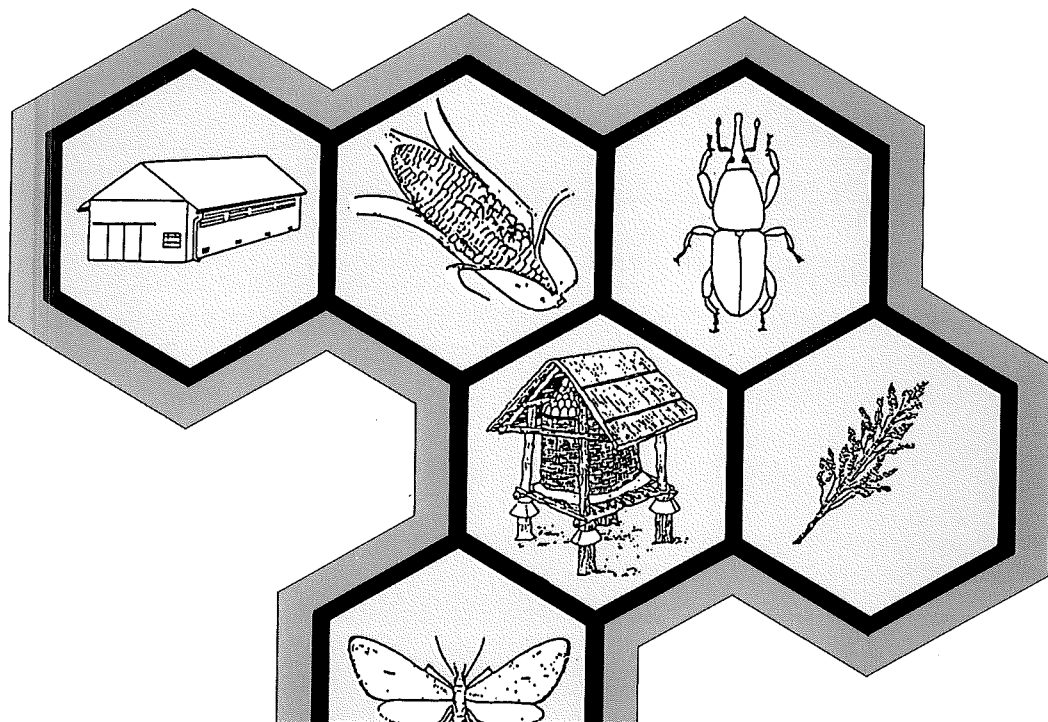




MANUAL ON THE PREVENTION OF POST-HARVEST GRAIN LOSSES

J. GWINNER R. HARNISCH O. MÜCK

PREVENTION OF POST-HARVEST GRAIN LOSSES



9 Pest Control Using Fumigants

The fumigants used in pest control are given separate attention due to their properties and the special application techniques required.

The main area of use of fumigation lies in the control of insects, their eggs, larvae and pupae in the stored produce. As the fumigants are highly toxic to mammals, treatment also has a useful side effect on rodents.

This also means, however, that fumigants are extremely toxic to humans and that therefore fumigations should only be carried out by well-trained staff.

Correctly applied, fumigants are entirely successful. The tiny gas molecules easily penetrate large stacks of grain right into the individual grains, reaching and killing all stages of development of the pests.

Gases do not have any long-term effect due to their high volatility.

9.1 Areas of Application for Fumigants

The most important areas of application for fumigants are the treatment of bag stacks in stores or bulk grain in silos. Additionally fumigants are used in sealed chambers, gas-tight containers or wagons to disinfect produce.

When fumigating a bag stack, it is necessary to cover the stack with a gas-tight sheet and hermetically seal it, thus ensuring that the required concentration of gas is maintained for the entire exposure period.

Treatment of an entire warehouse can only be carried out when the structural conditions enable the store to be tightly sealed. Most stores do, however, have gaps or cracks in critical places, such as along the joint between the roof and the walls, making space fumigation impossible. There are only very few fumigable stores in the world. A fumigable store for village use has been presented in Section 4.4.1.

Special fumigation chambers are excellently suited for the treatment of smaller amounts, but these are often not available on the spot. Stack fumigation therefore is the most practicable and convenient method in most cases. Particular attention is therefore given to this type of fumigation below.

9.2 Fumigants

Mainly two fumigants are used in pest control:

Phosphine (PH_3) and Methyl Bromide (CH_3Br).

Apart from this Hydrogen Cyanide (HCN) is applied especially in case of fumigating mills.

9.2.1 Phosphine

9.2.1.1 Properties

- Very good penetration of stored produce, can even penetrate brickwork
- Spreads well in enclosed spaces

- Disperses rapidly on ventilation after fumigation
- Has generally no negative effect on germination capacity
- Leaves no gaseous residue after ventilation
- Has carbide or garlic-like smell which serves as warning agent. In case of frequent dealing with Phosphine, however, this is not always noticeable
- Acts relatively slowly
- Is self-igniting if present in high concentrations in the air (higher than 1.8 % vol.)
- Corrodes copper e.g. electrical cable and contacts

9.2.1.2 Toxicity of Phosphine

- Phosphine is effective against all stages of development of insects (eggs, larvae, pupae, adults).
- Phosphine is highly toxic to warm-blooded animals, and is thus very dangerous to human beings.
- There have been no known cases of chronic poisoning as a result of repeated intake of sub-lethal doses.

9.2.1.3 Formulations and Forms of Packaging

Phosphine is available as aluminium phosphide (AlP) and as magnesium phosphide (Mg_3P_2).

Magnesium phosphide liberates phosphine more completely and more rapidly at temperatures below 20°C than aluminium phosphide does. Both formulations are available in various forms and packs, as follows:

- **Tablets:** Each weigh 3 g and yield 1 g of PH_3 . They are sold in various sizes of packs.
- **Pellets:** Weigh 0.6 g and yield 0.2 g of PH_3 . They are also sold in various sizes of packs.
- **Bags (sachets - only as aluminium phosphide):** Contain 34 g of preparation and yield 11.3 g of PH_3 . They are sold individually, in bag chains (10 connected bags) or in bag blankets (with 100 bags). The bags are ready for use - never open them!
- **Plates (only as magnesium phosphide):** Weigh 206 g and yield 33 g of PH_3 . They are sold individually or in strips containing 16 plates.

