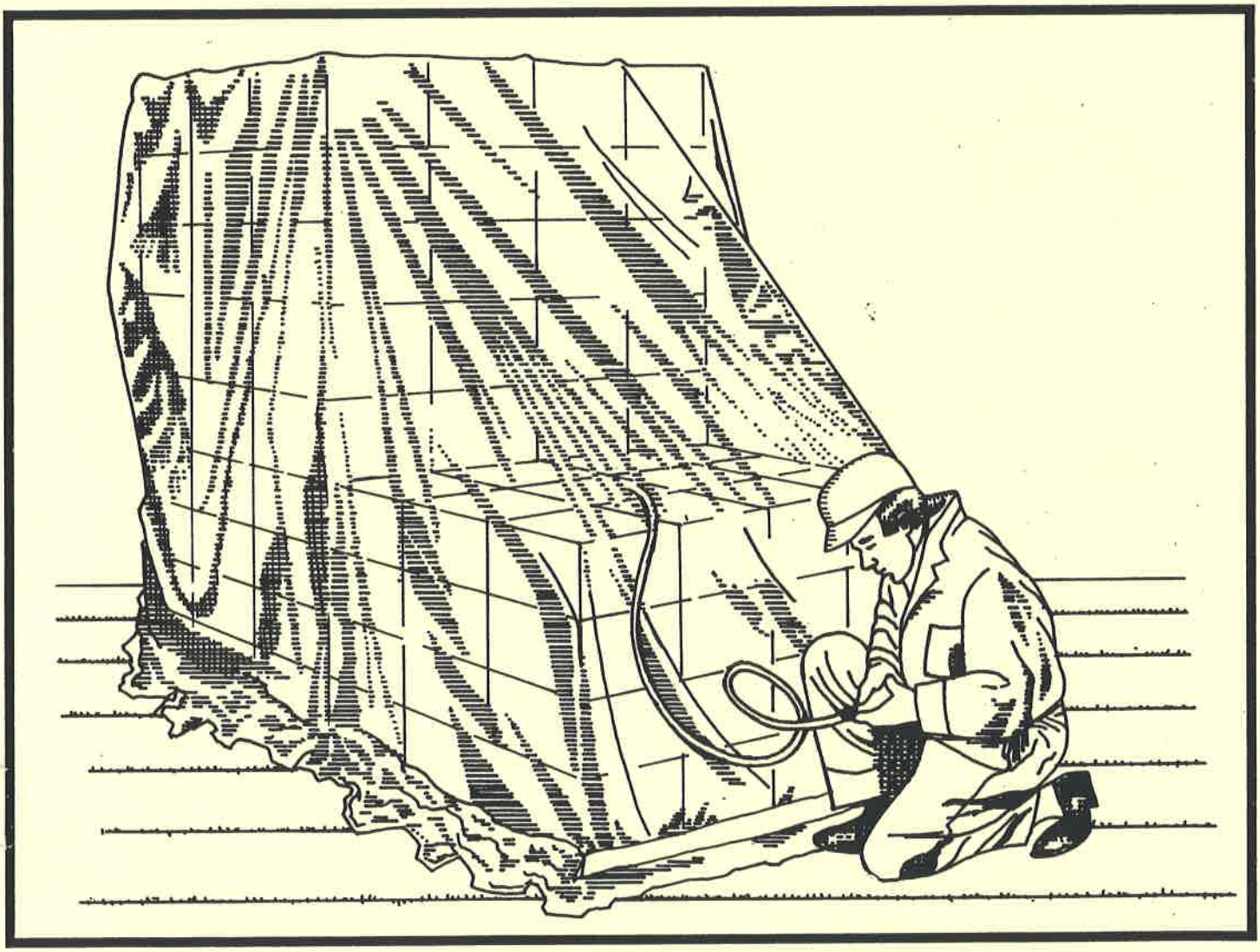
AGRICULTURAL COMMODITY FUMIGATION



This manual was developed in cooperation with the Georgia Department of Agriculture.

COOPERATIVE EXTENSION SERVICE / THE UNIVERSITY OF GEORGIA COLLEGE OF AGRICULTURE / ATHENS

PREFACE

This training manual is intended to provide you with the information you will need to meet the standards of the Environmental Protection Agency for pesticide certification, and prepare you to take an examination given by the State Department of Agriculture based on this manual. It is not intended that this training will provide you with all the information you will need for effective and safe fumigation of agricultural commodities. Industry often has training courses and more detailed information in handling their products.

Certification based on this manual covers the use of fumigants for agricultural commodities only, and not soil fumigation or structural fumigation for wood destroying pests (such as termites).

ATTENTION!

Pesticide Precautions

1. Observe all directions, restrictions and precautions on pesticide labels. It is dangerous, wasteful and illegal to do otherwise.

2. Store all pesticides in original containers with labels intact and behind locked doors. "KEEP PESTICIDES OUT OF THE REACH OF CHILDREN."

3. Use pesticides at correct label dosage and intervals to avoid illegal residues or injury to plants and animals.

4. Apply pesticides carefully to avoid drift or contamination of non-target areas.

5. Surplus pesticides and containers should be disposed of in accordance with label instructions so that contamination of water and other hazards will not result.

6. Follow directions on the pesticide label regarding restrictions as required by State or Federal Laws and Regulations.

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AGRICULTURAL COMMODITY FUMIGATION

INTRODUCTION

Insect pests cause enormous losses annually in stored raw agricultural commodities, bulk and packaged processed foods and animal feeds. These losses are incurred by producers as well as food processors, warehousemen, retail handlers and subsequently the consuming public. In addition to actual consumption of products, insects may contaminate the products and make them unfit for seed, human consumption or even animal feed. Most insects are highly mobile and move about inside and outside structures, infesting and/or contaminating new commodities. In order to determine potential damage and plan control measures, know the type or species of insect involved. Identification and some knowledge of their life cycle and habits will aid in preventing and controlling infestations when they occur.

Due to the location of some insect infestations deep within the mass of grain or in packaged commodities, use fumigants to control these infestations. A fumigant is a poison gas which when released into a confined space will kill insects exposed.

Since fumigants are pesticides, fumigators should be familiar with the general considerations in pesticide use: the laws and regulations, safety, environmental effects and labels and labeling. The information given here on fumigation is meant to be used in conjunction with the core manual for all categories of pesticide applications, Extension Special Bulletin 15, *Applying Pesticides Correctly.*

INSECTS

Common insects which infest agricultural commodities may be separated into four groups according to their feeding habits. Internal feeders feed and develop entirely within the kernels of grain. Examples of these are the rice weevil, granary weevil and angoumois grain moth. External feeders are insects that feed from the outside of the product even though they chew through the outer coat and devour the inside. Examples are the lesser grain borer, drugstore beetle, flat grain beetle, cadelle and cigarette beetle. Scavengers feed on grain only after the seed coat has been broken, either mechanically or by some other insect. Members of this group are the most common insects in processed commodities. Examples are the confused flour beetle, red flour beetle and sawtoothed grain beetle. Secondary pests feed only on materials which are out of condition, damp and have some mold growth. An example of this group is the yellow mealworm. Occasional exceptions to these feeding habits may be found; however, as a general rule each of these insects will feed as indicated.

The following keys will help determine which insects are present in agricultural commodities. (See Figure 1 and Figure 2, pages 7 and 8.)

Careful periodic inspection of stored agricultural commodities is essential to the insect control program. Insects have a very high reproductive potential which combined with a short life cycle, permits an incipient infestation to become damaging within a short period of time.

