Carbon disulphide

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Carbon disulphide (CS_2) was one of the first fumigants employed on a large scale. Its use in France, in 1869, against the grape phylloxera is a landmark in the history of applied entomology. It was injected into the soil to control the insects infesting the roots of the grapevine. For many years afterwards, CS_2 was widely used as a soil or space fumigant. Its tendency to burn or explode presents a hazard, and many explosions have been recorded during its use as a fumigant (Hinds, 1911; Fleming and Baker, 1935).

Carbon disulphide penetrates well and is still the only fumigant used in certain parts of the world. It is of practical value in tropical countries where the high temperatures favour volatilization.

Carbon disulphide is commonly formulated in mixtures with nonflammable ingredients for fumigating grain.

TOXICITY

Judged on the basis of lethal dosages, CS_2 ranks rather low among the insect fumigants because relatively large dosages by weight are required.

Carbon disulphide is toxic to humans. Because it is used in certain manufacturing processes, it is an important industrial poison. High concentrations of the vapour produce a narcotic effect and, if exposure is continued, unconsciousness and death may ensue from paralysis of the respiratory cent ret Repeated exposure to low concentrations for periods of a few weeks or longer may result in a variety of nervous manifes tations, which may make correct diagnosis difficult (Canada, Department of National Health sod Welfare, 1957). Persons exposed to low concentrations may lose their ability to detect the odour of the chemical and thus may continue to work in a toxic atmosphere without being aware of it (Hinds, 1917).

PROPERTIES OF CARBON DISOLPHIDE
Alternative name : carbon bisulphide
Abbreviation used in this manual: CS_2

Odour	Sweetish when pure; impurities, such as hydrogen sulphide, give characteristic unpleasant odours
Chemical formula	CS_2
Boiling point	46.3C

Freezing point	-111 C
Molecular weight	76.13
Specific gravity	
gas (air = 1)	2.64
liquid (water at 4C = 1)	1.2628 at 20C
Latent heat of vaporization	84.1 cal/g
Flammability limits in air	1.25 to 44% by volume
Solubility in water	0.22 g/100 ml at 22C
Pertinent chemical properties	Flash point about 20C and ignites spontaneously about 100C
Method of evolution as fumigant	By evaporation of liquid; now used more often in nonflammable mixtures
Commercial purity	99.99%

Natural vapour pressure at different temperatures

0C (32 F) 127.3 mm Hg
10C (50F) 198.1 mm Hg
20C (68F) 297.5 mm Hg

25C (77F) 351.1 mm Hg
30C (86F) 432.7 mm Hg
40C (104F) 616.7 mm Hg

Weights and volumes of liquid

1 lb (avdp) at 20C has volume 359.2 ml
1 U.S. gal weighs 10.53 lb (4.775 kg)
1 Imp gal weighs 12.63 lb (5.728 kg)
1 kg has volume 791.89 ml
1 litre weighs 1.2628 kg

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	Percent	g/m	lb/1 000 ft
20	0.002	0.06	
50	0.005	0.15	
100	0.01	0.31	
200	0.02	0.62	
321	0.032	1.00	

500	0.05	1.56	0.10
1 000	0.10	3.11	0.19
5 138	0.514	16.00	1.00
20 000	2.0	62.28	3.89

[1] Ounces per 1000 cubic feet or milligrammes per litre

Absorption of high concentrations may take place through the skin as well as by inhalation. Prolonged contact of the skin with high concentrations of vapour or with the liquid may result in severe burns, blistering or neuritis (Canada, Department of National Health and Welfare, 1957).

A full discussion of the toxicology of CS_2 is given in a joint FAD/WHO report (1965a).

EFFECT ON PLANT LIFE

Hinds (1917) found that CS_2 in insecticidal fumigations did not reduce the viability of dry seeds (normal moisture content for safe storage). The percentage germination of moist seeds was significantly lowered. Kamel and Shahba (1958) found that the germination of cereal grains (wheat, barley, millet and rice) was not affected with normal fumigation concentrations (250 g/m for 24 hours). Fifteen kinds of vegetable seeds were also not affected, the only

exception being eggplant seeds. King et al (1960) experimented with CS_2 as an ingredient of fumigant mixtures with carbon tetrachloride and sulphur dioxide. The seeds used were barley, oats, wheat, rice, cotton and two varieties each of maize and grain sorghum. They concluded that the CS_2 in combination tended to reduce germination, especially after prolonged storage. The reduction was greater when sulphur dioxide was included in the formulation.

Growing plants and nursery stock are severely injured or killed when treated with gaseous CS_2. However, CS_2 applied as a dilute emulsion in water to the earth surrounding the roots of evergreen and deciduous nursery stock in the field is effective against some insects, such as the larvae of the Japanese beetle, without causing injury. For details of these treatments and the specific plant reactions to them, the original work of Fleming and Baker (1935) should be consulted.

EFFECT ON PLANT PRODUCTS

Certain fruits (strawberries, raspberries, blackberries, peaches, plums, red currants and gooseberries) in marketable condition were found to be tolerant to fumigation with CS_2 at 100 g/m (6.25 lb/1 000 ft) for 2 hours at 27C. Their flavour and appearance were not affected. Blueberries did not keep well following treatment, and part of the bloom was removed (Osburn and Lipp, 1935). There appears to be no record of the application of CS_2 fumigation to fruit in commercial practice.

Previously, CS_2 WAS used extensively in fumigation chambers for the treatment of plant products, such as dried beans and peas. Although still used to some extent for this purpose, it has been largely replaced by methyl bromide, which is nonflammable and more easily volatilized.

Majumder et al (1961) reported that CS_2 affects the taste of coffee when used to fumigate monsooned (high moisture content) beans and Calderon et al (1970) that it reducer) loaf volume of bread made from fumigated wheat .

RESIDUES IN FOODSTUFFS

Theoretically, from the results of in vitro studies, CS2 may react with peptides and amino acid groups in foodstuffs of vegetable origin (FAO/WHO, 1965a). However, reaction products of CS_2 fumigation in foudstuffs have not, apparently, been demonstrated as residues.

The available information refers to the possibility of CS_2 itself appearing as residue in fumigated material. Studies of the retention of the fumigant in flour, wheat, rolled oats and the ingredients of bread showed that residues following normal aeration will not persist in cooked foods, such as bread and rolled oats (Lynn and Vorhes, 1957; Munsey et al 1957) .

METHODS OF ANALYSIS

Determination of Vapours

For determination of insecticidal concentrations in the field the thermal conductivity analyser may be used after appropriate calibration for CS_2

(Kenaga, 1958). A chemical method that is fairly rapid and convenient has been described by Fleming and Baker (1935). It is based on direct iodometric titration after the vapours are absorbed by alcoholic potassium hydroxide.

For protection of personnel from the poisonous effects of low concentrations and for the measurement of higher levels, glass detector tubes with ranges as low as 5 ppm and up to 3 200 ppm are available. Also infra-red gas analyzers can be used for carbon disulphide. Instruments that will detect concentrations from 0.5 ppm to more than 39 000 ppm can be obtained.

Determination of Residues

Dunning (1957) and Keppel and Munsey (1957) described adaptations of Lowen's dithiocarbamate method for the determination of CS_2 in fumigated products. Berck (1965a) included it among the fumigant gases which may be analysed by gas chromatography. Bielorai and Alumot (1966) described an electron-capture yes chromatography method sensitive to parts per thousand million, although with standard mixtures the recovery was 50 percent or

less. Whitney (1962) discussed methods of inhibiting CS_2 decomposition during gas chromatography procedures.

APPLICATION

Carbon disulphide is available in metal cans or drums of various sizes and is readily poured from a large container into a smaller one for application .

The boiling point of CS_2 (46C) is well above normal temperatures, and in space fumigations some means of rapid volatilization must be provider! in order that the needed concentrations may be reached as quickly as possible. For small-scale work, the liquid may be poured onto some absorbent material such as jute cloth (burlap), which is then suspended in the space. The liquid may also be applied as a fine spray from a spray pump, preferably from outside the building.

An apparatus for rapid vaporization of CS_2 for use in atmospheric fumigation chambers is described by Weigel et al (1927). The CS_2 is poured into a shallow pan containing coils of 0.5 inch (1.3 cm) seamless copper tubing through which hot water is circulated. The temperature of the water must be kept well below 96C because this is the lowest temperature reported for the ignition of CS_2 in contact with copper. The authors recommend that the temperature of the water in the coil should not exceed 84C.

Grain fumigation with CS_2 is discussed in Chapter 10.

PRECAUTIONS

Flammability

The low ignition temperature of CS_2 makes it a dangerous fire hazard.

Cans or drums containing liquid CS_2 should be stored in cool, shaded, well-ventilated rooms, never under direct sun. In very hot weather, it may be necessary to spray the containers with cold water to prevent excessive rise in temperature. Contact of the vapour with a steam pipe or an electric light bulb may be enough to ignite it. Even the heat generated by a heavy blow could set off an explosion. The spark from static electricity or from an electric motor is a particularly dangerous source of ignition.

Great care must therefore be exercised in handling this material and strict precautions must be adopted during fumigation. If the grain to be fumigated is heating or is likely to do so, pure CS_2 should not be used.

Carbon tetrachloride

Carbon tetrachloride (CT) may be used alone as a fumigant but because of its low toxicity to

insects, high dosages or greatly prolonger) exposure periods are needed. It has, however, been used alone for grain fumigation, usual ly when there is a shortage of more toxic materials.

At recommended insecticidal concentrations, CT does not affect the germination of seeds (King et al, 1960) hut it may be injurious to growing plants, nursery stock, fruit and vegetables*. Majunder et al, (1961) reported that the taste of coffee may be affected from monsooned (high moisture content) beans fumigated with CT.

*** Roth (personal communication, 1967) states that CT in high concentrations near the saturation limit in air for exposures of 4 hours and upward at 25 to 30C was injurious to seeds of the conifers Pinus, Picea, Larix and Thuja but apparently nut of Cupressus.**

PROPERTIES OF CARBON TETRACHLORIDE
Alternative name : tetrachloromethane
Abbreviation used in this manual : CT

Odour	Characteristic and well-known
Chemical formula	CCl_4
Boiling point	76.8C
Freezing point	-22.8C

Molecular weight	153.84
Specific gravity	
gas (air = 1)	5.32
liquid (water at 4C = 1)	1.595 at 20C
Latent heat of vaporization	46.4 cal/g
Flammability limits in air	Nonflammable
Solubility in water	0.08 g/100 ml at 20C
Pertinent chemical properties	Nonflammable and nonexplosive, relatively inert
Method of evolution as fumigant	By evaporation of liquid. Used more often in a mixture to reduce flammability of more toxic fumigants or to act as a carrier for better distribution

Natural vapour pressure at different temperatures

0C (32F) 32.9 mm Hg
10C (50F) 56.0 mm Hg
20C (68F) 91.0 mm Hg
25C (77F) 114.5 mm Hg

30C (86F) 143.0 mm Hg

40C (104F) 215.8 mm Hg

Weights and volumes of liquid

1 lb (avdp) at 20C has volume 284.4 ml

1 U.S. gal weighs 13.3 lb (6.032 kg)

1 Imp gal weighs 15.95 lb (7.235 kg)

1 kg has volume 626.959 ml

1 litre weighs 1.595 kg

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	**Percent**	**g/m**	**lb/1 000 ft**
10	0.001	0.06	
50	0.005	0.31	
100	0.01	0.63	
159	0.016	1.00	
200	0.02	1.26	

500	0.05	3.14	0.20
1 000	0.10	6.29	0.39
2 543	0.254	16.00	1.00
20 000	2.0	125.85	7.86

[1]Ounces per 1000 cubic feet or milligrammes per litre

CT fills a useful role in the fumigation field as an ingredient of mixtures, principally for grain fumigation. It is nonflammable in any concentration in air, and serves to reduce fire hazards of other fumigants, such as ethylene dichloride, carbon disulphide and acrylonitrile. Furthermore, the distribution of some liquid-type fumigants in a grain mass is aided by the presence of CT as one of the ingredients (Berck, 1958).

TOXICITY

Although, compared with other commonly used fumigants, CT is not very toxic to insects, it is now known to be extremely poisonous to human beings. Toxicity to humans is attributed mainly to extensive liver damage (Rouiller, 1964).

Human poisoning may be acute as the result of exposure to high concentrations but in practice it more often occurs as a chronic condition from comparatively low concentrations

inhaled over extended periods of time. In recent years the threshold limits established by the American Conference of Governmental Industrial Hygienists have been progressively lowered until they are now at 5 parts per million (ppm) for continuous daily exposure to CT. This fumigant is now listed by the above agency in the category of industrial substances suspected of carcinogenic potential for humans (ACGIH, 1981).

There are two important considerations in CT poisoning. According to Rowe (1957) the vapours are not detectable by smell below 70 ppm in air. It should also be made known that CT does not "mix" well with alcohol:

"Persons who are prone to imbibe too heavily or too frequently show a considerably greater susceptibility to carbon tetrachloride poisoning" (Torkelson et al 1966)

RESIDUES IN FOODSTUFFS

Evidence is strong that CT is taken up physically and without chemical reaction in grain and grain products (Pepper et al, 1947; Lynn and Vorhes, 1957). Jagielski et al (1978) found residual CT in fumigated wheat and maize three months after treatment and a substantial proportion of this appeared in milled fractions, especially the bran. Small amounts (up to 0.03 mg/kg) could be detected in bread made from the treated flour. There is no positive evidence available on the presence or absence of CT metabolites in treated grain or other foodstuffs (Kenaga, 1967).

The toxicological significance of even small amounts of residual CT is not known, but the FAO Panel of Experts on Pesticide Residues in Food (FAD/WHO, 1980) suggested that guidelines be lowered below those previously recommended. They indicated that the following levels should be used as guide lines:

Cereal grains	50 mg/kg
Milled cereal products (for baking and cooking)	10 mg/kg
Milled cereal products (for consumption Without cooking)	1.01 mg/kg
Bread and other cooked cereal products	0.01 mg/kg

METHODS OF ANALYSIS

In the field determination of this fumigant, both the thermal conductivity analyser (Kenaga, 1958) and the interference refractometer can be used. It is important to point out that such methods are not applicable to CT in fumigant mixtures and should only be employed when CT is applied alone. Glass detector tubes are available for measuring low levels of CT in the 5 to 50 ppm range.

Residual CT in cereal grains, milled products and other stored foods can be determined by gas chromatography in the parts per thousand million range (Bielorai and Alumot, 1966; Heuser

and Scudamore, 1969b). A cold extraction procedure for removal of CT from wheat and maize was found more effective than steam distillation (Scudamore and Heuser, 1973). Landen (1979) described a method for microassay of CT in drinking water and beverages.

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Chloropicrin

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Chloropicrin is a powerful tear gas; it is one of the most toxic to insects of the fumigants commonly used today. It is sometimes added in small proportions to other fumigants, e.g., hydrogen cyanide and methyl bromide, to serve as a warning agent (see Chapter 3).

Although the tear gas effect of Chloropicrin is helpful in preventing persons from staying in dangerous concentrations during the fumigation process, it is also a handicap because fumigated commodities are unpleasant to handle for some time after fumigation. Even comparatively small amounts diffusing from the treated material may be extremely irritating. If it were not for this disadvantage, Chloropicrin would be useful for commodity treatments as

it penetrates effectively into many materials.

Chloropicrin is also toxic to nematodes and certain fungi and it has found wide application as a soil fumigant.

Chloropicrin is corrosive to metals and care should be taken to protect metal surfaces and equipment during treatment.

T0XIClTY

In humans, a concentration of 2.4 g/m can cause death from acute pulmonary oedema in one minute (Hanslian, 1921). concentration us low as I ppm of Chloropicrin in air produces an intense smarting pain in the eyes, and the immediate reaction of any person is to leave the vicinity in haste. If exposure is continued, it may cause serious lung injury.

PROPERTIES OF CHLOROPICRIN
Alternative names: trichloronitromethane, nitrochloroform
Strongly irritating tear gas

Chemical formula	CCl_3 NO2
Boiling point	112C
Freezing point	-64C

Molecular weight	164.39
Specific gravity	
gas (air = 1)	5.676
liquid (water at 4C = 1)	1.651 at 20C
Flammability limits in air	Nonflammable
Solubility in water	0.227 g/100 ml at 0C
Pertinent chemical properties	Nonflammable; relatively inert; corrosive in presence of moisture
Method of evolution as fumigant	By evaporation of liquid from pure compound or mixed with carbon tetrachltride. Sometimes dispersed as aerosol with methyl chloride as carrier.
Commercial purity	99%

Natural vapour pressure at different temperatures

0C (32F) 5.7 mm Hg
10C (50F) 10.37 mm Hg
20C (68F) 18.3 mm Hg
25C (77F) 23.8 mm Hg

30C (86F) 31.1 mm Hg
40C (104F) 51.1 mm Hg

Weights and volumes of liquid

1 lb (avdp) at 20C has volume 274.7 ml
1 U.S. gal weighs 13.76 lb (6.243 kg)
1 Imp gal weighs 16.51 lb (7.489 kg)
1 kg has volume 605.69 ml
1 litre weighs 1.651 kg

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	**Percent**	**g/m**	**lb/l 000 ft**
20.1	0.00001	0.00067	
20	0.002	0.13	
50	0.005	0.34	
100	0.01	0.67	
149	0.015	1.00	

200	0.02	1.34	0.08
500	0.05	3.36	0.21
1 000	0.10	6.72	0.42
2 380	0.24	16.00	1.00
20 000	2.0	134.46	8.40

[1]Ounces per 1000 cubic feet or milligrammes per litre

However, it is evident from the preceding statement that an individual will not willingly tolerate concentrations that are actually injurious (Torkelson et al, 1966).

EFFECT ON PLANT LIFE

Chloropicrin is extremely phytotoxic and plants exposed to its vapours are often completely destroyed. Even when added in small amounts to other fumigants for warning purposes, it is likely to be toxic. For instance, methyl bromide containing small amounts of chloropicrin should not be used to fumigate plants, fruit or vegetables. When used for soil fumigation, it kills weed seeds and any living plant material present.

Nevertheless, it is possible to fumigate certain seeds with concentrations of chloropicrin toxic to insects without impairing germination (Hsin, 1959; Metzer, 1961; Solodovnik et al, 1963).

Metzer recommended that seed treatments with this fumigant be conducted at temperatures lower than 27C.

EFFECT ON PLANT PRODUCTS

Chloropicrin should not be used for the fumigation of fresh fruit or vegetables. It may be used on bagged or packaged plant products at atmospheric pressure if ample time is allowed for postfumigatior aeration. The irritating vapours must be allowed to diffuse before the material is handled or consumed.

If chloropicrin is present in fumigated flour, it may have a bad effect on the baking quality, but this effect disappears once the material is fully aerated.

RESIDUES IN FOODSTUFFS

From available evidence it appears that the residue problem with this fumigant is confined to unchanged chloropicrin persisting in the treated foodstuff. There has been no indication of a significant residue from reaction products under normal conditions of fumigation, but the formation of inorganic nitrites and nitrosamines has been postulated (FAD/WHO, 1965a).

Getzendaner et al (1965) found that in dry beans and field peas fumigated with chloropicrin at 32 to 64 g/m for 24 hours at 25 to 26C, residues were not in excess of 2 mg/kg after 4 days of aeration. With the same treatments most of the fumigant disappeared from maize, peas,

beans, wheat flour, breakfast food and chicken feed but even after 3() days measurable amounts of chloropicrin, up to 9 mg/kg, persisted in wheat flour and up to 16 mg/kg in chicken feed. In the other materials the residues were less than 2 mg/kg. Flour containing 3.7 my/kg of chloropicrin before baking cuntained no measurable amounts afterwards. These authors point out that the physical state of the material being fumigated may have an important bearing on the amount of initial residue.

METHODS OF ANALYSIS

Methods for the determination of chloropicrin in air are given by Daecke and Kraul (1961), Berok and Solomon (1962a), and Ioanid et al (1963). The method used by Getzendaner et al (1965) for analysing chloropicrin residues in fumigated foods was sensitive from 0.1 to 100 mg/kg. Kanazawa (1963) and Berck (1965a) described gas chromstographic methods for determining this fumigant.

APPLICATION

Chloropicrin is commonly marketed in glass bottles containing 1 pound of the liquid. For safety, the bottles are packed individually in cans, which must be opened with a can opener. The fumigant is also available in steel cylinders containing 25 to 180 lb (11.5 to 81.5 kg) and is said to be noncorrosive to the containers if they are kept tightly closed.

Chloropicrin is difficult to vaporize at ordinary temperatures. In fumigation chambers it may

be poured onto a crumpled jute (burlap) sack over which a powerful draught of air may be directed from a fan or blower when the fumigation starts. For volatilizing in flour and mill fumigation, it is sometimes mixed with methyl bromide or methyl chloride in a cylinder and discharged as a mist, from which the chloropicrin is rapidly volatilized.

Its application as a grain fumigant is described in Chapter lO and as a "spot" fumigant in Chapter 8.

PRECAUTIONS

As stated above, because of the tear gas effect, a person would be unable to remain in a dangerous concentration of chloropicrin for more than a few seconds. Great care should be taken to prevent unauthorized persons from approaching a fumigation site because the tear gas effect is so powerful that they may become temporarily blinded and panic-stricken, which, in turn, may lead to accidents. If it is necessary for the operator to expose himself to any concentrations of this fumigant, a canister especially designed for protection against "organic vapours and acid gases" should be fitted to the respirator.

For the use of chloropicrin as a warning gas, see Chapter 3.

Dichlorvos (DDVP)

Dichlorvos, sometimes called DDVP, is the common name of dimethyl 2,2dichlorovinyl

phosphate. Discussion of this material is pertinent to this manual, despite its high boiling point and low vapour pressure, because for certain usages it is discharged as a true gas to control insects in the open spaces of structures. It is also used as a contact insecticide, but a description of this type of application is outside the scope of this manual (Attfield and Webster, 1966).

PROPERTIES OF DICHLORVOS
Dimethyl 2,2-dichlorovinyl phosphate
Alternative name : DDVP

Chemical formula	CCl2 = CHO.P0.(OCH3)2
Boiling point	120C/14 mm
Freezing point	Below -18C
Molecular weight	221
Specific gravity	
gas (air = 1)	7.6
liquid (water at 15.6C = 1)	1.44 at 15.6C
Density	0.142 kg per litre at 20C
Flammability limits in air	Nonflammable. Applied as fog or spray, flammability would be governed by

	solvent used
Solubility in water	Slight (about 1%)

Pertinent chemical properties

Stable to heat. Undergoes hydrolysis in presence of water. Corrosive to black iron and mild steel. In absence of moisture, noncorrosive to aluminium, nickel and stainless steel. Nonreactive with Teflon and polyethylene. Stable in presence of hydrocarbon solvents.

Method of evolution as fumigant

(a) By direct evaporation of liquid concentrate by means of heat.
(b) By volatilization from pressurised cylinders with inert Freon-type gases as carriers.
(c) By slow volatilization from resin strips (adult flies and mosquitoes only).
(d) By evaporation from resin cylinders (glasshouse fumigations).

Natural vapour pressure at different temperatures

20C (68F) 0.0108 mm Hg
10C (50F) 0.0041 mm Hg
30C (86F) 0.0272 mm Hg
60C (140F) 0.2985 mm Hg

Volatility (saturation - see also Table 2)

At 10C, 51.5 mg/m
At 20C, 131 mg/m
At 30C, 318 mg/m

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	**Percent**	**mg/m**	**oz/l 000 ft**
20.1		1.00	
1.0		10	
2		20	
5	O.005	50	O.05
10	0.01	100	0.1
15	0.015	150	0.15
20	0.02	200	0.2

[1]Ounces per 1000 cubic feet or milligrammes per litre

Because of its low vapour pressure dichlorvos is unable to penetrate into materials. Therefore, it is of no value as a commodity fumigant.

Used as a fumigant, dichlorvos has found effective use at very low concentrations against houseflies, mosquitoes and mushroom flies. At higher concentrations it is effective against cockroaches and a wide range of storedproduct insects. It has been used successfully against moths and the cigarette beetle in tobacco warehouses. Recommendations for free space use are summarized in Schedule Q. Its application as A glasshouse fumigant is discussed in Chapter 12.

An important characteristic of dichlorvos is the fact that it hydrolyses slowly in the presence of water, and this process is accelerated in the presence of alkali and reduced in the presence of acid. An end product of hydrolysis may be dichloroacetic acid. Consequently, formulations and spaces treated with the insecticide may exhibit a vinegar-like odour if hydrolysis has occurred to any extent.

TOXICITY

The toxicity of dichlorvos to mammals is moderately high by ingestion, inhalation and absorption through the skin. It is a direct inhibitor of the enzyme cholinesterase but it is detoxified relatively quickly (Hayes, 1963). Although dichlorvos is a potential alkylating agent of DNA and RNA in vitro, this potential is apparently not realized in vivo owing to the rapid degradation in mammals. Investigations for possible carcinogenic effects of dichlorvos have

shown no increased incidence of tumours in experimental animals (Blair et al, 1976); this and other studies support the view that any potential for producing cancer in humans by dichlorvos would be extremely low (Anon, 1977; FAD/WHO, 1977). Studies for teratogenic effects have shown no serious changes in the progeny from treated animals (Schwetz et al, 1979; Wrathall et al, 1980).

On the other hand, insect cholinesterase inhibited by dichlorvos is not readily reactivated, and in consequence intoxication is irreversible (O'Brien, 1960). This reaction is typical of the dimethyl phosphate insecticides.

EFFECT ON PLANT LIFE

Dichlorvos in the concentrations used for control of glasshouse pests is not generally phytotoxic. Pass and Thurston (1964) listed 42 plants, including 20 flowering plants, which were not injured by exposure for 15 hours at 20C to dichlorvos vapours generated at the rate of 1.5 fluid ounces (U.S.) of 90 percent concentrate per 10 000 cubic feet (eriaivalent to 204 mg/m of dichlorvos vapour which in full concentration, would be above the saturation point of 131 mg/m at this temperature). The only adverse effect noted was a slight discoloration or fading of chrysanthemum blooms. Glancey and Naegele (umpublished data, 1965) also reported that dichlorvos was safe to use for the insecticidal fumigation of glasshouse plants, except that one variety of chrysanthemum (Shasta) showed severe leaf burning. However, Harnlen and Henley (1979) were unable to obtain satisfactory control of green peach aphid and twospotted spider mite on a number of indoor ornamental plants in continuous room

fumigation tests. They found that a multiple fumigation treatment at seven-day intervals with dichlorvos impregnated polyvinyl chloride resin strips in polyethylene hags was more effective, but some injury to the plants did occur.

RESIDUES IN FOODSTUFFS

The amount of dichlorvos absorbed can vary considerably with different food materials. In measurements of residues absorbed in prepared meals during disinfestation of aircraft it was noted that margarine contained three times as much as the cooked meal and the beverages approximately one tenth as much (Dale et al, 1973).

Table 13 summarizes some information on the persistence of dichlorvos in certain foodstuffs exposed to the insecticide when discharged as a vapour. Dichlorvos breaks down rapidly after application, so the residues decline to very low levels during storage and shipment. The higher the temperature and moisture content of the material or its environment, the more rapid is the breakdown. In studies on the use of dichlorvos in mills at temperatures ranging from 18 to 22C, dichlorvos residues degraded within a period of 2 4 weeks, depending on the kind of product treated (Wirthgen and Raffke, 1979).

It may be concluded that, when dichlorvos vapour is applied to closed spaces containing foodstuffs, rapid hydrolysis leads to the disappearance of significant residues of this chemical in a very short time.

The toxicological evaluation of dichlorvos is that 10 mg/kg in the diet, equivalent to 0.5 mg/kg of body weight per day, is the level that will cause no toxicological effect; the estimated acceptable daily intake for man is 0 to 0.004 mg/kg of body weight (FAD/WHO, 1978b).

METHODS OF ANALYSIS

Determination of Vapours

Concentrations of dichlorvos in confined spaces can be measured by several different methods including cholinesterase inhibition (Webley and McKone, 1963; Heuser and Scudamore, 1966), calorimetric (Bracha et al, 1963; Mukherjee et al, 1973), titrimetric and bioassay procedures (Muthu et al, 1973). Gas chromatographic methods can provide rapid, specific and sensitive determinations (Bond et al, 1972; Bryant and Minett, 1978). Samples from the atmosphere can be taken directly by gas syringe and injected into a gas chromatograph or they may be collected by passing a known volume of air through glass tubes packed with potassium nitrate and taken to a gas chromatograph, as described by Bryan and Minett (1978).

TABLE 13. - RESIDUES OF DICHLORVOS IN FOOD

	Insect species	Concentration dichlorvos vapour	Temperature	Duration of exposure	Residue dichlorvos observed

		Applied	**Saturation**			
		mg/m		**C**		**mg/kg**
Cocoa beans	Ephestia elutella (Hbn.)	0.04 to	131	18	54 days	Whole beans, surface layer near strips, 0.02
in sacks		0.05				
in store	(moths only)	(from resin strips)				Whole beans, middle of top sacks, 0.01
Meat	-	*05	84	13-15	24 hours	Minced meat 0.33 Bacon 0.32 Steak 0.23 Fat 0.17
Mushrooms (a)	Megaselia halterate (Wood)	218	131	17-20	-	Nil 3 hours after exposure
Mushrooms (b)	Sciarid and Phorid flies	2120	131	17-20 ?	4 hours	Nil 24 hours after exposure with 1,2 or 3 consecutive

						applications

*** Concentration of 0.5 mg/m lasted for 30 minutes, no vapour detectable after 3 hours. SOURCES: Schulten and Kuyken (1966) for cocoa beans: Miller and Aitken (1965) for meat:**

Hussey and Huges (1964) for mushrooms (a); Snetsinger and Miner (1964) for mushrooms (b).

Determination of Residues

The dichlorvos remaining in food material can be extracted and coricentrated by using appropriate solvents for the type of food concerned. Details of methods for such extractions with subsequent analysis by gas chromatography are given by various authors (Abbott et al, 1972; Bond et al, 1972; 1 a Hue et al, 1975; Schmidt and Wohlgemuth, 1979).).

APPLICATION

A simple method of vaporizing dichlorvos as a fumigant for closed spaces is to place the required amount of liquid concentrate in an open dish or beaker and heat it on a hot plate. An ordinary electric fan or blower placed close to the source may be used to disperse the vapours to effect even distribution.

Jensen et al (1961) described a mechanical system for dispersing known amounts of dichlorvos. This system was originally designed for fly and mosquito control in aircraft, but

would also be suitable for use in a wide variety of structures requiring routine applications at regular or intermittent intervals.

Dichlorvos is also available in cylinders mixed, up to 20 percent by weight, with Freon-type inert propellants. This method of vaporization is very convenient but is more expensive.

For the control of flies and mosquitoes attacking humans and animals in houses and buildings, resin strips each containing about 20 percent dichlorvos by weight are extremely effective. By slow vaporization these strips will maintain concentrations up to 0.44 mg/m in a tightly closed room at 23.3C. Concentrations of 0.15 to 0.25 mg/m are fully effective against flies and mosquitoes within 30 minutes. Use of these strips is not an effective method for controlling cockroaches and stored-product insects.

The application of this chemical as a fumigant in glasshouses is discussed in Chapter 12.

Dosages and Concentrations

In the literature and in trade publications, dosages of dichlorvos are expressed in different ways. Sometimes both the metric and British systems are used in the same prescription. Equivalents of some of the more common methods of expressing dosage are given in the table of properties of dichlorvos .

PRECAUTIONS

Concentrations Toxic to Humans

According to the threshold limit set by the American Conference of Governments I Industrial Hyigienists (ACGIH, 1981), the maximum perrmissible concentration of daily exposure to humans is 1 microgramme (g) per litre (1 mg/m). Hayes (1963) stated that tests have shown that men can withstand brief exposure to air concentrations at least as high as 6.9 g/l without clinical effect or depression of blood cholinesterase; intermittent exposure totalling 5 hours daily at a concentration of ().5 g/l produces no clinical effect and no effect on red cell cholinesterase, but does cause a gradual moderate reduction of plasma cholinesterase.

Zavon and Kindel (1966) studied the effect of prolonged exposure, up to six months, on humans exposed to the low concentrations of dichlorvos not exceeding 0.01 g/l of air generated from resin strips of the type marketed for control of flies and mosquitoes in houses. They concluded that the handling and use of the resin vaporizers, under recommended conditions, would be unlikely to result in adverse effects among persons so exposed.

Durham et al (1959) studied the effects of exposure to dichlorvos in human volunteers, not wearing respirators, who worked in a tobacco warehouse where the insecticide was applied at regular intervals to control insects. They concluded that the conditions would be safe for workers where dichlorvos was applied twice a week or less at 70 mg/m.

Dichlorvos is easily absorbed through the skin and if even small amounts of formulations

containing this insecticide are spilled on the clothes or body, these may produce very serious results requiring medical treatment (Hayes, 1963).

Respiratory Protection

When dichlorvos is being applied as a fumigant indoors or in glasshouses, those applying the insecticide must wear an industrial-type respirator (gas mask) with a filter-type canister which gives full protection against organic vapours and acid gases (see Chapter 3 Table 8). A small cartridge-type respirator of the kind described in Chapter 3 does not give adequate protection when dichlorvos is being used for industrial purposes.

FIRST AID

The following is a summary giving the salient information on first aid and subsequent treatment by a physician for poisoning or suspected poisoning by dichlorvos. The manufacturers of this insecticide supply special booklets on first aid and treatment, with detailed information for physicians arid a list of important precautions to be taken during formulation.

Warning symptoms include weakness, headache, tightness, in the c-nest, blurred vision, nonreactive pin-point pupils, salivation, sweating, nausea, vomiting, diarrhoea and abdominal cramps.

In all cases of suspected poisoning, remove the patient from further exposure to the poison, restore breathing anti get medical help immediately. Details of the accident, including the name of the poison, the quantity involved anti how the accident occurred, i.e. by inhalation ingestion or by skin contact, should be supplied to the doctor or hospital emergency centre.

