusing a pesticide. The Michigan Department of Labor and the Michigan Department of Public Health have required standards for employees who work in confined spaces and potentially toxic work environments. Contact these organizations for more detail. In general, these requirements include:

- Teaching employees about the nature of the hazards involved.
- Taking specified safety precautions.
- Providing and correctly using required protective and emergency equipment.

The information given here is to help you understand the need for following safety procedures and some general instructions about those procedures. Safety suggestions cannot cover all situations. **Follow the label (and labelling) instructions — it's the law.** Remember there is no substitute for good common sense.

Fumigant Poisoning Symptoms

Be aware of the following fumigant poisoning symptoms. Fumigants can penetrate the lining membranes of an exposed person's respiratory and gastrointestinal tracts. When this happens, the person may have a headache, dizziness, nausea, vomiting, muscle weakness, blurred speech, mental confusion, seizures, tremors or skin irritation, have trouble breathing or feel eye irritation.

Phosphine poisoning symptoms include a bluish discoloration of the skin, chest pressure, thirst, anxiety, abdominal pain and crampy diarrhea.

Halocarbons (such as methyl bromide) may cause additional symptoms such as shock, decreased blood pressure, increased pulse and breathing rate, and increased sweating.

Threshold Limits

Threshold limit values (TLV) refer to airborne concentrations of substances and represent conditions under which nearly all workers may be repeatedly exposed day after day without harmful effect. Individuals vary in their sensitivity to chemicals. A few workers may experience discomfort from concentrations at or below the threshold limit. Check the label of the specific fumigant for its TLV.

A strong-smelling gas may be added to an odorless fumigant so that people can smell when a harmful gas is present. Such a gas is valuable for warning or alerting operators or others near the fumigation. But do not rely on the odor as the only means of detection. Remember:

- People vary in their ability to detect odors and levels of odors.
- The warning gas may have different physical properties than the fumigant and work at a different rate from the fumigant, providing a false sense of security.
- Odors do not tell you the concentration of fumigant present.
- You may lose the ability to smell the particular warning agent.

Warning gases are useful but are not foolproof. Use them as one tool, not as the *only* tool!

Respiratory Equipment

If your work requires respirators, your employer should have a formal respiratory protection program. The program must include all requirements outlined in the OSHA Respiratory Protection Standard (29 CFR 1910.134). The program must have written operating procedures for educating respirator users, performing maintenance, and cleaning and storing respirator equipment. Respirator training is critical to use these devices safely and effectively. The training supplied in this book does not meet OSHA respirator training requirements.

Check the fumigant label to learn which respiratory equipment should be used for a particular product. Here are some general guidelines to indicate when respiratory protection is necessary. The specific types of respiratory equipment are described later in this chapter.

Always wear some type of respiratory protection anytime you enter a grain storage area. A dust mask can protect against molds and dusts, which may cause allergies or similar respiratory problems. When applying grain protectants (especially in grain storage structures or other confined spaces with limited air movement), you should wear a half-face or full-face cartridge respirator. The cartridge used in these respirators must be specifically approved for protection against pesticide vapors and particulates. The cartridge label will tell you if the cartridge is approved for use during pesticide applications.

Cartridge-type respirators are not suitable for protection against fumigants. For phosphine-producing fumigants, a canister gas mask (full-face) can provide protection for phosphine levels up to 15 ppm. The effective life of a particular canister varies according to fumigant concentration, humidity and the respiratory rate of the applicator. Maximum limits are stated on each canister.

No canisters are currently approved for protection against methyl bromide or sulfuryl fluoride, or for use in oxygen-deficient environments such as those produced during fumigation with CO_2.

Fumigant labels require the use of specific respiratory protection equipment during most fumigant applications. Labels also state maximum fumigant concentrations in which applicators can work without respiratory protection. If gas concentrations are greater than the levels specified on the label, then workers must use respiratory protection equipment.

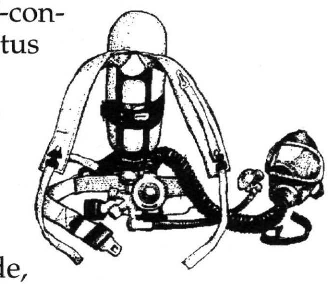
During application of phosphine-producing fumigants, if the concentration exceeds 0.3 ppm TWA, a canister-type gas mask, self-contained breathing apparatus (SCBA), or supplied air-line respirator and SCBA combination must be worn. At concentrations exceeding 15 ppm or when gas concentrations are not measured, workers must wear SCBA or a supplied air-line respirator with SCBA combination. After application of the fumigant and reentry into the fumigated site, a SCBA or supplied air-line respirator with SCBA combination must be worn if the concentration within the fumigated site is not known.

Workers exposed to methyl bromide levels greater than 5 ppm or workers in areas where CO_2 concentrations exceed 1 percent must wear a SCBA or supplied air-line respirator with SCBA combination.

Atmosphere-Supplying Respirators

Respirators that provide air from a source other than the air the wearer is working in are called atmosphere-supplying respirators. These respirators are very different from those that purify the air surrounding the wearer.

There are two main types used by fumigators: self-contained breathing apparatus (as shown at right) and supplied-air respirators. Atmosphere-supplying respirators are the only respirators that are approved for use when applying methyl bromide, sulfuryl fluoride or carbon dioxide.



1. Self-contained breathing apparatus (SCBA). The fumigator wearing a SCBA does not need to be connected to a stationary breathing source, such as an air compressor. Instead, the full-face mask is attached to a tank of air carried on the back of the fumigator. It lets the fumigator move more freely and comfortably than many other respirators. But SCBA is somewhat heavy and bulky, so it can make it difficult to do strenuous work.

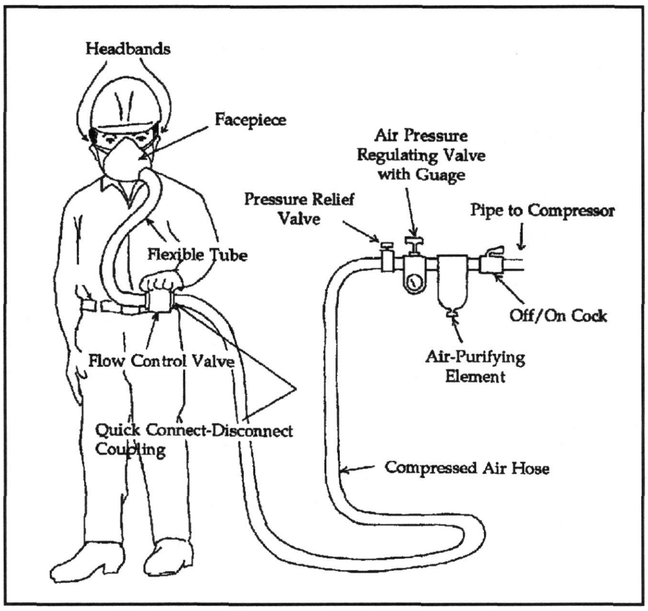
A person wearing SCBA can carry enough air for about 20 to 30 minutes. A high-pressure cylinder of compressed air supplies air to a regulator. The regulator reduces the pressure and delivers breathing air to the facepiece.

There are two types of SCBA regulators available: demand and pressure-demand. It is very important to understand the difference in operation of these two types.

- A **demand** pressure regulator supplies air to the facepiece when the wearer inhales and creates a partial vacuum in the facepiece. A good fit is essential because contaminated air can leak in if the facepiece fits improperly.
- A **pressure-demand** regulator allows continuous airflow into the facepiece. It supplies more air on demand when the wearer inhales. The constant positive pressure in the facepiece forces any leakage out of the facepiece and provides very good protection.

(Note: Self-contained breathing apparatus (SCBA) is very different from self-contained underwater breathing apparatus (SCUBA), and they cannot be interchanged.)

2. Supplied-air respirators. The most common supplied-air respirator used by fumigators is the airline respirator. Airline respirators supply compressed air from a stationary source through a hose. Airline respirators may have demand or pressure-demand or continuous-flow designs. The air may be supplied to a facepiece, helmet or hood, or a complete suit.



Airline Respirator

The demand or pressure-demand airline respirator operates much like the same types of SCBA respirators except that the airline system supplies air through a small diameter hose.

Continuous-flow airline respirators provide continuous breathing air, rather than air on demand. Instead of a regulator, these respirators have an airflow valve or opening that partially controls the airflow.

Airline respirators have the advantage over SCBA respirators of long continuous use. They are also lightweight, cause little breathing resistance and discomfort, and have moderate initial cost and somewhat low operating cost. However, if the hose is cut, burned, kinked or crushed, the wearer is no longer protected. Compressors may fail or the storage tank may become empty. Some airline respirators here auxiliary self-contained air supplies that can be used in escape situations.

Air-purifying Respirators

Respirators of this type remove particulate matter from the air or remove toxic vapors. These respirators are limited in their capacity to purify air by:

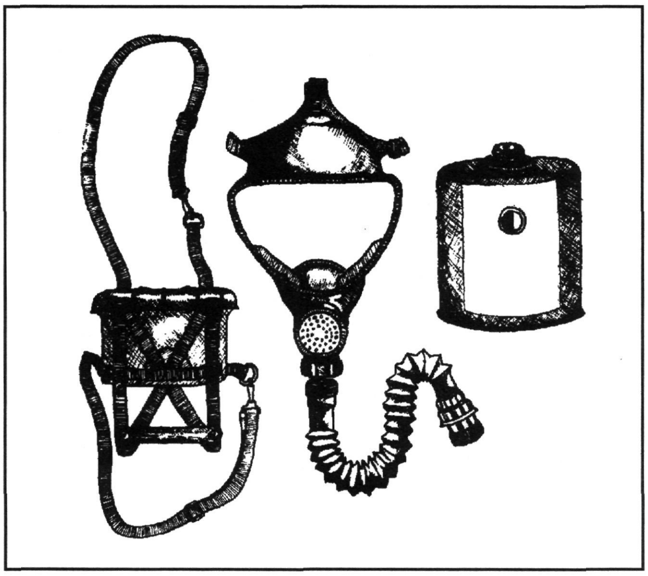
- The size of the cartridge or canister.

- The ability of the contents of the cartridge or canister to remove the toxic substance.
- Proper fit.

Improperly fitted respirators tend to leak around the face.

Gas Mask or Canister Respirators

Each canister has colored stripes that indicate its type and limitations. For example, a gray stripe around the top of the canister indicates that it has a filter for removing dust or other particulate matter. Canisters approved for protection from hydrogen phosphide are coded yellow with an orange stripe. In addition to checking the color coding, you should be certain that written instructions included with the canister state that it is effective against the fumigant you will use.



The canister you select should be made by the manufacturer that makes the mask that you plan to use. Canisters become relatively hot when they are near the end of their effectiveness. Some have a color gauge or window that shows when they are about to become ineffective.

Several variables affect how long a canister can be safely used:

- The type of canister.
- The size of the canister.
- The kind and concentration of gas breathed.
- The length of the exposure period.
- The user's rate of breathing.
- Whether more than one gas is present.
- The temperature and the humidity at the time of use.

Never use a canister after the expiration date listed on it. Several additional signs may alert you to an expiring canister. Feel the canister occasionally. Is it hot to touch, or are you having difficulty breathing? Do you smell an odor or taste something odd? Are your eyes or nose irritated or do you feel nauseated, dizzy or ill? If you feel any of these symptoms, **get to fresh air immediately.**

MSHA/MIOSHA (Mine Safety and Health Administration/Michigan Occupational Safety and Health Act) consider fumigants to be hazard gases rather than pesticides. Masks and respirators that are approved for pesticides are not intended for protection from fumigants. Be sure that you select a respirator approved for use with fumigants.

A gas mask, when put together and fitted correctly, is a compact air-purifying unit that protects against the harmful gases or vapors listed on the canister label. When the wearer inhales, the air enters the canister through the bottom and passes into the interior. Here the air is chemically purified — the harmful gases and vapors are neutralized or adsorbed. The purified air then passes through the corrugated rubber tubing into the molded channel of the facepiece. Some of these channels direct the purified air to the lenses to reduce fogging.

When the wearer exhales, the air is forced out of the facepiece through the exhalation valve, which is designed so that the wearer can hear and talk. This valve outlet also serves as a drain for moisture that may form from the operator's breathing within the facepiece. An inhalation valve at the bottom of the canister prevents the exhaled air from being expelled through the canister. Gas masks may be used for very low levels of hydrogen phosphide or chloropicrin. Only SCBAs should be used for all other fumigants.

Care of Respiratory Equipment

Each person should have his/her own respirator and canister. Do not share canisters! Preferably, you should not reuse canisters, especially following an emergency. If the canister is to be reused, write down the date used, length of time and gas concentration. When you finish using a canister, destroy or ruin the top so that no one else can use it.

Be sure to clean and disinfect the respiratory mask after each day's use and at least once a month. If you cannot disinfect the mask immediately, wipe the inside with a clean cloth, preferably one wet with isopropyl alcohol. To sanitize masks, make a solution of cleaner-sanitizer and warm water, and immerse the mask in this solution.

Scrub the mask's inside and outside with the cleaning solution and a sponge. Then thoroughly rinse the mask with warm water and let it dry. During cleaning, look for tightness of connections and rubber deterioration, and check the facepiece for a tight seal. Keep a record of these cleanings and inspections.

Be sure that only experienced persons make replacements or repairs to your respirator and that all parts used are designed for that particular respirator.

After cleaning and inspecting the mask, place it in the carrying case. When not in use, always keep the mask in the case to protect it against dust, sunlight, heat, extreme cold, moisture or damaging chemicals.

Fitting and Testing the Respirator

The respirator must fit well to protect the wearer effectively. Federal regulations (OSHA) require fit testing for everyone wearing a respirator. No one should wear a respirator when conditions prevent a good seal. These conditions inculde facial hair that lies along the sealing area of the respirator, such as beards, beard stubble, sideburns or mustaches. This is most important when the respirator relies on a tight facepiece fit to get maximum protection.

Put your chin into the lower part of the facepiece and pull the headbands back over your head. For a firm and comfortable fit against the face at all points, adjust the headbands as follows:

1 Make sure that the straps lie flat against the head.
2. Tighten lower or neck straps.
3. Tighten the side straps.
4. Place both hands on headband pad and push it toward the neck.
5. Repeat operations 1 and 2.
6. Tighten forehead or front strap a few notches.

How the respirator fits is very important. It needs to be comfortable, but it also must form a tight seal against the face. Facial hair will prevent a tight seal. OSHA requires that a worker's respirator fit properly and that the it be tested for its facepiece-to-face seal.

Fit Tests

Three methods are currently acceptable for fit testing: the taste test, the odorous vapor test and the irritant smoke test.

- **Taste test.** The wearer tries to taste a chemical substance, usually saccharin, while wearing the respirator. Someone places an enclosure over the wearer's head and shoulders and then sprays a test agent inside. If the wearer can taste a sweet taste, then the fit is not satisfactory and adjustments must be made.
- **Odorous vapor test.** This test uses banana oil and must be done in two separate rooms. In the first room, the applicator puts on the respirator and then enters the second room. In the second room, someone else saturates the outside of the respirator with banana oil. If the wearer cannot smell the chemical, then the respirator fits.
- **Irritant smoke test.** An irritant smoke, such as stannic chloride or titanium tetrachloride, from a smoke tube is blown toward the person wearing the respirator. If the wearer cannot detect the smoke, the respirator fits. The smoke causes a strong reaction in an unprotected wearer — usually, coughing or sneezeing. Because this strong response is involuntary, this is the preferred testing method.

  The respirator wearer should check the fit each time he or she puts on the respirator by using one F of these simple field tests.
- **Negative pressure test.** This test is usually used with canister (gas mask) respirators to test for tightness. Pinch off the breathing tube or close off the inlet of the canister with the palm of your hand. Inhale so that the facepiece collapses then hold your breath for 10 seconds. A respirator with a tight seal will remain collapsed while you hold your breath. If it is leaking, readjust the head straps and repeat the test.
- **Positive pressure test.** The manufacturer's instruction sheets for the respirator usually include this test. Place the palm of your hand or thumb over the valve guard and press lightly. Exhale gently into the respirator, causing "positive pressure" inside the facepiece. The respirator fits properly if you

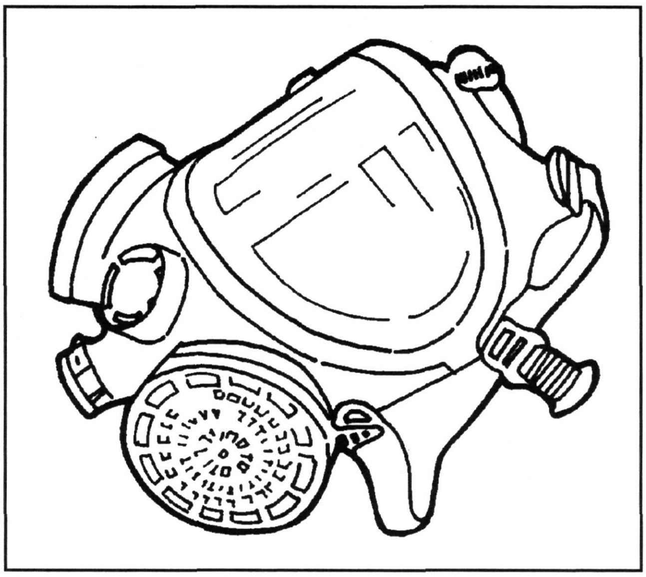
do not detect outward leakage in the facepiece. If it is leaking, adjust the straps and test again.

If you cannot find the leak in the facepiece, check the hoses and connections to make sure they are tight and in good condition. Each new canister comes with a new rubber washer for the mask hose. This washer must be in place when attaching the hose to the canister — otherwise vapors could enter at this point. Be sure to check for this washer.

If a leak still exists, try a new corrugated breathing tube. If this takes care of the leak, destroy the defective breathing tube. If after removing the seal or your hand from the canister inlet you find you cannot breathe, the canister has a blockage. Destroy and replace it. If the respirator is an air-supply type, check the facepiece and breathing tube. If the respirator is a self-contained breathing apparatus (SCBA), check the air tank for amount of air, leakages and valve efficiency. Check the test valves, connections and hose on supplied-air respirators.

Using the Respirator

The respirator should always be ready for use. When it is not being worn on a job, it should be on hand for emergency use if needed. The following checklist is for proper use of your respirator.



Before the Job

1. Study the fumigant label and determine the type of hazard to determine what type of respirator to use. If the air is deficient in oxygen — less than 19.5 percent — do not use a gas mask and canister — use an air supply respirator. If in doubt, always use an air supply respirator.
2. Remove the respirator from its case and check all rubber parts and fittings for deterioration and tight fit.
3. If you are using a gas mask, check the canister for an expiration date and, if canisters are used more than once, for effective time still left. If in doubt, use a new canister.
4. Select the proper canister for the gas used. Make sure that it is the proper canister by reading the label carefully. Also make sure the canister was made by the same manufacturer as the mask it is to be used in.
5. If you are using a new canister, put in the new rubber washer that comes with each canister.
6. Remove tape covering the intake port on the bottom of the canister.
7. Connect mask and canister.
8. Put on the respirator in fresh air.
9. Check for proper fit and leaks.
10. Check the time and decide when you should be out of the fumigated area.
11. Enter the contaminated area cautiously. Return to fresh air immediately if you detect irritating gases or odors or if other symptoms make you uncomfortable.

After Finishing the Job

1. Clean and inspect the respirator.
2. Record the date of cleaning and, if you reuse canisters, the amount of time you used the canister.
3. If the canister's effective time has expired, mutilate the top so that it cannot be used and discard it.
4. Put the respirator in its carrying case and place it in the storage area.

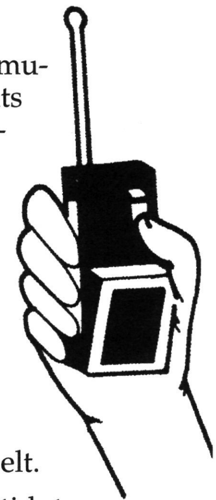
Other Protective Equipment

Requirements for protective clothing vary with each fumigant, so **read the fumigant label and use the protective equipment it lists.** The label may require wearing impermeable clothing during exposure.