All phosphine formulations are ready-for-use in the forms described above.

9.2.1.4 Generation of Gas

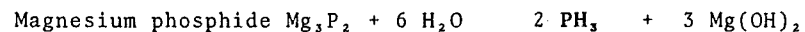
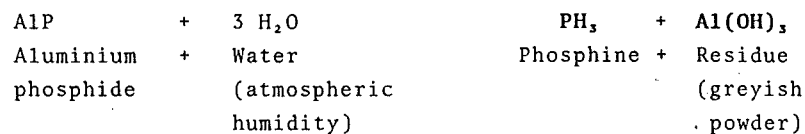
Phosphine (PH_3) is generated as a result of temperature and moisture (in the air) reacting with the solid aluminium or magnesium phosphide.

In the case of sachets the generation of gas is slowed down because of the absorption of humidity by the sachet itself. This should be borne in mind when determining the duration of the exposure time (see Section 9.2.1.5).

The generation of gas starts immediately when the container holding the fumigant is opened. Anyway, concentrations which are likely to be dangerous to humans are not reached until at least one hour later. This period may be even longer if the temperature and the relative humidity are low.

The decomposition of the formulations is never complete. Only approximately 98 % of the phosphine is liberated during fumigation. The powdery residue still contains 2 % of unreacted aluminium phosphide (or 0.2 % in the case of magnesium phosphide) and must be collected after fumigation. Tablets and pellets therefore should be placed on a sort of tray or piece of cardboard. The powder is disposed of by pouring it into water mixed with a detergent, thus fully liberating the gas. This should be done in the open air in order to avoid the inhalation of the fumes!

Chemical reaction when generating phosphine:



9.2.1.5 Factors Influencing the Success of Fumigation

Recommended Application Rates

The recommended application rates for phosphine are as follows:

Application	Tablets	Pellets	Bags
Fumigation	3 - 6/t	15 - 30/t	1 Bag/2-6 t
under sheets*	2 - 4/m ³	10 - 20/m ³	1 Bag/1.5-4 m ³
Fumigation of air-tight containers, incl. silos	2 - 5/t	10 - 25/t	1 Bag/1-5 t

* When fumigating bag stacks, the calculation of the dosage may be made on the basis of the amount of stored produce (in t) or the volume of the stack (in m³).

The concentration of gas initially established first leads to the insects being narcotized before they are finally killed. The resulting reduction in their respiratory activity means that they take in less of the gas. Should the gas concentration drop rapidly as a result of insufficient sealing or damaged tarpaulins, the pests will reawaken after a certain period without having received a lethal dose.

Good sealing is the most important fact when fumigating as this will lead to excellent success.

Exposure Time

The minimum exposure time depends on the temperature, the relative humidity and the formulation used, and on whether there is any resistance against phosphine.

The following minimum periods should be adhered to under all circumstances (figures in days):

Air Temperature	Tablets	Pellets	Bags
10 - 15°C	6	5	8
16 - 25°C	5	4	6
over 25°C	4	4	5

With a r.h. of below 60 % up to 6 days and more

In case of resistance: at least 3 days more in each case

Fumigation is ineffective if the relative humidity is below 30 %.

When mites are present, a minimum exposure period of 10 days is required.

The lower the temperature and/or the relative humidity, the slower the chemical reaction to generate phosphine and the longer the exposure times required will be.

Under arid climate conditions the relative humidity under a sheet may be raised by placing bowls of water beneath the pallets or by sprinkling water underneath the pallets. However, under no circumstances must the fumigant come into direct contact with the water.

The basic principle is - the longer the gas is able to act, the better is the success. This, however, presupposes that the stored produce is perfectly sealed during the entire fumigation.

Sealing

The most important prerequisite for the success of fumigation is the quality of the sheet and the sealing in order to maintain the necessary concentration of gas for the entire exposure period.

- Fumigation sheets

A fumigation sheet has to meet specific requirements:

- highly gas-tight (including any seams)
- sufficiently resistant to tearing
- of low weight (max. 200-250 g/m²)
- highly resistant to ultraviolet light and temperature

Many plastic materials do not fulfil these requirements as they are either not sufficiently gas-tight and resistant to mechanical damage or too heavy for handling.

The strips of the sheet should be welded together and the edges of the sheet additionally reinforced to prevent them from tearing apart.

Sheets with glued seams are not always able to withstand tropical weather conditions. Stitched seams cause gas loss due to the holes made by the needle on sewing.

The size of the sheet should be selected so as to enable fumigation of one stack with a single sheet. Standardized stack sizes are of considerable advantage.

- Care of fumigation sheets

Good storage and careful handling prevents damage and extends the life of fumigation sheets. They should be folded together neatly and stored on pallets. If the sheets are carelessly thrown in a heap in the corner of the store, rodents may use them as nesting sites and severely damage them.

When placing the sheets over the stacks, care should be taken to avoid any holes or tears. Do not drag sheets along the ground or over pallets, but carry them instead! Do not walk on the sheets when folding them up, as small stones and grains will make holes in the sheets.

The sheets must be checked regularly. Any holes or tears must be repaired immediately. Small tears can be sealed using insulating tape on both sides of the sheet, and larger ones by sticking a piece of sheet material over them. A special adhesive may be required for this.

