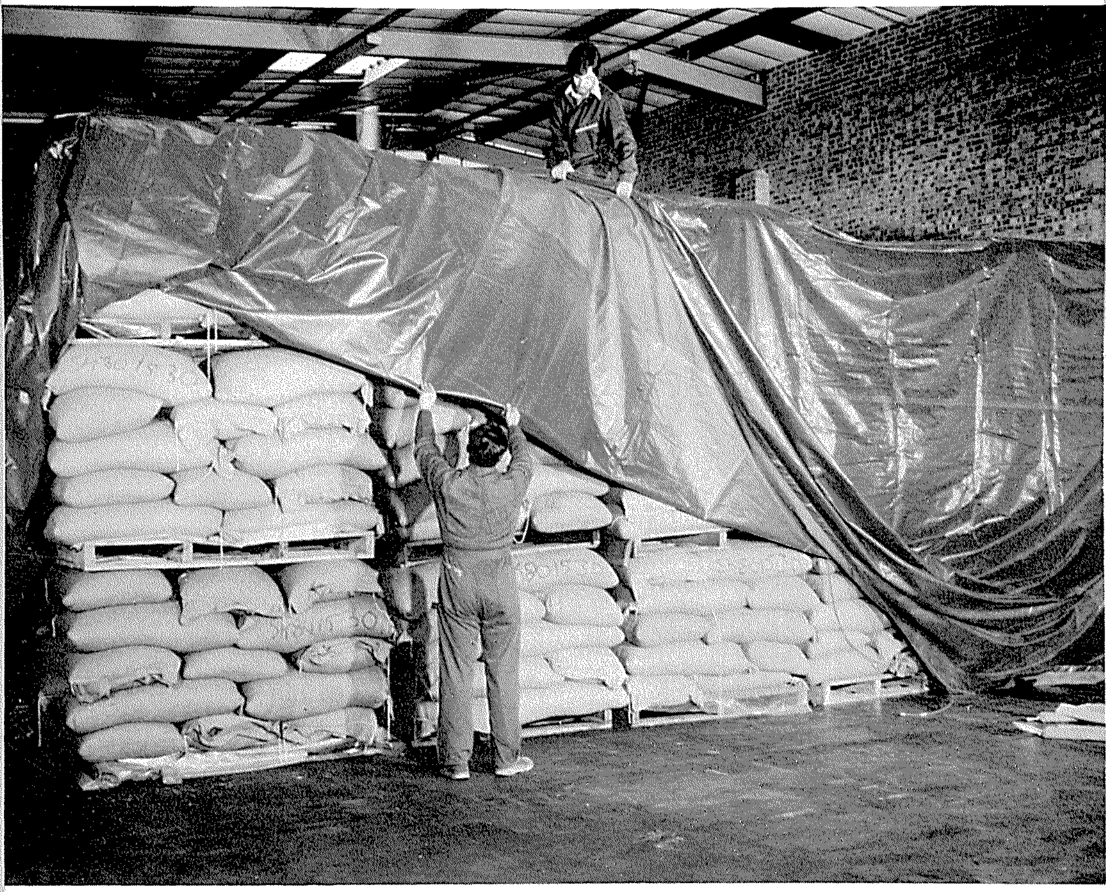
Manual of pest control for food security reserve grain stocks

FAO PLANT PRODUCTION AND PROTECTION PAPER

63



FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Manual of pest control for food security reserve grain stocks

Prepared by
The Storage Department
of the
Tropical Development Research Institute
Foreign and Commonwealth Office
Overseas Development Administration
Slough, United Kingdom

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER
63

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS
Rome, 1985

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-66
ISBN 92-5-102235-6

PREFACE

With the widespread gradual development of Food Security Reserves of Stocks of Foodgrains in the Developing Countries, as a part of the individual country's food security programme, the need for keeping these foods safe is obvious. Much of this grain is being held for periods of one to two years. There is little experience in this relatively long-term conservation of foodgrains in large quantities in the tropical and subtropical regions of the world, but it is known that insect, fungal, rodent and bird pests constantly threaten the quality and quantity of the food available in these reserves.

The Food and Agriculture Organization of the United Nations (FAO) is assisting many countries in the development of their food security programme. One aspect of this assistance, to help in the prevention of loss of quantity and quality of the reserve stocks, is the aim of this manual.

The manual was prepared at the request of and for FAO by the Storage Department of the Tropical Development and Research Institute (formerly the Tropical Products Institute) under the general supervision of D.J.B. Calverly, Head of the Storage Department which has personnel broadly experienced in all aspects of the general subject.

Based on an outline agreed between FAO and the Storage Department of TDRI, development of the manual was directed by D.J. Webley, Head of the Department's Chemical Control Section at that time, and included substantial contributions from many staff members of the Storage Department. FAO and TDRI wish to acknowledge, with gratitude, the assistance of all those who have made this manual possible. Professional supervision and review in the FAO was by the Plant Protection Service, Plant Production and Protection Division. Inasmuch as this manual is intended primarily as a direct training tool or a guide for personnel directly involved with the problem of keeping food safe, literature references are not included.

C O N T E N T S

INTRODUCTION		1
1.	STORAGE STRUCTURES	5
	Type of storage	5
	Choice of site	5
	Warehouse design	5
	Silo design	9
	Rodent and bird proofing	10
	Maintenance of storage structures	13
	Operation of storage structures	16
2.	GRAIN QUALITY STANDARDS MEASUREMENT	21
	Quality standards	21
	Quality assessment	24
	Sampling methods	27
3.	CAUSES OF GRAIN DETERIORATION	37
	Moisture content, relative humidity and temperature	37
	Moulds	38
	Insects	40
	Detecting insect infestation	60
	Arachnids	64
	Detection of mites	65
	Vertebrate pests	65
	Detection of rodents	67
4.	PEST CONTROL METHODS	69
	Choice of insecticides and fumigants	69
	Treatment of store fabric	70
	Fumigation	81
	Insect control in bulk grain	124
	Routine insecticide treatments in stores	129
	Control of vertebrate pests	138
	Maintenance of safety	145
5.	ROUTINE STORAGE PROCEDURES	151
	Store preparation	151
	Beginning of storage	151
ANNEX 1 - Control Techniques Alternative to Pesticide Use		155
ANNEX 2 - Detailed Design of Warehouses		159
ANNEX 3 - Measurement of Relative Humidity, Moisture Content and Temperature		161
ANNEX 4 - Sampling Inspection of Bagged Cereal		169
ANNEX 5 - Sieves		171
ANNEX 6 - Descriptions of Insecticides Used in Storage		173
ANNEX 7 - Tables of Insecticide Properties		177
ANNEX 8 - Insecticide Application Rates		181
ANNEX 9 - Properties of Liquid Fumigants		183

ANNEX 10 - Fitting Sheets to Stacks 187

ANNEX 11 - Storage Volumes 190

ANNEX 12 - Glossary of Terms for Pesticide Use 191

ANNEX 13 - Symbols and Abbreviations Used 193

INDEX 194

LIST OF ILLUSTRATIONS

1. Fumigable stores in Kenya 6

2. Essential features of a grain storage warehouse 7

3. Common points of rodent entry into buildings 11

4. Rodent proofing for doors and air vents 11

5. Steel "guillotine" half-door for rodent proofing 12

6. Rodent proofing around pipes 14

7. Proofing measures to prevent rodent entry through foundations 15

8. Bag elevator 17

9. Eaves ventilation with shutter opening outwards 18

10. Suggested design for grain quality assessment table top 25

11. Simple bag sampling spears 25

12. Correct and incorrect ways of using a sampling spear 29

13. Possible errors arising from spear sampling 30

14. Double tube sampling spear 32

15. Produce flow sampler with sack and sample bag 34

16. Coning and quartering 35

17. Riffler divider for dividing grain samples 35

18. Boerner divider 36

19. Relative humidity/moisture content isotherm 37

20. Complete metamorphosis 41

21. Incomplete metamorphosis 42

22. *Sitophilus oryzae* 44

23. *Sitotroga cerealella* 45

24. *Acanthoscelides obtectus* 47

25. *Tribolium castaneum* 48

26. *Ephestia cautella* 50

27. *Oryzaephilus surinamensis* 51

28. *Rhyzopertha dominica* 52

29. *Trogoderma granarium* 53

30. *Cryptolestes ferrugineous* 54

31. *Tenebroides mauritanicus* 55

32. *Lasioderma serricorne* 56

33. *Stegobium paniceum* 57

34. *Carpophilus dimidiatus* 58

35. *Ptinus tectus* 59

36. Various forms of insect traps 61

37. Moth pheromone traps 63

38. *Acarus siro* 66

39. Spraying inside walls of a bag store in Swaizland 71

40. Pneumatic sprayer 75

41. Hydraulic sprayer 76

42. Motorized knapsack sprayer 77

43. Spraying pump 78

44a. Halide lamp for detecting methyl bromide leaks 94

44b. Detector tubes for detecting methyl bromide leaks 95

44c. Thermal conductivity meter for measuring methyl bromide 96

45. Infra-red absorption meter for measuring phosphine 98

46. Bioassay tube 100

47. Methyl bromide fumigation under gas-proof sheets: making pits in top of stack 102

48. Methyl bromide fumigation under gas-proof sheets: laying out gas lines and jets 103

49. Methyl bromide fumigation under gas-proof sheets: sheeting the stack 104

50. Methyl bromide fumigation under gas-proof sheets: putting sandsnakes in place 105

51. Methyl bromide fumigation under gas-proof sheets: pressurizing the cylinder 106

52. Methyl bromide fumigation under gas-proof sheets: opening the cylinder 107

53. Methyl bromide fumigation under gas-proof sheets: checking for leaks with the halide lamp 108

54. Methyl bromide fumigation under gas-proof sheets: putting up warning notices 109

55. Folding a fumigation sheet 111

56. Folding the middle sheet of three joined sheets 112

57. Layout for a multiple sheet fumigation 113

58. Layout of methyl bromide jets 114

59. Correct and incorrect methods for connecting jets 115

60. Piping layout for a very large stack 115

61. Methyl bromide cylinders and fittings 117

62. Aluminium phosphide preparations 119

63. Disposal of spent aluminium phosphide powder 120

64. Stack spraying 130

65. Automatic mist blower 132

66. Dichlorvos dispensers used in a confined store 135

67a. Thermal fogger 136

67b. Protective clothing for space treatments 137

68. Simple containers and covers for rodent bait 141

69. Mouth to mouth resuscitation 149

70. Cyprus bins for hermetic storage 156

71. Whirling hygrometer 162

72. Drum hydrograph 163

73. Meter for measuring moisture in grain 164

74. Reethorpe moisture meter 165

75. Cera tester 166

I N T R O D U C T I O N

STORAGE POLICY

This Manual provides operating guidelines for the storage of national reserve grain stocks and their protection from pest damage and deterioration. National reserve stocks are held against the possibility of famine or severe grain shortage. They consist mainly of cereal grains, such as maize, paddy rice, sorghum, millet and wheat. The storage techniques for these cereals cannot be looked at in isolation from the storage structures and the condition of the grain coming into storage. The Manual, therefore, deals with the four aspects:

Storage Structures
Grain Quality
Pest Damage and Deterioration
Pest Control

The national policy for reserve storage must cover the size of the stocks;its procurement, storage and disbursement; the type and ownership of the storage facilities; the financing of the stock and the management organizational structure. Operational guidelines are needed for the operation of the programme, selection of stocks, purchasing, transport, storage, stock rotation, distribution or disposal.

The Manual discusses storage only from the point of view of prevention of damage and loss in quality, but the way in which storage is managed will depend on the overall management policy and on the degree of importance and resource allocation that is given to maintain good storage conditions. It will, therefore, help to improve storage practices if management understands the storage problems that exist and formulates a general policy giving a clear guide to those who have day to day responsibility for the stocks.

STORAGE TECHNOLOGY

The first question to ask is what level of storage technology should be used. The technology must be appropriate to the individual country situation, but it is equally desirable to use the best technology available. At the preset time much of the grain stored centrally in developing countries is in sacks and the available technology mainly relies on chemical pest control. The Manual is, therefore, to a large extent concerned with bag storage in conventional structures using conventional techniques, which rely on fumigation as the main method of insect pest control. Standards of practice in these techniques are often quite inadequate for long-term storage and the Manual has been produced to assist the radical improvements that are necessary to prevent heavy losses in such situations.

At the same time it must be recognized that there are serious limitations to storage in sacks in open warehouses as a method of preserving quality in long-term storage, and it is believed that sealed storage, either as a form of hermetic storage or using controlled atmospheres of carbon dioxide or nitrogen, should play a significant part in reserve storage. These "new" techniques are after all only developments of storage procedures that are centuries old. Pest control is also potentially more effective in bulk than in bagged grain, whether by insecticide admixture, aeration or by other means. Current changes are generally towards capital-intensive bulk handling and away from labour-intensive bag handling. The Manual, therefore, also looks to these developments, giving guidance on pest control in bulk grain in Chapter 4 and discussing alternative non-chemical pest control techniques in Annex 1.

PESTICIDE REGULATION

Most countries have regulations regarding the use of pesticides on foodstuffs, and many have adopted the international maximum limits for pesticide residues recommended by the FAO Codex Alimentarius Commission. This is also the policy of this Manual, which recommends for admixture treatments only those pesticides that have had maximum residue limits suitable for grain storage admixtures recommended by the Codex Commission or by the FAO/WHO Joint Meeting on Pesticide Residues. The main reliance is on the use of the fumigants phosphine or methyl bromide, for which there is worldwide acceptance. The use of insecticides is restricted mainly to wall or space treatments with the possible additional spraying of the outside surfaces of stacks. Countries forbidding the addition of insecticides to grain are therefore, more dependent upon fumigation. However, the admixture of insecticides at the start of storage is particularly useful for flat bulk storage and guidance is given on this technique.

LOSSES IN STORAGE

The chances of losses occurring over a long period of time are high unless adequate precautions are taken. They are in nature loss of weight and loss of quality and acceptability. If these losses are not prevented, there may be a total financial loss of the whole or part of the reserve stocks. In such circumstances the highly damaged grain might be left occupying the reserve store, causing cross infestation of other grain and existing only on paper as a famine reserve. Moreover, once deterioration and loss have occurred corrective treatments cannot restore the quality or replace the loss. Thus a vital objective in the storage programme must be to keep loss at a negligible level from the very beginning. This means aiming for a nil infestation level by the best means available. There must be adequate financial provision for this.

Loss and deterioration in storage occur because either the condition of the grain received into store was unsatisfactory, the storage structures are unsatisfactory or the storage management is inadequate and unfavourable conditions are allowed to develop.

Good storage must begin with cereals entering storage in good condition, but deterioration of the grains may begin before harvest and continue through the harvesting, drying, threshing and transportation stages. In the tropics, grain crops are likely to be infested in the fields by storage insects and the developing infestation within the grain may be carried as a hidden infestation into the store. Fungi and bacteria may attack grains, especially in wet harvesting conditions, and rodents and birds may attack the standing crop leaving damaged grains more susceptible to attack by micro-organisms and insects in store. Premature harvesting may result in a high proportion of immature grains that, because of their high moisture content, will deteriorate rapidly in store. If harvesting is delayed too long then the mature grain may be attacked by insects, micro-organisms and vertebrate pests and may be physically damaged by cracking through repeated natural wetting and drying.

Poor threshing may result in cracked or broken grains or contamination with soil and other foreign matter. Rapid drying or overdrying, may result in cracked grain leading to more rapid deterioration in storage. The grain itself may then have properties unsuitable to long-term storage through deficiencies in the seed coat or endosperm.

Many of these factors that contribute to the damage of grain before storage may be very difficult to control, but the key to successful long-term storage is to set a high standard and to maintain good inspection in support of the standard, as described in Chapter 2. Cleaning and drying to a safe moisture content will inhibit the growth of micro-organisms and reduce insect infestation. These operations need to be carried out in the best possible way. Furthermore, as described in Chapter 4, consignments must be efficiently fumigated, before going into store, as a general routine measure.

Deterioration during storage is influenced by the store design, which affects the storage environment. A store should be structurally sound and waterproof, but this is not sufficient to prevent deterioration. Growth of micro-organisms occurs when grain is exposed to high humidities and the seriousness of insect infestation tends to increase at higher temperatures. Tropical temperatures are typically conducive to maximum biological activity. A well-designed store needs to include features that limit high humidities and temperatures, keep pests out and do not give them ideal conditions in which to breed.

Even when the requirements for a good store have been fulfilled, deterioration may still occur if the store is poorly managed. Reservoirs of insect infestation may develop if grain residues build up through poor standards of hygiene or if infested produce remains in store longer than is necessary. Poorly controlled ventilation may lead to undesirable high humidities and temperatures. Poor structural maintenance may lead to rodent infestation.

Regular inspection followed by prompt action can prevent a hidden infestation from causing a major loss. Such inspection, backed up by regular hygienic measures and prophylactic treatments, is described in Chapter 5. The judicious combination of good store management, careful inspection and early and efficient control measures can ensure a high standard of storage practice. These are the essential requirements if serious losses are to be avoided.

1. STORAGE STRUCTURES

TYPE OF STORAGE

Long-term storage may be in bag or bulk. The choice may depend mainly on the way grain is normally handled, to avoid unnecessary changes from bulk to bag handling. The common method of long-term storage in the tropics is in-bag storage in warehouses figure 1. Bulk storage in silos, in specially constructed hermetic stores such as the Cyprus bins or in underground stores, may also be used. However, storage on the floor in flat bulk stores is not recommended for long-term storage, because of the difficulties of turning the grain and of pest control. Silos may be too expensive for reserve storage. Broad requirements for both bag and bulk stores are given and ways in which existing and new stores may be made suitable for long-term storage are described. A degree of flexibility may be desirable if the storage must be used sometimes for commodities other than the grain reserves. Warehouses would, in such circumstances, have an advantage over custom-built bulk stores. The main difference between transit and reserve stores is that the former are used more and, therefore, need better access and flooring, whereas reserve stores need better security and better storage conditions. The reserve storage site is also likely to need drying, cleaning and bagging plants. This equipment is not described in the Manual, but that does not imply that such equipment is unnecessary.

CHOICE OF SITE

The stores should be located well away from industrial odours, which might taint the grain, and away from living or working quarters, to allow safe aeration of the fumigants used in the store. Access to the site should be adequate, especially during rainy seasons, and it should not be prone to flooding, inadequate drainage or earth subsidence. The soil load-bearing capacity should be tested for adequacy.

Soil preparation may require the removal of organic material and 'black cotton' soils. Foundations should be proofed against termites, if these pests are likely to occur. Warehouses in tropical zones should be oriented with their long sides facing the prevailing wind or, if there is little or no wind, they should preferably be sited with the long side of the building in the east-west axis and the doors on the north or south facing sides. The stores should be provided with electricity and preferably also water, sewerage and drainage.

WAREHOUSE DESIGN

General requirements

The most suitable structures for long-term bag storage are well-designed, single-storey warehouses with capacities from 500 to 2 000 tonnes (figures 1 and 2).

A warehouse or group of warehouses should possess an external fumigation plinth, so that infested produce can be fumigated before entering the warehouse, and a completely separate chemical and equipment store. A separate store for empty bags may also be needed. The warehouse and its outbuidlings should have a security fence.

The warehouses should be structurally simple. Local conditions and prices will usually determine the choice between steel or reinforced concrete frames and local or imported materials. Similarly the choice between portal frames and locally constructed, lattice frames will depend on on-site costs and ease of construction. Internal columns are not desirable, but are less of a disadvantage in long-term stores than in short-term stores, where rapid handling is more important. Warehouses must be suitable for produce to be fumigated. In normal warehouses this is achieved by fumigating the stacks under gas-proof sheets, but with greater capital cost special warehouses can be built with gas-proof wall and roof materials and with specially designed doors, vents and openings that can be sealed. These buidlings can be fumigated in their entirety.