The need to wear gloves when handling fumigants also varies. For example, gloves may not be required with liquid fumigants but **are** necessary with some solid fumigants. Read the label!

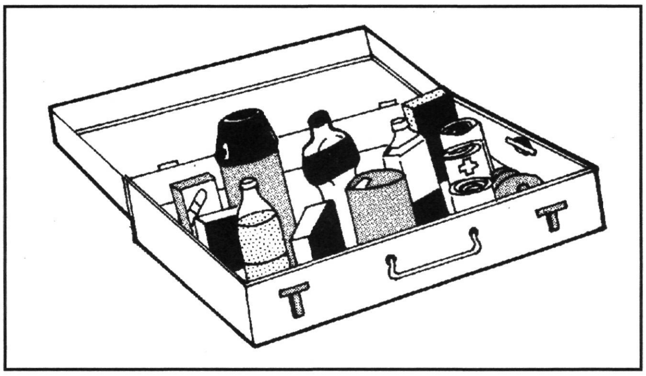
If you spill chemical on your clothing, gloves, shoes, adhesive or other bandages, get to fresh air and remove all contaminated clothing right away. Do not wear the clothing again until you have washed and aired it for several days. If you spill a liquid fumigant on absorptive clothing, shoes, etc., do not wear it again.

Whenever possible, workers should have two-way radio communication when applying fumigants or entering treated areas in emergencies.



In case of an emergency, the following should always be available:

- An emergency air-supply respirator, especially if fumigators are using a canister-type respirator.
- A safety harness or rescue belt.
- First aid equipment and antidotes, where applicable.



Detection Equipment

Detection equipment must be a part of every fumigator's operational and safety equipment. If used properly, detectors can:

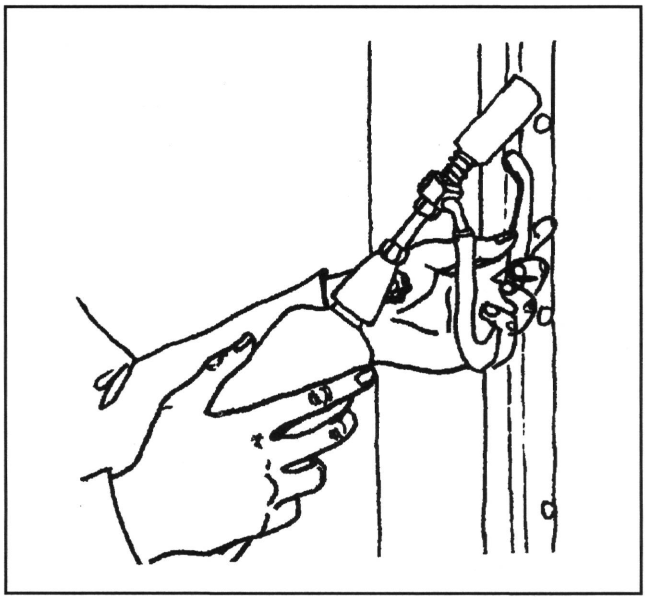
- Alert the fumigator to hazards.
- Detect excessive leaks in a building or poor seal of tarpaulins.
- Help to figure out the dosage requirements in future fumigations.
- Determine full fumigant concentrations during actual exposure.
- Measure the success of aeration by detecting the presence or absence of fumigant vapors.

Be sure your detector can be used for the fumigant you are using, that it is calibrated for your fumigant and that you know how to read it. Be certain the accuracy and range detector is suitable. For example, a halide detector can be used to find methyl bromide leaks but is not sensitive enough to determine if you have aerated the area long enough for unprotected reentry.

The following sections describe some of the detectors available. This is not a recommendation of specific types — many good products continue to be developed.

Halide Gas Detector

Halide gas detectors can be used to detect leaks but are not sensitive enough to measure amounts that would be harmful for unprotected humans.



The halide gas detector can detect the presence and approximate concentration of certain halide gases (including methyl bromide and Freon) in the air at levels of 55 ppm or greater. The detector passes the air to be tested over a red-hot copper plate or cone through or over which flame is passing. The intensity of colors given off by the flame indicates the presence and concentration of halide gas in the air.

The detector must be operated at its most sensitive rate; that is, when the flame is reduced to the lowest rate sufficient to keep the reactor plate or cone red-hot. Also, when using the detector at night, the flame has a bluish cast that should be considered when determining colors.

Most halide detectors are similarly constructed, differing only in detail by the various manufacturers. They are readily available at refrigeration supply dealers.

Halide detectors usually work well with few problems. The burner head orifice is extremely small and must be kept free of clogging with dust or other debris. The reaction plate or cone will need replacing occasionally.

To use a halide leak detector, hold a lighted match in the window opening of the burner tube and turn the valve slowly to the left. After the reaction plate or copper plate has heated to red-hot, adjust the flame to the minimum size to maintain that color. The detector is now ready for use. Hold the open end of the search hose on, in or near the area or article to be tested. As the air sample drawn into the burner passes over the heated reaction plate or cone, the flame color changes if methyl bromide or any other halogen is present.

Because an operating halide leak detector contains an open flame, safety practices must be strictly followed. When it's not in use, do not store the detector in a frequently inhabited room — because the fuel is a flammable gas under pressure. The detector cannot be used in the presence of flammable or explosive gases such as gasoline vapors and some halide gases such as ethylene dichloride or methyl chloride. Do not use the halide detector in mills, elevators or other enclosures where a possibility of dust explosion exists.

Thermal Conductivity Analyzers

Thermal conductivity analyzers (TCA) are instruments specifically designed for determining the concentration of fumigant gases within the chamber or other enclosure during a fumigation.

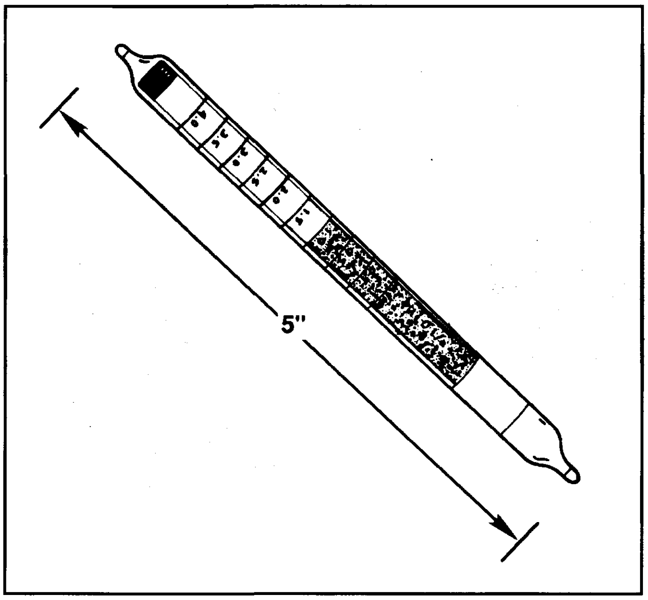
Several types of TCA are available, including the fumiscope. TCA can be light in weight, readily portable by hand and completely contained in one compact cabinet, and require no auxiliary equipment. Electrical current passes through a wire and the final temperature of the wire is affected by the composition of the air around it. To do this, it contains a thermal conductivity cell, a meter, a gas pump and controls, and it may contain a gas flow meter. It operates on regular 115 volt alternating current or battery power. It also includes a gas drying tube that should be filled with Dri-rite to absorb atmospheric moisture.

When using the TCA, keep in mind that the instrument is sensitive to several gases and these must be eliminated for a true reading. Carbon dioxide may occasionally be a problem in this regard, particularly with fruits. If a prefumigation test showed significant quantities, a tube of sorbing material (usually sodium hydrate, such as Caroxite, a Fisher Scientific Company product), should be placed in the sampling line.

If you use long sample lines into the area being fumigated, a small vacuum pump may be used to draw the air-gas sample from the test point to the end of the line. This speeds up the readings on the gas analyzer.

Glass Detector Tubes

These sealed tubes use a pump or bellows to draw the air being sampled through the tubes. The tubes are specific for each fumigant and produce a color reaction proportional to the concentration of fumigant present. For some fumigants, high range and low range tubes are available. The high range determines effective concentrations and the low range measures whether concentrations are safe for people to work. They are also used to determine if the commodity has been vented enough after fumigation.



To use the glass detector tubes, break the seals at each end of the tube and then draw a measured amount of air through the tube by the pump or bellows. You can read directly from the printed scale on the tube or use extension tubes to read at a more desirable site.

Interference Refractometers

These instruments use the differences in the refractive index of gases to measure fumigant concentrations. They are simple to operate and the readings are reproducible under uniform conditions if the instrument is calibrated carefully.

Detector Badges

These badges are worn by workers to monitor their gas exposure levels. Most badges must be sent to a lab for analysis, but more recently badges have been developed for chemicals such as phosphine that give immediate information by changing colors as exposure increases. This warning allows workers to leave the area and get protective equipment to finish the fumigation.

Transporting a Fumigant

Many fumigants (methyl bromide, phosphine and others) are considered hazardous substances as well as hazardous materials and therefore are covered by U.S. Department of Transportation (DOT) regulations. For example, if you are transporting 1,000 pounds or more of methyl bromide, or 100 pounds or more of phosphine, you must comply with DOT's regulations for transporting hazardous materials.

The DOT regulations require that packages and vehicles containing hazardous materials be clearly marked and ensure that drivers are qualified to operate equipment safely. The regulations also cover safety issues related to packing, handling, labeling, placarding and routing hazardous materials. For more information about the DOT regulations and what is required to comply, call the DOT Motor Carrier Division (517-336-6580). For a copy of the regulation and other publications explaining requirements, call the Michigan Trucking Association at 1-800-682-4682.

Fumigants can be impossible to control if leaks, spills or other accidents occur. The following general precautions are critical when transporting fumigants:

- Do not transport fumigants by public transportation such as subways, buses, trains or taxis.
- Do not transport fumigants through tunnels without the knowledge and permission of the proper authorities.
- Do not transport fumigants in closed vehicles in the same airspace with people — for example, inside a car.
- Do not transport fumigants in a horizontal position. **Keep the cylinders in an upright position.** Be sure that you have secured them to stay in that position.
- Mark the vehicle that you are using to transport the fumigant by attaching the appropriate placards (as required by the Department of Transportation) to the front, back and sides of vehicles.
- Mount cylinders to protect them from rear-end collision.
- Do not remove the valve protection bonnet until immediately before fumigant application.

Spills, Leaks or Accidents

If an accident occurs, be prepared to:

- Evacuate the area; if in transport, drive to an isolated area away from people if you can do this safely.
- Do not allow unprotected persons to enter the leak area until the gas level is below TLV-TWA (threshold limit values).
- Wear positive pressure SCBA for entry into affected area.
- Stop the leak or contain the spill.
- If you cannot stop a cylinder from leaking, move the cylinder outside, making sure to observe strict safety precautions.

Call CHEMTREC, 1-800-424-9300, for information about handling the emergency. This hotline is open 24-hours a day.

We don't know who said it, but we agree, "Do not be the fastest fumigator; be the oldest."

REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. Employers are required by law to provide applicators with the protective equipment required on the pesticide label. True or false?

2. What is a threshold limit value (TLV)? Where can you find the TLV for a fumigant?

3. Why can't you rely on smelling the fumigant to know when the fumigant is present and that you may be in danger?

4. There are no canisters approved for protection against methyl bromide or sulfuryl fluoride, or for use during fumigation with CO2. True or false?

5. SCBA is a respirator that uses very light canisters. True or false?

6. What is the difference between a demand pressure regulator and a pressure-demand regulator?

7. What is the difference between SCBA and supplied-air respirators?

8. Supplied-air respirators are available with only demand pressure regulators. True or false?

9. SCUBA — respiratory equipment used for deep water diving — cannot be used as respiratory equipment for fumigation. True or false?

10. What are the factors that affect how long a canister can be safely used?

11. If you are wearing a gas mask and begin to taste something odd or feel nauseated, you should speed up your work to finish the fumigation more quickly. True or false?

12. Masks and respirators that are approved for other pesticides may not be intended for protection from fumigants. True or false?

13. When you finish using a canister, you should:

a. Put it back in the package to recycle.
b. Throw it in the trash.
c. Ruin the top before discarding so that no one can use it.
d. Save it for possible use in an emergency.

14. Where should you store your respirator?

15. Facial hair such as beards and sideburns may make it impossible to fit your facepiece tightly. True or false?

16. Describe the one of the three fit tests that can be used to check the fit of a new respirator. Describe the one of the two tests the person wearing the respirator can use to check the fit each time the respirator is worn.

17. Where can you find information about the respirator and other protective equipment needed for the particular fumigant you want to apply?

18. Detection equipment can be used to:

a. Detect excessive leaks in a building or tarp.
b. Help to determine dosage requirements in future fumigations.
c. Determine full fumigant concentrations during actual exposure.
d. Measure the success of aeration by detecting whether fumigant vapors are present.
e. All of the above

19. When using a halide detector at night, the flame has _________ that should be considered when determining the colors that indicate gas concentrations.

a. a orangish cast
b. a bluish cast
c. a tendency to fade
d. less strength

20. Do not use a halide detector in mills, elevators or other enclosures where possibility of dust explosion exostos. True or false?

21. What do thermal conductivity analyzers (TCA) do?

22. List some of the precautions to take when transporting fumigants.

23. Which of the following would be wise to do if you spill a fumigant?

a. Evacuate the area.
b. Do not allow unprotected persons near the leak area until the gas level is below the TLV.
c. Both a and b.
d. None of the above.

APPENDIX TO CHAPTER 2

Safety Precautions Checklist for Fumigation

This checklist is provided to bring together the major considerations for fumigation jobs. It emphasizes safety steps to protect lives and to prevent fires. The checklist is general and cannot be expected to apply to all fumigants in all types of situations. **It is to be used only as a guide and is not part of the certification examination.**

Prepare the Site and Commodity

Become fully acquainted with the site and the commodity to be fumigated, including:

1. The general layout of the structure, connecting structures, and escape routes above and below ground. Draw or have a sketch of the structure to be fumigated.

   a..Check equipment to ensure that product flow has ceased and that equipment has been made as tight as possible to prevent drafts or leakage.

   b. Check all spouts, conveyors, conduits, heat pipes or other possible openings leading from the areas to be fumigated.

2. The number and identification of persons who routinely enter the area to be fumigated, and the proximity of other persons and animals.

3. The specific commodity, its mode of storage and its condition.

4. The previous treatment history of the commodity, if available.

5. Accessibility of utility service connections.

6. Nearest telephone or other communication facility.

7. Emergency shut-off stations for electricity, water and gas.

8. Current emergency telephone numbers of local health, fire, police, hospital and physician.

9. Name and phone number of administrator of structures involved.

Select the Fumigant

Select a registered fumigant or combination of fumigants for the type of work to be done.

1. Read the label. Make certain the fumigant has been approved for the required work. Look for the site/commodity/pest combinations that are appropriate for the job.

2. Check, mark and prepare the points of application if the job involves spot fumigation.

3. Study directions and precautions on the label and in the manufacturer's instruction manual.

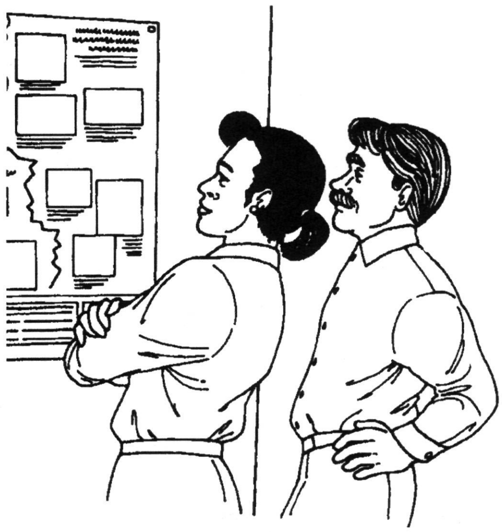
4. Notify the local health department, fire and police and other security personnel, The Poison Control Center, and the occupants of the structure and neighboring structures about the proposed location, chemicals, date and time of application, the type of gas mask and other safety equipment required, and the fire-hazard rating.

5. Inform local medical personnel of your fumigation practices and specific materials you will use.

6. Provide authorities with literature about safety measures for the materials to be used.

7. Arrange for standby equipment and replacement parts, and outline an alternate plan of action for an emergency disruption of the fumigation.

8. Inform all employees of the operational schedule, potential hazards to life and property, required safety measures and emergency procedures.



9. Prepare warning signs for posting near treated areas, provide for security of buildings, and arrange for any necessary security persons so that all entrances and exits may be observed.

10. Have first aid equipment (including antidotes) available.

11. If possible, plan for application from outside the structure.

12. Seal all cracks, crevices, open fireplaces, broken windows, holes, pipes, chutes and conveyors.

13. Plan to ventilate the treated space and commodities after the required exposure time is reached. Make this plan before you begin the treatment.

14. Identify the areas to be used for fumigant storage, and provide the conditions required by the manufacturer's directions.

15. Make sure that no open fires, motors, or hot surfaces such as heat pipes or electric fixtures are within the space to be fumigated.

16. When necessary, provide fans for even distribution of the fumigant.

17. Provide gas sampling or detection devices.

Personnel

Determine the tasks of each person assisting with the fumigation.

1. Assign at least two workers to each fumigation.

2. When entry into a fumigated area is essential, use a "buddy" system—two workers, or groups of two.

3. Know the locations of all entrances and exits.

4. Know the location of all fumigants and aerating fans.

5. Rehearse the fumigation plan so that each worker knows what he/she is to do and the exit route available.

6. Remove rings, jewelry and watches as required. Have gloves, if needed.

7. Make certain that all workers actively taking part in a fumigation are in good physical condition, and that they:

a. Have physical examinations at least annually. Employee health records should be current.

b. Abstain from alcoholic beverages 24 hours before and 24 hours after a fumigation job.

c. Have no colds or other conditions that impair breathing.

d. Are not undergoing medical or dental treatment, unless a physician certifies they may work with fumigant chemicals.

(e) Do not have punctured eardrums.

8. Instruct all workers about first aid, emergency procedures, antidotes and decontamination.

9. Report any accidents to the employer or supervisor. Persons handling fumigants should be cautioned to report all indications of illness or physical discomfort, regardless of how minor they may seem. Some examples are dizziness, diarrhea, nausea, headaches and lack of coordination.

10. Instruct all workers about the hazards that may be encountered if selected chemicals are misused, and about the selection, operation and maintenance of protection devices.

11. Have the necessary protective equipment and know where emergency equipment is located.

Just Before Application of Fumigant

Follow these last-minute preparations:

1. Open all doors and drawers inside building.

2. Shut off pilot lights and gas lights and disconnect electrical equipment. Put out fires.

Selected Bibliography

MSU Extension's chemical recommendations for stored grain are published annually in Extension bBulletin E-1582, *Chemical Control of Insects & Nematodes in Field and Forage Crops* by D.A. Landis and G.W. Bird. Other resources are listed below.

United States Department of Agriculture. 1986. *Stored-Grain Insects.* Agriculture Handbook Number 500. Washington, D.C.: U.S. Government Printing Office.

Bauer, F.J. (Ed.). 1984. *Insect Management for Food Storage and Processing.* St. Paul, Minn.: American Association of Cereal Chemists.

Raney, H.J., et al. (Eds.). 1987. *Management of On-Farm Stored Grain.* Lexington, Ky.: Cooperative Extension Service, University of Kentucky.

Weinzierl, R.A. (1990 [revised annually]). *Insect Pest Management Guide for Stored Grain.* Extension Circular 1242. University of Illinois, Urbana-Champaign, Ill.: Cooperative Extension Service.

REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. ________ are a primary stored grain pest. The adult is easy to identify by its long snout.

   a. Weevils.
   b. Indian meal moths.
   c. Beetles.
   d. Lesser grain borers.