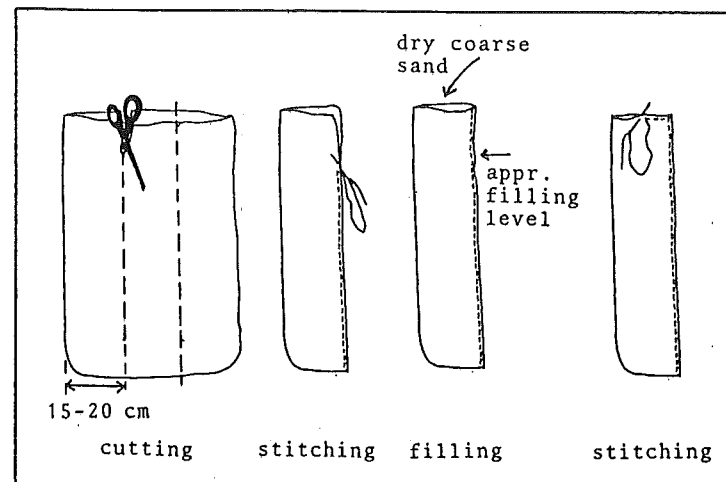
- Material for sealing the fumigation sheet to the floor

Even the best quality sheets are of no use if they are not well sealed to the floor. The sealing technique is described in Section 9.2.1.7. The best-proven method is to use sand snakes, which has a number of benefits:

- high flexibility (good adaptation to the floor)
- sufficient softness (no damage to sheets)
- sufficient weight (to keep the sheet pressed to the floor)
- easy to make

The following materials are required to make sand snakes:

- old grain bags cut in half or thirds lengthways and stitched together at the cut edges:



- old fumigation sheets or tarpaulins cut into suitably-sized pieces and stitched together in a sausage shape

- hose foil:

supplied in running metres which can be cut into suitably-sized sections and the ends knotted or welded.

Sand snakes should have a diameter of at least 10 cm and be 1 - 1.5 metres in length. Fill them with just enough sand to enable them to bend and to adapt to any uneven areas of floor. Never fill sand snakes tightly as they will get too rigid to fulfil their purpose.

Sand snakes should be placed so that they overlap by at least 1/4 of their length.

Stones, palettes, wooden beams or other similar materials are unsuited as they are not flexible enough and may

damage the sheets. Never use bags filled with stored produce for sealing purposes as they may be infested and provide a starting point for reinfestation.

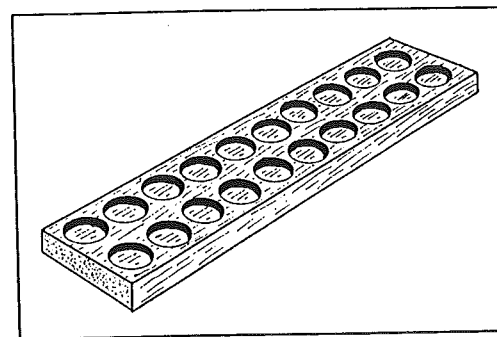
A further method of sealing is the use of **paper and paste**. A prerequisite for this type of application is a smooth and well cleaned floor. Mix a thick paste of water with wheat flour. Wallpaper paste is even better if it is obtainable. Spread a coat of paste in those areas where the sheet will be layed on the floor. Lay strips of paper 15 - 20 cm wide on top of this coat and cover them as well with paste. Place the sheet along the centre of the paper strips, coat it again with paste and place a further layer of paper on top of it. Finally give the upper layer of paper a further coat of paste. When the paste dries, you will have a lasting, gas-tight seal.

This method does not apply to the corners of stacks where folds form. Sand snakes have to be used here.

Application

It has already been mentioned that for safety reasons, residue from tablets, pellets and bags must be collected after fumigation. While this is a simple matter with bags, there are difficulties involved in collecting the powdery residues from tablets and pellets. Tablets and pellets must therefore be placed on trays or pieces of cardboard and never simply distributed on the stacks.

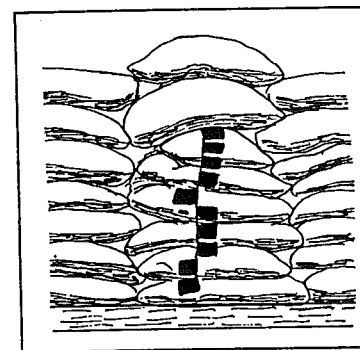
Egg-boxes provide the best trays, as a single tablet can then be placed in each segment. Wooden planks with holes drilled in them just large enough to take a single tablet or pellet also make excellent trays. Wooden planks from old pallets may be used to make these.



Place the trays/cardboards under the pallets, distributing them evenly, or directly at the side of the stack before sealing.

As there is a danger of self-ignition with large concentrations of phosphine, tablets and pellets should not touch each other.

Chains of bags should be used in preference to single bags. These are then attached to the stack by wedging the first bag of the chain between two bags of grain in the stack.



Ventilation

At the end of the fumigation process, the fumigant must be thoroughly removed from the stored produce and the store by means of extensive ventilation before the store can be released again for general access (see Section 9.3).

The minimum ventilation period for phosphine is three hours.

Where aeration is reduced due to a lack of ventilation facilities, the period must be extended to at least six hours.

If there is no gas detector available (see Section 9.3), the ventilation period should be extended to 6 - 12 hours in order to avoid any risks.

9.2.1.6 Resistance to Phosphine

Correct execution of fumigation will lead to complete control of storage pests so that there is generally no possibility of resistance developing.

Poor fumigation practices have, however, led to resistance against phosphine to alarming proportions worldwide, and the tendency is increasing.

Resistance to phosphine was first discovered in countries in which space fumigation was performed in stores which were not gas-tight.

Today it is an undisputed fact that the development of resistance in storage pests is particularly favoured by poor sealing and the resulting loss of gas. When the gas concentration drops too rapidly the pests have the chance to survive and to reproduce.

The following measures should be taken:

- Good store hygiene and management
- Correct dosage and application of fumigant
- Complete sealing of the stored produce or store to be fumigated
- Sufficient exposure time

9.2.1.7 Fumigating a Stack of Bags with Phosphine

Fumigation work must only be performed by trained staff. For each fumigation, one person is responsible as head of the fumigation team from preparing the fumigation to the release of the store for general access. The head of the fumigation team is responsible for the success and safety of the fumigation.

The fumigation of bag stacks can be divided into 5 steps:

- preparations
- application of the fumigant and sealing
- controls during fumigation
- ventilation and release of the store
- cleaning up work

The safety regulations (see Section 9.4) and the instructions provided by the fumigant manufacturer must be followed during the entire fumigation process.

All the activities involved in the 5 steps are described below.