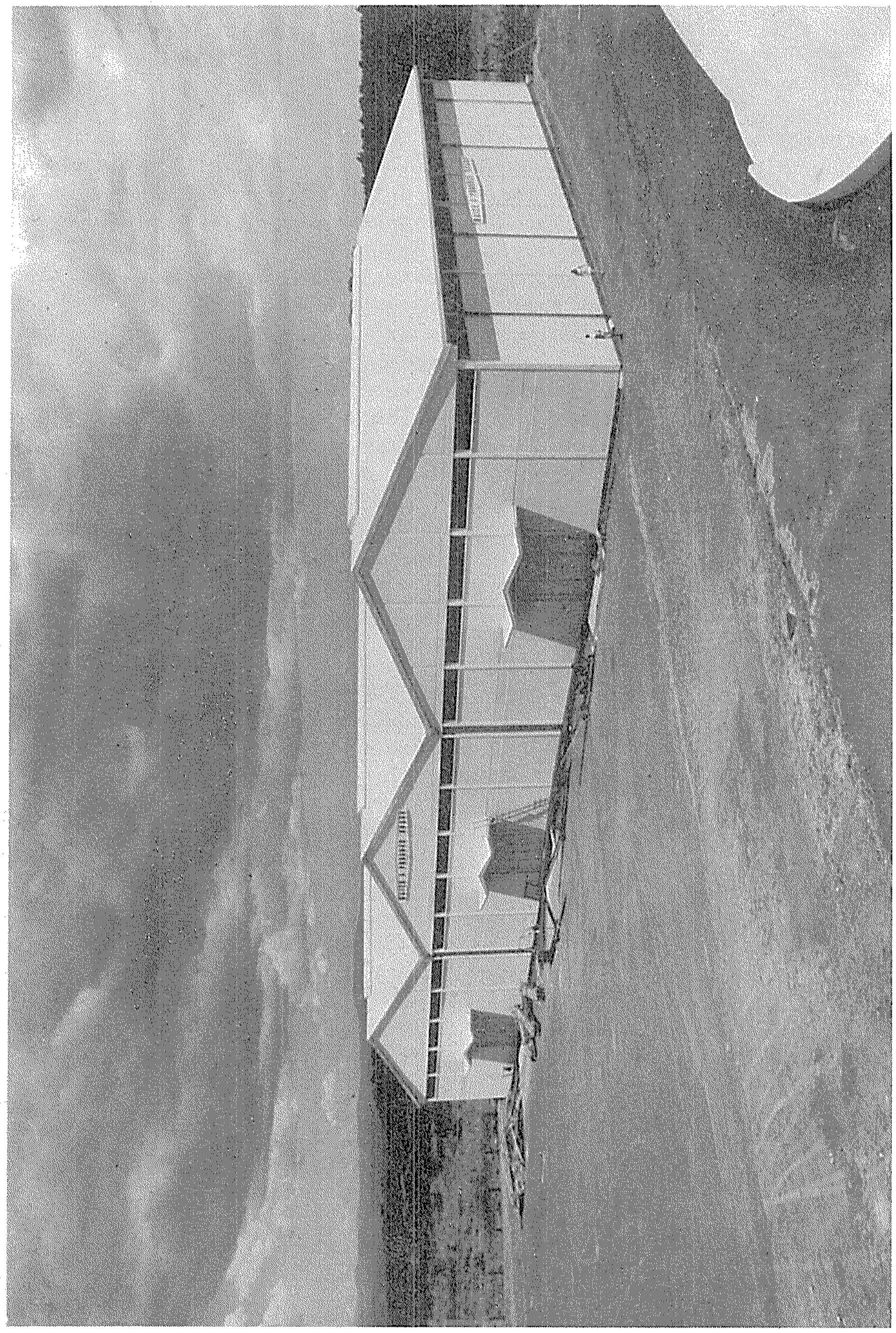


Figure 1. Fumigable stores in Kenya.

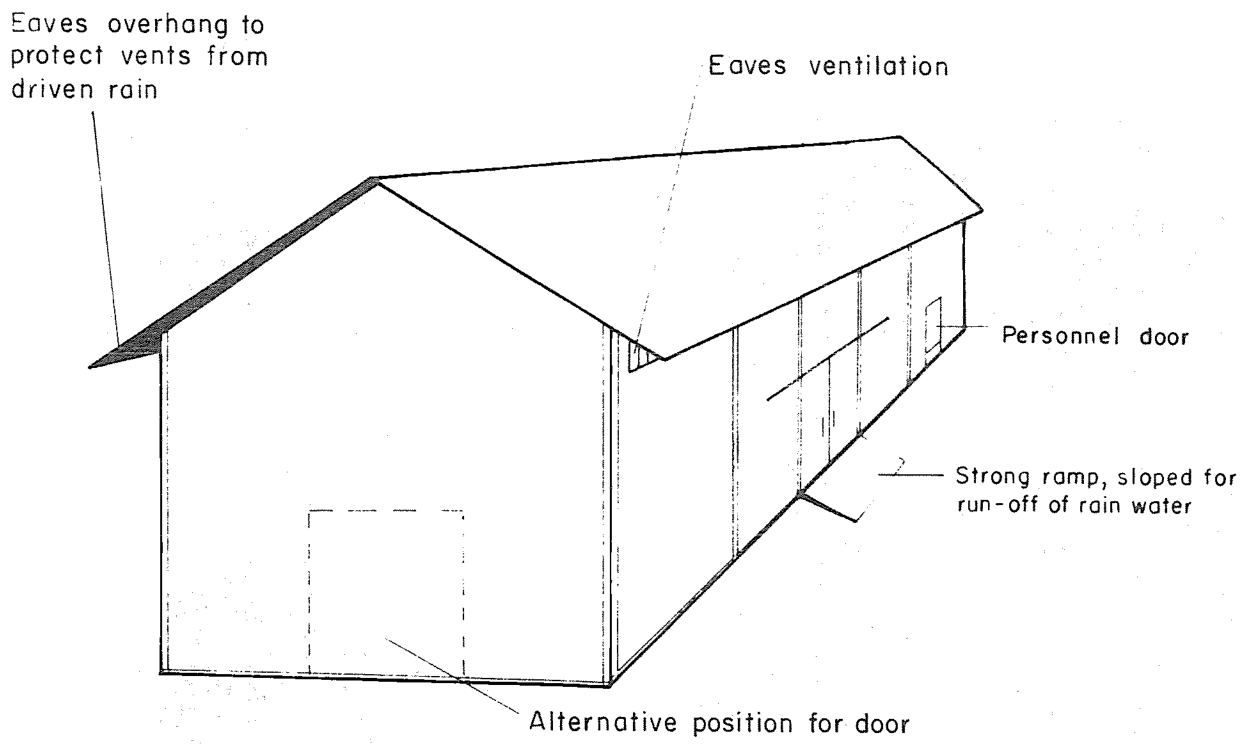


Figure 2. Essential features of a grain storage warehouse.

Pest control requirements

A number of design measures may prevent pests from infesting both warehouses and silos. Some of these measures are rarely used in commercial or transit storage but become very necessary in reserve stores because of the longer storage period. The following measures reduce the collection of dirt and sites for infestation.

Floors. Concrete floors should be of monolithic construction or gaps between slabs should be sealed with hot bitumen. A hardener (carborundum) may be incorporated when laying the final surface.

Internal junctions. The junctions between floors and walls and between floors and columns should be rounded out with fine-aggregate concrete fillets, cast in situ. All roof-to-wall joints should be sealed with mastic.

Walls. All cracks should be filled in. Walls should be rendered smooth with cement plaster, sealed and painted with light coloured paint.

Sills and ledges. These should be kept to a minimum and sloped to reduce accumulation of dirt. Angle iron should be accessible for cleaning.

Openings. Openings, such as eaves, may be covered with insect mesh, principally to exclude moths. (It is not usually possible to exclude all insects.)

Several measures are needed to prevent rodent and bird entry. These are given in the section on "Rodent and Bird Proofing". More detailed warehouse design is given in Annex 2.

Suitability of existing structures for bag storage

Single-storey buildings with the following features are most suitable.

Roof. A simple, steep double-pitched roof (not less than a 20º angle) with uninterrupted cladding and straight sides. Asbestos cement sheet, corrugated galvanized steel or aluminium sheet roof cladding, not tiles, slate or thatch. No ridge ventilation and preferably few roof lighting sheets. No cracks, loose sheets, holes, missing beading or washers or signs of leaks.

Floor. A smooth concrete floor (not timber), in good repair with a moisture vapour barrier to allow grain to be fumigated and to keep bags dry.

Entrances. A few well-secured entrances.

If the structure is basically sound it should be possible to improve the suitability for exclusion of pests, as described above and in the section on "Rodent and Bird Proofing". Structural deficiencies that are difficult to remedy, include:

- Site deficiencies
- Badly cracked floors that allow moisture, vapour and rodent entry.
- Multiple doors with gaps and openings that allow rodent entry and make the building insecure.
- Numerous internal columns that cause stacking and fumigation problems.
- Buildings of an unsuitable size (very small), which have low utilization of avilable space and relatively expensive to manage. Buildings of less than about 3m high and $100m^2$ in floor area are not recommended.

SILO DESIGN

General requirements

Vertical silos or bins can be suitable structures for long-term bulk storage, provided that the grain can be aerated and fumigated or treated with insecticide. Bins may be constructed of metal or concrete, depending on availability of materials, cost, bin capacity, importance of moisture migration and gas tightness and availability of construction expertise. Capacities of bins vary greatly (50 to 5 000 tonnes), although 500 to 1 000 tonnes would be preferred for long-term storage. Bins are usually placed in rows sharing central conveyors above and below, with common elevators at one end. When built in rows the bins often share walls or are connected by interstitial walls. The spaces formed by joined walls or interstices are also filled with grain. The outer walls should have a light-coloured,reflective surface to keep the temperature down.

Aeration

All silos should have aeration facilities. Even if the grain is dry at intake, moisture migration and condensation can occur, and unless the grain is moved, aerated or re-dryed, severe mould damage can result after long storage periods.

Aeration is not a form of drying. Its purpose is to cool the grain or to reduce temperature and moisture gradients. Bins with flat bottoms may have aeration ducting on the floor or a perforated floor with an air chamber below. Small performations are required for sorghum and millet. Hopper-bottomed bins are not easy to aerate satisfactorily, because an even air flow through the grain is hard to achieve.

The ease of emptying of hopper-bottomed bins makes turning the grain simpler. Turning is not a substitute for aeration, but it helps to alleviate the effects of moisture migration or condensation by mixing the grain.

Requirements for pest control

All silos need to be equipped with either fumigation or insecticide application facilities, as these are essential to control insect infestation. The choice between fumigation and insecticide application as a method of control is discussed in Chapter 4, "Insect Control in Bulk Grain". In either case, a holding or spare silo will be needed if it is necessary to treat grain already stored or to re-treat such grain with an insecticidal spray or with an aluminium phosphide fumigant.

For effective fumigation the silos need to be gas tight. If methyl bromide is the fumigant used, then gas recirculation equipment is also needed. If aluminium phosphide fumigants are used, the tablets, pellets or other proprietary formulation must be added to the grain flow to achieve satisfactory distribution of the gas in bins more than 10m deep (see Chapter 4, "Insect Control in Bulk Grain"). This can be done at intake or, if it is done subsequently, then the grain must be turned into another bin. In bins less than 10m deep it is possible to distribute the fumigant sufficiently by the use of suitable probes (see Chapter 4, "Insect Control in Bulk Grain"). However, such bins are of small capacity, usually about 400 tonnes or less.

A water supply is needed for insecticide application. The bins need not be gas tight, but ancillary grain-handling equipment should be fully mechanized and self-emptying (hopper-bottomed) bins are preferable; especially if the grain may need treatment at discharge or re-treatment during transfer to another bin for further storage. Satisfactory treatment requires a continuous, steady flow of the grain and, for this reason, if flat-bottomed bins are used, they should be equipped with sweep augers or an intervening garner bin should be provided.

Sealing

Gas-tight bins must have sealable closures at aeration duct inlets and outlets and at grain filling and emptying holes and manholes. Natural rubber should not be used in any of these fittings, but either neoprene or butyl rubber is suitable. Steel gas-tight bins require neoprene washers on nuts and bolts and bitumen mastic sealing strips on all wall and floor joints and at the eaves.

Concrete gas-tight bins require sealing at the top. The gas tightness of the structure must be checked (see Chapter 4, "Insect Control in Bulk Grain"). (If there is a large gap in the eaves, but the bin is otherwise gas tight, it may be possible to fumigate with phosphine with gas tight sheets laid over the grain).

Hygiene

Many of the design features applicable to warehouses are also valid for bins. Hygiene should be encouraged and dirt traps avoided. Joints must be filled with mastic and ledges inside concrete silos should be filleted to slope at 45º. Concrete wall and floor joints should be rounded out with cement fillets and metal joints with mastic. Aeration floors and ducts, bin elevators and conveyors must be accessible for maintenance and easy to clean, particularly elevator boots. The installation should provide for dust extraction and grain cleaning and for the use of portable suction cleaners powered by electricity. Bins not sealed for fumigation generally have gaps at the eaves, which must be blocked or screened with strong, fine mesh, to reduce entry by insects and birds, if they are needed for ventilation.

Climatic control

All bins should be painted white externally, so that temperature fluctuations in the grain are kept to a minimum. Different materials require different primers and concrete is normally painted with emulsion paint and steel with gloss paint.

Mould growth may be prevented by ensuring that grain is dry on tentry to the silo and by the use of aeration facilities. The instrumentation that should be fitted to monitor the temperature and humidity of the grain is described in Annex 3.

Suitability of existing structures

Existing bulk storage facilities for grain or similar commodities can be modified for long-term storage if only minor changes are needed. Examples of acceptable modifications would be the installation of an insecticide sprayer or sealing the outlets and eaves of a well-constructed silo. More difficult modifications, such as installing a damp-proof floor or sealing leaky plates, would probably not be worth undertaking.

Existing facilities may include flat bulk storage, but because the grain cannot be turned easily and pest control is difficult, flat stores are not recommended for long-term storage.

RODENT AND BIRD PROOFING

Rodent proofing

Stores made of non-rodent proof materials (earth floor, wooden structure) may require expensive proofing measures, such as the laying of a concrete floor and partly lining the structure with metal sheet. In concrete or metal stores, proofing is a matter of sealing or guarding all possible routes of entry into the store. The more common points of rodent entry are shown in figure 3.

Doors

Badly-fitting hinged doors may allow mice or rats to squeeze underneath. A small rat can squeeze through a 10mm crack and a small mouse through a 6mm crack. If the aperture is not wide enough for a rat, it may soon be enlarged by gnawing, but this can be prevented by fitting a metal kicking plate to the base of the door (figure 4). Sliding doors are particularly difficult to proof unless they are designed to be very close filling. Door ends should be fitted with a plate that narrows the gap with the floor and the wall to less than 5mm when the doors are closed and extends 1.5m from the floor. The erection of a moveable metal barrier, 1m high, inside the doors will prevent rodents from getting past the doors into the store (figure 5).

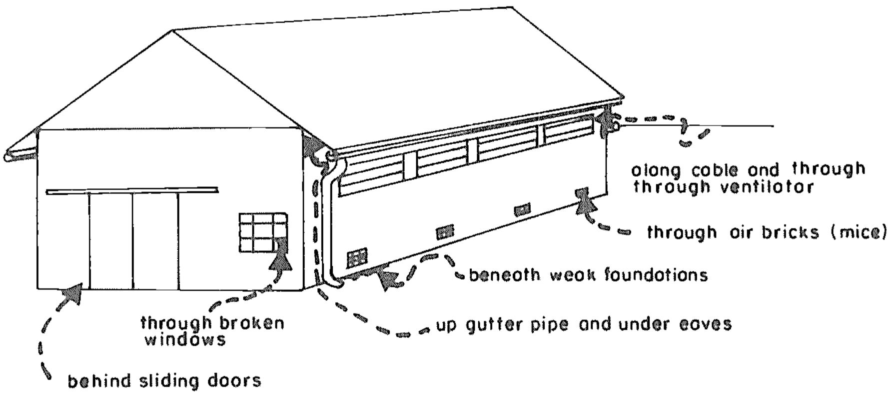


Figure 3. Common points of rodent entry into buildings.

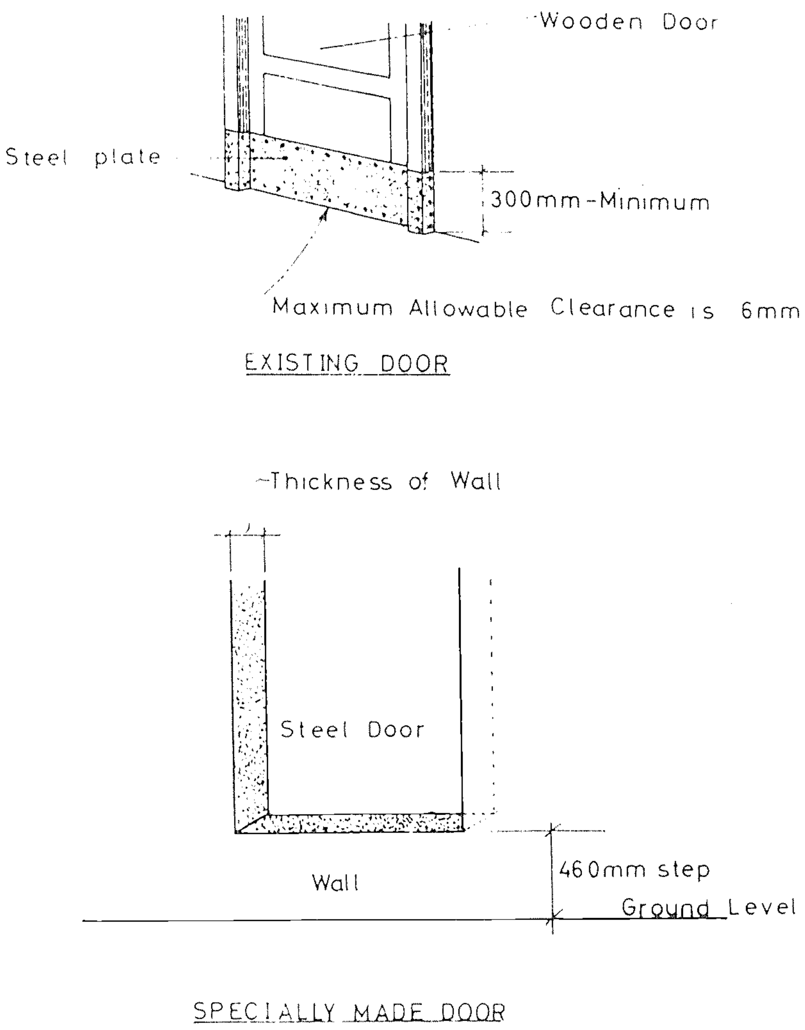


Figure 4. Rodent proofing for doors and air vents.

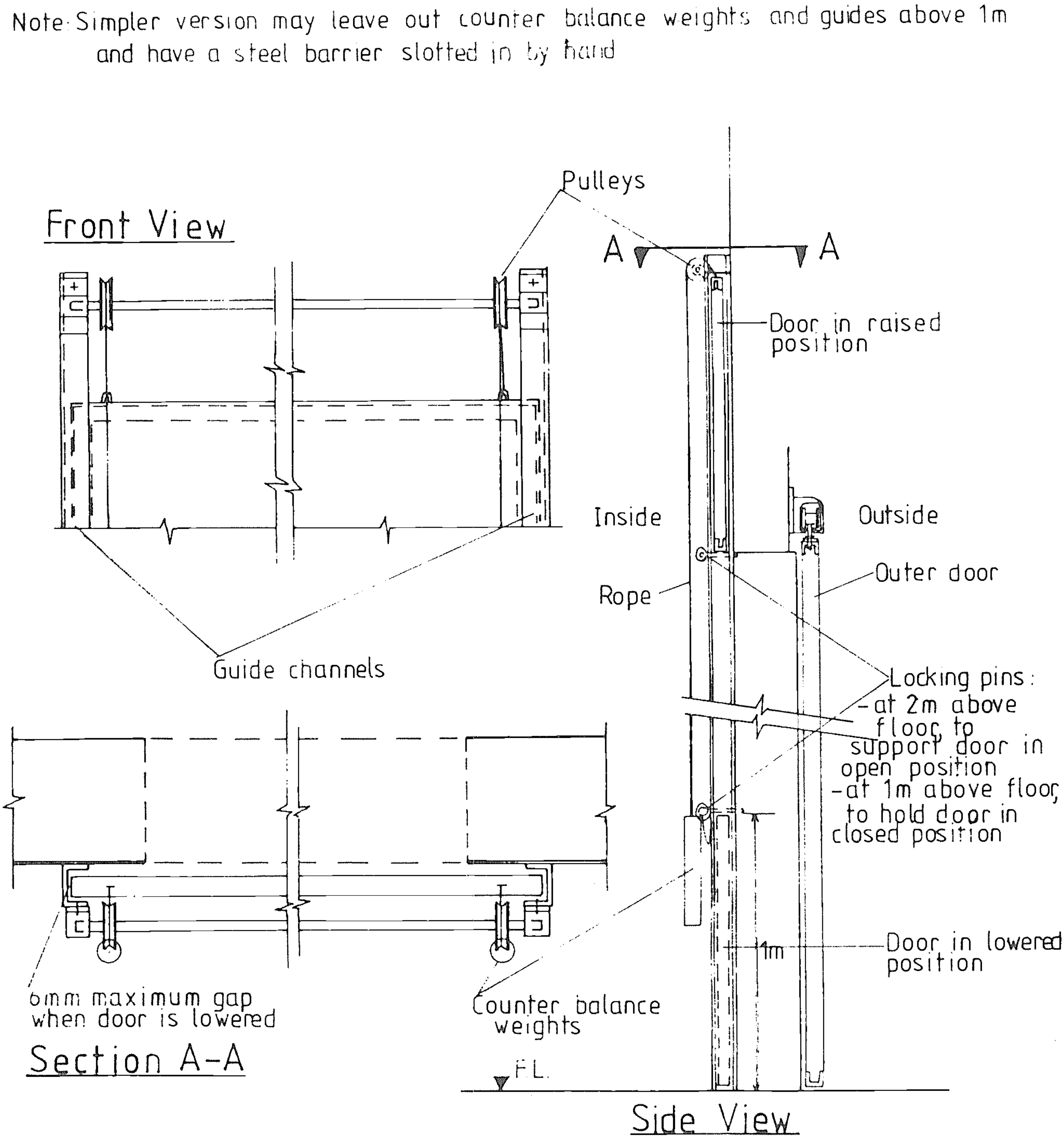


Figure 5. Steel "guillotine" half-door for rodent proofing.