2. ____________ are a primary stored grain pest found in wheat but rarely in corn. The adult's head points downward.

   a. Weevils.
   b. Indian meal moths.
   c. Beetles.
   d. Lesser grain borers.

3. __________ are secondary stored grain pests. The adults are usually reddish-brown to black and have forewings that form a hard shell over the obdy.

   a. Weevils.
   b. Indian meal moths.
   c. Beetles.
   d. Lesser grain borers.

4. Lesser grain borers can be found in any part of a grain mass. True or false?

5. ______________ commonly inhabit the outer parts of a grain mass. Some populations have developed resistance to malathion. They produce fine silky webbing as they feed and move about.

6. All insects found in grain must be considered pests. True or false?

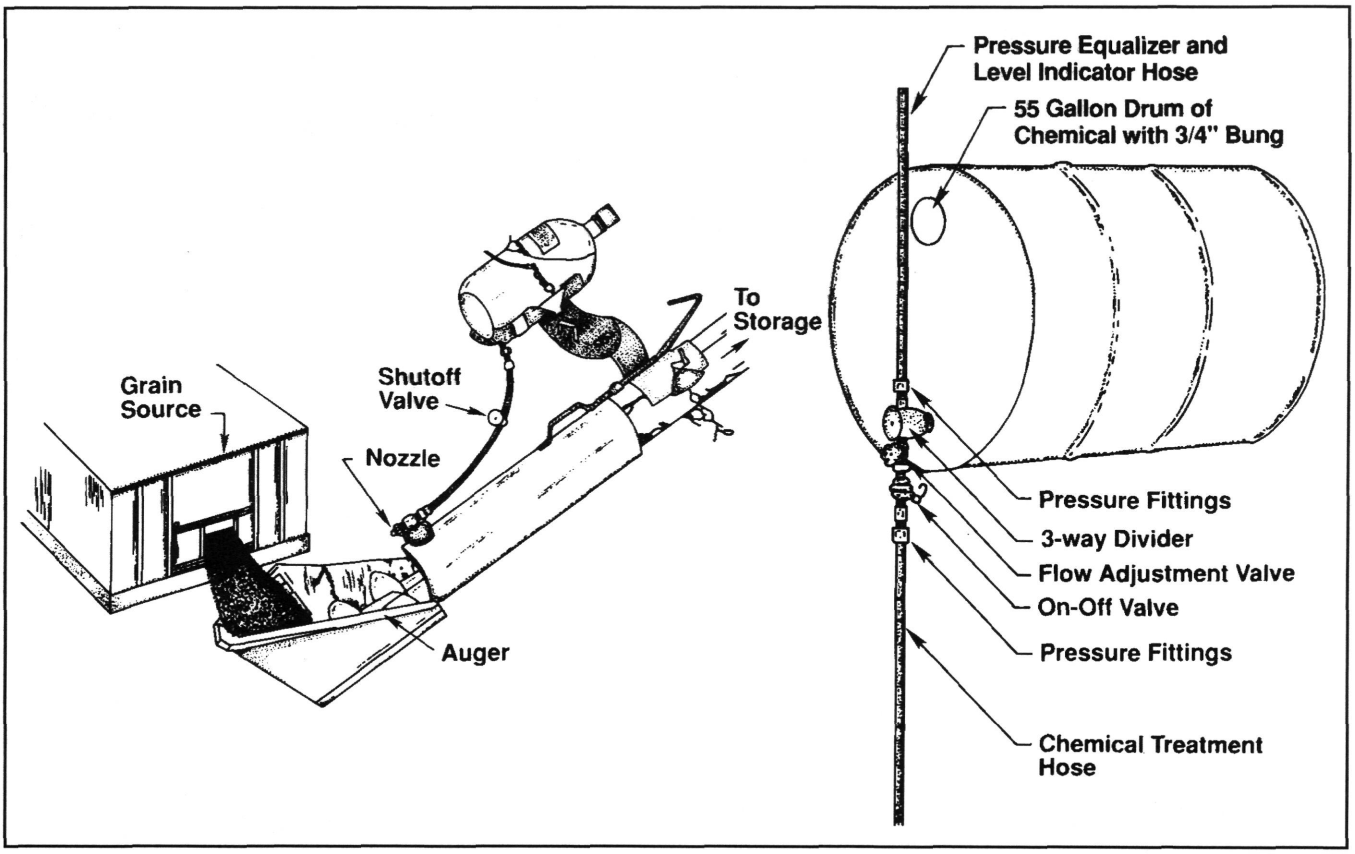


Figure 7. Gravity flow applicators for insecticides.

Spray and dust applicators are commercially available; grain handlers also may choose to custom design their equipment. Sprays delivered under constant pressure may provide a more uniform delivery rate than gravity flow applicators. The uniformity of coverage — that is, whether each kernel is coated — required for effective insecticide activity allows for some flexibility in application methods. Research has shown that it is not necessary to obtain uniform coverage of all kernels. It is important that the applicator apply insecticide at a consistent rate throughout all grain layers.

To deliver the desired insecticide rate, it is usually best to apply the treatment as near as practical to the grain's destination. This reduces the amount of insecticide left on grain- moving equipment and retains the deposit remaining on the grain. A coarse spray application such as that from a flooding nozzle produces maximum deposits on grain and minimum losses to aerosol grain dusts.

Aeration for Pest Management Control

The importance of aeration for successful grain storage was discussed in Chapter 3. Proper aeration practices can control insects in several ways. By preventing moisture migration, aeration helps to limit mold growth; an absence of mold prevents the proliferation of fungus-feeding insects. Aeration also cools any hot spots, and this temperature reduction slows insect development and prolongs the effectiveness of insecticide treatments.

Moisture and Fine Material

Whenever plans include storing grain during summer months, drying to moisture levels of 12 to 13 percent is recommended. This range is drier than the preferred condition for stored-grain insects, and it slows their buildup. In addition, insecticides applied directly to grain persist longer on dry grain than on moist grain.

Fine material (in corn, called BCFM, or broken corn and foreign material) in stored grain causes several problems. Broken kernels, weed seeds and other crop debris often spoil at moisture levels generally considered safe for whole kernel storage. Concentrations of fine material reduce air flow and prevent uniform aeration of a grain mass. Extremely fine particles form aerosol dusts that can explode.

Fine material also contributes to most insect problems in stored grain. Many secondary beetles depend on fine material to survive and reproduce. These insects release metabolic heat and moisture that contribute to the survival and reproduction of additional secondary pests and weevils.

Cleaning grain to remove fine material reduces the survival of the most common pests. Rotary cleaners and aspirators are more effective than perforated or screened sections of augers.

Protectant Insecticides

Several protectant insecticides are registered for use in grain storages or directly on harvested grains. It is important to remember that protectant insecticides are not fumigants. Most stored-grain insecticides, whether applied to prevent infestation or to control an existing problem, are contact poisons. Residues on treated grains may provide insect control for over one year. Their activity, however, is limited to the grain on which they are directly applied. Another problem is that pests are developing resistance to residual insecticides.

These insecticides do not readily form a gas and will not kill insects present in untreated portions of the grain mass. Fumigants act as gases that spread throughout the closed space into which they are released. They dissipate readily, and no effective insecticidal residue remains several days after aeration. The stability of stored grain insecticides and the duration of their effectiveness is determined by grain temperature and moisture. Temperatures below 40 degrees F not only prevent insect activity but also retard the breakdown of insecticides.

Application Methods

Grain can be treated in several ways as it is augered into storage or transferred from bin to bin. One simple and effective device is the gravity flow applicator (Figure 7). This applicator delivers an insecticide solution to grain as it flows into an auger, conveyor belt or similar grain transfer equipment. It requires no electrical or mechanical power source. Its successful use does, however, require that the applicator know the delivery rate of the auger. This value can be easily computed by determining the time required to move a known quantity of grain into storage. Stored-grain insecticides are effective when applied in 5 gallons of water per 1,000 bushels of grain. Table 5 lists grain delivery rates and flow rates for application of 5 gallons of solution per thousand bushels. Be sure to follow labeling requirements.

Table 5. Flow Rates for Application of 5 Gallons of Insecticide Solution per 1,000 Bushels of Grain.

Auger delivery rate (bushels per hour)	Application rate for insecticide solution (fluid ounces per minute)
500	5.3
600	6.4
700	7.5
800	8.5
900	9.6
1,000	10.7
1,200	12.8
1,400	14.9
1,600	17.1
1,800	19.2
2,000	21.3
2,200	23.5
2,400	25.6
2,600	27.7
2,800	29.9
3,000	32.0
4,000	42.7

lower part of the cylinder is not perforated and contains a smaller plastic catch-tube capped with an open funnel.

The top of the 14-inch cylinder is capped. The bottom is closed by a removable, tapered plug. Insects crawl through the perforations into the trap. Then they drop through the funnel into the lower catch-tube and cannot escape. Although specific food, aggregation or sex attractants can be used to lure insects into this trap, the random movement of insects within grain produces substantial captures even in unbaited traps.

Plastic probe or pitfall traps should be placed just below the grain surface or probed into grain to a depth of about 12 feet. To probe the traps into grain, a metal collar is screwed onto a probe extension section. This collar holds the trap in a vertical position as it is pushed into the grain. The top of the trap contains openings where a rope can be attached so that the trap can be removed from the grain mass.

Leave pitfall traps in place for one to four days. Increasing the trapping period increases the likelihood that insects will be captured. Because these traps depend on insect movement, they are not effective in grain colder than approximately 50 degrees F where insects are inactive.

Additional traps designed for monitoring stored-grain insects include corrugated cardboard traps. These traps hold an oil lure that attracts and kills insects that are active near the trap. Corrugated cardboard traps might be used on the surface of a grain mass to detect insect presence. They are also effective around bagged seeds or feeds in warehouses.

Paper sticky traps baited with attractants are also available. The most commonly used of these traps contains the Indian meal moth pheromone. It is used to detect Indian meal moth in or around stored grain or grain products. Paper sticky traps are also used to monitor flight activity of the lesser grain borer, cigarette beetle, and several other pests in warehouses and processing plants.

Preventing Insect Infestations

Controlling established infestations of stored-grain insects is often difficult. Usually, preventing infestations is more profitable and successful than getting rid of existing problems. Some preventive steps include:

- Thorough sanitation.
- Application of an insecticide to the empty storage.
- Proper cleaning and drying of grain.
- Application of protectant insecticides when extended storage is planned.
- Adequate aeration for temperature and moisture management.

Sanitation

An important rule for successful grain storage is that new grain should never be stored atop old, carry-over grain. When this rule is ignored, insects that infest old grain will readily move into the new grain placed in the same storage. Preventing insect carryover within a bin is the aim of cleaning bins thoroughly before adding new grain. Your cleanup should include removal of all grain that may be caked or webbed on the bin walls and all grain and debris on the bin floor.

Anyone doing cleanup work inside a dusty storage facility should always wear a dust-filtering mask. Although removing the perforated floor is impractical in most bins, when possible, clean up the subfloor plenum. Also remove grain and grain debris from combines, wagons, augers, etc. Piles of spilled grain near bins also are sources for insect infestations. Be sure to remove these infestation sources before moving new grain into storage.

Bin Sprays and Empty Bin Fumigation

Applying a registered insecticide to the walls and floor of empty bins supplements but does not replace cleanup efforts. Insecticide residues control insects that are in hard-to-clean cracks and crevices or beneath the perforated floor. Apply sprays to the point of runoff. Thoroughly treat all cracks and crevices and around doors. Applicators applying empty-bin sprays inside storage structures should wear a cartridge or canister respirator to prevent inhalation of insecticide vapors.

Directing extra spray to and through perforated flooring will provide some control of insects in the subfloor plenum. But maximum control of insects in this space requires fumigation or removal of the perforated floor and thorough cleanup.

Fumigating empty bins to control insects in the subfloor plenum may be necessary if grain will be held in storage for more than one month during warm weather from June through October. Use a registered fumigant according to label directions.

Table 4. Minimum number of Samples for Determining Temperature, Moisture, and Insect Levels in Round Bins.

Bin diameter	Temperature probes: Shallow	Temperature probes: Deep	Moisture and pest determination: Shallow	Moisture and pest determination: Deep
Less than 24 feet	2	3	2	5
Greater than 24 feet	2	5	3	10

SOURCE: Adapted from H.J. Raney et al. (Eds.). (1987) *Management of On-farm Stored Grain.* Lexington, Ky.: Cooperative Extension Service, University of Kentucky.

Shallow samples should be taken at or just below the surface of the grain mass. Deep samples should be taken from various depths determined by sampling equipment and ability to probe the grain mass. One shallow sample and one deep sample should be taken from the center of the grain mass, especially if fine material is concentrated in the central core.

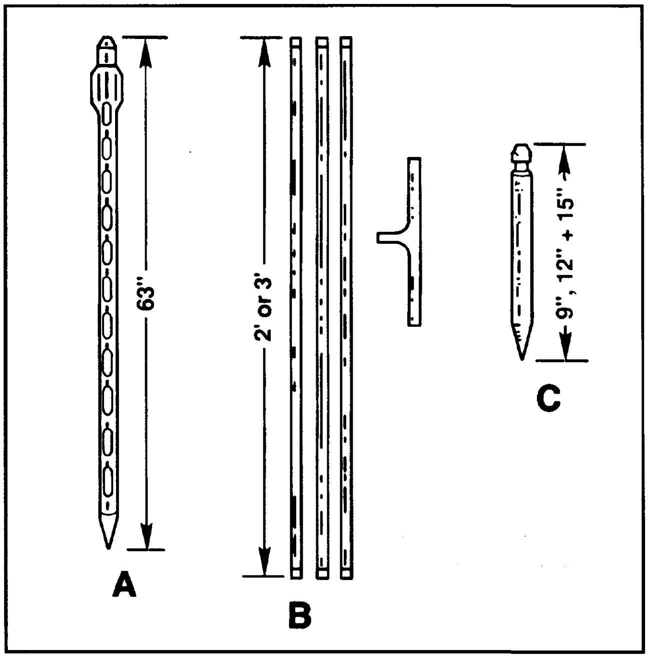


Figure 5. Equipment for grain sampling: (*A*) partitioned grain trier, (*B*) probe extensions and handle, and (*C*) cup sampler for use on deep-bin probe.

compartments opening upward. Grain industry suppliers sell 3-, 5-, 10- and 12-foot triers.

Deep-bin or deep-cup probes can be used to collect samples from greater depths within a grain mass. The sample cup is attached to the end of a metal probe and inserted closed into the grain mass. Extension sections added to the top of the metal probe allow insertion of the sample cup to the desired depth. Pulling up on the probe opens the sample cup, and it fills with grain. If grain has settled within a storage, it is usually very difficult to insert a deep-bin cup beyond 10 to 15 feet below the surface.

Collecting samples from depths greater than 10 to 15 feet requires a vacuum sampler or power probe. A shop vacuum can be modified to collect samples from depths as great as 20 to 30 feet. Hydraulic or mechanically powered probes can collect samples from depths as great as 100 feet.

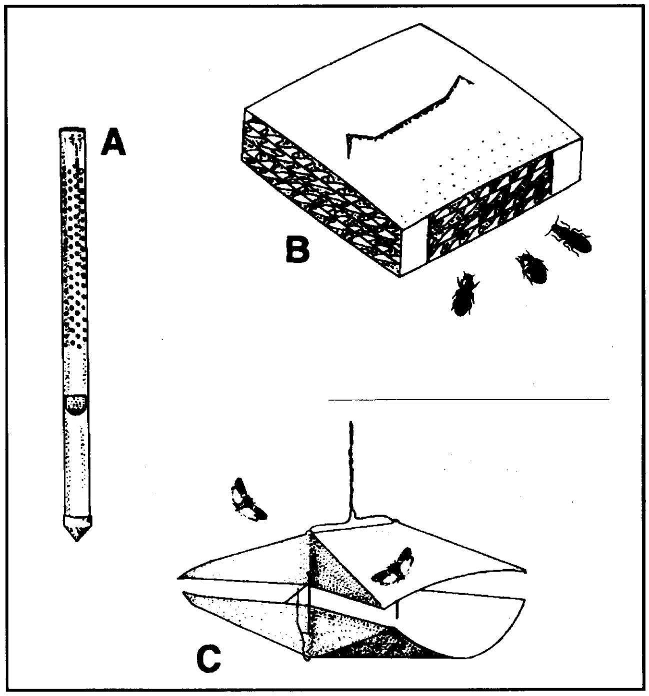


Figure 6. Traps for monitoring insects in stored grain: (*A*) plastic probe or pitfall trap, (*B*) corrugated cardboard trap, and (*C*) paper sticky trap.

Traps

Several types of traps are available to monitor stored-grain insects (Figure 6). You may need to use a variety of these traps.

A plastic probe or pitfall trap can be inserted into stored grain. This trap has a 14-inch-long, clear plastic cylinder, 1 inch in diameter with perforations drilled through the upper part. The

Others, such as the weevils and the larger black flour beetle, feed more easily on grain that is high in moisture. Storage at moisture levels of 12 to 13 percent reduces the growth of insect populations, but some species will invade grain held at even low moistures.

Insect Damage

Insects damage stored grain directly by eating kernels and reducing the weight and feed value of the infested commodity. Stored grain insects also produce heat and moisture that contribute to mold growth and spoilage. Owners of infested grains first suffer the losses that occur before sale; and then when delivering grain, they face discounts or quarantines if grain samples contain live insects. The number of insects and the type of grain are factors in deciding if grain will be discounted for insect infestation. The Federal Grain Inspection Service (FGIS) has standards for grain insect infestation, but local elevators may assign discounts based on stricter standards. Insect-damaged kernels also cause grade reduction and price discount.

Detecting Insect Problems

To manage stored-grain insects effectively, operators of grain storage facilities must examine grain for insect infestation before it is unloaded and moved into storage. Then regular inspections must be repeated throughout the storage period. Inspectors can use manual or hydraulic probes that withdraw grain samples from incoming loads during the initial inspection. These samples should be screened using an appropriate grain sieve. The screenings (material that passes through the sieve) should be examined for the presence of insects.

The size and shape of sieve openings vary for different grains. If the grain temperature is less than 60 degrees F, the inspector should let the screenings warm to room temperature before examination so that any insects will become active. Their movement makes it easier to detect their presence. Do not move infested loads into storage with uninfested grain — this can infest all the grain in the storage.

Once grain has been stored, regular inspections are necessary to measure grain temperature and moisture and to detect insect infestations. Although the number of samples necessary to determine grain condition has not been set, the minimum number of samples suggested for round bins is given in Table 4. Keep in mind that increasing the number of sample sites increases the accuracy of the information obtained.

If temperature measurements are unusually high at any sites, collect samples from these areas to figure out moisture content and presence of insects. It also is especially important to check for insects in samples from the grain surface and from areas where fine material is concentrated. Infestations often begin in these locations.

Sampling Grain

One standard sampling tool used to collect grain samples is the partitioned (or compartmentalized) grain trier (Figure 5). The inspector inserts the trier into the grain at about a 10 degree angle from vertical. The sample compartments should be closed and facing slightly upward. Rotating the handle opens the compartments. Use three quick, short, vertical strokes to force grain into each compartment.

After the trier is filled, close the compartments and remove the trier from the grain. Use a grain canvas or eavestrough to catch the sample when the trier is opened. Triers also can be used to collect surface samples by inserting the trier horizontally just below the grain surface with the

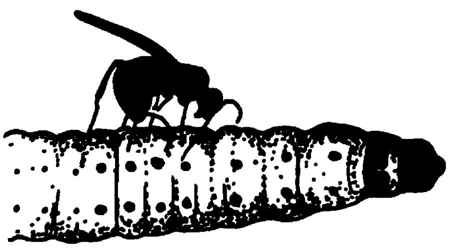
Table 3. Number of Live Insects Required for Federal Grain Inspection Service Designation as "Infested"

Grain	Insect density per kilogram of grain
Wheat, rye, triticale	- more than one weevil, or - one live weevil plus any other live pest insect, or - no live weevils, but two or more other live pest insects.
Corn, barley, oats, sorghum, soybeans	- more than one live weevil, or - one live weevil plus five or more other live pests, or - no live weevils, but ten or more other live pest insects.

mass, usually the surface, but also the bottom of the grain mass just above perforated drying floors or aeration ducts.