If dichlorvos has been swallowed, induce vomiting (in fully conscious patients only) by stroking or tickling the back of a patients throat with a finger. Do not give salt water as this may involve serious risk.

If the patient has been poisoned by external contact with dichlorvos, remove contaminated clothing immediately and wash the skin thoroughly with soap and water; use plenty of water in rinsing. If dichlorvos gets into the eyes, wash it out immediately using running water for at least 10 minutes.

Emergency treatment personnel should be aware that atropine is the antidote of choice for treatment of dichlorvos poisoning. However, atropine should never be administered unless warning signs of intoxication appear.

Information for Physicians

Regardless of the route of absorption, dichlorvos inactivates the cholinesterase enzymes of both the blood and tissues. Intoxication produces signs and symptoms of excessive cholinergic stimulation. Diagnosis may be substantiated by plasma and red cell cholinesterase analyses

using the Michel method (J. Lab. Clin. Med., 34: 1464, 1949) or the Ellman colorimetic method (Biochem. Pharmacol., 7: 88, 1961). Atropine should be given intravenously in doses of I to 2 mg; if cyanosis is present, the atropine should be given intramuscularly while simultaneously initiating measures to improve ventilation. Atropine administration should be repeated at 5- to 10- minute intervals until atropinization is complete. A mild degree of atropinization should be maintained for at least 24 hours and in severe cases for at least 48 hours. Morphine, adrenaline, tranquilizers and similiar substances are contraindicated.

Complete recovery may be anticipated even in those cases where severe poisoning has occured and after many hours of artificial respiration. A patient should be watched continuously for 48 hours when the exposure has been severe enough to produce symptoms. No further exposure to any organophosphorous or carbamate insecticide should be allowed until the blood cholinesterase, as determined by blood tests, has returned to normal.

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Sulphuryl fluoride

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Sulphuryl fluoride has been developed as an effective fumigant for controlling dry wood termites. This gas has outstanding dispersion and penetrating qualities which permit it to infiltrate termite tunnels and crevices and destroy the insects. Sulphuryl fluoride does not escape through plastic sheets used in structural fumigation as rapidly as methyl bromide or other organic fumigants. Because this gas is odourless, chloropicrin, discharged separately, is recorernended as a warning agent.

PROPERTIES OF SULPHURYL FLUORIDE

Odour	None
Chemical formula	SO_2F_2
Boiling point	-55.2C
Melting point	-120C
Molecular weight	102.06
Specific gravity	
gas (air = 1)	2.88
liquid (water at 4C = 1)	1.342 at 4C
Latent heat of vaporization	79.5 BTU/lb at -55.2C
Flammability limits in air	Nonflammable

Solubility in water	0.075 g/100 g at 25C
Pertinent chemical properties	Noncorrosive, relatively unreactive and harmless to wide variety of household materials
Method of evolution as fumigant	From steel cylinders under natural pressure
Commercial purity	99%

Natural vapour pressure at different temperatures

10C (50F) 9 150 mm Hg
25C (77F) 13 442 mm Hg

Weights and volumes of liquid

1 lb at 4C (39.2F) has volume 338 ml
1 U.S. gal weighs 11.17 lb (5.069 kg)
1 Imp gal weighs 13.42 lb (6.087 kg)
1 kg has volume 745.1 ml
1 litre weighs 1.342 kg

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	Percent	g/m	lb/l 000 ft
25	0.0005	0.0228	
20	0.002	0.091	
50	0.005	0.228	
100	0.01	0.456	
200	0.02	0.91	
239.6	0.024	1.00	0.062
500	0.05	2.278	0.142
1 000	0.10	4.556	0.285
3 833.2	0.383	16.00	1.00
20 000	2.0	91.12	5.695

[1]Ounces per 1000 cubic feet or milligrammes per litre

TOXICITY

Although highly toxic to humans acutely exposed, there have been few reports of accidental poisoning. This may be due to the fact that sulphuryl fluoride aerates very rapidly from fumigated buildings and also because, in its present usage, it is only applied by properly qualified operators. Its mammalian toxicity by inhalation, is about equal to that of methyl bromide.

Sulphuryl fluoride is generally very toxic to all postembryonic stages of insects (Kenaga, 1957b; Bond and Monro, 1961), but the eggs of many species are extremely resistant. It has been suggested that this resistance is largely due to the impenetrable nature of the eggshell layers to this chemical (Outram, 1967).

EFFECT ON MATERIALS

The effect of sulphuryl fluoride on materials found in houses and on plants and products has been summarized by Gray (1960) as follows.

"In laboratory and field tests, sulphuryl fluoride has shown no objectionable colour, odour, or corrosive reactions to photographic supplies, metals, paper, leather, rubbers, plastics, cloths, wallpapers or any other of a large number of articles fumigated.

"Sulphuryl fluoride has little or no effect on the germination of weed and crop seeds; however, it is in jurious to green plants, vegetables, fruits and tubers. Sulphuryl fluoride is sorbed less than methyl bromide in wheat, wood flour and many other materials."

Meikle and Stewart (1962) found that in fumigation with this compound the residual fluorides in foodstuffs are low except in certain proteinaceous foods which have a solvent system, such as fat in cheese and meat.

At the present time the manufacturers of a proprietary fumigant of sulphuryl fluoride (Dow Chemical Company, 1963) state specifically:

"Under no conditions should sulphuryl fluoride be used on raw agricultural food commodities, or on foods, feeds or medicinals destined for human or animal consumption. Do not use on living plants."

METHODS OF ANALYSIS

Determination of Vapours

Gross determination of concentrations of sulphuryl fluoride may be made with the thermal conductivity meters described in Chapter 4. fly using known concentrations of the gas, these instruments may be calibrated to read the gas concentration in terms of oz/1000 ft. For instruments of known calibration for methyl bromide, A straight-line relationship exists for reading concentrations of sulphuryl fluoride. For example, a reading of 7 g/m is equivalent to 4 9 of sulphuryl fluoride/m3. The accuracy of thermal conductivity meters decreases with decreasing concentrations to the point where the readings become unreliable at concentrations of sulphuryl fluoride below 4 g (approximately 960 ppm)/m3. However, this is

sufficiently accurate for normal commercial fumigation practices. Heuser (1963) described two analytical methods suitable for sulphuryl fluoride determinations under field conditions. These methods would also be useful for checks on the efficiency of the thermal conductivity analysers. For monitoring residual concentrations of this fumigant during the aeration of buildings, the manufacturers are careful to point out that the halide lamp described above under methyl bromide is not suitable for sulphuryl fluoride. It is recommended that a special device developed by them be used (Gray, 1960; Dow Chemical Company, 1963). The infra-red analyser described in Chapter 3 can be used for sensitive analysis of this fumigant. The Dow Chemical Company now recommends a modified portable SO2 analyser for excellent accuracy, fast measurements and low cost.

APPLICATION

Sulphuryl fluoride for termite control is most often applied to residences or other buildings, which are covered with gas-proof sheets. The fumigant is discharged directly from siphoned cylinders under its own vapour pressure. No auxiliary source of heat is required. The cylinders are placed on platformtype scales and the dosage read directly by change in weight. Metering devices are not safe and are not recommended. This fumigant will discharge through 0.3 cm (inside diameter) thick-walled polyethylene plastic tubing at the rate of 2 to 2.5 kg per minute.

For the purpose of monitoring gas concentrations so as to provide efficient and economical treatments to control termites in buildings, the manufacturers of sulphuryl fluoride supply

special guide charts. These charts give factors for calculating the variables likely to be encountered during a fumigation and are best used in conjunction with the thermal conductivity analyser (Stewart, 1966).

PRECAUTIONS

Concentrations Toxic to Humans

The threshold limit for sulphuryl fluoride is 5 ppm for repeated eighthour exposures five days per week (ACGIH, 1981). The short-term exposure limit should not exceed 10 ppm (see Chapter 3, Table 7).

Respiratory Protection

In proper practice with this material there is no need for the operator to be exposed to the fumigant. In planning a fumigation, care should be taken to eliminate the possibility of anyone breathing any concentration. This is not only good general fumigation practice, but is also particularly important with sulphuryl fluoride because the standard respirator canister affords protection for a very short time, owing to the nature of the gas. According to instructions on the label issuer) by the manufacturer, a special canister designed for sulphuryl fluoride and other acid gases is required.

Protection from concentrations up to 32 g/m for 15 minutes can be obtained with the

appropriate canister. For higher concentrations of sulphuryl fluoride, or for longer periods of time, air-supplied or selfcontained breathing apparatus should be used.

FIRST AID

The manufacturers of sulphuryl fluoride supply a booklet giving detailed recommendations for first aid, with suggestions to the physician.

The following condensed information on first aid is supplied on the manufacturer's label:

"Send for a doctor in case of accident. If a person should be overcome from breathing this gas, immediately place patient in fresh air, face downward, with head slightly below level of lungs. Keep warm. If breathing stops, give artificial respiration.

Note to physician: First symptoms expected are those of nausea, respiratory irritation and central nervous system depression; excitation may follow. Treat symptomatically. There is no known antidote."

Acrylonitrile

Owing to its low limits of flammability, acrylonitrile is never used alone as a fumigant but always in a mixture with another suitable material, which reduces the possibility of fire or explosion. A commonly used formulation was made up of acrylonitrile 34 percent and carbon

tetrachloride 66 percent by volume. In practice, therefore, the effects of acrylonitrile fumigation were dependent on the action of the mixture.

Acrylonitrile itself has a comparatively high boiling point. When the mixture is used in atmospheric furnigations, it is necessary to hasten evaporation by pouring the liquid over a piece of jute (burlap) or similar cloth placed in an evaporating pan near the ceiling, and, if possible, in the air stream from a nearby circulating fan or blower.

The mixture of acrylonitrile and carbon tetrachloride has been found useful for the following purposes:

> **1. As a "spot" fumigant in mill, bakery and processing machinery.**
>
> **2. For use in atmospheric chambers for fumigating tobacco (Tenhet, 1954; Childs and Overby, 1967), nutmeats (shelled nuts) and dates. It does not penetrate into certain closely packed materials as readily as methyl bromide and therefore is not usually recommended for use with flour and other milled products.**
>
> **3. For the vacuum fumigation of tobacco (Tenhet, 1957).**
>
> **4. For fumigation of buildings to control dry wood termites.**

PROPERTIES OF ACRYLONITRILE

Alternative names: vinyl cyanide, cyanoethylene, propene nit rife

Odour	Penetrating odour, bitter taste
Chemical formula	CH_2 : CH.CN
Boiling point	77C
Freezing point	-82C
Molecular weight	53.06
Specific gravity	
gas (air = 1)	1.83
liquid (water at 4C = 1)	0.797 at 20C
Flammability limits in air	3 to 17% by volume
Solubility in water	7.5 g/100 ml at 25C
Pertinent chemical properties	Flash point (open cup) 4C
Method of evolution as fumigant	By evaporation from liquid. Because of flammability mixed in practice not more than 34%, with carbon tetrachloride 66%

Natural vapour pressure at different temperatures

0C (32F) 33.0 mm Hg
10C (50F) 54.8 mm Hg
20C (68F) 87.5 mm Hg
25C (77F) 105 mm Hg
30C (86F) 140 mm Hg
40C (104F) 214 mm Hg

Weights and volumes of liquid

1 lb (avdp) at 20C has volume 569
1 U.S. gal weighs 6.64 lb (3.014 kg)
1 Imp gal weighs 7.97 lb (3.615 kg)
1 ml 1 kg has volume 1 254.7 ml
1 litre weighs 0.797 kg

Dosages and concentrations of gas in air (25C and 760 mm pressure)

By volume		Weight per volume	
Parts per million	**Percent**	**g/m**	**lb/l 000 ft**
20	0.002	0.04	

50	0.005	0.11	
100	0.01	0.22	
200	0.02	0.43	
461	0.046	1.00	
500	0.05	1.10	0.07
1 000	0.10	2 17	0.135
7 373	0.74	16.00	1.00
20 000	2.0	43.40	2.71

[1]Ounces per 1000 cubic feet or milligrammes per litre

TOXICITY

Acrylonitrile is highly toxic to humans when ingested, inhaled or absorbed through the skin. It exhibits many of the effects of hydrogen cyanide and is a severe skin and eye irritant. There are indications that acrylonitrile is associated with certain types of cancer in workers exposed over long periods of time (Tierney et al, 1979) . A threshold limit value of 2 ppm was proposed in 1950 for adoption by the American Conference of Governmental Industrial Hygienists.

Acrylonitrile is very toxic to insects. It was found to be the most toxic of the more important fumigants used against several stored products insects (Bond and Monro, 1961; Lindgren et al, 1954; Harein and Soles, 1964; Rajendran, 1980). (See also Chapter 14, Table 16.) The present use of acrylonitrile as a grain fumigant is under review in some countries because of suspected toxic effects to humans. Consequently, its future use may be limited or prohibited on this account.

EFFECT ON PLANT LIFE

Seeds

Acrylonitrile alone or in mixture with carbon tetrachloride is reported as not affecting the germination of a wide range of vegetable, cereal and flower seeds (Glass and Crosier, 1949; L indgren et al, 1954) . However, C.H. Richardson (1951) found them both detrimental to the germination of m a i z e .

Plants and Trees

Acrylonitrile is highly toxic to nursery stock and growing plants. It is not recommended as a plant fumigant either alone or in mixture.

EFFECT ON PLANT PRODUCTS

Fresh Fruit

Acrylonitrile seriously damages many fresh fruits (Claypool and Vines, 1956) .

Veqetables

Pradhan et al (1960) in India found that a 1: 1 mixture by volume of acrylonitrile and carbon tetrachloride could be employed to control the potato tuber moth, Phthorimaea opercullela (Zell.), in stored potatoes without in juring the tubers.

Cereals

Acrylonitrile-carbon tetrachloride mixtures have been recommended fur the control of insects in stored grain (Cotton and Young, 1943; Ruppel et al, 1960) .

RESIDUES IN FOODSTUFFS

There is little information available on the residues remaining in material streated with acrylonitrile . The fumigant sorbed by several commodities and desorption may require many days, depending on the type of commodity and the aeration conditions. Residual fumigant was found to desorb most rapidly from groundnuts and maize and slowest from wheat (Dumas and Bond, 1977). In admixture with carbon tetrachloride was found to disappear from spelled walnuts more rapidly than carbon tetrachloride (Berck, 1960). Residues of both

fumigants were lower following vacuum fumigation for three hours than after treatment at atmospheric pressue for 18 and 48 hours .

METHODS OF ANALYSIS

A number of procedures using gas chromatography that will give rapid and precise analysis of acrylonitrile have been developed. Gawel (1979) described a headspace gas-chromatographic method for determination of concentrations down to 0.005 mg/kg, and Dumas and Bond (1977) gave a method for extraction of residual acrylonitrile from food materials.

Detector tubes described by Dumas and Monro (1966) may be used for field determinations at both fumigation and threshold limit concentrations. The presence of carbon tetrachloride in admixture has no effect on the readings for acrylonitrile.

APPLICATION

Owing to the high boiling points of the two components of the acrylonitrile-carbon tetrachloride mixture, special provision has to be made for rapid volatilization in atmospheric fumigation. Childs and Overby (1967) described the use of cotton rope wicks drawn through the bottom of a shallow steel pan. At the beginning of the treatment, liquid fumigant is poured into the pan and a fan blows air over the wicks for the time needed to complete volatilization.

Minor fumigants

In addition to the more important fumigants discussed above there are others with limited use, often for some specific application. The compounds listed in Chapter 2, fable 1 for reference purposes and which are not further discussed, are ethyl formate, methyl formate and parsdichlorobenzene.

Besides the fumigants given in Table 1, there are a few compounds that should be mentioned; these either show promise for future applications, or have a restricted use at present.

ACETALDEHYDE

Acetaldehyde is a naturally occuring volatile compound that is toxic to insects as well as certain fungi, bacteria and yeasts. Tests on fruit and vegetables have shown that it can be used to control some insects, such as aphids and thrips, without undue injury to the fresh produce (Aharoni et al, 1979, 1980). Concentrations up to 3 percent for 30 minutes have been applied to apples as a fungicidal treatment without causing injury to the fruit (Stadelbacher and Prasad, 1974).

The boiling point of acetaldebyde is 21C, it has a characteristic pungent odour and is flammable at concentrations of 4 percent or greater. Acetaldehyde is less toxic to mammals than other commercial fumigants, such as ethylene dibromide. It has a narcotic action on the nervous system and causes irritation to the eyes and mucous membranes. Large doses may

cause death by respiratory paralysis. This compound is suspected of having carinogenic activity in humans (Obe et al, 1979); however, it is not likely to be hazardous as a residue on fresh produce because it does not accumulate in tissues (Fidler, 1968).

Plant tissues may absorb acetaldehyde but it is metabolized to acetic acid, ethanol and carbon dioxide. Acetaldehyde occurs naturally in fruit and vegetables, it is used as a flavouring agent and has been registered as a food additive in the United States. This compound and other naturally occurring volatile compounds, such as ethyl formate, may have some potential as future replacements for fumigants that leave harmful residues.

AZ0BENZENE

This compound (boiling point 293C) is a crystalline solid which has proved useful in the past for the control of mites in greenhouses. It acts as a vapour formed by heating the pure crystals by means of steam pipes, hot plates or lamps; it is also evolved by igniting a powder in a pressure fumigator. Many glasshouse plants and blooms are tolerant, but there has been some discoloration of red flowers (Pritchard, 1949). Flowers of the African voilet (Saintpaulia) are reported to be susceptible to damage (Brown, 1951).

CHL0R0F0RM

Chloroform (boiling point 61C) is not highly toxic to insects but it has shown considerable promise as a constituent of liquid-type fumigants, in which it serves as a carrier for other

more toxic ingredients, such as ethylene dibromide and carbon disulphide. Chloroform is nonflammable when mixed in air in any proportion. However, it is listed as being a compound which is "suspect of inducing cancer" by the American Conference of Governmental Industrial Hygienists (ACGIH, 1981).

DICHLORONITROETHANE

This fumigant (boiling point 124C) was introduced some years ago and appeared useful for treating grain, other stored products and soil. It gives warning by odour and irritation of the eyes. It may be strongly corrosive to metals in moist atmospheres.

ETHYLENE CHLOROBROMIDE

Ethylene chlorobromide is effective against the oriental fruit fly, but it is not as toxic as the closely allied ethylene dibromide (Balock and Lindgren, 1951). It has a lower boiling point than EDB. The effect of this fumigant on fruit and plant material is similar to that of EDB. It has not come into general use, although it has been adequate in many fields of application for which EDB is also suited (Benschoter, 1960, 1963; Wolfenbarger, 1962; Sinclair et al, 1964; Richardson and Roth, 1966).

METHYL ALLYL CHLORIDE

This gas, also called methallyl chloride, has been suggested as a grain fumigant and has been

used experimentally in mixtures with other fumigants. In laboratory tests it has ranked above carbon disulphide and ethylene dichloride against eight species of stored-product insects (Lindgren et al, 1954) and it is considerably more toxic than carbon tetrachloride, although less toxic than ethylene dibromide. Methallyl chloride has a boiling point of 72C and is nonflammable in concentrations toxic to insects. In field trials in Russia it has shown promise as a fumigant for cereal grains and pulses and is significantly less expensive to apply than chloropicrin and methyl bromide (Cherkovskaya, 1963, 1966). Methallyl chloride also shows promise for fumigation of individual sacks of grain (Taylor, 1975).

METHYLENE CHLORIDE

Methylene chloride has been found useful as an ingredient of fumigant mixtures (see Chapter 7). It is nonflammable and has a boiling point of 40.2C. In itself it is toxic to insects, but ranks low in toxicity in comparison with other commonly used materials (Back and Cotton, 1935).

NICOTINE

Nicotine (boiling point 247C), vaporized in different ways, was formerly used extensively as a glasshouse fumigant. The most convenient method of volatilizing it is by the use of pressure cans; these are ignited to send off dense clouds of smoke containing the vapours of nicotine. In a glasshouse, it was found that the nicotine concentrations fell off rapidly and little or none remained one hour after discharge (Richardson et al, 1943a). When the nicotine was evaporated slowly, the concentration was maintained only as long as evaporation continued

and the introduction of fumigant was equal to the loss through leakage(Blackish, 1953). Delicate flowers and tender shoots may be injured by nicotine applied in any way.

Nicotine fumigation in glasshouses has been largely replaced by the aerosol technique described in Chaper 12. Nevertheless, it is still used under certain conditions, for example when convenience in application is important.

PROPYLENE DICHLORIDE

In empty containers, this compound (boiling point 96.4C) compares favourably with many other fumigants in toxicity to insects. It has been tried as a grain fumigant, usually in mixture with carbon tetrachloride, but so far has not been widely adopted (Cotton, 1963).

SULPHUR DIOXIDE

Sulphur dioxide (SO_2) should be mentioned if only to point out its disadvantages. It is the oldest fumigant known to man (Cotton, 1963), having been used from time immemorial by burning sulphur.

Nowadays it is sometimes used as an ingredient of liquid grain fumigants. Intrinsically it is quite toxic to insects. It also serves as a warning gas in these mixtures on account of its intensely irritating properties to humans. It is rapidly sorbed by any material undergoing treatment; it has a deleterious effect on grain and flour and is highly corrosive to metals

(Cotton, 1963).

METHYL CHLOROFORM (1,1,1 - TRICHLOROETHAME)

This compound has been tested as a possible substitute for carbon tetrechloride; it is slightly more toxic to insects than the latter but less toxic than ethylene dichloride. Its boiling point (74C) and volatility are very similar to those of carbon tetrachloride. The vapour density of methyl chloroform is sufficiently greater than air that effective penetration into grain masses can be expected. When used as a 1 : 1 mixture with ethylene dichloride, an enhanced toxic effect was noted and the two compounds were found to interact physically to affect the distribution of each other in a grain bulk (UK, 1978).

Tests have indicated that residues of methyl chloroform should not be a toxic hazard in fumigated grain; no adverse effects were noted on bread made from fumigated wheat and virtually no residue could be detected in the loaves (UK, 1978).

Methyl chloroform is less toxic to humans than several other halogenated hydrocarbons of comparable function, including carbon tetrachloride. Animal and human toxicological data indicate that this compound should have little potential for producing permanent organic injury in humans, provided anaesthetic concentrations, sufficient to depress the respiratory centre, are not exceeded (Steward et al, 1969). The threshold limit value is 350 ppm (ACGIH, 1981). For the detection of low concentrations of methyl chloroform, the halide leak detector and glass detector tubes may be used.

CARBON DIOXIDE

Carbon dioxide (CO_2) is an ingredient of our normal atmosphere and is not to be considered as a poisonous fumigant in the ordinary sense. Nevertheless, it has an important role in insect control (see Chapter 11).

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7. Fumigant mixtures

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Fumigants are sometimes marketed in mixtures with other compounds.

There are a number of practical reasons for combining fumigants, the more important being:

1. The flammability risk of the toxic ingredient is reduced or prevented altogether by the addition of another chemical. Examples are the addition of carbon dioxide to ethylene oxide or methyl formate and of carbon tetrachloride to acrylonitrile or

carbon disulphide.

2. With liquid-type fumigants in grain fumigation, mixtures may be made to provide ingredients whose vapours have differing rates and patterns of diffusion. After the liquid has been applied to the surface the ingredients evaporate. The distance the ingredients diffuse downward depends largely on the extent to which they are sorbed by the grain. It may, therefore, be necessary to have various types of ingredients in the mixture to kill insects at various depths and locations in the grain (Kenaga, 1957a). An example is a mixture of ethylene dibromide, ethylene dichloride, carbon disulphide and carbon tetrachloride, which is used for grain fumigation in farm storage units and country elevators.

Similarly with gaseous fumigants, mixtures may be used to obtain complementary advantages. Phosphine is used in combination with methyl bromide in treatments of materials such as oil-seed expeller; the phosphine penetrates deeply into the material while the methyl bromide gives more control on the outer surfaces (Wohigemuth et al, 1976).

3. A highly volatile fumigant such as methyl bromide may diffuse downwards too rapidly, so that the upper part of a load of infested goods may not receive an adequate insecticidal treatment. Another less volatile fumigant, such as ethylene dibromide, is added to ensure that the material at the top is properly fumigated. A mixture of this type may be useful under tropical conditions when commodity

temperatures may range as high as 38C (Majumder and Muthu, 1964).

4. The principal toxic ingredient may be diluted so that its distribution becomes more uniform. Carbon tetrachloride, though only moderately insecticidal in itself, aids in the distribution of other fumigants, such as ethylene dibromide, which does not diffuse well through masses of grain (Berck, 1958).

Although fumigant mixtures are very useful for many types of application, especially for the treatment of grain in bulk and for local or spot fumigations, it should be pointed out that their use involves certain complications. As indicated above, the ingredients may settle out in different parts of the fumigation system. This may result in a situation whereby the more toxic material is acting against one part of the insect population while the less toxic ingredients are acting against the remainder. Erratic results may thus be recorded unless full provision is made to allow time for the less toxic materials to exert their maximum effect.

Another objection, which is possibly more serious, is the fact that commonly used methods of field analysis of vapours, such as the thermal conductivity analyses, will not differentiate between the components of the mixture so that is is not practicable to attempt to keep a check on the effective distribution of the toxic ingredients. Any reading taken with this type of instrument is meaningless under these conditions. A gas chromatograph or an infra-red analyser would provide the necessary information in the field, or samples could be brought to the laboratory for immediate analysis. Kenaga (1957a) has suggested the use of the mass spectrometer for the analysis of mixtures but this expensive instrument would have to be

used in the laboratory.

Some fumigants that have been Found effective in mixtures are discussed below. They are given in the alphabetical order of the more insecticidally active ingredient of the mixture. The proportions of fumigants in a liquid state at normal temperatures are usually expressed in terms of volume. Mixtures containing volatile ingredients, such as methyl bromide, are expressed by weight of the components.

Acrylonitrile

Because of its flammability, acrylonitrile is never applied alone but always in admixture with nonflammable materials. Mixed with carbon tetrachloride it has been used as a local fumigant and for the fumigation of tobacco. Mixed with chloroform or methylene chloride it has been employed with some success for fumigating buildings against dry wood termites (Young, personal communication, 1967). Although in comparison with methyl bromide these mixtures do not have a deleterious effect on houshold materials, such as sponge rubber, they do not aerate after fumigation as rapidly as methyl bromide or sulphuryl fluoride.

Ruppel et al (1960) concluded that mixtures of acrylonitrile with carbon tetrachloride were not fully satisfactory against pests of stored maize in Colombia as compared with the EDC : CT 3 to 1 mixture commonly used in that country.

Carbon disulphide

In mixture with carbon tetrachloride, carbon disulphide (CS_2) is very useful for grain fumigation, especially in tall, upright silo storage units and in all storage units equipped with adequate recirculation systems. Enough carbon tetracilloride should he incorporated in the mixture to eliminate the fire hazard. A mixture commonly marketed for these purposes contains, by volume, 16.5 percent CS_2 82.5 percent carbon tetrachloride and 1.0 percent inert ingredients.

Another mixture useful for gravity distribution in concrete or metal grain bins contains 24 percent CS_2, 71 percent chloroform and 5 percent ethylene dibromide by volume.

Chloropicrin

The highly insecticidal and lachrymatory properties of chloropicrin have been put to use by mixing this chemical with other materials for the fumigation of grain in farm or bulk storage units. It has been marketed in a mixture with methyl bromide or carbon tetrachloride (Cotton, 1963). A mixture of chloropicrin and methyl chloride 85 : 15 is recommended for forced distribution fumigation of grains (USDA, 1967).

Ethylene dibromide

Ethylene dibromide (EDB) is an ingredient of many important fumigant mixtures. As indicated in Chapter 6 it is highly insecticidal, and under normal conditions the residues remaining in foodstuffs are of a low order. These advantages are offset by the fact that EDB is considered to be very hazardous to mammals and is highly sorbed by materials undergoing fumigation. As a result, there may be poor penetration during actual treatment and prolonged persistence of the vapours in the fumigated commodity during the aeration process. Attempts to utilize the advantages and overcome the disadvantages have resulted in the formulation of a wide variety of mixtures. It is not possible to describe these in detail here. For the present purpose the subject may he discussed unifier two headings: liquid formulations and mixtures with methyl bromide.

LIQUID FORMULATIONS

Alone or with other toxic fumigants EDB is commonly mixed with carbon tetrachloride (CT) as a grain or local spot fumigant. The inclusion of CT as a high proportion of the formulation appears to add greatly to the effectiveness of EDB, principally because CT acts as an eluant for EDB in a column of grain and assists effectively in its downward migration (Berck, 1958). The following are some liquid formulations containing EDB in admixture with other materials (percent by volume) that have been widely used:

Grain Fumigants

EDB 5:	CT 95 - General grain fumigant

EDB 7:	Ethylene dichloride (EDC) 29: CT 64 - Gravity distribution grain fumigant
EDB 7:	Carbon disulphide (CS_2) 12: CT 81 Gravity distribution in flat storages
EDB 3.5:	EDC 10: CS_2 10: CT 76.5 - Gravity distribution in flat storages
EDB 5:	CS 24: Chloroform 71 - Gravity distribution grain fumigant

Local (spot) fumigants

EDB 20:	EDC 20: C! 60
EDB 59:	EDC 9: CI 32
FDB 15:	CT 85

ETHYLENE DIBROMIDE-METHYL BROMIDE MIXTURES

Mixtures of EDB with methyl bromide have been found useful for three main purposes:

- in the tropics to treat bagged plant products under gas-proof sheets;

- as local fumigants for treating food handling equipment in mills and food processing plants generally;

- as a fumigant for grain stored in bulk.

Bagged goods. In India, mixtures of the two fumigants in various proportions have been recommended for application under sheets or in chambers to treat different types of commodities in bags under warehouse conditions (Majumder, 1962). Treatment with the fumigant mixtures accompanied by simultaneous prophylactic applications of liquid insecticides to prevent reinfestation is known as the "Durofume" process (Majumder and Muthu, 1964). These authors give detailed recommendations for the proportions of the two chemicals required to achieve the best results with different materials.

A special applicator for administering fumigant mixtures of EDB and methyl bromide, which is particularly suitable for treating stacked commodities under gas-proof sheets, has been described by Majumder et al (1962). This consists of a brass or stainless steel tube held horizontally, containing the EDB. Above this there is a vertical scaffold into which a can of methyl bromide may be inserted. The methyl bromide can is pierced at the bottom by a probe, which connects to one end of the tube containing the EDB. The methyl bromide with its natural vapour pressure forces the EDB out through a discharge nozzle at the other end of the horizontal tube so that the mixture may be led through a distribution system above the stacked commodity.

Local fumigants. A mixture of seven parts of EDB and three parts of methyl bromide (weight to weight) has found wide use as a local or spot fumigant. This is best introduced by special applicators into holes bored at strategic points in the food handling equipment. This subject is dealt with in more detail in Chapter 8.

Bulk grain fumigation. The mixture has been found effective for bulk grain. The proportions of the two fumigants may vary according to the material being treated and the method of application. For cereal grain treatments the ratio of 70 : 30 EDB to methyl bromide is recommended for gravity distribution in smaller bins or farm storages. For forced distribution systems, 30 : 70 EDB to methyl bromide is used. Majumder et al, (1963) found that the presence of methyl bromide improved the penetration and distribution of EDB in columns of grain and milled materials, the most effective proportions varying according to the material under treatment.

Dawson (1967) has taken out a United States patent for a yelled fumigant composition made by agitating different amounts of methyl bromide and ethylene dibromide in mixture with 3 to 5 percent by weight of colloidal silica. The gel thus produced retards the evaporation of the constituent fumigants and thus affords a convenient method for applying them to grain.

Insect toxicity. From the limited amount of laboratory evidence available to date, it appears that mixtures of these two fumigants are intrinsically more toxic to stored product insects than methyl bromide alone and at least equally as toxic as ethylene dibromide alone (Kazmaier and Fuller, 1959). These authors also concluded that the mixtures killed the

postembryonic stages of Tribolium confusum more rapidly than either fumigant alone.

Penetration of flour. Heuser (1964) studied the pattern of diffusion through flour at 25C of the two components of a 1 : 1 by weight mixture mixture of EDB and methyl bromide. He found that the methyl bromide components in insecticidal concentrations could penetrate to 18 in (45 cm) after 48 hours, but EDB only penetrated effectively to 2 in (5 cm) after the same time. He concluded that if EDB is used "in hightemperature zones to produce a longer lasting insecticidal effect in the surface layers than is obtained with M. B. (methyl bromide) for example where the gasproofing of fumigation sheeting is suspect, then its addition should be regarded as a supplement only, and not as in any Way replacing a proportion of the methyl bromide dose".

Ethylene dichloride

Compared with most modern fumigants, ethylene dichloride (EDC) is intrinsically not very toxic to insects but its mixture with CT, usually in the proportion by volume of 3 : 1 EDC to CT, has been used throughout the world as a successful fumigant for stored grain in a variety of structures. It has proved effective under tropical conditions in Africa (Hall, 1963). Its use for this purpose is contingent on a long exposure period, usually not less than 14 days, before the grain is turned or the fumigant aerated (Thompson, 1964). Such long exposure periods do not appear to have adverse effects on the grain. It may be applied either by gravity distribution or forced distribution systems.

This mixture has also been widely used as a seed fumigant. Properly used it does not have an adverse effect on the germination of seeds (Kamel and Shahba, 1958; Cotton, 1963; Parkin 1963).

Methyl bromide-phosphine

A method for the combined use of methyl bromide and phosphine has been tested for treatments in oil-seed expeller, a dense material in which methyl bromide does not easily penetrate (Wohigemuth et al, 1976). The phosphine is found to diffuse into the expeller to give control while methyl bromide is effective on the outer surfaces. Furthermore, mixtures of methyl bromide and phosphine have been shown to have a joint action that improves the insecticidal effectiveness of both compounds (Bond, 1978; Bond and Morse, 1982; El Lakwah, 1978).

In this treatment, the phosphine-producing formulation is distributed evenly over the surface of the goods and, after sealing, the methyl bromide is applied through a tube by a double jet to vaporize in the Free space above the goods. Dosage of 56 g/m methyl bromide and 4.4 g/m phosphine at 29.5C for 72 hours gave satisfactory control of Khapra beetle larvae.