Ventilators and eaves

Expanded metal screens or wire netting (figure 4) should be permanently fitted to windows and ventilators to prevent rats entering, and the eaves should be sealed with concrete or other material. To block entry through corrugations under roof sheets, suitable strips of thin sheet metal can be clipped into "combs", attached firmly, comb-side up, to the wall plate and pressed into the corrugations so that the "teeth" of the comb block the holes. Rats and mice should be prevented from gaining access to the upper part of a building by fitting metal baffles to all pipes and cables that lead to the roof or window level. In brick buildings or other rough-walled structures, a band of gloss paint around the outside, below window level but at least one metre above ground, will make the brickwork too smooth for rodents to climb. Rodents may enter buildings through holes around pipes (figure 6), which should be closed with metal or concrete.

Electrical conduits should be made of metal and cables should be metal-sheathed or armoured where they enter walls or floors (figure 7) and at other points where they may be exposed to attack by rodents. Exposed timbers, accessible to rodents, should have at least the accessible edges and corners protected by sheet metal. Broken drain covers should be repaired. Warehouses of rubber or plastic are readily penetrated by rodents and should be located away from rodent harbourages and completely surrounded by a rodent-proof fence.

Proofing materials

Kicking plates. Should be at least 0.92mm thick galvanized steel sheet (not aluminium) and approximately 300mm high. This is fixed to the outer face of the door, finishing within 6mm of the threshold or step. Plates should also be fixed to any exposed door.frame.

Baffles. Should be formed of at least 0.83mm thick galvanized steel sheet and should project at least 250mm from the wall, pipe or cable to which they are fixed.

Expanded metal. Should be 6mm mesh, coated with stove-dried black asphaltic paint.

Paint bands. Should be at least 150mm in height and applied to a surface that has been previously rendered with cement and sand. One coat of primer should be applied before two undercoats and a final top coat of hard gloss. Light-coloured paint should be used to allow rodent marks to be clearly seen.

Bird proofing

There should be a minimum of ledges suitable for birds, and attrative nearby roosting sites (such as large trees) should be reduced. All high level openings into the store should be screened with 20mm mesh. This mesh, especially if it is made of flexible material, may not completely exlude the smallest birds but it will deter most of them. The store and surrounding area should be kept clear of spillage and attractive food debris.

MAINTENANCE OF STORAGE STRUCTURES

Need for maintenance

Maintenance of a storage strucure is the work involved in keeping it in its correct functional or designed condition so that defects do not occur. Maintenance commences as soon as a new building is taken over and continues during the useful life of the building. Failure of maintenance may result in serious losses of stored produce, for example losses that could be caused by a leaky roof.

Maintenance programme

Maintenance works should be carried out to a planned programme, which must not be delayed or interrupted by repair or improvement work. The maintenace work required may include:

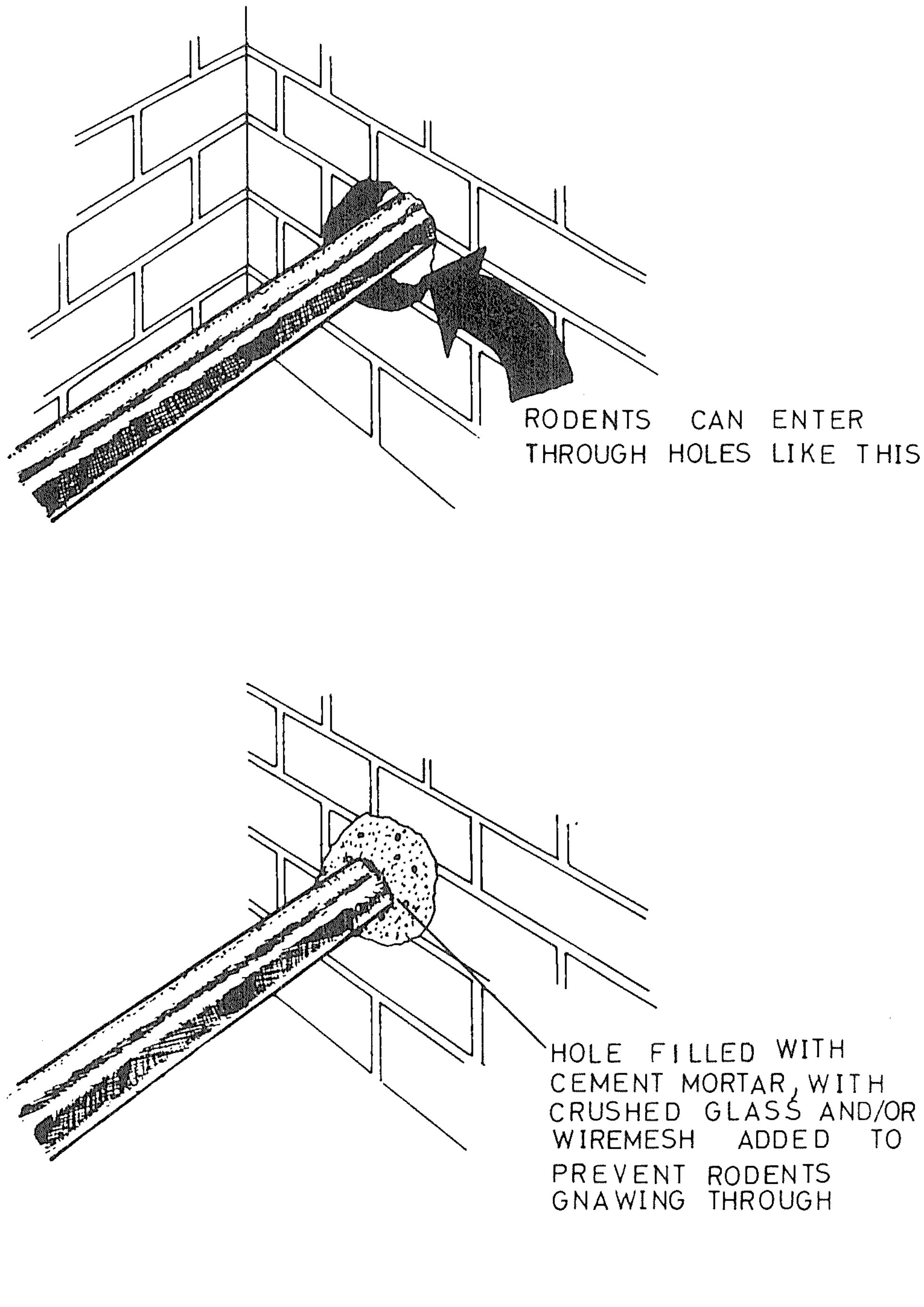


Figure 6. Rodent proofing around pipes.

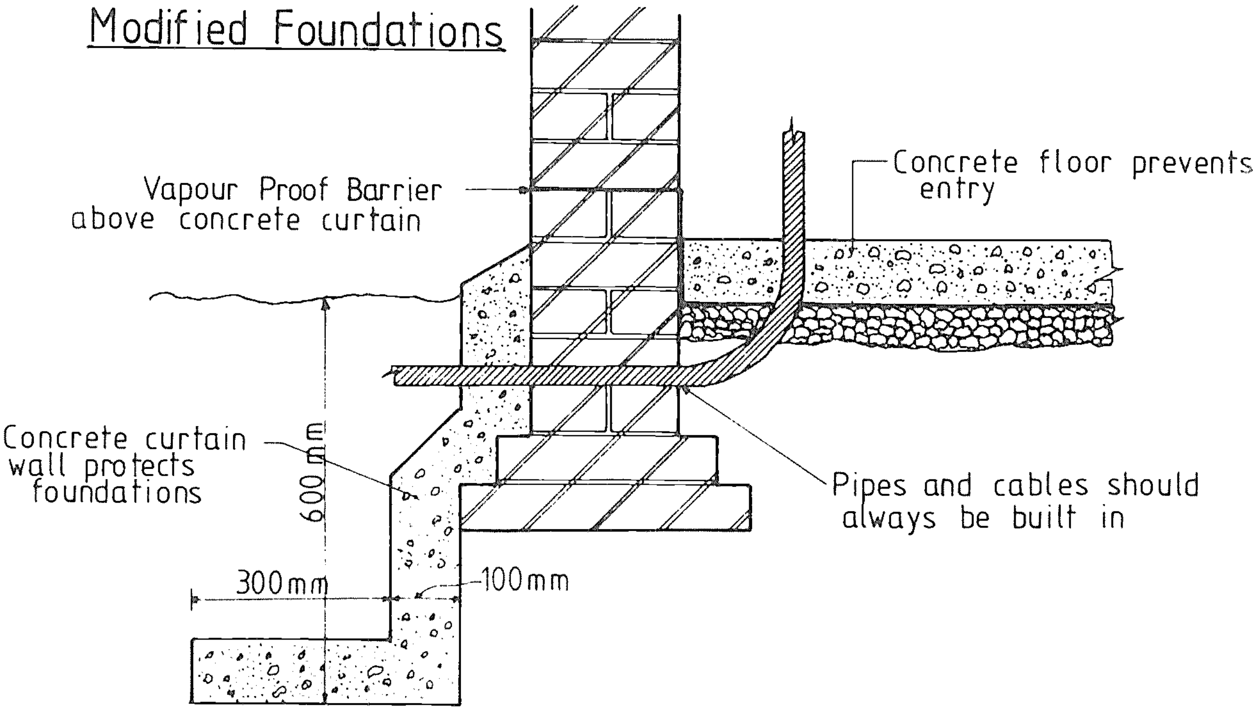


Figure 7. Proofing measures to prevent rodent entry through foundations.

Preventing weather from entering the buildings by:

- Regular inspection of the roof, especially after strong winds.
- Regular inspection and cleaning of roof, gutters and rain-water channels and drainage to keep free of accumulating dirt, leaves and trash and to avoid flooding.
- Regular inspection and adjustment of shutters and doors.

Preventing deterioration of the building by taking regular inspection and corrective action in:

- Repainting roof structure, walls, wood and metal work.
- Repairing minor cracks and faults in the structure.
- Repairing concrete fillets and bitumen seals, as necessary, during cleaning of structures.

Preventing the security of the building becoming ineffective by regular inspection and corrective actions on:

- Insect screens.
- Rodent/bird mesh and rodent guards.
- Security of doors and windows.
- Security bars and fences.

Preventing the breakdown of equipment and plant by regular inspection of and corrective actions on:

- Machine lubrication and servicing.
- Replacement of worn parts.

The areas of maintenance listed below may be subject to legal requirements and to inspection and control by insurance companies.

- Safety and fire prevention equipment.
- Boilers, pressure vessels and compressors.
- Hoisting and lifting epuipment.
- Weighing machines, scales and meters used for commodity sales.
- Provisions under national laws and regulations, and regional and local bye-laws, for conditions of work in buildings and on plant, including safety and protection, hygiene and sanitation, lighting and provision of services.

OPERATION OF STORAGE STRUCTURES

Condition of grain

Grain admitted into store must be dry, clean and disinfested. Cleaning and drying is not covered in this Manual. Infestation control is described in Chapter 4. Routine hygiene measures are described in Chapter 5. Regular checks of moisture content and temperature of the grain while it is in storage should be made with the instrumentation described in Annex 3. Instruments to measure the temperature and humidity of the store atmosphere are illustrated and described in Annex 3. The importance of low, even moisture content and temperature levels is described in Chapter 3, "Moisture Content, Relative Humidity and Temperature in Relation to Infestation and Deterioration", and Table 5 gives "safe" moisture contents.

Handling in warehouses

The use of labour and bag elevators is advised in handling (figure 8) rather than the use of fork lift trucks. The latter will rarely get sufficient use in a reserve store to justify their purchase and palletization will reduce the volume of grain that can be stored in a building of a given size, because the stack heights will be lower and the gangways wider.

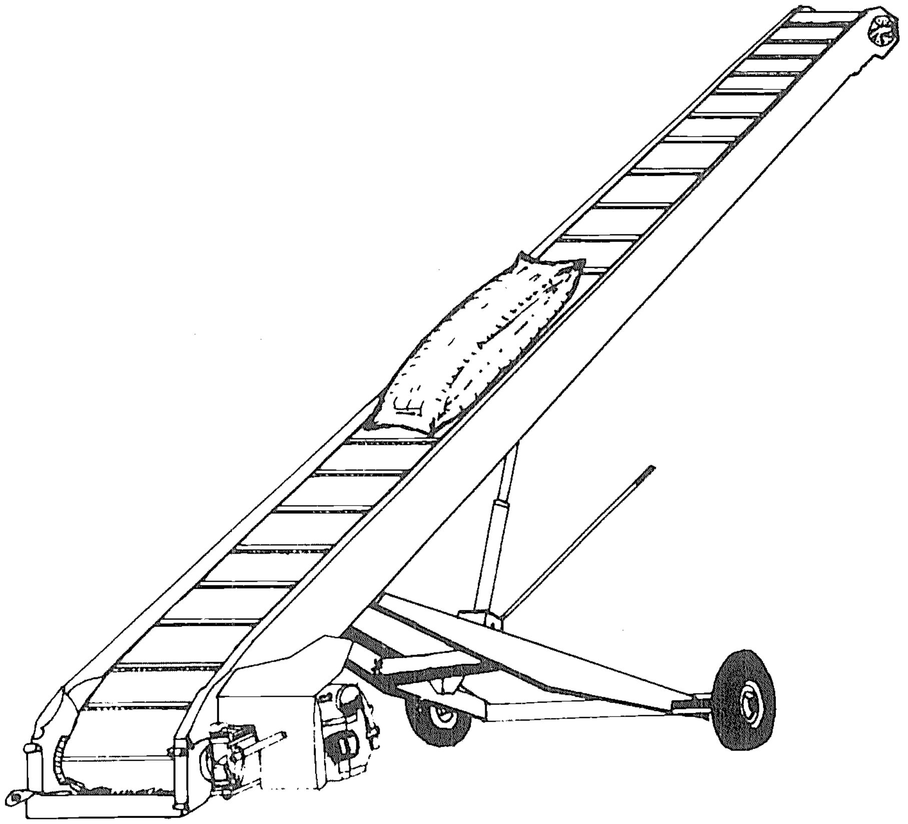


Figure 8. Bag elevator.

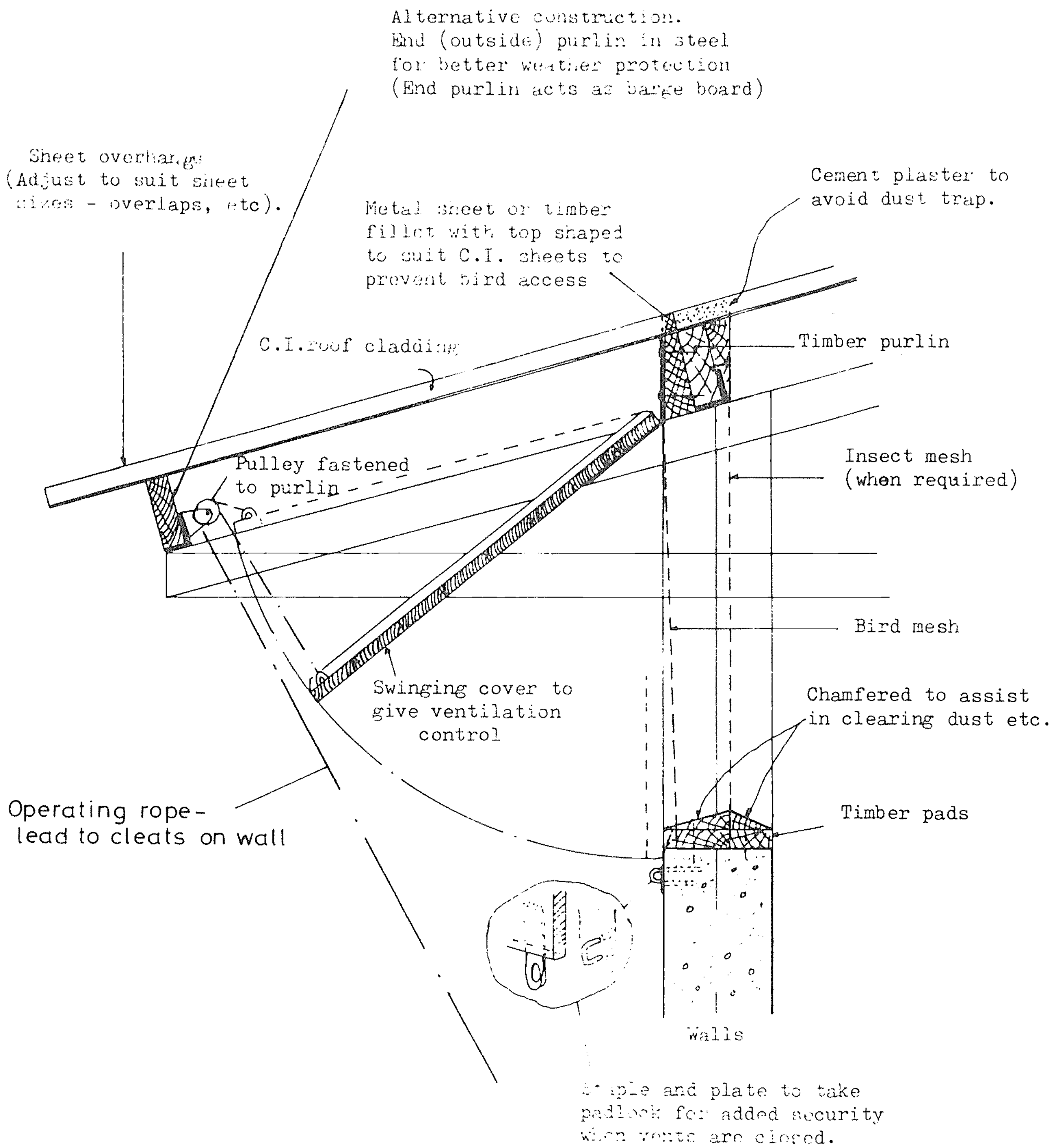


Figure 9. Eaves ventilation with shutter opening outwards.

In a reserve grain store stacks should be built carefully, making the best use of floor space. The following dimensions are advised:

Maximum stack height (for cereals in jute bags)	6 m
Minimum gap between stacks	1 m
Minimum gap between stacks and walls or columns	1 m
Minimum gap between stacks for gangways	2 m

Stacks should be built on dunnage made of timber pallets to the following approximate dimensions:

	thickness		width		length(mm)
3 boards	25	x	200	x	2000
5 runners (on edge)	20	x	100	x	1000

Brick runners with crossed board covers may be satisfactory for long-term storage if stout timber is in short supply. The approximate dimensions for such boards are 10 x 100 x 1 000 to 2 000 mm. Essentially, boards should be at least 100mm off the floor, and the gaps between boards not more than 300mm wide.

Stack heights should be limited to 6m for ease of construction and to assist fumigation. Stack length and width should be as large as possible to increase utilization of the store, but limitations to stack size may be imposed by fumigation techniques (Annex 10).