Caterpillars reach approximately 3/4 inch in length and are cream-colored. They produce fine silky webbing as they feed and move about. Mature larvae pupate within silken cocoons. Adult moths fly and mate in the bin headspace, where they may be seen resting on the bin walls and roof. The Indian meal moth has a wingspan of about 3/4 inch. The outer portion of each forewing is reddish brown or copper-colored. This insect often presents a special management problem because many populations have developed resistance to the insecticide malathion.

Additional pests that sometimes infest stored grains include psocids (booklice) and grain mites. These soft-bodied pests feed on grain-rotting fungi. An abundance of psocids or grain mites often means that mold is deteriorating the grain.



Not all insects in grain are pests. Parasitic wasps, predaceous fly larvae and predaceous Hemiptera (true bugs) attack certain grain pests. It is to your benefit to know and protect these "good guys." In addition, many field insects are accidentally carried to grain bins where they cause no damage.

Insect Biology and Grain Infestations

The behavioral and biological characteristics of stored-grain insects are important to management decisions. For example, an insecticide treatment incorporated in the surface of a grain mass may provide adequate control of the Indian meal moth, but such an application will not control a secondary beetle or weevil problem in the core of the grain mass. Cleaning grain to remove fine material will greatly reduce infestations of several secondary beetles, but this action is of limited value for controlling weevils or other primary pests.

Although some stored-grain insects may infest maturing grain crops in the field, the extent of field-originated storage problems is minor in Michigan. Infestations more commonly develop when insects move to new grain from carry-over grain, from small amounts of grain not cleaned from empty bins, from feed supply buildings and from grain debris beneath perforated floors of bins.

Most pest species can fly at least short distances to reach new grain. Pest migration to stored grain and development within the grain depends on suitable air and grain temperatures. Common drying and aeration practices usually produce moisture and temperature conditions that allow a fall-harvested crop such as corn to remain nearly insect-free during the first winter of storage. As air and grain temperatures increase during spring and summer, insects move into stored corn and reproduce rapidly.

When corn remains in storage through additional seasons, normal winter cooling causes some insect mortality, but many individuals, although inactive, do survive. Insect density usually increases with each year of storage. The level of insect buildup for any duration of storage varies among bins according to grain conditions (moisture, temperature, amount of fine material and mold), proximity of pest sources and the use of insecticides.

Pest-specific information presented on the reverse side of the picture sheet at the end of this manual provides details on the biology of several major stored-grain pests. Some generalizations will help you understand the population dynamics of these insects. First, these pests reproduce rapidly — females of the various species can produce between 50 and 500 eggs each. In optimum conditions, individuals of several major species develop from egg to adult in approximately four to six weeks; a few species develop only one generation per year.

Although temperatures for optimum development differ among species, most develop rapidly and successfully at temperatures between 75 and 90 degrees F. Stored-grain insects are mostly inactive at temperatures below 50 degrees F. Cooling grain to temperatures below 50 degrees F for an extended period kills some of these pests, and mortality is even greater at lower temperatures.

Some pest species can, however, survive extended exposure to temperatures at or below freezing.

Grain moisture affects which species are present and how big the population is. Several pests, including foreign grain beetle, hairy fungus beetle and the mealworms, feed on fungi that develop in grain that is too wet.

CHAPTER 4

STORED GRAIN INSECT IDENTIFICATION, DETECTION, AND PREVENTION

Identification of Pest Groups

Many species of insects inhabit stored grain. Because they are small and look similar, stored grain insects can be difficult to identify. It is always wise to have any insects collected in stored grains identified by a knowledgeable expert. With the correct identification, you can choose the best control.

This chapter offers a general introduction to insects that occur in storage. Stored-grain insects can be divided into three major groups: primary (or internal) pests, secondary beetles and surface-feeding caterpillars. The following sections provide general information about these pest categories. Specific information about individual pests is presented on the reverse side of the picture sheet included at the end of this manual.

Primary (or Internal) Pests

The most damaging pests of stored grain are those that develop within grain kernels. Adults deposit eggs on or in whole kernels, and larvae develop hidden within the kernels. Damage caused by internal pests makes grain more susceptible to infestation by insects that feed externally on grain or grain debris. The common primary pests of grains in the Midwest are the weevils: rice weevil, maize weevil and granary weevil. Other primary pests include the lesser grain borer and the Angoumois grain moth.

Weevils are an easily recognizable group of stored-grain insects. Adults are small (between 1/16 and 1/8 inch in length) and easy to identify by their long snouts. Once the weevil larva completes development, the adult emerges from the damaged kernel. It then feeds, mates and deposits eggs as it moves about the kernels. Inspectors may designate grain as "weevily" when in fact other insects are actually present.

Another primary pest found in wheat but rarely in corn is the lesser grain borer. Identification of this pest is possible because the adult's head points downward, not forward, from the front section of the body. These insects may be found in any part of a grain mass — they are **not** restricted to the grain surface.

Larval stages of the Angoumois grain moth also feed within grain kernels. This insect can infest grain in the field. Storage infestations usually are limited to the surface layer of a grain mass.

Secondary Beetles

A second group of stored-grain insects includes the secondary beetles, sometimes called "bran bugs" or fungus feeders. These beetles develop and feed outside grain kernels, within cracked or damaged kernels, or on molds associated with wet grain. Most insects commonly collected in stored grain in Michigan are secondary beetles. These insects range from 1/16 to a 1/2 inch in length. Adults of most species are reddish brown to black, and their forewings are hardened to form a shell over the body. Larvae of common species are cream-colored and cylindrical.

Species often collected in Michigan include the sawtoothed grain beetle, flat grain beetle, rusty grain beetle, foreign grain beetle, hairy fungus beetle, larger black flour beetle and red flour beetle. Like the weevils, these beetles inhabit all parts of the grain mass, not just the grain surface. They feed on several types of grains, but their buildup in any grain depends on broken kernels (or other fine material) or fungal growth on moist grain. Concentrations of stored-grain beetles raise grain temperature and moisture and therefore enhance continued population growth.

Surface-feeding Caterpillars

The third major group of stored-grain pests is the surface-feeding caterpillars. The Indian meal moth is the best known in this group. These insects commonly inhabit the outer parts of a grain

3. Grain is dried primarily to:

a. Prevent spoilage.
b. Deter insect infestation.
c. Both a and b.
d. None of the above.

4. What are the three major problems with broken kernels and fines in stored grain?

5. Using screened sections in an auger to reduce fines can cause kernel damage by skinning the kernels as they are pushed over the screen. True or false?

6. If grain is loaded into the center of the bin, most fine material will accumulate ___________.

a. Around the edges of the bin.
b. At the bottom of the bin.
c. In a central core beneath the spout.
d. There is no pattern in where fines will accumulate.

7. The major objective for aerating dried grain in storage is to prepare it for possible fumigation. True or false?

8. What causes stored grain to become wet and form a surface crust?

9. ___________ is the first sign of a potentially severe spoilage problem.

a. Crusting.
b. Grain that turns purple.
c. Grain that moves too easily.
d. Grain that freezes.

10. Cooling grain by aeration in the fall and warming by aeration in the spring helps to ___________ .

a. Lower temperatures.
b. Raise temperatures.
c. Equalize temperatures throughout the bin.
d. None of the above.

11. Begin a cooling cycle of aeration whenever the average day-night temperature is ______ to _____ degrees F cooler than the grain mass.

12. To determine that a cooling or warming cycle is complete, it is wise to measure temperatures at ______________.

a. The center of the mass.
b. Around the edges of the mass.
c. Different times of the day.
d. Several locations throughout the grain mass.

13. To aerate and manage stored grain effectively, leveling the __________ is essential.

14. During winter, check dry grain at least ___________. During spring and summer, check ________.

a. Twice per month; weekly.
b. Once per month; weekly.
c. Twice per month; twice weekly.
d. Weekly; daily.

15. You can check grain condition effectively without entering the storage. True or false?

Review the safety precautions at the end of this chapter. **Working with stored grain can be very hazardous and you should know how to protect yourself and others.**

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two companions allows one of them to administer first aid while the other goes for help.

- When working inside a bin, always wear a particle respirator that filters fine dust and mold spores.
- Protect children by keeping them away from equipment, vehicles and flowing grain.
- Avoid working in overfilled, peaked bins — crawling about in these bins can cause grain to flow and block exits.
- Maintain proper and effective shields and guards on hazardous equipment.

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REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. Following ________________ will help you avoid pest problems in stored grain.

   a. Market plans.
   b. Proper storage practices.
   c. Weather forecasts.
   d. What your neighbor does.

2. Why is it important to avoid grain damage during drying if you intend to store grain for long periods of time?

despite outdoor temperature and humidity until you have controlled the heating. If heating cannot be stopped, you will have to remove the grain to dry, clean or sell it.

Temperature sensors can be permanently attached to cables within a storage to improve monitoring (Figure 4). These sensors may be especially important in large storages that may be difficult to sample manually. However, stationary sensors provide information about conditions only at the points where they are installed. Problems that develop between sensor locations may not be detected until damage has become widespread and severe.

Automatic aeration control systems are also available that depend on readings from one or more temperature sensors. These devices can enhance management capabilities, but they do not replace actual inspection of stored grains. Using automatic aeration controllers can be especially risky during spring warm-up when continuous aeration may be necessary to prevent condensation layers from forming within the grain mass.

Safety Precautions When Working With Stored Grain

Stored grain, especially flowing grain, presents many hazards. The following safety precautions are very important:

- Do not enter a bin of flowing grain.
- Do not enter a bin to break a crust or remove a blockage when unloading equipment is running, whether grain is flowing or not. Restarted flow is a hazard.
- Before entering a bin, lock out the circuit controlling unloading equipment and post a warning so that no one else starts this equipment.
- Do not enter a bin without knowing whether any grain has been previously removed from that bin, especially if crusting is evident.
- Do not trust a surface crust to remain intact.
- Do not depend on a second person to start or stop equipment when you shout — equipment noise can prevent him/her from hearing you. Also, the second person may be unable to complete the task soon enough.
- When entering a bin that contains grain of poor quality or when you don't know whether grain was previously been removed, work with two companions outside the bin. The person in the bin should wear a safety rope or other approved bin entry equipment. The companions outside the bin should be able to help the person exit without entering the bin. One outside companion cannot do this. The presence of

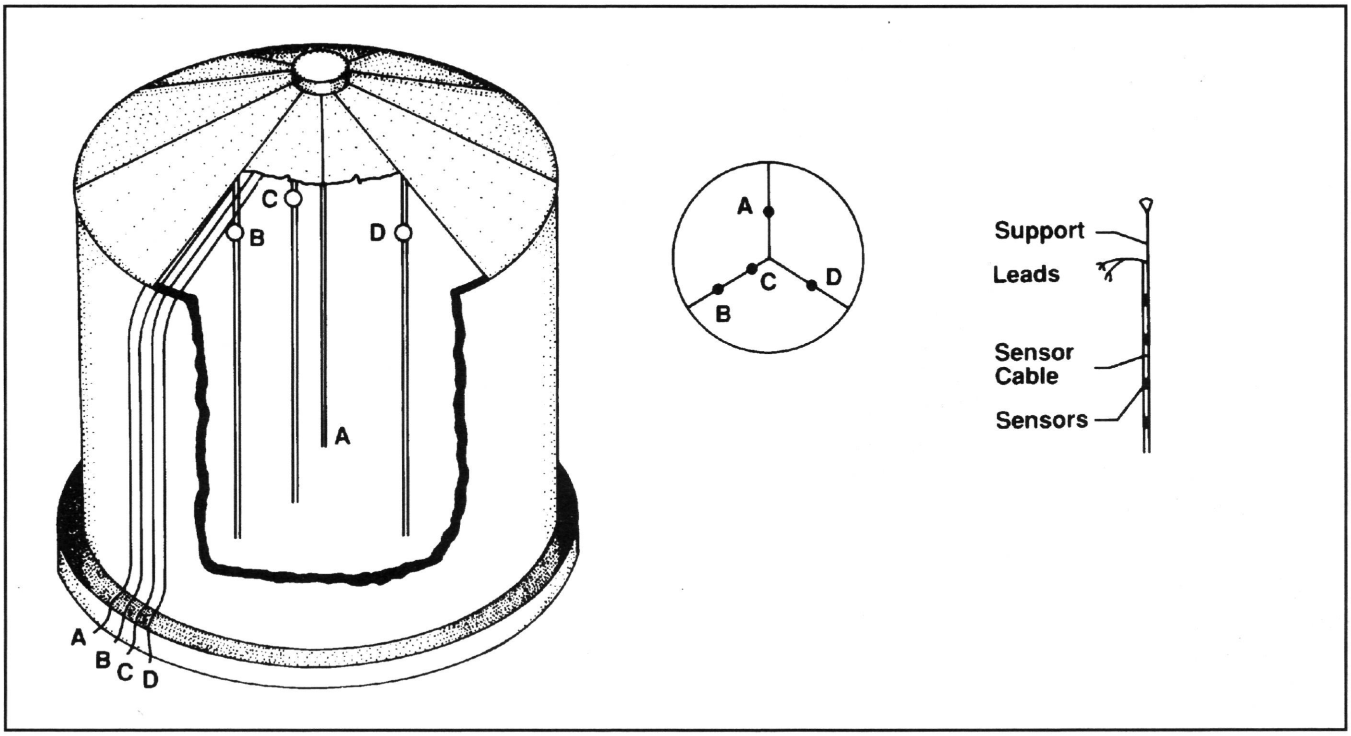


Figure 4. Temperature sensors on permanent cables. Four cables are suspended from the roof. Three are midway between the center and the wall, and one is very near the center.

undesirable moisture changes, you should end each aeration cycle as soon as the temperature front has passed through the entire grain mass. This may be of greater importance if you are using high-capacity aeration fans or drying fans.

During winter storage in Michigan, use aeration to cool grain to temperatures of 35 to 40 degrees F. Initiate a cooling cycle whenever the average day-night temperature is 10 to 15 degrees F cooler than the grain mass. If you operate the aeration fan(s) continuously until the cooling cycle is completed, you will prevent a condensation layer from forming within the grain mass.

When using air flow rates of less than 0.2 cfm per bushel, there is no need to stop aeration during periods of high humidity. Cooling the grain mass is more important than concerns about any minor re-wetting of small amounts of grain. With air flow rates of greater than 0.2 cfm per bushel, each aeration cycle is short enough that it can be interrupted for one to two days during warm, humid conditions. But if there are any signs of heating, run the fans continuously, no matter what the weather, until you cannot detect hot spots.

Confirm the completion of a warming or cooling cycle by measuring the temperature of the grain or exhaust air. If you are using a negative pressure system to draw air downward through the grain, you can measure the temperature at the fan exhaust. If you are using a positive pressure system to push air upward through the grain, measure the temperature 6 to 12 inches below the grain surface. When the temperature front has passed through the entire grain mass, temperatures measured at these specified locations will drop suddenly to levels approximately equal to the average outside air temperature early in the aeration cycle.

It is important to remember that a single temperature reading may be deceiving. Pockets of fine material or areas of moldy, crusted grain may exist within the grain mass. These problem areas may remain much warmer than the overall grain mass. Once a cooling or warming cycle has been completed, it is wise to measure temperatures at several locations throughout the grain mass.

To determine temperature at the center of the bottom of the bin, you may need to withdraw a small amount of grain through the bin's unloading auger. Measure the temperature of this grain immediately after it is taken from the bin.

Freezing grain can further decrease the possibility of spoilage and provide some insect control, but freezing also can produce certain problems. Rewarming frozen grain in the spring may produce condensation that can immediately freeze and form ice. Frozen chunks of grain can block air flow and clog unloading systems. To prevent excessive condensation and freezing problems, spring rewarming cycles should be initiated for frozen grain whenever average air temperatures are approximately 10 degrees F warmer than the grain mass. It is not necessary to rewarm grain to temperatures above 50 to 55 degrees F.

A final concern about aeration involves peaked grain. It is important to understand that peaked grain is extremely difficult to manage. Condensation problems resulting from moisture migration are greatest in the peaked grain at the center of the bin. In addition, fine material that is especially susceptible to spoilage is concentrated in this central peak. The increased grain depth at the center of the bin plus the air-blocking effect of fine material severely reduce air flow in a part of the grain mass that needs aeration. To aerate and manage stored grain effectively, leveling the grain surface is essential.

Monitoring Grain Conditions

Monitoring grain conditions at regularly is extremely important for successful grain storage. During winter, check dry grain at least twice per month. During spring and summer, check the grain weekly.

To check grain condition effectively, you will need to enter the storage. You cannot make effective observations by only looking in through roof hatches and smelling the exhaust air. Observers should look for moisture or crusting at the grain surface and be attentive to any musty, moldy odors. You will need to probe grain to detect any caking or heating problems below the grain surface.

To figure out grain moisture levels and to check for insect pests, you will need to withdraw grain samples from several locations within a storage. Grain triers, deep-bin cup probes, vacuum samplers and hydraulic probes may be used to collect subsurface samples of grain. Most bin supply companies and grain industry service companies sell sampling equipment.

Any heating problem in stored grain is a sign of potentially severe damage that can ruin large quantities of grain. To cool confined hot spots, immediately aerate grain whenever the outside temperature is less than about 10 degrees F warmer than the overall grain mass. If heating is extreme or widespread, aerate day and night grain, moisture condenses from the air onto the cold grain. This entire process, often termed "moisture migration," produces the wetting and crusting of surface grain (Figure 2).

Crusting of surface grain is the first sign of a potentially severe spoilage problem. You will have severe problems by spring when warming occurs if you do not correct moisture migration. Where crusting occurs, the grain surface should be raked, stirred or even removed, and aeration should be started immediately.

Cooling stored grain by aeration in the fall prevents convection currents by lowering the temperature of the center of the grain mass to a level near that of the outer portions of the grain mass. Aerating to warm grain uniformly in the spring and early summer also prevents moisture migration by equalizing temperatures throughout the bin.

You also can effectively use aeration fans to push air upward or pull air downward through grain. Air moving in either direction will create a moving temperature front similar to a warm front or cold front often described in weather forecasts (Figure 3). The movement of a temperature front completely through the grain (from bottom to top or from top to bottom) represents one warming or cooling cycle. Once a cooling or warming cycle has been initiated, operating the aeration fan(s) continuously prevents the formation of a condensation area where warm and cool grain meet.

The time required to complete a warming or cooling cycle depends almost entirely on the rate of air flow. Air flow is measured and expressed in cubic feet per minute per bushel (cfm/bu). Air flow, not fan horsepower, indicates aeration capacity. Estimates of cooling or warming cycle durations based on air flow rates are given in Table 2.

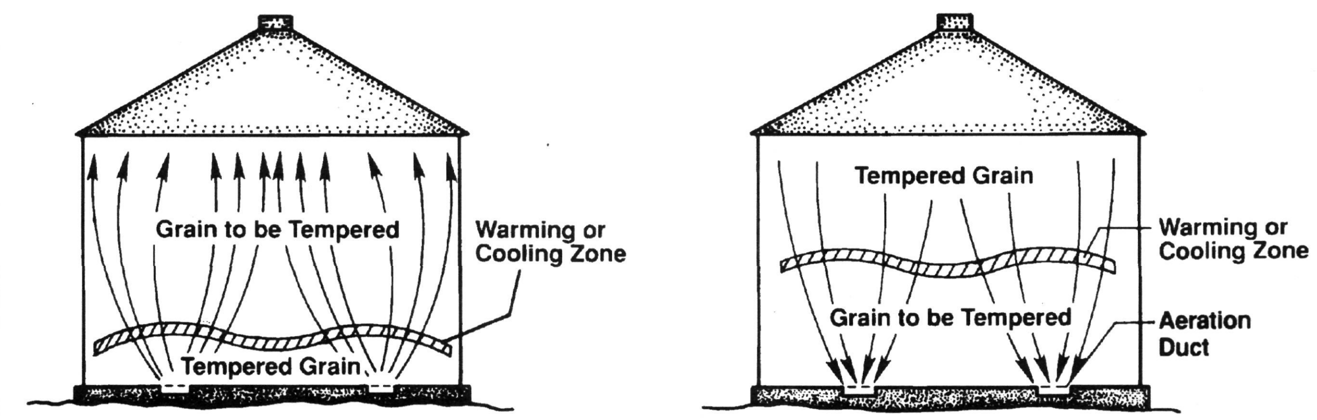
Table 2. Approximate cooling and warming times for the aeration of stored grain.