- Preparations

- Inform all people who work in the store and all those who live in the vicinity of the store about the forthcoming fumigation!
- Ensure that there is no danger to residents!
- Clean the store!
- Measure the length, breadth and height of the stack:

Example: Length (L) 6 m
Breadth (B) 4 m
Height (H) 3 m

- Calculate the volume of the stack:

$$L \times B \times H: 6 \text{ m} \times 4 \text{ m} \times 3 \text{ m} = 72 \text{ m}^3$$

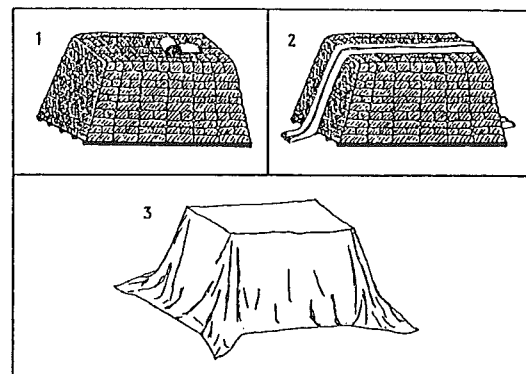
- Calculate the number of tablets, pellets or bags in accordance with the recommended application rate e.g. 2 tablets/m³:

$$2 \text{ tablets/m}^3 \times 72 \text{ m}^3 = 144 \text{ tablets}$$

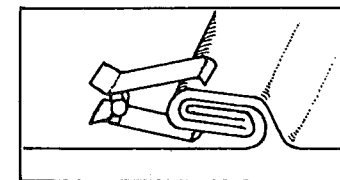
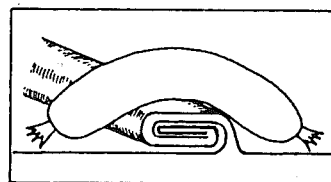
- Round the number up or down according to the size of the packs in order to use up all open tubes (with 30 tablets/tube use 5 tubes of 30 tablets = 150 tablets).

- Check the folded sheets for damage!

- Spread the fumigation sheet over the stack as follows:



- Place the folded sheet on the stack (1)!
- Unfold the sheet over the sides of the stack (2)!
- Pull the sheet over the stack so that at least 1/2 m is on the floor on all sides (3)!
- When covering the stack with more than one sheet:
 - Roll the sheets together so that they overlap by at least 1/2 m!
 - Keep the rolled part together with clips or with sand snakes on top and adhesive strips at the sides!



- Distribute a sufficient number of sand snakes around the stack!

Example:

Stack circumference: $6\text{ m} + 4\text{ m} + 6\text{ m} + 4\text{ m} = 20\text{ m}$

Required overall length of sand snakes:

$$1\frac{1}{2} \times 20\text{ m} = 30\text{ m}$$

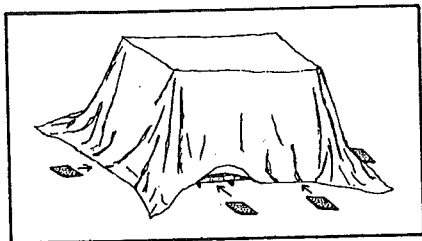
- Evenly distribute the closed fumigant containers around the stack so that they are at hand; e.g. 1 tube with 30 tablets next to each tray/cardboard
- Keep a breathing mask with a new filter ready in case of emergency!

- Application of the fumigant and sealing

- When using tablets or pellets:

- Open the containers, tubes or flasks one after another and distribute the tablets or pellets on the trays / cardboards without touching each other!

- Lift the side of the sheet and push the trays / cardboards under the pallets!



In case that pallets are not available for any exceptional reason, place the trays/cardboards on the floor next to the stack.

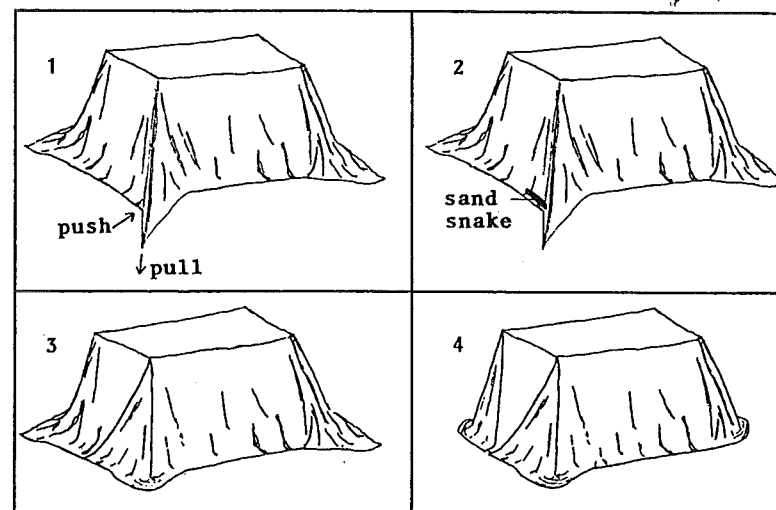
- When using bag chains:

- Open one tin of bag chains after another and fix the bag chains at regular intervals by pushing one bag between two bags of grain in the stack (see illustration on page 219)!

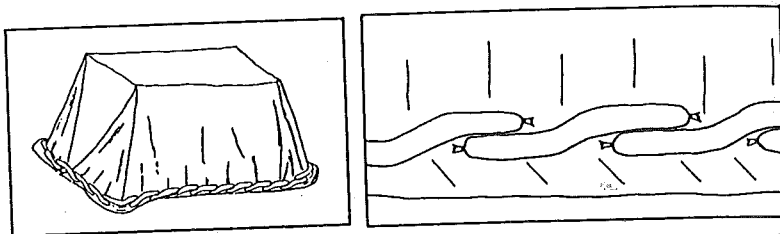
- Unfold the fumigation sheet smoothly over the stack (1)

- Place a sand snake as shown in (2)

- Fold the sheet over the edge of the stack (3, 4)



- Ensure that the sheet is lying flat on the ground!
- Distribute the sand snakes on the sheet around the stack so that they overlap for 1/4 of their length!