Methyl chloroform

Methyl chloroform (1,1,1 - trichloroethane) has been tested under field conditions in mixtures

with ethylene dichloride and the trials have shown that the two compounds interact physically to improve distribution of each component through grain bulks (UK, 1978). When applied with methyl chloroform, EDC is carried to a greater depth than when used alone, and the two compounds seem to act jointly to give a much enhanced toxic effect on insects. The physical properties of methyl chloroform relating to distribution and persistence compare favourably with carbon tetrachloride as does its toxicity to insects and mites. The available toxicological evidence suggests that it is a much safer compound than carbon tetrachloride for a pest control operator to use and tests on residues suggest that it should not be a toxic hazard in grain. The potential of methyl chloroform as a substitute for carbon tetrachloride in fumigant mixtures may be indicated by further testing in the future.

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8. Space fumigation at atmospheric pressure

The term "space fumigation" is convenient for the designation of a wide range of treatments in enclosed spaces, which either contain infested materials or residual insect populations. The calculation of the dosage of fumigant to be applied is based primarily on the volume of the space. Other factors, such as the amount of a given commodity in the space, are sometimes introduced into the calculation for dosage. If facilities are available for the determination of fumigant concentrations at frequent intervals during exposure, it is advantageous to calculate the dosage on the basis of minimum concentration to be maintained in every part of the free air space during the required exposure time.

Fumigation may be successfully carried out in any structure that can be made sufficiently gas-tight for the length of time required. Infestations may often be dealt with on the spot without the necessity of moving the affected material.

Sealing Methods and Materials

Since sealing techniques are common to all types of fumigation, these are outlined first. In practice, the choice of materials is largely influencer) by their availability.

NARROW CRACKS AND SMALL HOLES

Masking tape, heavy kraft paper applied with flour paste, caulking compound, paint-on adhesives, froth packs of Styrofoam, etc. may be used to cover or seal small cracks and holes. A vinyl plastic sealing compound is available that can be sprayed over all holes, cracks and crevices. This method, sometimes called "cocooning", is effective but requires a compressor for air, a spray gun and a hose. Instructions for carrying out the process are provided by manufacturers of the plastic; a full description is also given by Roop (1944). Webley and Harris (1979) describe the sealing and fumigation, using phosphine, of mud-brick stores in Mali.

LARGER CRACKS, CREVICES AND OPENINGS

Heavy kraft paper applied with flour paste and impregnateti with a heavy grease or sheet of polyethylene sealed with masking tape may be used for larger openings. The vinyl sealing

compound described above in the cocooning method can be applied to bridge larger openings and it will provide a relatively gas-impermeable, durable seal.

VENTILATORS OR OUTSIDE OPENINGS

Heavy kraft paper can sometimes be used but polyethylene sheeting is relatively inexpensive and can be re-used several times. It can be tied with ropes to make a tight seal around a ventilator.

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Fumigation Chambers

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To conduct fumigations of commodities on a nonemergency basis, it is advisable to install a specially designed fumigation chamber. For many commodities the infestation may be controlled by fumigation at atmospheric pressure. Vacuum fumigation is recommended for the treatment of certain densely packed or absorbent materials. It is also used when a rapid

turnover of certain goods is required. This technique is discussed in Chapter 9.

The purpose of a fumigation chamber is to allow fumigations to be carried out efficiently, safely and economically. The basic elements for design and construction should be incorporated in all chambers with variations made to suit individual needs. An effective fumigation chamber must be:

- **soundly constructed so as to be gas tight;**
- **provided with an efficient system for applying and distributing the fumigant;**
- **provided with an efficient system for removing fumigant at the end of treatment;**
- **sited so as to handle infested goods conveniently;**
- **sited and operated so as to present no hazard to personnel working with or near the chamber (UK, 1973).**

There is room for very wide variation in the design of atmospheric fumigation chambers. The fumigant to be used, the siting and size of the chamber, the type of goods and methods of handling, the availability of building materials, as well as the expenditure that can be allowed for increased efficiency and ease of operation, must all be taken into consideration. If chambers are used constantly or are loaded with heavy materials, a sturdy construction is necessary (Figure 22). However, light, portable chambers made from plywood or similar material may be appropriate for some types of treatment. A simple portable plywood chamber that was designed for travel from one forestry nursery to another is illustrated in Figure 23.

A portable gas-tight tent (shown in Figure 26) was devised by Brown and Heseltine (1964) and a full description of its construction and operation was given by these authors. It proved to be very useful for the fumigation of small commodity lots and for nursery stock.

STATIONARY CHAMBERS

Location

While the safest arrangement is to have the fumigation chamber located outside the main buildings, there may be circumstances in which it is safe to have it inside. If the chamber is properly constructed and equipped, it may be placed in a well-ventilated part of a building not regularly used by employees. When a chamber is located where people are constantly working it may be separated from the working space by an additional wall with a ventilated space between.

The cost of loading and unloading the chamber largely determines the cost of fumigation. Therefore, by choosing 8 site which will permit the handling of goods in an efficient and economical manner, these costs can be reduced to a minimum. Some suggestions for locating a chamber in a warehouse are given in Figure 24.

After the removal of treated materials from a chamber, fumigants continue to diffuse. Therefore, the commodity must be kept on an open platform or in a well-ventilated room for 24 hours after treatment.

One important way to protect employees from exposure to fumigants is by means of a well designed exhaust system. This system should be equipped with one or more fans or blowers powerful enough to draw a continuous draught of air through the door into the outside atmosphere. A movement of air equivalent to one complete air change every one to three minutes in the empty chamber is recommended. If the chamber is located near dwelling houses, the exhaust pipe should terminate well above the roof of the building so that fumes may not enter occupied rooms during the aeration process. In some countries the spent fumigant is absorbed by passing the exhaust gases through absorbing solutions and degrading to harmless end products (Mori, 1980). For chambers up to 56 m in capacity (2 000 ft), an exhaust stack reaching 4 m (13 ft) above the roof or any any nearby structure should be adequate. When fumigants are thoroughly mixed with air, they dissipate rapidly on discharge into the open air from the fumigation chamber.

If the chamber is to be permanently fixed inside a building, it may incorporate a part of the floor, two existing walls and even the ceiling. A generalized plan indicating some of the essential features of an atmospheric fumigation chamber is shown in Figure 25. Suggestions for constructing a chamber from various materials, together with details of accessory equipment, are given below.

Size

The chamber size should be such that it can normally be loaded to its full capacity. There is, however, no difficulty in fumigating a partly filled chamber. While the dimensions of a

fumigation chamber can only be decided by the owners, as a general guide a chamber should be approximately twice as long as it is wide with a height of 2-3 m. Even distribution of fumigant is more easily obtained in such a chamber than in a square one or one more than 3 m high.

FIGURE 24. - Possible positions for fumigation chamber in relation to storage facilities (UK, 1973)

FIGURE 25 - Generalized plan of an atmospheric fumigation chamber.(J.E. King)

The maximum economic size is probably of the order of 100 m3. If a greater capacity is required, two or more smaller chambers often prove more economical and easy to handle. One chamber can be unloaded and reloaded while the second chamber is in use. The dimensions of the chamber are as important as the overall capacity, particularly where mechanical handling machinery is used. for instance, the size of pallets, if used, will dictate the proportions of the length and width. The height will depend on whether goods are loaded manually or with a fork lift truck (UK, 1973).

Construction Materials

The most satisfactory type of chamber, and one which is likely to give the minimum of trouble from leakage, is one with a concrete floor, walls of brick or poured dense concrete or other similar solid building materials and a flat roof of reinforced concrete. Chambers made of

timber framing covered with sheets of material are likely to produce initial difficulties in sealing and continuing difficulties due to deterioration or damage. When made of light materials, chambers are prone to leakage and may need an impermeable flexible film lining on the inner surface or regular renewal of the painted finish.

Paints should be applied, preferably by spraying, to give a continuous, impervious surface. A relatively durable finish can be obtained with an alkali-resisting primer followed by two coats of black oil paint and two coats of white. The use of the two colours facilitates inspection of damage after the chamber has been used (UK, 1973).

Construction

Walls. The outside walls of the chamber may be constructed wholly or in part of concrete, concrete blocks, sheet iron, plywood or tongue and groove boards. All these materials may also form part of the inner lining, but careful sealing of all joints and seams is essential.

Rough concrete and brick sorb fumigants and, if used, must be covered with hard finishing cement, with two or three layers of asphalt paint applied over its surface.

Plywood sheets, held by a framework of 5 x 10 cm (2 x 4 in) timbers, may be used for the interior walls of chambers.

All seams between sheets and at junctions of the floor with walls and ceiling must be

carefully sealed with materials such asphalt cement or similar caulking compounds. With plywood it is advisable to seal all the inside surfaces with a primer, which is then covered with a suitable resin-base varnish. This protects the wood from moisture and reduces loss of fumigant through sorption by the wood.

If a plywood-lined chamber is to be subjected to rough usage with heavy bays or cartons, it is suggested that a sheet-metal lining be added. All joints and nail holes in the sheet metal should be carefully soldered.

When tongue and groove boards are used, they must be in two layers, placed diagonally, with a layer of roofing paper between. Insulation may be pieced between the layers if required. All joints must be sealed with great care, using a suitable cement. The inside surface should then be covered with a plastic film lining or with a primer and varnished as recommended above for plywood.

If a chamber detached from a building is to be used in the winter, it is recommended that the outer walls be of cement or brick. The inner wall may be made of plywood, which is separated from the outer wall by insulating material and a vapour barrier. Careful attention must be paid to the proper sealing of the plywood to prevent an accumulation of fumigant in the interspace.

Sheet or corrugated iron has been used successfully in warmer climates for the walls of chambers. When metal is used, great care must be taken to ensure proper sealing. All seams

and joints are liberally filled with mastic end the edges of the overlapping sheets covered with mastic tape. In chambers of this type, the ends, top end bottom of the corrugated iron well rest firmly in neoprene gaskets. It is necessary to have more support members than in a standard sheet iron building, in order to reduce expansion end contraction (Barnes and Reilly, 1956).

Ceiling. Lighter gauges of the materials recommended for the walls may be used for the ceiling. With plywood, a thickness of 1 cm (0.4 in) is usually sufficient. A detached permanent chamber must have a roof above the ceiling to provide all-year-round protection from the weather.

Floor. When the chamber is in constant use, and especially for treating bagged goods, a concrete floor is best. This should be reinforced to bear the greatest expected load. The concrete must be hard-finished to provide a gasproof, nonabsorptive surface. Tongue and groove lumber or plywood, satisfactorily sealed as described above, may be used if built to withstand the loads. Plywood flooring of 1.2 cm (0.5 in) is often suitable for plants and nursery stock if it is well finished in the way described above.

Doors. The chamber can be provided with one or two doors, depending on its size and function. For larger chambers the use of two doors allows the loading of untreated material in one end of the chamber with unloading after treatment from the opposite end (Figure 24a and b). If a chamber is located inside a building, it may be built through a dividing wall with loading and unloading doors on opposite sides of the wall. The segregation of untreated and

treated stock in this manner reduces the possibility of crossinfestation.

The door should be as light as possible, it must give a gas-tight fit and it should be of good quality to withstand constant use. A stiff steel or timber frame clad with sheet metal on the inner surface may be satisfactory. The size of the door will be governed by the requirements for loading and unloading, but the smaller the door the easier it is to ensure a gas-tight fit.

Lift doors, which are raised above the chamber during loading and unloading, are very practical when a chamber is inside a building, because they are out of the way when open and do not interfere with the movement of the goods. Lift doors are operated by means of a counterweight and, if this works properly, opening and closing are easy.

Doors sliding on rails are better for installation on the outside of a building, where they can be rolled out of the way along an outside wall. An ordinary hinged door may be installed in a chamber if the materials to be treated can be moved in and out easily. Generally, the doors may be made of the same wood or metal materials, suitably finished, as recommended for the walls.

Door gasked. Proper closure is important because fumigants, such as methyl bromide, escape readily through improperly sealed doors. The best seal is provided by a continuous strip of rubber or neoprene that is soft enough to give a good seal but resilient enough to recover well after continued pressure. Natural rubber may deteriorate after some time if used with methyl bromide, but is readily renewed. Overhead doors or hinged doors should fit neatly

into flanges. The best seal is obtained with three strips of rubber, two on one surface, with a gap between that is just wide enough to receive the third gasket, which is on the opposite face. Sliding doors will carry only one strip of gasket on one surface, and this should therefore be 2.5 to 5 cm (1 to 2 in) wide. With all types of doors, particular care must be taken to make a gas-tight join between gasket strips, especially at the corners; this is best effected by liberal use of the adhesive material.

<u>Door clamps</u>. Door clamps are relied on to give a tight seal, and experience has shown that they should be placed not more than 30 cm (1 ft) apart all the way round the edge of the door.

For overhead and hinged-type doors, refrigerator door fasteners are recommended. Small, hinged doors not greater than 1.8 m (20 ft2) in area may be closed with ordinary sash fasteners 20 cm (8 in) apart. Sliding doors are forced against door frame gaskets by screw fasteners (Barnes and Reilly, 1956).

If the floor of the chamber is above the outside floor or ground level, the clamps may be extended all along the bottom. A sloping ramp is then required to load and unload the chamber. This may be drawn back when the door is closed. If the chamber floor is at outside level, it is not possible to clamp the bottom of the door unless special provision is made. A suggested arrangement is a shallow trench in the cement floor, which should be wide enough to allow sideways movements of the door and fasteners.

Circulation and venting. Proper circulation and postfumigation venting of the fumigant/air mixture are essential in atmospheric chambers. Efficient circulation ensures that the fumigant is rapidly and evenly dispersed throughout the chamber so that no part of the load is overdosed or underdosed, while forced ventilation removes the fumigant so that the chamber can be safely unloaded after the treatment. Circulation and forced ventilation are essential in large fumigation chambers and advisable even for small ones. A variety of fan systems can be used to achieve adequate circulation or ventilation and their size and capacity are governed by the volume of the chamber and the flow rate required. More details on types of fan systems are given by the U.K. Ministry of Agriculture, Fisheries and Food (UK,1973).

It is suggested that with most treatments of commodities the rate of air flow should give approximately one complete change of air every one to three minutes, based on the volume of the empty chamber. In selecting fans or blowers, due consideration must be given to friction in the exhaust pipe and other ducts in the system. Suppliers of equipment will provide the necessary specifications of the equipment required for a particular installation.

When nonflammable fumigants such as methyl bromide or ethylene dibromide are used, no protection from sparking is needed. With HCN, and other fumigants with wide flammability limits, the motors of fans should be totally enclosed or, preferably, placed outside the chamber, with the blade shaft inserted in a gas-tight connexion in the wall.

The system should be designed so that the same fan will be used for circulation and venting. One method is to place the exhaust door, or port, near the fan so that when it is opened the

fumigant/air mixture will be blown out into the open air. Another way is to use a blower with a large inlet and outlet. A diameter of 18 cm (7 in) is suitable. The outlet is fitted to a pipe of the same size. By means of a suitable blast gate or valve operated from outside, the air can be recirculated throughout the chamber by means of ducts or blown out through the exhaust stack into the open air.

If the ducts are used to draw the fumigant/air mixture from the bottom to the top of the chamber, distribution will be greatly improved from the beginning of the treatment. Ducts are best made from galvanized iron; the diameter required to give the suggested air flow of one complete change of air every one to three minutes will depend on the size of the chamber. A suggested arrangment is shown in Figure 25.

<u>Exhaust door or port</u>. The exhaust port may be a small door in the wall of the chamber; it should be at the opposite end of the chamber from the door so that after treatment, during venting and unloading, fresh air is drawn through the chamber from the open door. This exhaust port may slide open or move on hinges as a trapdoor. Experience has shown that the trapdoor may become a serious source of leakage. Great care must be taken to ensure that this door fits tightly in suitable gaskets and is firmly latched so that gas leakage is kept to a minimum. It is advisable to have the port in an accessible place so that it can be constantly checked.

<u>Heating and liqhting systems</u>. A heating system is required if the chamber is used in cold weather. Sorption of fumigant on foodstuffs increases as the temperature decreases and,

therefore, at lower temperatures larger amounts of fumigant are required and postfumigation ventilation is slower. As a general rule the temperature of the chamber and its load should be 15C or above. If steam or hot water is available, it may be conducted through pipes set on opposite walls. A standard heating unit with blower may be used, which will also serve for fumigant circulation. However, such a blower should not be used for postfumigation venting unless the heat is turned off. Only nonflammable fumigants should be used in contact with steam pipes.

Electric or radiant heaters may be used if they provide adequate heat at short notice and if the elements are totally enclosed so that glowing wires may not come in contact with the fumigant. It is important to protect the heating units from mechanical damage and to protect the goods being fumigated from scorching or damage by the heater.

Lighting inside the chamber is often necessary since windows are usually omitted from fumigation chambers. The lights should be arranged so that the loading does not obscure them and they must be adequately protected against damage.

<u>Application equipment</u>. Gaseous-type fumigants are introduced from outside the chamber through tubing. Copper tubing is preferred for permanent installations, although a type of plastic tubing, which is not affected by the fumigant, may be used. The size and type of tubing will vary according to the fumigant used. Methods of application of important fumigants have already been given under separate headings in Chapter 6.

It is recommended that gaseous-type fumigants, such as HCN and methyl bromide propelled into the chamber under pressure, be discharged into a shallow galvanized iron evaporating pan, above 10 cm (4 in) wide and 5 cm (2 in) deep and two thirds the length of the chamber, which is suspended from the ceiling well above the load. This will speed evaporation and distribution, especially if the circulation fan blows downward above the surface of the liquid.

Liquid-type fumigants, such as ethylene dibromide, may be poured from a measuring cylinder into a small evaporating pan near the door. When nonflammable fumigants are used, they may be evaporated after the door is closed by warming the pan with a small, totally enclosed heater or heat lamp.

Accessories. There are several items of equipment that contribute to safety or help to achieve good results in the use of a fumigation chamber. All chambers that are not under constant surveillance during actual fumigation should be padlocked from outside. Also, a warning notice should be hung, or tacked, on the door while treatment is in progress. A small window or marine port (obtained from a marine hardware store) permits a view of the inside of the chamber so that thermometers or other instruments can be read from the outside.

One or more thermometers are essential for obtaining accurate readings of temperature in the free air space and in different parts of the load. The thermometers may be entirely inside the chamber or they may have gauges or dials on the outside with cables leading to the sensitive bulbs placed, as required, inside the chamber.

Sampling tubes for fumigant analysis, the number to be determined by the requirement to obtain samples of the gas from all representative parts of the space under fumigation, are useful accessories, which can aid in achieving efficient treatments. If they are installed at the time the chamber is built, they are available for use any time. The most practical arrangement is to have several copper connexions of about ().5 cm (0.25 in) outside diameter set at intervals at convenient points along one or more walls of the chamber. These are carefully sealed at both ends with removable caps or plugs. For sampling, the caps are removed and plastic or copper tubes leading to the gas analysis equipment are fitted to the outer ends of the desired sampling tubes.

When a chamber is inside a building, it is advisable to have a red electric light bulb over the door. This is turned on during the treatment to indicate that gas is inside the chamber. With fixed chambers, it is desirable to have an offset control panel on which as many as possible of the recording instruments, electric switches, valve handles and other controls are situated. Such a unit simplifies operations and improves the appearance of the installation.

Pressure Leakage Test

Atmospheric chambers must retain the fumigant during the exposure period without appreciable loss through leakage to the surrounding atmosphere. The gas tightness of a chamber can be checked by a simple test where a positive air pressure is created and maintained in the chamber for a set length of time. An opening should be provided in the chamber to use a blower or other means to introduce air for creating the positive pressure.

This pressure can be measured with an open-arm manometer filled with kerosene, which records the difference in kerosene levels in the two arms of the manometer. The time lapse for the chamber pressure to recede from 50 to 5 mm should be 22 seconds or longer. Inability to develop or maintain adequate pressure indicates considerable leakage and the chamber should be checked for leaks at seams, gaskets and other points. Repairs should be continued until the time for the pressure to recede is more than 22 seconds (for testing yes tightness of large structures see Chapter 11).

A smoke bomb or other device may be used in an effort to determine the areas of leakage (USDA, 1976).

Operation

Loading. The manner of loading the chamber will depend on the type of commodity and the method of handling it . A space of at least 30 cm (12 in) should be allowed between the top of the load and the ceiling. Goods can be stacked close to the side walls, provided they are not too near the heating units, but they should be kept clear of the end walls and at least 50 cm from the circulating fan. Bagged or packaged goods should not be placed directly on the floor. If these goods are not placed on platforms or pallets, a wooden floor rack with ample space between the slats should be provided. When methyl bromide is used, no extra space need be left between individual packages and bags because this fumigant penetrates well.

Temperature. The next step is to take the temperature of the material to be fumigated. Probe

type "meat" thermometers have a pointed end and are suitable for placing in many materials. They are slow to respond, however, and sufficient time must be allowed for a correct reading. It is advisable to take temperatures in at least four well-separated points in the load. The temperature in the free air of the chamber should also be accurately determined.

For the purpose of selecting the appropriate dosage of fumigant, it is best to take the lowest temperature recorded, either in the commodity or the free space. As a general rule the temperature of the chamber and its load should be 15C or above. Under certain circumstances, the fumigator should take into consideration the temperature at which the material was kept for several days before the treatment, because this factor might influence the response of the insects during the fumigation. This point was discussed fully in Chapter 2.

<u>Computinq the dosage</u>. The dosages for various fumigants and commodities are given in the Schedules. In some instances the concentration x time (c x t) products have been worked out and are given also; their use is dependent upon an accurate determination of concentrations present in the chamber throughout the treatment. Table 14 gives the ml per 100 ft (2.83 m3), equivalent to certain dosages in terms of mg/l for a number of fumigants. For practical purposes, one mg/l is equivalent to one oz/ 1 000 ft 3.

<u>Closure</u>. When it is time to start the fumigation, the door is firmly clamped. (With liquids, discs or tablets this may be done after the fumigant is dispensed.) With most of the fumigants commonly used in chambers, the amounts introduced as dosage do not usually exert a significant positive pressure, especially when a full load sorbs some of the gas, or when there

is a small amount of leakage. Therefore, all exhaust vents or ports must be tightly closed before the fumigant is introduced. If it is found in practice that considerable positive pressure is produced by the gas, one of the exhaust vents may be left slightly open while the fumigant is being introduced. If the fumigants that are used occupy a comparatively large part of the air space, 8 vent must be left open during application. Examples of such fumigants are the mixtures of ethylene oxide with carbon dioxide, and of ethylene dichloride with carbon tetrachloride.

Chambers used in the open may be equipped with small air pressure relief valves or exhaust tubes, which can be closed or capped as soon as application is finished.

APPLICATION OF FUMIGANT

The general manner in which each of the more important fumigants may be applied has already been described in Chapter 6.

Gaseous-tvpe Fumigants

Fumigants, such as HCN and methyl bromide, are discharged from cylinders or other containers placed outside the chamber. When HCN is dispensed into an atmospheric chamber, it is necessary to apply additional pressure to the cylinder. This may be done with a tyre pump, in accordance with detailed instructions supplied by the manufacturer. When cylinders are used, they are placed on a platform scale and accurately weighed. The required

dosage is then deducted from the total weight and the scale set at the lower point. The discharge valve on the cylinder is opened and closed quickly when the weight bar is again in balance.

Liquid-type Fumigants

Fumigants which are liquids at room temperatures are poured into a shallow tray or trough inside the chamber or are poured onto burlap sacks or similar material from which they quickly evaporate. After the chamber door is closed, the circulating fans are started and the draught across the liquid or the sacked material hastens evaporation. As stated before, some fumigants with high boiling points, such as EDB, should be gently heated with a hot plate to hasten volatilization.

TABLE 14 - DOSAGE TABLE FOR FUMIGANTS USED IN SMALLER CHAMBERS

Quantities of liquid in millilitres per 100 cubic feet at 20C equivalent to dosages in pounds per 1 000 cubic feet (to be used for measuring smaller quantities of liquids before evaporation in small chambers).

	lb/l 000 ft							
	0.0625	0.25	0.5	0.75	1	2	3	4
	Millilitres of liquid/100 ft							

Acrylonitrile 34% + carbon tetrachloride 66%	2.1	8.5	17.0	25.6	34.1	68.2	102.3	136.4
Carbon disulphide	2.2	9.0	17.9	26.9	35.9	71.7	107.6	143.5
Carbon tetrachloride	1.8	7.1	14.2	21.3	28.4	56.8	85.2	113.6
Chloropicrin	1.7	6.9	13.7	20.6	27.4	54.9	82.3	109.7
Ethylene cholorobromide	1.7	6.7	13.4	20.1	26.8	53.6	80.5	107.3
Ethylene dibromide	1.3	5.2	10.4	15.6	20.8	43.7	62.6	87.4
Ethylene dichloride 75% + carbon tetrachloride 25%	2.1	8.4	16.9	25.3	33.8	67.5	101.3	135.1
Ethylene oxide at 7C	3.2	12.7	25.5	38.2	51.0	102.0	153.0	204.0
Hydrogen cyanide	4.1	16.5	32.9	49.4	65.9	131.8	197.6	263.5
Methyl bromide* at 0C	1.6	6.5	13.0	19.5	26.1	52.2	78.3	104.4
Propylene oxide	3.4	13.6	27.3	40.9	54.5	109.1	163.6	218.2

Conversion factors

100ft= 2.83m3- 11b = 16oz - loz/1 000 ft=g/m= mg/litre (approx).
1 fluid oz (Br) = 28.4 ml
1 fluid oz (U.S.) = 29.6 ml
1 ml = 0.035 fluid oz (Br)
1 ml = 0.034 fluid oz (U.S.)

*** Methyl bromide is often dispensed as a liquid held under pressure in a graduated measuring glass, as a "280-ml applicator"**

HCN Discs

If HCN discs are used in a chamber, they are scattered by the operator. In small chambers of up to 28 m (1 000 ft) capacity, the discs can be scattered from the partly opened door. For this type of application, the fumigator must always wear a respirator.

Fan Circulation

After the fumigant is applied in the closed chamber, the circulating fans are operated for 15 to 30 minutes. With many commodity treatments, this initial circulation will suffice. When continuous or intermittent circulation is required, as for some fruit and plants, this is mentioned specifically in the fumigation schedules, which follow Chapter 15.

Exposure Time

The period of exposure to yaseous-type fumigants begins when the discharge of the fumigant is completed. With liquids and discs, the exposure should be timed from the moment the door is firmly closed.

The exposure periods for the various kinds of treatment at atmospheric pressure are given in the fumigation schedules. Fruit, vegetables, plants, bulbs and nursery stock are exposed usually for 1.5 to 4 hours; seeds and plant products, for 16 to 24 hours. For particularly sorptive commodities that may substantially deplete fumigant concentration, some allowance for this depletion may be necessary (see Thompson, 1970).

Venting and aeration

At the end of the treatment, venting should be commenced by opening the exhaust port or valve and starting the fan. The chamber door should be opened slightly to allow fresh air to flow in. At least 10 or 15 minutes should elapse before the door is fully opened. The time of this interval will depend on a number of factors, but the door should not be fully opened until the operator is assured by appropriate chemical tests, instrumental tests, or from long experience, that it is safe to enter the chamber to begin unloading. First aid kits and gas masks should be available and in good condition at all times.

MOBILE AND PORTABLE CHAMBERS

Fumigation chambers which can be readily moved from one place to another provide a

flexible means of disinfestation. Such chambers, like the one illustrated in Figure 26, are often similar in construction and operation to stationary chambers, but of the lightest possible weight. The portable chambers shown in Figures 23 and 26 have already been discussed. Two other types, making use of a convenient water seal for closure, are described below. These may only be used for fumigants such as methyl bromide and ethylene dibromide which are only slightly soluble in water. The actual surface of water exposed to the fumigant is small and does not affect the gas concentration significantly.

Portable Drum Fumigator

A small fumigation chamber (Figure 27), about 200 1 (7 ft) in volume, can be easily made from a clean steel or iron drum of the same size (50 gallons), as described by Johnson (1940). The best closure is a water seal arrangement with a lid fitting into a collar, or trough, built round the outside of the drum.

The head of the drum is cut out with a cold chisel and the rough edges smoothed. The collar is made of 20- to 24- gauge galvanized sheet metal and is tightly soldered or welded to the drum. The top of the collar should be about 2.5 cm (1 in) below the rim of the drum, so that if water is spilled it does not fall into the drum. A tap or plug near the bottom of the collar permits drainage.

The lid or cover is made of the same material as the collar. It consists of a disc and a rim, which fit neatly into the collar as illustrated in the figure. Disc and rim are carefully soldered

or welded to provide a gas tight seam. One or two handles on the lid facilitate lifting.

A small fan or blower is necessary for the proper distribution of the fumigant. It may be operated by electricity from an ordinary lighting circuit or a battery, or manually by a hand-crank on the outside of the chamber with a chain drive connected to the blower axle. The manual arrangement is practical, as no reliance is placed on electric power. However, a special connexion must be fitted where the crank axle passes through the chamber wall. Heat may be provided by ordinary light bulbs, manually or thermostatically controlled. Fans and heating bulbs should be placed below the rack on which the load rests. This rack may be made of rat wire of 12 mm (0.5 in) mesh, or similar material.

Where continuous circulation is required in a small chamber, a suitable small fan, with a high impedance motor, can be connected in series with electric light bulbs located on the outside of the chamber to serve as a rheostat. In this manner, the fan may be operated continuously during the fumigation periods with no increase in temperature because of the heat developed by the motor (Richardson and Roth, 1966).

Equipment such as dispensing tubes, plungers and thermometers may be inserted through gas tight fittings, for example rubber stoppers, in holes in the lid or sides. The water seal in the collar is satisfactory for fumigants such as methyl bromide or ethylene dibromide, which are only slightly soluble in water.

Methyl bromide may be dispensed from the 280 ml applicator already described, or from 20

ml ampoules which are placed in clips in a tray inside the lid before it is closed; the ampoules are thus broken by the plunger.

It should be pointed out that if an ampoule containing 20 ml of methyl bromide is released inside a drum of 200 l (approximately 50-gall) capacity, the resulting concentration will be about 170 mg/l (10.5 lb/1 000 ft or 170 g/m). With this concentration, injury to growing plants may occur even if the exposure period is shortened to give an appropriate concentration x time (c x t) product. For plants, therefore, it is better to use the type of applicator illustrated in Figure 27 so that a small dosage may be applied.

FIGURE 27 - Portable drum fumigator for use with fumigants slightly soluble in water.

A. Lid
B. Drum
C. Thermometer
D. Plunger
F. 1-lb can CH3 Br
F. 28U-cc applicator
G. Evaporating pan
H. Water jacket
I. Drainage tap
J. Handle
K. Metal grille
L. Circulating fan

M. Heating lamps

If ethylene dibromide is used, the required amount is poured as a liquid into the evaporating pan. This can be done through a stopper after the lid is closed. Ethylene dibromide evaporates slowly and it should be heated with a small heating element without exposed wires, placed below the evaporating pan, in order that a full concentration of gas may be reached at the beginning of the treatment.

When the lid is placed in the water collar, it is necessary to release some of the air trapped inside the drum in order to allow the rim to be well below the water level and to prevent positive pressure being developed inside the drum. The air can be allowed to escape through one of the stoppers in the lid.

The drum should be painted on the inside with a primer and then given a resinbased varnish or other finish appropriate to the fumigant principally used.

<u>Mobile Water-Sealed Fumigator</u>

The fumigator illustrated in Figure 28 is particularly suitable for use in large nurseries or similar establishments, where there is a fairly continuous flow of material requiring treatment.

The figure shows clearly the essential features of the fumigator. It has a water-seal to make a

gas tight system and is designated primarily for use with methyl bromide for the treatment of nursery stock or rolls of turf which may harbour Japanese beetle larvae or other soil pests. With minor alterations to the design, other water-insoluble fumigants could be used. It is safe to use methyl bromide gas under an aluminium cover, but the liquid should never be left in contact with the metal for any length of time because of the possibility of fire.

The air pressure release valve prevents the top section of the fumigator from being too buoyant and keeps it well seated in the water seal. Also, positive pressure created by the introduced fumigant may be released through this valve.

Mobile fumigation chambers that have facilities for applying and circulating the fumigant and employ gaskets to give gas tight seals are produced commercially. Models with capacities of 10 and 20 m are available.

Plain Steel Drums with Clamp-Type Lids

Where steel drums, equipped with removable, clamp-type covers and rubber gaskets, are available, they can be used as fumigation chambers without modification, except possibly for the holes required for the insertion of tubing and wire. The rubber gasket provides an adequate seal, but it should be checked occasionally for tightness.

FIGURE 28 - A water-seal fumigator with mobile base. Cover section fits inside trough when ready for fumigation

(Plant Pest Control Division, U.S. Department of Agriculture)

A. Cable attached to overhead pulley system to raise and lower cover section

B. Pressure relief valve

C. Internal electric fan

D. Connexion for fumigant applicator

E. Place for load

F. Water drainage point

G. IU-cm trough filled with water for sealing cover section

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Fumigation under sheets

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Sheets retaining fumigant vapours for a sufficient time when placed over infested materials may provide a safe and effective method of fumigation. The word "tarpaulin" has in the past been used to describe these sheets, but this term is considered to be too general and may lead to a misunderstanding of the properties required for satisfactory treatments. Materials

spitable for this type of work have been called "gas-proof sheets" (UK, 1974). This is a more descriptive term, although, in fact, all the materials so far used have been shown to differ somewhat in their permeability to fumigants (Phillips and Nelson, 1957).

This technique has widened the usefulness of fumigants by making it possible to treat infested materials without moving them from their place of storage or diverting them from their usual trade channels. Under some conditions it is possible to retain the sheets over the stacks of goods after fumigation and aeration, so that continuous protection is provided against reinfestation, contamination by bird droppings, water leaks, dust and dirt.