Air flow rate (cfm/bu)	Cooling hours		
	Fall	Winter	Spring
0.05	300	400	240
0.10	150	200	120
0.20	75	100	60
0.25	60	80	48
0.33	45	61	36
0.50	30	40	24
0.75	20	27	16
1.00	15	20	12
1.25	12	16	10
1.50	10	13	8

Source: B.A. McKenzie et al. 1980. Managing Dry Grain in Storage. AED-20. Ames, Iowa: Midwest Plan Service, Iowa State University.

Times are based on a 60-pound bushel and a 10o and 15o F difference between grain temperature and average outdoor air temperature. These are estimates only — use a thermometer or temperature sensor to detect the passage of a warm or cold front.

Aeration for temperature management rarely significantly dries or re-wets stored grain. A temperature front moves through a grain mass approximately 50 times faster than a drying or wetting front. Therefore, aerating even during periods of high humidity re-wets only a small portion of the grain mass. Even so, to avoid



Positive pressure—cooling or warming zone moves up through the grain.

Negative pressure—cooling or warming zone moves down through the grain.

Figure 3. Movement of temperature fronts through grain. The temperature of the grain behind the front is approximately equal to the average outside air temperature.

Storing clean grain with a minimum of fine material helps prevent many hard-to-manage storage problems. Techniques often used to minimize fine material in storage are cleaning and core removal.

Cleaning grain before binning is the most effective way to limit problems caused by fine material. Although perforated or screened sections of augers remove some fine material during grain transfer, rotary cleaners and aspirating equipment are more efficient. The perforated or screened sections may cause some kernel damage by "skinning" kernels as they are pushed over the perforations or screen.

Unfortunately, cleaning grain does not usually increase its market value. Fine material in grain has value as livestock feed and as weight in marketed grain. Some producers and grain handlers believe removing fine material unnecessarily reduces the marketable volume of grain. This is especially so when there is no market or local use for the cleanings. Even so, any new grain drying or storage facilities should include cleaning equipment or plans that allow future addition of such equipment. Cleaning is a useful management practice, and future grade standards may make cleaning a necessary practice in some situations.

Core removal, another approach to managing fine material, involves loading grain into round bins without cleaning and without using a grain spreader to distribute kernels and fine material. If you load grain into the center of the bin, most fine material will accumulate in a central core beneath the spout. Figure 1 shows how removing grain at regular intervals during the bin filling process removes the core of fine material.

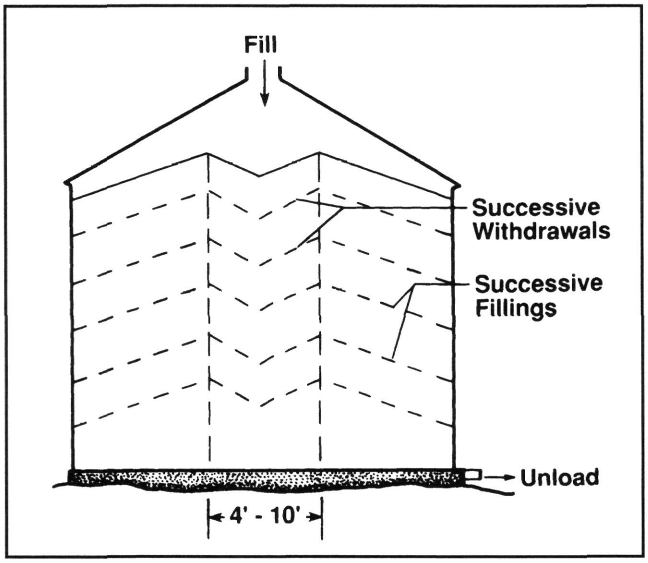


Figure 1. Withdrawals during filling remove most fines from the 4- to 10-foot central core of round bins.

Some producers try grain spreaders to manage fine material. However, these spreaders can concentrate fines in a "donut" away from the center of the bin.

Aerating Stored Grain

The major objective of aerating dried grain in storage is temperature management. To understand the importance of temperature management, you need to know the patterns of heat and moisture movement within a bin.

Grain is commonly placed in storage at temperatures of 50 to 80 degrees F, depending on the crop and harvest season. Within a storage, grain occupies 40 to 70 percent of the available volume. Air between grain kernels occupies the remaining space. The temperature of this air equals that of the surrounding grain.

As outdoor temperatures decline in the fall and winter, grain and air temperatures near the bin walls also drop. The insulating characteristics of grain prevent temperatures in the center of the grain mass from falling as rapidly. Resulting temperature differences produce convection currents. The cooling of air near the bin walls makes this air more dense ("heavier"), and it settles toward the bin floor. As air moves across the floor toward the center of the bin and upward through the grain, it warms and becomes less dense.

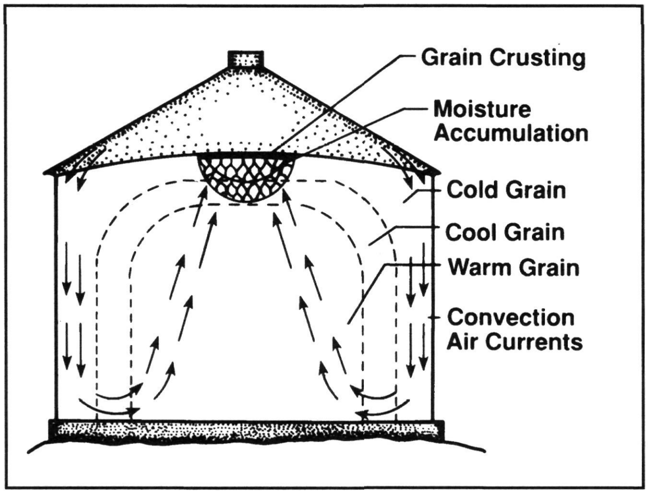


Figure 2. Patterns of winter moisture migration.

This lighter air rises through the center of the bin and continues to increase in temperature. Its moisture-holding capacity increases as it warms, and the rising air absorbs small amounts of moisture from the surrounding grain. Grain near the top of the grain mass, like that near the outer walls, is cooler than this rising air. As moisture-laden air rises through and is cooled by the cold

CHAPTER 3

STORED GRAIN MANAGEMENT

Grains produced in Michigan may be stored for periods of a few weeks to a few years before being fed to livestock or processed. The profitability of storage depends not only on market demand but also on maintenance of grain quality. It is important to remember that pests can be a problem during the storage of grain.

You must follow proper storage practices to manage successfully the pests that attack stored grain. Insecticides, fungicides, rodenticides and fumigants should be viewed as supplements to, not replacements for, sound storage practices. This chapter addresses the general management practices that prevent infestations of stored grain. These practices include drying, cleaning, aerating and monitoring.

Drying Grain for Storage

This manual does not discuss in detail methods for drying grain. (For such information, see the publications listed at the end of this chapter.) Drying methods do, however, influence grain quality. High-speed, high-temperature drying produces more stress-cracked corn kernels than does low-temperature, natural-air drying. Kernels with stress cracks break more readily during handling, and broken kernels are more likely to spoil and invite insect infestations.

It is important that producers and grain handlers attempt to minimize grain damage during drying, because only high-quality, undamaged grain can be stored successfully for long periods. People dry grain primarily to prevent spoilage and to deter insect infestation. Table 1 lists safe storage moistures that prevent damaging levels of fungal infection in various grains. Insect infestations can occur at these moistures. For safe storage of grains damaged by drought, frost, harvest damage, etc., grain moisture should be reduced at least 1 percent below the values listed in Table 1.

Table 1. Maximum safe storage moistures for various grains and soybeans.

Grain	Moisture*
Shelled corn and sorghum	
To be sold as #2 grain by spring	15%
To be stored up to 1 year	14%
To be stored more than 1 year	13%
Soybeans	
To be sold by spring	14%
To be stored up to 1 year	12%
Wheat, barley, oats, etc.	13%
Sunflowers	
To be stored up to 6 months	10%
To be stored up to 1 year	8%

Source: B.A. McKenzie et al. 1980. Managing Dry Grain in Storage. AED-20. Ames, Iowa: Midwest Plan Service, Iowa State Univrsity, Ames, Iowa.

*Values listed are for aerated, undamaged grain not treated with any fungicidal chemicals.

Cleaning Grain and Managing Fine Material

Broken kernels and foreign material ("BCFM" or "fines") create three major problems in stored grain:

- Broken kernels are more susceptible to spoilage than unbroken kernels.
- Many insects that infest stored grains need broken kernels and fine material to survive.
- Concentrated fine material decreases air flow from aeration fans. Spoilage, insect infestation and reduced air flow can increase the temperature within pockets of fine material and the resulting "hot spots" often enlarge and cause surrounding grain to deteriorate.

These problems are worse when the fine material is concentrated in certain parts of the storage.

3. Remove plastic covers from mattresses.

4. Remove food, feed, drugs and medicines; or place all in tightly sealed containers. Sealing freezers and refrigerators will not prevent fumigant gases from getting inside.

5. Make a final check to make sure all occupants, pets, fish and plants have been removed from the structure.

6. Place warning signs at all entrances and exits.

7. Place security persons where they may observe all entrances and exits.

Application Procedures and Fumigation Period

During the actual fumigation:

1. Apply all fumigants following the manufacturer's recommendations.

2. Post areas to be treated immediately before application.

3. Apply fumigant from outside where appropriate.

4. Caution workers applying fumigants not to enter the area where fumigant gas or vapor is being discharged, except in extreme emergencies.

5. Take into consideration prevailing wind and other weather factors.

6. Provide security persons where required.

Postapplication Operations

Conclude your duties by:

1. Providing security persons where necessary.

2. Ventilating and aerating within structural limitations.

3. Turning on all ventilating or aerating fans where appropriate.

4. Using a suitable gas detector before reentry to determine fumigant concentration. Some fumigants do not provide adequate odor warning, and some areas aerate slowly. Check for sorption in walls or other areas with limited air flow. May need to seal, wait and test again.

5. Removing warning signs when aeration is complete.

6. Disposing of empty containers.

7. Returning unused chemicals to properly and clearly labeled containers. Store them properly.

7. Secondary stored grain pests are those that feed on broken kernels, fine material or fungal growth on moist grain. True or false?

8. Stored-grain insects are mostly inactive at temperatures below ________ F.

a. 65 degrees.
b. 60 degrees.
c. 50 degrees.
d. These pests are always active, regardless of temperature.

9. Storage at moisture levels of ________ percent reduces the growth of insect populations, but some species will invade grain held at even low moistures.

10. To manage stored-grain insects effectively, when should you first inspect a load of grain for insects?

11. If you are inspecting grain screenings and the grain temperature is less than 60 degrees F, what can you do to improve the likelihood that you will find all of the insects?

12. Where are the critical sites to sample for insects?

13. Why aren't plastic probe or pitfall traps effective in temperatures colder than approximately 50 degrees F?

14. Usually, preventing infestations is more profitable and successful than getting rid of existing infestations. True or false?

15. List several ways to prevent stored grain infestations.

16. New grain should never be stored ____________.

a. In November
b. On top of old, carryover grain.
c. When temperatures are below 50 degrees F.
d. When temperatures are above 50 degrees F.

17. If you don't have time to clean a bin, applying an insecticide before loading the grain will stop infestations. True or false?

18. List some of the problems caused by fine material.

19. Protectant insecticides are contact poisons. How does this limit their long-term effectiveness?

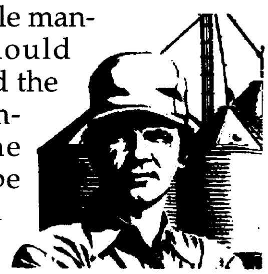
CHAPTER 5

CONTROLLING EXISTING STORED GRAIN INFESTATIONS

Existing infestations of stored-grain insects are difficult to manage. This chapter will look at fumigation and some of the alternatives. Be sure also to study Chapter 2, which addresses safety precautions for fumigators.

Stored Grain Management Without Fumigation

When you find insect pests in stored grain, there are several possible management practices you should consider. If you have detected the infestation early and the number of pests is very low, the most profitable action may be to clean and move the grain immediately without any chemical treatment. This option may be especially appropriate if you are carefully monitoring with traps and infestations consist of secondary beetles. Moving and cleaning grain can get rid of many of these beetles.



During cool weather, aerating to cool the grain below 50 degrees F can prevent insect activity and extend the period of safe storage. Further cooling provides some degree of control, but some stages of most pests can survive cold temperatures. Keep in mind that once grain has been cooled, fumigation may be ineffective or prohibited until the grain has been rewarmed.

Sometimes insect infestations are limited mostly to the surface of a grain mass. You may be able to incorporate an insecticide with a rake to control light infestations of Indian meal moth that are near the grain surface. If you do not incorporate the insecticide, you will not control the Indian meal moth larvae that are a few inches below the grain surface. Before treating, rake webbing from the surface. You still may need to fumigate.

Sometimes secondary beetles are confined to a central core where fine material is concentrated. One option is to remove the central core. This will reduce the risk of the beetles severely damaging the rest of the grain. The grain removed from the core can be cleaned, treated with a registered insecticide and returned to the same bin. The remaining grain containing less fine material will not be insect-free, but additional management and successful storage of this grain will be easier once you have removed the excess fine material in the center of the storage.

If you have clean, empty storage available, you can move infested grain into that storage and treat it with a protectant insecticide. Grain also should be cleaned during the transfer. Residual insecticides will not immediately kill the immature insects that are developing within grain kernels. But the residues will control the adults that emerge from the kernels. Residues will persist on grain and prevent reinfestation for awhile. Grain moisture and temperature affect the amount of time that residues are effective.

Fumigation

Infested grain that cannot be treated successfully in any other way should be fumigated. Information presented in the following sections explains some of the procedures for fumigating stored grain. However, besides studying the information printed here, **you must read and understand the fumigant label and the instructional materials that are provided with the fumigant.**

Effective fumigations result from exposing the target pest to the required concentration of gas for the required time.

These conditions will occur if you:

- Thoroughly seal the storage.
- Correctly apply the proper amount of fumigant.
- Leave the storage sealed for the required period of time.

Overapplying a fumigant will not compensate for failing to seal a storage, failing to distribute the fumigant properly or failing to keep the storage sealed for the necessary time.

General Instructions for Fumigants

Many recent regulations that affect fumigant use are printed as part of the use directions on fumigant labels and supplementary instructional material (legally considered part of the label). Label instructions are considered law. Applicators who violate label instructions are liable to criminal and civil proceedings.

Two Trained Applicators

Most label statements require two trained, properly equipped applicators to be present during introduction and venting of fumigants. Working with another person has been a long-standing industry recommendation. Specifically, many labels require that two applicators work together whenever fumigant application or gas monitoring requires entry into or work within the confined space where a fumigant is applied.

Sealing Grain Bins

Before introducing the fumigant, inspect all bin surfaces for holes or loose seams. One method of finding holes or leaks is to use smoke. Before filling the bin or silo, release a smoke canister inside the bin. Mark points where the smoke escapes with dye, paint, or other marking substances. Later seal these areas with a caulking compound or sealant. Only caulking compounds or sealants approved by the Food and Drug Administration (FDA) can be used inside the bin or in other areas where grain will contact the treated surface.

If the bin or silo already contains grain, you will need to inspect the seal without the help of smoke. Just before the fumigation begins, cover roof ventilators and aeration ducts with plastic bags. Gather the bags at the base and tape them into place. Close and seal doors with a foam sealant or tape. Also make sure that the roof-wall junction is tight.

Gas Detection Devices

Revised labels for fumigants require the use of sensitive gas monitoring devices during fumigant application and before warning placards can be removed from fumigated storages. Devices that provide adequate sensitivity include gas detector tubes and matching pumps. (See Chapter 2 for more details.)

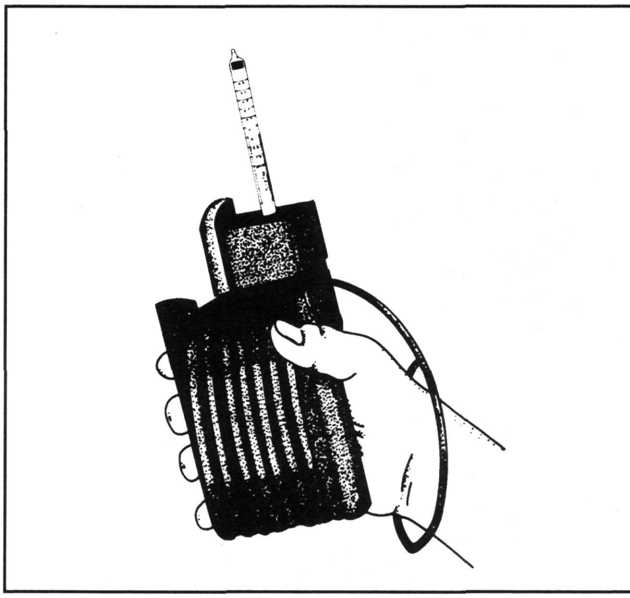


Figure 10. Draeger pump with a gas detector tube attached.

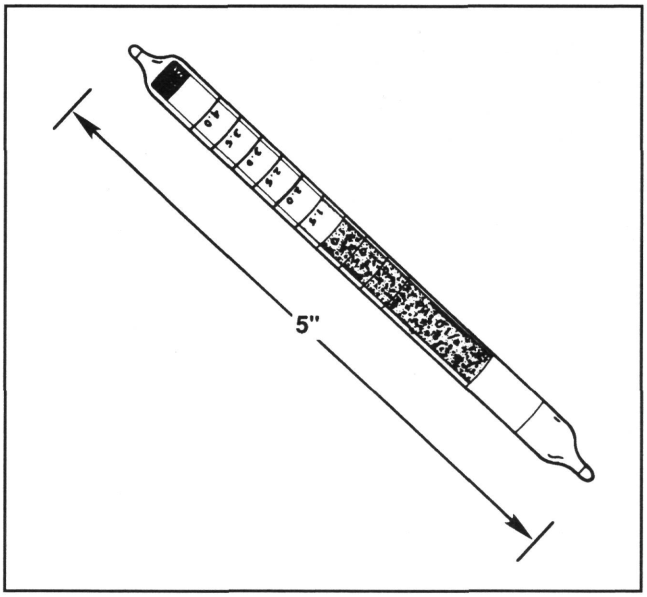


Figure 11. Gas detector tube showing a reading of 1.0.

Detector tubes are sealed glass tubes filled with a specific reactive solid. The applicator breaks off both ends of the tube just before use and attaches one end to a calibrated pump. The pumps use a bellows, bulb or piston-type syringe to draw a precise volume of air through the detector tube (see Figure 10). A change in color of the solid material within the tube tells you that fumigant is present. The gas concentration can be read directly from the scale on the glass tube, as shown in Figure 11. Detector tubes are specific for a single fumigant.

Although tubes and pumps manufactured by different companies may be very similar, accurate readings require matching detector **tubes and pumps from the same manufacturer. Do not mix different brands of equipment.**

Low-range detector tubes that accurately show low levels of fumigant concentrations are required for label-specified monitoring practices that provide information for worker safety. High-range tubes may be useful for detecting fumigant leaks. These tubes are scaled for measuring much higher concentrations of fumigants. They are especially useful for monitoring gas concentrations in storages to figure out whether necessary fumigant levels have been reached.