Figure 1. Inspecting grain for insects

FIGURE 2.
MOTHS: KEY TO SOME SPECIES COMMONLY ASSOCIATED WITH STORED FOOD

Harold George Scott

1. Caterpillars 2
   Adult moths 5

2. Pinkish larvae up to 3/5-inch long living in silken tubes and producing matter webbing in the infested food (*Anagasta kuhniella*) ..... MEDITERRANEAN FLOUR MOTH
   Whitish larvae with or without black or orange markings 3

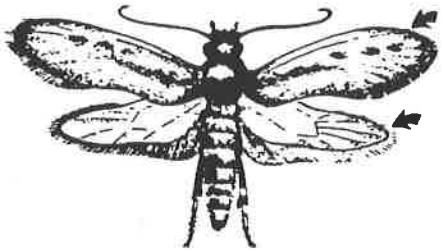
3. Black head and prothorax; orange markings at both ends of the body; living in silken tubes (*Phralis forinalis*) ..... MEAL MOTH
   Without black head and prothorax 4

4. White to greenish-white larvae producing matter webbing in the infested food (*Plodia interpunctella*) ..... INDIAN MEAL MOTH
   Whitish; not producing matted webbing; living inside kernels of grain (*Sitotroga cerealella*) ..... ANGOUMOIS GRAIN MOTH

5. Wings unicolorous to slight spotted; long fringe at rear of wings (*Sitotroga cerealella*) ..... ANGOUMOIS GRAIN MOTH
   Wings heavily dark marked 6

6. Distal half of front wings dark; basal half light (*Plodia interpunctella*) .... INDIAN MEAL MOTH
   Wings not so marked 7

7. Basal and distal thirds of front wings dark; middle portion of front wings light *Pyralis farinalis*) ..... MEAL MOTH
   Front wings pale gray with transverse wavy black markings (*Anagasta kuhniella*) ..... MEDITERRANEAN FLOUR MOTH



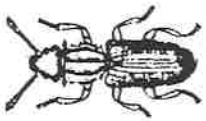
Angoumois Grain Moth

U.S. Department of Health, Education, and Welfare; Public Health Service; Communicable Disease Center, Training Branch, Atlanta, Georgia—1973

FIGURE 3.
BEETLES: PICTORIAL KEY TO SOME SPECIES COMMONLY ASSOCIATED WITH STORED FOODS

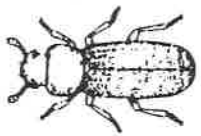
Harry D. Pratt

PRONOTUM WITH 6 TEETH ON EACH SIDE
BEAK ABSENT, SPECIES ABOUT 1/8 INCH LONG



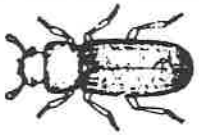
SAW-TOOTHED GRAIN BEETLE
Oryroephilus surinamensis

PRONOTUM WITHOUT TEETH ON EACH SIDE
BEAK ABSENT

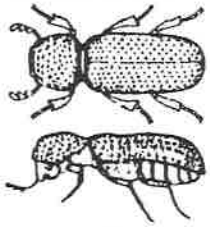


SMALL BROWNISH SPECIES
LESS THAN 1/4 INCH LONG

HEAD VISIBLE FROM ABOVE
1/8 INCH LONG OR MORE

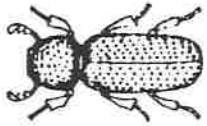


HEAD HIDDEN UNDER PRONOTUM
LESS THAN 1/8 INCH LONG



CONFUSED AND RED FLOUR BEETLES
Tribolim confusum and *costaneum*

FORE WING WITH ROUGHENED SURFACE

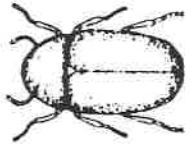


LESSER GRAIN BORER
Rhyaopertha dominico

FORE WING WITH LINES

DRUG STORE BEETLE
Stegobium paniccum

FORE WING SMOOTH

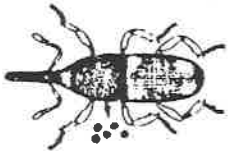


CIGARETTE BEETLE
Lasioderma serricarne

LARGER BLACKISH SPECIES
1/4 TO 3/4 INCH LONG

PRONOTUM WITHOUT TEETH ON EACH SIDE
BEAK PRESENT, SPECIES ABOUT 1/8 INCH LONG

EACH FORE WING WITH 2 PALE SPOTS
PRONOTUM WITH ROUND PUNCTURES



RICE WEEVIL
Sitophilus aryza

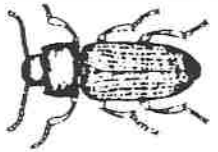
EACH FORE WING DARK
PRONOTUM WITH ELONGATE PUNCTURES

GRANARY WEEVIL
Sitophilus granarius

FLATTENED BEETLES
1/4 TO 1/2 ICHE LONG
PRONOTUM SEPARATED BY STRONG
CONSTRICTION FROM BASES OF WINGS

CADELLE
Tenebroide mauritanicus

CONVEX BEETLES
1/2 INCH LONG OR MORE
PRONOMUM NOT SO STRONGLY
SEPARATED FROM BASES OF WINGS



YELOW MEAL WORM
Tenebrio molitar

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, Communicable Disease Center, Training Branch, Atlanta, Georgia – 1958

Moths

Angoumois grain moth—adults are about the size of a clothes moth, (wingspan of 1/2 to 2/3 inch) yellowish-white with pale front wings, and the hind wings characteristically pointed. Eggs are laid on or near grain. On hatching, the minute white larvae bore into the kernels of grain and feed on the inside of the kernels. When mature the larva eats its way to the outer portion of the grain, leaving only a thin layer of the outer seed coat intact. Pupation takes place just under the seed coat. When the adult emerges from the grain, it pushes aside the thin layer of seed coat leaving a small trap door covering its exit point from the kernel. Eggs hatch in from four days to four weeks. The larval state normally lasts 20 to 24 days. The entire life cycle may be completed in about five weeks; however, the larvae may lie dormant over winter in colder areas.

Indian meal moth—adults of this moth have a wingspread of about 3/4 inch. The front wings are tannish on the front third and reddish-brown with a coppery luster on the back two-thirds. The hind wings are grayish-white. The eggs are deposited on or adjacent to the larval food. They hatch in from two days to two weeks. The entire life cycle may require from four to six weeks under warm conditions; however, this may be considerably longer under cold conditions. Indian meal moth larvae spin large amounts of silk and leave a solid web over heavily infested food or feed material. Rapid build-up of infestations may occur since as many as 350 or more eggs may be laid by each female.

Mediterranean flour moth—the front wings of this moth are a pale grey with wavy black lines running across them. It can be distinguished from the Angoumois grain moth by the fact that the hind wings are rounded at the tips rather than pointed. When resting the front of the body is raised giving the wings a distinct downward slope with the tip of the abdomen protruding up between them. Eggs of this insect are laid in accumulations of food material and hatch in from three to six days depending on the temperature. The entire life cycle from egg to adult is usually passed in from nine to 10 weeks. This moth is a pest of all kinds of grain, meal, prepared food, dried fruits, nuts and candies. The almond moth closely resembles the Mediterranean flour moth.

Beetles

Sawtoothed grain beetle—adult sawtooth grain beetles are small brownish beetles about 1/10 inch long. It can be easily recognized by the six saw-like projections on each side of the thorax. Eggs of the beetle are laid singly or in small masses, in crevices in the food supply or freely in items such as flour or prepared foods. The larvae are small, usually about 1/8 inch in length. The head of the larva is flattened so that the mouth parts project straight ahead rather then downward. The last segment of the abdomen is tapered and has no dorsal projections. Most of the feeding is done by the larvae and they frequently feed on material damaged by other insects. Eggs of this insect hatch in five to 12 days and the larvae feed for one to four months or longer depending on temperature and food supply. An adult may live and feed for as long as three years.

Red flour beetle—adults are small, shiny, oval, reddish-brown (1/4 inch long) beetles. This insect is similar in appearance to the confused flour beetle. It can be distinguished from the confused flour beetle by a close examination of the antenna. The confused flour beetle has the antenna gradually enlarged to form a club, whereas the last three segments of the red flour beetle antenna enlarge abruptly to form a distinct club. Eggs of this beetle are laid in cracks, on bags or directly on the food material. These eggs hatch in five to 12 days into small brownish-white worms, which become fully mature in one to four months depending upon temperature and food supply. A complete generation may be completed in three to four months when thetemperature is high. Adults may live as long as three years. The red flour beetle adults are strong fliers and frequently infest farm stored grain whereas the confused flour beetle is more often a pest in flour mills, large granaries and warehouses.