The information given in this manual should be sufficient to enable the operator to carry out simple small-scale treatments under a wide variety of conditions. If large-scale operations are contemplated, it would be advisable to consult the British bulletin (UK, 1974), which discusses the subject at some length. Particular attention should be given to details of piping and fumigant discharge suitable for large stacks.

MATERIALS FOR SHEETS

In recent years, the development of new plastic materials has led to the introduction of types of sheeting which are well suited for fumigation covers. The sheets used for particular jobs vary according to the amount of rough handling and the weather likely to be encountered. There have been several critical studies on the diffusion of methyl bromide (Phillips and Nelson, 1957; Waack et al, 1955) and phosphine (Wainman et al, 1975; Kashi et al, 1977)

through various materials which might be used for fumigation sheets.

Sheets made of polyethylene or polyvinyl chloride film are suitable for use on the ground or to cover stacks in protected situations. The types most often used for fumigation have a thickness of 0.1 mm (0.004 in). Sheets of this gauge weigh less than 100 9 per m (2 lb per 100 ft2) and are easily handled even in large sizes. When sheets are to be used several times a thickness of 0.15 mm is recommended. Sheets made of these films tear easily on sharp corners or projections. They are not recommended for use on high buildings or structures when there is any possibility of high winds which may tear them to shreds. In some countries where the sheeting material is inexpensive and easily obtainable, it is often more economical in terms of labour to discard low density sheets instead of folding them up for further use.

For use in large-scale operations outdoors in exposed situations, coated fabrics are more suitable. Types that have been successfully used are nylon or terylene fabrics coated on troth sides with neoprene, polyvinyl chloride, or butyl rubber, and cotton fabrics, coated on both sides with neoprene.

Coated cotton fabrics appear to be more permeable to methyl bromide than the others. It has been found that a smooth slippery surface makes handling easier, especially if both sides of the fabric are coated (Brown, 1959).

Manufacturers of coated nylon fumigation sheets supply them with ropes sewn in plain hems on all four sides to facilitate clamping large covers together. For most fumigation purposes,

the sheets are purchased in rectangular shapes. In certain circumstances, the overlapping of sheets is inconvenient and in such cases tailored covers may be more practical. For example, for the fumigation of large pyramids of groundnuts in northern Nigeria special covers tailored to the shape of the pyramids are used (Figures 29 and 30).

FUMIGATION OF STACKS

The goods most often fumigated under sheets are cereals and other plant products in bags. Cereals in cartons, dried fruit in boxes and tobacco in boxes or hogsheads can also be treated in this way. The fumigation of buildings under sheets is discussed in the following sections.

An important consideration in this type of treatment is the most efficient utilization of a sheet of a given area; the dimensions of the stack should be such as to provide the maximum volume. Appendix 1 contains a table of maximum volumes together with a formula for calculating them, based on data supplied by Bower (1961).

Today, the principal fumigants used for this work are methyl bromide and phosphine. Ethylene oxide and HCN have also been used, but HCN does not penetrate as well as methyl bromide (Redlinger, 1957c).

For further information on the use of fumigants for plant product fumigation under gas-proof sheets, the following references may be consulted:

Ethylene oxide-carbon dioxide mixture: Plant products generally, Thompson and Turtle (1953); snails in imported cargoes, Richardson and Roth (1963 and 1965).

Hydrogen cyanide (HCN): Plant products generally, Thompson and Turtle (1953); rice, Redlinger (1957c).

Methyl bromide: Plant products generally, Brown (1959); Hall (1963); Harada (1962); Hayward (1963); Puzzi et al, (1966); cotton seed, Hingorani and Kapoor (1964).

Phosphine (generated from aluminium or magnesium phosphide): Plant products generally, McGregor and Davidson (1966); Puzzi et al (1966); Esin (1967); rice in sacks, Gogburn and Tilton (1963); grain sorghum in sacks, Hubert (1962); maize, Lochner (1964a), flour in polythene-clad sacks, Wainman et al (1975), shrink-wrapped pallets of bagged cornmeal, Leesch and Highland (1978).

Ethylene dibromide-methyl bromide mixture: Majumder and Muthu (1964).

Dosages

Recommended dosages for this type of fumigation are given in Schedule P.

Preliminary Precautions

In addition to the usual precautions taken before any treatment, which have already been

discussed, it is essential in fumigation under sheets that, after treatment, the gas escaping from the stack does not endanger any persons working or living in the vicinity. The fumigations may be conducted inside sheds, warehouses and similar structures, which furnish protection from bad weather (Figure 31). Such an arrangement is satisfactory if there is no possibility that gas may diffuse into occupied rooms or quarters. Very often the work can be safely done in warehouse rooms in which the windows can be kept open.

Suitable warning signs indicating type of fumigant and date of application should be placed on all stacks while fumigation is in progress, whether indoors or outdoors. First aid kits and gas masks should be readily available.

Preparation of Stack

A first step is to make certain that there will be no leakage of fumigant downwards during treatment. There is no serious loss or danger if the stack is placed on firm ground or on a good cement floor. If the floor is not gasproof, another gas-proof sheet, or even rolls of tar paper overlapped and sealed with masking tape, may be placed on the floor and the stack built above it.

When using methyl bromide or other similar fumigant it is essential that special provision be made to prevent the fumigant from discharging directly into sacks near the gas outlet. A suitable space may be provided by lifting and moving some bags from the top layer. In small piles, four bags may be propped against each other to form a "dome". Under this is laid a pan

or can to receive the liquid discharging from the end of the outlet tube (see Figure 20). In larger stacks, a long space two bags deep and two bags wide should be made by lifting adjoining bags to form a trench. For these larger volumes, the outlets of the gas lines should be either spray nozzles, which ensure volatilization of the fumigant before the liquid reaches the bags or the sheeting, or open tubes leading into pans or cans in the manner already described.

If electrical power and outlets are available, one or more 25- or 30- cm (10or 12 in) fans, the number varying according to the size of the stack, aid greatly in distributing the fumigant.

Placing Sheets

Sheets of standard sizes are easily placed on rectangular or square stacks. It is preferable to have sheets large enough to cover the individual stacks. At least one foot of sheeting should be left on all sides of the stack to provide room for sealing the edges to the floor.

If the sheets are not large enough to cover the stack, one or more must be joined by rolling the edges together. According to Brown (1959), a satisfactory seal for methyl bromide fumigation may be obtained by rolling together about 1 m (3 ft) of the edges of each of the adjoining sheets. "The leading edge of the first sheet is folded back three feet. The second sheet is laid to overlap the first so that the edges lie together then these edges are held together and rolled until all the overlap is taken up. When covering a large stack, joins may have to be made in two directions." When sheets on stacks exposed to the wind or on

buildings are joined, clamping of the rolled junctions is necessary. This technique is described in the following section, "Fumigation of buildings under sheets".

Under some conditions, such as those encountered in west Africa with the large pyramidal stacks, the rolling together of sheets is impracticable. Sealing with sprayed plastic has been tried with success but the standard practice is to use tailored covers for these stacks.

The edges of the sheets are best sealed to the floor by "snakes", plastic tubes about 10 cm (4 in) in diameter, filled with sand or water, which gives an efficient seal on level ground or floors. The use of water is very convenient because the tubes may be drained and rolled up between treatments. In emergency, some of the bags of the material already fumigated may be used, but a seal is difficult to obtain with these. Chains weighing not less than 2 kg per m (1.5 lb per ft) may also be used, but care must be taken that these do not damage the fabric. Outdoors, earth may be dug and piled closely around the base of the stack. Rips and holes appearing in the fabric may be repaired with adhesive or masking tape.

Applying Gaseous Fumigants

When gaseous fumigants, especially those containing methyl bromide, are applied indoors, respirators must be worn (see Figure 17).

For large piles the fumigant is applied from cylinders under pressure. With cylinders of methyl bromide discharging into high stacks, additional pressure in the cylinders may be needed

before the full dosage is dispensed. For many treatments with methyl bromide, 1 lb cans are convenient (see Figure 17). The special applicator for discharging the ethylene dibromide-methyl bromide mixture (Majumder et al, (1962) has been described in Chapter 7.

Acpiving Aluminium Phosphide

Tablets, pellets, sachets or other formulations used for generating phosphine may be applied to the stack before it is covered with the sheets. With long stacks it may be safer or more convenient to apply them as the sheeting work proceeds. It is often convenient to place paper trays containing the proportional number of tablets or pellets in strategic positions throughout the stack. The sachets are obtainable in lots of ten, bound together by string. These strings may be draped over the stacks in evenly spaced positions before the fumigation sheets are laid on.

Under normal circumstances, when the generation of the phosphine takes place slowly, it is not necessary to wear a respirator. When tablets, pellets or sachets are directly handled, rubber gloves should be worn. After the edges of sheets are secured with sand snakes, tape or other suitable material, warning signs should be placed on all sides of the stack. If the stacks are properly sealed, workers need not vacate the premises but good crossventilation must be maintained during working hours and periodic tests with detector tubes or other suitable analyser should be made to ensure that no one is exposed to concentrations above the threshold limit value.

Fan Circulation

With gaseous fumigants, the fans should be operated for 15 minutes at the beginning of the treatment. Operation of the fans for a longer time will not greatly improve gas distribution and may tend to force the fumigant out, especially if the seal at the base of the sheets is poor.

Fan circulation is not recommended for phosphine treatments and should not be necessary if proper distribution is made of the aluminium phosphide before fumigation begins.

Leakaqe

When methyl bromide is being used, a careful check should be made with the leak detector around the entire base of the stack immediately after the fan is turned off. If the covering is made of more than one sheet, the rolled junctions should also be tested. Any serious leak can thus be found and corrected at once.

Aeration

During the process of airing, the operators must wear respirators while working on the stack or in its vicinity, until it is shown by an appropriate test that dangerous concentrations of the fumigant are not present. Aeration should be begun by quickly lifting several sheets of each corner of the stack. After an interval, more of the sheeting may be lifted. When it has been demonstrated by the use of the leak detector, or by other chemical tests, that high

concentrations of fumigant have diffused away, the sheets may be carefully drawn off the stack.

Special precautions, such as opening all doors and windows and running exhaust fans, should be taken when airing a stack indoors. Careful checks should be made to determine that the indoor space is safe for human occupancy.

Paper Coverings

A specialized method of stack fumigation is the use of kraft paper for covering dried fruit. This technique is an inexpensive and simple means of effective fumigation and subsequent storage. It is particularly useful on farms .

The enclosure is made by framing stacks of fruit boxes with 2.5 x 10 cm (1 x 4 in) timber and covering it with paper. The paper used by Barnes and Reilly (1956) consisted of two layers of heavy kraft paper with an asphalt laminant reinforced with sisal fibres.

The shape and construction of the stacks are important to success. They should be built on 10 x 10 cm (4 x 4 in) foundations to protect the fruit from ground moisture and to facilitate gas circulation. The frame is covered by carrying the paper up one side, across the top, and down the other side, allowance being made for 30 or 45 cm (12 or 18 in) widths for sealing on the ground. The paper strips are lapped about 8 cm (3 in) and then battened with laths. Since the cover papers shrink after weathering, allowance should be made for this by spacing the frame

boards 2 m (about 7 ft) apart to take the edges of the 2.5 m (8 ft) wide paper. The paper cover is sealed to the ground with sand or fine soil. The seal should cover the paper on the ground completely and should be 15 to 20 cm (6 to 8 in) high against the sides of the structure. Head room above the boxes is necessary for gas circulation; if the stacks are not under a roof, they should be peaked to allow rainwater to run off. Tears in the paper may be repaired with masking tape.

After fumigation, several months' storage is provided by the enclosure, and reinfestation by insects is prevented. This technique, or modifications of it, could be applied to a number of similar storage problems.

FUMIGATION OF BUILDINGS UNDER SHEETS

Some buildings can be rendered gas tight only by the costly and time consuming sealing of individual cracks and holes, and it is often much easier to cover the entire structure with sheets (Figure 32). An early successful application of this technique was the commercial control of dry wood termites in dwellings. Formerly, thick kraft paper was laid over the buildings, but this material has been largely replaced by the modern types of plastic sheets already described.

The effectiveness of this method of insect control was demonstrated during the campaign to eradicate the Khapra beetle in California, in the course of which many large mills, grain elevators and warehouses were completely covered and fumigated with methyl bromide. In

one of the treatments, the volume fumigated under covers was 113 000 cm (4 million ft) (Armitage, 1956). Rasmussen (1967) reported on a critical study of methyl bromide fumigation to control long-horn beetles in houses covered with gas-proof sheets during treatment.

The technique for fumigating large structures is basically the same as that already described for stack fumigation. There are a number of special requirements, however, brought about mainly by the fact that the covering sheets may be situated high above the ground and be exposed to winds of considerable velocity (Armitage, 1958).

Sheets. Although polyethylene sheeting may be used, the danger of its being torn by high winds, or even totally destroyed, has led to the use of the tougher, but much heavier, nylon or terylene fabrics coated with plastic. The weight of this material, best suited for covering buil dings, varies between 200 and 440 g/m (6 and 13 oz/yd2).

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Fumigation of large structures

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Recently, phosphine generated from aluminium phosphide has been successfully applied for the fumigation of large buildings, such as warehouses, which can be rendered sufficiently gas tight to retain the vapours. Special attention must be paid to the possibility of reaction with copper and copper alloys, as discussed in Chapter 6.

ADVANCE PRECAUTIONS

Preliminary Inspection and Arrangements

The structure to be fumigated should be carefully inspected at the outset so that unusual features or potential problems can be taken into consideration before the fumigation is started. Such matters as sources of leakage, commodities that will absorb large amounts of fumigant, possible damage to commodities, arrangements for gas analysis, safety of personnel, etc. should all be noted so that appropriate arrangements can be made beforehand. In preparation for fumigation, a check list of the various duties to be performed should be made - a fumigator should never trust to memory or assume that essential things have been done. It is important to instruct the fumigation crew carefully, show them any special problems or hazards and inform them of emergency procedures in case of an accident.

Compliance with Official Regulations

The use of fumigants is often regulated by local or state governments. Regulations are designed to protect the health of those applying the chemicals and of the public in general.

Regardless of whether the treatments are made regularly in permanent installations or are carried out once only in a particular place, it is necessary that all regulations be observed.

Advance Notice of Treatments

It is usually advisable to inform local fire departments of large-scale treatments, especially if an entire structure or building is to be fumigated. The police should also be warned if the work is being done in a built-up area.

Guards

If the fumigation is being done in a place accessible to the public or adjoining public thoroughfares, it is necessary to employ one or more guards to keep unauthorized persons from approaching the fumigation site or from interfering with the operation. The guards are employed to keep outsiders away while the fumigation is being prepared, during the gas application, during the treatment and until the entire fumigation area has been declared "gas free" after the treatment has ended.

Warning Notices

Regardless of whether guards are employed or not, properly worded warning signs should be posted on all sides of a fumigation site. These signs should have clearly printed letters at least 5 cm (2 in) high, with wording such as:

DANGER
FUMIGATION WITH POISON GAS
(name of particular fumigant)
KEEP OUT
BY ORDER

The date of application of the fumigant should be included on the warning notices for those treatments where there is a possibility that the notices may not be removed at the end of the fumigation, e.g. on freight containers, railway box cars or other transportation vehicles. Notices printed on cardboard are often available from the fumigant manufacturer or dealer.

Respirators

Fresh, unused respirator canisters, specifically designed for protection against the particular fumigant to be employed, should be provided for each operator likely to be exposed to any concentration of the gas. A minimum number is two canisters per operator. One is to be used during application of the fumigant and, if there is exposure to any fumigant during this operation, it should be replaced by a new one before the aeration process begins.

Careful checks of individual respirators, carried out under the supervision of the foreman or leader, should be made by all operators concerned. All precautions and procedures outlined in Chapter 3 (Respirators) should be carefully followed.

PREPARATIONS FOR FUMIGATION

Sealing

Particular attention must be given to the proper sealing of a structure, as this may constitute the difference between the success and failure of a fumigation. Brick or cement buildings in a good state of repair can usually be fumigated by sealing all external openings by any of the methods listed at the beginning of this chapter. Doors and windows should be firmly closed and almost invariably should be taped or caulked. If the entire building cannot be made gas tight, it may be covered with gas-proof sheets in the manner described in the previous section.

Circulating Fans

When methyl bromide is being used, artificial circulation should be provided by means of fans to prevent stratification of this heavy gas and to ensure even distribution. One 40 cm (16 in) fan is usually suffi cient for every 1 400 m (50 000 ft). Provision should be made to switch the fans on or off from outside the building.

Plan for Gas Discharge

All fumigations which are not strictly routine in nature must be carefully planned. If a particular operation is complicated or conducted on a large scale, it is well to have the duties

and movements of each employee typed out on a specially drawn-up work sheet. When fumigating buildings, warehouses or ships with more than one floor or deck, it is advisable to include a plan on this sheet showing the location of each fumigant cylinder and gas outlet and all exits and entrances. When crews are fumigating large structures by releasing the fumigant from inside, it is sometimes advisable to place directional signs at strategic stairways, doors or turnings. Sometimes it is helpful to chalk arrows and other marks on the floor to indicate the direction and order of movements.

The work should be organized so that at no time will the operators pass through a room or space in which the gas has already been discharged. In buildings without basements, discharge should start on the top floor in order that the crew may work toward the prearranged exit on the ground floor. If there is a basement or cellar, a special plan may have to be made. Usually, the main floor may be omitted while one crew releases the fumigant in the upper floors and another works in the basement. The main floor is not treated until the others have been traversed and all operators, except those concerned with the final discharge, have left the building.

It is most important that operators should not be releasing fumigants inside a building for more than 30 minutes. It is better that a 15- to 20- minute period be allowed for each person. If the gas release cannot be done properly within that time by the available staff, more workers should be allocated to the crew during the preliminary planning.

In large operations, it is good practice to have the crew working in pairs; if an accident occurs

to one person, the other can bring him into the fresh air or summon assistance. Each member should be fully acquainted with the role of the others in the team. When the discharge of the fumigant is to be done by operators moving inside the structure, a full rehearsal of the procedure should be carried out at least once before the actual fumigation is started.

Calculation of Dosage

All dosage recommendations are made on the basis of the volume (cubic content) of the structure. For regularly shaped square or rectangular buildings, dosages are calculated by multiplying length by width by height. If the buildings are irregular, the volume of each unit should be calculated separately, and then all added together. If the building has a peaked roof, the average between the height of the sidewall and the distance from the lowest floor to the top of the roof may be taken as the height dimension (third multiple) in calculating the volume of the structure.

No allowance should be made for space occupied by commodities, materials, machinery or furnishings. Dosage recommendations are given in Schedules P and Q.

Provision for Ventilation

If possible, some provision should be made in advance for starting postfumigation ventilation before the fumigators enter the buildings. If front and rear doors can be opened from the outside, a strong draught can be created to dilute the gas concentrations appreciably when

ventilation is started.

When the roof ventilators are covered with plastic sheeting or kraft paper, they can be quickly and safely uncovered at ventilation time and the fans can be started.

Final Checks

When all preparations are completed, several checks should be made before the fumigants are applied.

1. **Sources of ignition. All possible sources of fire should be eliminated. All pilot lights and gas and oil burners should be extinguished. It is particularly important that thermostaticallycontrolled, high temperature electrical equipment of any kind be disconnected during the fumigation. HCN is inflammable at the high concentrations that may be present during initial discharge of the gas. Methyl bromide may react in the presence of a flame or glowing wire to form hydrobromic acid, which may be corrosive or injurious to many materials.**

2. **Warning signs. Ascertain that the warning signs are properly placed on all possible entrances to the building, and, in large-scale operations, at strategic points on the approaches to the building.**

3. **Outside telephone. Locate a nearby telephone of ready and constant access which**

may be used in case of emergency.

4. Guards. See that the guards or watchmen are at their proper stations before gas discharge begins. They should prevent unauthorized persons from entering the building or interfering with the work of the fumigation crew.

5. Check on evacuation. As a final essential measure, the foreman fumigator, accompanied if necessary by senior crew members, should visit every floor and room of the structure calling in a loud voice a warning, such as: "Poison gas fumigation to begin everybody out." Failure to observe this precaution in the past has led to serious accidents, including at least one fatality. During the visit these operators will also have an opportunity to see if all other preparations are properly completed.

APPLICATION OF THE FUMIGANT

While the fumigant is being applied, all persons engaged in or associated with this operation should wear respirators (gas masks). The only permissible exception to this rule concerns the operators working in the open, or in some well-ventilated place, under conditions in which any gas that escapes from the equipment is immediately diluted and dissipated. The respirators should not be removed until the workers indoors have reached fresh air, the fumigant has been completely discharged, and all the valves and piping have been closed so that no fumigant can escape from the system.

During the application, unauthorised persons should not be allowed to approach or talk to the operators engaged in the discharge of the fumigant. The organization of fumigant discharge was also discussed earlier under "Plan for gas discharge". Special techniques for HCN and methyl bromide are given later in this chapter under the headings for each gas.

PRECAUTIONS DURING TREATMENT

During the course of the treatment regular checks should be made for leakage of the fumigant. This is necessary for safety and also to prevent a failure of the treatment. The sections dealing with the properties and uses of fumigants include descriptions of methods of leak detection.

When guards are posted during large-scale operations they should be on duty during the whole period of treatment.

FUMIGANT ANALYSIS

As an aid to effective fumigation, sampling tubes should be connected to strategic points throughout the structure. During the fumigation, samples may be drawn at intervals and analysed by one of the methods already described for the fumigant being used. If concentrations at any point fall below an established level, more fumigant may be introduced as required.

VENTILATION

The operators should wear respirators when they approach or enter the building.

Openings from Outside

In accordance with preparations made before fumigation, when airing begins, as many doors and windows as possible are opened from the outside. Ventilators and fans with readily accessible switches may be started. The operators should then withdraw from the immediate vicinity of the fumigated structure. At least 30 minutes should elapse before the fumigators enter the building to open more doors and windows and to start other ventilators. At the beginning of aeration, the building should be entered only for short periods of time. The process of ventilation may be divided into stages, with ample time given to each one. After being in the building for a short period, the operators should withdraw into fresh air, remove their respirators, and wait for 15 minutes or more before putting them on again and re-entering the structure.

Tests for Gas-free Condition

As soon as the crew foreman determines that the structure is properly aired, the appropriate chemical tests for residual fumigant, already described, may be carried out.

Particular attention should be paid to the retention of gas in highly sorptive material such as

flours, meals and jute bags. This retention may be unduly prolonged by introducing cold air into a building that was warm during the fumigation. Serious accidents may result from closing such a building again and warming it up and causing the release of sorbed gas into the atmosphere. In cold weather, therefore, after the preliminary aeration, all doors and windows should be closed, the building heated to above 24C for two or three hours, and the aeration repeated. Under exceptional conditions, this process may have to be repeated two or three times before all material is safely free of gas.

After chemical tests have shown that both the structure and its contents are free from toxic concentrations, the building may be declared gas free and reoccupation permitted.

APPLICATION OF HCN

The materials from which HCN may be volatilized as a fumigant were listed in Chapter 6. The techniques for their practical application in building fumigation are described here.

Pot Method

The generation of HCN by the action of sulphuric acid on a cyanide salt is usually referred to as the pot method, although wooden barrels are often used as well as crocks or pots. This is not as convenient as the other two methods described below, which have largely replaced it, but it lends itself to emergency treatments.

Handling Chemicals

Sulphuric acid, 66 Beaume, is usually supplied in 45 1 (10 gall) carboys in wooden frames. It is advisable to divide this into smaller amounts in bottles; for this operation, a tilting frame is recommended. Acid should be poured slowly and with caution.

The sodium cyanide eggs, usually 25 9 (l oz) each, should be kept in tightly closed containers, away from heat and moisture, until they are needed.

Precautions

Sodium cyanide is a powerful stomach poison, which can also cause serious poisoning by being absorbed through cuts and exposed skin. All persons handling the dry sodium cyanide, and mixing the sulphuric acid in water before fumigation begins, should wear rubber gloves and tight fitting goggles.

Chemicals are made ready in the following proportions according to the systems of measurement used.

	Metric	**British**	**U.S.**
Sodium cyanide	1.0 kg	1.0 lb	1.0 lb
Sulphuric acid	1.5 litres	1.2 pints	1.5 pints

Water	3.0 litres	2.4 pints	3.0 pints

(Actually, it has been shown by chemical test that a 1 : 1.5 : 2 United States formula yields more gas than the one given. However, it has been observed that the smaller quantity of water used may result in a crystallization of the residue, which makes the emptying of the containers after fumigation more difficult (Back and Cotton, 1942).

Dosage

If properly generated according to the method given here, O.45 kg (1 lb) of sodium cyanide will generate 0.25 kg (8 oz approximately) of HCN gas. For many building fumigations at temperatures above 20C, the dosage of HCN gas recommended is 8 g/m (8oz/l 000 ft).

Use and Placing of Generators

Earthenware crocks up to 18 1 (4 gall) capacity or clean, water-tight 227 l (50 gall) wooden barrels should be used as generators. For largescale operations in mills and warehouses, the barrels are safer to use. The generators may be set out in groups of three or four on each floor of the building, each in a galvanized iron washtub, if available. The tub should contain a pailful of water with several handfuls of washing soda to neutralize any acid that may leak or spill from the barrel. The generators may be conspicuously numbered in the order of their use, in accordance with the need for careful planning discussed previously.

Preparing for Generation

After the generators are set out in their final positions, the required amount of water is poured into each. Then the required amount of acid for each generator is measured into pails. Next, the acid is poured carefully and slowly into the water in the generators.

Caution: never, under any circumstances, pour water into sulphuric acid - always acid into water

The next step is to count the number of sodium eggs required for each generator and to place them in double-walled kraft paper bags or flour sacks. The bags or sacks are then carefully placed 30 or 60 cm (1 or 2 ft) away from the generator, where they can be easily seen and reached.

Generating the Fumigant

After the final preparation and inspection of the buildings have been made, the respirators, fitted with anticyanide canisters, are put on. Gas generation is started at the farthest point from the final exit (see previous sections for discussion of planning). As each generator is reached, the operator carefully lowers the bag with cyanide into the acid, without allowing any liquid to splash on his person. Then he moves quickly to the next generator and repeats the same procedure at each station until he reaches the final exit.

Cleaning Generators

After the fumigation is finished and the structure has been thoroughly ventilated, the residue must be emptied and the generators cleaned. Sometimes the chemical reaction is incomplete and therefore it is advisable to wear a respirator while handling the generators and emptying them. The residual material should be taken to properly approved sites for disposal. The empty generators should then be thoroughly washed with fresh water and the liquid disposed of in the manner already suggested.

Special Pressure Generators

Special generators made of acid-resistant metals are available from some manufacturers of sodium cyanide. They permit the generating of HCN outside a structure. The acid is placed at the bottom of the metal generator and the sodium cyanide, preferably in egg-shaped form, is suspended above in a metal basket. The lid of the generator is then tightly clamped down with thumbscrews. When the charge of HCN is to be released, the basket of sodium cyanide eggs is plunged into the acid and the generated gas flows through a rubber hose into the fumigation space. This method is especially suitable for releasing HCN into fixed installations.

Liquid HCN

If liquid HCN is available in steel cylinders, this is one of the most convenient ways of applying it on a large scale. This method is commonly used in countries where HCN is manufactured, or

where it may readily be shipped. (Note that a time limit is set for the return of cylinders see Chapter 6).

The cylinders are always discharged from the outside of the structures being fumigated. This feature adds to the convenience and safety of the method. For fumigation of buildings and ships, the HCN must be forced under pressure through piping. For this purpose, air compressors are connected to a special valve on the head of the cylinder to drive the liquid through a siphon tube out of the discharge valve into the lines (see Figure 20).

Some premises, which are regularly fumigated with HCN, have a permanent piping system of copper tubes and the necessary connexions. When buildings are fumigated occasionally, a temporary piping system made of rubber hose is used.

The manufacturers and suppliers of liquid HCN in cylinders supply comprehensive and detailed manuals covering all aspects of its application, together with full instructions for the installation of piping systems.

Absorbed HCN

The use of HCN absorbed in porous materials such as cardboard discs, which has already been described, is a convenient method of dispensing the gas. The hermetically sealed cans hold a standard amount of HCN, usually 0.5 or 1 kg (1 or 2.25 lb) approximately. Some brands are available with small amounts of added warning agents, such as chloropicrin.

The use of HCN discs must be carefully planned according to the system already described.

Cooling. The discs should be precooled for several hours before treatment begins. This can be done by immersing the cans in tubs of water containing ice, by placing them in a refrigerator overnight, or by surrounding them with dry ice. The use of dry ice is especially suitable during hot weather.

Protection of floors. To prevent floors or floor coverings from being marred, the discs may be emptied onto sheets of corrugated or ordinary wrapping paper of about 1 m (1 yd).

Opening cans. The cans are quickly opened with the special can opener, as illustrated in Figure 21. Respirators must always be worn when cans of discs are opened or distributed.

Distributing cans. In the fumigation of large buildings with two or more floors or many rooms, it is advisable to open the cans at the points of distribution and immediately cap them with the fibre caps that act as protection for the cans during shipment. When fumigation is started, this provision enables the operator to empty the cans and scatter the discs.

Scattering the discs. The fumigating crew of not less than two men should work according to a prearranged plan and proceed toward the final exit in the manner already described.

In hot weather, HCN evolves rapidly from the discs and the operators may have to move quickly to avoid working in poisonous atmospheres.

Disposing of discs. Under normal conditions, the used discs are free of HCN by the time the structure is opened for ventilation. Nevertheless, all discs should be carefully gathered and burned in the open, or taken to an approved disposal site.

APPLYING METHYL BROMIDE

Liquid methyl bromide should not come directly in contact with painted surfaces. This can be avoided by volatilizing the spray in the free air or by discharging the liquid into metal pans or cons with a large surface area.

The fans provided for methyl bromide fumigation should be operated for 15 to JO minutes at the beginning of a fumigation. Once equal distribution has been attained, the gas/air mixture remains in equilibrium almost indefinitely and the methyl bromide does not stratify during the period of fumigation. However, if gas analysis at any time indicates unequal distribution, or any additional fumigant is discharged during treatment, the fans should he operated again for as long as is considered necessary.

Direct Discharge from Cylinders

Methyl bromide cylinders may be placed, according to dosage requirements at strategic points throughout the structure so that the valves may be fully opened by the operators, wearing respirators, as they retreat toward the final exit.

In large operations, or in structures with high ceilings or roofs, stand pipes (curved copper tubing directed upward) are often attached to the cylinder outlets. In this technique, a short "T" is fitted to the top of the pipe to discharge the gas laterally and prevent contact with the ceiling.

Hot Gas Method

Methyl bromide may be discharged from outside the building by passing it through a heat exchanger after it leaves the cylinder. This is the method already described for the fumigation of buildings under tarpaulins.

Recirculation Method

Another method, applicable in low structures that are not covered by tarpaulins, is the use of plastic ducts similar to those used in the fumigation of grain by the recirculation technique. To prevent the collapse of plastic ducts at bends, short metal ducts of the same diameter are introduced into the line wherever it is necessary to change direction. A fan draws air from the ground floor and forces it through the duct back into the building through an upstairs window. Methyl bromide is introduced through tubing on the intake side of the fan and is thus distributed throughout the building.

Pressure Method

For discharging methyl bromide into flour mills or other tall buildings from the outside, the fumigant may he forced through the lines by compressed air. The liquid flows through flexible copper tubing of 9 or 12 mm (0.375 or 0.5 in) outside diameter. At the outlet end, each tube is pinched to give an aperture of 2 mm (0.08 in) width. The outlets are directed laterally or upward, but never downward. Some manufacturers add nitrogen or another inert gas above the liquid in the cylinder in order to supplement the natural vapour pressure of the fumigant. This combination is usually sufficient to start the methyl bromide through the lines, even in tall buildings. When the cylinder is half empty, additional pressure up to 10.5 kg/cm(50 lb/in2) may be provided from a compressor in order to complete the discharge.

APPLYING PHOSPHINE

A number of formulations for generating phosphine are available for the fumigation of large structures. When tablets or pellets of aluminium phosphide are used, they are distributed on trays or thick paper at intervals throughout the building. Similarly, magnesium phosphide plates are laid out to give an even dispersion of the required dosage. If there are one or more storeys, the operators start at the top floor and work downward toward the final exit. As suggested in Chapter 6, under normal conditions evolution of the phosphine is delayed and it is not necessary to wear respirators if the distribution can be completed in a few minutes. If there is a possibility of considerable delay, or under conditions of high temperature and humidity, respirators should be worn at the discretion of the official supervising the fumigation.

For small structures, where the work can be completed in a few minutes, sachets may be employed by suspending them evenly on thin rope as from a washing line.

At the completion of the fumigation and aeration, the residual powder from the tablets or pellets or the used plates or sachets must be carefully collected and safely disposed of, as described in Chapter 6.

Mill fumigation

Methyl bromide and phosphine are effective in the fumigation of modern concrete, stone or brick mills that can be made sufficiently gas tight to retain the fumigant. HCN may be satisfactory for mills which allow more leakage, such as ones with frame or sheet metal construction. number of special measures must be carried out when mills are fumigated in order that the fumigant may penetrate all parts of the machinery and equipment. These are especially important with HCN because it does not penetrate well into accumulations of flour, meal or other sorptive materials.

PREPARATIONS FOR HCN FUMIGATION

The following is a summary of the more important measures to he taken (Cotton, 1958):

1. **<u>Before stopping the mill</u>. Shut off the source of grain fed to the mill. Then continue to run the machinery until 811 parts of the milling system are empty. At**

the same time, remove elevator bootslides so that stock may be pulled out and not carried forward. Use a rubber mallet or a similar device that will not damage the equipment to hammer all parts of the machinery from which accumulations of flour, meal or dust can be dislodged.

2. <u>After stopping the mill</u>. All machines, ducts, bins and conveyors in the entire mill should be thoroughly cleaned. All infested material collected in cleaning the mill should be removed to the fumigation chamber and fumigated or the debris should be taken outdoors and buried. All doors to conveyor boxes and bins, and those leading to enclosed machinery, should be opened as widely as possible to aid gas penetration. It is especially important to open the "dead" spouts into which the fumigant penetrates with difficulty.