- All work has to be performed in order to be finished within one hour due to the ensuing generation of gas.
- If the stack is built on a porous or sandy floor, a sheet must be already placed underneath in the moment of stacking to prevent the gas from escaping into the ground. Fasten it to the sheet covering the stack at the side as shown above in the section on preparations for fumigation.
- Attach warning signs to the stack and to the door of the store!
- Lock the store!
- **Controls during fumigation**
 - Make a regular check of the seals!

- Ensure that no unauthorized persons enter the store during the entire fumigation period!
- Only allow the most essential work to be performed in the store and care for good ventilation when work is taking place! Measure the concentration of the gas from time to time in order to ensure that there is no danger to staff (see Section 9.3)!

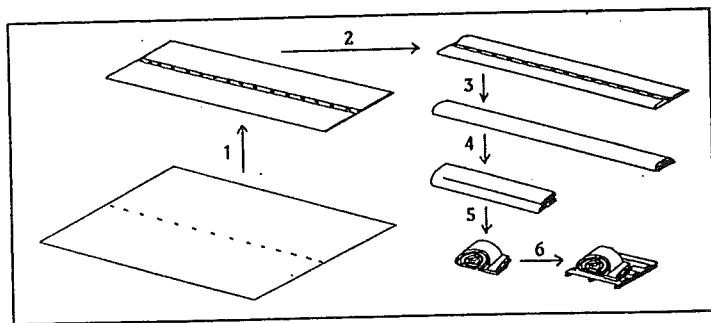
- Ventilation and release of the store

- Open doors and windows to ventilate the store!
- Wear a mask with a new filter (Type B) for phosphine!
- Remove the sand snakes!
- Turn up the sheet at the corners of the stack!
- Leave the store and ventilate for at least one hour (the longer the better)!
- Remove the fumigation sheet from the stack completely (wearing mask)!
- Ventilate for at least a further two hours (the longer the better)!
- Measure the phosphine concentration (see Section 9.3) in the store wearing a mask and release the store for general access if the reading is below 0.1 ppm, or continue ventilating if the concentration is still above this level!

- Cleaning up work

- Collect the residues of the tablets, pellets or bags!
- Dip the powdery residue of tablets and pellets into water mixed with a detergent and take care not to inhale the fumes!
- Rinse out empty phosphide containers (cans, tubes, bottles) with water, destroy them to prevent reuse, and bury them!
- Bury used fumigant bags or bag chains!
- Check the sheet for damage and repair it if necessary!
- Fold the sheet together properly as follows:

Lay together both edges to meet at the middle until you have reached a width of 1 - 1.5 m on either side of the centre line (1, 2). Then fold the sheet in half first crosswise (3), then lengthwise (4) and roll it up (5)!



- Store the folded sheet on a pallet (6)!

- Remove the warning signs from the doors!

9.2.1.8 Fumigating Silos Using Phosphine

Silos can best be fumigated during filling. Care must be taken to seal all openings with kraft paper and paste, or with impermeable coverings. The fumigant is added to the produce on the conveyor belt at regular intervals or thrown into the silo from above through a hatch during filling. This is done in line with the quantity of loaded grain.

Example:

A silo with a capacity of 500 tons is to be filled completely. This is being carried out at a rate of 20 t/h. With a dosage of 3 tablets/t, 60 tablets would have to be added every hour. It would be practical to add 5 tablets every five minutes to ensure good distribution of the gas.

If an automatic dispenser is available, it should be set at 1 tablet per minute.

Automatic dispensers are available both for tablets and pellets.

As the filling of a silo takes a considerable time, the staff may be endangered by the generation of gas. Therefore masks must be used when the fumigant is applied manually.

If a silo is not being filled completely, additional fumigant must be applied in line with the remaining silo capacity (m³).

The residues of the fumigant must be removed from the stored produce before it is forwarded:

- Bags are collected at the grain outlet by being caught in a large-meshed screen.
- Tablet and pellet residue is removed using an aspirator.

9.2.1.9 Fumigation of Bulk Produce with Phosphine

Bulk grain can also be treated under a fumigation sheet. Fumigation should be performed in line with the instructions given in Section 9.2.1.7.

If the height of the bulk produce is less than 2 metres, tablets, pellets (on trays) or sachets may be distributed onto the stored produce at regular intervals and collected again after fumigation. Blankets (1 blanket for each 100 - 300 t) are particularly well-suited for this purpose.

If the height of the pile is over 2 metres, then tablets, pellets or narrow bags must be probed into the produce at regular intervals. This requires good preparation and a good team, as it should take no longer than one hour from opening the first container with fumigant to the final seal being made.

The residue can only be taken out in such cases by means of mechanically cleaning the bulk produce when it is removed from the store (see Section 9.2.1.8).

9.2.2 Methyl Bromide

9.2.2.1 Properties

- Excellent penetration of stored produce
- Acts quickly
- Volatilizes relatively quickly on ventilation
- Is neither inflammable nor explosive
- Is liquid at temperatures of below 4°C and normal atmospheric pressure
- Is three times as heavy as air and thus settles
- May reduce germination capacity
- May leave residues particularly in stored produce containing fats and be detrimental to their smell. Stored produce containing fats must therefore only be fumigated a single time with methyl bromide.

9.2.2.2 Toxicity

- Methyl bromide is effective against all stages of insects.
- Methyl bromide is highly toxic to warm-blooded animals and is thus very poisonous to humans. It may be absorbed both by inhaling and through the skin, meaning that it is absolutely essential to wear protective clothing when dealing with this fumigant.

- Repeated intake of even the smallest amounts of methyl bromide in the human body leads to accumulation of bromide and ultimately to chronic poisoning with possible lethal outcome.

It is absolutely essential when fumigating with methyl bromide that the work is only performed by well-trained, responsible staff. Incorrect application is extremely dangerous both for the user and for persons nearby.

The use of methyl bromide should thus be restricted.

9.2.2.3 Forms of Packaging

Methyl bromide is supplied in liquid steel cylinders of various sizes and in cans. The choice of the form of packaging by the user depends on the amount required.

9.2.2.4 Generation of Gas

Methyl bromide is gaseous at temperatures of above 4°C, but is kept in a liquid state under pressure in gas cylinders in a similar form to butane or propane. If the valve is opened, the methyl bromide is released and volatilizes in the air to become effective as a fumigant.