Lesser grain borer—adults are dark-brown, cylindrically-shaped beetles about 1/8 inch in length with the head nearly hidden by the thorax when viewed from above. The larva is a thick-bodied, cylindrical, rather grub-like form. The head of this larva is retracted into the thorax to about the level of the mandibles so that only the mandibles show. Both beetles and larvae cause damage to grain. Each female beetle lays 300 to 500 eggs and deposits them, singly or in clusters on or around grain. The larvae complete their development within the grain kernels. In warm weather the complete life cycle from egg to adult requires about one month; however, this may be extended to two months or more in cooler temperatures.

Rice weevil—adults of this weevil are reddish-brown and about 1/8 inch long. There are

four light red or yellow spots on the wing covers of this species and the punctures on the pronotum are round. The legless larva has a short, stout, whitish body and tan head. Both adults and larvae feed on a wide variety of grain. The female bores a hole in a grain kernel, deposits a single egg in the depression, and seals the hole with a gelatinous fluid. Each female may lay as many as 300 to 400 eggs in her lifetime of four or more months. The larval and pupal stages are spent inside the grain, with the adults emerging through an irregular exit hole. These exit holes are usually the first sign of grain damage and by the time this is noted serious damage may have occurred to the grain. The entire life cycle may be passed in as little as four weeks; however, this time is greatly prolonged during cool or cold weather.

Drugstore beetle and Cigarette beetle—these are closely related beetles that feed on similar materials and are similar in appearance. The adults of both species are brown, cylindrical and about 1/10 inch long. The head of the cigarette beetle is bent downward so the beetle has a distinct "hump-backed" appearance. The drugstore beetle has distinct longitudinal lines on the back and does not have the "hump-backed" appearance. The larvae of both species are about 1/6 inch in length, grub-shaped or C-shaped and near white in color. The cigarette beetle larva has considerably longer hairs on its body giving it a more "fuzzy" appearance. Prepared foods and spices as well as tobacco items and other products are fed on by these insects.

Cadelle—adult cadelles are elongate, oblong, flattened, blackish beetles about 1/3 inch long. The larva is one of the largest of the grain infesting insects and is easily recognized. It is about 3/4 of an inch long, fleshy, with the abdomen terminating into two dark horny points. The head, thoracic shield and two horny points are black. Both the larva and adult feed on grain and have the destructive habit of going from kernel to kernel devouring the germs. The female deposits her eggs in clusters in food material and these eggs hatch in seven to 10 days in warm weather. The larvae complete their growth in two to 14 months after which they seek a secluded place to transform into the pupal stage. Both larvae and adults can live for long periods without food and often remain in the woodwork of bins from one season to the next. When new grain is put into an infested bin it becomes infested in a short time.

Mealworms—the adults of both the yellow and dark mealworm are brown or black, about 1/2 inch long and occur throughout the United States. Adult yellow mealworms are shiny black and the dark mealworm is dull black. Larvae of both species are elongate, cylindrical and somewhat harder than the larvae of most stored product insects. The yellow mealworm larva, "golden grub," is sold as fish bait in many areas. Full grown larva are more than an inch long. Mealworm adults are easily confused with ground beetles, but examinations of the hind leg will reveal five tarsal segments for ground beetles and only four for mealworms. Mealworm adults are rather slow moving while ground beetles move rapidly. Both mealworm adults and larvae are usually found in dark, damp places in spoiled grain products. Under adverse temperature and food conditions, this insect may remain in the larval stage for as long as 600 days.

Dermestids—as a group, these beetles scavenge and feed on animal matter. Certain species belonging to the genera Trogoderma, Anthrenus, and Attagenus, vary their diet by feeding on grains or grain products. Generally the adults in this group are oval-shaped varying in color from reddish-brown to black with all variations in between. Larvae of this group of beetles have prominent hair or bristles, often of a characteristic shape which aids in their identification. Worldwide the khapra beetle, *Trogoderma granarium* is the most destructive member of this group. Although this species was present in a few locations in the Western United States at one time, the infestations have been eliminated. More recently several infestations were found in spice warehouses in the United States. These have also been eliminated. Strict quarantine measures have kept this destructive beetle from becoming established in the United States.

Corn Sap Beetle—in addition to being present in fields feeding on damaged grain this insect feeds on moldy and decaying products in storage. Corn sap beetles may be recognized by its short, truncate wing covers which leave the tip of the abdomen exposed. This beetle is small, 1/10 to 1/8 inch long, and dark brown with lighter colored wing covers.

Flour or grain mites—these pests are pale, grayish-white, smooth, wingless, soft-bodied creatures. They are microscopic in size and have sparse long hairs on the legs and back. Mites are not insects, instead they have eight long legs which places them into the spider group. When present in large numbers, the grain or flour mites promote sweating, impart a disagreeable odor to the grain and may cause damage by feeding. Fortunately, the mites that

feed on stored products are preyed on by predacious mites, which usually become abundant enough to kill the grain mites in a comparatively short time.

FUMIGATION TYPES

Space Fumigation

The below several methods of space fumigations are presently in use:

1. Chamber and vault fumigation
2. Vacuum chamber fumigation
3. Vehicle fumigation: railroad car, truck or van
4. Tarpaulin fumigation
5. Spot fumigation
6. Empty building fumigation: warehouse, grain elevator, food processing plant, mill, restaurant
7. Farm grain storage fumigation
8. Fumigation of beehives, supers and other beekeeping equipment.

Types and Nature of Fumigants

A number of fumigant active ingredients formerly used have either been cancelled entirely or had their uses strictly limited in the U.S. All space fumigant products, and several soil fumigant products (especially those containing chloropicrin and/or methyl bromide) are now labeled "Restricted Use."

The active ingredients still legal to use are:

1. Methyl bromide
2. Chloropicrin
3. Aluminum phosphide
4. Magnesium phosphide
5. Sulfuryl fluoride
6. Calcium cyanide
7. DDVP
8. Ethylene oxide

Fumigants are by nature broad spectrum pesticides that can act as respiratory poisons, anesthetics or narcotics or enzyme poisons. They are chemically simple molecules, but they can exert potent and wide-ranging effects on the target organisms. Because of their gaseous nature and acute inhalation toxicity, fumigant products are labeled as Toxicity Category I with the signal word "Danger", or "Danger-Poison" with the skull and crossbones symbol.

Methyl bromide is formulated as a liquid and vapor under pressure. It is odorless, non-flammable and not generally corrosive nor irritating to eyes as a vapor. It is not highly toxic by the oral route but it is highly toxic by inhalation. Because of this, and because it is odorless, many formulations contain chloropicrin as a warning agent. Methyl bromide products are used both for space and soil fumigation. If trapped inside tight clothing next to skin, methyl bromide can cause severe skin burns. Do not use to fumigate materials whose composition includes the sulfur (e.g. hair, fur, leather, and rubber goods) because of an undesirable chemical reaction with sulfur.

Figure 4. Methyl bromide cylinders

Chloropicrin is a heavy, colorless, non-flammable chemical with an irritating tear gas odor. Like methyl bromide, it is highly toxic by inhalation but moderately toxic orally. If added to methyl bromide formulations at a concentration of two percent or less, it is considered to be an active ingredient that augments the fumigant activity of the methyl bromide.

Aluminum phosphide and magnesium phosphide are space, commodity and rodent burrow fumigants. The formulations include pellets, tablets and a "prepac rope"; they are solids that react with moisture to liberate hydrogen phosphide (phosphine), a gas highly toxic to insects, humans, rodents and other forms of animal life. It is thus absolutely necessary to keep aluminum phosphide and magnesium phosphide products DRY in storage. Phosphine ignites spontaneously in air at concentrations about 1.8 percent by volume. Some formulations include ammonium carbamate, which liberates ammonia gas and carbon dioxide to reduce the fire hazard posed by phosphine. Ammonia also serves as a warning agent.

Sulfuryl fluoride is a space fumigant. It is a colorless, odorless, non-flammable gas formulated in cylinders under pressure. The fluoride ion is believed to be the primary toxicant.

Figure 5. Phosphine (aluminum phosphide) cylinder

Calcium cyanide products are no longer produced in the U.S. but old stocks may still be found occasionally and used if in good condition. It is used for rodent burrow fumigation. The toxic activity is due to the liberation of hydrogen cyanide gas produced by reaction of calcium cyanide with atmospheric moisture. Cyanide is a potent respiratory poison. Hydrogen cyanide is colorless and has the odor of almonds.