Other gas monitoring devices such as halide leak detectors and thermal conductivity meters may be used to detect leaks or determine internal concentrations of gas during fumigation. These devices **do not** provide label-required levels of sensitivity necessary for determining safety needs such as the need to wear a respirator.

Respiratory Protection

Fumigant labels require the use of specific respiratory protection equipment during most fumigant applications. Labels also state maximum fumigant concentrations in which applicators can work without respiratory protection. Chapter 2 describes respiratory equipment used during fumigation and explains how to fit a respirator. Your respirator must fit properly (forming a tight seal around your face) to protect you from the fumigant.

Warning Placards

Labels specify the wording and content that must appear on warning placards. Some information may need to be written in both English and Spanish. Warning placards cannot be removed and the commodity may not be processed or fed until a certified applicator measures the gas concentrations. After aeration, the applicator checks the gas concentrations to confirm that they are below levels specified for each fumigant.

Selected Bibliography

MSU Extension's chemical recommendations for stored grain are published annually in Extension bulletin E-1582, Chemical Control of Insects & Nematodes in Field and Forage Crops by D.A. Landis and G.W. Bird. Other resources are listed below.

Bauer, F.J. (Ed.). 1984. Insect Management for Food Storage and Processing. St. Paul, Minn.: American Association of Cereal Chemists.

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United States Department of Agriculture 1986. Stored-Grain Insects. Agriculture Handbook Number 500. Washington, D.C.: U.S. Government Printing Office.

Weinzierl, R.A. (1990 [revised annually]). Insect Pest Management Guide for Stored Grain. Extension Circular 1242. Urbana-Champaign, Ill.: Cooperative Extension Service, University of Illinois.

REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. If you detect an infestation early, cleaning and moving the grain may be successful if the pests are __________.
   a. Weevils.
   b. Secondary beetles.
   c. Mites.
   d. Inactive.

2. You may be able to control __________ by removing the central core and incorporating an insecticide into the surface of the grain.

3. If you move infested grain into clean storage to treat it with a protectant insecticide, you should also ________________.
   a. Fumigate the grain.
   b. Return the grain to the original storage as soon as possible.
   c. Clean the grain.
   d. All of the above.

4. If you know that you are unable to keep the storage sealed for the prescribed exposure time, you should increase the dosage of the fumigant. True or false?

5. The pesticide label instructions are the law and you must follow them or face possible criminal or civil proceedings. True or false?

6. How do you know if two people are required to work together when applying a specific fumigant?

7. Describe how to use smoke to check the seal of an empty bin.

8. What does it mean when the color of the solid material inside a gas detector tube changes color?
   a. The temperature is too hot to measure gas.
   b. The temperature is too cold to measure gas.
   c. The tube is ineffective and probably past its expiration date.
   d. Fumigant is present in measurable concentrations.

9. _____________ detector tubes are useful for making decisions about worker safety. ___________ detector tubes are useful for detecting fumigant leaks and for measuring whether necessary fumigant levels have been reached in the treatment area.
   a. Low-range, high-range.
   b. High-range, low-range.

10. How can you determine which respiratory protection equipment is necessary when applying a specific fumigant?

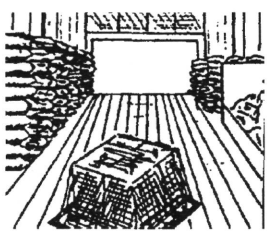
11. Warning placards can be removed after the applicator checks the gas concentration and confirms it is below levels specified on the fumigant label. True or false?

CHAPTER 6

FUMIGATION WITH TARPAULINS, TRUCKS AND RAILCARS

All methods of fumigation have one factor in common – some means to hold an adequate concentration of fumigant for the time necessary to control the pest. Commodities may be fumigated in trucks, railroad cars, ships or bins or under tarpaulins. This chapter will explain some requirements for fumigation with tarpaulins and in railroad cars and trucks. The appendix to this chapter describes standard tarpaulin fumigation equipment. Chapter 7 discusses the specialized area of shipboard fumigation.

Tarpaulin (Tarp) Fumigation



With the development of suitable devices for measuring gas concentrations, tarpaulin fumigation and fumigation in other temporary enclosures has become a reliable method of quarantine pest control. While there is more risk in using this type of enclosure than a permanent chamber, the fumigation, if properly managed can be safe and effective.

Although the term "tarpaulin" is often used to describe canvas cloth coated with water-repellent materials, this type **is not suitable** for fumigation. Typical tarps for fumigation are made of vinyl, polyethylene plastic or coated nylon.

The following sections explain some of the procedures for performing a tarp fumigation.

Load Arrangement

The load should not exceed two-thirds of the volume of the enclosed space unless otherwise specified by individual treatment schedules. The maximum size of the enclosure that can be treated adequately is determined by the availability of materials and equipment, operational considerations, and the capability to supervise and monitor the fumigations properly. Enclosures that can be covered by a 40-foot by 100-foot tarpaulin have been used successfully. For proper gas circulation, the tarpaulin should be 2 feet above the load and 1 foot from the sides and ends of the load.

Stack the commodity on pallets to permit air movement along the floor and arrange it so that the stack will be uniform in shape. Painting or marking the designated stacking pattern on the floor makes it easier to obtain a uniform enclosure. Arrange the commodity so that there is proper gas circulation and distribution throughout the load. Leave an inch or more space between individual stacks of pallets.

With multiple stacks, each uncovered stack must have approximately 10 feet of space around it. This will allow for approximately 5 feet of working space between enclosures after the tarpaulin is in place.

Gas Penetration and Distribution

With the load properly arranged for adequate air circulation, the gas should penetrate and distribute evenly. The fumigant will penetrate most

cargoes without difficulty, except finely milled products such as cottonseed. With such products, provide 5 feet of space in every dimension, since penetration may be very slow.

Non-permeable materials can exclude all the gas or resist penetration. Some common types are cellophane, plastic, and waxed, laminated and waterproofed papers. Tight wooden packing cases are also somewhat gas impermeable. These not only resist penetration but retain the gas that does penetrate for long periods and makes aeration difficult. Remove or open all non-permeable material. When there is a non-permeable wrapper or container, open the entire top or side and place the package with the open portion on the side.

Wrappers of untreated kraft paper or burlap, and containers of slatted wood or corrugated cartons are usually easily permeable and need no particular precautions unless they contain non-permeable liners.

Fan Arrangement and Operation

Use two axial-type (blade) fans of approximately 2,500 cubic feet per iinute (CFM) for each enclosure up to 35 feet in length (approximately 5,000 ft^3). Place one fan on the floor at the rear of the load facing the front, and the other fan at the front of the load on a raised platform facing the rear. For enclosures more then 35 feet long and up to approximately 7,500 ft3, add a third fan on a raised platform in the center of the load facing the rear. For between 7,500 and 10,000 ft^3, place a fourth fan on the floor in the center of the load facing toward the front.

Larger enclosures(up to 25,000 ft may require up to seven fans to provide adequately for gas circulation. Enclosures layer than 25,000 ft^3 require advance approval by the Michigan Department of Agriculture and will require proportionally more circulation equipment.

Operate fans during gas introduction and for 30 minutes after that, or until the gas is distributed well. Fan operation should be extended only if fumigant distribution is not adequate as shown by the gas concentration readings. Fans also should be operated during any subsequent gas addition, but only for a period sufficient to ensure proper distribution as indicated by the thermal conductivity readings. Note that fans must remain in operation during fumigation of plant material.

Placement of Gas

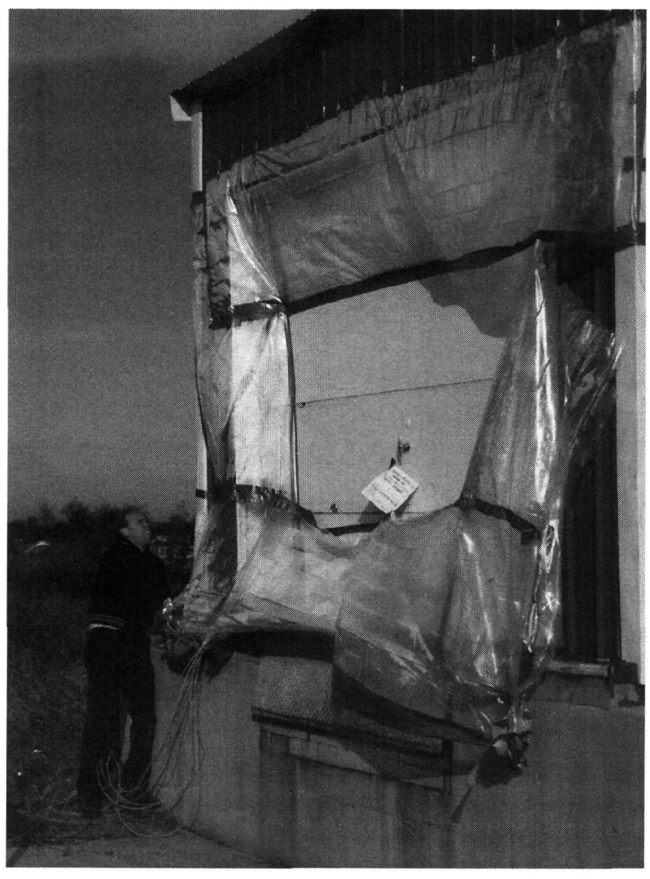
After you have positioned the fans properly, place the gas supply line so that it introduces the fumigant directly into the airstream above the load. Attach the end of the supply line near the top fan. If the load length requires additional fans, then place additional gas lines by the additional fans above the load.

Attach these lines securely — the vibration created by the gas passing through the line could cause them to tear through the tarpaulin or be displaced and not directed into the airflow. Place a piece of non-permeable sheeting over the load in front of and below each gas supply line. This prevents any liquid from coming into contact with the commodity.

Placement of Gas Sampling Tubes

Place a minimum of three gas sampling tubes in spaces beneath the cover for fumigations up to 10,000 ft^3. Position the leads to allow a reading to be taken from the following locations:

- Front of the load — 3 inches from the floor
- Center of the load — midway from the bottom to top of load
- Rear of the load —at the extreme top of the load.



For fumigations up to 25,000 ft3, use six gas sampling leads at the following positions:

- Front of the load — 3 inches from the floor.
- Upper front quarter section.
- Center of load — midway from bottom to top of load.
- Upper rear quarter section.
- Lower rear quarter section.
- Rear of load — at the extreme top of the load.

Any enclosure larger than 25,000 ft3 must be approved in advance and will require proportionally more sampling tubes.

Use leads of sufficient length to extend from the given positions to at least 30 feet beyond the cover and to converge at one location for taking readings. Do not splice leads.

Before starting the fumigation, test the sampling leads for tightness. Connect a lead to the thermal conductivity analyzer, and seal the far end of the lead by placing a finger over the end. The ball in the flow meter will fall to zero if the lead connections are tight. Lead blockage or pinching also can be determined at this time.

Fix the leads securely in place under the tarpaulin and correctly label each lead's position at the instrument end so that data can be easily and correctly recorded.

Temperatures

You will need to take temperature readings of air in the stack and of the commodity. Use a bimetallic long stem thermometer that has been calibrated. *(Note that when fumigating rooted plant material for Japanese beetle control, the temperature of the soil ball determines the rate and duration of fumigation.)*

Covering the Stack

The final preparation is to find areas that might tear or snag the tarpaulin. If you cannot eliminate them, the corners must be covered with burlap or other suitable padding material.

After you have completed all preliminary operations, the load is ready to be covered by the tarpaulin. Be extremely careful to avoid snagging or tearing the tarpaulin. Sufficient supports must be provided to hold the cover 2 feet above the load to avoid obstructing the airflow.

The tarpaulin must be large enough to provide a floor lap of no less than 18 inches around all sides of the load. Carefully lay the tarpaulin out to prevent excess folds or wrinkles along the floor, especially around the corners. When you have the cover secured in place, there must be approximately 2 feet of open space above the load and 1 foot of open space around the sides and ends of the load.

Sealing the Tarpaulin

Use sand or water snakes (minimum diameter 3 inches) to seal the edges of the tarpaulin to the floor. Two rows of snakes along the sides and three rows of snakes on the corners will be required. Snakes should overlap each other approximately 1 foot. It is extremely important to place the snakes properly because the base of the tarpaulin will be the area where the greatest amount of leakage could occur.

The corners are difficult to seal because of the material that gathers there. A good procedure is to lay two sand snakes around the corner and work the tarpaulin in until it lies reasonably flat. A third snake lying on top of the other two will provide additional weight, forcing the tarpaulin close against the surface.

Give special attention to that area where the gas supply lines, electrical cords and sampling tubes extend from under the tarpaulin. When you have the snakes in place, the tarpaulin must have about 1 foot of free space on all sides of the load for gas circulation.

When you have finished making the enclosure, inspect again for tears or openings before introducing the gas. A gastight enclosure is essential.

Volume Measurement and Dosage Calculation

Carefully measure the enclosed space to be fumigated. Measure length, width and height accurately! Do not estimate. A difference of as little as 12 inches in total dimensions could result in an error of up to 15 percent or more in dosage requirements. If the sides of the enclosure slope outward from the top to bottom, measure both top and bottom and average the two to determine the dimension. (Height should be uniform and not require adjustment.)

To decide the dosage for the proposed fumigation, read and follow all directions listed within the fumigant application instructions. The application summary supplies information concerning dosage, exposure time, tolerance of pest, target insects, commodity, and other valuable information that you should read and understand before the fumigation.

Conducting the Fumigation

Before introducing the gas, do the following:

1. Turn on all fans and the thermal conductivity (T/C) analyzer and check for proper operation.

2. Allow air to mix for several minutes.

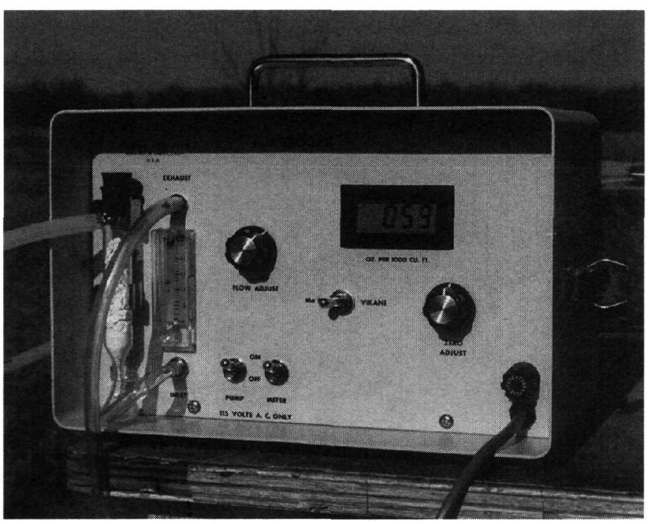
3. Take a set of T/C analyzer readings to determine if any contaminant gases are present that may affect fumigant concentration readings.

4. Put the volatilizer into operation. Water must stay at or above 150 degrees F.

5. Place the fumigant cylinder with gas introduction line on the scale and take an initial scale reading. (The weight of the introduction line will affect the reading.)

6. Check all aspects of the operation before releasing any fumigant.

- Is the area secure and are warning signs in place?
- Are all persons not working on the fumigation out of the area?
- Is the tarp free of rips and tears?
- Is all the equipment functional?
- Are all gas supply line connections tight and free of leaks?
- Is safety equipment, particularly approved respiratory protection, available at hand and functional?



After checking all details, observe the gas introduction. When using large cylinders, open the gas valve slightly and close it again. Check all connections on the gas introduction line for leaks with a halide detector. If all is secure, continue with gas introduction. The gas introduction line should feel hot, which means that the gas is vaporizing well as it leaves the cylinder. Continue introducing the fumigant until you have released the proper amount.

Remember that operation of fans should be curtailed as soon as possible to avoid excess gas leakage. Once good distribution is shown, the fumigant and air mixture should remain stable for the entire fumigation period. Operate the fans for short periods when the T/C analyzer shows lack of uniformity in gas distribution or when you add more gas. (Note: Fumigation of plant material requires that fans be in constant operation throughout the treatment.)

You may have some problems getting the final amounts of gas from the cylinder. In these instances, consider the running time of the fans — continued air movement in the enclosure is a contributory factor to increased leakage. Take the T/C analyzer reading 30 minutes after the gas is introduced. If you find there is a good distribution pattern at a sufficiently high concentration, turn off the fans. Allow the remainder of the gas to discharge at a slow rate with intermediate running of the fans for dispersal.

Treatment time will depend on initial concentration. Normally, by the end of the 30-minute period, the gas introduction will be completed and the readings on the T/C analyzer should show normal distribution and penetration pattern for the gas.

Testing for Leaks

After introduction of the fumigant, test for leakage with a halide detector. Since you do not know the concentration of gas, you **must** wear a self-contained breathing apparatus (SCBA) while making this check.

Test around the perimeter of the tarpaulin on the floor, especially at corners and where electric, gas sampling and gas introduction lines are present. Use extra snakes or other materials as necessary to eliminate leakage. Use tape to seal holes in the tarpaulin.

Do not attempt to correct for excessive leakage (when concentration readings are less than 50 percent of the minimum) in any tarpaulin enclosure by adding more gas. Quickly evacuate the remaining gas from such an enclosure, get rid of the problem and construct a new enclosure. Start a new treatment in the new enclosure. **Commodities intended for food or feed may not be retreated.**

Exhausting the Fumigant and Aeration

When the exposure period is complete, exhaust the fumigant from the fumigation enclosure. Check the level of residue fumigant within the chamber, using the detector tubes, before allowing unprotected access to the commodity.

A fumigant must be aerated according to the Environmental Protection Agency (EPA) label requirements and Occupational Safety and Health Administration (OSHA) regulations. Aeration procedures are designed to provide safe working conditions during aeration and to assure that commodities are safe for handling, storage and further transportation. The fumigator must check the atmosphere within the enclosure following aeration to ensure that the fumigant level is below 5 parts per million (ppm).

The following procedures describe aeration of bulk and containerized commodities under indoor and outdoor conditions.

All fumigations and aeration must be conducted in an area restricted to all persons except those supervising the fumigation and employees of the fumigator performing fumigation-related activities.

The secured area is the entire structure used for fumigation or an area that extends 30 feet from the fumigation enclosure. If a wall of gas-impervious material is less than 30 feet from the fumigation enclosure, the wall is the edge of the secured area.

The secured area must be delineated with a physical barrier such as ropes, barricades or walls.

The area must have warning signs clearly posted to indicate that hazardous fumigants are being applied. All warning signs (placards) must meet appropriate fumigant labeling requirements, including specific warnings, information and language.

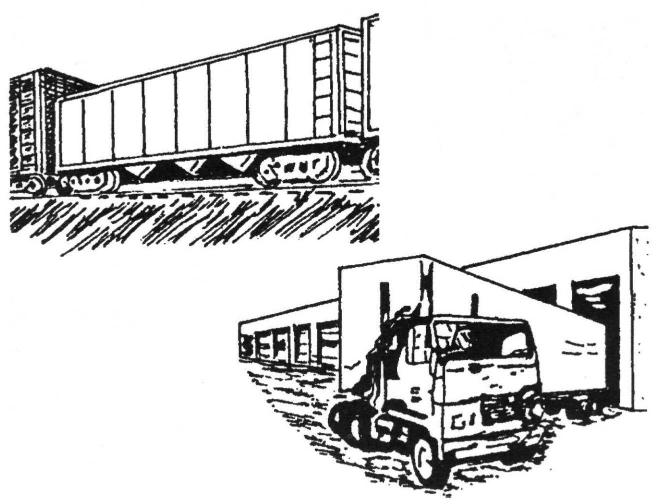
Do not operate motorized vehicles in the immediate area during fumigation and aeration.