It is important that sufficient space is available to enable the gas to disperse, as condensation of the methyl bromide will otherwise ensue.

9.2.2.5 Factors Influencing the Success of Fumigation

Recommended Application Rates

The recommended application rates in the fumigation of grains and grain legumes in stacks of bags under a fumigation sheet is 20 - 40 g/m³.

For fumigation of empty stores the recommended dosage is 20 - 25 g/m³.

It is essential that the recommended application rates are adhered to, as the success of treatment will be inadequate if the dosage is too low. This will further encourage the development of resistance. If the produce is properly covered and sealed, the recommended dosages will be perfectly adequate. If the amount of methyl bromide is too high, the maximum residue limit may be exceeded.

For effective fumigation of silos, devices for the recirculation of the gas are necessary, as it will otherwise settle at the bottom of the silo.

Exposure Time

Methyl bromide acts more rapidly than phosphine.

The exposure time is generally 24 hours. In empty stores the exposure time should be 30 - 40 hours.

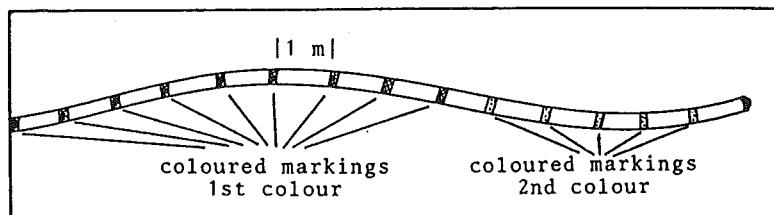
Due to the danger of bromide residues being left in the fumigated produce, this period should not be exceeded.

Quality of Sealing

The same criteria for sealing apply as for phosphine described in section 9.2.1.5.

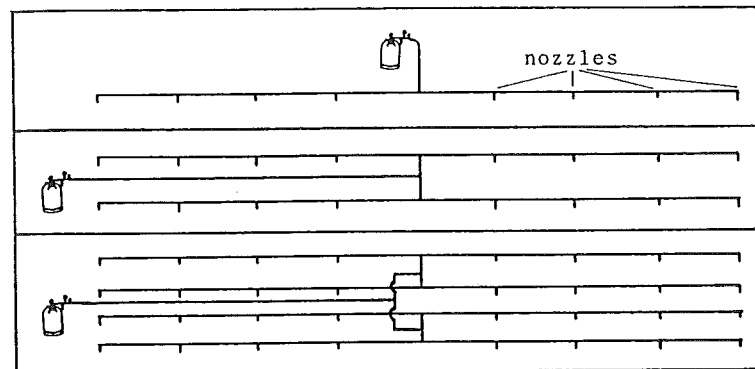
Application

Methyl bromide is applied from steel cylinders using a polyethylene tube ending in a nozzle. Simple rubber tubes are not suitable for this purpose. The tube should have coloured markings at intervals of 1 m and another colour for the final five metres (see Section 9.2.2.6).



More convenient are tube systems with several outlets, as they enable application of the fumigant at more than one point at the same time. There should be one point of application for every 9 m² on the top surface area of the bag stack. Nozzles should be spaced about 3 m from each other and at least 1.5 - 2 m from the edges of the stack.

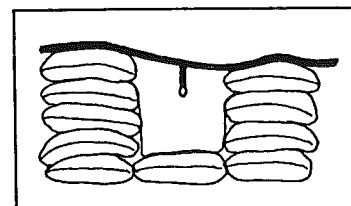
In order to have approximately the same pressure on all nozzles, the endings of all branches of the system must be at equal distances from the cylinder. This is best achieved by arranging the tubes in a H-shape (see illustration below). There should not be more than 5 nozzles per branch.



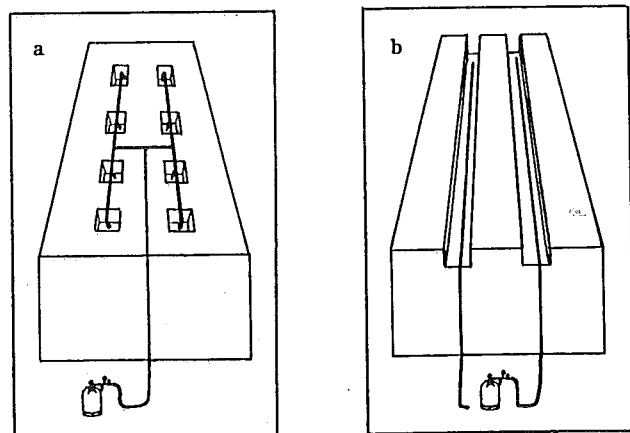
Methyl bromide will settle on the bottom of the stack as it is heavier than air. Application must therefore be made to the top of the stack in order to allow the gas to penetrate the produce.

In order to prevent any condensation of the gas (due to cooling as a result of the methyl bromide evaporation), air ducts or pits (one pit per nozzle) must be provided by restacking the bags in the top layers. This allows rapid air and heat exchange.

The ducts and pits should be lined with sheets or empty bags in order to prevent the methyl bromide to drop onto the stored produce.



The tube system is placed so that each nozzle ends in an air duct or pit. The main tube is passed under the sheet to the outside (a):



When using individual tubes instead of a tube system, these should be laid from the point where the cylinder is located to the opposite side of the stack (b).

In order to ensure that the gas is well distributed when using individual tubes, the overall dosage should be applied gradually by pulling out the tube little by little using the coloured markings as a kind of dosage divider. At least three metres of the tube must remain underneath the fumigation sheet for safety reasons.

The dosage is controlled by observing the weight of the cylinder during the application. The cylinder must thus be placed on a set of scales.

Ventilation

The ventilation period for methyl bromide is at least 6 hours. In poorly ventilated rooms this period should be extended to at least 12 hours.

9.2.2.6 Fumigating Stacks of Bags Using Methyl Bromide

Sealing, control measures during fumigation, ventilation, release of the store and cleaning up work are the same as for fumigation with phosphine (see Section 9.2.1.7).

The only differences are in the preparations and in the application which are dealt with here.