3. <u>Machinery piping system</u>. Fumigation of the various units of the mill and its machinery is assisted by the installation of a special piping system equipped with nozzles which automatically deliver equal quantities of fumigant to each unit. An installation of this type leads to a considerable saving of fumigant. Also, it may eliminate the necessity of dismantling and cleaning the machinery, and labour costs may thus be greatly reduced. The manufacturers of liquid HCN supply information on the planning and installation of such systems.

PREPARATIONS FOR METHYL BROMIDE AND PHOSPHINE FUMIGATION

These two fumigants penetrate well into accumulations of sorptive mill products and trash lying in a mill. Therefore, if methyl bromide is used, the cleaning programme required before HCN fumigation can be delayed until after the fumigation is completed. In fact, this is recommended because the insects are killed where they are and the debris does not need to be moved to a special fumigation chamber.

All doors or vents to bins, conveyors and machinery should be opened as already outlined for HCN fumigation. Further information on the biology and control of insects in flour mills is given by Hill (1978).

Local fumigation

Local fumigation is the treatment of isolated insect infestations in buildings. In mills, the term is applied particularly to the fumigation of individual machines and enclosed equipment that harbour insects. The popular term "spot fumigation" applies to this type of treatment as well as to treatments of isolated outbreaks in stored grain, which are discussed in Chapter 10.

The fumigants used for this work are pure compounds or mixtures that evaporate slowly and do not diffuse quickly from the treated locality into the main space of the building. Some of the more common formulations are given in Schedule R and in Chapter 7. Although these vapours diffuse slowly, they kill insects only when the equipment is fairly tightly enclosed. It is usual to apply the fumigants during weekends or at night after the mill has been shut down.

They should be applied regularly every two or three weeks. A regular programme of local fumigations may keep insect populations at a low level throughout the year. This contributes to the production of goods free from infestation. However, only in exceptional circumstances does such a programrne eliminate the need for occasional general fumigations. Local fumigation may be done by alert and competent mill employees who are assigned to this work and specially trained for it. (See also White et al, 1957; Cotton, 1961, 1963; Hill and Armstrong, 1952; Hill, 1978.)

PREPARATIONS

Before local fumigants are applied, the mill should be run dry. The milling stock should not be removed until after treatment. All vents from milling machinery to the outside should be closed and other steps taken to reduce draughts in the mill system as much as possible. Dead spouts and filled suction lines should be cleaned.

PRECAUTION

In all applications of local fumigants, the operators should wear industrialtype respirators fitted with the proper canisters. Care should be taken not to spill liquids on skin or clothing.

METHODS OF APPLICATION

There are two principal methods for the application of local fumigants in mills: hand

application and injection by automatic applicators.

Hand Application

When the fumigants are applied by hand, the dosages for each locality may be poured from the shipping drums into litre or quart bottles, which are then placed individually beside each particular point of application. It is best to use bottles graduated in millilitres or fluid ounces so that the correct dosage may be applied at each station. The operators should work in pairs.

With hand applications, the usual procedure is to start at the top of the building and work quickly downward from floor to floor as the liquids are poured or dashed into the individual units. After each application, the opening is tightly closed. The empty bottles may be abandoned and picked up when the building is finally aerated after fumigation. Windows should be left open during application but closed on each floor as the team works downward.

When application is completed, all doors or other entrances should be closed and locked. Warning signs should be posted at all possible entrances and a guard placed on duty; these and other precautions should be generally the same as for all building fumigations.

If possible, the mill should not be opened until 24 hours have elapsed from the time of application. If only one night i allowed for treatment, exposure may be shortened to 12 or 16 hours. At the end of exposure, all doors and windows should be opened to provide as much

ventilation as possible. Appropriate tests for lingering fumigant should be made with detector tubes or other suitable equipment to ensure that gas concentrations are below the threshold limit value before the building is reoccupied.

Automatic Injection

This type of application is confined to treatments of milling machinery. The fumigant is discharged in equal, predetermined dosages from special equipment operated by compressed air, which are supplied by the fumigant manufacturers or blenders (Figure 35). The liquid is injected through small holes specially bored at selected points in the milling machinery. Because this is essentially a machinery fumigation, the building may be fully ventilated during treatment.

Automatic injection in mills is a specialized treatment and details of dosage, location of injection points and other technical considerations are determined after an inspection of the premises has been made by representatives of the companies supplying the fumigants and the applicators.

A similar type of treatment has been used For the control of insects in the wooden linings of railway box cars (Dawson, 1962; Schesser, 1967).

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Fumigation of bagged goods in ships and barges

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Plant products in bags may readily be fumigated with methyl bromide while they are still loaded in ships and barges. If proper provision is made for the even distribution of the fumigant throughout the load any full cargo space may be fumigated. An important consideration is that in large spaces it may take some time to complete thorough aeration after treatment (Monro, 1947b; Markin, 1963). Treatment of bulk grain in cargo ships is discussed in Chapter 10.

Phosphine may also be used For treatments in barges if the longer exposure periods recommended For the use of this Fumigant are practicable. As stated in Chapter 6, due consideration must be paid to the presence of coppercontaining equipment in the structure. A procedure for the use of phosphine in combination with methyl bromide for the fumigation of bulk loaded expeller in barges and coasting vessels has been developed by Wohlgemuth et al (1976).

FUMIGATION PROCEDURE

Methyl bromide

The methyl bromide cylinders are placed on the open deck and Cannected ted to copper or olyethylene tubing leading into the holds and ending in one or more T-shaped nozzles. At least one 25- or 30-cm (10- or 12-in) circulating fan should be placed as near as possible to the bottom of each hold and, when the gas is released, the fans should be operated for 30 minutes in order to prevent stratification and to aid distribution of the yes. Fans are also useful in hastening aeration after fumigation.

The penetration of methyl bromide is outstanding and the gas will escape unless adequate precautions are taken for sealing. A single ordinary canvas tarpaulin is not sufficient to contain the gas during the fumigation period. However, three canvas tarpaulins in good condition are able to prevent leakage, especially if they are dampened. Suitable sizes of special tarpaulins with a plastic coating impervious to methyl bromide may be obtained to cover the hatches. If suitable or sufficient tarpaulins are not available, strips of tar paper joined together by various widths of brown paper glued with flour paste should be laid down above the hatches, with ordinary canvas tarpaulins then placed on top. Canvas tarpaulins usually provide sufficient cover for the ventilators.

Many modern ships have steel rolling hatch covers, called "McGregor type", which require no extra sealing for methyl bromide fumigation. These covers are lowered into place off their dollies onto a rubber gasket and the full weight is sufficient for a good seal. If the dollies are warped after rough use the side bolts may be used to pull them down into place.

When methyl bromide is used, the ships' officers, with their knowledge of the construction of the vessel, may be of great assistance to ensure that adequate sealing is obtained. They can point out possible sources of leakage, help check the ventilation system and openings between bulkhead on older ships and also see that hatch covers are secured properly (Monro, 1969).

Phosphine

Phosphine may be applied in barges loaded with bagged goods according to the procedures described below in this chapter for wheeled carriers.

PRECAUTIONS

If the cargo space of a vessel is fumigated while the ship is in port, it is recommended that the entire crew be evacuated while the fumigation is in progress. Warning notices should be prominently displayed at gangways and entrances to accommodations and a guard should be stationed at each gangway to prevent unauthorized persons from going aboard. No one should be allowed to return to quarters until the ship has been certified "gas free" by the fumigator in charge. Further information on the safety procedures recommended for fumigation of ships in port can be obtained from the Inter-governmental Marine Consultative Organization, MSC Circular 298, 23 January 1981 (IMCO, 1981) or to subsequent documents as they are updated.

SMALL-SCALE TREATMENTS

On board ship there may be rooms usable as fumigation chambers. Ammunition and other storage lockers are usually gas-tight and of sufficient size for treating small amounts of infested goods. Fumigation is conducted in the same way as in a regular chamber. Extra care must be taken during aeration because, in the absence of a proper exhaust vent, the gas will diffuse out through doors and portholes.

Fumigation of empty cargo spaces

Empty holds in cargo ships or on some passenger vessels often have residual populations of stored-product insects. If the infestation is localized, it can be controlled by spraying with a suitable insecticide. This method, however, cannot be relied upon for complete eradication. Usually, a complete fumigation is required (Monro, 1969).

Aerosols, which are fogs, mists or insecticidal smokes produced by various devices, have already been mentioned in the Introduction. They can be used to treat populations of stored-product insects in empty holds, and are satisfactory for killing the insects exposed in the open. Some information on the use of dichlorvos for control of insects in empty cargo ships is given by Bond et al (1972). However, all of these materials, including dichlorvos, have poor powers of penetration and are not as efficient as fumigants for obtaining complete control throughout the structure.

When a fumigant is used, one or two boards covering the bilges in each side of the ship should be removed. Piles of dunnage, if present, should be broken up to allow penetration of the gas from every side.

METHYL BROMIDE

Methyl bromide penetrates well into cracks, crevices and spaces under boards. In such places there are accumulations of grain and other foods in which the insect populations are able to multiply and from which they spread to the cargoes and other parts of the ship.

The fumigation of empty holds with methyl bromide follows the same basic procedure already described for loaded cargo spaces. Fans placed at the bottom of the holds are again absolutely necessary to give proper gas distribution. Recommended treatments are given in Schedule Q. It will be noted that dosages are lower and exposure periods shorter than those for loaded spaces.

To eradicate Irogoderma beetle infestations, more particularly Irogoderma qranarium Everts, increased dosages of methyl bromide are needed (Slabodnik, 1962; see Schedule Q).

HYDROGEN CYANIDE

HCN may also be used in empty holds although it does not diffuse very well through residual debris from plant products to reach deep-seated infestations. The most convenient method to

apply HCN in ships is by means of the impregnated discs. These are often kept on hand for medical quarantine fumigation against rats.

With HCN, the general preparations and precautions are the same as for methyl bromide, with the following points of difference.

> **1. The ordinary canvas hatch tarpaulins, if in good condition, are satisfactory for HCN fumigation; it is advisable to use two to each hatch.**
>
> **2. If fans are used for distribution of HCN within the hold, they must be explosion proof.**
>
> **3. The discs are distributed as widely as possible in the hold by lifting the tarpaulins on each corner of the hatch in turn; this work is facilitated by removing the four corner hatch boards before the fumigation.**
>
> **4. The tarpaulins are then battened down securely.**

AERATION

Procedure and precautions for the ventilation of empty cargo ships are the same as already described for loaded ships. The gases diffuse more quickly from the empty holds and, under conditions favourable for aeration, the holds may be entered two or three hours after the

hatches are opened.

Railway cars and other wheeled carriers

Some wheeled carriers may be used for fumigation. Treatment in such vehicles is often convenient and may show considerable economy in time and labour. By making a treatment of infested goods in a carrier, at least four manipulations, involving loading and unloading the vehicle and the fumigation chamber, are avoided. Furthermore, the fumigation kills the insects in the free space of the carrier and live pests do not remain behind to infest or invade the next load. In this way a great deal of possible cross-infestation may be avoided.

RAILWAY CARS

Railway companies are usually willing to permit fumigations in their equipment. It is, of course, essential to solicit their cooperation before treatments are planned.

In some countries, the standard railway cars (wagons) are well built and constitute in themselves excellent fumigation chambers; steel cars are especially suitable. Refrigerator-type cars, by the very nature of their construction, are usually gas tight if all openings are carefully sealed. (It is important to remember that in the cars using ice, drainage pipes from the ice bunkers should be plugged during the fumigation). In all railway cars, the wooden floor is likely to be the principal site of leakage. Some cars that are not sufficiently gas tight may be

readily sealed by some of the methods already described. Also, 8 leaky car could be covered with a gas-proof sheet and fumigated, if a satisfactory seal can be made at ground level and around the rails. When railway cars are to be fumigated, they are usually isolated on separate sidings and kept there while under gas. This arrangement is, of course, essential if the cars are covered with sheets. In some countries, under certain circumstances, railway cars may be allowed to travel while still under gas. Appropriate warning signs are placed on the main doors or hatches, with instructions for the adequate airing of the car before it is entered for inspection or unloading.

In France and in the United States, there are special fumigation chambers with railway tracks running into them so that the cars may be fumigated singly or in groups. Some of the chambers are designed for fumigation at atmospheric and others at reduced pressures. This arrangement has the advantage of allowing treatment of both the inside and outside of the vehicles, a consideration which may be important from the quarantine point of view, especially at border points.

The fumigation of railway cars under gas-proof sheets, as described above, may seem to eliminate the need of constructing permanent chambers. In plant quarantine practice, however, the choice of method against the threat of introduced pests should be made on the grounds of efficacy rather than of convenience or economy.

TRUCKS AND CARGO TRAILERS

Highway vehicles that can be rendered gas tight are suitable for the fumigating of goods loaded into them. In general, the same considerations apply as for railway cars.

For certain operations, the use of gas-proof sheets, particularly of the light-weight polyethylene type, is a convenient and effective improvisation. In this work, the trucks or trailers may be driven onto a gasproof groundsheet and then covered with another sheet, which is sealed to the lower one with snakes in the usual manner, thus providing a gasproof structure around the vehicle.

FREIGHT CONTAINERS

Fumigation of many commodities is carried out in freight containers and other transport units that are designed for carriage on vehicles. The procedures for treatment of these containers are much the same as for railway cars and cargo trailers. They may be fumigated while stationary or the treatment may be continued "in transit". Procedures for fumigation of tobacco with phosphine in freight containers, along with efficacy of the treatment, have been outlined by Childs et al (1971).

If the freight containers undergoing fumigation are to be loaded on ships, the guidelines given by the Inter-governmental Maritime Consultative Organization (IMCO, 1981, or subsequent recommendations) should be followed.

FUMIGANTS FUR CARRIER TREATMENTS

In practice, methyl bromide and phosphine are the materials most commmonly used for wheeled carriers containing plant products, because these two yeses penetrate effectively into many commodities. Ethylene dibromide was used successfully in the United States for truck fumigation in the campaign against the Mediterranean fruit fly in Florida. Truckloads of oranges were run into atmospheric chambers equipped with ducts specially designed for cirulating the fumigant/air mixture through the load (Grierson and Hayward, 1959).

APPLICATION OF FUMIGANTS

In general, the techniques of sealing sod fumigant application are the same as those already described for the atmospheric chamber or gas-proof sheet fumigations.

Methyl bromide

Fumigation of bagged grains, meals and other plant products in carriers, such as railway cars, is easily done with methyl bromide in cans (0.45 or 0.68 kg) or in steel cylinders. This fumigant should always be applied from outside a railway car using 6 mm (0.25 in) polyethylene or copper tubing attached to the cylinder or to the special opener/applicator designed for cans. The tubing is inserted through a crack between the door and door frame, through a roof vent or possibly through a hole drilled in the floor. The discharge end of the tube is plugged sod a hole drilled through both walls 3-4 cm below the tip, then the end of the tube is attached close to the ceiling at the centre of the car, so that the methyl bromide mist can be directed over the commodity and toward both ends of the car.

The dosage to be applied is determined according to the size of boxcar as well as the temperatures of the atmosphere and the commodity. Temperatures above 10C with exposure periods of 12 to 18 hours are recommended for this treatment. After applying the proper dosage the tubing is withdrawn and the opening sealed. At the end of the fumigation period all doors and vents are opened to allow as much circulation as possible. At least 30 to 60 minutes are required to aerate the free space of the car, but appropriate detecting equipment should be used to make sure that no methyl bromide is present when personnel enter to unload the car. Respiratory protective equipment should be worn when checking for fumigant in the car.

Phosphine

Various formulations for generating phosphine are used in fumigating railway cars and other carriers. Tablets or pellets of aluminium phosphide may be used by placing them in moisture-permeable envelopes and attaching these at intervals to the wall of the carrier or placing them in shallow cardboard boxes on top of the load (Schoenherr et al, 1966; Schesser, 1967). To avoid the possibility of combustion, only two tablets or ten pellets should be inserted in each envelope. Prepacks, with pellets appropriately separated from one another in a specially prepared plastic strip and covered with permeable paper, are supplied by some manufacturers for convenient application of the fumigant. They ore sometimes attached to the inner side of the door just prior to closing and sealing. If sachets are used they may be strung by a thin rope above the load. Lochner (1964b) gave a full description of the use of aluminium phosphide tablets for the fumigation of maize in bags or in bulk while in transit in

railway cars. Magnesium phosphide in tablets, pellets or embedded in moisture-permeable plastic plates is also available for use in a similar way.

PRECAUTIONS

The general precautions for railway cars and freight containers are similar to those already recommended for buildings and ships.

If a line of cars is being treated, it is advisable to put the usual gas warning sign on a special stand, which is staked in a conspicuous spot beside or between the railway tracks at each end of the line. Railway sidings chosen for holding cars during fumigation should be at least 100 m from any dwelling or building regularly occupied.

Where in-transit treatments are carried out, warning signs should be placed in conspicuous locations near each door of the carrier. They should be firmly fixed so that they are not easily lost or removed before the car or container is opened for aeration. For such in-transit treatments the warning signs should indicate the date of fumigation as well as the type of fumigant. Prior to unloading of fumigated vehicles, appropriate tests should be made to ascertain safety of the cargo area.

The success of in-transit fumigations is particularly dependent on good construction of the railway car or freight container and effective sealing methods.

FAN CIRCULATION

Fan circulation is essential in carrier treatments for fresh fruit, vegetables, plants and nursery stock when using a fumigant such as methyl bromide. This is to ensure proper evaporation and distribution of the fumigant in treatments of short duration (2 to 4 hours).

In fumigation of bagged grain and plant products, the exposure periods are at least 12 hours. If the fumigant is evenly distributed above the load at the time of application, subsequent fan circulation is unnecessary.

BULK GRAIN TREATMENTS

Fumigations of bulk grain may be carried out in railway cars and in wellbuilt trucks. The principles and techniques are essentially the same as for bulk grains in flat storages (as described in Chapter 10). Alumirlium phosphide tablets applied by probes or sachets inserted in the bulk may be used. Liquidtype fumigants have also been used in open-top transit trucks with the grain being covered with a gas-proof sheet after application. A canvas tarpaulin can be used as an additional cover (Gray et al, 1964).

Gaseous-type fumigants such as methyl bromide, may also be used if provision is made for adequate recirculation with special equipment (see Phillips and Latta, 1953; USDA, 1963).

Individual package fumigation

Techniques for applying small doses of a fumigant to individual bays, packages or other containers show considerable promise for use either in emergencies or where converitional fumigation equipment is not available. There are at present two factors which may assist the development of such methods for practical use. First, some modern packaging materials are sufficiently gas tight to retain the vapours for the length of time required for successful treatment. Second, there are fumigants which can be applied conveniently to containers and which also have physical properties, such as slow evaporation or diffusion, that are suitable for this purpose.

In India, ethylene dibromide was injected into grain, stored in jute bags, at the rate of 10 ml per bag. This either killed the insects present or drove them out (Pingale and Swaminathan, 1954). Experiments with injection of four other fumigants into insecticide-impregnated jute bags containing grain confirmed the greater efficacy of EDB for this purpose. Control was not complete in non-impreynated bags (Muthu and Pingale, 1955).

The use of small cardboard discs held in aluminium foil, as described in Chapter 6, has been found useful for bag treatments (Muthu, 1964). These discs are illustrated in Figure 36. In Ghana, EDB was successfully used on individual jute bags with polyethylene liners as described in Chapter 6 (Hall, 163).

It should be noted that EDB is now considered to be hazardous to human health and, therefore, care should be taken to ensure that no one is exposed to its vapours and treater) grain should be thoroughly aired so that residue is reduced below the FAD guideline levels

(FAD/WHO, 1980).

In the United Kingdom, two tablets of aluminium phosphide were inserted individually into bags of wheat and rye resting on gas-proof sheets. One tablet was placed near the middle anti one near the mouth of the hag. Tablets were deposited either by hand or with a special probe dispenser. The gasproof sheets were then wrapped over small groups of bays and well overlapped. After five days of exposure, the sheets were removed. This treatment gave good control of a representative collection of species of stored-product insects and mites, although some adults of the granary weevil, Sitophilus qranarius, survived in cold wheat used in one test. It appears that this method holds promise for treatments of sacked grain in farm storages or other places where little special skill is required. for the control of certain insect species, such as the granary weevil, the dosage per bag should be increased to three tablets (Heseltine and Thompson, 1957).

Using polyethylene-lined sacks, Proctor and Ashman (1972) achieved good control of insects in bags of groundnuts being transported from Zambia to the U.K.. When a 0.6 9 aluminium phosphide pellet was applied in jute or woven polypropylene sacks of 32-82 kg capacity and lined with polyethylene 63.5127.5 m thick, the c x t product for phosphine exceeded 50 mg h/l, and 10C percent mortality of all stages of the test insects, including Sitophilus zeamais Mots. was recorded. Although many liners in sacks split during transportation, this did not affect the efficiency of the phosphine fumigation or permit reinfestation.

PACKAGING LINE TREATMENTS

Treatments on the packaging line are of concern at present in the food processing industries, and the subject falls more in the realm of industrial rather than agricultural practice. Some discussion of the techniques is given here, not only because they are interesting examples of how fumigants may be used, but also because similar methods might be applied to solve more strictly agricultural problems.

Packaging line treatments have helped to keep certain food products, such as dried fruit and vegetables, free from infestation as they leave the processing plant (Simmons and Fisher, 1946). The technique is applicable when the packages are made of materials, such as cellophane and fibreboard, through which fumigants do not diffuse very quickly. The fumigants are dispensed into the individual packages from automatic machines, which can be calibrated to give an accurate dose. Application may be made before or after the contents are placed in the package. The best stage is just before the package enters the unit which seals the wrapping. The wrappings generally used are sufficiently gas tight to maintain an insecticidal concentration of the fumigant long enough to kill any insect stages present in the package.

To protect plant workers, exhaust hoods, approved by health authorities, should be installed to draw fumes away from the working area (Mayer and Nelson, 1955). Also, appropriate analytical tests should be made to ensure that threshold limit values for the fumigants are not exceeded. Experience has shown that fumigants diffuse away from the packages fairly rapidly after application, sometimes within 48 hours. Thus, it is considered that these treatments do not create any hazard to consumers.

Fumigants used for this type of application include methyl bromide, ethyl acetate, ethyl formate and propylene oxide. In the past, methyl bromide has been mixed with high proportions of carbon tetrachloride for package treatments.

Propylene oxide and ethylene oxide are also applied to certain packaged foods, especially dried fruit, to prevent microbial spoilage and to control insects.

Dosages for packaging line treatments vary greatly according to the product, material used for packing, method of packing and fumigant used.

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9. Vacuum fumigation

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In vacuum fumigation, most of the air in the chamber is removed before the fumigant is introduced. It is, therefore, necessary to have a specially constructed chamber, usually made of steel, that is capable of withstanding external pressure up to one atmosphere. The

installation also includes a pump able to evacuate the chamber in not more than 10 to 15 minutes, and valves and pipes for introduction and exhaustion of the fumigant. A vacuum fumigation installation is illustrated in Figure 37.

The primary object of vacuum fumigation is to hasten and improve the penetration of the fumigant into the material undergoing treatment. It was originally developed for this purpose when hydrogen cyanide (HCN) was the principal fumigant used. The advent of methyl bromide and phosphine, with their greater powers of penetration into many materials, made vacuum fumigation less important for the treatment of certain commodities.

Today, the technique is used chiefly in plant quarantine work (Richardson and Balock, 1959) and for fumigating tobacco (Tenhet, 1957) and other materials, such as compressed bales of jute bags (Monro and King, 1954) and pressed dates (Brown and Heuser, 1953a), which are difficult to penetrate at atmospheric pressure. It is also used in some food manufacturing industries for the fumigation of packaged cereals and prepared foods.

The fact that a vacuum treatment may be completed in 1.5 to 4 hours, as opposed to 12 to 24 hours for atmospheric fumigation, may commend it for use when a quick turnover of goods is necessary, as, for instance, at a busy seaport.

Vacuum fumigation cannot be used with certain tender plants, fruits and vegetables which are unable to withstand reduced pressure.

A vacuum fumigation installation is considerably more expensive than an atmospheric chamber of the same capacity. The decision as to whether the vacuum technique should be adopted should be made by weighing the possible advantages against the greater cost of installation.

Fumigants

The number of fumigants which may be safely and conveniently used in vacuum fumigation is strictly limited on account of various technical considerations. The materials principally employer) at present, in approximate order of importance, are:

> **1. Ethylene oxide/carbon dioxide mixture, which has a wide use in the food industry for treating processed and unprocessed foods. With considerably increased dosages it is also used for sterilizing food. It can also be used for sterilizing other materials, but this is outside the scope of the present manual; for general reviews of gaseous sterilization see Rauscher et al (1957); Bruch (1961).**
>
> **2. Methyl bromide, as a general purpose fumigant in this field.**
>
> **3. Hydrogen cyanide, formerly widely used but replaced largely by ethylene oxide and methyl bromide.**

IMPORTANT. Under no conditions should phosphine, generated or dispensed in any manner,

be used in vacuum fumigation. This compound is unstable at reduced pressures.

Methods

In recent years, considerable research has been undertaken on the methods of conducting vacuum fumigation for obtaining the best results with certain fumigants used on certain materials.

Basically, there are two main methods: sustained-vacuum fumigation and nearly complete restoration of the pressure, either simultaneously with the introduction of the fumigant or some time later (Page et al, 1953). The choice of one of these methods depends to some extent on the material being treated. Thus, fruit, vegetables and growing plants are usually completely ruined if they remain exposed for more than a few minutes to a pressure below 250 mm (10 in) of mercury. Seeds, grains, cereals and dry plant products are generally able to withstand these low pressures without ill effects.

SUSTAINED VACUUM FUMIGATION

The pressure in the loaded chamber is reduced to betwen 25 to 150 mm (1 to din) of mercury. The fumigant is then introduced, causing usually only a small rise in pressure. No further alteration is made to the pressure in the system until the end of the treatment which may last for 1.5 to 4 hours, at which time atmospheric pressure is restored by allowing air to enter. The

fumigant/air mixture is then pumped out. The cycle of air introduction and evacuation may be repeated several times, A process referred to as "airwashing", until it is considered safe to open the door for unloading (Page et al, 1953). This method is used widely all over the world for treating tobacco, grains, flour and meals. Even in this type of vacuum treatment, gas distribution may not be entirely uniform; some chambers are equipped with recirculating systems and others with fans. Some living plants are able to tolerate sustained vacuum treatments at pressures in the region of 380 mm (15 in) of mercury. Such treatments may be useful in the control of borers or other insects inside stems or other plant tissue.

A substantial number of dormant, nonfoliated plants, roots and bulbs can be fumigated safely under a sustained vacuum of 100mm (4in) at an exposure period of 2 to 3.5 hours, as shown in Schedule F. In some cases, a higher vacuum can be used without injury.

ATMOSPHERIC PRESSURE RESTORED

Following the creation of the initial low pressure, atmospheric pressure may be restored in the chamber in several different ways, which may be summarized as follows:

1. **Gradual restoration of atmospheric pressure. The required dosage of fumigant is discharged and air is then slowly introduced until a pressure just below atmospheric is reached after 2 hours in a 3-hour exposure period (Monro, 1958b).**

2. **Delayed restoration of atmospheric pressure. Following discharge of the fumigant,**

the vacuum is sustained for about 45 minutes and the air is introduced rapidly into the chamber (Brown and Heuser, 1953a, b, 1956; Monro and King, 1954).

3. Immediate restoration of atmospheric pressure. After the fumigant is discharged, atmospheric pressure is rapidly restored in the system by opening one or more valves leading into the chamber. This method, rather unscientifically described as the released vacuum or dissipated vacuum method, has been used extensively in North America for the fumigation of baled cotton (USDA, 1915).

4. Simultaneous introduction of air and fumigant. In this technique, special metering equipment is provided whereby the fumigant is introduced simultaneously with air so that 8 constant proportion of fumigant to air is maintained until the entire dosage has been introduced (Lepigre, 1949).

At the end of the treatment by any of these procedures, sir washing is carried out as described above for the sustained vacuum technique.

In a series of experiments using compressed bales of jute containing larvae of the cadelle, Tenebroides mauritanicus, it was found that the relative efficacy of these four methods, from the viewpoint of insect mortality, was in the same order as listed. In effectiveness, the sustained vacuum technique occupied an intermediate position, immediately below method 2. The results of these experiments are summarized diagrammatically in Figure 38 (Monro, 1958c).

It must be emphasized that, while the information given here may be useful as a guide for the investigation of vacuum fumigation techniques, each problem will have to be solved separately, due consideration being given to the commodity involved, the species of insects and their stages and the climatic factors in the country where the work is being done.

Equipment

A detailed discussion of the structure and operation of available mechanical devices for vacuum fumigation is not given in this manual. Each manufacturer supplies the information pertaining to his product. Some information on the construction and performance standards of vacuum fumigation chambers has also been given in Sec. IV - Part 1 of Plant Protection and Quarantine Manual (USDA, 1976). In Countries where the method is used, the responsible scientific authorities would work out treatments they consider best for dealing with their own particular problems.

FIGURE 38 - Diagrammatic comparison of mortalities of larvae of Tenebroides mauritanicus (L.) in five methods of vacuum fumigation of compressed bales of jute bags at 25C. facie bale contained 300 bags and measured 50 x 50 x 60 cm.
(Monro, 1958c)
Locations are:
A. Upper free space
B. On top of bale

C. Inside top bag
D. 12 cm from top surface
E. Centre of bale
F. 12 cm from lower surface
G. Underneath bale
H. Lower free space

Some suggested vacuum fumigation treatments are given in Schedule P. They are to serve mainly as a guide in the operation of small chambers of less than 25 m (1 000 ft) capacity for plant quarantine purposes.

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10. Fumigation of grain in bulk

The fumigation of sacked grain was discussed together with that of stored products in Chapter 8, because the techniques for the treatment of all sacked materials are basically the same. On the other hand, the fumigation of grain stored in bulk presents special problems of gas distribution, and it is necessary to deal with this subject separately.*

Fumigants are used for disinfesting grain in most countries of the world. The chemicals used and the methods of application vary greatly. Differences in technique may be influenced by the nature of the crops and by the wide range of climatic conditions encountered. The effect

of type and condition of grain on the efficacy of fumigation has been described by Harein (1959). One of the most important variables lies in the diversity of structures used for storage. The shape, size and type of construction of each particular structure create special problems in achieving and maintaining the concentrations required for the control of the insects and mites present in the grain.

The more important grain-infesting insects are cosmopolitan; they have been transported through international commerce to many parts of the world. A treatment effective in one country may therefore be successfully adapted in another if due allowance is made for the variables mentioned in the preceding paragraph. The relative amount of destruction caused by certain species varies somewhat from continent to continent or from country to country. Therefore, the most serious pests of grain may differ in their order of importance from one area of the world to another.

The dosages of the various fumigants as given in Schedules A and B are recommended as guides. Experience gained in a given country, or under specialized conditions, may indicate the need for modifications.

It was stressed in Chapter 2 that there are great variations in the susceptibility of insects to different fumigants, not only among species, but also between stages within a given species. Treatments given in this chapter should be adequate to deal with all insect species and their stages which feed and develop inside or outside the grain. Additional dosages may be needed for special conditions. All stages of the Khapra beetle, Troqoderma qranarium, other beetles

of the genus Trogoderma, and the cadelle, Tenebroides mauritanicus, show exceptional resistance to ethylene oxide and to halogenated hydrocarbon fumigants, such as methyl bromide, ethylene dibromide and ethylene dichloride. When these insects are present in the grain, it is advisable to double the dosages given in Schedules A and B of fumigants containing these ingredients. On the other hand, these insects are quite susceptible to hydrogen cyanide and additional treatment is not needed with this fumigant.

*** Contact insecticides are often applied to grain as it is run into storage. The use of these is often subject to rigid governmental regulations on account of the poisonous residue problem. There are wide variations in practice or in regulations in different countries. Formulations containing pyrethrins, malathion or other insecticides are permitted by some governments. A detailed discussion of these insecticides is outside the scope of this manual.**

A number of different techniques are described here, some of which are peculiar to certain countries or districts. From this selection, suitable applications may be adapted or devised to solve local problems.

It should be pointed out that in some countries there are strict government regulations concerning the choice of materials that may be applied to grain for disinfestation purposes. The treatments discussed in this chapter have been practiced in some countries, but not necessarily in all. Before grain fumigation is undertaken, therefore, it is necessary to make sure that the use of the chosen material is not against the regulations of the country where the treatment is to be carried out or of any country to which the grain may be exported.

When a storage place is partly full, insects may be present not only in the bulk of the grain but also on the walls. If control is to be effected solely by fumigation, the dosage should be the same as for a full storage. As an alternative measure, contact insecticides may be applied to the walls either as a spray or as a smoke if appropriate means are used for preventing the contamination of the grain. If only the grain needs to be fumigated, the method of surface application described below may be used. If the moisture content of the grain is not high, the surface of the mass may be covered with a gas-proof sheet to prevent the vapours from diffusing upward into the empty space.

As already stated, the shape and size of a given storage unit are important considerations. Grain storage units are usually broadly classified for fumigation purposes as follows:

1. Upright (vertical) storage. In this type, the height is greater than the length or width. It is mainly found in the form of silo bins in storage units with elevators. In cross-section the bins may be almost any shape but are usually circular or rectangular.

2. Flat (horizontal) storage. One dimension, either length or width, is greater than the height. This type includes a wide variety of structures, including many temporary (sometimes called "distress") storage units. Railway freight cars (wagons) or motor vans (trucks or lorries) may be included under this heading.

3. Farm-type bins and storage units. These are usually small and often loosely

constructed and their treatment requires special consideration.

In the following description of methods of grain fumigation, mention will be made of special applications suited to these three types of storage.