In general, the larger the floor area the greater is the percentage utilization of the available volume. However, small warehouses may be cheaper to construct than larger ones and projected designs should be examined to determine the optimum size in relation to both utilization and cost.

Ventilation

The operation of ventilation should depend on the external climate and activity in the store. When there is work in the store, then as much air movement as possible is advisable and sliding doors may be opened to allow the breeze to come in, although this may also allow insects and birds to enter the building. When there is no movement of produce in or out of the store, it is sensible to keep ventilators closed by day in hot-dry climates but opened at night when temperatures fall. In warm-wet climates it is sensible to ventilate at all times, except when the relative humidity rises above 70 percent at 25ºC. Ventilators should be operated regularly. This can be done from outside the store if correct design is used (figure 9).

Aeration of bins should be undertaken either when the instruments indicate (Annex 3) that this is necessary or when it is noticed that there is something amiss, e.g. musty smell or mould. Aeration with humid air must be avoided, especially if the grain is colder than the air.

2. GRAIN QUALITY STANDARDS MEASUREMENT

In Chapter 1, the type of storage structure and the maintenance of the structure to a standard necessary for long-term storage of grain has been considered. Good storage must begin with cereals entering storage in good condition. In this Chapter the required quality standard of the grain and the methods by which the standard is determined are considered.

QUALITY STANDARDS

Intrinsic quality

Different grain types and varieties may be distinguished and identified by variation in intrinsic or natural properties, such as shape, size, colour, flavour, odour and chemical composition. These variations may be shown in differences in hardness, flowability, angle of repose, bulk density, thermal conductivity, relative humidity/moisture content equilibrium, nutritional value and susceptibility to mould and insect infestation (Table 1). These properties determine the natural quality of the grain.

TABLE 1. A guide to the relative susceptibility of some cereal grains to infestation by primary insect pests.

INCREASING SUSCEPTIBILITY ↑	Triticale
	Soft Sorghum
	Soft Wheat
	Hard Sorghum
	Soft Maize
	Hard Wheat
	Hard Maize
	Bulrush Millet
	Finger Millet

Acquired quality

The intrinsic quality of the grain may be altered by deficiencies in development, physical damage, the presence of foreign matter, infestation and abnormal moisture content.

Grain development

Underdeveloped grain appears thin and paper-like, has diminished nutritional value and deteriorates fairly quickly. Shrivelled or wrinkled grain usually results from grain having been harvested and dried before maturity. The ageing of grain depends both on the variety and on its post-harvest treatment. These qualities may make the grain unsuitable for reserve storage.

Physical damage

Broken or cracked grain is likely to be more susceptible to insect and mould infestation, increased oxidation leading to rancidity and the release of free fatty acids and the spread of these effects to whole grains.

Foreign matter

Between harvest and storage, grain invariably acquires a certain amount of foreign matter, such as chaff, stems, leaves, crop and weed seeds and other plant materials; insects, mites, dead animals or animal parts, animal excreta and other animal material; and dirt, stones, metal, glass and other mineral material. The presence of foreign matter reduces the quality and value of the grain and may result in changes in physical characteristics, such as bulk density and flowability, increased infestibility due to greater attractiveness to pests, changes in thermal conductivity leading to variations in temperature and moisture content, damage to handling equipment by hard objects or dirt and trash, and taint caused by pesticides, oil or similar contaminants.

Infestation

Grain may suffer infestation by insects, rodents or moulds. This may result in loss of weight of grain, alteration in the nutritional value, contamination with the excreta of pests and micro-organisms leading to spoilage of colour, odour and flavour, toxicity to animals through development of mycotoxins (e.g. aflatoxin), and the spread of these effects to undamaged grain.

Abnormal moisture content

An abnormal moisture content lying outside the standard limits or not in equilibrium with the ambient climatic conditions may result from inadequate or excessive drying or the accidental or deliberate addition of water.

Abnormally high moisture contents may result in increased likelihood of infestation by insects and moulds, particularly in non-aerated conditions, and in an increased metabolic rate leading to loss of germination, heating, chemical changes and premature ageing.

Abnormally low moisture contents may result in cracked and brittle grain and in secondary pests attacking the broken grain. Low moisture content grain is likely to remian in much better condition than high moisture content grain.

Grain standards for long-term storage

The previous two sections show that it is necessary to select grain carefully if it is to be stored for several years and still remain fit for human consumption. This requires the objective assessment of grain quality and the establishment of standards based on those qualities of the grain regarded as most important in determining its suitability for long-term storage, but with due regard to local conditions and requirements.

A standard establishes (for a particular grain type) either minimum or maximum values, which may not be exceeded for each of the selected qualities. If both minimum and maximum values are set for a particular quality, intermediate values may be made the basis for a series of graded standards.

Most countries have standards for controlling the quality of grain entering commerce. These may also be used for selecting grain for food security stocks, but may have to be upgraded in some instances to meet the more stringent requirements of long-term storage. It is outside the scope of this Manual to suggest standards for each situation, but examples are given in Table 2. Where standards do not exist, they may be drawn up on the basis of the following recommendations.

TABLE 2. Examples of quality standards for grains entering reserve stores.

1. Maize (Adapted from the Maize Marketing (Grading for Local Purchase) Regulations 1965, Kenya)

	percentage
Moisture content not to exceed	13
Admixture not to exceed	2
Foreign matter not to exceed	1
Broken grains not to exceed	2
Insect damaged grains not to exceed	2
Discoloured grains not to exceed	2
Immature or shrivelled grains not to exceed	2
Tolerance for living insects (free-living or hidden)	NIL

2. Wheat (Adapted from the Grading of Wheat for Local Purchase Rules, 1964, Tanzania)

Moisture content not to exceed	13
Foreign matter not to exceed	1
Broken grains not to exceed	2
Insect damaged grains not to exceed	2
Immature/shrivelled grains not to exceed	5
Heat damaged grains not to exceed	3
Discoloured grains not to exceed	2
Tolerance for living insects (free-living or hidden)	NIL

3. Paddy (Adapated from the Cereals Grading Rules, 1965, India)

Moisture content not to exceed	13
Foreign matter not to exceed	1
Admixture (including impure varieties) not to exceed	5
Broken grains not to exceed	2
Insect damaged grains not to exceed	1
Immature/shrivelled grains not to exceed	2
Discoloured grains not to exceed	2
Tolerance for living insects (free-living or hidden)	NIL

Grain for long term storage should:

- be as fresh as possible, not older than the crop harvested before the current (or most recent) procurement season. For imported grain this provision should be written into the contract with the supplier.
- contain very little foreign matter. Generally speaking, a maximum permissible percentage foreign matter content of 1.0 percent should be allowed. If this is not readily attainable, grain cleaners should be used.
- have a percentage moisture content not exceeding that in equilibrium with 65 percent relative humidity (see Chapter 3, Table 5).
- be substantially free from physically damaged grain (maximum 2 percent).
- be substantially free from insect and mould damaged grain (maximum 2 percent), with a nil tolerance for live pests.
- be free from contaminants of any kind, except those for which tolerance levels have been imposed.
- be a variety suited to local conditions and known to retain good condition and palatability after storage.

The above requirements should not be excluded from any standard. Some typical standards are given for guidance in Table 2.

QUALITY ASSESSMENT

Preliminary selection of grain should be carried out properly at buying points at the earliest possible stage to ensure that consignments unlikely to be suitable for long-term storage are rejected before being transported to the secuity stock warehouses.

Basic requirements

The basic requirements for carrying out grain quality assessments are:

- properly trained personnel with proven ability to judge the quality of grain fairly and accurately.
- the availability of proper facilities and equipment.
- precisely defined standards and methods of assessment.

Facilities and equipment

Satisfactory quality assessment of food grains can be achieved only under the right working conditions. Ideally, a small, well-illuminated office with natural light should be provided. Failing this, an area of level ground shaded from sun, wind and rain may be adequate. Good light, but not direct sunlight, is important. The Quality Assessor should be able to observe the colour of the grain and to see fine details, such as insects and damage. He should not attempt to work in poor light.

A work bench or table having a top measuring not less than 80 x 200 cm is essential. Part of the table top, measuring not less than 80 x 80 cm, should be covered with scratch-proof white material, such as melamine. The detailed analysis of grain samples requires such a base to work on. The remainder of the table top should be covered with equally tough material, not necessarily white but strong enough to withstand frequent scraping. Metal sheet is ideal. The table top should be surrounded by a wooden or metal rail, raised not less than 5 cm above the working surface, to prevent the loss of sample material over the sides. The whole structure should be strongly built and capable of holding at least 50 kg of grain (figure 10).

All quality assessment work should be done on representative samples of the grain. To obtain such samples from consignments, appropriate sample collecting equipment, sample containers and sample dividing equipment are required. Details of such equipment and sampling procedures are given in the section on "Sampling Methods".

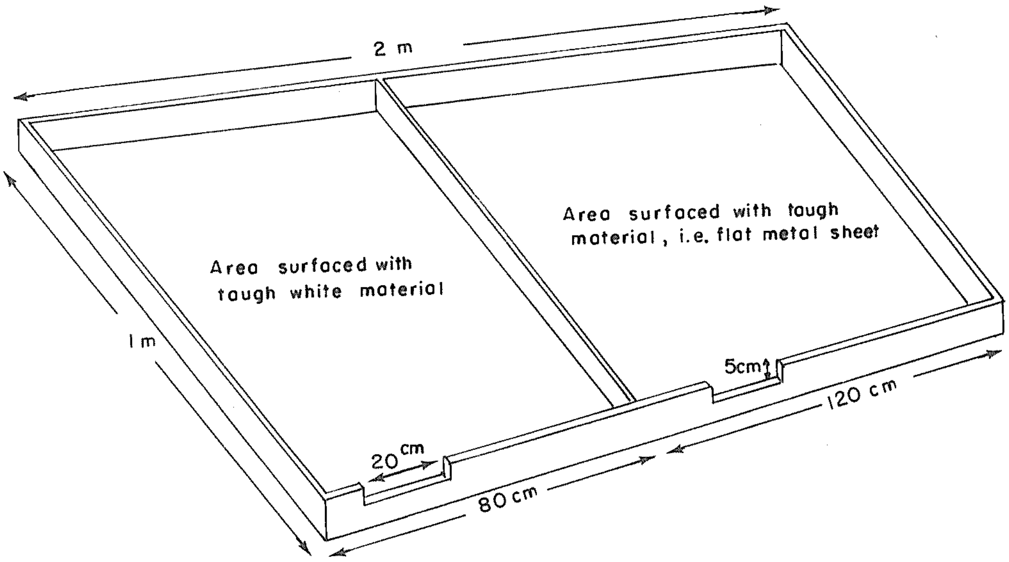


Figure 10. Suggested design for grain quality assessment work top.

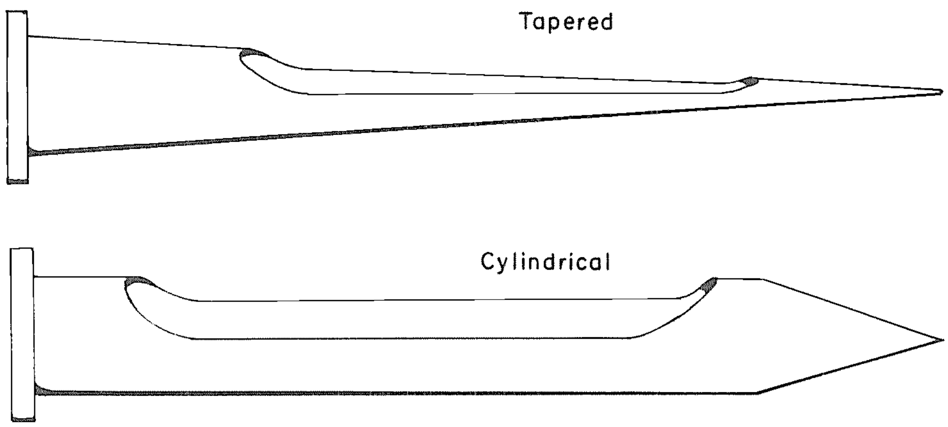


Figure 11. Simple bag-sampling spears.

Sieves are needed for the determination of foreign matter content. These are discussed in Annex 5. For the determination of percentage moisture content a *Grain Moisture Tester* is required (Annex 3).

A simple *balance*, capable of weighing up to 2.5 kg with an accuracy of 0.1 g, is necessary for weighing samples and the fractions of material separted out from them during analysis.

If samples consist of whole bags of grain, a *platform scale* will be needed. Such a scale is normally available at grain marketing centres.

Other necessary items of equipment are:

Scoops, made out of metal or tough plastic, of various sizes, are useful for scooping up sample material.

Tweezers, 10 to 12 cm long and fine pointed; needed for picking up grains or other material for close examination.

Brushes, of various sizes, for sweeping sample material into scoops and keeping the work surface of the table tidy.

Sample pans, of various sizes. Those needed for containing the fractions of material separated out from samples during detailed examination are commonly 15 x 15 x 15 cm and triangular.

Magnifying glass (x 5)

Pocket calculator

Method of assessment

A complete method for assessing the quality of a grain consignment cannot be given, as it will vary with the grain and with the individual country's standards and methods. A handbook on sampling and quality determination should normally be available.

Foreign matter content, moisture content abnormalities, infestation and broken grains are the most important acquired qualities that need to be assessed, because of their influence on many other aspects of grain quality. The actual methods employed may depend on the point of inspection, the size of the consignment and whether the consignment is delivered in bags or in bulk. However, any method of quality assessment will involve a number of standard operations as follows:

- A gross inspection to determine the apparent condition of the grain. Grain that is obviously infested by insects or moulds, for example, may be rejected immediately or allowed to be offered again following a suitable treatment.
- Determination of the quantity of grain in the consignment, by weight or number of bags, preparatory to selection of representative samples.
- Selection of primary samples, mixing of these to form a bulk sample and the extraction of submitted, working and sub-working samples (Annex 4). For maize, the working sample is normally 100 to 200 g.
- Determination of moisture content of the working sample (see Chapter 3, "Moisture Content, Relative Humidity and Temperature in Relation to Infestation and Deterioration" and Annex 3).
- Sieving of the working sample to determine foreign matter content and presence of insects (Annex 4).
- Separation of broken, damaged, defective and diseased grains and determination of the percentage of each fraction.
- Assessment of the results of this analysis in relation to a standard.
- Acceptance or rejection of the consignment. A consignment may be rejected completely or a suitable treatment may be specified, after which the grain may be reassessed.

All the information collected during the inspection and analysis should be recorded on a suitable report form.

An example of a grading procedure for wheat is given, for guidance only, in Annex 4.

SAMPLING METHODS

Principles of representative sampling

If the grain quality were completely uniform throughout a consignment, a sample of almost any size from any part of the bulk could be used to determine the overall quality. Unfortunately, grain is rarely, if ever, uniform in composition owing to differences arising from harvesting, variation between varieties, different exposure to pests and contamination, variation in cleaning efficiency and in separation of fine and coarse particles in transportation.

The only completely accurate way of assessing grain quality would be to examine every part of the consignment, but this is obviously impractical due to the large quantities involved. Consequently, samples must be taken in such a way that they are as representative as possible of the whole consignment.

First of all, it is important to ensure that all parts of the consignment have equal opportunity of being sampled. For example, on a truck loaded with bags of grain, only those bags forming the top and sides of the load are immediately available for sampling. The outer bags must be moved to provide the bags of grain underneath with the same opportunity to be sampled.

The best way of ensuring that all parts of a consignment of grain have equal opportunity of being sampled is to arrange for the bags to pass through a sampling station on the way into or out of the truck or store. The Sampler then has complete access to all parts of the consignment and can choose how and when to sample, without unduly disturbing the movement of the bags of grain.

It is important to ensure that a sufficient number of primary samples are taken if a good representative sample is to be obtained. At the same time, the number of samples taken has to be consistent with various constraints, such as the time available for obtaining and analysing samples. The number of primary samples needed to represent a large consignment of grain is proportionally smaller than the number of primary samples needed to represent a small consignment (Table 3).

TABLE 3. Number of bags (primary sampling units) taken for sampling

Number in consignment	Number to be taken
Up to 10	Every bag
11 to 100	10, drawn at random
More than 100	Square root (approximately) of the total number of bags, drawn at random according to a suitable scheme

NOTE: Based on International Standards Organisation, Recommendation 950-1969 (E)

The bags should not be selected in a regular, easily-identifiable manner, e.g. every 5th, 10th, 15th, nor from good or bad parts of the consignment. The best methods is random selection, using random number tables (Table 4).

Random number tables

The selection of units (bags) for primary sampling should be done with random number tables. Such tables are composed of numbers produced in a completely random manner, usually by a computer and from a definite range of numbers.

When reading random number tables, the numbers may be read across the table from left to right starting at the top or in any other way. However, the numbers must continue to be taken in the same way, until the work has been completed or until the end of the random number table has been reached.

Selection of primary sampling units

The bags should be selected at random from consignments of 11 to 100, bags using the random number tables (Table 4).

For a consignment of more than 100 bags, International Standards Organisation, Recommendation 950,1969 (E) recommends that the number of bags to be sampled should be approximately equal to the square root of the total number of bags in the consignment. To ensure that the sample bags are randomly selected, the following procedure may be employed.

Bags must pass the sampling station in batches, each batch consisting of the approximate square root (n) of the total number of bags in the consignment. If the consignment is very large, or has to be handled quickly, it may be necessary to employ several samplers.

The first n numbers within the range 1 to n should be selected, in order, from the random number table. The random numbers should be used in the order they are obtained from the table to extract one bag from each batch for sample taking. For example, from 600 bags about 25 bags should be taken. If the first two random numbers under 26 selected are 23 and 11 this means that the 23rd bag in the first batch of 25 should be sampled, the 11th bag in the second batch of 25 bags should be sampled and so on through the 25 batches. When minimum weights are prescribed for primary, bulk, or submitted samples, these should never be rigidly adhered to, because the addition or subtraction of grain in order to make samples weigh exact amounts effectively interferes with their representative nature.

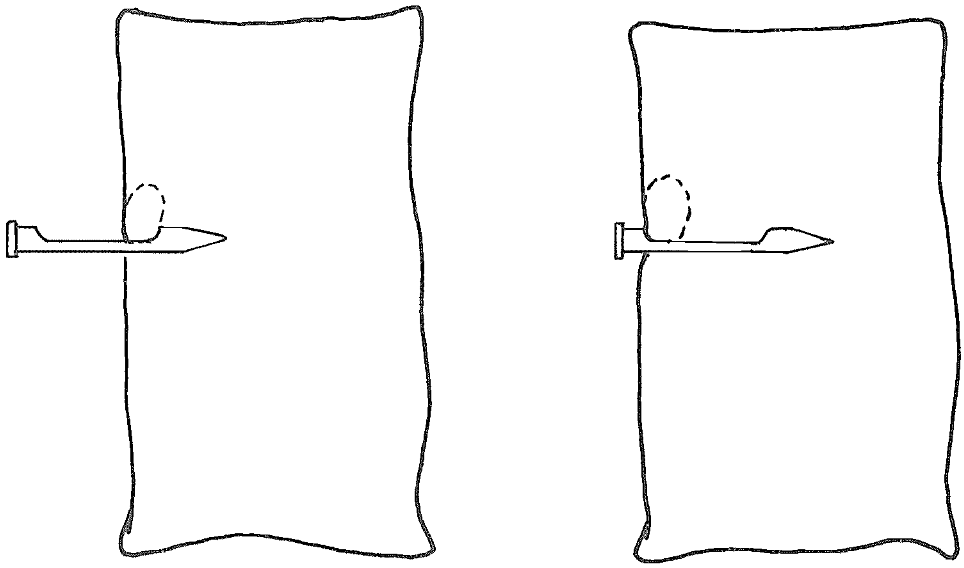
Fquipment for obtaining primary samples from bagged grain

The simple bag-sampling spear

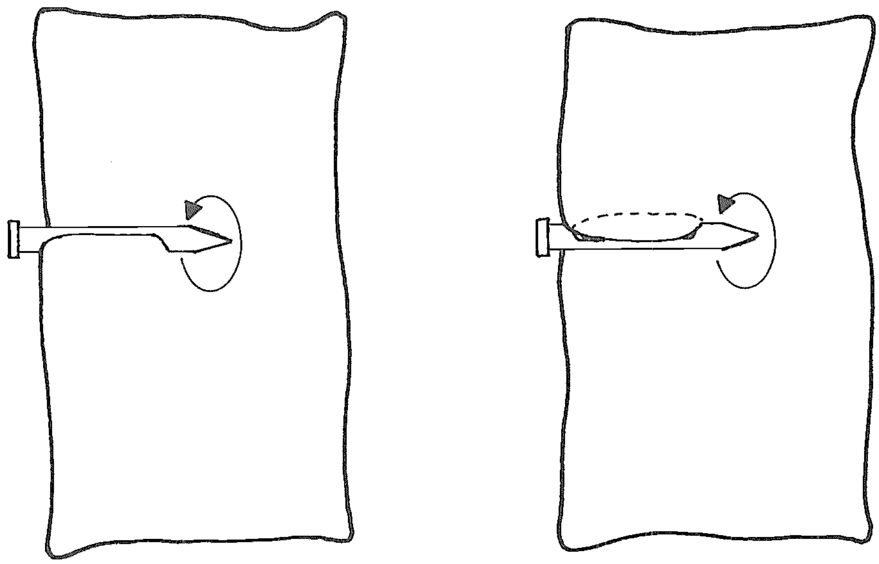
This is the most commonly used type of equipment for taking samples from bags. The two main variations in design are illustrated in figure 11.