- Preparation

- Calculate the required amount of methyl bromide on the basis of the recommended application rate!
- Calculate the volume of the stack!

Example: Length 8 m
 Breadth 5 m
 Height 3 m

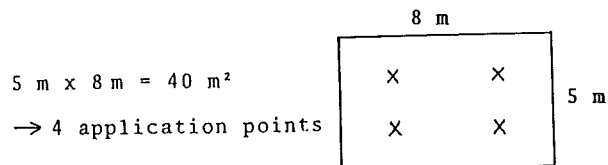
$$\text{Volume: } 8 \text{ m} \times 5 \text{ m} \times 3 \text{ m} = 120 \text{ m}^3$$

- Calculate the required amount of methyl bromide!

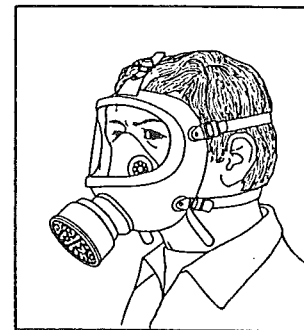
With a recommended application rate of 20 g/m³:

$$20 \text{ g/m}^3 \times 120 \text{ m}^3 = 2400 \text{ g}$$

- Determine the number of application points according to the top surface area of the stack!



- Depending on the size of the stack, prepare one or more air ducts or one pit for every application point in the top layer of bags by restacking the bags!
 - Line the ducts or pits with sheets or empty bags!
 - Lay out the tube system with the predetermined number of nozzles or one individual tube in each air duct!
 - Seal the stack entirely with fumigation sheets (see Section 9.2.1.7)! Pay particular attention to the outlets of the tubes!
- Application**
- Wear a full face mask with a new Type A breathing filter (brown coloured ring)! In contrast to working with phosphine, this mask must definitely be worn on applying methyl bromide.



- When using branched tube systems:

- Connect the main tube to the cylinder!
- Determine the weight of the methyl bromide cylinder!
- Calculate the weight it should have at the end of the application!

Initial weight of cylinder:	18500 g
Calculated amount to be used:	- 2400 g
Final weight to be reached:	<hr style="width: 100px; margin-left: 0;"/> = 16100 g

- Commence the dosage by opening the valve on the cylinder!
- Check the amount of the gas already applied by watching the loss of weight of the cylinder!
- Stop the application by closing the valve as soon as the calculated final weight of the cylinder has been reached!
- Uncouple and seal the tube!
- Check for any leaks in the sealing using a halide lamp!

- When using individual tubes with only one outlet:
- Calculate the partial dosages for the application points chosen!

Total amount to be applied: 2400 g
 Divided up into 4 partial dosages:

$2400 \text{ g} / 4 = 600 \text{ g}$ at each application point

- Calculate the weight of the cylinder after each partial dosage!

Initial weight of cylinder: 18500 g

Weight after each partial dosage:	- 600 g = 17900 g
	- 600 g = 17300 g
	- 600 g = 16700 g
	- 600 g = 16100 g

16100 g = final weight of cylinder

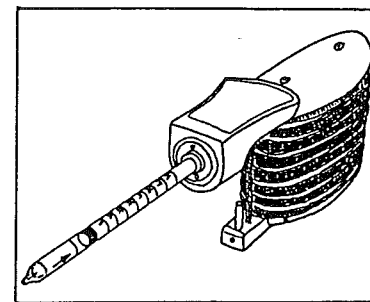
- Connect a tube to the cylinder!
- Commence application and control the weight loss of the cylinder!
- when the first partial dosage has been applied, pull out the tube up to the next application point by using the coloured markings (in the example: 4 m)! Continue application in this way!
- Stop the application when the calculated final weight of the cylinder is reached!
- Uncouple and seal the tube!
- Repeat this procedure if more than one single tube has been laid out for the application!
- Check for leaks in the sealing using a halide lamp!

The presence of people not involved in the procedure and all work in the store is strictly prohibited for the entire duration of the fumigation.

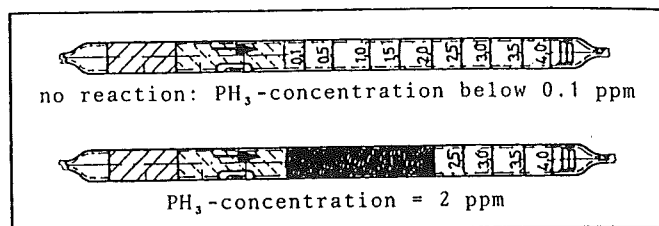
For safety reasons the application must be finished within 10 - 15 minutes. This necessitates a good preparation and organisation.

9.3 Measuring the Gas Concentration in the Air

Before the store can be entered without danger, the gas concentration must be tested. For this purpose a gas detector is used, consisting of a bellow pump and an insertable glass tube:



The tubes are specific for certain types of gases. To take a reading, break open a tube at both ends and insert it into the pump in the prescribed direction. Then hold the detector in the air to be measured and draw it into the tube by pressing and releasing the suction rubber. The number of strokes needed to take a reading is stated in the instructions. The gas concentration can be directly seen by the change of colour in the calibrated tube:



The maximum admissible levels are 0.1 ppm (= 0.15 mg/m³) for phosphine and 5 ppm (= 20 mg/m³) for methyl bromide. Only if the values are below these limits the store can be released for access.

The presence of methyl bromide can also be tested using a halide lamp. This is particularly useful for tracing leaks in the sealing for fumigation.

A halide lamp consists of a small burner which is run on commercially-available propane or butane gas. A small piece of copper is fixed in the flame, giving the flame a green colour. The flame produces an air current inside a fixed tube. Move the end of the tube along any potential areas of leakage (wearing a mask!). If methyl bromide is leaking out anywhere, the flame through will turn bluish.

Be sure to follow exactly the manufacturer's instructions for the use of halide lamps.