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Methods of grain fumigation

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The differences between methods of grain fumigation are related primarily to the type of fumigant initially applied to the grain mass. Gas-tight structures that will retain a sufficient concentration of fumigant for the required period of time are essential for effective treatments. For the fumigant phosphine, gas tightness is particularly important because this gas can penetrate to escape much more easily and rapidly than other fumigants. The standard of gas tightness recommended by the Australian Committee on Agriculture (Winks et al, 1980) for fumigation with phosphine requires structures to be sealed so they can maintain an excess internal pressure from 500 Pa (2 in water gauge) to 250 Pa (l in water gauge) for not less than

5 minutes in filled structures of 300 to 10 000 tonnes capacity. The roofs of structures sealed to this standard must be painted white to reduce thermal expansion of the atmosphere within the headspace.

In the case of phosphine it is essential to maintain uniform concentrations for sufficient periods of time to kill all insects present; high dosage rates do not compensate for inadequate standards of gas tightness with this fumigant. The objective of the fumigation must be complete control of all stages of all species of pest so that resistance to the fumigant does not develop.

DIRECT MIXING (VERTICAL STORAGE)

By this method, the fumigant is applied to the grain so that it is distributed as evenly as possible from the beginning of the treatment. Direct mixing is often employed when infestation is general throughout the mass and when there is access to the grain stream during filling or transfer from one bin to another. Only solid or liquid-type fumigants are used in this way. Fairly even distribution of the gas with good control of the insects can usually be obtained.

The solid-type fumigants used for this treatment are aluminium phosphide tablets or pellets evolving phosphine and granular calcium cyanide evolving hydrogen cyanide. Aluminium phosphide tablets or pellets can be inserted in the grain stream by hand or with an automatic dispenser calibrated to deliver a dosage appropriate to the rate of loading in the bin (Figure

39). Calcium cyanide is usually discharged from an automatic applicator. Also, aluminium phosphide powder formulation in paper bags may be added to grain as bins or silos are filled. In this case, it is necessary to provide for removal of the bags after fumigation is complete.

A convenient method for applying bags of aluminium phosphide to grain in vertical storages involves a permanently installed system of pipe-, fixed vertically to the walls of the bins or silos (Anon, 1980). With this system the fumigant is applied in long narrow bags 22 x 6 cm, by hooking the bags to a chain at prescribed intervals and suspending them in the pipe. There are caps at both ends of the pilling system; the top cap is equipped with a coupling to retain the chain holding the fumigant bags and the bottom cap is threaded for easy cleaning of the pipe. Small portals in the piping permit the fumigant to diffuse out arid penetrate into the grain mass. This system eliminates the need for turning the grain to disperse the fumigant and allows easy removal of the bags of expended dust residue after the treatment. It should be noted that this system is not designed for tablets or pellets of aluminium phosphide and could be hazardous if high concentrations of the gas evolve in a confined space.

Liquids may conveniently be applied to the grain by means of ordinary watering cans with the sprinklers left on or by means of ordinary piping or tubing of not more than 1 cm (0.375 in) internal diameter. The required dosage for each lot of 1 000 bushels (36 m) of grain may be applied from one sprinkler can to each lot as it passes on the heft. If necessary, by prearrangement with the weigher, there can be a one- or two minute break between 1 000 bushel drafts. This arrangement also enables the fumigator to keep a check on even application of the fumigant. In upright storages of grain, in order to ensure adequate

distribution at the top and bottom of the mass, an extra dosage at the rate required for 1 000 bushels may be placed at the beginning of the run for the first 1 000 bushels and the same amount sprayed or sprinkled on the surface of the grain mass to control surface infestation.

Storage bins of the vertical type usually have manhole covers in the ceiling and these are usually closed immediately to prevent loss of fumigant. If there is no roof to the storage unit, the grain should be covered with a gasproof sheet of the type already described in Chapter 8.

For this work there are also available automatic applicators which apply the liquid continuously or intermittently. It should be pointed out that devices merely emptying drums with a preset discharge valve are inaccurate, because the pressure of the liquid above the valve varies from the time the container is full until it is almost empty, and a higher proportion of the dosages is therefore discharged into the grain at the beginning of the run. The only reliable automatic device is one employing a gear pump equipped with a bypass so that there is a constant pressure of the fumigant on the discharge orifice, the excess fumigant being returned to the drum. In this way, the fumigant is applied to the grain stream at a constant rate of discharge according to the dosage required.

<u>Precaution</u>. In the application of fumigants to grain streams, care should be taken that fumes are not inhaled. Liquid-type fumigants are especially hazardous because vapours may be given off before the grain enters the storage.

<u>Warning</u>. When grain fumigants are atomized or sprayed into closely confined spaces, or into

a shallow space above the grain surface, the concentration of fumigant may exceed 2 percent by volume in air. Canister-type respirators will afford no protection under these conditions. It is better for the fumigator to remain outside and to apply the fumigant through an opening (see Chapter 3 Figure 8). If it is absolutely necessary for operators to enter such a space during fumigations, air-line or self-contained respirators should be worn.

As the grain enters vertical storage units, currents of air containing fumigant vapours may be forced up into the working space. Operators may therefore be exposed to fumes even when working outside the structure being treated. Under these circumstances, it may be necessary to wear respirators fitted with the proper canisters.

Many modern silos have windows running along either side of the head house, and these should be kept open whenever possible so that a good cross-draught of fresh air is produced. Under such conditions of good ventilation, respirators need not necessarily be worn; however, gas detection equipment can be used to ensure that harmful levels of fumigant are not present.

Dosage and Exposure

Dosages of fumigants recommended for the mixing-in-grain technique are included in Schedules A and B. Dosage in fumigation of grain by direct mixing is modified by the kind of grain treated and the gas tightness of the structure. Wind forces, thermal expansion of the internal gas and changes in atmospheric pressure can also influence gas loss from storage

structures (Mulhearn et al, 1976).

The dosages in the schedule shown for upright storage units apply to steel or adequately gas tight concrete bins. The rates should be doubled for wooden bins. Unless specifically mentioned in the text or schedules there is no definite exposure period in this type of fumigation. However, the grain should be left undisturbed for at least 72 hours. The usual practice is to leave the grain for a much longer period so that the fumigant vapours are gradually dissipated by leakage from the structure. Fumigants applied and left in this way should not contain ethylene oxide.

The importance of proper aeration of fumigated grain used for seed especially under tropical conditions, is demonstrated by the work of Caswell and Clifford (1958) in Nigeria. An ethylene dichloride and carbon tetrachloride mixture (3:1) was applied to maize in jars, which were immediately sealed with air-tight lids, according to the local custom. Although the actual germination of the seeds was not significantly affected, root and shoot development of young plants was seriously impaired when the maize was kept sealed under fumigation for more than one month.

SURFACE APPLICATION (FLAT STORAGE)

The surface application method has so far been used mainly with liquidtype fumigants. The liquids are sprayed evenly over the top surface of the grain and the vapours slowly evolve and diffuse downward through the bulk. This method is usually employed only when the grain

cannot conveniently be turned or as an emergency measure.

Diffusion may be slow and distribution with some fumigants is often not uniform. Carbon tetrachloride has given good distribution in grain in deep bins in the U.K. following a single surface application, and there are a number of standard fumigant mixtures which have been used for this purpose. Less hazardous substitutes for carbon tetrachloride, such as methyl chloroform, may be used for this type of treatment in the future. Unmixed carbon disulphide has been used in many countries, although its tendency to burn or explode is well known. Propylene oxide has been used in France and Algeria. In this type of treatment, the grain is usually not aerated and the vapours remain in the grain until dissipated by leakage.

The fumigants usually recommended for this type of work and suggested rates of application are summarized in Schedules A and B.

The selection of methods of application of fumigants to the surface of stored grain is influenced by the size and type of storage. Methods are therefore discussed under two main headings: large hulk fumigations and small or farmtype storage fumigations. In all storage units with all techniques, the fumigants diffuse more evenly through the moss when the surface of the grain is level. Therefore, if at all possible, every reasonable effort should be made to level the grain surface before the fumigant is applied.

<u>Larqe Bulk Fumigation</u>

The liquid-type fumigants are usually applied to the surface of bulk grain by means of sprayers. If the surface area is large, power sprayers may be used. If possible, application should be made from outside the bin or storage through a manhole, roof hatch, window or door. However, in large Flat storage units it may be necessary for the operator to walk across the surface of the grain as shown in Chapter 3, Figure 9.

In treating large bulks of grain by surface application, extraordinary precautions, over and above those already mentioned, should be taken to protect the operators The men applying the fumigant should wear airline or self-contained oxygen or compressed air respirators.

With all types of sprayer the nozzles are removed to facilitate the rapid application of the liquid to the surface of the grain. for bulks up to 30 000 bushels, a sprayer which delivers the liquid at the rate of 35 to 55 1 (8 to 12 gall) per minute is suitable. This may be effected by using a bronze gear pump operating at about 90 revolutions per minute in conjunction with a 3.5 hp gasoline engine or the power take-off from a tractor. For larger bulks, adequate hose and a pump capable of throwing a stream about 25 m (75 ft) at the rate of 450 1 (100 gall) per minute should be used.

Hazards to personnel applying liquid fumigants in large flat storages may be greatly reduced if the grain is sufficiently level to permit sleds to be drawn across the surface from one end to the other. The spray nozzles may be placed on a spray boom mounted on the sled and adjusted to distribute the required dosage in an even spray on both sides as the sled is pulled across the storage by means of a rope or chain. If the storage space is wide, two or more sleds

should be pulled simultaneously across the surface so that the operators can leave the building immediately after the fumigant has been applied.

Methyl bromide

Although methyl bromide is sometimes considered impractical for surface application, when deep penetration of a grain mess is involved, it has been successfully used for such purposes. Ooffe and Nolte (1957) fumigated a large bulk of maize 5 m deep in a flat storage unit measuring 70 x 60 m using gasproof plastic sheets. The fumigant was applied at the rate of 48 9 per m for an exposure of 24 hours in a grain mass where the temperature varied from 11 to 22C. It was discharged under the gas-proof sheets over the surface of the grain from 64 evenly spaced outlets in polyethylene tubing connected to two 70 kg cylinders of fumigant.

A method for treatment of high vertical bins of grain by applying methyl bromide with carbon dioxide has been developed by Calderon and Carmi (1973) . The carbon dioxide acts as a carrier and will take the methyl bromide down through the grain mass to the bottom of the bin. Carbon dioxide from blocks of dry ice or from pressurized cylinders is applier) at the surface of the grain with the methyl prornide. When the dry ice is used, blocks 1 - 2 kg in size are spread over the surface of the grain and the methyl bromide is released through a garden sprinkler or, preferably, through a spray nozzle that is positioned centrally on the surface of the grain. When carbon dioxide in pressurized cylinders is used it is released simultaneously with the methyl bromide. Special cylinders have been developed to allow sufficiently rapid release of carbon dioxide (2 .6 kg/min) and it is vaporized by passing through a hot water

vaporizer. Dosages of 50 g/m methyl bromide and 200 - 250 g/m carbon dioxide at 20C and above are used.

It has been found that the downward movement of the carbon dioxide-methyl bromide mixture into the grain may be so rapid in some treatments that the concentration in the upper layers is reduced to give a low c x t product; in such cases the dosage of carbon dioxide should be reduced by 10 - 20 percent. If the bins are properly sealed, the internal pressure may rise 10 15 cm on a water gauge due to expansion of the gases.

This method has been used successfully for ten years as a routine treatment of grain in vertical silos in Israel (Navarro, 1981).

Phosphine

In flat storage units, in which the depth of the grain does not exceed 10 m (about 30 ft), tablets, pellets or sachets containing aluminium phosphide may be used. To simplify application, it is advisable to level the surface of the grain as much as possible before the work is begun.

The fumigant is usually applied by probing into the grain (Figure 40). Probes specially designed for the purpose are used to insert the fumigant into the grain, bet under farm coniditions ordinory 2 .5 cm (l in) diameter iron pipe may be used (Watters, 1967). The number of tablets or pellets used per probe is determined by dividing the total amount of fumigant to be

used by the number of probings to be made. For large areas of grain surface, a convenient method for measuring the distances for application is with a rope or stout cord, marked at appropriate intervals, stretched from opposite walls. In most storage units where there is considerable air space above the grain bulk, or when it is considered that significant loss of fumigant may occur above the load, it is advisable to c over the entire mass with gas-proof sheets.

Large masses of grain may also be treated by distributing the fumigant over the surface and covering with gas-proof sheets to allow the gas to difuse into the grain. McGregor and White (1969) have successfully fumigated stacks of bulk cottonseed 32 m long, 20 m wide and 10 m deer' in this way. Analysis of gas concentrations showed that the phosphine diffused throughout the mass of cottonseed and an appreciable concentration was still present 120 hours after the fumigant was applied. Wainman et al (1974) described the successful fumigation, using pliosphine, of 750 tonnes of wheat in inflatable butyl rubber silos.

Large quantities of grain can also be treated in the holds of cargo ships in an "in-transit" shipboard fumigation procedure. Redlinger et al, (1979) found that good dispersal of the gas and control of insects was obtained when aluminium phosphide tablets were spread on the grain at intervals during the loading operation (i.e. when the hold was 33, 67 and 95 percent full). In these treatments the fumigant is allowed to remain in the grain during the voyage of the ship and until the cargo is removed.

Note. When fumigants are used for treatments on ships the guidelines given by IMCO (1981,

or subsequent recommendations) to provide for safety of the ship's crew end longshoremen should be strictly adhered to.

FARM STORAGE FUMIGATION

The gas tightness of the structure is particularly important in small storages, because the mass of grain is not large enough in itself to retain vapours once leakage begins at any point. Steel, concrete or tight wooden structures are usually satisfactory without alterations. For small cracks or openings a caulking gun may be used to apply compounds that will give a semipermanent gas-tight seal. Most wooden storages are leaky and it may be necessary to line the floor and walls on the inside with stout roofing paper or plastic sheeting and to nail boards over any visible openings in the walls. If it is inconvenient to move grain, the paper or plastic sheeting may be applied to the outside of the bin or building, but this is not as effective as an inside lining. If possible, do not fumigate during windy weather because strong air currents hasten leakage.

Experience has shown that results are not usually as good in small bulks of grain as in large bulks. One reason is that there is often a poor kill on the top surface. Also, in small bulks good control is more difficult through the mass in grain that is "tough" or has excessive dockage.

The use of aluminium phosphide tablets has proved effective for the treatment of small storages. See discussion above for details of this method. If aluminium phosphide is used, it is

recommended that a tarpaulin or polyethylene sheet be placed carefully over the surface of the grain after the tablets are applied.

The best way to apply a liquid fumigant to small storages is by spraying the surface from the outside of the building with the aid of a stirrup pump. Some liquid fumigants, such as chloropicrin, are supplied in l lb (0.45 kg) cans or bottles. In some applications, it is convenient and satisfactory to puncture the cans or open the bottles, invert them and thrust the opening about 15 cm (6 in) below the surface of the grain. It is recommended that the openings be stuffed with wads of cotton or cellucotton to prevent too rapid loss of the liquid, but loosely enough to produce a wick effect that will allow the liquid to flow gradually into the grain. This method permits accurate and economical distribution of the dosage since the required number of containers may be spaced evenly on top of the grain.

Piles of grain, large or small, may be treated by surface application in any of the ways described above. However, only partial kills may be expected if the grain is not covered with 8 gas-proof sheet either before or immediately offer application of the fumigant. This method should be attempted only in calm weather.

At best, fumigation of piles outdoors is a temporary expedient. If at all possible the grain should be moved into a storage or carrier and treated in a more effective way.

SURFACE INFESTATION

With certain species of insects, such as the Indian meal moth, Plodia interpunctella (Hbn.), infestation may be confined to the top of the grain. This problem cannot be solved by the usual method of surface application of fumigants because the vapours diffuse down through the grain, and it would thus be necessary to treat the whole mass at great expense in order to deal with grain near the surface. Also, turning the grain only spreads the infestation throughout the entire bulk of grain. In silo bins or other storage units, which can be made air tight above the grain surface by closing manholes and other openings, surface infestations can be treated with materials such as dichlorvos to obtain control, particularly infestations of some of the moths, Slow release resin strips that will give off 20 mg dichlorvos per m per week have been found to give satisfactory control of moths in granaries (Schmidt and Wohigemuth, 1979). Surface sprays of dichlorvos may also be used; in this type of application appropriate precautions regarding exposure of personnel should be taken.

For storages with ventilators, where dichlorvos vapour may be lost, an aerosol emission system has been found superior to the slow release strips (Bengston, 1976). Using a dosage of 1 g dichlorvos per 100 m , released at daily intervals, satisfactory control has been obtained in commercial storages in Australia. The safety and reliability of the system were found to be satisfactory.

It should also be pointed out that incipient surface infestations of insects may be arrested by using pyrethrum, malathion or other approved materials applied as a fine mist in the space over grain. Ultra low volume sprayers that produce very fine particles of spray give good results.

"HOT SPOT" FUMIGATION

Treatment of localized areas in a grain mass is often a useful technique for dealing with incipient infestations. These "spots" are usually recognized and defined by a local rise in temperature. Liquid-type fumigants applied through tubes or aluminium phosphide tablets are the best materials to use. In this type of work the tendency is to underdose. Enough fumigant should be applied to maintain the required lethal concentration, not only in the region of infestation, hut also in the margins surrounding it for I or 2 m (3 to 6 ft) in every direction (Note: Results are improved if the marginal applications are made first in a ring surrounding the "hot spots", followed by those applier) to the spot itself. The vapours from the marginal treatments tend to slow down diffusion of the fumigant from the infested spot.) For liquids applied in a flat or farm-type storage, 8 good rule is to use enough to treat the known area and also the grain from the surface to the floor.

Methods of application and dosages are the same as for surface applications.

RECIRCULATION

For the treatment of bulk grain, recirculation of the fumigant by means of permanent or temporary installations provides an effective and economical means of insect control. This method was first investigated in Europe in connexion with the development of fixed installations for drying grain in silo bins. Subsequently, it has been widely adopted for use in grain silos and with fixed or temporary drying equipment. One of the more important

advantages of the method is that lengthy exposure periods are unnecessary. In addition, distribution of fumigant throughout the grain mass may be improved.

Recirculation is only practicable when the walls of the storage units are sufficiently gas tight to prevent the fumigant/air mixture from being forced out while under positive pressure from the blowers. Many concrete silos may be used without further alteration, but with some it has been found necessary to apply sealers to the inside walls. For this purpose, the best materials are an internal bituminous coating covered by two layers of rubber-based paint.

In addition to its use in permanent installations, recirculation has been successfully improvised as an emergency technique, especially for dealing with problems associated with the long-term storage of crops. Many diverse structures used for grain storage have been fumigated, including oil storage tanks, cargo ships, Quonset huts, cottonseed storage tanks, conventional silo bins and ordinary steel railway cars.

The recirculation method is usually advocated for methyl bromide, hydrogen cyanide or liquid type fumigants but it has not been recommended for phosphine. Because mixtures of phosphine and oxygen may produce explosions at reduced pressures, considerable care has been taken in the past to avoid procedures that might bring about such effects. However, test treatments with phosphine in large grain storages have shown that this fumigant can be dispersed more rapidly and uniformly by a recirculation procedure to give more effective and economic treatment than other methods (Cook, 1980).

The procedures used for recirculation of phosphine are in the developing stages and may be subject to variation and refinement in the future. Possible hazards that may arise in employing this technique are not fully known and require further investigation. As both these procedures and the precautions needed for recirculation of phosphine are somewhat different to those developed for other fumigants, they are outlined separately after discussion of the older established methods.

Fixed Installations

Permanent recirculation systems designed for fumigants other than phosphine and of the type illustrated diagrammatically in Figure 41 are most useful in grain silos at ports or other transfer points where grain is not stored for lengthy periods. The structure and operation of such equipment will not be discussed in detail; this information is furnished by the engineering companies which design the equipment according to the needs of each particular establishment.

Temporary Adaptations

Recirculation methods have been devised for utilizing existing aerating systems in storage units. This is effected simply by providing some means of returning the air which has passed through the grain back into a blower so that continuous circulation is achieved. A similar system for fumigation only may be installed in a storage not already equipped for aeration.

Although the air flow rates in a given aeration system are considerably reduced by the addition of a return duct, the blowers used are adequate to provide the required flow of fumigant/air mixture.

In existing aeration systems, recirculation may be effected in the following ways:

> **1. By provision of portable flexible tubing which may be connected at the bottom to the aeration duct in the hopper and at the top by means of a specially constructed duct leading through the manhole or other opening into the top of the storage; the portable tubing and upper duct can be moved to any storage bins requiring treatment (Figure 42).**
>
> **2. Where several adjoining bins are used, a single metal duct can serve as the return and be joined through the top and bottom manifolds to any bin as required.**
>
> **3. An empty bin can serve as the return duct if suitably connected to an adjoining infested bin; however, use of this may necessitate extra fumigant to maintain full concentration throughout the system.**
>
> **4. Two filled and infested bins can be connected and treated at the same time, the fumigant being drawn down through one and up through the other.**

Where there is no existing aeration system, a perforated plate can replace the gate in the

unloading spout, a duct run from this plate to the blower and a duct or flexible tube run to the top of the bin, thus completing the circuit. In that arrangement, the static pressure is likely to be high, but a portable blower of sufficient power can be provided.

The gaseous-type fumigants may be recirculated upward or downward through the grain according to convenience or an existing direction of flow. In practice they are usually released into the system near the blowers.

FIGURE 41. - Permanent installation for fumigation of grain in silos by recirculation.(Societe anonyme Mallet)

Air Flow Requirements

In the design and installation of fumigant recirculating systems, advantage may be taken of knowledge already obtained in the study of the aeration of stored grains. There are four basic factors influencing the design of such systems.

1. A rate of air flow through the grain adequate both for circulation of the fumigant and cooling of the grain is 1 litre of air per minute for each 50 1 of grain (0.025 ft per minute for 1 bushel).

2. The air flow through grains varies according to the species and condition of the grain. Shedd (1953) has published a chart from which the pressure drop per foot

depth of various grains may be read in terms of inches of water. These values may be used to calculate the total resistance to air flow of a given depth of grain in storage. When the grain has been stored for some time, it will pack and a "pack factor" is applied to the calculation to allow for this.

3. The ducts offer resistance to air flow. Charts are available in standard heating, ventilating and air-conditioning guides or manuals for calculating the friction loss in ducts for different air flows. Factors are given for calculating additional resistance at elbows in the ducts.

4. It is necessary that particular attention be paid to the provision of a well-designed air distribution system at the bin bottom; otherwise there may be an excessive loss of pressure at this point. Even with satisfactory systems using large distribution cones, antigrading devices or perforated grills, the loss of pressure at the point of entry of the air into the bin bottom may be larger than the fall in the rest of the column of grain. This is due to the high air velocity at this point compared with that higher up in the bin where the flow is more evenly distributed over the crosssection.

With calculations based on these four factors, it is possible to determine the capacity of a blower capable of bringing about the required air flow in a system consisting of a given storage and the ducts attached to it.

The gaseous-type fumigants are best suited for the recirculation technique and are usually

discharged into the system just behind the blower. Liquidtype fumigants are not usually recommended in this type of application, except in case of emergency. Liquid types (if used) may be sprayed over the grain surface before the recirculation starts.

Dosages

The rates of application for the fumigants recommended for use with recirculation are given in Schedule A.

Exposure

In the average silo bin, 15 to 20 minutes are required to replace the original air by the fumigant/air mixture. Unless the system leaks, it is advisable to recirculate the gas/air mixture at least two, and preferably four or five times. This will ensure the thorough mixing of air and fumigant in all parts of the grain mass.

At the end of 24 hours (the usual maximum exposure period for this type of treatment), the duct is disconnected from the top of the storage and the blower is operated for at least three hours while the fumigant vapours are driven into the open air above the structure.

Detailed Calculations

Fumigant manufacturers supply booklets and brochures containing detailed information on

how to carry out the necessary calculations outlined above, together with recommendations for the types of blowers and other equipment needed.

FORCED DISTRIBUTION

Application of methyl bromide and some of the liquid-type fumigants has been made in storages without modifying existing aeration systems. By operating the blowers, fumigant applied at the top of a storage may be drawn down to the bottom or when introduced at the bottom, may be forced up to the surface. It is necessary to have the means to determine when the gas/air mixture has reached the bottom or top of the mass. This may be done for methyl bromide and liquid-type fumigants containing organic halides with the aid of a thermal conductivity gas analyses, or even with an ordinary halide leak detector. When liquid-type fumigants are used, it has been the practice, especially if a thermal conductivity analyser is available for checking, to force the vapours back to the surface every 24 hours.

With this technique, at the end of the required exposure the residual vapours are partially exhausted into the open air by means of the blowers. However, by the process of desorption, the fumigant concentration may build up in the intergranular air spaces, and exhaustion by blowers may have to be repeated a number of times at intervals of several hours.

Because this method is simple and does not require the extra ducts needed for the recirculation, it appears, superficially, to offer an inexpensive and convenient method of grain fumigation, especially as no modification of existing aeration systems is required. However, it

has been found that the method, referred to as "forced distribution", has several disadvantages both in theory and in practice. These are concerned principally with difficulties in obtaining even distribution of the fumigant as compared with the ordinary recirculation technique described above.

When this method is used, dosages are based on those recommeded for recirculation in Schedule A, but it is probable that these would have to be increased by at least 50 percent.

RECIRCULATION PROCEDURES FOR PHOSPHINE

Two procedures have been tested for the recirculation of phosphine in grain storages. The first, which has been successfully used in a number of trials, employs extremely low air flows to give a complete air change within the grain mass in 8 to 12 hours (e.g. approximately two air changes within the 18to 20-hour period required to release phosphine from the tablets). For example, a large tight steel or concrete storage bin would have a small return pipe (ca 150 mm diameter) connected from the top of the bin to the inlet of a 2 hp blower and then to the aeration system at the bottom of the bin for circulation of the fumigant. Aluminium phosphide tablets or pellets at the recommended rate are broadcast over the surface of the grain before the bin is sealed. When the concentration of phosphine in the headspace has reached 300 - 600 ppm, the blower is activated to circulate the gas through the grain mass. Concentrations of 320 - 340 ppm have been found dispersed throughout the entire grain mass within 12 hours of the first day of treatment with this technique. The blower should be run for 24 to 30 hours, with the fumigation continuing for at least three days and preferably for

five days. Using this method, it is claimed that the dosage of fumigant can be reduced and the exposure time shortened substantially (Cook, 1980).

The second method, which has been developed only recently, uses a probe inserted in the grain to carry the fumigant down and through the grain mass. A small aluminium probe, perforated with 3 mm holes in the lower 4.5 m, is pneumatically drilled into the grain and a small high speed blower fixed at the top to carry the fumigant-air mixture down through the probe. The fumigant-air mixture brought in from the headspace over the grain is introduced on the suction side of the blower and is blown down the probe to disperse laterally and displace the intergranular air in the grain. With this method the fumigant was found to radiate out from the probe at a relatively uniform concentration in a 3 350 tonne bin of grain in 24 hours of blower time (Cook, 1980).

GENERAL SAFETY PRECAUTIONS

The application of fumigants to large masses of grain in various types of structures and storage units involves the dispensing of considerable amounts of fumigant. Under these conditions, safety measures are of prime importance, not only to protect the operators, but also those working in the vicinity. It is also necessary to ensure that all fumigated grain is thoroughly aerated before it is released to customers or consumers. It is therefore considered advisable to recapitulate the precautions required.

Operators. Only fully trained and qualified operators should be entrusted with the fumigation

of grain in commercial storage units and installations. Most countries have national or local regulations covering the licensing of operators. Some manufacturers require that persons using their products receive the required training and they provide facilities for this. Such stipulations often do not apply to the use of fumigants at farm level. These are usually small-scale treatments and are often carried out by the farmers themselves; however, adequate instructions on both methods of application and precaution should be given.

Application. The operators must be fully protected at the time of application. This is especially important in connexion with liquid-type fumigants. Proper ventilation of the working space where the materials are being applied is most necessary.

Other persons working in the vicinity must be warned that a fumigation is in progress. Appropriate warning signs should be posted wherever necessary.

Recirculation and forced distribution. While circulation and distribution of the fumigant are being undertaken, persons working in the building or in adjoining ones must know that these operations are in progress and take the necessary precautions to protect themselves.

Careful checks should be made of all recirculation equipment, fixed or temporary, to ensure that there is no significant leakage of the fumigant from any part.

SAFETY PRECAUTIONS FOR PHOSPHINE

In addition to the general precautions necessary for all fumigants, special care should be exercised with phosphine to avoid subjecting it to any condition that might produce fire or explosion. It must be stressed that this fumigant can be employed safely under normal conditions of fumigating without undue hazards; fire or explosions are not likely to be produced in conditions normally recommended in fumigation procedures. However, phosphine will react with oxygen to produce Flame or explosion at high concentrations and also over a range of low pressures.

The spontanteous flammability of phosphine is well known. Commercial formulations are designed to release the gas slowly so that the concentration remains well below the flammability level. However, manufac turers advocate caution against any practice that will cause rapid release or allow high concentrations of phosphine to build up.

1. **Formulations should never be allowed to come in direct contact with any liquid, particularly water, as this may cause rapid release of the gas.**

2. **No formulation should be used under any condition which will allow the gas concentration to reach the lower level of flammability (1.79 percent by volume). It should never be confined in small gas-proof enclosures, such as plastic bags, nor should it be packed in envelopes or dumped in piles where excessive levels of the gas could build up.**

In addition to flammability at 1.79 percent, phosphine can react with oxygen to produce an

explosion at lower concentrations if it is subjected to reduced pressures. In carefully controlled experiments with pure materials and very low pressures, phosphine has been found to combine with oxygen in an explosive chain reaction (Dalton and Hinshelwood, 1929). This reaction is promoted by other gases, including nitrogen and carbon dioxide, but it seems to be reduced by moisture.

The possible significance of this reaction to the use of phosphine in recirculation systems is not known at this time. Experimental evidence suggests that the reaction occurs at pressures well below those expected in commercial recirculation systems. however, until all of the conditions that will promote the reaction are known, great care should be taken in any treatment where phosphine might be exposed to pressure changes. Further research and development on all aspects of the procedures, including investigations on the conditions produced in recirculation systems (e.g. pressure changes, the presence of dust and other gases, etc.) are needed before it can be generally recommended.

AERATION

Aeration procedures vary according to the fumigants used and the type of installation.

Methyl bromide, chloropicrin and hydrogen cyanide should not be kept in the grain beyond the prescribed exposure periods. It is also not usually recommended that aluminium phosphide be left on the grain beyond normally recommended exposure times. Exposure periods for all grain fumigations are given in Schedules A and B.

Liquid-type fumigants containing ethylene dibromide, ethylene dichloride and carbon disulphide in admixture with carbon tetrachloride or chloroform are often left on the grain until the normal turning procedure is undertaken. The vapours tend to dissipate gradually during this process.

After completion of the required exposure period in ordinary-type silos and elevator bins, the grain is turned onto the belts and elevators and transferred to a new bin. In recirculation and forced distribution systems, fixed or temporary valves are opened or ducts disconnected, at the top of the silo bins and the blowers are operated for 3 to 4 hours to blow fresh air into the grain and thus ventilate the fumigant from the mass. In all these aeration procedures precautions must be taken to protect people in the vicinity so that they are not exposed to the fumes as they are being exhausted.

On the completion of treatment of smaller amounts of grain, such as in farm storage units or under sheets, no elaborate procedures are required. It is usually only necessry to allow fresh air to gain access through all available openings and to allow this aeration to continue until the residual vapours have completely dissipated. Residues of aluminium phosphide will sooner or later be removed from the grain by turning.

Special care should be taken to ensure that adults, children and animals are not exposed in any way during this time.

When any of the above aeration procedures are satisfactorily completed, at least 24 hours

should elapse before the grain is released to consumers or processors. At temperatures below 15C, longer waiting periods should be enforced to ensure that the final small amounts of residual vapours have been dissipated.

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Selected literature

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Grain fumigation is a broad subject. What may be considered basic information and principles have been presented in this chapter. There is a steady flow of publications on this subject in national and international journals and in the official government publications of many countries. Valuable and specific information is snmetimes only available in instruction booklets and brochures put out by fumigant manufacturers. The following literature references should be consulted as a guide to sources of more detailed information, on recirculation and forced distribution:

Berck (1975); Brook and Redlinger (1954); Brown and Heseltine (1949); Cotton and Walkden

(1951); Holman (1960b); Howe and Klepser (1958); Lindgren and Vincent (1960); Monro (1956); Philips (1952, 1955, 1956, 1957b); Phillips et al (1953); Phillips and Latta (1949, 1953); Redlinger (1957b); Sergeev et al (1965); Storey (1967, 1971a, 1971b); Whitney and Kenage (1960).

11.Fumigation and controlled atmosphere storage

In addition to the poisonous gases that are used for pest control, the normal gases of the atmosphere can be altered to achieve control. The use and manipulation of natural components of the atmosphere, e.g. oxygen, nitrogen and carbon dioxide, to preserve food is referred to as "controlled" or "modified" atmosphere storage. Controlled atmosphere techniques are widely used in the storage of perishable commodities such as fruit, vegetables, cut flowers, etc. to retard ripening and reduce spoilage from micro-organisms. Also, they will control some insects in these products (Morgan and Gaunce, 1975; Aharoni et al, 1981). The most extensive use of controlled atmospheres for insect control is on grain and similar commodities. Here the atmospheres are modified by removing the life-supporting oxygen or by adding high levels of carbon dioxide.

Although the principle of modified atmosphere storage has been used since antiquity, e.g. in hermetic storages, a number of procedures have been developed in recent years to replace the normal atmosphere of a storage for the purpose of controlling pest organisms. In many

respects the practice of using modified atmospheres for insect control is closely related to fumigation. Gas-tight enclosures are required, many of the procedures are closely related and the problems are often similar to those found in fumigation. When carbon dioxide is used, it is applied as a fumigant and it functions in a similar way.

Controlled atmosphere procedures are an appropriate substitute for the fumigation of some commodities because the gases involved do not leave harmful residues and often the atmospheres provide superior conditions to normal storage in air. In some cases the two procedures may be used in a complementary way to increase effectiveness of a treatment; carbon dioxide increases the toxicity of a number of fumigants to insects (Jones, 1938; Kashi and Bond, 1975).