The fumigator and supervisor must use approved respiratory protection SCBA, air-supplied respirator or a combination unit when:

1. Installing the exhaust system.
2. Opening the tarpaulin for aeration.
3. Removing the tarpaulin if measured levels are above the threshold limit value of 5 ppm.
4. At any time during the fumigation/aeration process when there is risk of exposure to concentrations above the TLV (threshold limit value). This includes any time when you do not know the concentration — such as with spills, leaks or other emergencies — and when within 30 feet of the fumigation enclosure before final release.

Railcars, Trucks and Cargo Trailers

The basic procedures and concerns about fumigating railcars, trucks and trailers are similar to that of fumigating under tarps. Most railway cars made of steel are suitable for fumigation and require only minimum sealing. Refrigeration cars are practically airtight, and if you seal drainage pipes and vents properly, they are suitable for fumigation. Wood plank flooring of older railcars may leak if not sealed properly and should be checked before fumigation.



A railcar that cannot be made airtight can be covered with polyethylene sheeting or other type of tarpaulin (see below) and then fumigated. Railcars may need to be moved off to the side onto a separate track during fumigation.

Depending on the local regulations, the railcars may even be able to travel during fumigation. Another option is to fumigate several railcars at once under a large enclosure. This method saves both time and money.

Most trucks and cargo trailers are manufactured similar to railcars and should be fumigated the same. A fumigation method that could be used for trucks and trailers uses two polyethylene sheets. Place one sheet on the ground and drive the vehicle or trailer onto the sheet. Drape another sheet over the vehicle, leaving at least a 2-foot space above the top of the vehicle or trailer to allow for adequate airflow. Seal the two sheets by placing sand or water snakes on top of the adjoining sheets similar to sealing a tarpaulin placed over a container.

Fumigate with Caution

The handling and use of fumigants to control pests in enclosures, containers and commodities is an endeavor that should be taken seriously. Carelessness or ignorance could result in serious injury of the fumigator or innocent bystanders, destruction of the usefulness of the product being treated or failure to control the pest.

Follow the recommendations presented in this chapter and obey the manufacturer's Environmental Protection Agency (EPA)-approved label to ensure a safe and effective fumigation. **Remember, you should fumigate only when no other alternative can solve the problem.**

REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. The tarpaulins used for commodity fumigation are canvas cloths coated with water-repellent materials. True or false?

2. For proper gas circulation, the tarpaulin should be ____ foot/feet above the load and ____ foot/feet from the sides and ends of the load.

3. Why should you stack the commodity on pallets as you prepare it for tarp fumigation?

4. Finely milled products will be more difficult for the gas to penetrate and you should provide 5 feet of space in every dimension becauae penetration may be very slow. True or false?

5. What should you do if a commodity is wrapped in an unpermeable material?

6. How big an enclosure (in cubic feet) can be aerated by two fans of approximately 2,500 CFM?

7. To fumigate a tarpaulin enclosure of more than _____ ft^3 requires approval from _______________ prior to fumigation.

a. 25,000; The Michigan Department of Agriculture.

b. 25,000; The Michigan Department of Natural Resources.

c. 18,000; The Michigan Department of Agriculture.

d. 18,000; The Michigan Department of Natural Resources.

8. You should have fans operating continuously during a fumigation only if you are fumigating plant material. True or false?

9. Gas supply lines should be located by fans at the _____ of the load.

a. Bottom.

b. Top.

10. Where should you place the three gas sampling tubes for fumigations up to 10,000 ft^3 ? Describe the location where you should be able to take readings from the tubes.

11. What should you do to sharp corners before securing the tarp over the commodity?

12. The tarpaulin must be large enough to provide a floor lap of no less than ____ inches around all sides of the load.

13. Describe how to place sand or water snakes to seal the tarp to the floor.

14. A difference of as little as 12 inches in measuring the total dimensions of the area to be treated could result in an error of up to 15 percent when calculating dosages. True or false?

15. After you begin introducing the fumigant, the gas introduction line should feel _________, which means that the gas is vaporizing well as it leaves the cylinder.

a. Cold.

b. Hot.

c. As if it is vibrating.

d. None of the above. You can't feel these sensations through the thick tube.

16. What should you do if you begin fumigation and leaks occur so that concentration readings are less than 50 percent of the minimum effective level?

17. The fumigator must check the atmosphere within the enclosure following aeration to ensure that the fumigant level is below 25 parts per million (ppm). True or false?

18. How should you secure the area around the tarpaulin fumigation?

19. When during tarpaulin fumigation are the fumigator and supervisor required to wear respiratory equipment?

20. Do not operate motorized vehicles in the immediate area during fumigation and aeration. True or false?

21. A railcar that cannot be made airtight can be fumigated under a tarpaulin. True or false?

APPENDIX TO CHAPTER 6

Standard Equipment for Tarpaulin Fumigation

The following are standard equipment used in many tarpaulin fumigation situations. **This list is to be used as a reference and is not part of the certification examination.**

a. Tarpaulin

b. Sand or water snakes, or adhesive sealer

c. Padding

d. Framework and supports

e. Fans

f. Electrical wiring

g. Tape

h. Gas sampling tubes

i. Gas supply line

j. Volatilizer

k. Scales or dispensers

l. Halide leak detector

m. Self-contained breathing apparatus (SCBA) or supplied-air respirator

n. Gas analyzer

o. Tape measure

p. Thermometer

q. Warning signs

r. Exhaust blower and ducts

s. Fumigant

t. Detector tubes

a. Tarpaulin (to cover commodity). Although the term "tarpaulin" is often used to describe a canvas cloth coated with water- repellent materials, this type is not suitable for fumigations. The tarpaulins used for commodity fumigations are made of materials such as vinyl, polyethylene plastic or coated nylon. Four millimeter (4 mil) vinyl or polyethylene plastic sheets are approved for one use; 6 mil up to four uses; rubber or coated nylon of 10 to 12 mil is permitted for multiple uses.

The tarpaulin must be in good condition with visible holes or tears mended before the applicator introduces the gas. After repeated use, the tarpaulin may develop small pinholes and no longer be usable. Do not use a tarpaulin that appears worn.

b. Sand or water snakes, or an adhesive sealer (to seal the tarpaulin to the floor). Sand or water snakes (canvas, cloth or polyethylene tubes filled with sand or water) should be a minimum of 3 inches in diameter and 4/5 filled. Although sand snakes are generally 4 to 6 feet long, there are no restrictions on length. Water snakes may extend to 100 feet or more. Wet sand also makes an effective seal.

c. Padding (to protect tarpaulin from damage). Burlap mats or similar protective material must be placed over sharp corners or other places that might damage the tarpaulin and allow fumigant to leak.

d. Framework and supports. Use suitable temporary supports of wood, metal or other material (but not the commodity containers themselves). These supports are used to support the tarpaulin and provide open space above and around the load.

e. Fans. Fans or blowers circulate and thoroughly mix the fumigant and air. Axial-type (blade) fans are efficient in most situations. The number and placement of fans will depend on the particular fumigant and the commodity volume and arrangement. Before fumigation, the air velocity must be determined for each fan. To determine air velocity, use an anemometer (wind meter) or a wind speed indicator, or do some simple calculations.

The air velocity produced by a fan is measured in cubic feet per minute (CFM). Measure air movement 12 inches from the face of the fan. Take a minimum of three readings: one from the center and others from points toward the outside of the fan. Then average the readings. If you use an anemometer, each measurement should be for one minute, so that the result is in feet per minute. If you use a wind speed indicator, convert the reading in miles per hour to feet per minute by multiplying the miles per hour by 88.

Calculate the area of the fan by first measuring the radius (R) —the distance from the center of the fan to the end of the blade. The formula used to figure the area is Pi times the radius squared (PiR^2), where Pi equals 3.1416 (22/7). The final answer should be in cubic feet per minute. Therefore, if the radius of the blade is given in inches and not feet, the factor 1/144 must be multiplied in to convert square inches to square feet. The full formula would be:

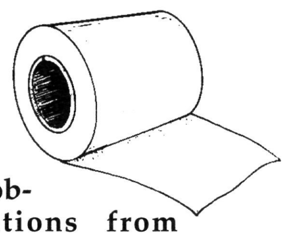
feet per minute x R^2 (in inches) x Pi x 1/144 = CFM

Example. If average air movement is 1,600 feet for one minute from a fan having a 7-inch radius (14-inch diameter), the calculations are as follows:

$1600 \times 7^2 \times 22/7 \times 1/144 = 1{,}700$ cubic feet per minute (CFM)

f. Electrical wiring (to operate fans and gas measuring unit). Sufficient wiring is necessary to connect fans into existing outlets and to operate the thermal conductivity (T/C) gas analyzer.

g. Tape (to prevent or mend openings in the tarpaulin). Use any adhesive made of gas-impervious material.



h. Gas sampling tubes (to obtain fumigant concentrations from pre-selected areas within the tarpaulin enclosure). Low sorptive polyethylene-type tubing with a 0.25-inch outside diameter is preferred. Do not use softer plastic type-tubing for long sampling tubes because it has higher sorptive qualities. Avoid using brittle tubing. Usually you will need three to five leads for each tarpaulin enclosing up to 10,000 Ft.3 of space.

i. Gas supply line. The gas supply line carries the fumigant from the cylinder or can to the inside of the enclosure. When using a cylinder, a length of copper tubing 1/4 to 3/8 inch diameter is connected to the cylinder nozzle. A volatilizer or other measures may need to be taken to assure volatilization.

Introduction of gas from a 1- or 1.5-pound can requires a fitting especially designed for this purpose. The fitting has a clamp that pierces the can, allowing fumigant to escape through a plastic hose. Depending on the surrounding temperature, the gas supply line may need to be placed in hot water. The use of canned fumigant is allowed but not recommended if more than one can is necessary for the required dosage.

j. Volatilizer. When temperatures surrounding the tarp enclosure are below 60 degrees F or if you are using large quantities of a fumigant, you must use a volatilizer to convert a liquid fumigant to a vapor. The fumigant should be introduced through the tubing at the rate of 3 to 4 pounds of gas per minute. The gas introduction tube should feel hot to the touch as a good measure of satisfactory vaporization. Or you can monitor the water temperature in the heat exchange.

If a commercial-type volatilizer is not available, a simple volatilizer can be made using a 25-foot coil of 3/8-inch (outside diameter) copper tubing. The copper tubing is then submerged into a hot water bath. The water bath must remain hot to volatilize the fumigant properly.

k. Scales or dispensers (to accurately weigh fumigant dosage from the cylinder). A commercial-type scale that will accurately weigh in 1-pound increments is necessary. Special dispensers calibrated in quarter pounds up to 3 pounds are available for measuring small amounts of a particular fumigant. The dispensers attach directly to the cylinder valve.

l. Halide detector (to detect halide gas in fumigant mixtures). Fumigators use the detector to locate fumigant leakage around chambers, application equipment and temporary enclosures, and as a safety device around fumigation sites. It is not legal for low-level measurements of fumigants. It may be necessary to use a detector tube to determine lower densities of fumigant.

m. Self-contained breathing apparatus (SCBA). SCBA must be worn anytime the concentration of a fumigant in a work area exceeds the threshold limit value (TLV) or is unknown. Approved, positive pressure, full-face SCBA is required.

n. Gas analyzer (to measure gas concentrations). A thermal conductivity (T/C) gas analyzing unit suitable for measuring fumigant concentrations should be available.

o. Tape measure. The tape measure is used to measure the dimensions of the enclosure to figure out the adequate fumigant dosage.

p. Thermometer. The thermometer is used to measure the temperature of the air and the material to be fumigated.

q. Warning signs. Suitable approved signs in conformity with label requirements must be posted around the area of fumigation in both English and Spanish.

r. Exhaust blowers and ducts. An exhaust blower that can be connected to large-diameter ducts removes fumigant from the enclosure at the end of the exposure period. The blower should be capable of completely changing the air in the enclosure every 3 minutes.

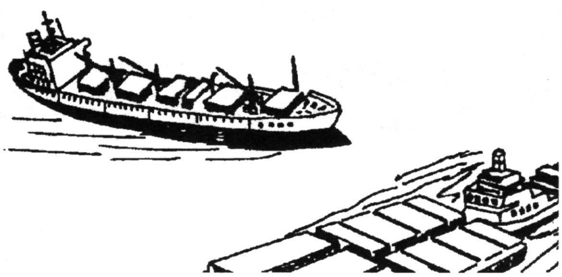
s. Fumigant. It is very important to have the most effective fumigant and the proper amount of fumigant on hand to ensure eradication of the target pest(s) and completion of the fumigation.

t. Detector tubes. Detector tubes work with an air pump that draws specific amounts of air (usually 100 milliliters) through the detector tubes. The drawn air reacts with a specific chemical reagent (depending on the fumigant) within the detector tube, creating a stain. The person taking the reading measures the stain to determine the concentration of the fumigant remaining within the fumigation chamber.

CHAPTER 7

SHIPBOARD FUMIGATION

Ship fumigations are highly specialized and are done when products requiring fumigation must be treated before they can be unloaded. Because of the unique problems that can occur with ship fumigation, a specialty firm may need to be employed for this task.



The first step is to measure the size and depth of the space to be fumigated and the cargo. Some ship holds are so large that they cannot be fumigated successfully when filled with grain or other commodities, unless recirculation of the fumigant or other techniques for gas distribution are used. If you make the proper provisions, any full cargo space can be fumigated. All piping, bilge openings, ventilator openings and hatches must be sealed off. Heating and ventilator systems may be helpful in bringing the cargo to optimum temperatures and for aeration.

It is essential that you have close cooperation with the responsible ship's officer, ship's agent, the USDA and the Coast Guard inspector (if involved). Coast Guard notification may be required. The port authority and fire and police departments should be notified, and guards arranged for, if necessary. If you are fumigating most of the cargo space, you should obtain a list that identifies the entire crew and ensure that all leave the ship during fumigation. No one should be allowed to return until the ship is clear of fumigant.

The Federal Grain Inspection Service (FGIS), in cooperation with the Agricultural Research Service (ARS) and the grain, fumigant and maritime industries, have researched proper, effective and economical fumigation methods for bulk grain in transit aboard ocean-going vessels. The ARS has provided the FGIS with recommendations for transit fumigation of bulk grain aboard several types of vessels based on the these studies.

The FGIS has issued policies and procedures for the in-transit fumigation of bulk grain aboard certain carriers using aluminum phosphide fumigant formulations registered by the U.S. Environmental Protection Agency (EPA). *(Note: Pesticide registrations are being updated and you should confirm that aluminum phosphide is currently registered for your use before application.)* The following sections explain the FGIS-recommended procedures.

In-transit fumigation of bulk grain in vessels is approved only within the parameters described in this section. The vessel types approved for in-transit fumigation are:

- Bulk dry-cargo vessels, including ocean-going barges.
- Tanker-type vessels.
- Liquefied natural gas (LNG) carriers converted to bulk carriers.
- "Lakers" or "'tween-deck" vessels with the same structural characteristic as bulk dry-cargo vessels.

These vessel types are acceptable only when certified applicators state that they have inspected the vessel and found it to be suitable for fumigation. Acceptable vessels **must not contain** interior bulkheads, structures or decks within the tanks or holds that could block penetration of the gas throughout the grain mass. For example, a 'tween decker with decks made of steel grating may be fumigated provided the vessel is otherwise suitable for fumigation. Wing tanks on acceptable vessels may be fumigated under this chapter. If the wing tanks have bleeder holes connected to the main hold or tank and bleeder holes remain open, the main hold or tank connected to the wing tank also must be fumigated.

Acceptable Bulk Commodities

Commodities that are acceptable for in-transit fumigation are barley, corn, flaxseed, mixed grain, oats, rough rice, rye, sorghum, soybeans, sunflower seed, triticale and wheat. Other raw commodities listed on approved labeling also may be fumigated in transit.

Acceptable Fumigant Formulations

EPA-registered aluminum phosphide formulations (either pelletized or granular) are the only approved formulations for in-transit fumigation.

Fumigant Application Methods

Acceptable Fumigant Application Methods

The applied dosage must be within the guidelines of the EPA-registered product label and labeling. The following application methods are provided as guidelines.

1. Surface treatments.

a. Spread the fumigant formulation (packaged to retain residual dust; i.e., belts, ropes, blankets, strips, sleeves, etc.) on the exposed grain surface. If possible, anchor packages to prevent shifting during transit.

b. Uniformly spread, scatter, or step pellets or tablets into the exposed grain surface.

2. Subsurface treatments.

a. **Trenched-in.** Place fumigants (packaged to retain residual dust) in a shallow trench approximately 1 foot deep. Cover with grain such that only the two ends of the package remain visible above the grain surface.

b. **Short probe.** Use a tube constructed of polyethylene or other material, approximately 5 feet long, to apply pellets or tablets. Insert the probe into the grain to a depth of at least two-thirds of its length. Fill with tablets or pellets to at least one-half of the tube's length, and then remove from the grain. Be careful to avoid rapid removal of the probe from the grain — this can cause the pellets or tablets to be deposited on the grain's surface. Also, bridging of the pellets or tablets within the probe must be avoided. Bridging occurs when pellets or more likely, tablets arch together to plug the probe. Inserting fumigants (packaged to retain residual dust) to a depth of 5 feet also meets the short probe condition.

c. **Long probe.** Use a tube of polyethylene or other material approximately 16 feet long to apply pellets or tablets. Insert the probe into the grain to a depth of at least 13 feet. Pour pellets or tablets into the probe and slowly extract the probe from the grain. Probing must be done uniformly over the entire exposed grain surface. Bridging of the pellets or tablets within the probe must be avoided. Inserting fumigants (packaged to retain residual dust) to a depth of 13 feet also meets the long probe condition.

d. **Long probe/short probe combination.** Use at least one long probe in the four corners of the hold. Apply the remaining dose using the short probe method.

e. **Tubing system.** Use corrugated slotted tubing constructed of polyethylene or similar material with a minimum diameter of 3 inches. Install at least two 250-foot lengths of the tubing before loading in a way that will provide for the uniform distribution of fumigant.

Mix approximately one-fifth to one-third of the total amount of aluminum phosphide formulation to be applied to each hold or tank with grain. Pour it down the slotted tubing from the top end. Mix no more than 3,320 pellets or 665 tablets of fumigant per bushel of grain. Fill no more than two-thirds of the vertical portion of the slotted tubing with the formulation/grain mixture. After you have poured the mixture down each tube, add at least 1 bushel of grain without any formulation. The remainder of the dose may be applied by any surface or subsurface method.

f. **Recirculation System.** Install corrugated slotted or similar tubing in a way that will provide for the uniform distribution of the fumigant. Attach a fan or other device to the tubing to enhance fumigant distribution. Apply fumigant using any surface or subsurface method. During transit, the fan forces the high gas concentrations in the head space to the lower portions of the hold.

Acceptable Separation Materials

Bulk grain above or below a permeable separation material, such as burlap or woven polypropylene, may be fumigated. Bulk grain below impermeable separation materials, such as wood, plastic or cardboard, cannot be fumigated in transit.

Suggested Application Methods by Commodity Depth and Exposure Time

Table 6 recommends specific fumigant application methods for various commodity depths and fumigant exposure time in vessels.

Table 6. Minimum Fumigant Exposure Time (In Days) by Commodity Depth.

Application Method	Commodity depth < 6 meters*	6-12 meters*	12-20 meters*	> 20 meters*
Surface	9	15	Not recommended	Not recommended
Trench	8	15	18	Not recommended
Short probe	8	15	18	Not recommended
Long/short probe	4	12	18	Not recommended
Long probe	4	10	18	Not recommended
Tubing/recirculation	4	7	9	9

NOTES: - Cooler temperatures may lengthen fumigant exposure time.
- Grain depths less than 3 meters may be fumigated using any method with a 5-day exposure time.

* Convert meters to feet by multiplying meters by 3.28. One meter equals 3.28 feet.

Shipboard Procedures

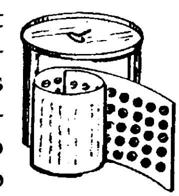
The aluminum phosphide fumigant formulations may be applied to the grain aboard acceptable vessels only after loading of the grain into the hold or tank is completed. Partially loaded or slack holds or tanks may be fumigated if you do not load additional grain later into that hold or tank.