Generally, sampling spears having a maximum external diameter of about 12 mm are designed for small grains, such as wheat, while 25 mm diameter spears are suitable for larger grains. For good penetration into a bag, the sampling spear should be 40 to 45 cm long. Shorter sampling spears are not good enough for obtaining material from deep inside bags. More even sampling is achieved with the cylindrical type of sampling spear, although this instrument is harder to push into a bag than the tapered type and tends to leave large holes in bag fabric. Correct and incorrect ways of using the sampling spear are shown in figure 12. Several small horizontal samples are better than a few large samples obtained by inserting the sampling spear at an angle and allowing grain to flow through the open handle end of the spear.

The main disadvantage of obtaining samples with this type of instrument is that if foreign matter or defective grain is very unevenly distributed in the bag, the haphazard nature of spear sampling could lead to a distorted quality assessment (figure 13).

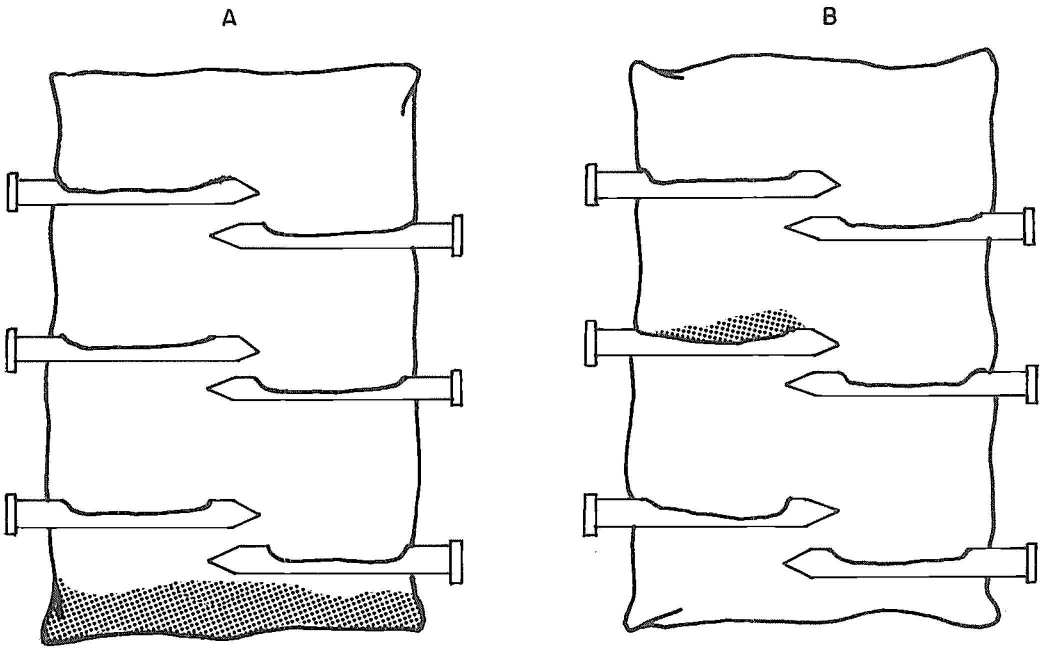


Incorrect. A sampling spear inserted with its open side facing upwards is filled with grain from the outer few centimetres only.



Correct. A sampling spear inserted with its open side facing downwards and then turned through 180° collects a more representative sample.

Figure 12. Correct and incorrect ways of using a sampling spear.



A — Excessive amounts can be missed.

B — Small amounts can give over-estimations of what is actually present.

(Shaded areas represent possible aggregations of foreign materials or defective grains)

Figure 13. Possible errors arising from spear sampling.

TABLE 4. Numbers 1 to 100 randomized, with repetition within blocks permitted. (Note: 100 is represented by 00)

73 47 50 81 37	99 33 23 41 87	70 17 91 52 73	13 64 12 22 56	41 11 09 87 67
72 74 49 15 76	86 71 97 12 78	48 35 68 27 51	56 05 67 82 93	17 47 14 17 82
97 30 18 66 35	62 67 99 63 47	30 40 36 18 58	47 26 24 62 24	38 26 91 18 69
09 62 27 30 42	72 76 36 81 49	65 19 64 42 45	64 87 61 34 25	73 19 38 97 06
61 56 92 94 75	90 21 60 17 69	94 09 77 34 41	27 31 15 18 87	85 44 58 77 56
40 45 21 69 38	44 71 05 95 02	55 47 69 97 63	29 87 40 30 06	75 72 12 97 93
71 36 67 15 74	76 81 87 44 65	75 04 26 75 91	18 25 39 18 34	62 33 76 55 70
81 47 31 22 32	62 42 02 56 80	08 25 20 55 93	34 22 07 78 36	88 72 10 64 50
07 50 66 70 98	34 56 88 42 66	48 94 00 92 67	12 09 98 83 48	36 91 35 41 83
14 80 26 50 50	19 18 26 21 08	95 60 74 72 97	01 21 14 81 04	54 86 28 52 62
17 90 57 54 48	30 65 15 13 17	70 81 78 93 72	59 21 93 32 87	96 46 87 52 06
06 60 60 48 97	18 65 64 46 96	55 85 73 77 02	07 87 59 33 71	88 47 70 13 81
46 66 98 62 98	84 90 60 64 74	86 00 11 53 63	44 61 93 35 83	70 83 36 54 14
22 39 12 36 78	64 76 18 44 56	61 86 31 84 24	56 18 95 42 28	42 78 46 25 74
62 40 81 48 31	29 41 23 37 67	60 29 27 70 77	99 07 71 78 13	60 02 82 85 12
63 23 85 13 53	93 93 76 82 45	29 39 67 50 13	85 08 61 22 48	71 83 89 27 39
28 38 93 22 61	67 66 54 53 58	71 95 55 82 72	28 34 94 87 16	62 76 58 96 34
31 69 03 31 27	33 68 54 84 48	82 50 75 05 28	09 06 27 21 76	36 96 11 89 82
92 17 82 54 42	66 84 27 52 68	48 25 35 92 25	19 45 11 86 96	70 15 67 03 71
72 23 78 50 85	84 19 57 98 57	27 27 18 37 11	81 29 93 12 36	35 95 66 87 59
33 90 61 20 23	01 73 37 75 91	39 78 16 86 66	69 60 21 77 56	32 33 36 11 19
77 20 63 33 26	38 19 94 69 65	84 24 08 88 50	21 31 41 64 53	30 85 55 62 99
44 41 90 90 34	36 46 14 15 51	61 45 78 72 02	31 54 00 42 57	16 74 68 43 22
23 30 15 89 06	63 33 88 49 96	29 34 71 00 32	93 77 02 97 84	63 08 36 96 50
87 11 78 24 39	77 14 29 71 38	85 11 82 35 46	46 00 74 48 79	26 03 46 70 70
76 82 02 80 57	35 98 02 63 11	79 20 15 38 19	89 14 20 47 11	06 00 41 38 50
39 87 83 58 72	35 75 75 81 55	48 80 73 84 95	52 52 37 06 22	78 76 03 26 92
33 38 19 49 42	28 12 27 13 75	30 29 96 17 96	06 46 75 75 21	08 87 87 85 07
24 64 16 87 72	15 91 76 71 83	21 13 66 51 64	06 78 19 88 96	64 78 27 21 16
13 77 53 95 17	14 96 12 68 55	21 30 57 97 71	09 23 57 55 04	77 26 52 07 53
24 84 24 46 77	11 83 83 19 27	22 38 50 63 67	04 15 12 34 01	95 14 72 48 26
62 08 91 79 38	69 21 23 90 93	13 27 34 58 64	14 45 29 02 53	06 57 92 57 71
51 02 66 99 85	20 43 65 67 69	82 06 04 96 37	94 80 67 70 58	65 15 87 21 70
55 63 95 22 96	24 10 25 73 19	52 84 04 51 89	82 15 55 45 66	62 20 14 14 34
84 36 50 90 24	30 54 77 92 84	36 50 04 87 00	62 85 18 41 09	64 98 64 00 04
72 53 85 61 90	20 90 49 02 34	62 44 65 84 78	79 50 31 92 09	24 69 27 12 90
98 46 89 72 14	97 23 66 64 20	15 03 79 37 82	46 60 11 19 37	33 21 70 66 22
06 24 34 88 30	15 45 54 17 35	00 36 54 73 00	35 51 22 67 90	23 24 44 41 35
58 04 12 76 64	86 67 89 49 16	42 68 37 98 71	24 43 90 05 76	73 23 95 33 18
41 84 53 49 74	89 35 92 48 41	43 22 75 96 75	47 51 00 81 92	34 86 03 32 65

Double tube sampling spears

Double tube sampling spears consist of two metal tubes, one fitting closely inside the other and each with several slots corresponding to similar slots in the other tube (figure 14). Spears of this type may vary in length from 45 cm to 3.5 m, and in width from 12 mm to 50 mm. By turning the inner tube through 180 degrees, the intake apertures can be opened or closed, as required.

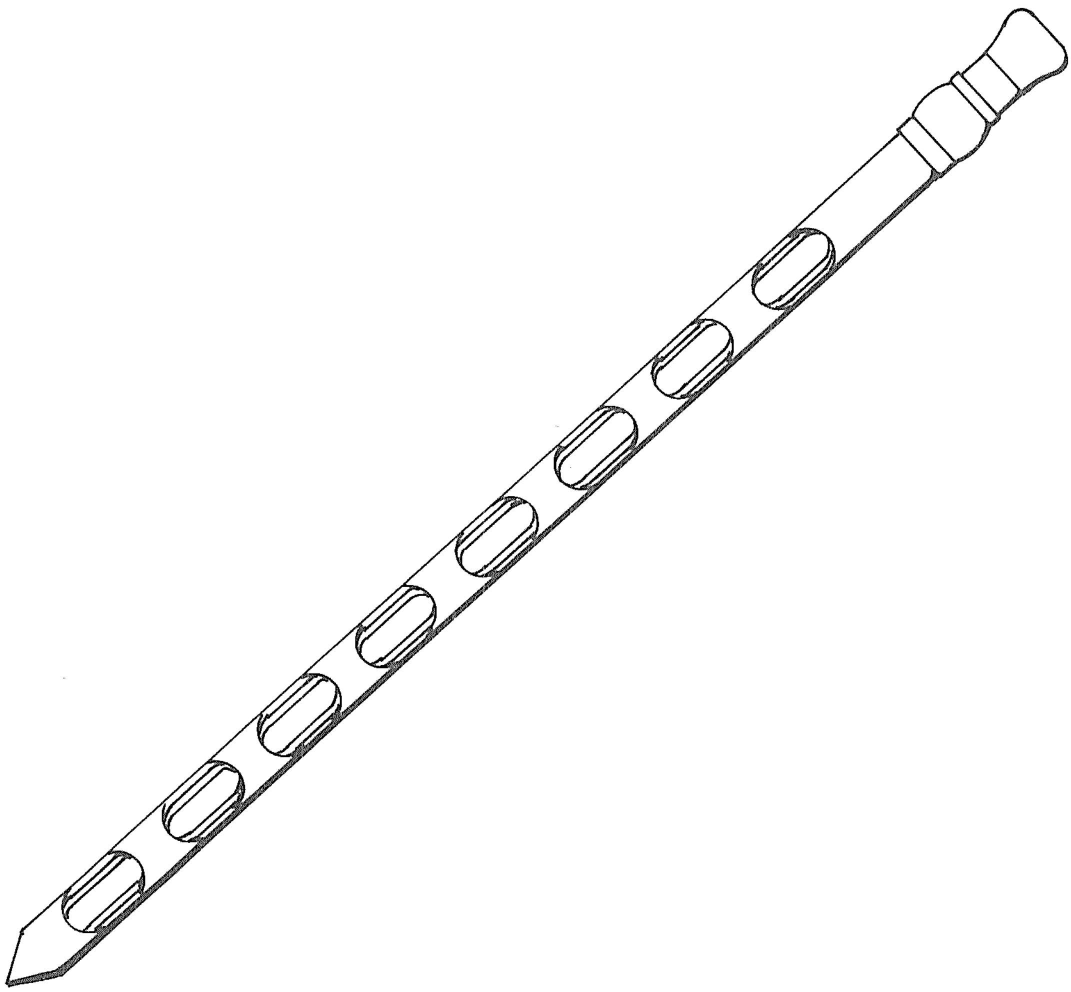


Figure 14. Double tube sampling spear

The spear should be inserted into the grain with the tubes in the closed position until the desired sampling position has been reached. The inner tube should then be turned to the open position. Grain will be collected from several identifiable positions along the line of penetration. Before withdrawing the sampling spear, the inner tube should be turned into the closed position to prevent loss of sample material as the spear is removed from the bag.

Sample material can be removed from the spear either by pouring it through the open end of the handle or by holding the spear in the horizontal position, with the intake apertures facing downwards, opening them, and extracting the sample in small heaps corresponding to the original sampling positions.

Double tube sampling spears are designed primarily for obtaining smaples from vertical lines of penetration in bulk grain, although small versions may be used for sampoing bagged grain.

The produce flow sampler

The produce flow sampler (figure 15) can extract a truly representative sample from a bag of grain. The bag of grain should be tipped into the hopper at the top, which has a capacity of at least 100 kg. The outlet of the hopper is closed by a bung (stopper) until the operator is ready to commence sampling. When the bung is removed the grain falls through on to a cone, which is positioned to ensure that the flow of grain is distributed equally on all sides. Most of the grain is directed into a bag attached to the underside of the collecting funnel, but some of the grain is trapped by four vents arranged equidistantly around the base of the cone and directed via a separate spout into a sample container. The size of the sample depends on the dimensions of the vents, which can be altered by interchangeable parts. The produce flow sampler was designed for sampling bags as they are off-loaded from a truck.

Subsampling

Coning and quartering

The primary samples, taken as described above, should be bulked and a representative working sample obtained from the bulk sample. From the moment the first primary sample is taken through to the extraction of the last working subsample, it is important to ensure that all the grain in the larger unit has equal opportunity of being included in the sample being removed from it. The method, known as "coning and quartering", is a simple but effective way of doing this. The only equipment required is:

For 50 kg or more of grain: a clean, smooth floor, preferably covered with a tarpaulin, a shovel and a suitable length of flat timber or sheet metal.

For smaller quantities of grain: a smooth, preferably metal-topped table, a scoop and a suitably-sized piece of flat timber or sheet metal.

The grain sample to be mixed and reduced should be tipped into the centre of the working area (figure 16). The shovel or scoop should be used to turn the heap of grain from the edge towards the centre, working around the heap several times to ensure that mixing is as thorough as possible. Occasional breaking down and reconstruction of the heap will help with the mixing. After the grain is mixed, the cone should be flattened with the board so that its height is less than the width of the quartering board. The heap should then be divided into quarters, using the board, first by dividing it into two approximately equal halves and then halving again. Two diagonally opposite quarters of the grain should be removed from the working area, and the remaining grain should be thoroughly mixed as described above. It should be noted that any dust or small particles associated with each quarter belong to it and must be collected together with the grain.

The above procedure should be repeated as many times as are necessary to reduce the sample to the desired size. If coning and quartering starts on the floor with a large quantity of grain, the operation may be transferred to a table with appropriate equipment when it is convenient to do so.

Sample dividers

Alternatively, the mixed bulk may be subsampled with a sample divider such as a riffle divider. This consists of several rectangular mouthed funnels, arranged side by side, so that alternate funnels lead to opposite sides of the apparatus (figure 17). The funnel assembly is fitted inside a box with a shallow hopper at the top and open at the bottom. The three identical sample boxes are designed so that the funnel assembly box can sit on two of them while the third is used to pour a sample through the hopper.

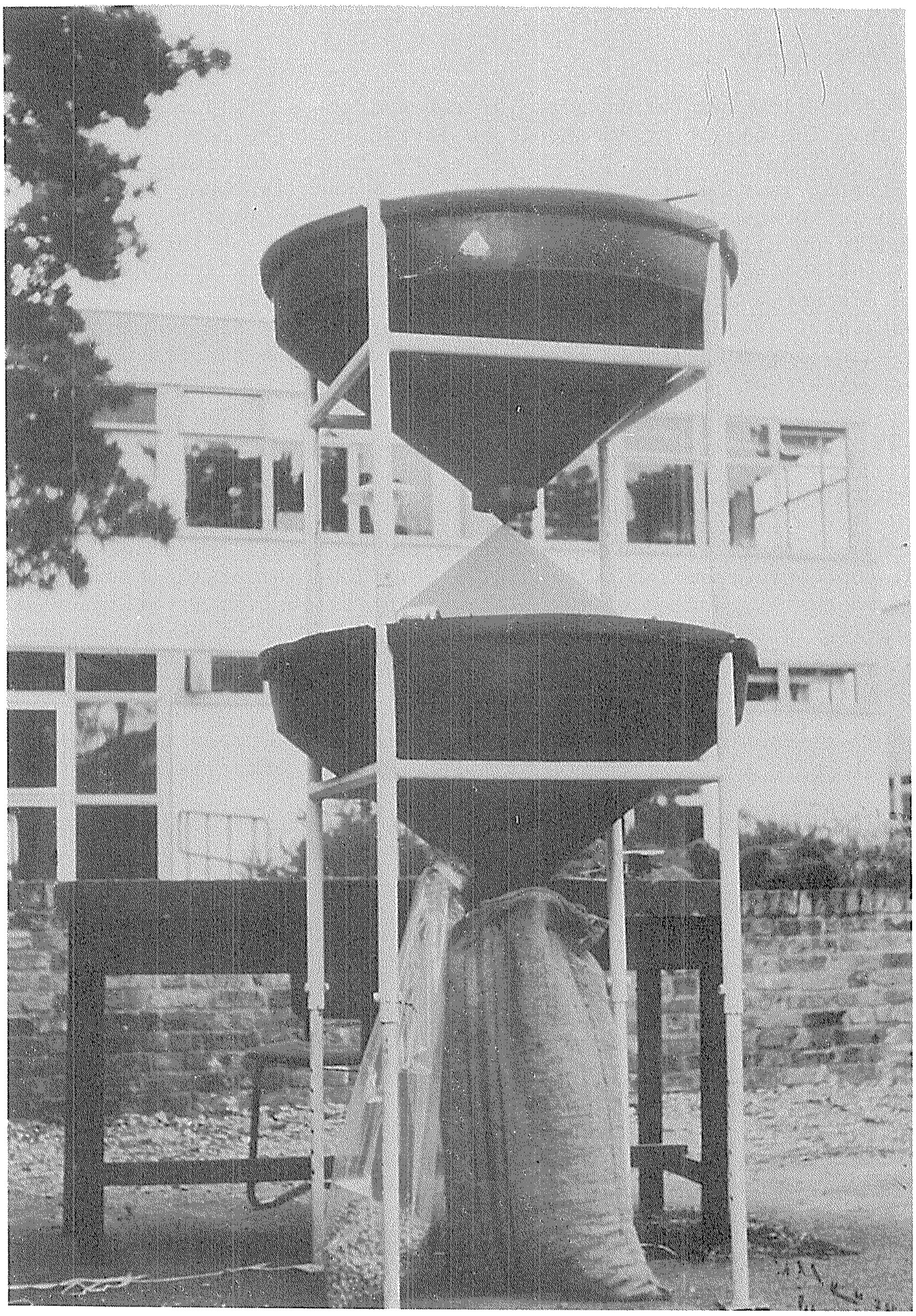


Figure 15. Produce flow sampler with sack and sample bag.