DDVP, also known as dichlorvos, is a contact and stomach insecticide with fumigant and penetrant action. It is used for the protection of stored products. Since it is an organophosphate, handle it with the precautions generally used with organophosphate products. It is somewhat corrosive and should be kept dry in storage.

Ethylene oxide is a colorless toxic, flammable liquified gas which presently can be used as a fumigant on spices, black walnuts and copra. It is formulated with carbon dioxide or dichlorodifluoromethrane to reduce flammability.

Advantages and Disadvantages

Since fumigants are wide spectrum pesticides, space fumigation which is properly carried out, will kill all species of insects and rodents that are likely to be found in the commodities being fumigated. Fumigants, being gases, penetrate into nooks and crannies of a structure or commodity that cannot be reached by pesticide sprays and dusts. Pests are rapidly killed and the fumigant gas does not leave unsightly, odoriferous or hazardous residues if the site is properly aerated after fumigation.

Fumigation does have certain disadvantages. Since fumigant products are broadly toxic and hazardous to use, fumigations must be done by highly skilled and experienced licensed fumigators. Because space fumigation is done only in enclosed spaces, tightly seal structures or sites to be fumigated. All humans and other non-target organisms must vacate the premises for a period of 24 hours or longer. Some fumigants may damage items in the enclosure being fumigated and such items should also be removed. The cost of fumigation may be higher than the costs of other methods of pest control. Fumigants leave no protective residue and pests may reinfest the fumigated site or commodity immediately after treatment.

To select a fumigant, take into consideration the following characteristics as they apply to the site to be fumigated. (See also Table 1, page 12.)

1. Volatility and penetration power
2. Corrosiveness, odor, flammability or explosive potential
3. Warning capabilities and detection methods
4. In the case of commodities, effect on seed germination and quality of the finished or processed product
5. Decomposition time of the fumigant chemical or its residues
6. Disposal of spent materials or containers
7. Availability, ease of application and cost

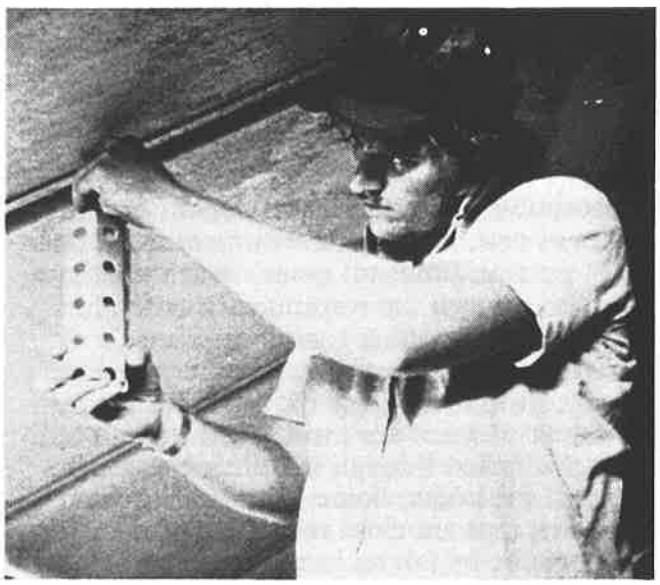


Figure 6. DDVP strips

Table 1. Essential Properties of Fumigants in Common Use for Insect Control[1]

Name and Formula	Molecular Weight	Boiling Point (°C at 760mm. pressure)	Solubility Water (g./100ml.)	Flammability (% by volume in air)
Chloropicrin $CCL_3\ NO_2$	164.39	112.0	Insoluble at 20°C	Nonflammable
Dichlorvos (DDVP) $CCl_2 = CHO.PO.(OCH_3)_2$	221.0	120° C/14mm	Slight	Nonflammable
Ethylene Oxide $CH_2O.CH_2$	44.05	10.7	Very soluble at 20°C	3-80
Hydrocyanic acid gas HCN	27.03	26.0	Very soluble at 20°C	6-41
Methyl bromide CH_3Br	94.95	3.6	1.3 at 25°C	Nonflammable
Phosphine PH_3	34.04	−87.4	Very slightly soluble	Highly flammable
Sulfuryl fluoride SO_2F_2	102.06	−5.2	0.0075 at 25°C	Nonflammable

[1]From Monro. Manual of Fumigation for Insect Control.

FUMIGATE EFFECTIVENESS FACTORS

Fumigants are used in various formulations and dosages according to the nature of the commodities and pests involved. Consider the following factors that modify fumigant effectiveness when selecting a formulation:

1. Pests
2. Temperature
3. Moisture
4. Air Movement
5. Structure, site or commodity to be fumigated

Pests

Susceptibility to fumigants depends on the species of pest, stage of development, and habitat. In general, fumigant gases reach the tissues of insects through the respiratory system. In most insects, breathing is accomplished through a series of openings in the outer skeleton called spiracles. Once oxygen from the air and fumigant gases are inside the insect's body, they are diffused through the thick cell membranes of the insect. Some primitive insects and mites, that are close relatives of the insects, breathe by taking in air through the cuticle which covers the whole body. The life stage of the insect that is least active metabolically is the most difficult to kill by fumigation (e.g., pupae, hibernating adults). Fumigant labels give dosages needed for different species and different life stages of those species. For this reason a knowledge of pest biology is important for the fumigator.

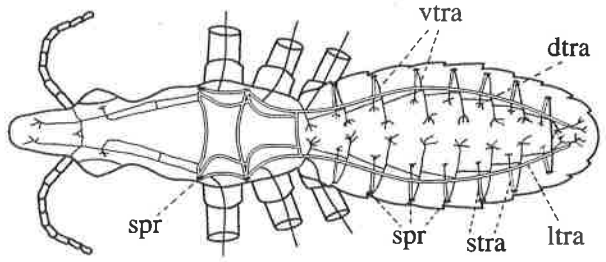


Figure 7. Diagram of a horizontal section of an insect showing arrangement of the principal tracheae. dtra, dorsal tracheae; ltra, main longitudinal tracheal trunk; spr, spiracles; stra, Spiracular tracheae; vtra, ventral tracheae.

Insects that have been fumigated with methyl bromide die slowly. They may at first be unable to walk or fly in a normal manner. They usually come to rest on their backs and eventually are unable to recover from that position; however, they may move their heads, legs or antennae several days before they finally die. (Some fumigants may anesthetize insects so that they appear to be dead shortly after fumigation only

to revive and resume normal life.) Persons accustomed to seeing quick kill are sometimes disappointed on observing insects that have been exposed to lethal dosages of slow-acting fumigants. Such insects are doomed to die eventually.

Temperature

Sublethal concentrations of the fumigant gas may result if fumigation is done at abnormally high or low temperatures. At low temperatures, the fumigant vaporizes and diffuses more slowly. Insect activity and metabolism are likewise slowed down. These factors tend to retard killing action, especially at temperatures below 10°C (50°F); thus, at lower temperatures, use higher dosages as well as longer exposure times to achieve a successful fumigation. Fumigant labels generally warn that the product is not to be used when temperatures are below 40°F (5°C). On the other hand, at excessively high temperatures, fumigants vaporize faster and may dissipate so soon that lethal concentrations are not maintained long enough to kill pests. This is true especially if the seal of the fumigation site is less than perfect. In the range of normal fumigating temperatures (60 to 80°F), the concentration of the fumigant needed to kill a given state of an insect species decreases with the rise in temperature; this is mainly due to the increased rate of respiration of insects in response to the rise in temperature. Death occurs more quickly in the higher end of the normal temperature range.

Moisture

Adequate moisture is required for release of the actual toxicant, phosphine, in aluminum phosphide and magnesium phosphide products. At relative humidities below 25 percent, or grain moisture below 10 percent, release of phosphine requires more time. Excessive moisture may interfere with fumigant action by reducing fumigant concentration within a commodity. Thus, as in the case of temperature, there is an optimum for moisture. Product labels give appropriate information as to moisture effects.

Air Movement

Fumigate when there is little air movement. Regardless of how well the enclosure to be fumigated is sealed, windy conditions can create problems.