When you plan to add another lot of grain at a different elevator on top of a previous lot, you may fumigate only after all the grain has been loaded into the hold or tank. Certification of the first lot is withheld pending the proper application of the fumigant after completing the grain loading in the second lot.

The fumigated holds or tanks must remain closed for the entire voyage. They should not be opened at sea unless an emergency exists, such as structural damage, fire, etc. Appropriate respiratory protection equipment and fumigant gas detection equipment must be on board the vessel and at least two crew members must be knowledgeable in their use.

Recirculation of the Fumigant

For a fumigation to be completely effective, the gas must reach toxic levels in all areas of the confined space. The fumigant, when released in a closed space, naturally seeks to become equally distributed throughout. This state is called equilibrium. This means that when you sample the concentration of the fumigant in the top, bottom, sides, corners or middle, you will find the same concentration everywhere.



Given enough time, fumigant gases will naturally seek equilibrium. But in some fumigations it is best to help the gas along by installing a mechanical system to pump or recirculate the fumigant to aid in achieving equilibrium. Grain storage fumigation is a good example, because grain can pack to form a dense mass that is difficult for the fumigant to penetrate.

Some systems are available that can be added to various types of storages (ships, bins, silos or flat storages) for recirculating fumigant gases. This recirculation of the fumigant will establish a uniform gas concentration throughout the storage.

Certified Pesticide Applicator's Responsibilities

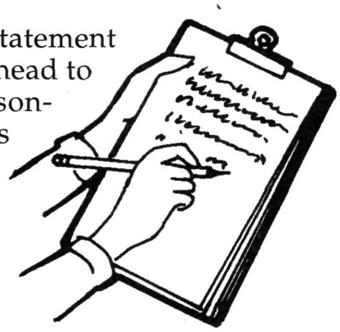
For shipboard fumigation, the certified pesticide applicator must:

1. Inspect or ensure that other qualified individuals inspect the holds or tanks for suitability to retain the fumigant gas for the entire voyage. This inspection may be conducted anytime before fumigation. The FGIS recommends that you inspect before loading, when the holds or tanks are empty. Your inspection must consider all aspects of the vessel's ability to retain the fumigant for the entire voyage. Structures and systems to evaluate include but are not limited to the following:

a. Integrity of hatch covers, vents, man hatches and other openings to the holds or tanks. In particular, check the condition of gaskets on all openings.

b. Structural or other systems that may allow the fumigant to leak from one area to another, such as coffer dams, pumping systems, all-weather tunnels, keel ducts, bilges, smoke/fire detection or suppression systems, deck lockers, bulkheads and decks.

2. Identify the holds or tanks that cannot be fumigated because they cannot retain the fumigant. In particular, carefully inspect holds or tanks that extend under the vessel's housing structure have or a common bulkhead to living quarters to ensure that no fumigant can leak into these areas.



3. Provide a written statement on the company's letterhead to the FGIS or agency personnel showing which holds or tanks are suitable for fumigation and which are not. The reason for unsuitability must be included in the statement. This statement must be signed by the certified pesticide applicator conducting the inspection and the officer in charge of the vessel.

4. Determine the fumigant application method and the amount of fumigant to be applied to each hold or tank.

5. Prior to fumigation, meet with the officer in charge of the vessel in the presence of FGIS or agency personnel. Provide each party with a copy of the EPA-registered label from the fumigant formulation and a written statement on company letterhead signed by the certified pesticide applicator and the officer in charge of the vessel, specifying the following information:

a. The identification of the holds or tanks to be fumigated.

b. The method of application of the fumigant formulation.

c. The safety precautions to be followed by the vessel's crew during the voyage, symptoms of exposure to the fumigant and the first-aid procedures to be followed if an accidental exposure occurs.

d. The location of personal respiratory protection and gas detection equipment for on board the vessel, and acknowledgment that at least two crew members have been instructed in their use.

e. A listing of areas on the vessel that you have determined are safe and not safe during the fumigation.

f. A checklist of areas that must be monitored, at least daily, for fumigant leaks.

g. Instructions for aerating the holds or tanks. The instruction must specify that no one should aerate the holds or tanks at sea unless an emergency exists.

h. Instructions for the retrieval and disposal of fumigant formulation residue and its accompanying packaging, such as sachets, bag blankets or sleeves, upon arrival at the destination port.

6. Apply the fumigant formulation from a **factory-sealed** container. When applying, the certified pesticide applicator should:

a. Apply the fumigant formulation at the dosage prescribed on the EPA-registered label.

b. Consider the application procedure(s) recommended in this chapter based on hold depth and exposure time.

c. Close and seal all openings to the hold or tank after completing application of the fumigant formulation.

d. Verify that the fumigant is being contained within the hold or tank and is not a hazard to the vessel's crew by testing for leaks with an appropriate detection device.

7. Install warning placards on all entrances to all fumigated holds or tanks. Placards must be placed on the outside of each man hatch. Each placard must exhibit the skull and crossbones symbol, include the fumigation date and fumigant formulation used, and state that the fumigated hold or tanks are not to be aerated until arrival at the destination port. Placards in English and the principal language of the crew should be used when possible.

8. Provide a written statement on company letterhead to the officer in charge of the vessel and official personnel, signed by the certified pesticide applicator, indicating:

a. The date of the fumigant formulation application.

b. That the application of the fumigant formulation was according to EPA, U.S. Coast Guard and FGIS regulations and instructions.

c. The holds or tanks that received treatment.
d. The type and quantity of fumigant formulation used in each hold or tank, including the cubic capacity and the depth of each hold or tank.
e. The method of fumigant formulation application.
f. The destination of the vessel and the estimated voyage time.
g. That the openings to all fumigated spaces were closed and placarded and checked to ensure no fumigant was leaking at the time of the vessel's departure.

REVIEW QUESTIONS

Write the answers to the following questions and then check them with the answers in the back of this manual.

1. List some of the local authorities who should be informed before you fumigate a ship.

2. If you are fumigating most of the cargo space, what precautions should you take for the crew during fumigation?

3. Vessels approved for fumigation must not contain interior bulkheads, structures or decks within the tanks or holds that could block the penetration of gas throughout the grain mass. True or false?

4. How can you find out which commodities are acceptable for in-transit fumigation?

5. If you plan to add more grain at a different elevator on top of a previous lot:

   a. you should fumigate when convenient.
   b. you cannot fumigate this type of load.
   c. you must wait to fumigate until all the grain has been loaded.
   d. you should check with the elevator operators whether both loads need fumigation.

6. Fumigated holds or tanks can be opened at sea if you are concerned that you will have limited time when you are at port. True or false?

7. The FGIS recommends that the best time for the certified applicator to inspect the holds and tanks for suitability to hold fumigant is:

a. When the holds or tanks are empty.

b. Immediately after the holds or tanks are filled.

c. Several weeks prior to fumigation.

d. None of the above. This is not the responsibility of the applicator.

8. The certified pesticide applicator conducting the inspection must provide a written statement to FGIS or agency personnel identifying which holds or tanks are suitable and which are unsuitable for fumigation. True or false?

9. Prior to fumigation, the certified applicator must meet with __________ to discuss in detail the procedures and precautions for the fumigation.

a. The Cooperative Extension Service.

b. A representative of EPA.

c. The officer in charge of the vessel.

d. All of above.

10. Which of the following are true statements about placards?

a. They must be posted on all entrances to fumigated holds or tanks.

b. They must be placed outside each man hatch.

c. They must include a skull and crossbones symbol.

d. They must be written in English and, preferably, any other principal language of the crew.

8. d
9. a
10. Check the fumigant label for directions.
11. True

Chapter 6

Tarps, Trucks & Rail cars

1. False
2. 2, 1
3. To allow air circulation along the floor.
4. True
5. Open the non-permeable wrapper or container.
6. 5,000 ft^3
7. a
8. True
9. b
10. Front of load 3 inches off floor; center of load midway from bottom to top of load; rear of load at extreme top of load. Should be able to take readings 30 ft from the cover at one location.
11. Pad them with burlap or other material if you can't eliminate them.
12. 18
13. See first paragraph in section "Sealing the Tarpaulin."
14. True
15. b
16. Quickly evacuate gas from enclosure, get rid of problem leak(s), construct a new enclosure. Start a new treatment if the commodity is not food or feed.
17. False — 5 ppm.
18. Secure area with a physical barrier such as ropes and post warning signs.
19. See the four points in section "Exhausting the Fumigation and Aeration."
20. True
21. True

Chapter 7

Shipboard Fumigation

1. Port authority, fire and police departments, and possibly the Coast Guard.
2. Identify the entire crew. Ensure that all leave during fumigation and no one returns until the ship is clear of fumigant.
3. True
4. Check the fumigant labeling.
5. c
6. False
7. a
8. True
9. c
10. All are true.

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STORED GRAIN INSECTS AND MOLDS

Controlling Stored Grain Insects: To minimize damage in stored grain, empty and thoroughly clean all grain and grain debris from bins and apply a registered insecticide to bin surfaces. Store clean, dry grain that contains a minimum of foreign material. If grain is to remain in storage for a month or more between May and October, apply a protectant insecticide to the grain as it is binned. Once a bin is filled, use protectant insecticides on the grain surface and in the bin head-space. Cool the grain as soon as possible to slow insect development. Monitor grain temperature and moisture and check for insect infestations at least once per month.

1. **The Rice Weevil,** *Sitophilus oryzae*, is a snout beetle that averages 3/32 inch in length. Adults are reddish brown to black with 4 light red to yellow blotches on the wing covers. Unlike the granary weevil, the rice weevil has fully developed hind wings beneath the wing covers and can fly. Adults live 4 to 5 months, and each female deposits 300 to 400 eggs. Legless, cream-colored larvae feed within kernels of corn, wheat, rice, and other grains. Development from egg to adult requires about 4 weeks in warm (21 to 30°C, 70 to 85°F) grain.

2. **The Granary Weevil,** *Sitophilus granarius*, is a brown to black snout beetle 1/8 to 3/16 inch long. It lacks hind wings beneath the wing covers and cannot fly. Adults live an average of 7 to 8 months, and each female deposits 50 to 250 eggs. Granary weevils feed on a wide variety of grains, with the legless larval stage developing inside kernels. Maturation from egg to adult requires approximately 4 weeks in warm grain.

3. **The Confused Flour Beetle,** *Tribolium confusum*, is shiny, flattened, reddish brown, and approximately 1/8 inch long. It is the most abundant insect in U.S. flour mills and a common pest in raw grain where adults and larvae feed on broken kernels and grain fragments. Mature larvae are cylindrical, 3/16 inch long, and white to yellow. Development from egg to adult spans 6 weeks in warm grain or several months in cold grain.

4. **The Red Flour Beetle,** *Tribolium castaneum*, is often found with the confused flour beetle, and the two are nearly identical. The antennae of adult red flour beetles enlarge abruptly near the tips, while confused flour beetle antennal segments enlarge gradually from base to tip. The sides of the confused flour beetle's head capsule are expanded and notched at the eyes, producing a ridge over the eyes which is absent on red flour beetles. Immature stages and life histories are identical to those listed for the confused flour beetle.

5. **The Larger Black Flour Beetle,** *Cynaeus angustus*, is commonly found in high-moisture grain. Adults are reddish brown to black and 1/4 inch long. Larvae are yellow to tan, approximately 1/2 inch long, and cylindrical with three pairs of thoracic legs. Adults live 6 months to 1 year, and development from egg to adult usually requires 6 to 10 weeks.

6. **The Foreign Grain Beetle,** *Cryptolestes pusillus*, is flattened, reddish brown, and only 1/16 inch long. Antennal length also helps to identify this insect, as its antennae are 2/3 as long as the body. The flat grain beetle is very common in stored grain, but is not a primary pest, as adults cannot survive on unbroken kernels. This beetle often occurs in grain damaged by the rice weevil. Larvae of the flat grain beetle prefer to feed on the germ of kernels (especially wheat). Development from egg to adult requires 5 to 9 weeks.

7. **The Sawtoothed Grain Beetle,** *Oryzaephilus surinamensis*, is a flattened beetle about 1/10 inch long with six sawtoothlike projections on each side of the prothorax. Both larvae and adults feed on many grains and grain products. Adult females deposit 40 to 285 eggs over an average life span of 6 to 10 months. Larvae resemble the confused flour beetle, but possess hairlike projections on legs and abdomen. Complete development from egg to adult requires 4 weeks in warm grain.

8. **The Hairy Fungus Beetle,** *Typhaea stercorea*, is a brown, hair-covered beetle 1/10 inch in length. It feeds primarily on moldy grain (especially corn). Although it may be common in corn, it does not feed on undamaged kernels.

9. **The Rusty Grain Beetle,** *Cryptolestes ferrugineus*, is closely related and very similar in appearance and life history to the flat grain beetle. Antennae of male rusty grain beetles are less than half the length of the body.

10. **The Lesser Grain Borer,** *Rhyzopertha dominica*, is 1/8 inch long and dark brown to black. The head protrudes downward from the prothorax, and the antennae are sawtooth-edged. Larvae are C-shaped, white with brown heads, and approximately 1/8 inch long. Adult females each deposit 300 to 500 eggs on grain, and larvae bore into and develop within the kernels. Infested grain is riddled by the tunneling of adults and larvae. Maturation from egg to adult requires a month in warm grain.

11. **The Indianmeal Moth,** *Plodia interpunctella*, has reddish brown, coppery markings on the outer portion of its front wings. The wing span averages ¾ inch. Indianmeal moth larvae are cream-colored caterpillars about ½ inch long. Female moths deposit 100 to 300 eggs each, and development from egg to adult takes 6 to 8 weeks in warm grain. As larvae feed on grains and grain products, they secrete silken webbing that forms a mat over the infested commodity.

Controlling Stored Grain Rots, Germ Damage, and Molds: Store clean, sound grain in clean tight bins at a moisture content below 13% and a temperature below 10°C, 50°F. Aerate and cool high-moisture grain as soon as possible. Monitor grain temperature and moisture at weekly to monthly intervals. Even a slight rise in temperature means that spoilage is occurring.

12. **Grain spoilage due to molds (storage fungi).** Spoilage of surface grain is intensified by moisture transfer to the upper layers in bins not provided with adequate aeration. Here are the results of bin burning. More than 25 different fungi cause storage rots. The majority are species of *Aspergillus* and *Penicillium*. Storage fungi cause loss of germination, dark germs, bin burning, mustiness, and heating. These are the final products, NOT the beginning stages, of invasion by storage fungi.

13. **Aspergillus flavus** can cause ear rot following insect feeding or drought stress. A greenish yellow mold grows on and between the kernels. This fungus produces potent aflatoxins at a moisture content of about 18% in equilibrium with 85% relative humidity and temperatures of 12 to 38°C, 54 to 91°F. Fluorescence under a black light is NOT conclusive proof that aflatoxins are present. The U.S. FDA has set a maximum level of 20 parts per billion for aflatoxins in food or feed shipped in interstate commerce. Aflatoxins have been implicated in primary liver cancer in humans.

14. **Blue eye** may be due to numerous fungi. *Aspergillus glaucus* has colonized these corn germs. This fungus, as well as *A. restrictus*, can start to colonize grain at a moisture content just above 13.5%. At 15% moisture and above other fungi (such as *Aspergillus candidus*, *A. ochraceus*, and *A. flavus*) begin to develop.

15. **Fusarium moniliforme** causes the most common kernel or ear rot of corn. Rot seldom involves the whole ear. The caps of individual kernels or groups of kernels develop a salmon pink to reddish brown discoloration. As infection progresses, kernels show a powdery or cottony-pink mold. Kernels infected late in the season develop whitish streaks in the pericarp; other field fungi also produce this symptom. Infection commonly follows some form of injury. *Fusarium* will NOT attack grain in storage if the seed is sound at harvest, although high-moisture corn on the cob may be invaded in cribs. This species of *Fusarium* may cause encephalomalacia in horses.

16. **Fusarium and Penicillium** discolored the germs of these kernels. Several species of *Penicillium* form toxins which are carcinogenic, hemorrhage lungs and brains, or cause edema and liver damage.

17. **Blue eye** due to invasion of species of *Penicillium*. The germ is usually the first part colonized by storage fungi. Storage molds are active within narrow limits. When these are reached, another fungus or fungi "takes over."

18. **Split kernels with light to severe dock damage.** The germs soon become discolored after invasion by storage molds. This series of kernels shows progressive colonization and varies from slight dockage (top) to severe dockage (bottom).

19. **Storage fungi in wheat germs.** Discoloration may be evident externally or by removing the pericarp (germ covering) and examining the embryo. Germs lightly discolored throughout or discolored just at the tip are likely to be moldy and may later turn dark. The mold may be tan, white, black, blue, bluish green, yellowish green, or pinkish red.

For chemical control suggestions and other control measures, consult the Extension Entomologist or Plant Pathologist at your land-grant university, or your county Extension office.

Photo credits: University of Minnesota (1-8, 10, 11, 14, 18, 19), Van Waters & Rogers (9), University of Illinois (12, 13L & R, 15, 16, 17), C. W. Horne (13C).

STORED GRAIN INSECTS AND MOLDS


1. Rice weevil


2. Granary weevil


3. Confused flour beetle


4. Red flour beetle


5. Larger black flour beetle

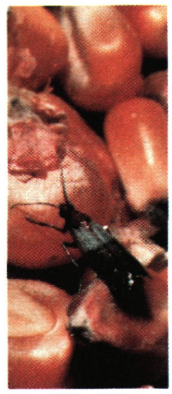

6. Foreign grain beetle


7. Sawtoothed grain beetle

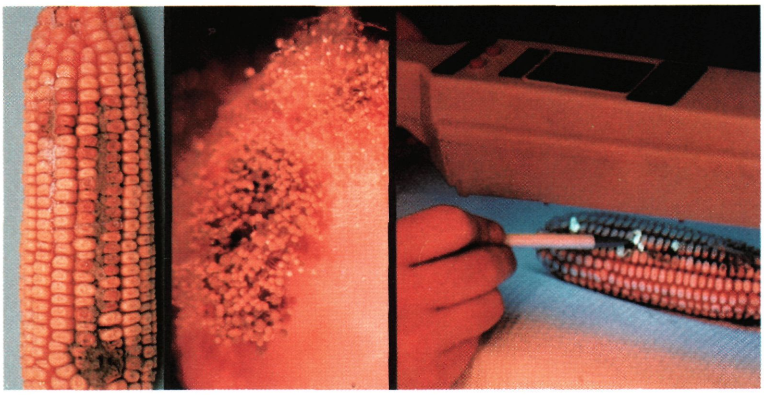

8. Hairy fungus beetle


9. Rusty grain beetle


10. Lesser grain borer

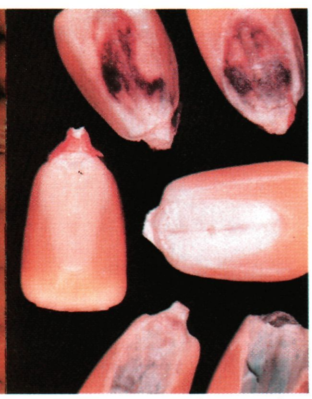

11. Indian-meal moth


12. Grain spoilage due to molds


13. *Aspergillus flavus*. L. ear rot; C. growing on a corn kernel; R. under a black light

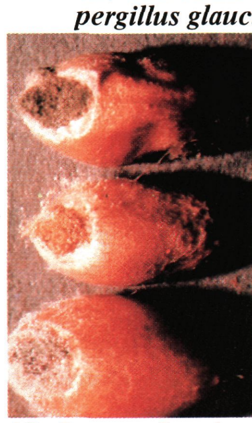

14. Blue eye (L) due to *Aspergillus glaucus*


15. *Fusarium moniliforme* L. ear rot; R. white streaks under seed coat


16. *Fusarium* (above), *Penicillium* (below)


17. Blue eye (*Penicillium*)


18. Split kernels with dock damage


19. Storage fungi in wheat germs