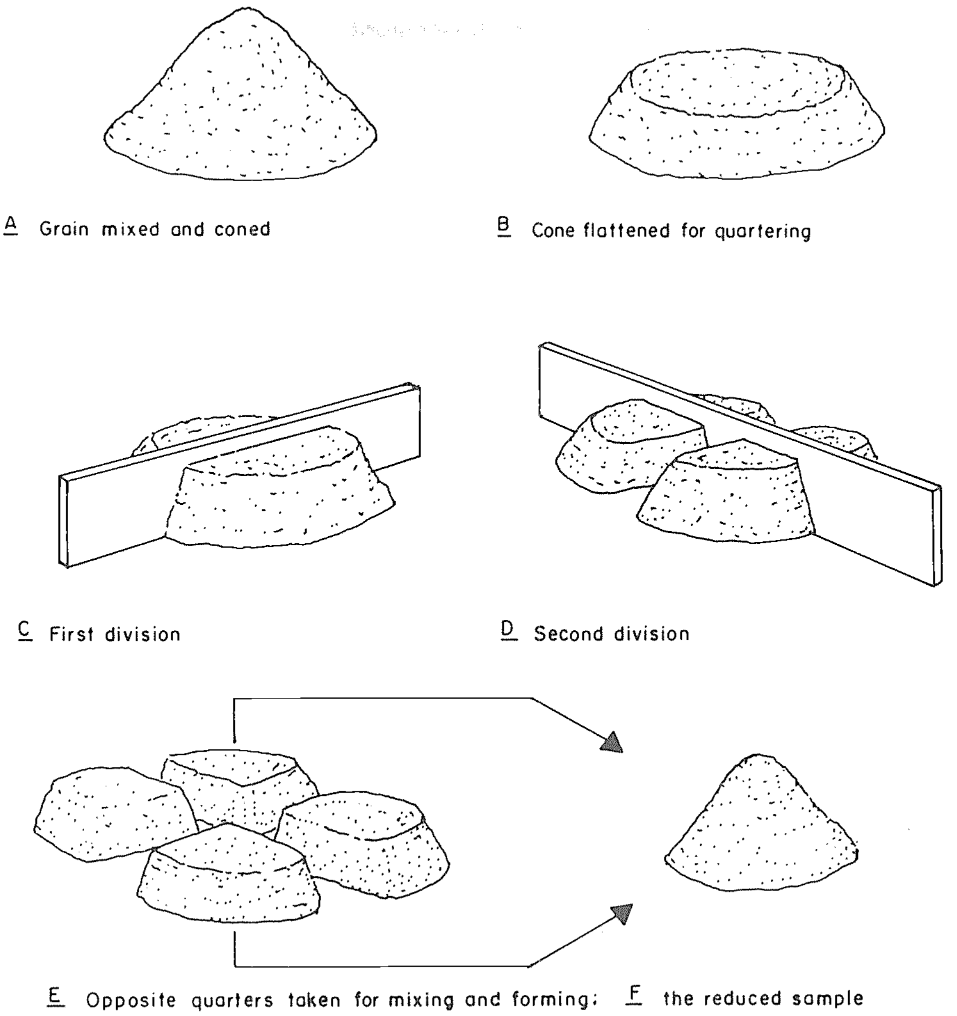


Figure 16. Coning and quartering.

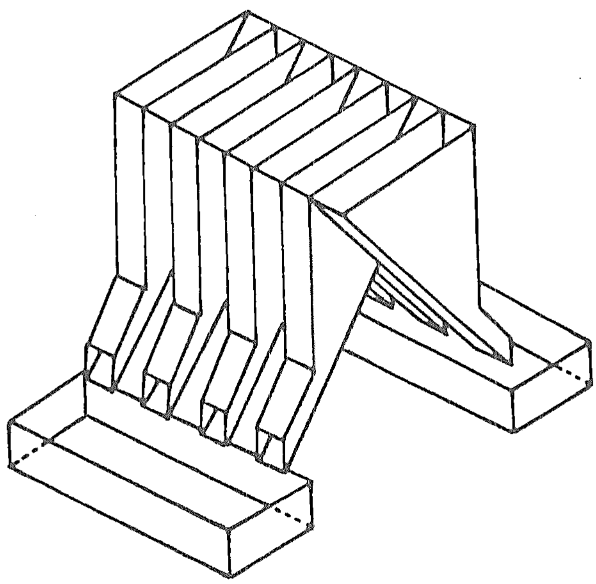


Figure 17. Riffler divider for dividing grain samples.

The sample to be divided should first be thoroughly mixed (as for coning and quartering). It should then be scooped or swept into one the sample boxes and shaken gently until the surface of the grain is level. One long side of the box containing the sample should be placed against the side of the hopper and the grain slowly tipped into the divider. If this is done properly none of the sample should be lost, and it should be divided more or less equally between the two sample boxes underneath the funnel assembly. If further division is required, the above procedure should be repeated with the contents of either sample box as often as necessary.

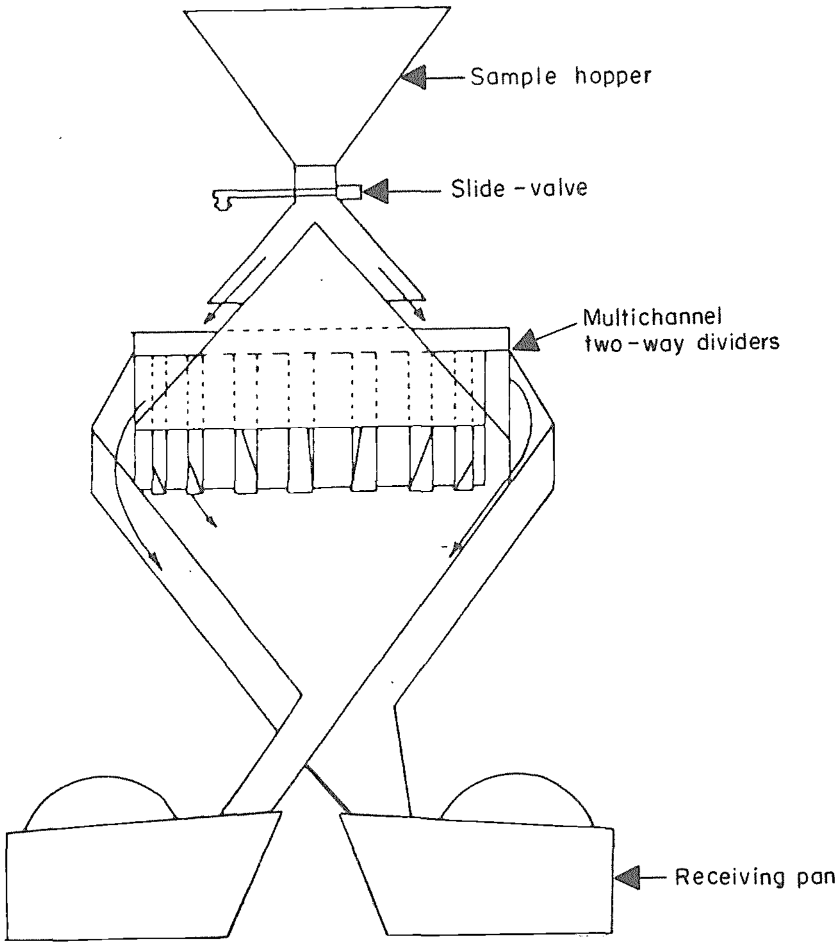


Figure 18. Boerner divider.

Two sizes of the riffle divider are most suited for dividing grain samples: the 12.7 mm slot divider, for larger grains, such as maize, and the 6.4 mm slot divider, for small grains, such as wheat.

The Boerner divider (figure 18) divides the sample into two approximately equal halves in identical receiver pans. The Boerner divider is superior to the riffle divider in producing reduced samples of equal quality and quantity, but it is very much more expensive and less suitable for routine quality assessment requirements.

3. CAUSES OF GRAIN DETERIORATION

The four main agents responsible for deterioration of grain in storage are moulds, insects, mites and vertebrate pests (rodents and birds). An understanding of the physical and nutritional requirements of these organisms and a knowledge of their behaviour and interactions will assist in the early detection of infestation and in evaluating the need for preventive treatments. This will increase efficiency and reduce the use of pesticides by preventing the build-up of pest populations.

MOISTURE CONTENT, RELATIVE HUMIDITY AND TEMPERATURE IN RELATION TO INFESTATION AND DETERIORATION

Grain is hygrosopic and a definite moisture relationship exists at equilibrium between the grain and the intergranular air. Damp grain (high moisture content) has damp air (high relative humidity) around it and dry grain (low moisture content) has dry air (low relative humidity) around it. When several values of the relative humidity (RH) of the air are plotted against the equilibrium moisture content of a type of grain at a fixed temperature the resulting graph is called the moisture sorption isotherm (figure 19).

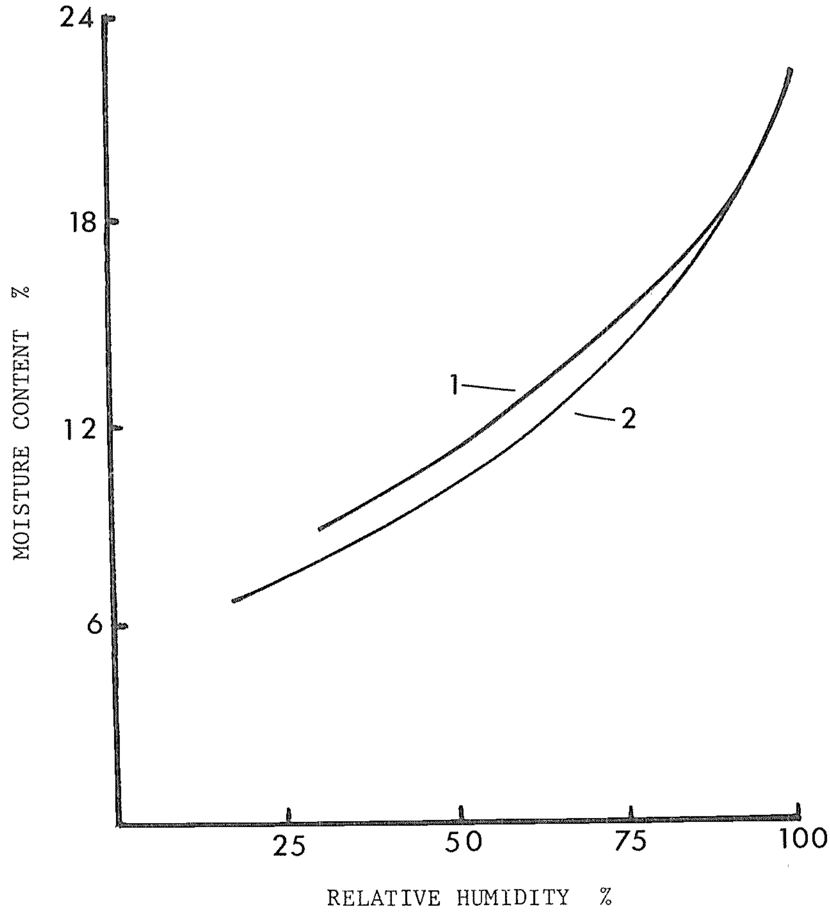


Figure 19. Moisture sorption isotherm for yellow flint maize at 28°C, showing (1) adsorption and (2) desorption curves.

Using the isotherm, a measurement of the RH of the air at a given temperature can be used to determine the moisture content of the grain, or vice versa. The growth of moulds and bacteria and insect infestation are directly related to the amount of water in grains and in the intergranular air. If the water content is low there will be low mould growth and low infestation. The moisture contents which correspond to an intergranular RH of 65 percent are called "safe" moisture contents. Typical safe moisture contents for different grains are given in Table 5. Mould growth generally occurs only at an RH in excess of 65 percent (Table 6).

TABLE 5. Maximum permissible moisture contents for cereals

	Normal Storage	Reserve Storage
	Percentage	
Wheat	13.5	11 - 12
Maize	13.5	10 - 11
Paddy	12-13	10 - 12
Rice	13	10
Sorghum	13-15	10 - 11
Millet	16	14

The moisture content figures given for normal storage are for equilibrium with 70 percent RH, but as Table 5 shows, for reserve storage lower moisture contents in equilibrium with an RH of 65 percent or less are required. At and below the safe moisture content, no appreciable metabolic activity occurs and there is no significant development of moulds or micro-organisms. Insects can continue to develop below the safe moisture content, although at slower rates. The limiting RH for insect development varies greatly between species, and exceptionally may be as low as 30 to 35 percent. Grain with a moisture content less than 9 percent is safe from most insects other than *Trogoderma granarium*.

Grain masses have a low thermal conductivity and low specific heat. Unless the heat given off by respiration in moist grain is ventilated, spontaneous heating can occur. Local heating due to the activity of insects and micro-organisms can create a local rise in temperature and moisture content, a "hot spot", which may lead to further deterioration and germination of the grain. Sometimes, if there is a temperature gradient in the grain, moisture movements can occur and the moisture content may rise above the safe level in the cooler parts. Therefore, under-dried or unevenly dried grain can create serious problems in reserve storage, and there must be adequate sampling to ensure the true moisture content of every part of the stock is below the safe figure. The rate of deterioration is strongly influenced by temperature and is much slower at low temperatures. Both moisture content and temperatures of a grain bulk must be monitored, because both are important. Variations of temperature may give strong indications of problem areas such as hot spots or of future condensation problems.

If disturbing changes in temperature or moisture content are noted, ventilation or aeration must be used. In severe cases redrying may be necessary.

MOULDS

Many different types of moulds (fungi), notably *Aspergillus* and *Penicillium* species, attack stored produce and are a major cause of damage. The fungi are plant-like organisms that feed on stored produce by breaking down and digesting the tissues. Fungi can attack produce either in raw or processed form.

Conditions for mould growth

Fungi are always associated with moisture and cannot develop in completely dry conditions. The minimum air relative humidity (RH) for fungal growth varies among different species, but growth of most fungi will be prevented if the RH is less than 65 percent (Table 6).

TABLE 6. Minimum relative humidity for the growth of common storage fungi at optimum temperature (26° - 30° C)

	Percentage
Aspergillus halophilicus	68
A. restrictus, *Sporendonema*	70
A. glaucus	73
A. candidus, *A. ochraceus*	80
A. flavus	85
Penicillium, depending on species	80 - 90

It is important, therefore, that reserve grain should be dried to below the moisture content that is at equilibrium with air at 65 percent RH (Table 5), and that it be kept below that moisture content during storage. Even at a low temperature some mould development may occur if the RH is above 65 percent.

Most fungi reproduce by tiny, air-borne spores, which are widespread and cannot be excluded from the storage environment. The spores are highly resistant to dry conditions and will remain viable for extended periods of time. Spores may also be spread in grain by insect pests and insect damage increases the susceptibility of grain to fungal attack.

Mycotoxins

Many fungi produce compounds known as mycotoxins, which are among the most toxic substances known. These toxins, particularly aflatoxin, have been shown to be the cause of death in animals as a result of moudly produce being incorporated into animal feed. Fowls and young farm animals are particularly susceptible to these toxins, but they can also harm larger animals, including humans.

Detection of damage caused by fungi

In extreme cases fungal damage is very obvious. The infected produce may be discoloured, changed in texture, or the green, blue, gray, white or black fruiting bodies of the fungus may be visible and there may be an unpleasant odour. However, in the earlier stages, fungal infections may be overlooked. The most obvious signs of infection in bulks of grain are grain heating and moisture movement. Fungi alone or together with insects are major causes of "hot-spots" in grain. These are caused by the release of heat during the metabolism involved in fungal growth. Moisture is also produced leading to acceleration of mould growth. The examination of individual grains may also reveal swelling and discolouration of the grain embryo (the germ) in the early stages of mould development.

Control measures

It is not practical to control fungi on stored foods by the application of fungicides. Fungal growth must be prevented by maintaining conditions in which fungi cannot develop, e.g. by keeping grain below the safe moisture content level in conditions that minimize moisture migration and its effects,and by keeping grain free from infestation by insects and mites. Moisture content should be routinely checked so that any rise may be detected before large-scale deterioration has occurred. Remedial measures such as aeration, turning or drying, may be applied.

Grain that has been badly affected by mould should not be retained in reserve grain stores. Such grain must be analysed for the presence of mycotoxins before being offered for sale either as human food or for livestock. If grain has been only slightly affected by mould, the affected parts should be separated and discarded and the remainder dried.

INSECTS

Insects are a major cause of deterioration of stored produce in tropical and sub-tropical countries and the control of insect infestation is a major part of storage management. Insects have become adapted to widely diverse habitats and diets and many species have become successfully adapted for development in stored produce and in the dry storage environment. Within a few months, sufficient progeny can develop from a single pair of insects to infest seriously several tons of produce. Inadequate control measures may prove worthless if small numbers of surviving insects lead to rapid reinfestation. However, not all insects are pests that need to be controlled. An understanding of the factors that determine insect population growth should lead to more effective control of insect pests.

Insect development

The adult and juvenile stages of many insects not only appear very different, but also behave very differently.

Many types of insects develop by the process known as complete metamorphosis (figure 20) from the eggs laid by the adult female. A tiny larva hatches from the egg and begins to feed. As it grows, the larva sheds its skin (moulting) on several occasions, until the final moult (instar) changes into a non-mobile form known as a pupa. The pupa is an intermediate form between the larva and the fully-formed adult and, after several days as a pupa, the adult emerges from the pupal case. The emerged adult is fully mature and, apart from minor changes in colouring and cuticle hardness, no further development takes place. In an alternative form of development (figure 21), known as incomplete metamorphosis, the immature stages resemble the adult, differing only in minor aspects such as size and the development of the wings. The juvenile stages, commonly known as nymphs, grow by a series of moults, with the fully-formed adult emerging from the final moult.

Orders of insects

Many different groups of insects (orders) can be found in stored produce, but most of the important pests are either of the Coleoptera (beetles) or Lepidoptera (moths).

Coleoptera

The order Coleoptera includes the beetles and weevils. The adults can be identified by their front wings that are modified to form hard, thick protective structures known as elytra, which cover the fragile hind flight wings when at rest. (Most insects have two pairs of wings.) The body of most Coleoptera is hard and the mouthparts of both larvae and adults are normally tough and adapted for biting and chewing. The Coleoptera develop by complete metamorphosis.

Lepidoptera

The order Lepidoptera includes the warehouse moths. Adults possess two pairs of large, membranous wings used in flight. The body and wings are covered with scales, and whereas the larvae are caterpillars that have mouthparts adapted for biting and chewing, the adults can

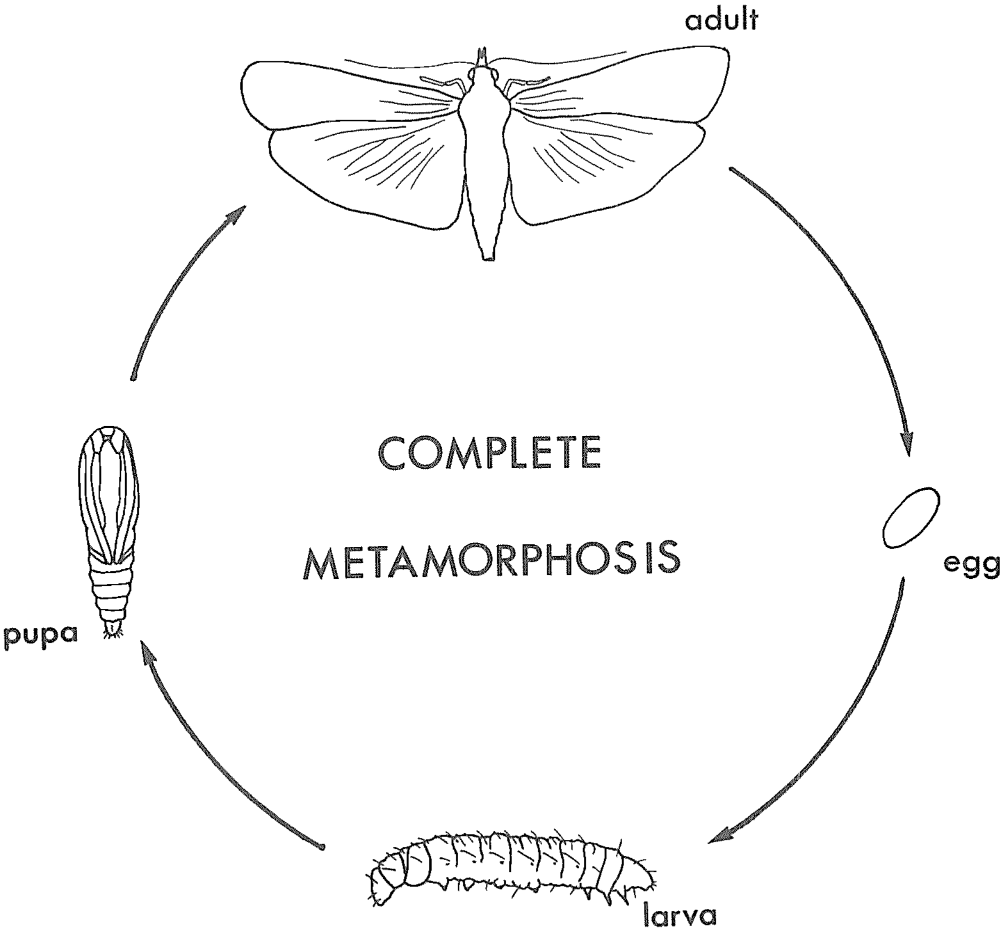


Figure 20. Complete metamorphosis.