Since sound pest management should, where possible, promote programmes that integrate appropriate control procedures and minimize the use of toxic chemicals and also since many of the requirements for fumigation are similar to those needed for controlled atmospheres, a brief account of controlled atmosphere procedures is given here.

Basic requirements

Controlled atmosphere systems depend on either depletion of oxygen to asphyxiate organisms or the addition of carbon dioxide to act directly and kill them. In these treatments the new atmospheres are maintained for an adequate period to kill all stages of the

organism, and they should have no adverse effect on the commodity. To achieve this the treatment requires:

- **a storage structure capable of containing the gas;**
- **a source of suitable gas or a means of producing the required atmosphere;**
- **a method of maintaining the atmosphere for the required period of time;**
- **a method of aerating to remove the altered atmosphere after the treatment.**

It should be noted that the controlled atmospheres, which are toxic to pest organisms, are also dangerous to humans and precautions are necessary to ensure that no one is exposed to them without special protection. Although nitrogen itself is non-toxic to humans, the absence of oxygen or the presence of high levels of carbon dioxide is lethal.

LOW OXYGEN ATMOSPHERES

Oxygen deficient atmospheres are produced by flushing a storage with nitrogen to displace the normal nitrogen-oxygen atmosphere. Liquid nitrogen from tanks may be used as a gas source (Banks and Annis, 1977). Exothermic inert atmosphere generators that consume the oxygen to leave principally nitrogen have been tested and show promise for insect control (Storey, 1973). These generators burn propane or other hydrocarbon fuel to give an

atmosphere of less than 1 percent oxygen with about 10 percent carbon dioxide and 89 percent nitrogen. Oxygen can also be removed by the metabolic activity of micro-organisms and insects in hermetic storages, thus producing an atmosphere where insects cannot survive.

For complete insect control the level of oxygen must be maintained below 1.2 percent for one week, at temperatures above 35°C, or more than 24 weeks at 15°C (Table 15).

TABLE 15. SUGGESTED EXPOSURE TIMES FOR COMPLETE [)ISINFESTATION OF GRAIN AT LESS THAN 12 PERCENT MOISTURE CONTENT, WITH ATMOSPHERES OF 0 1.2 PERCENT OXYGEN IN NITROGEN.

Grain temp. (°C)	Exposure time (weeks)
15	24
18	15
20	6
23	4
26	3
30	2
35	1

Source: Banks and Annis, 1977.

CARBON DIOXIDE ATMOSPHERES

Insects are generally killed more rapidly by carbon dioxide than they are by lack of oxygen. A concentration of 6n percent carbon dioxide will give over 95 percent control of most stored grain insects after a fourday exposure at 27°C or higher (Jay, 1971); however, longer periods are needed for complete kill. Banks (1979) suggested that an initial level exceeding 70 percent carbon dioxide and maintained above 35 percent for ten days is appropriate for complete insect control at temperatures above 20°C.

The carbon dioxide gas is applied to storages from a vessel of liquid carbon dioxide with appropriate vaporizers and pressure regulators to control flow rate (Jay and Pearman, 1973). Carbon dioxide in the form of dry ice has also been used for the treatment of grain in freight containers (Banks and Sharp, 1979; Sharp and Banks, 1980) and in conjunction with fumigation of grain with methyl bromide (Calderon and Carmi, 1973).

GAS TIGHTNESS REQUIREMENTS

Structures used for controlled atmosphere treatments must have a high degree of gas tightness for the process to be effective and economical. They must be of sound construction and suitably modified so that gross gas loss through apertures, such as ventilators, open eaves and imperfections in the fabric, is prevented. Changes in temperature, atmospheric

pressure and wind forces can have a pronounced effect on gas loss from the storage structure. For storages of 300 to 10 000 tonnes capacity a gas tightness that corresponds to a decay time of 5 minutes for an applied excess pressure drop of 2 500 to l 500, 1 500 to 750 or 500 to 250 Pa in a full storage has been found satisfactory (Banks et al, 1980). This specification corresponds to a whole area of no more than 1.0 cm²(0.16 in.2) in a 2 000 tonne storage.

Gas is added to maintain concentrations at the required level in a storage over the entire exposure period. One of the main reasons that gas loss occurs is the diurnal temperature variation in the neadspace of storage structures. This is less in concrete structures than in unprotected metal bins. Diurnal temperature fluctuations can be reduced by insulation, painting with a highly reflective white paint or by placing a false roof on the bin to leave a ventilated air space next to the permanent roof.

SEALING PROCEDURES

In structures other than welded steel, e.g. concrete, bolted or riveted metal, sealing of the entire fabric of the structure may be necessary. Bolted metal bins can be sealed by treatment of each lap joint and bolt location with silicon rubber sealant, thixotropic acrylics or by application of liquid envelope, "cocoon" type, polyvinyl chloride coatings. Concrete surfaces also may need to be coated with a good sealant that will prevent yes loss and protect the concrete from high levels of carbon dioxide. The permanent sealing of a 16 000 tonne capacity shed for fumigation or modified atmosphere storage of grain has been described by Banks et al (1979).

In bins that are very tightly sealed, some precautions are necessary to avoid unusual stresses on the structure caused by external or internal pressure changes. To prevent such changes in a bin that is sealed for a controlled atmosphere treatment, a pressure relief valve must be installed. If the bin will withstand the pressure, an operating level of + 1 000 Pa (4 in water gauge) appears to be suitable. Lower levels can be used but they should not be less than + 250 Pa. A simple U-tube valve of 8 cm (3 in) I.D. tubing with a liquid trap provides a convenient and fool-proof venting system (Banks and Annis, 1977).

TESTING FOR GAS TIGHTNESS

Structures can be tested for gas tightness using a pressure test system (static testing or pressure decay testing) or a procedure using carbon monoxide as a tracer gas. The pressure decay system is satisfactory for routine testing of bins and is given in some detail here. Further information on testing of storage structures for gas tightness may be found in the publications by Banks and Annis (1977) and Banks (1982).

To test a sealed structure by the pressure decay method, air is introduced by the gas introduction system from a blower capable of producing 6 m/min (212 ft^3/min) at 2 500 Pa (10 in water gauge). Pressure differentiels can be measured conveniently on a portable water gauge similar to that shown in Figure 43. If a pressure of 2 500 Pa cannot be reached with such a blower, there may be too much restriction between the blower and the bin or the bin is less gas tight than required (e.g. 3.1 m/min at 2 500 Pa for a 2 000 tonne bin). Care should be taken to ensure that pressure within the bin does not exceed the engineering limitations

of the bin or of the sealing that is used. When a pressure of 2 500 Pa or the design limit is achieved, air input is cut off in such a way that no air is lost back through the blower. Pressure decay on the water gauge is then related to the period of time involved.

Procedures for establishing controlled atmospheres

Controlled atmosphere storage can be viewed in two phases - the "purge phase" where the normal atmosphere is replaced with the prescribed atmosphere and the "maintenance phase" where the atmosphere is maintained for the desired period of time (Banks and Annis, 1977).

NITROGEN ATMOSPHERE

Purge Phase

Liquid nitrogen supplied directly from a road tanker is passed through a heat exchanging facility where it is vaporized and brought to ambient temperature. It is then passed through a flow meter (e.g. "Rotameter") into the gas introduction system of the bin. Five cm (2 in) I.D. PVC drainage piping can be conveniently used to carry the gas. A flow of 3 m/min (106 ft^3/min) has been found to be suitable for purging of bins from 300 to 7 000 tonne capacity, although this rate may be substantially increased (e.g. to 8 m3/min) in bins fitted with aeration ducts modified to introduce gas. However, when gas in introduced directly into the

bin at the walls, an increased input rate may be less efficient at lowering the oxygen tension. In cases where a low efficiency distribution system is used, pockets of air may remain which are not purged directly but in which the oxygen is removed through the slower diffusive and convective forces. In these instances a slower purge rate allows these processes to occur and is not wasteful of gas.

FIGURE 43. Water gauge for static testing or for pressure decay(Friesen, 1976) measurements.

A vent of at least 50 cm²(10 in) must be left open in the roof during the purge to prevent dangerous pressure build-up.

It is important that the heat exchanging facility is adequate to bring the gas close to ambient temperature (within 2°C). Cooling of the grain near the introduction point may result in moisture migrating to the cold area on long storage and is also detrimental to the insecticidal efficiency of the process. At 3 m /min (106 ft³/min) three Forced draught heat exchangers in parallel using 0.4 kW (0.5 h.p.) fans, with an atmospheric exchanger downstream in series, have been found to be just as effective. If icing occurs downstream of the exchangers, the input flow must be reduced.

Gas input must continue uninterrupted until the headspace has been reduced to about 1 percent O2. Purging in the grain mass occurs generally by the passage of a sharp front through the grain and direct displacement of the interstitial air. In the headspace where free gas mixing occurs, decay is exponential. When the headspace has reached 1 percent O2, the purge

may be terminated, the top vent and introduction ports closed and the maintenance input of gas commenced.

The quantity of nitrogen required for the purge is strongly dependent on the ratio of the volume occupied by the bulk to the total storage volume (the filling ratio). Barley has a higher porosity and will require more nitrogen than wheat. In one trial with barley where the filling ratio was 0.80, a volume of 1.9 m^3 N_2/tonne was consumed. At 3 m3/min the purging of a 2 000 tonne bin of wheat takes about 12 hours.

<u>Maintenance Phase</u>

After termination of purging, gas input at a lower rate is continued to maintain the atmosphere. The input rate required is determined by the bin capacity, its degree of gas tightness and the weather. At present it is best to adjust the maintenance rates by systematically reducing the flow of gas until the atmosphere is just maintained. At the correct rate, with grain temperatures exceeding ambient ones, the oxygen tension at the base of the bin will rise slightly during the day and fall to about 1 percent at night. The headspace tension should remain low. If the grain temperature is below ambient, or if the atmosphere contains more than 3 percent CO_2, effects will be seen in the headspace, not at the base.

The exposure periods recommended for different grain temperatures with 1 percent O_2 in nitrogen have been given above in Table 15. These figures are tentative and subject to revision when further laboratory studies are completed. Sitophilus oryzae is one of the most

tolerant grain pests in low oxygen atmospheres, and if there is any doubt about what species are present, the exposure for this pest should be used. In commodities where the pests are Tribolium spp. and Oryzaephilus spp. only, shcrter exposure tames, half of those given, may he used. Currently available data for Rhyzopertha dominica are insufficient for an exact recommendation, but it is considerably more susceptible than Sitophilus oryzae and should thus be controlled by the exposures given. Exposure times should be based on the minimum temperature within the grain, not average temperatures. (For further details see Banks and Annis, 1977).

ATMOSPHERE FROM INERT ATMOSPHERE GENERATORS

A number of inert atmospher3e generators with capacities ranging from 1.4 m^3 (50 ft^3)/h to 2 800 m (100 000 ft^3)/h and capable of producing atmospheres with less than 1 percent oxygen are available on the market. Storey (1973) conducted tests in a 40 x 5.5 m (130 x 18 ft) silo containing 544 tonnes of wheat with two generators, each one capable of generating 420 m^3 per h of inert atmosphere (<0.1 percent 02' 8.5 - 11.5 percent CO2 plus N2). Using 3 cm (1.5 in) drain feeder pipes connected at the bottom of the bin, he was able to reduce the oxygen level throughout the bin to 1 percent or less in 48 hours. The oxygen deficient atmosphere moved upward through the grain mass with very little intermixing with the normal atmosphere at a rate about 2.4 m (8 ft)/h. In another bin that was purged with the inert atmosphere prior to filling with grain, the oxygen level throughout the bin, including the headspace, was reduced to less than 1 percent within 24 hours.

Similar tests were carried out by Navarro et al (1979) in welded steel bins containing about 1 200 tonnes of wheat with a generator producing exhaust gases at a rate of 144 m /h. When the generator was in a recirculation arrangement so that the gases were blown in through the roof of the silo and drawn back into the converter through a pipe at the base, the average oxygen concentration was reduced to 0.2 percent in 60.3 h (purge phase). During the maintenance phase, which lasted 21 days, the oxygen concentration was maintained below 2 percent by intermittent operation of the generator for a total of 19.5 h.

It should be pointed out that the moisture content of the wheat was affected by purging with this atmosphere, particularly in the upper layer at the region of introduction of the gases. A plastic sheet was placed below the point of gas entry to prevent moistening of the grain.

CARBON DIOXIDE

Grain Storages

Three procedures for establishing high concentrations of carbon dioxide in large silo-type bins have been tested by Jay (1980). These are based on introducing the gas at the top of a filled storage, at the bottom of the storage or with the grain stream during filling. A procedure for introducing the gas at the base of the storage with subsequent recirculstion has been found to be effective in controlling a natural infestation of insects and is deemed to be commercially feasible (Wilson et al 1980).

For the latter treatment, liquid carbon dioxide supplied in cryogenic tankers is vaporized in a heat exchanger and the gas is diluted with air to give approximately 80 percent carbon dioxide and 20 percent air. The gas stream is maintained above 30°C with a superheater and introduced at the base of the bin through a 75 mm diameter iron pipe. When the carbon dioxide concentration at the top of the bin reaches a constant level, gas input is stopped and the atmosphere so established is recirculated through a 50 mm diameter plastic duct leading from the bin apex to the introduction port at the base. With the gas tightness standards specified above, this procedure will give a concentration of carbon dioxide >70 percent initially and this can be maintained at > 35 percent for ten days without requiring additional gas.

Freight Containers

Successful tests have also been carried out with carbon dioxide for disinfestation of freight containers loaded with wheat. In trials on gastight general purpose containers filled with commodity and dosed with 37 - 55 kg of crushed dry ice spread over the goods, plus 44 kg in blocks packed in insulated boxes, Banks and Annis (1980, 1981) found that the carbon dioxide level remained over 35 percent for a period of seven days or more and killed all of the test insects.

Tests have also been made for treatment of grain under gas-proof sheets with carbon dioxide (Banks and Annis, 1980).

Termination of treatment

After a controlled atmosphere treatment is terminated, the modified atmosphere is gradually displaced by entry of air from outside. The rate at which this happens depends on a number of factors, such as gas tightness of the storage, contents of the storage and the weather, and it may be increased by making larger openings or by active ventilation with a blower. A 2 000 tonne bin with 5 cm (2 in) diameter openings at the top and base may reach acceptable oxygen levels of 16 percent from the established 1 percent in less than two weeks (Banks and Annis, 1977).

Care should be taken to avoid structural damage from the reduced pressures caused by rapid emptying of a tightly sealed storage. Steel bins have been severely damaged by rapid removal of grain without sufficient venting.

NOTE: Before emptying tightly sealed bins, open access doors or vents to allow adequate air to enter as grain is removed.

Safety precautions

Adequate precautions should be taken when working in areas close to controlled atmospheres or on entering storages that have been treated to avoid any harmful effects. Nitrogen atmospheres containing less than 14 percent oxygen or more than 5 percent carbon

dioxide may be dangerous to human life. Personnel entering a nitrogen atmosphere containing less than 10 percent oxygen may collapse without warning and become uncon scious. Carbon dioxide produces respiratory discomfort, lightheadedness and nausea, and unconsciousness may occur in less than five minutes in 9 percent CO2. In any case, where unconsciousness or respiratory distress occurs through exposure to a controlled atmosphere, the victim must be taken immediately to fresh air.

Portable oxygen monitors or carbon dioxide analysers should be available on the work site as well as air-line or self-contained breathing apparatus. Gas masks with canisters provide no protection against low oxygen or high carbon dioxide atmospheres. All enclosed working areas close to controlled atmospheres should be well ventilated and gas reservoirs should be kept outside if possible (Banks and Annis, 1977).

Problems associated with modified atmosphere storage

In sealed systems, moisture may migrate and condense to produce problems, particularly in grain above 12 percent moisture content. High carbon dioxide or low oxygen atmospheres can inhibit mould and toxin formation and preserve germination under moist storage conditions. However, spoilage will occur once the modified atmosphere is removed unless the grain is dried or processed within a short time (Banks, 1981).

Once the modified atmosphere is removed the commodity is open to infestation unless

otherwise protected.

Grain kept under a modified atmosphere may develop taint; at higher moisture levels (> 16 percent) this taint may be difficult to remove (Banks, 1981; Shejbal, 1979).

High levels of carbon dioxide may cause structural problems in reinforced concrete storages by reducing alkalinity of the steel (Hamada, 1968). The significance of this reaction in grain storage is currently under investigation.

Choice of treatment

When a controlled atmosphere procedure is going to be used, the choice between using the nitrogen (oxygen deficiency) method or the carbon dioxide method may be determined by several factors. The amount of time available for the treatment, the suitability of the structure for holding the gas, the availability of the gases or equipment for producing them and the overall cost of the operation are all important. Carbon dioxide generally kills insects faster than nitrogen (oxygen deficiency) and requires a less stringent standard of gas tightness (Jay, 1980). The comparative cost of controlled atmosphere treatments will depend on the availability and cost of the gases, the amount required and transportation costs, as well as the costs of equipment and labour.

Fumigation, controlled atmospheres and forced aeration

The choice of treatment to be used for controlling insect infestations will vary with the type of problem and the relative merits of the treatment. Fumigants can usually be used effectively in storages prepared for controlled atmosphere treatments, as the standards of gas tightness that are required are generally more stringent for the controlled atmospheres. Also, the quantity of material required, the application costs and the exposure time are usually much less for fumigants than for controlled atmosphere treatments. On the other hand, controlled atmosphere procedures avoid the use of chemical pesticides, leave no harmful residues and can provide superior storage of grain. A combination of fumigation with controlled atmosphere procedures may have some potential, as the effectiveness of fumigants is enhanced by carbon dioxide.

In addition to controlled atmospheres, the forced aeration of grain is closely allied with insect control procedures and may be an integral part of a pest management programme. Calderon (1972) suggested that "a sensible use of ambient or chilled air for aeration of grain offers new possibilities in many parts of the world for preservation of grain without (or with very little) use of chemicals." The use of fumigants and controlled atmospheres together with forced drying procedures and aeration should be considered as complementary conservation methods that form part of an overall pest management programme.

It must be pointed out that controlled atmosphere procedures are in early stages of development and progressive changes are likely to be made with further experience and research. A select bibliography on controlled atmosphere and aeration procedures up to 1981 is given below and may be referred to when extensive use of these procedures is planned.

Selected references

CONTROLLED ATMOSPHERE TREATMENTS

Bailey (1955); Banks and Annis (1977, 1981); Banks et al (1979); Banks and Sharp (1979); Calderon and Carmi (1973); Hyde (1962, 1969); Jay (1980); Jay and Pearman (1973); Kruger (1960); Navarro et al (1979); Press and Harein (1966); Press et al (1967); Rannfelt (1980);'Sharp and Banks (1980); Shejbal (1980); Storey (1973); Vayssiere (1948).

AERATION AND FORCED DRYING

Armitage and Burrell (1978); Burges and Burrell (1964); Burrell (1967); Calderon (1972); Friesen (1976); Hearle and Hall (1963); Holman (1960a); Navarro (1976); Oxley and Wickenden (1963); Williams (1973).

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12. Glasshouse fumigation

For many years, fumigants were used for the routine control of insect pests in glasshouses. Calcium cyanide dust, generating hydrogen cyanide (HCN) with the aid of the moisture of the air, and nicotine, volatilized as a gas by ignition or other means, were both commonly employed.

Recently, the aerosol method of dispersing insecticides and evaporation from steam pipes have found wide favour for glasshouse work, largely because considerable volumes of glasshouse space can be treated quickly and economically.

Although it was previously stated that the subject of aerosols lay outside the scope of this manual, it is impossible to discuss glasshouse treatments without taking into account the various ways in which the insecticides are dispersed. Therefore, a brief outline of the use of fogs, liquified gas aerosols, smokes and actual fumigants will be presented with the intention only of indicating some of the general methods employed to control insects and related pests on plants in glasshouses.

CALCULATING SPACE VOLUME

In computing the dosage of insecticide to be applied, the cubic capacity of the glasshouse must be known. In calculating this, any space occupied by plants, benches, soil and other material should be ignored.

If the house consists of one span (lean-to-type), or is divided at the pitch of the roof into two even spans, the area of the cross-section may be calculated as the average height multiplied by the width. Thus, capacity of house = average height x width x length.

When the roof is of unequal span, it may be considered as consisting of two lean-to sections and the volume is calculated as the sum of these two sections.

PREPARATION FOR TREATMENT

When aerosols , fogs, smokes, steam pipe fumigants and gases are applied, it is necessary to close all vents. Temperatures should be maintained above 20C but kept below 35C. For this and other reasons, application is usually made in the evening. It is not practicable to carry out treatments when the wind velocity is above 16 kilometers (10 miles) per hour because when the wind outside is too strong, there is uneven distribution of the insecticide in the glasshouse, resulting in underdosing in some places and overdosing in others to the point of plant injury.

EXPOSURE TIME

The time of exposure for aerosols, fogs and smokes is usually two to three hours, after which all the vents are opened. By this time most of the material has dispersed or settled. However, when fumigation takes place with most of the available insecticides and acaricides (chemicals which kill mites), and with HCN generated from calcium cyanide, it is usual to leave the house

under gas until early the following morning.

APPLICATION

Liquified Gas Aerosols

In connexion with glasshouse work, the term "aerosol" is used to describe the form in which the insecticide is dispersed after it leaves a special cylinder (sometimes called bomb) in which it is dissolved in a volatile liquid held under pressure. On discharge into the open the liquid vaporizes and leaves the particles of insecticide suspended as a fine mist in the air. This form of application is distinguished from the generation of fogs and smokes.

A wide range of common insecticides and acaricides have been used for dispensing from small aerosol cylinders carried in the hand. These include such materials as lindane, malathion, dichlorvos (DDVP, Vapona) and DDT, used principally as insecticides.

Not all insecticides can be effectively dispensed from liquified gases, because there are sometimes technical difficulties in finding suitable solvents and in producing formulations that do not cause clogging of the nozzles at the time of discharge. As a general rule, the toxicants with higher vapour pressures are more effective; this may be partly due to A fumigation effect (see Introduction). At present, too little is known about the mode of action of aerosols on insects and mites.

Before discharging the aerosol, many growers place the cylinder or bomb in warm water at,but not above, 38C for half an hour or so. This increases the pressure in the container and thus gives better distribution when the aerosol is released.

<u>Low cost</u>. The aerosols are popular at present among growers because a glasshouse of 1 400 m (50 000 ft) volume may be treated in about three minutes at a very low cost.

<u>Pests controlled</u>. Aerosols are used to control many of the pests that attack glasshouse crops. However, aerosols cannot penetrate soil and they are not effective against slugs and snails. Scale insects are controlled to some extent but, for satisfactory results, treatments have to be repeated at regular intervals.

<u>Precautions</u>. Many of the materials used in aerosols are extremely toxic to human beings, including the carrier gases such as methyl chloride. It is necessary, therefore, that persons applying aerosols should wear a respirator and protective gloves and clothing. The respirator should be of the industrial type described in Chapter 3 and the canister recommended is for "organic vapours, acid gases, smoke and dust."

The protective clothing consists of a work suit completely covering the arms and body and long rubber gloves. After application is completed the protective clothing and gloves are removed and all skin areas exposed to the aerosol are thoroughly washed with soap and water. If operations are extensive, the working shoes should also be removed.

Warning. On no account should smoking be allowed in the vicinity while aerosols are being discharged or at any time during treatment until such time as the glasshouse has been fully aerated. Aerosols may be sources of fire or explosion; more particularly, methyl chloride is a highly flammable gas.

Smokes

Insecticidal and acaricidal smokes are particularly useful in smaller glasshouses. The toxicants are mixed with a combustible material in a special container, which allows ready ignition and discharge. These containers are usually tins or waxed containers and are popularly called "pressure fumigators" or "smokes". The range of materials available in this form is more restricted than in the aerosols. Azobenzene, nicotine, lindane, dichlorvos and others have been used.

Generally speaking, the smokes cause less plant injury than the aerosols and, therefore, the grower has to pay less attention to choice of material and to other technical considerations.

Warning. Smokes diffuse readily into offices and living quarters attached to glasshouses. Care must be taken either to prevent diffusion or to evacuate such spaces while treatment is in progress.

Fags

The production of "fogs" is, in effect, a modification of a spraying technique. By means of compressed air, spray concentrate solutions are forced through atomizers so that small droplets are formed. This method has been used for dispersing a number of insecticides and acaricides by means of portable fog-generating machines (Pritchard, 1949).

Gaseous Fumigation

True vapours or gases are still used in certain ways for glasshouse pest control.

Steam pipe fumigation. A method of some value is to paint a slurry of some toxicant on the steam pipes. The gas is usually volatilized during the night. The insecticide lindane has been used in this way and the vapours of naled (Dibrom) and dichlorvos have also been successfully used for the control of a large number of pests. In commercial application of both naled and dichlorvos, protective clothing and suitable respirators are required.

It is often necessary to repeat this type of treatment regularly once a week to obtain adequate control. (It should he mentioned that sulphur for the control of powdery mildew is often volatilized in this way or by using thermostatically controlled heating units.)

Calcium cyanide. HCN, generated from calcium cyanide, once very generally used, is still employed occasionally to solve certain problems or to serve as a variation of the aerosol technique. The form of calcium cyanide best suited for glasshouse work has the consistency of sea sand. Although moisture in the air is necessary for the generation of HCN from calcium

cyanide, excessive moisture in the glasshouse cuts down the efficiency of the treatment by dissolving the gas; this may also lead to considerable plant injury. It is important that there should be no standing water on the walks where the dust is applied because a complex reaction takes place which reduces the amount of gaseous HCN given off. Therefore, it is the practice not to water the plants for several hours before fumigation.

Wearing a respirator with the special canister for HCN, the operator starts from the far end of the house and works toward the final exit door at the opposite end. He carefully pours a thin stream of cyanide from the tin container onto the concrete floor of the house taking care always to move away from the dust and never to cross back over a place already treated.

The dosage of calcium cyanide varies according to the pests to be controlled and the susceptibility of the varieties of plants present. Many plants will not tolerate more than 0.5 to 0.75 g/m (0.5 to 0.75 oz/ 1 000 ft). Hough and Mason (1951) have published full lists both of the glasshouse pests which can be controlled with certain dosages and also of the plants which will tolerate these treatments.

Calcium cyanide is particularly useful for a clean-up campaign in empty glasshouses. Under these conditions, dosages of 16 to 32 g/m (16 to 32 oz/l 000 ft) of the powder are employed for exposures of not less than 24 hours. The maximum dose is required to eradicate red spiders. As no plant injury is involved in this treatment, a considerable amount of sealing can be done.

Calcium cyanide, which reacts with moisture to give off HCN, must be handled with great care (See Chapter 6).

Methyl bromide Chamber

Methyl bromide is not usually a suitable fumigant for general release in a glasshouse, mainly because it diffuses so rapidly through small leakage holes that it is difficult to maintain the concentrations needed to kill the pests. However, for glasshouses that can be made sufficiently gas tight, it has been used effectively for disinfestation purposes. A chamber for atmospheric fumigation with methyl bromide is of considerable help for dealing with localized infestations on a few plants or for treating stock coming in and going out. Establishments that ship considerable amounts of material under quarantine often operate their own chambers under the supervision of quarantine officials.

A small chamber of a type described in Chapter 8 with an exhaust vent leading outdoors, can be installed in a well-ventilated part of the premises. Usually such a chamber need not exceed about 6 m (200 ft) in capacity.

A handbook giving the tolerances of many plants to methyl bromide has been produced by the U.S. Department of Agriculture (USDA, 1977).

FIELD FUMIGATION UNDER SHEETS

The development of light weight plastic sheets has made it possible to cover sizable areas of land so that volatile chemicals can be contained for sufficient time to effect a treatment either of the soil or of vegetation above the ground. The use of this technique for the control of weeds and of soil-infesting insects and nematodes, is well known. This method has also been used successfully to deal with infestations above ground level.

In California, large beds of strawberry plants infested with cyclamen mites are covered with white polyethylene sheets (tarpaulins), normally 30 x 60 m (100 x 200 ft) in size (Allen, 1957). The tarpaulins are sealed down at the edges with earth or placed under a narrow moat of water. Methyl bromide from cylinders is discharged as "hot gas" under the sheets through plastic hose used for irrigation (soil soakers), so as to give an even distribution of fumigant over the area. Recirculating blowers are also used.

When transparent plastic sheeting is used in full daylight, there is considerable overheating of the plants. This is avoided for the most part by using opaque material. Nevertheless, temperatures under the sheets must be carefully observed by using thermocouples or thermistor thermometers. Exposure is for two to three hours, according to seasonal conditions, with the dosages varying from 24 to 48 g/m (1.5 to 3 lb/ 1 000 ft) as the temperatures decrease under the sheets from 30 to 10C.

In summer, fumigation should be done between crops. Some differences in tolerance to the fumigation are shown by varieties of strawberries, and injury may often be avoided by treating the plants when they are dormant. In the summer, fumigation is best done early in

the morning or during the evening. There is evidence that this treatment has a stimulating effect on plant growth. However, it is not recommended that fumigation be done solely for this effect when the mites are not present, because stimulation may sometimes result in small leaves, flowers and fruit (Allen, 1957).

Plastic-coated nylon fumigation sheets were used in a campaign to eradicate overwintering larvae of the oriental fruit moth in the okanagan Valley of British Columbia (Monro, 1958b, c). The insects were lodged on or in the soil and debris in an orchard into which had been dumped some infested waste from a canning factory.

Measures to control the European pine shoot moth by field fumigation with methyl bromide of ornamental pines in commercial nurseries and private properties are described and illustrated in detail by Carolin et al (1962), Klein and Thompson (1962) and Carolin and Coulter (1963).

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13. Plant quarantine treatments

In plant quarantine work, the object of fumigation is to obtain complete mortality of 81 l stages of the pest against which the treatment is directed. For each prescribed treatment, experimental work has defined certain conditions required to bring about this degree of control. A minimum certification statement of conditions should always contain the dosage,

exposure time, and temperature. More exact conditions may be added, such as the minimum concentration x time (c x t) product of fumigant required, or a load factor may be introduced to modify dosage according to the amount of commodity present. Sometimes other factors are stipulated, such as the maintenance of a given humidity in the system during treatment or the amount of vacuum, when applicable.

To be effective, the stipulated conditions must be attained in practice every time the treatment is made.

It may be helpful to review here the more important technical considerations involved in plant quarantine fumigation.

<u>Volatilization of fumigant</u>. A particular treatment calls for a certain dosage or concentration of fumigant for a certain length of time. To attain the desired result, the full concentration must be present from the beginning of the treatment. The beginning of the exposure period can be counted only from the time the fumigant is fully volatilized. Furthermore, if the fumigant evaporates slowly after it is introduced into the system, progressive sorption of the fumigant by the commodity may prevent the attainment of the concentration x time product needed to kill the pest organism in the time allotted.

This consideration is particularly important in treatments of perishable products, such as flowers, growing plants, fruit and vegetables, where the exposures are comparatively short periods of two to four hours. Even when volatile fumigants, such as methyl bromide, are used

in treatments at temperatures below 20C, the fumigants evaporate slowly if they are not artificially heated before or after they enter the chamber. If at all possible, methyl bromide should be introduced as a "hot gas", in the ways already described. If that is not convenient, it should be discharged onto a heated evaporating pan inside the chamber. Ethylene dibromide may be evaporated rapidly in pans placed on hot plates or by means of efficient vaporizing nozzles.

Methyl bromide is recommended for use in certain treatments down to 4C. Such treatments are likely to fail if the fumigant is not fully volatilized when it is introduced.

<u>Leakage</u>. Leakage from the structure in which treatment is being done may render the treatment ineffective. It is necessary to undertake regular checks of the gas tightness of all chambers, railway cars, trucks or other spaces used for quarantine fumigations. Methods of testing structures for gas tightness are described in Chapters 8 and II.

<u>Chemical analysis</u>. In practice, the attainment of effective concentration x time products is the only way of ensuring complete control. Therefore, during actual treatments of the quarantined commodities, determinations should be made at regular intervals of time of gas concentrations in different parts of the system to ensure that the necessary concentration x time products are attained.

<u>Test insects</u>. Usually, it is inconvenient to make chemical analyses during every treatment. These analyses may be supplemented by the regular use of test insects. The response of the

test insects should be approximately the same as that of the most resistant stage of any pest likely to be encountered. If the reactions of the test insects are related to the results of periodic analyses of the fumigant concentrations, a constant check can be made on the effectiveness of the treatment.

<u>Loading</u>. In the fumigation of produce, such as fresh fruit and vegetables shipped in the normal carrier, the disposition and amount of the load will have to conform to commercial practices at reasonable costs of transportation. It is essential, however, for adequate space to be left at the top and bottom of the load to allow for proper circulation of the fumigant/air mixture. This may usually be ensured by the use of false floors and by the allowance of 30 or 60 cm (1 or 2 ft) of space between the top of the load and the ceiling. The regulations or administrative instructions of quarantine authorities often contain specific requirements for the amount and arrangement of the loads.

<u>Circulation of the fumigant</u>. In short exposures of two to four hours, proper distribution of the fumigant throughout the structure can be attained only by artificial circulation or by thorough premixing of the fumigant/air mixture. Proper conditions of uniform distribution by such means must always be provided in all plant quarantine treatments, including vacuum fumigation.

When tender plants, fruit and vegetables are being fumigated, excessive and continuous air movements may lead to plant injury. With such materials circulation should be gentle and the output of the fans should be adjusted accordingly. Such adjustment, however, must not be

made at the expense of the efficiency of the treatment. Destruction of the quarantined pest is the primary and overriding consideration.

Humidity. Plant injury is minimized if high humidity is maintained during treatment without the deposition of free moisture. For practical purposes this means a relative humidity of 75 percent or slightly over. On the other hand, too much water on the fumigated material or condensed on the inside surfaces of the chamber will seriously reduce the efficiency of hydrogen cyanide (HCN) and ethylene dibromide (EDB), and may lead to considerable injury; with the less water-soluble methyl bromide, it may prevent the fumigant from reaching some of the pests.