Structure, Site or Commodity

In a structural fumigation, the more tightly sealed the structure, the more efficient the fumigation. Wood is porous and wooden structures, even when sealed well, will not retain fumigant gases as well as those constructed of metal, plastic, masonry or concrete. Cement blocks, however, pose a special problem because of their porous nature. Increased dosages and exposure times can compensate for the loss of gas through diffusion into porous building materials. Tarpaulin fumigation using a gas-proof sheet or cover is considered preferable to sealing a building with paper or tape and holding a fumigant within structural walls. Tarpaulin fumigation has the advantage of reaching the exterior wood areas (door, sills, etc.) which may be infested.

Figure 8. Sealing openings of storage bin

According to federal and state law, a pesticide label is a legal document, and use of a pesticide in a manner that is inconsistent with label directions is illegal. Thus, use a fumigant product only on sites or commodities listed on the label, the labeling or the applicator's manual. Product label directions discuss the factors that affect the efficiency of a product in the particular commodity to be fumigated.

Ideally, the fumigant should not change the quality or damage the treated commodity, leave any residue that could be hazardous during subsequent processing of the commodity or be harmful to the final consumer. In fumigation, as in any pesticide treatment of a raw agricultural commodity or packaged food product, consider the matter of "tolerance." The tolerance, or tolerated residue, is the amount of the pesticide active ingredient that is considered safe to consume and is legally permitted to remain in the commodity. Tolerances are expressed in parts per million, which is the same

value as milligrams per kilogram (1,000 grams). On methyl bromide product labeling, the tolerances are given for the raw agricultural commodities for which the chemical has an established tolerance, along with the stored product pests to be controlled, dosages and exposure times. Follow dosages and exposure times in order not to run the risk of exceeding legal tolerances in the commodity fumigated.

Grain fumigation is affected by type and condition of the grain size, shape and permeability of the kernels, and the amount of dockage (chaff, dust, etc.) in the grain. "Sorptive capacity" of stored grain refers to adsorption—the adhesion of the fumigant gas molecules to the external surface of the grain; it also refers to absorption—the holding of gas molecules withinthe kernel by capillary action. The sorptive capacity of a grain will increase with a decrease in kernel size and a corresponding increase in surface area. Permeability of seed coast is also a factor. Increased sorptive capacity means less gas fumigant in the surrounding air; hence, recommended dosages are generally higher for smaller grains such as wheat, rye or sorghum than for corn.

Solid space fumigants that release phosphine may be added directly as pellets or tablets to animal feed, feed ingredients and raw agricultural commodities stored in bulk. Treat commodities not stored in bulk (e.g., bagged) in the same way as processed foods; these should not come in contact with tablets, pellets or residual dust, except for brewer's rice, malt and corn grits for use in manufacture of beer.

Liquid fumigants may also be applied as gases directly onto or into the commodity or space to be fumigated.

HANDLING SAFETY

Personnel

- Assign at least two persons to each fumigation.
- In circumstances where entry into a fumigated area must be made, use a "buddy system" of two persons.
- Employees actively taking part in a fumigation should be in good physical condition and:
  1. Should have a physical examination at least once a year and more often if health conditions require such. Maintain up-to-date health records for each employee of a fumigation business.
  2. Should abstain from alcoholic beverages and medical or recreational drugs for 24 hours before and 24 hours after a fumigation job.
  3. Should NOT participate in a fumigation if they have colds or other respiratory problems that make breathing difficult.
  4. Should NOT participate in a fumigation while undergoing continuing medical or dental treatments unless authorized to do so by the physician or dentist in charge.
- All personnel should be instructed in first aid and other emergency procedures including personal decontamination.
- The use of specific antidotes, first aid procedures and symptomatic relief measures should be understood by all personnel.
- Report all accidents immediately to the employer or supervisor. Caution personnel handling fumigants to report all indications of illness or physical discomfort regardless of their apparent minor nature. These may include but not be restricted to any or all of the following: dizziness, diarrhea, nausea, headaches and lack of coordination.
- Instruct all personnel as to the hazards that may be encountered because of carelessness or misuse of fumigants and in the selection, operation and maintenance of all protective equipment and safety procedures required by the fumigant of choice.

Protective Equipment

Use protective equipment to prevent injury or loss of life.

It is necessary to follow exactly the label recommendations concerning specific protective equipment and clothing for each fumigant product.

Label requirements for protective clothing and equipment are related to threshold concentrations of the fumigants in fumigated spaces. This makes reliable detection devices a must for any fumigator, to ensure health and safety of personnel, as well as to comply with the law, since the pesticide label is a legal document.

If the concentration of fumigant in the working area, as measured by a direct reading detector device, exceeds the threshold concentration specified by the EPA for that fumigant, all persons in the fumigation area must wear the protective equipment specified on the label. This will be either a NIOSH/MSHA approved self-contained breathing apparatus (SCBA) or a combination air supplied/SCBA respirator.

Threshold concentrations are given below for some space fumigants which may still be legally used.

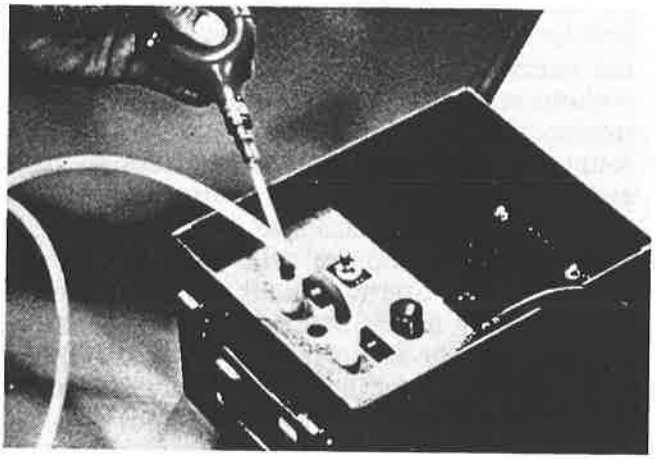


Figure 9. Gas detector

Fumigant	Threshold Concentration (ppm)
Methyl Bromide	5.0 (TLV) a
Chloropicrin	0.1 (TLV)
Cyanide	10.0 (TLV)
Hydrogen Phosphide (phosphine)	0.3 (TWA) b
Sulfuryl Fluoride	5.0 (TLV)

a Threshold Limit Value (any time during fumigation)

b Time Weighted Average over an 8-hour period

If the concentration of methyl bromide in the worker area, as measured by a pump and appropriate detector tubes (e.g., Draeger, Kitagawa, MSA and Sensidyne) does not exceed 5 ppm, no respiratory protection is required. If this concentration is exceeded AT ANY TIME, all persons in the fumigation area must wear a NIOSH/MSHA self-contained breathing apparatus (SCBA or combination air-supplied/SCBA respirator.

Workers must not be exposed to hydrogen phosphide levels above 0.3 ppm as an 8-hour Time Weighted Average (TWA) during application. Up to 15 ppm, or TO ESCAPE FROM levels up to 1500 ppm, a NIOSH/MSHA approved full face gas mask, hydrogen phosphide canister combination may be used. Above 15 ppm, or if concentrations are unknown, use a NIOSH/MSHA approved SCBA. Respiratory protection must be available at the site of application in case it is needed when applying aluminum phosphide within a structure; it need not be available for outdoor applications.