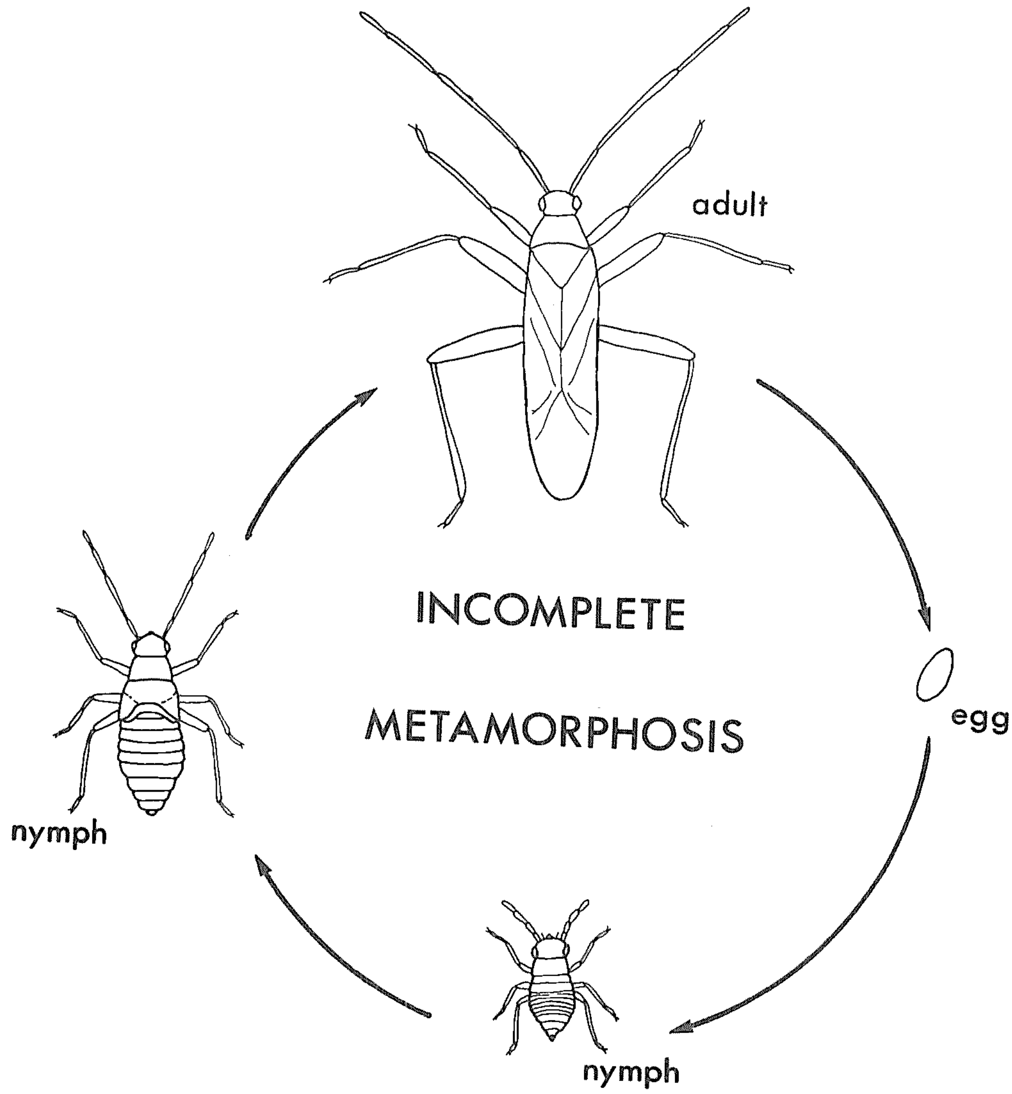


Figure 21. Incomplete metamorphosis.

take in only liquids through tube-like sucking mouthparts. The Lepidoptera develop by bomplete metamorphosis.

Hemiptera

The Hemiptera are the order of insects accurately referred to as bugs. They have mouthparts adapted for piercing and sucking, and the species associated with stored produce are predatory animals that feed upon true storage pests. They are, therefore, to some extent beneficial to the storekeeper. Hemiptera develop by incomplete metamorphosis (figure 21).

Psocoptera

The Psocoptera, booklice or dust lice, are small, delicate insects (usually less than 1 mm long) with long, thin antennae. They are frequently found associated with stored products but do not usually cause appreciable damage on their own and may be partly dependent on moulds and the eggs of other insects for food. They are frequently associated with mouldy paper material or sacks and the presence of large numbers in a store may indicate poor hygiene.

Hymenoptera

This is a large insect order, which includes the wasps and ants. Ants are frequently found in stored produce but do not cause much damage alone. Many species of parasitic wasp, which are found associated with many common storage insects, lay their eggs inside the living bodies of insect larvae and the developing wasps eat the tissues of the host larva, eventually killing it. Parasitism of this type may be of great importance in the natural control of pest populations. Some parasitic wasps can detect larvae developing inside cereal grains and parasitize them by drilling through the hard grain in order to pierce the body of the larva.

Other orders

Insects from other orders are frequently found associated with stored produce but seldom cause significant damage. Among the commoner orders found in stores are the flies (Diptera), termites (Isoptera), earwigs (Dermaptera) and cockroaches (Dictyoptera).

Primary and secondary pests

It is convenient to separate the pests associated with stored produce into primary and secondary pests. The term "primary pest" is used to describe those pests attacking previously undamaged commodities. They are frequently highly specialized for infesting certain types of commodities. Secondary pests, however, are restricted to commodities that have already been partially damaged, either mechanically (by grinding, milling, processing or accidentally during handling) or by the action of a primary pest. The secondary pests include many less specialized, general feeders, which attack a wide range of produce. The typical life cycle of primary pests is given in the descriptions to figure 22, *Sitophilus* spp., figure 23 *Sitotroga cerealella* and figure 24 *Bruchidae*. In each case the larval and pupal development stages take place entirely inside a grain after the eggs have been deposited onto or into the grain or pulse seed. All or almost all the damage takes place during this period of hidden development which may take most of the insect's life.

Typical examples of secondary pests are the beetles *Tribolium* spp. (figure 25) and the moths *Ephestia* spp. (figure 26). Both of these pests are particularly associated with milled or broken produce but can frequently be found in whole cereals. They feed within the bulk of the produce and their eggs are simply scattered on or within the infested produce. The moths can cause severe contamination of the product by the webbing produced by the larvae.

Other life-styles

It is most essential to control the insects that are primary and secondary pests. Other insects found in stores include the parasitic Hymenoptera and predatory Hemiptera,

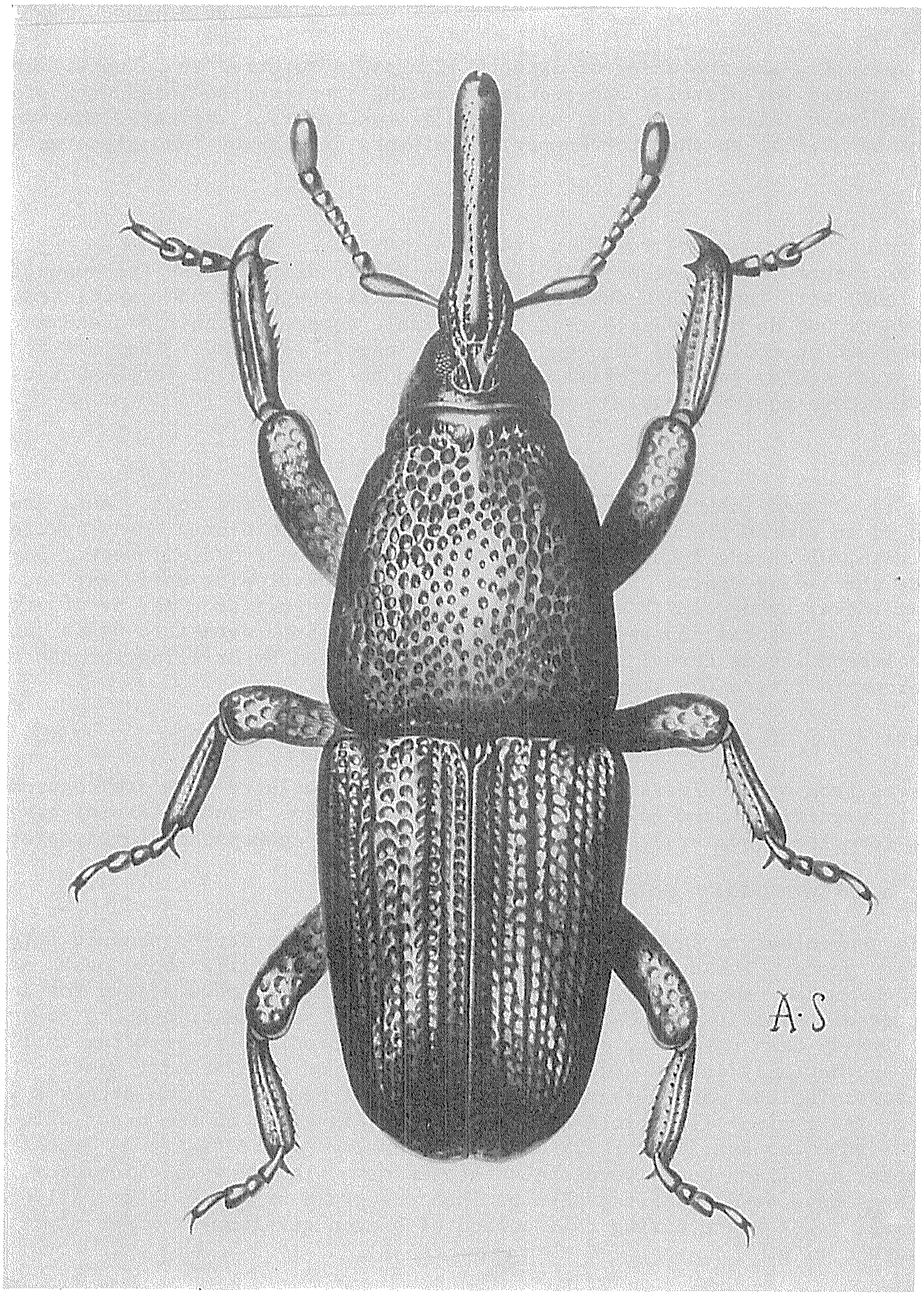


Figure 22. Sitophilus oryzae (2-4 mm).

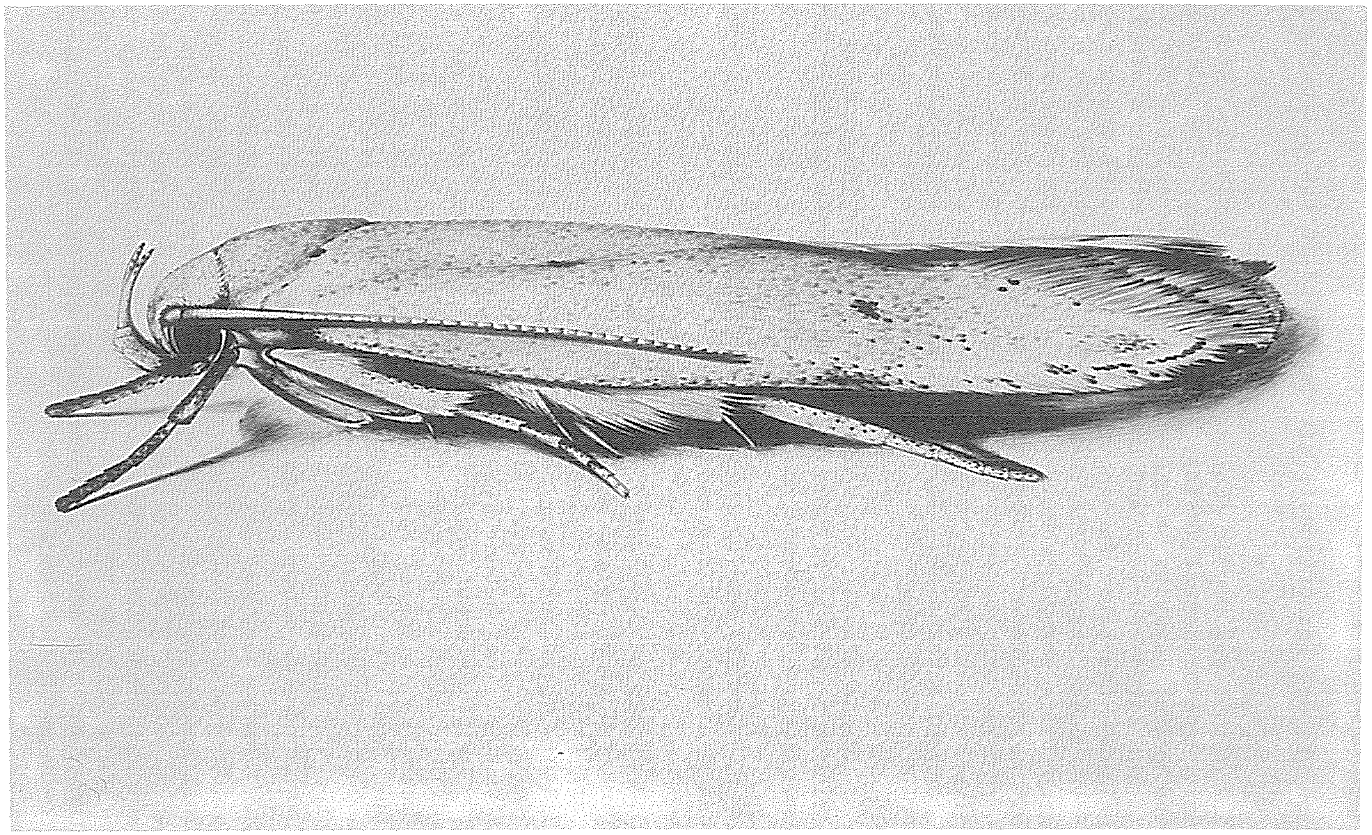


Figure 23. Sitotroga cerealella (forewing length 5-10 mm).

which have already been described, and insects of many different orders that feed predominantly on fungi. Some of these may be classified as secondary pests of stored produce, but others are true fungus-feeders that cause only incidental damage to the stored product. However, the presence of large numbers of fungus-feeding insects in a store may indicate that a quantity of mouldy produce is present and requires attention.

Common storage insect pests

Some common storage insects pests are described in the following notes to figures 22 to 35.

Figure 22. *Sitophilus oryzae* (Coleoptera, Curculionidae). Rice weevil. A major widespread primary pest of cereal grains, especially wheat. The adult female bites a small hole in the grain, deposits an egg within, and then seals the cavity with a plug of waxy secretion. The larva develops and pupates entirely within a single grain, which is hollowed out inside by the larva feeding. The infestation of grain is not externally visible even at the pupal stage. The resulting adult bites its way out of the grain leaving a characterisitc emergence hole roughly circular in shape but with an irregular edge (in contrast to the prefectly round holes caused by *R. dominica* and the "seedcoat flap" left by *Sitotroga cerealella*). The adults also feed on whole cereal grains leaving large irregularly-shaped cavities. Development from egg to adult take a minimum of about 26 days at 30°C and 70 percent RH. The adults live four to five months, during which females may lay 300 to 400 eggs.

S. zeamais. Maize weevel. *S. zeamais* is generally larger than *S. oryzae*, prefers larger grains (rice and maize), flies more actively and has a longer development period (30 days minimum). It is not common in dry climates.

S. granarius. Granary weevil. An important pest of grain in temperate countries. It is larger than *S. oryzae* and does not fly.

Figure 23. *Sitotroga cerealella* (Lepidoptera, Gelechiidae). Angoumois grain moth. An important primary pest of cereal grains throughout the tropics and in warm temperate regions. Eggs are laid on the cereal grains, often pre-harvest, and the larvae bore into the grain immediately after hatching, completing their development entirely within the grains. The infestation is not externally visible at this stage. Before pupation, the larva creates a chamber just beneath the surface of the grain, thus creating a small circular "window" of translucent seedcoat. After pupation, the adult moth pushes through this window, leaving a small but characteristic round hole at the edge of which the seedcoat usually remains as a partial covering. The adult moth flies actively but is short lived and does not feed. The female lays a large number of eggs in a few days. Development takes five weeks or longer. As the adult cannot penetrate far into densely-packed grain, infestations in grain stored in bulk are generally confined to the outermost exposed layers of the bulk, but quite serious infestations can develop in bagged cereals.

Figure 24. *Acanthoscelides obtectus* (Coleoptera, Bruchidae). Dried bean beetle. An important primary pest of pulses, especially of varieties of *Phaseolus vulgaris*, in tropical and subtropical climates. It attacks beans ripening in the field before harvest as well as in store. The larva develops entirely within a single bean, eventually forming a pupation chamber just under the seed coat, at which stages the infestation becomes evident as a circular "window" on the surface of the seed. The adult that emerges from the chamber is short lived and does not feed; the female lays about 50 eggs rapidly and freely among the beans.

Callosobruchus chinensis and *C. maculatus* have a similar life cycle to *A. obtectus*, but the egg is cemented to the bean and the larva passes straight into the bean. Cowpea and gram are particularly susceptible. *C. rhodesianus* is similar but apparently restricted to eastern and southern Africa.

Zabrotes subfasciatus is similar in habits to the *Callosobruchus spp.*, but it is particularly associated with *Phaseolus vulgaris*.

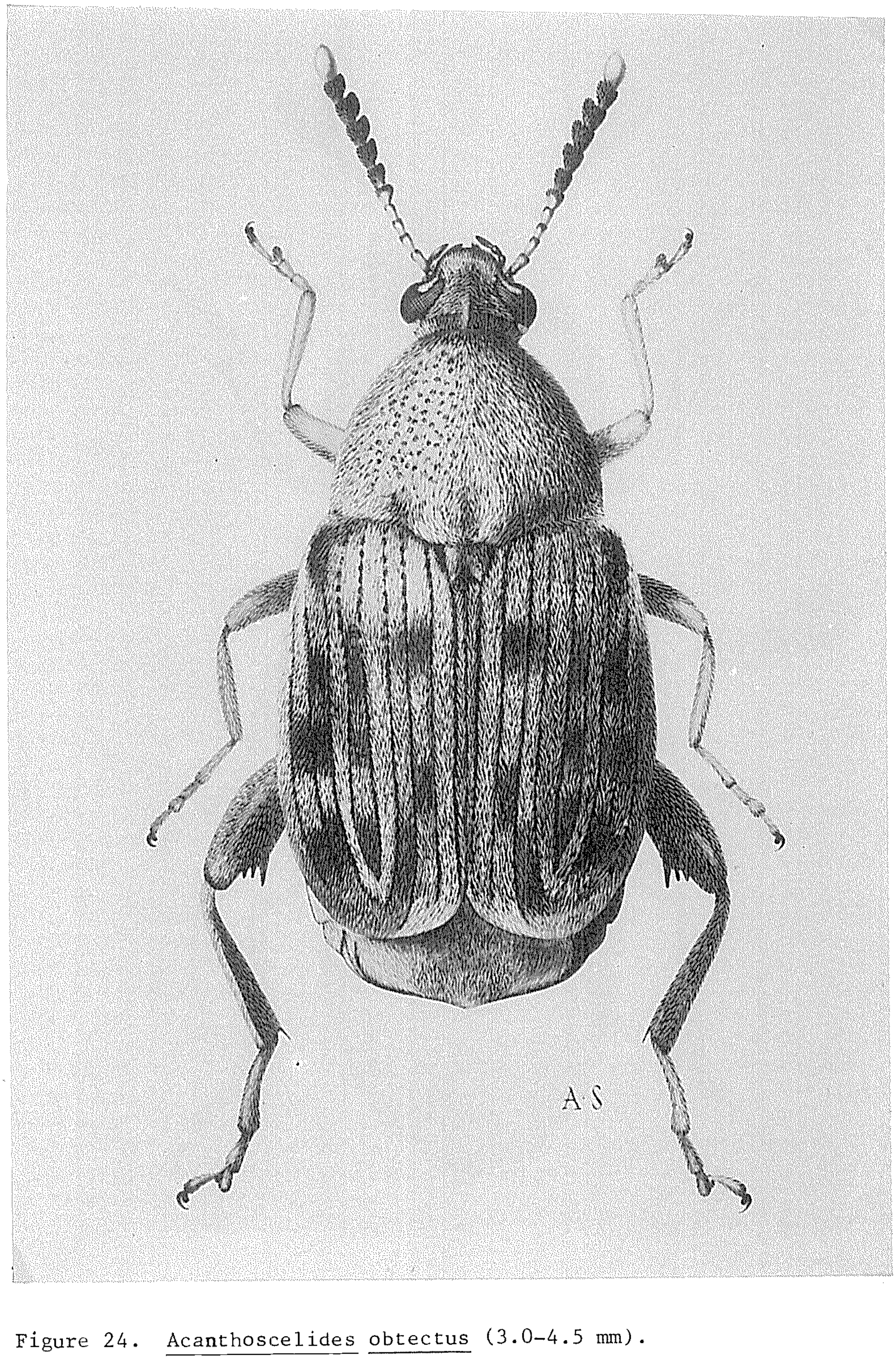


Figure 24. Acanthoscelides obtectus (3.0-4.5 mm).