Effective humidity control systems are available commercially. These employ spray nozzles through which a fine spray of water is driven by compressed air. Close humidity control is ensured by sensitive "humidistats."

Postfumigation treatment of plants. Injury to growing plants may be reduced by treatment appropriate to the fumigant used. Plants to be exposed to methyl bromide and ethylene dibromide should not be watered for 24 hours unless there is danger of wilting. On the other hand, growing plants fumigated with HCN should be gently but thoroughly washed with water to minimize subsequent injury.

FUMIGATION AND COLD STORAGE

For some plant quarantine treatments, fumigation is combined with cold storage to obtain greater control of insects. The San Jose scale, Quadraspidiotus perniciosus (Comstock), and larvae of the coaling moth, Laspreyresia pomonella (1.), are controlled more effectively on apples with methyl bromide treatment followed by storage at -0.5C than by the use of either of these treatments alone (Moffitt, 1971; Morgan et al 1974, 1975). Also a combination of cold storage for two to four days at 0 to 2C followed by fumigation with methyl bromide (c x t product 75 mg h/l and 10C) is effective in eliminating eggs of the cutworm Spodoptera littoralis (Boisd.) from chrysanthemum cuttings (Powell, 1979). Dosage schedules for fumigation plus refrigeration of fruits are given by USDA (1976).

The possibility of causing injury to fruit with methyl bromide or other fumigants should be taken into account whenever these combined treatments are planned. Benschoter (1979) showed that injury to 'Marsh' grapefruit from methyl bromide varies with early, mid and late season fruit and is greater when fumigation is followed by cold storage than when the fruit is held at ambient temperature. Fumigators are encouraged to make test treatments on small quantities of fruit before applying the combined treatments to commercial shipments.

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14. Experimental fumigations

From time to time, users of fumigants may want to carry out a small scale "test" fumigation to determine the suitability of a treatment. For instance, when a commodity or pest organism,

not normally fumigated, requires treatment, a number of questions will arise. The choice of fumigant, conditions of the treatment, including dosage, exposure time and temperature, possible effects on the commodity, possible residues, as well as effectiveness in controlling the pest organism, all need to be considered. Even in well-established fumigations, unexpected problems sometimes arise and tests are needed to determine the cause. Small scale tests are also used to check for resistance of insects to fumigants (see FAO, 1975 for methods for detection and measurement of resistance to fumigants).

In addition to conducting experimental treatments for testing procedures, it is good practice to use insects themselves for test purposes in assessing effectiveness of routine treatments. It is rewarding to spend time on the examination of fumigated insects because the observations and recorded results may also be useful for planning future treatments. The assessment of insect mortality requires great care and good judgement to make reliable decisions as to the effectiveness of a fumigation.

In this chapter, procedures for carrying out small-scale experiments are described. The descriptions refer mainly to the two fumigants methyl bromide and phosphine; however, somewhat similar procedures will apply for other fumigants. The practice of using insects for testing effectiveness of treatments is outlined along with methods of handling and rearing the insects. Also included in this chapter are examples of some of the problems encountered in fumigation treatments, along with discussion on ways to avoid these problems.

Experimental treatment

Small-scale tests are carried out in specially constructed small fumigation chambers or other small containers that will accommodate the test material and can be made gas tight. Metal containers such as the portable drum fumigator described in Chapter 8, glass desiccators or flasks, may be adapted for such tests. Other equipment and material will consist of apparatus for measuring and transferring small amounts of fumigant, a source of the appropriate fumigant and in some cases equipment and methods for analysing gas concentrations. In addition, test insects are often needed for determining effectiveness of the treatment.

FUMIGATION CHAMBER

The general requirements for the fumigation chamber are similar to those outlined for larger chambers in Chapter 8. Good sealing of the door or cover of the chamber is especially important; if a glass desiccator is used, silicone grease on the ground-glass surfaces between the cover and flange will provide a good seal. In addition, some means of introducing the gas through a gas tight seal is necessary. Silicone rubber stoppers or septa fitted in the wall of the chamber to allow injection by a gas syringe are satisfactory for this purpose. If ampoules of liquid methyl bromide are used, an ampoule breaker similar to that shown in Figure 27 is required.

A small fan, magnetic stirrer or simply a swinging "punkah" type fan should be provided for

stirring the gas mixture in the chamber. If an electric fan is used, the motor should be of the spark-proof type. Fumigation chambers designed for phosphine should not have motors or other equipment containing copper.

Measurement of Volume

The volume of the chamber should be carefully determined so that dosage of fumigant can be calculated with reasonable accuracy. For rectangular or cylindrical chambers, measuring the dimensions may be adequate for determination of volume. For small chambers, such as desiccators or flasks, the volume is best determined by filling with water and measuring the volume of water in a suitable measuring container, e.g. a graduated cylinder.

Gas Syrinnes

For small chambers around 50 to 100 l in size, methyl bromide and phosphine are most easily applied as gases using gas tight syringes. The size of syringe required will be influenced by the volume of the fumigation chamber as well as the fumigant concerned. For example, a 500 ml syringe is likely to be suitable for most tests with methyl bromide using a chamber of 50 1 volume, while a 100 ml syringe would be adequate for the lower concentrations of phosphine that are needed.

FUMIGANT SOURCE

Methyl bromide

Small quantities of this fumigant can be obtained from 454 or 681 9 (1 or 1.5 lb) cans using a can-tapping device specially designed for the purpose (Figure 44). This device consists of a piercing unit made from a 6 mm brass connector fitted with a piercing tube and neoprene gasket at one end and two silicone rubber septa (discs) held in place over the outer end of the connector by a screw cap with a 1 mm hole drilled in the centre. A contoured stainless steel plate for receiving the connector is held firmly to the can by two 90 mm stainless steel clamps.

To pierce the can, the connector is screwed into the threaded hole of the contoured plate until finger tight and then given a quick half turn with a wrench to make the puncture and simultaneously to provide a gas tight seal as the gasket is compressed against the can. Can tapping devices such as this are available from scientific suppliers or they can be made in a machine shop. It should be noted that the use of materials that do not react with methyl bromide, e.g. neoprene, silicone rubber and brass, is important; aluminium fittings should nut be used.

FIGURE 44. Schematic drawing showing cross-sectional view of the can tapping device.

Samples of the gas are taken by placing the can on its side with the piercing unit pointing upwards, inserting the needle of the syringe through the hole of the brass cap to pierce the septa and allowing the methyl bromide to expand into the syringe as shown in Figure 45.

Special syringe-needles, with the hole in the side rather than at the tip, should be used to avoid the problem of blocking by particles of septa during the piercing operation. Best results are obtained when the screw cap is loosened slightly before piercing to allow some expansion of the septa. After the needle is withdrawn, the cap is again tightened to produce a tight seal and prevent escape of methyl bromide. The syringe may be flushed with a small amount of methyl bromide to remove air before the required sample is taken. If the fumigant is taken directly to the fumigation chamber, very little gas will diffuse from the syringe needle. However, shut-off valves for syringes are available or the needle tip may be inserted into a silicone septum to provide a temporary seal.

The fumigation chamber should be located nearby with appropriate ventilation to prevent exposure to the fumigant. Gas masks and suitable detection equipment should be available.

Phosphine

This gas is easily collected from commercial aluminium phosphide pellets immersed in a container of water, as described by Kashi and Bond (1975). A glass tube 27 mm in diameter drawn out to a narrow neck at one end is filled with water in a graduated cylinder and fitted (under water) with a silicone rubber septum, as shown in figure 46. A pellet is dropped into the cylinder of water and bubbles of phosphine are collected by displacement of the water in the glass tube.

The required quantity of phosphine is withdrawn through the septum with a gas syringe and

transferred to the fumigation chamber.

<u>NOTE</u>. It is advisable to flush the syringe with nitrogen before filling with phosphine to avoid the flame that may occur if sufficient oxygen is present. When drawing phosphine into the syringe, the plunger should be pulled slowly to prevent sudden pressure changes.

CALCULATION OF DOSAGE

The volume of undiluted methyl bromide or phosphine gas required to give a prescribed concentration in any small chamber can be easily calculated from the data given in Chapter 2, Table 2. for example, at 25C the weight of methyl bromide gas that can be contained in 1 m is 3 874.1 9, i.e. 3 874.1 mg in 1 lithe or 3.874 mg in 1 millilitre. To obtain the volume (no. of ml) of methyl bromide required to give 16 mg/l for a 10 1 fumigation chamber, divide the total weight of fumigant required (e.g. 160 mg) by the weight contained in 1 ml (e.g. 3.874 mg) to give 41.3 ml. Similar calculations are made for other temperatures and other fumigants.

FUMIGATION PROCEDURE

After the test material is placed in the fumigation chamber the opening is sealed and the fumigant applied. If test insects are used, care should be taken in selecting representative samples for reliable results.

Experimental fumigations are usually carried out under uniform temperature and humidity

conditions, usually 25C and 77 percent relative humidity, with exposure periods of five hours for methyl bromide and 20 hours for phosphine. However, treatments can be altered to simulate conditions present in commercial operations. At the end of the exposure period the chamber is opened to allow the fumigant to disperse in a fume hood or through properly constructed exhaust ducts.

In conducting experimental fumigations all of the precautions that are applicable to commercial treatments should be observed.

ASSESSMENT OF RESULTS

The type of information derived from a test fumigation will obviously depend on the objective of the treatment; however, much of the information can be obtained soon after the test is made. Effects on commodity, such as corrosion, colour, flavour or odour changes, may be evident immediately after the treatment. In the fumigation of living plants phytotoxic effects are usually evident within 24 hours. Other effects may be delayed depending on the type of commodity and type of treatment. Gas may continue to desorb from commodities for considerable periods after treatment, making establishment of residue levels difficult. One relatively well-known effect on wheat flour treated with methyl bromide only becomes apparent when a pungent odour is given off from hot bread made from the flour (see Chapter 6).

In assessing the results of test fumigations it may be useful to hold the test material for two

to three days, so that due allowance can be made for unexpected effects.

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Assessment of insect mortality

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NATURAL INFESTATION

If the insects infesting goods or premises are present in fair numbers, a reliable estimate of the success of a treatment may be made by collecting representatives of the species and stages present. If any of the insects are inside grains, seeds, nuts or other plant material, samples of these should also be taken. If possible, each sample taken from the different positions should weigh not less than 0.5 kg or 1 lb. It is important to collect from as many different positions as possible; small collections and samples from many positions give a better picture than large ones from only a few places. Where bags or packages are concerned, insects and samples should be removed both from the middle and the outside of as many containers as is practicable.

If sieving the infested material is necessary, it may be done at the actual fumigation site, but the insects collected in this way should be handled with care. Insects and samples of the infested material should be placed in small tins or pillboxes which are not absolutely air tight and taken to the office or laboratory as soon as possible. Here they should be transferred to clean jars or bottles containing some of the material they were feeding on. Fresh air must be available to the insects, and cloth, metal or plastic gauze should, therefore, be placed over the top of the new container in a way that will not allow the insects to escape. Petri dishes with the upper cover resting firmly on the lower dish are suitable because they usually do not permit escape and fresh air is able to reach the insects.

Appraisal of Mortality

It is unwise to attempt to appraise the results of the fumigation immediately in terms of insect mortality. With some fumigants, such as methyl bromide and ethylene dibromide, mortality may be delayed. Others, such as hydrogen cyanide (HCN), cause temporary paralysis and the insects may fully recover some time after they are restored to fresh air. It is advisable, therefore, to leave the insects in a warm place (20 to 30C) overnight before mortality counts are made and before definite conclusions are reached as to the success of the treatment. Some insects feign death. If gentle heat radiating from a 40- or 60-watt lamp is applied to the insects, the living individuals normally resume active movements within a short time.

Samples of the infested material, which may contain immature stages of the pests, (e.g. see Section 'Toxicity' under phosphine in Chapter 6) should be kept in 1 litre (2 pint) glass jars

covered with 20 mesh to the inch (2.5 cm) screening. This material should be kept, if possible, in a warm room (20 to 30C) at not less than 70 percent relative humidity and examined or screened periodically to watch for emergence of adults.

TEST INSECTS

Some thought and care must be given to the way in which test insects are used, otherwise conclusions based on their mortality may be misleading. For instance, if the insects are brought from a warm room and exposed in a treatment conducted at a much lower temperature, they might, with certain fumigants, be more likely to succumb than if they have been conditioned to the temperature of the fumigation for several hours or days before it begins. This and related aspects of insect reaction to fumigants were discussed in Chapter 2.

As a general rule, test insects should be exposed as adults, unless special information is needed on immature stages. The insects should not be placed in bare cages or other containers used for holding them during exposure; they should be put in with some of the normal food used in the rearing culture. The containers should not be jammed full with either food or insects. A container three quarters full of food with about 30 to 50 insects is a good arrangement. A better interpretation of results is obtained by dispersing the available test insect population in many places in small numbers rather than by concentrating large numbers in only a few stations.

<u>Test Capes</u>

Cages or containers may be improvised from available materials or bought from dealers. If the containers are exposed in the free space of a fumigation system or placed between packages or bays, tins with capacity of 30 to 60 ml (1 to 2 oz) may be used. At both top and bottom of the can a hole 2 cm (0.75 in) in diameter should be punctured and the hole closed on the inside by fine mesh or plastic screening, which should be soldered or strongly glued to the metal. The mesh of the screening will depend on the insects being used; 20 mesh to the inch (2.5 cm) is suitable far most purposes and is recommended for the two species mentioned below. Experience will show the best way to use available materials. Some insects will bore through cloth or plastic screening.

Other types of cages may be made from cylinders of metal or plastic gauze, a good size being 12 x 6 cm (5 x 2.5 in). The seam may be soldered or some of the wire wound in a spiral around the gauze cylinder while it is rolled firmly on a metal rod (Brown, 1959). The ends of the cylinder may be plugged with corks or cotton batting (some species may become entangled in the cotton).

As mentioned in Chapter 6, phospine reacts strongly with some metals, more especially copper. Copper, or copper containing alloys, should not be used in the construction of test cages to be used with this fumigant. Stainless steel is suitable if it is low in copper content. Generally, it is better to use plastic cages and screening for test purposes when working with phosphine.

Metal Probes

For the purpose of testing the reactions of insects inside a closely packed commodity, metal probes, available commercially, may be used. These have narrow, cylindrical pointed heads, which may be thrust deep into dense materials. These heads are small chambers 5 or 8 cm (2 or 3 in) long with narrow slits on three or four sides to allow the fumigant to diffuse in. The heads are threaded to the main stem of the probe so that the insects with their culture material may be put in and taken out. Probes may also be specially made in a laboratory or industrial machine shop.

Interpretation of Results

The same considerations already discussed for the handling of insects infesting the material, and for the interpretation of mortalities observed, apply also to test insects. As suggested, judgement must be exercised in assessing the results obtained. Until an observer has had considerable experience in using test insects to indicate the success or failure of commercial fumigations, he must be especially wary of undue optimism based on a few favourable results.

Species Used

For general fumigation work, the granary weevil, Sitophilus qranarius (or other species of Sitophilus) and the confused flour beetle, Tribolium confusum, are easily reared and are suitable to use for test purposes. Also, as Table 16 shows, they vary in their response to different fumigants. For instance, S. qranarius is more resistant to HCN and chloropicrin and T.

confusum is more resistant to CS_2, ethylene oxide and methyl bromide. If both insect species are available, it is advisable to test the one that is more resistant to the particular fumigant or mixture of fumigants being used.

TABLE 16. CONCENTRATION x TIME PRODUCTS* OF CERTAIN FUMIGANTS REQUIRED FOR THE CONTROL OF VARIOUS SPECIES OF INSECTS

Rearing Test Insects

For general use, the two species mentioned are best reared at 25C and 70 percent relative humidity in an incubator box. If an incubator is not available, rearing may be done in an ordinary office room in which the temperature does not fall below 20C. If necessary, moist conditions can be provided by placing the culture bottles in a box or small cupboard with a small fan blowing across a flat pan of water. Other methods of maintaining a reasonable humidity may be devised. The humidity is important because Tribolium, especially, does not rear well under dry conditions.

The insects are reared in screw-top glass jars of 1 litre (2 pint) capacity. The glass lids are replaced by discs of plastic or metal screening of not more than 20 mesh to the in (2.5 cm), which are fitted tightly by means of the screw tops after the insects are introduced.

Granary weevil. Place 350 9 (0.75 lb) of soft wheat in the glass jars. Introduce from 100 to 250 active granary weevils (100 adult weevils occupy approximately 1 ml in a measuring cylinder)

and leave them on the wheat for two to three days. If only small numbers are available, they should be left for a longer time; and it may take several generations before populations adequate for test purposes are built up. After five or six weeks, weevils will start to emerge. At this point it is a good idea to sieve and transfer the insects to fresh jars of wheat once a week. The date of transfer is marked on the fresh bottle. Regular weekly transfers provide for the starting of new cultures. The weevils are best used for test between two to four weeks after emergence from the kernels.

The granary weevil is able to survive for over a month at temperatures between 0 and 5C and is tolerant to temperatures as low as -10C for about two weeks. It is, therefore, suited for use as a test insect in fumigations at low temperatures.

<u>Confused flour beetle</u>. This insect is reared on whole wheat flour. The culture jar or bottle should be only about half full of flour. On the flour, place between 100 and 200 adults, which should be taken off by sieving through a 20-mesh screen after a week and placed in another jar. The new generation of 1 000 to 2 000 adults will begin to appear after about one month and these insects may be used for test purposes two to four weeks after emergence.

Adults of T. confusum should not be allowed to become too crowded in the culture bottles, because the insects emit a vapour which may be selftoxic. Overcrowding is indicated when the flour turns pink from reaction with this yes. In view of the fact that autointoxication is possible with the confused flour beetle, great care must be taken to make sure that test cages are well ventilated when in transit to and from the fumigation site.

The confused flour beetle is sensitive to low temperatures and is best used at temperatures above 10C.

<u>Other test species</u>. Other species of insects, more particularly species of beetles which are fairly easily reared, are suitable as test insects. The Khapra beetle is recommended by Brown (1959) because it is resistant to methyl bromide. This insect should be used only in countries where the species is endemic. Spider beetles (Ptinus spp.) are useful for tests at temperatures below 10C, but they are not as easily reared as the species mentioned above.

Information on the rearing and handling of many insect species suitable for use as test insects is given by Campbell and Moulton (1943).

Fumigation failures

The effectiveness of a fumigation depends on many factors - the properties of the fumigant, the gas tightness of the chamber, the nature of the commodity, the condition of the environment and the type and condition of the target organism all have direct effects on the treatment. Occasionally, well established treatments do not give the expected control or other unexpected effects may occur; very often the reasons for such results are not immediately apparent.

Throughout this manual many potential problems with the fumigants themselves or with the

fumigation procedure have been referred to. Most of these problems can be avoided or overcome by having a good working knowledge of the fumigants and by continually exercising care in their use. Some of the usual reasons for failures include:

- inappropriate choice of fumigant;

- improper application;

- uneven gas distribution;

- poor penetration of goods;

- loss of fumigant through leakage;

- temperature variations, especially low temperatures;

- excessive sorption by materials;

- insect resistance.

A fumigation treatment may be considered as a failure if the pest organism is not controlled or the commodity is damaged.

LACK OF CONTROL

Any insects that survive a fumigation do so because they have not absorbed enough of the toxicant for it to be effective. Dosage schedules are designed to cope with most variabilities, such as species, stage or condition of the insects, and they are made for a range of temperature conditions. Difficulties usually arise from unobserved or unusual conditions that prevent the fumigant from reaching the insects. Loss of gas through leakage or absorption can be a major reason for lack of kill and poor penetration into a commodity can be another.

Most problems concerning loss of gas can be avoided by proper preparation for the treatment and analysis of gas concentrations at appropriate locations during the exposure period. Information on gas concentrations gives the fumigator a high degree of control over the operation; it can give a good indication of gas dispersal, maximum levels attained, penetration into materials or loss from the space. Problems can usually be overcome by extending the period of fan circulation, by adding more fumigant or by extending exposure time.

Temperatures within a commodity or at different locations in a structure can vary greatly so that insects in areas of lower temperature may survive. Ranges of 10 - 20C or more in commodity and free space con occur, particularly in structures exposed to strong sunlight. It should be noted that at temperatures around freezing the effectiveness of a fumigant is quite variable and may not give control (see Chapter 2). Since fumigant effectiveness is closely related to temperature, the dosage must be adjusted to the lowest temperature for complete control.

Insect resistance (see Chapter 2) is a matter of great concern to those using fumigants because of the small number of fumigants available and because of the lack of effective alternatives. Any indication of resistance to fumigants should be thoroughly investigated. If control procedures become ineffective when conducted according to recommendations, a careful check should be made for resistant insects. The FAO(1975) method for detection and measurement of resistance can be used. If resistant insects are found, measures should be taken to eradicate the population completely and thus prevent dispersal to other areas.

DAMAGE TO THE COMMODITY

Although recommended treatments are designed to kill pest organisms without any effect on the commodity, unexpected injury to plants or damage to other materials does occasionally occur. Many of the different effects that fumigants can have on materials are given in Chapter 6. Information on the tolerance of various plants and plant materials are also given in the dosage schedules.

Some of the types of damage that should be guarded against include corrosion, fire or explosion and changes in odour or taste.

<u>Corrosive effects</u>. Damage may result if methyl bromide comes in contact with flame or hot wires to form the corrosive hydrobromic acid. Phosphine can damage electrical equipment with copper wires, particularly in conditions of high humidity.

<u>Odour and taste effects</u>. Methyl bromide occasionally reacts with flour to produce offensive odours during baking or in hot loaves of bread. A list of other materials that are adversely affected by methyl bromide is given in Chapter 6.

<u>Fire and explosion</u>. Although treatments are always designed to avoid any condition that will produce fire or explosion, accidents do occur at times. Containers of phosphine fumigant may occasionally flash when first opened due to release of accumulated phosphine gas. For this reason, they should always be opened out of doors away from any flammable material. Fires have occurred on grain ships when phosphine producing formulations that had been laid on the surface of the grain cargo shifted during the voyage to accumulate in one corner of the hold. Such formulations should always be used so as to avoid any possibility of high concentrations of phosphine accumulating in confined spaces.

Fumigation and dust explosions

Concern over a possible connection between the presence of fumigant in grain and grain dust explosions has been expressed; however, it must be pointed out that the matter is uncertain at the present time. Some tests have given evidence to suggest that there may be significant interactions between fumigant vapours and explosive dusts; tests with a mixture of 80 percent carbon tetrachloride and 20 percent carbon disulphide, which by itself is nonflammable, were found to lower the explosive concentration of commercial flour dust appreciably (Atallah, 1979). However, another investigation with three fumigant mixtures,

containing carbon tetrachloride and ethylene dichloride or carbon disulphide, showed that there was no increase in the severity of grain dust explosions and in some cases the vapours actually suppressed the explosion (Tait et al, 1980).

The uncertainty about any connection between fumigation and dust explosions will remain until further information is available. However, due precautions against creating a hazardous combination may be warranted, particularly with fumigants that have relatively low flammability limits.

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15. Training in fumigation

The effective and safe use of fumigants is dependent on a good knowledge of both the chemicals that are used and the procedures employed in fumigating. Present standards and restrictions on the use of pesticide chemicals also require the fumigator to know many things that were disregarded in the past. Personnel using fumigants should have practical knowledge of the pests they are dealing with, they should know the hazards involved in using fumigants and they should be familiar with methods of detection and analysis. Also, they should know safety and first aid procedures and have some knowledge of official regulations governing the use of these materials.

Many national or local governments require that fumigators be trained and licensed before

they are permitted to apply fumigants. A working knowledge of the technical and business aspects of pest control can be best achieved by a period of study and training. On-the-job experience is important, but this approach alone can lead to mistakes and offers fewer opportunities for career advancement (Osmun, 1976). Training courses should include instruction on the basic principles of fumigation and pest control, practical demonstrations on procedures and a period of apprenticeship with an experienced fumigator. Competence for certification is determined on the basis of written examinations and performance testing. Refresher courses are given in some countries to ensure that high standards of competence are maintained and that applicators become familiar with new developments as they take place.

From the viewpoint of the truly professional fumigator, every applicator should want to become certified, as this is the only way he is likely to be exposed to sufficient training to become professional. For the employer, the value of good training for his employees will be evident in their competence and ability to carry out the operations in an effective, safe and professional manner.

The information given in this book can serve as the basis for a course of instruction in fumigation. Chapters dealing with principles of fumigation, properties of fumigants, methods of analysis, safety precautions and protective devices are particularly important. A comprehensive course on fumigation would include the following subjects:

1. **General introduction to the principles of pest control, including a brief account of**

methods of food storage and preservation, infestation and destruction of food and other commodities by pest organisms, methods of prevention and control of infestations, integrated pest management programmes.

2. Principles of fumigation

a. Definition of a fumigant; choice of fumigant; vaporization of fumigants; latent heat of vaporization; law of diffusion; specific gravity and distribution; mechanical aids to diffusion, sorption and desorption; chemical reactions; residues.

b. Dosage and concentration; calculations for conversion of concentration values; concentration x time (c x t) products.

c. Toxicity to insects; bioassay techniques; comparative toxicity of various fumigants; effect of temperature, humidity and other gases on toxicity; fluctuations in insect susceptibility and effects of nutrition, species, stage and climatic changes on these; resistance testing.

3. Methods of detection and analysis - chemical methods, instrumental analysis, types of instruments available for field and laboratory use, instruments used for health safety.

4. Safety precautions and protective devices.

a. Threshold limit values; hazards; acute and chronic toxicity; detection of fumigants in the atmosphere; symptoms of poisoning; first aid measures and medical treatment.

b. General precautions in handling fumigants - in preliminary preparations; during application; during treatment; post treatment; protective clothing; respirators - self contained, air-line and canister type.

5. Properties of individual fumigants

a. General characteristics, including corrosive nature and inflammability; toxicity to insects; effect on seeds, bulbs, growing plants, dormant plants (phytotoxicity) and plant products including fresh fruit and vegetables, cereal products; effect on animal products; residues.

b. Detection of vapours; field analysis; methods of application; methods of sealing structures; methods of aeration.

c. Safety precautions - specific health hazards, methods of detection for health safety, symptoms of poisoning, respiratory and general body protection, first aid, medical treatment.

6. Biology, life history and identification of insects and other pest organisms. This is particularly important in insect control since control measures may vary with different species.

PRACTICAL TRAINING

Demonstrations plus active individual participation in performing the various procedures involved in fumigation are considered to be essential parts of any course of instruction. The practical training should demonstrate with step-by-step directions how to carry out various procedures. Similarly, it should emphasize the importance of systematic planning and conduct of every stage of a fumigation operation from initial planning to final clearance of fumigant. Planning should include the following steps:

1. Preliminary inspection of facilities to be fumigated.

2. Arrangements with officials and personnel, plus notification of appropriate authorities - fire, police departments, etc.

3. Materials required for the fumigation.

4. Duties to be performed by each individual of the fumigation crew.

5. Preparation of the facility to be treated.

6. Pre-application procedures.

7. Fumigant application and operations to be performed during the treatment (surveillance for gas leaks, analysis of concentrations).

8. Aeration and post-fumigation procedures.

A check list that gives a record of all equipment required and all duties to be performed should be made.

Demonstrations

Practical demonstrations of the following types may be considered.

1. Methods of storage; handling fumigants - solids, liquids, gases; proper disposal of used containers and end products remaining after a treatment.

2. Demonstration of equipment used for detection and analysis, e.g. halide leak detector, thermal conductivity analyses, glass detector tubes, interference refractometer plus infra-red analyses and portable gas chromatographs, if available.

3. Proper care and use of protective devices; respirators - self contained, air-line and canister types; safety blouses; first aid procedures.

4. Bioassay - treatment of test insects with fumigant; assessment of mortality; determination of LD(50) and LD(99).

5. Stack fumigation to include step-by-step planning of the various procedures involved in a fumigation - choice of fumigant; use of test insects; covering and sealing the stack with a gas-proof sheet; determination of volume of space to be fumigated and quantity of fumigant required; application of fumigant; analysis of fumigant; calculation of c x t product; safety measures; aeration. Factors such as sorption and desorption, effects of temperature and other atmospheric conditions should also be noted.

6. Other demonstrations and projects requiring active student participation can be designed to fulfill individual needs, depending on the nature of fumigation operations that are anticipated. For large-scale fumigations, such as warehouses, mills or ships, the importance of systematic planning and conduct of all aspects of the treatment should be emphasized.

APPRENTICESHIP

A period of on-the-job training with an experienced fumigator will enable the student to observe first hand many of the principles and practices described above. A period of at least six months, hut preferably one year, should provide enough experience to allow the new fumigator to use fumigants effectively and safely and to adapt his treatments to the varying

situations that he may encounter.

Fumigation schedules

The treatments listed in these schedules have been successfully applied in practice. Nevertheless, they are given here for the purpose of reference only. Modifications may have to be made, after preliminary trials, to suit local conditions. Although the schedules represent a wide range of treatments, they do not include all possible applications. Rather, an attempt has been made to select representative schedules from different parts of the world.

Instructions for application of fumigants are usually given on the label affixed to the container in which the fumigant is supplied. In some countries the information given on these labels, including dosage recommendations, is carefully controlled by legislation and, therefore, the use of the fumigant should conform to these national requirements.

A. Bulk fumigation of grain in upright storage.

B. Bulk fumigator of grain in flat storage.

C. List of plants that have sustained injury from fumigation with methyl bromide.

D. Methyl bromide fumigation of actively growing plants.

E. Methyl bromide fumigation of foliated, dormant plants.

F. Methyl bromide fumigation of non-foliated, dormant plant material.

G. Methyl bromide fumigation of orchids.

H. Methyl bromide fumigation of fresh fruit at atmospheric pressure.

I. Methyl bromide fumigation of fresh vegetables.

J. Ethylene dibromide fumigation of fresh fruit.

K. Ethylene dibromide fumigation of fresh vegetables.

L. HCN fumigation of fresh fruit.

M. HNC fumigation of dormant nursery stock.

N. Fumigation of flower bulbs and corms.

O. Methyl bromide fumigation of cut flowers and greenery.

P. Atmospheric and vacuum fumigation for the control of pests infesting packaged plant products.

Q. Fumigation of mills, empty structures, and tobacco warehouses.

R. Local (spot) fumigants for mills.

S. Fumigation of seeds.

T. Fumigation for controlling rodents and other mammalian pests, snakes, birds, snails, ants' nests, wasps and termites.

A valuable source of information for plant quarantine treatments is the Plant Protection and Quarantine Treatment Manual (USDA, 1976 with updated inserts) issued by the Plant Quarantine Division, United States Agricultural Research Service, Washington 25, D.C.,which is kept up to date by periodic revisions.

Guide to schedules A and B

INSECT SPECIES

Schedules are for all stages of both internal and external grain feeders.

Exception. With fumigants containing bromides or chlorides (halogenated hydrocarbons and chloropicrin) and with ethylene oxide, double the dosage for any species of Trogoderma (Dermestid beetle genus, which includes T.qranarium, the Khapra beetle) and for the cadelle,

Tenebroides mauritanicus, should be applied.

STRUCTURES

Schedules given are for concrete and metal structures. For wooden bins, only direct mixing and surface application are applicable, and for these the dosages should be doubled.

CARRIERS

Treatments of bulk grain may be made in carriers such as closed railway freight cars and road trucks. With due allowance for the tightness of these vehicles, dosages and exposures may be based on the recommendations in Schedule B. Liquid or solid-type fumigants may also be applied to grain in open vehicles if the grain is covered with gas-proof sheets after application of the fumigant (see Chapter 10).

ABBREVIATIONS

Fumigant mixtures by percentage composition (see Chapter 7)

<u>Example</u>. EDC75:CT25 means a mixture of 3 parts ethylene dichloride, 1 part carbon tetrachloride. All proportions are by volume unless other wise stated.

DOSAGES

Dosages in Column 2 are for major cereals, including shelled maize, unless otherwise stated under "Remarks." For Grain sorghum multiply rate given by 1.5 to 2 times. Dosages are based on full bins or storages. Special allowance must be made for partially filled structures.

MIXTURES

The fumigant mixtures given are representative of many combinations marketed. Other ingredients include chloroform, methyl allyl chloride and trichloroethylene. These are usually mixed with the more toxic ingredients: carbon disulphide, chloropicrin, ethylene dihromide or ethylene dichloride. Select the dosage from a similar mixture in this schedule containing the same more toxic ingredient.

TEMPERATURES

Schedules are given for grain temperatures of 21 to 25C. For other temperature ranges apply factors as follows:

10 to 15C	Multiply dosage by 1.5
16 to 20C	Multiply dosage by 1.25
25C and over	Use 0.75 of dosage given

It is inadvisable to attempt fumigation when the grain temperature is below 10C. Hydrogen cyanide (HCN) or calcium cyanide should not be applied at grain temperatures below 15C.

Fahrenheit equivalents can be obtained by reference to the Table in Appendix 2.

DOCKAGE

If there is dockage present, or the grain is "tough," add 25 percent to dosage already calculated.

SEED GRAIN

Where grain is to be used for seed, do not fumigate if moisture content is above 12 percent. Also, exposure periods for seed should not exceed 24 hours with fumigants containing methyl bromide or chloropicrin or 72 hours with any other fumigant. Do not use ethylene or propylene oxides (see Chapter 6 for effects of individual fumigants on seeds).

FORCED DISTRIBUTION

As stated in Chapter 10, forced distribution may be used without modifying existing aeration systems. Usually dosages given in the schedules for recirculation should be multiplied by 1.5.

HOT SPOTS

Treatments of localized areas of infestation (hot spots) in a L, rain mass are discussed in Chapter 10. A good material for this type of treatment is the mixture EDB 70: methyl bromide 30, by weight, applied at I kg/ 36 m (36 oz/1,000 bu) of grain. The fumigant is applied through tubes or metal pipes into the region of the hot spot.

FURTHER REFERENCES

For more detailed information on schedules for grain fumigation, consult USDA, (1982). Comprehensive information on fumigant residues is given by Lindgren et al (1968).

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