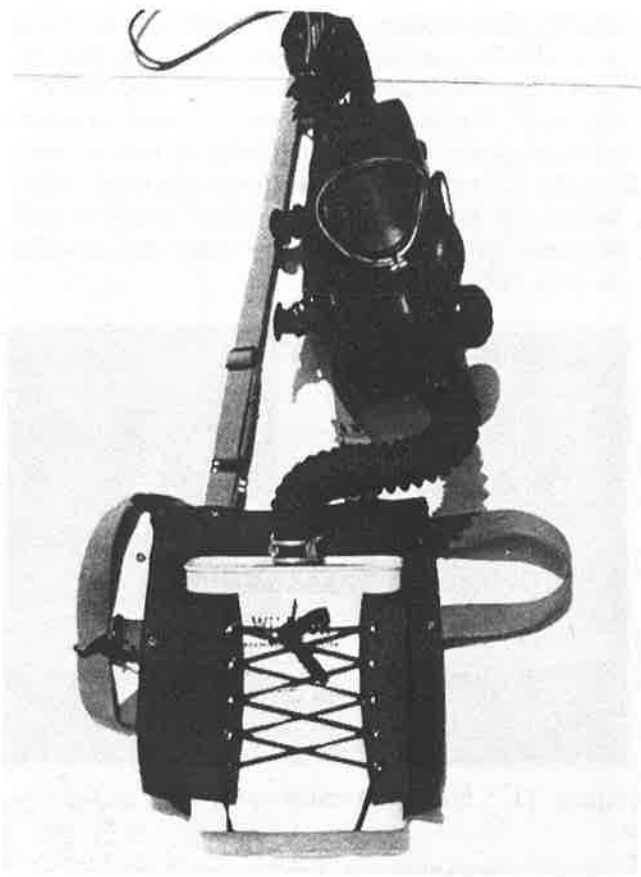


Figure 10. Gas mask and canister

With chloropicrin, no respirator protection is necessary if the concentration, as measured by a Matheson-Kitagawa detection device, does not exceed 0.1 ppm at any time during the fumigation. If it does, personnel in the area must wear a NIOSHA/MSHA approved air purifying respirator approved for organic vapors, an SCBA, or a combination air-supplied SCBA/respirator.

The threshold limit value for sulfuryl fluoride is 5 ppm, the level to which persons may be exposed daily for eight hours without adverse effects. The Short Term Exposure Limit (STEL) is10 ppm-the level persons may be exposed continuously for 15 minutes without adverse effects.

Storage, Handling and Disposal

Store all fumigant products in a locked, dry, well-ventilated place away from heat. Post as a pesticide storage area. Do not store fumigants in the same buildings occupied by animals or humans. Remember that *all pesticides should be kept out of reach of children.*

Handle methyl bromide cylinders carefully and do not drop, bump, drag or slid from one place to another. Transport them only on hand

trucks, fork trucks, or similar devices to which the cylinder can be firmly secured. Do not remove the valve protection bonnet and safety cap until immediately before use, and always keep in place when the cylinder is not in use. Empty cylinders must be closed securely with safety cap and protection bonnet in place and returned to the shipper; *they must not be used for any other purpose.*

Figure 11. Store pesticides under lock and key

Some aluminum phosphide products are supplied in relatively gas tight, resealable aluminum flasks, which should not be opened and exposed to atmospheric moisture any longer than is absolutely necessary to remove the products. Reseal tightly partially emptied containers and mark as partially used. Triple-rinse the flasks with stoppers with water. Offer for recycling or puncture and disposal of in a sanitary landfill or by other local and state approved procedures. Dispose of rinstate in the same way.

If properly exposed, the residual dust remaining after a fumigation with hydrogen phosphide products will be a grayish-white and contain only a small amount of unreacted aluminum ormagnesium phosphide. Residual dust from incompletely exposed product, the so-called "green dust" will require special deactivation and disposal procedures. Small amounts may be disposed of by a "dry" method. Dispose of large quantities disposed of by a "wet" method, in which the residual dust is deactivated in a detergent or surfactant and water solution. Detailed directions are given on the product labels and should be followed exactly.

Spill and Leak Procedures

Methyl bromide product directions recommend that in the event of a spill or leak, fumigating personnel should evacuate the immediate area of the spill or leak. Then use either a NIOSH/MSHA approval SCBA or a combination air-supplied SCBA respirator to go back into the affected area to correct the problem. Allow the spill to evaporate and do not permit any person to enter the spill area without respiratory protection until the concentration of methyl bromide is less than 5 ppm. Remove leaking containers to an isolated area and cover with a polyethylene sheeting (tarp) at least 4 mil. thick. The Place the edges of the tarp in a trench and seal with soil, tightly tamped down. Contaminated soil, water and other cleanup debris comprise a toxic/hazardous waste. If the Reportable Quantity(RQ) of 1,000 pounds of methyl bromide is exceeded, report the spill to the local Emergency Response Commission.

A spill of aluminum or magnesium phosphide products may generate high levels of phosphine, hence all personnel must wear SCBA for spill cleanup. Do not use water at any time to clean up these spills, as this will speed up the production of phosphine which could result in a toxic or fire hazard. The RQ for phosphine is 100 pounds.

If aluminum flasks have been damaged so as to leak, they may be repaired temporarily with aluminum tape, or the undamaged product may be transferred to a sound metal container. If a spill has occurred which is only a few minutes old, intact products can be returned to the original flasks or to another sound metal container, stoppered tightly. The alternate container must be properly labeled. If the age of the spill is unknown or if the product has been contaminated with soil, water or debris, gather the spillage up and place in a small open bucket of less than one gallon capacity, with no more than two or three pounds of spillage per bucket. Carry wet deactivation out on site if feasible; if not, carry spillage in an open vehicle to a suitable area and deactivated there. Small amounts of spillage (up to 18 pounds of product) may be spread out in an open area to be deactivated by atmospheric moisture. This area should be inaccessible to people or animals.

Good Practice Checklist

The checklist emphasized steps related to life safety and fire safety. The steps noted will apply to most fumigation operations but cannot be expected to apply to all fumigants in all types of fumigations. Use the checklist as an outline for a more detailed operating procedure for fumigations.

Preliminary Planning and Preparation

- Become fully acquainted with site and commodity to be fumigated, including:
  1. General layout of structure, connecting structures, adjacent structures, and escape routes, above and below ground.
  2. Number and identification of persons who routinely enter the area to be fumigated; proximity of other persons and animals.
  3. The specific commodity and its mode of storage and condition.
  4. The previous treatment history of the commodity, if available, to be aware of possible food residues.
  5. Accessibility of utility service connections.
  6. Location of the nearest telephone or other communication facility.
  7. Location of the emergency shut-off stations for electricity, water and gas.
- Ascertain and post current emergency telephone numbers, i.e., Fire, Police, Hospital, and Physician.

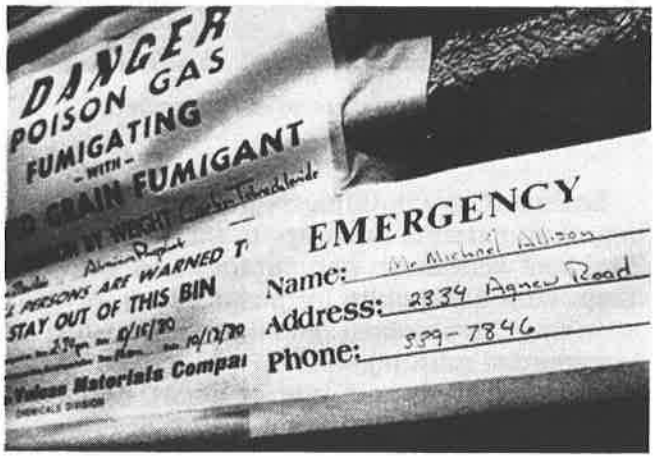


Figure 12. Current emergency information

- Select a fumigant or combination of fumigants, registered by EPA for the work involved.
- Study directions, warnings, antidotes and precautions on the label and in the manufacturer's instruction manual.
- Notify local fire and police authorities and other security personnel as to location, the chemicals to be used, proposed date and time of use, type of protective equipment required, and fire hazard rating.
- Make certain that local medical organizations (e.g., hospitals, emergency rooms) are informed of your fumigation practices and the specific materials in use.
- Provide authorities with pertinent safety literature on the materials to be employed.
- Arrange for standby equipment, replacement parts and an alternate plan of action.
- Inform all employees of the operational schedule, potential hazards to life and property and the required safety measures and emergency procedures.
- Prepare warning signs for posting treated areas. Provide for security of building and arrange for watchmen when required.
- Have available first aid equipment and antidotes where applicable.
- Plan for application from outside the structure where possible.
- Plan for ventilating the treated space and commodities when the required exposure is terminated. Do this before treatment is started.
- Areas used for storage of fumigant chemical should be properly identified and provide the conditions required by the manufacturer's directions.
- Make sure there are no open fire, motors or light switches that could spark or hot surfaces, such as heat pipes and electric fixtures, within the space to be fumigated.
- Provide fans for distribution of the fumigant where applicable.
- Provide gas sampling and/or detection device.
- Make a final check to clear all personnel and non-target animals from the space to be exposed to the fumigant.