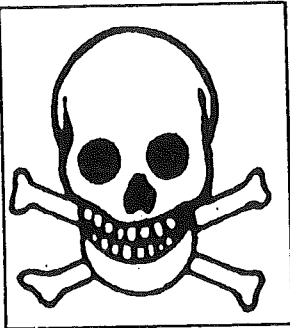
9.4 Safety Regulations

A number of the safety regulations listed in Section 8.4 equally apply to fumigants. The stipulations for storing insecticides stated in Section 8.4.1 are applicable

without exception to fumigants. Attention should essentially be paid to the general introductory rules given in Section 8.4.2. Also take note of the details concerning protective clothing, safe application as well as the correct disposal of empty packages and residue.

Additional attention should be paid to the following points when dealing with fumigants:

- Always work in pairs, never alone!
Should an accident occur during fumigation, it is important that someone is present to immediately remove the victim from the danger area.
 - Always have a gas mask with a new filter available in case of emergency!
 - Inform a doctor about the fumigants used and provide him with manufacturer's information (leaflets, label)!
 - Exclude the possibility of danger to other persons!
This means: inspect the store and its surroundings carefully before application to ensure that there are no unauthorized people in the danger area!
- Never fumigate stores which are directly adjacent to living quarters! The distance to any neighbouring houses or offices must be at least 10 metres.
- Lock the store once the fumigant has been applied and put up a warning sign on every door, stating the type of fumigant used, the date of treatment, the name of the person in charge of fumigation and the place where he can be reached.



POISON GAS
VERY TOXIC
DO NOT ENTER

From to
the locality is under fumigation with
PHOSPHINE / METHYL BROMIDE.

Entrance is strictly prohibited.

Responsible for the fumigation:

Name:

Address:

Phone No.:

- All keys to the store must be in the hands of the person in charge of fumigation.
- Never touch Phosphide tablets or pellets with your bare hands!
- Always wash your face and hands thoroughly after using fumigants!
- Monitor the gas concentration and pay attention to the maximum admissible level! Always wear gas masks!

Due to the high toxicity to mammals, the maximum levels in the air of 0.1 ppm for phosphine and 5 ppm for methyl bromide must not be exceeded. If the readings show the levels to be higher access to the store is not allowed.

- Notes on the use of gas masks and breathing filters:
 - Only wear gas masks in connection with breathing filters! Breathing filters are screwed into the masks. Always check that the mask is air-tight:
 - Put on the mask with the filter screwed in!
 - Close the opening of the filter by covering it with your hand!
 - Breathe in and hold your breath for a moment! If a vacuum persists the mask is air-tight.
 - People with beards should not execute work which necessitates wearing breathing masks, as complete air-tightness of the masks cannot be guaranteed.
- Select the correct filter:
 - For **phosphine**, only use **Type B** filters with a grey coloured label.
 - For **methyl bromide**, only use **Type A** filters with a brown coloured label.
 - Never use a Type B filter for phosphine for longer than 20 minutes effective breathing time! Do not reuse it for another fumigation, even if the limit of 20 minutes has not been reached.
 - Replace the A filter for methyl bromide after every fumigation! It can be used for the application (10 - 15 minutes) plus ventilation.

- Never use a filter:
 - if the expiry date is already past!
 - if it is damaged!
 - if it has already been open !
- Do not open new filters until you are about to use them!
- Clean the mask using soapy water after every usage and store together with the breathing filters in a dry, dust-free place (under no circumstances in the insecticide store)!
- Destroy and bury used filters!

9.5 First Aid

Poisoning as a result of fumigants has similar symptoms to insecticide poisoning:

Nausea, vomiting, diarrhoea, headache and stomach ache, dizziness, impaired vision, breathing difficulties, cramps and fatigue may occur, sometimes with considerable delayed reaction.

If there is any suspicion of poisoning, the person affected must be taken out of the working area immediately. He should be carried if possible, as any kind of physical exertion must be avoided. Ensure that he has sufficient oxygen supply and that he does not become cold!

Consult a doctor immediately!

In case of contamination of the eyes or the skin, act as described in Section 8.4.3!

9.6 Equipment

The following equipment is needed for fumigation and must be in stock at all times:

- Fumigant
- Gas-tight fumigation sheets
- If necessary, special clips to join two sheets together
- Sand snakes, sufficient in number
- Adhesive tape, pieces of sheet material and special glue to seal and repair the sheets
- Gas detector with detector tubes for phosphine or methyl bromide
- Halide lamp to check for methyl bromide leakage
- Gas mask (full face mask)
- Breathing filters A or B, depending on the gas used
- Protective clothing (see Section 8.4.2)
- Pieces of cardboard (e.g. egg boxes) or prepared wooden planks in which to place phosphide tablets or pellets
- For application of methyl bromide: tubes with nozzles and fittings and a set of scales on which to place the methyl bromide cylinder
- Warning signs
- Tape measure
- First-aid equipment

9.7 Further Literature

- Anonym. 1986. GASGA Seminar on Fumigation Technology in Developing Countries
- Anonym. Fumigation à l'hydrogene phosphoré, Detia, Laudenbach, 56 pp.
- Anonym. Phostoxin (German, English or French), DEGESCH, Frankfurt, 56 pp.
- Baur, F.J. (Ed.) 1984. Insect Management for Food Storage and Processing, St. Paul, 384 pp.
- Bond, E.J. 1984. Manual of Fumigation for Insect Control, FAO, Rome, 432 pp.
- Robbe, P. 1989. Index Phytosanitaire, Paris

10. Integrated Pest control

In order to prevent and control stored product pests, hygiene and chemical measures are generally used. There are also, however, biological and physical methods of control some of which are still at the research and development stage. Biological methods have little practical importance to date, but may well become a part of an integrated control concept in the future.

10.1 Mechanical Methods

These are generally methods which are aimed at separating the pests from the stored produce. While the main mechanical methods in small farm storage are sieving, picking out, or winnowing, use is made in larger scale storage of various cleaning installations. It is important to destroy any insects found in the by-products or left-overs immediately. Larvae living inside the grain are only inadequately eliminated.

- Packaging

Pests can be prevented by packing the stored produce well. This is, however, only the case if the material used is strong enough to resist any attack by the pests. It will often be difficult to obtain packaging material which meets this demand.

Jute and artificial fabric sacks, plastic foil, paper or containers made of wood or cardboard are in general use. They often do not afford any mechanical protection against pests.