APPLICATION PROCEDURES

Pre-Fumigation and Fumigation Period

- Detailed directions for various types of fumigations are given on the recently improved fumigant labels. Read the label and follow the label directions.
- Post areas to be treated, immediately before fumigation.
- Apply fumigant from the outside where appropriate.
- Personnel applying fumigants should enter into area where fumigant is being discharged only in extreme emergencies, and with mandatory respiratory protection.
- When fumigating, take into consideration prevailing wind and other factors that may affect the fumigation.
- Post warning signs.
- Provide watchmen where required. This is always necessary unless the fumigated area is completely locked or enclosed by a locked fence.

Post-Application Operations

- Provide watchmen where required and/or necessary.
- Allow enough time and use enough fans to ventilate and aerate in accordance with structural limitations.
- Turn on all ventilating or aerating fans where appropriate.

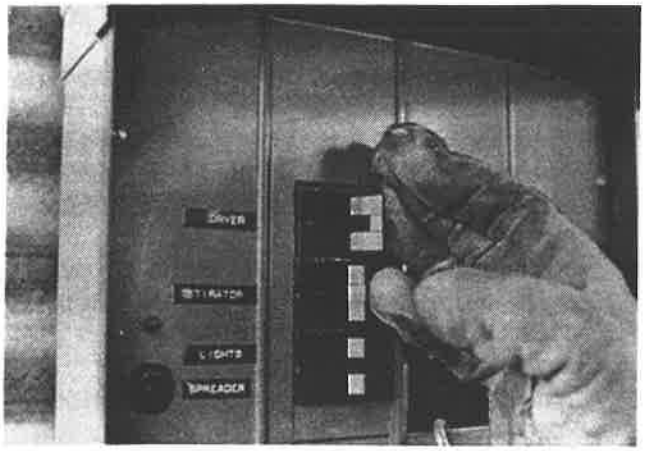


Figure 13. Turn off electrical power

- Before re-entry, use a suitable gas detector to determine fumigant concentration, so that appropriate precaution may be taken. Most fumigants do not provide adequate odor warning.
- Check for gas concentrations in areas which aerate slowly.
- Remove warning signs where aeration is complete.
- Dispose of empty containers and used canisters.
- Return unused chemicals in properly and clearly labeled containers to storage area.

General Fumigation Procedures

Building types—Virtually all frame or metal buildings can be fumigated if they are in good repair and tight, or can be made tight by sealing or tarping. Cement blocks pose a special problem because of their porous nature, but can be fumigated if an increased dosage and exposure time is allowed to compensate for the diffusion loss. There is no rule of thumb allowing for leakage. The applicator will have to exercise judgement from his observation of the building condition. Carry out fumigations in conformance with all local, state and national regulations.

Sealing the building—The most important part of the entire fumigation job lies in the preparation and sealing of the structure. A careful sealing job is the keynote to success. It pays off with a better job as well as savings in time and material. The properties of penetration and diffusion that make a fumigant an ideal fumigant also make it difficult to confine; therefore, for that reason, a good sealing job is necessary. High winds, for example increase fumigant loss and cause fumigant to drift to the leeward side of the building. If fumigation must be conducted on a windy day, apply more gas on the windward side to minimize the loss and drift.

Figure 14. Seal structure to be fumigated

Sealing of the building begins with the closing of all external openings to the building. Seal roof ventilators and chimneys by wrapping them with a tarpaulin, or plastic sheet, or by stripping the screened openings with a wide commercial maskingtape.

Close stairwells and interior doors. Replace any broken panes then wedge exterior doors and windows and lock. Caulk or tape cracks. Check for cracks in the floor, roof and around the eaves and seal them.

Take special care to seal partitions to adjacent storage or work areas in a building. Clear adjoining buildings sharing a common wall before fumigation, if possible. If this is not feasible, spread a glossy type of building paper, Sisal kraft or asphalt laminated paper, plastic film, or a heavily oiled kraft or wrapping paper to prevent the spread of the fumigant into undesired areas. In all such cases where the adjoining building is occupied, check frequently with a monitoring device during fumigation to insure the safety of the occupants. Check local regulations for specific requirements.

Appearance, economy and ease of cleanup will probably determine your choice of sealing materials.

Where time and neatness are factors, masking tapes and commercial caulking compounds will probably justify their extra cost. It is possible, however, to make your own paste by combining lubricating oil and a low grade of flour.

Computing the job—Dosage recommendations are made on the basis of cubic content. In square or rectangular buildings simply multiplying the interior length by width by height. In irregular-shaped buildings, find the cubic content of each unit then add them together to find the total. In the case of peaked roofs, the average height between sidewall and top of the roof may be used as the third multiple in calculating the cubic content. See the following diagrams and formulas for examples of calculations of volume. (See Figure 15, page 20.)

In taking measurements, do not make deductions for space occupied by machinery, commodities or furnishings. Exceptions to this rule apply to fresh fruit and vegetables. Follow recommended checklist for release and aeration procedures.

Phosphine is very corrosive to certain metals, such as copper wiring and brass sprinkler heads. It has been found that spraying the exposed metals with WD40 or Napa 12 to 34, will aid in retarding corrosiveness in some cases.

It is generally agreed that the person doing the fumigation should be the only one to have access to a key to the building being fumigated for safety reasons.

The disposal procedures for the phosphine residue will be on the label of the fumigant. Follow exactly as recommended. Also, notify city, county, and/or state agencies having jurisdiction over the disposal of toxic wastes prior to disposal.

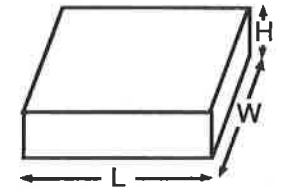
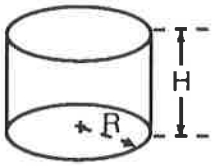
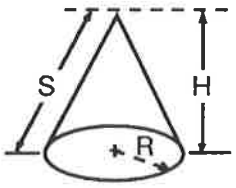
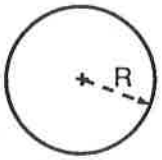
 Rectangular Cubicle	Volume = L × W × H Surface Area = 2 [(L × H) + (L × W) + (W × H)]
 Cylinder	Volume = 3.14 × R × R × H Surface Area = 6.28 [(R × R) + (R × H)] Area of Cylindrical Surface = 6.28 × R × H
 Cone	Volume = 1.05 × R × R × H Surface Area = 3.14[(R × R) + (R × S)] Area of Cone Surface = 3.14 × R × S
 Sphere	Volume = 4.19 × R × R × R Surface Area = 12.56 × R × R

Figure 15. Formulas for calculating volume

Tarpaulin Fumigation Procedures

When fumigating packaged commodities, follow the procedures below:

The stack—Stacks of stored commodities usually can be fumigated where they stand as long as the tarpaulin is large enough to cover the stack completely. If, however, material is being stacked expressly for fumigation (such as when unloading a freight car), it should be stacked in a square area to a height of five or six feet. Be sure to allow for a tarpaulin margin of at least two feet around the stack when the cover is laid over it. The stack should be on a concrete floor or other airtight surface. Where floors are not airtight (such as on a loading dock), caulk or seal cracks to prevent escape of the fumigant. Sisal kraft paper, or additional tarpaulin laid on the floor under the material to be fumigated can provide a satisfactory seal.

The gas expansion dome—Center four or more sacks, cartons or cases upright on top of the stacked material to form a gas expansion dome. This facilitates gas distribution for some fumigants. This is not required, however, for a solid fumigant, such as aluminum phosphide, which produces phosphine.

Tubing and evaporating pans—Copper, polyethylene, or saran tubing is used to inject the gas near the center of the expansion dome. Fasten the outlet of this tubing to an evaporating pan to prevent liquid fumigant from dripping on the commodity being fumigated, or splashing on the tarpaulin.

The tarpaulin—Polyethylene or gas proof, impregnated, tarpaulins should be used. Waterproofed canvas tarpaulins are not satisfactory. Before spreading the tarpaulins, sweep around the stack to provide a clean surface for sealing. Unroll or unfold the tarpaulin over the stack, providing a margin on the floor of two or three feet. Run the applicator tubing out from under the tarpaulin at a corner, which should be folded. If phosphine tablets or bags are used, there is no need for any special equipment. The tablets or bags can be put in trays and slid under the cover. Seal the tarpaulin by weighing it down with a row of bagged material or sand filled tubes. (Canvas or plastic tubing about four inches in diameter may be used for these "sand snakes.")

Applying the fumigant—Release the required amount of fumigant from outside the stack based on the cubic measurement of the stack. (See Figure 16.)

Removing the cover—When the fumigation period is over, pull the tarpaulin back only partially and leave it for about 30 minutes. This will allow the fumigated material to air out before the cover is removed completely. After aeration period, the tarpaulin can be removed, carefully folded and stored for next use.

Figure 16. Applying fumigant

Chamber Fumigation

Vacuum chambers—The rate of penetration of gas into the material to be fumigated is often an important factor, and is of course, related to the sorptive capacity of the treated material. The rate of penetration of the fumigant is greatly increased if fumigation is done in an airtight chamber from which the air has been exhausted. This type of treatment is called vacuum fumigation. The fumigant may be removed quite completely from the fumigated material by drawing a second vacuum after the proper period of exposure to the gas and then breaking this vacuum with air. This process is known as "air-washing".

Vacuum fumigation can be used to advantage when speed is an important factor, for usually the period required for effective kill of insects protected by plant materials (e.g., in baled cotton) is reduced to a small fraction of

that required under natural atmospheric conditions. However, the amount of fumigant needed is greatly increased when much plant material is present. Another advantage of vacuum fumigation is that workmen are not exposed to the gas.

Atmospheric chambers—A suitable low-cost fumigation chamber can be constructed. It consists of a gas-tight room with an appropriate door and a minimum of equipment, including applicator, exhaust blower and a small fan for even gas distribution. If the chamber is to be used where low temperatures are encountered, it should be equipped with some means of heating, preferably by steam pipes, to maintain at least 70°F during fumigation.

Figure 17. Warning signs on boxcar

Fumigation Vehicles Procedures

Railroad cars and trucks are the vehicles most frequently fumigated. Follow the procedures below when fumigating these vehicles.

- Place railroad cars or trucks on seldom used trackage or parking areas so that they will not have to be moved under fumigation.
- Liquid fumigants must always be applied from outside the vehicle usually by means of a 1/4 inch copper or plastic tubing attached to a can puncturer or to a fumigant cylinder. The tube may be introduced into the vehicle through a hole drilled in the floor near the center or through some other convenient hole, such as a crack in the door or some roof opening. Secure the discharge end of the tube near the ceiling at the center of the vehicle. This may be accomplished by fastening the tube to a pole, stick or some other support to hold the end of the tube near the ceiling. The discharge end of the tube is plugged and a hole drilled through the opposite walls of the tube about one to two inches below the tip to permit escape of the fumigant mist about the commodity load and toward the opposite ends of the vehicles.
- If solid fumigants are used, they can be applied directly on the floor of the vehicle on kraft paper or in trays. If the commodity is in bulk form, the fumigant can be put into it when it is being loaded or by the probe method, if the vehicle is already loaded. The exposure and aeration time as well as the dosage rate will be recommended on the label of the fumigant.
- Carefully seal all vehicle openings. Give particular attention to the space around doors, the eaves, and the floor. During application and fumigation, tightly seal up all openings used to introduce the gas tube and surrounding the tube. Any holes bored through the structure should be of a minimum size and carefully sealed following fumigation. Masking tape, caulking compound or greased paper may be used as sealing materials.
- Post warning signs conforming to Department of Transportation regulations on doors before applying the fumigant.
- After application of a liquid fumigant, such as methyl bromide with the proper dosage, withdraw the tubing and seal the hole used for application and keep sealed for 12 to 18 hours. A halide detector may be used to check sealed areas for leaks. The fumigated vehicle should not be moved during the exposure period.
- At the end of the fumigation period, open all doors and vents to allow as much air circulation as possible. It will usually require about 30 minutes to aerate after fumigation, but this must be determined by the use of a halide detector. Keep all persons out of the vehicle during fumigation and aeration and until such time as the halide detector shows no fumigant present. Only then is it safe to enter without wearing respiratory protection.

Grain Elevators (Silos) And Bulk Bin Fumigation

Methyl bromide is an effective fumigant for controlling insects in stored grain, if applied correctly. This type of fumigation requires additional equipment, such as recirculating blowers to be the most effective. Methyl bromide is an odorless gas; therefore, many formulations will include chloropicrin. Chloropicrin has a strong odor and serves as a "warning gas."

Methyl bromide, nerve gas, will penetrate quickly and deeply into sorptive materials that are packed loosely. Methyl bromide can be applied directly from pressurized cans or tanks, or it can be piped from cylinders located outside of the structure being fumigated. *Methyl bromide is heavier than air; therefore, it is one of the few fumigants that one should never wear gloves when handling.* It is possible for it to settle down inside the gloves and cause severe skin damage.

When using methyl bromide products in a grain bin or silo (elevator), the best results are obtained by the recirculation method. This necessitates the use of blowers, which are usually located outside at the bottom side of the silo or storage building. Ducts connected to the blowers go from the inside bottom to the top of the bin, so the air will go down through the grain and recirculate back to the top. This type of application results in more effective gas penetration into areas resistant to natural gravitational diffusion. Better insect control is provided by assuring a thorough distribution of the fumigant where vapors may be recirculated until the fumigant has penetrated into areas offering the greatest resistance to air movement. Prior to fumigant application, seal the grain storage facility as air tight as possible and insure that the recirculation system is operating properly. After the air flow has been established throughout the grain mass, introduce the methyl bromide formulation on the high pressure side of the blower. Continue recirculation system and allow at least 24 hours exposure time.

Figure 18. Recirculating ducts on storage building

Aerate the grain by disconnecting the return air duct and operating the ventilation system until exhaust air is free of fumigant traces, as indicated by a Halide Gas Detector, (one of the best instruments for checking the presence of methyl bromide). Also, check at the grain surface for possible pockets of methyl bromide that may not have aerated.

If no blowers are used for applying methyl bromide to a grain silo or bulk bin, it will be more effective to release the gas at the top of the structure (over the top of the grain). Since methyl bromide is heavier than air and will more than likely distribute itself down through the grain if allowed enough exposure time. The exposure time should be a least 96 hours. This, however, depends on the manner in which the grain is packed and the height of the mass. Aeration is accomplished by opening all vents, doors, etc. It may also necessitate the use of auxiliary fans.

Phosphine gas is another fumigant that is extremely effective for grain fumigation, as well as other commodities, whether they are in bulk or packaged. The dosage rate for grain storages when using phosphine gas depends on the type of storage, pests to be controlled, and commodity temperature. As with all fumigations, the structure must be sealed as tight as possible. In some cases, the whole structure will require complete cover with polyethylene or gas-proof tarpaulins.

Phosphine gas has remarkable penetrating and distributing power, therefore, no special recirculating equipment is required. The fumigant can be applied very simply, directly into the grain mass or the stream of grain as it is conveyed into the silo (elevator). The tablets or pellets can be manually discharged into the stream of grain or the application can be further simplified by using an automatic pellet/tablet dispenser while the commodity is being loaded. These dispensers can be obtained from the manufacturer of phosphine fumigants.

If however, the bulk commodity is already stored in a silo, bulk bin, flat storage, etc., the fumigant tablets or pellets can be inserted in the mass with a probe. These probes can also be obtained from the fumigant supplier.

The exposure time and aeration procedure will be as stated on the label of the fumigant.

The residue dust from the aluminum phosphide pellets or tablets will be removed automatically by the usual handling of the grain. (This is another advantage of this type of fumigation.) Subsequent to treating, no additional measure is required to render the bulk commodity marketable.

There is a fundamental difference between the fumigation of bulk and packed commodities with phosphine gas; with bulk products, the tablets or pellets are added directly to the

goods; packed commodities, however, are treated in such a way that neither the tablets, pellets, bags or plates, nor their residues come in direct contact with the goods.

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