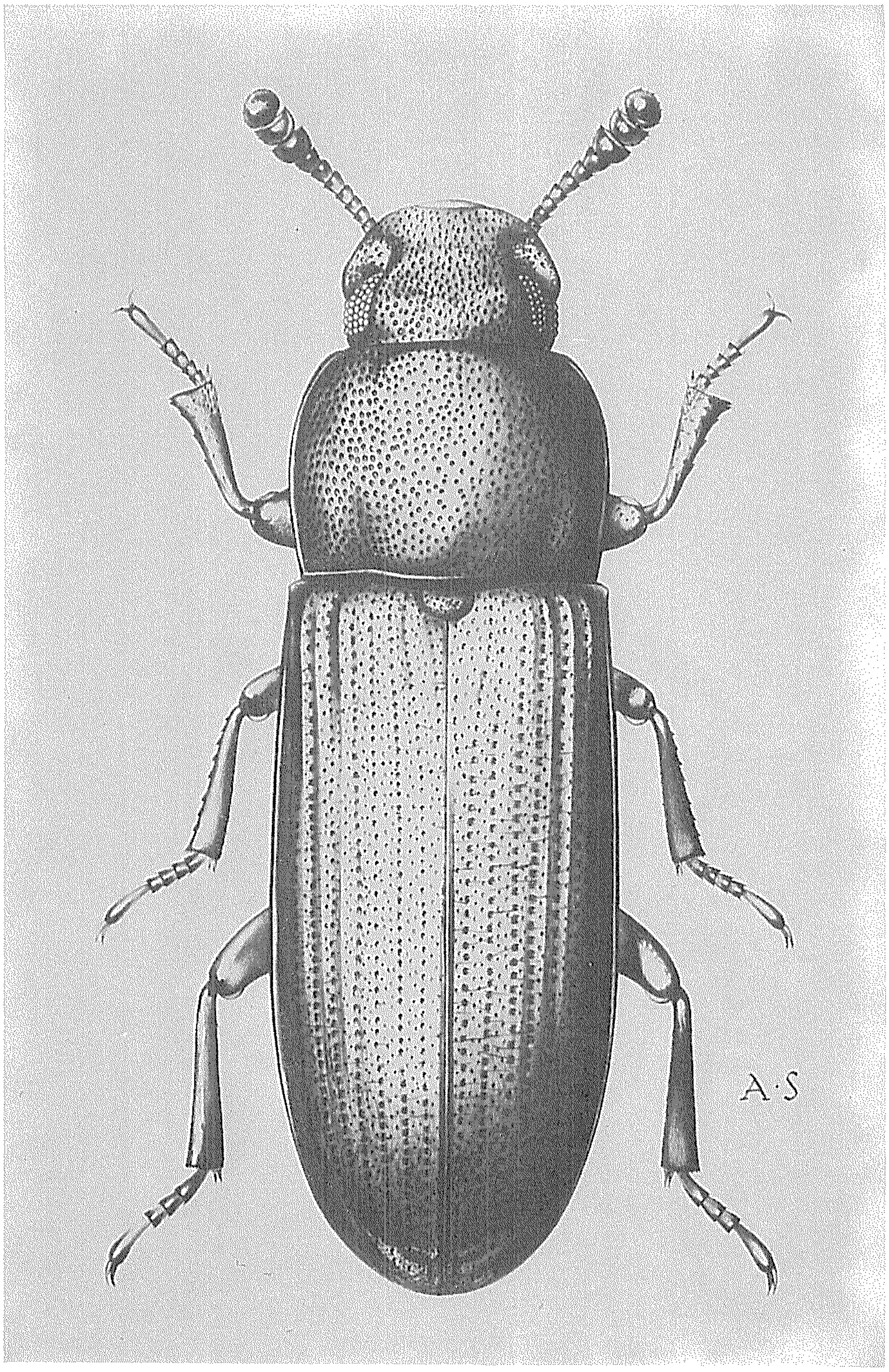


Figure 25. Tribolium castaneum (2.3-4.4 mm).

Figure 25. *Tribolium castaneum* (Coleoptera, Tenebrionidae). Rust-red flour beetle. A major secondary pest of most types of stored food commodities, especially common cereals and cereal products, prefers broken grains or flour to whole grains. Eggs are laid loosely in the foodstuff and development may take from three weeks (35°C) to 12 weeks. Adults live up to three years. *T. confusum*, the flour beetle, is more common in cooler temperate climates than *T. castaneum*.

Figure 26. *Ephestia spp.* (Lepidoptera, Phycitinae). Warehouse moth. These moths occur worldwide and the larvae are general feeders that will attack whole grains but prefer broken, damaged grain or meal. The adult moths live only one to two weeks and lay a large number of eggs (100-300) within a few days. Development takes six to eight weeks at about 25°C. Adults rest on store and produce surfaces or fly in the store. The larvae can form a dense silk webbing and construct silk cocoons for pupation, spoiling the appearance of stacks.

E. cautella is found in warmer climates, *E. elutella* in temperate climates *E. kuehniella* worldwide, especially on cereal products, while *E. calidella* and *E. figulella* occur less on cereals than on nuts and fruit. Other similar moths are *Plodia interpunctella*, the Indian meal moth, less serious in hot climates, *Corcyra cephalonica*, the rice moth, a pest of stored cereals particularly milled rice, and *Pyralis farinalis*, the meal moth, which prefers damp conditions.

Figure 27. *Oryzaephilus surinamensis* (Coleoptera, Silvanidae). Saw-toothed grain beetle. A common secondary pest of many commodities, predominantly associated with cereals and cereal products. It is tolerant of cold conditions, occurs worldwide and is one of the major pests of cereals in temperate regions. Development takes about three weeks over 30° and up to ten weeks at 18°C, the lower limit. Adults are long lived (six to ten months or longer).

O. mercator. This species is less tolerant of cold conditions than *O. surinamensis* and is known mainly as a pest of oilseeds.

Figure 28. *Rhizopertha dominica* (Coleoptera, Bostrichidae). Lesser grain borer. A major primary pest of cereal grains, especially wheat and rice, particularly important in rather dry, warm climates, because it is more tolerant of low moisture content than the *Sitophilus spp.* weevils, with which it competes. Both the adults and the larvae feed and bore through the grains forming characteristic circular tunnels. This tunnelling activity is this species' main method of movement as well as of feeding. The damage caused by each individual is therefore high, and the numbers of adults and larvae in samples are often underestimated, because a large proportion of the population is hidden inside the "tunnels" in the grains. The female lays several hundred eggs and development takes about one month.

Prostephanus truncatus. The larger grain borer. This species infests maize. It has a limited distribution, but appears to be spreading and now occurs as a pest in parts of East Africa as well as in Central America and the southern USA.

Figure 29. *Trogoderma granarium* (Coleoptera, Dermestidae). Khapra beetle. A major pest of cereals of variable distribution, but especially important in hot, dry climates that are unfavourable to other insects (40°C and less than 30 percent RH). The adults live only two weeks and do not feed. Development takes from about one month (over 35°C) to two months (over 22°C). In unfavourable conditions (e.g. cold) the larvae can enter a long resting phase (diapause), lasting several years. Eradication of the diapausing larvae (often hidden in crevices) is very difficult. Other *Trogoderma spp.* are generally less important.

Figure 30. *Cryptolestes ferrugineus* (Coleoptera, Cucujidae). Rusty grain beetle. A widespread scavenger pest of cereals and oilseeds, tolerant of cold conditions. The related *C. pusillus* and *C. pusilloides* may prefer warm humid climates.

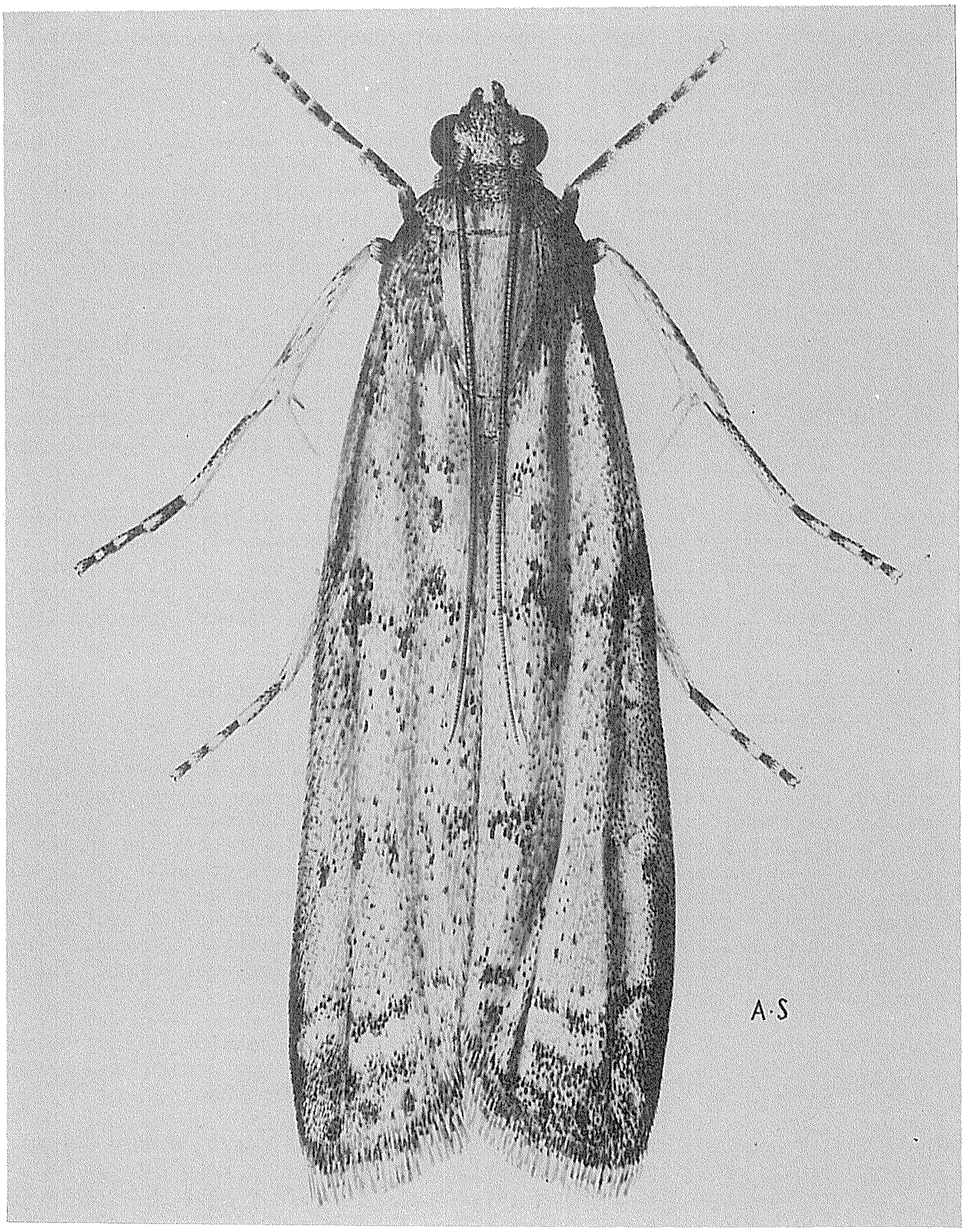


Figure 26. Ephestia cautella (forewing length 6-12 mm).

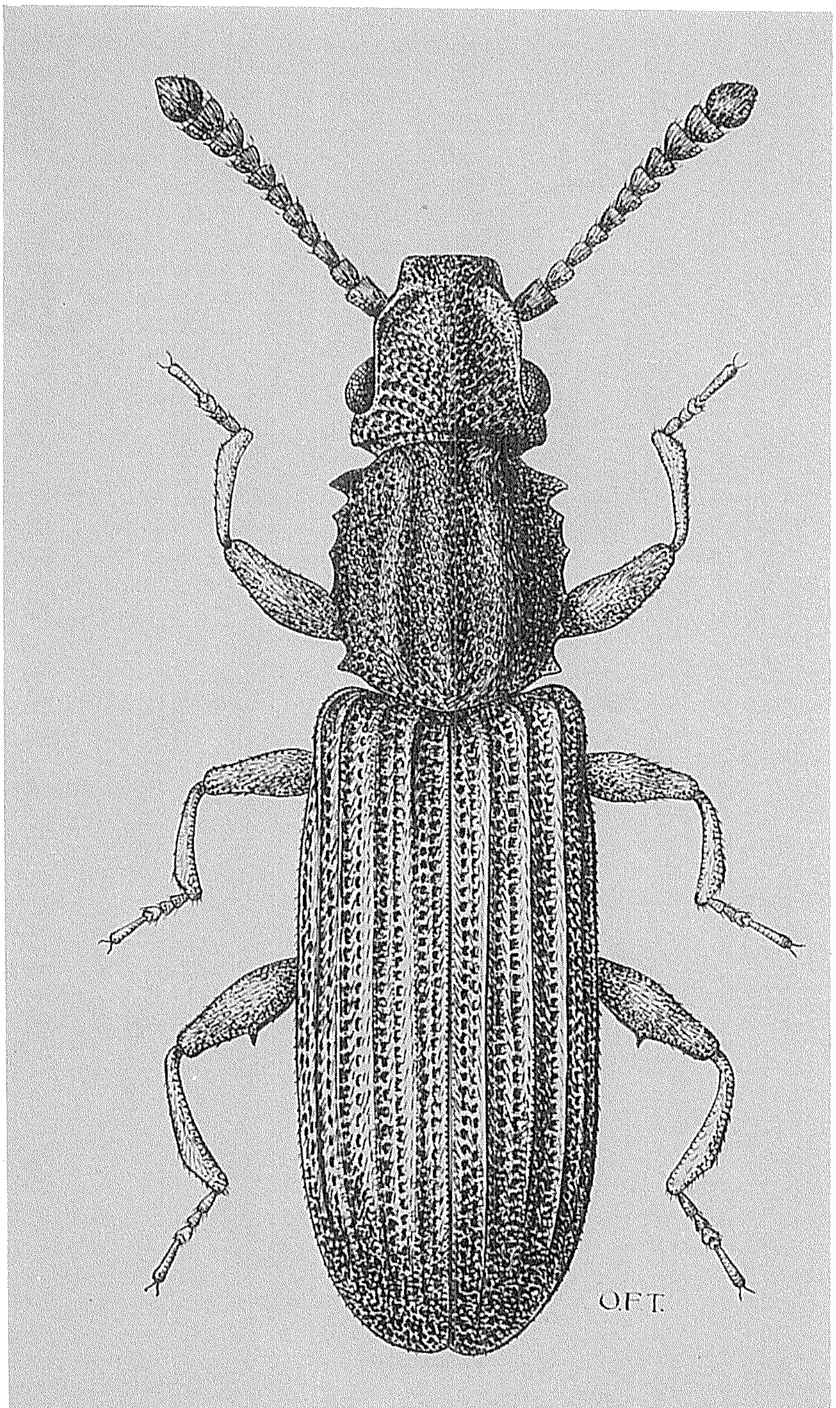


Figure 27. *Oryzaephilus surinamensis* (2.5-3.5 mm).

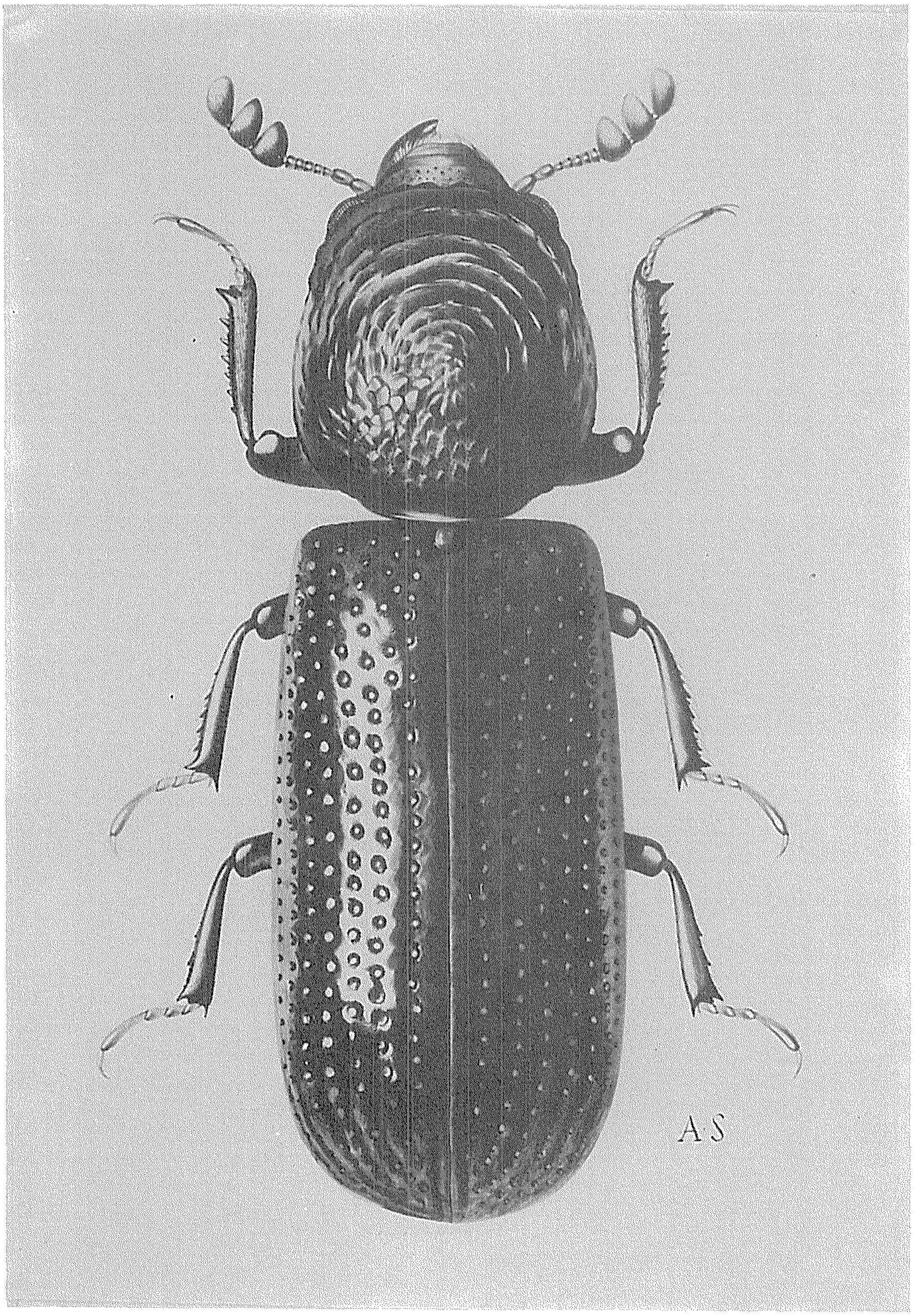


Figure 28. Rhyzopertha dominica (2.5-3.0 mm).

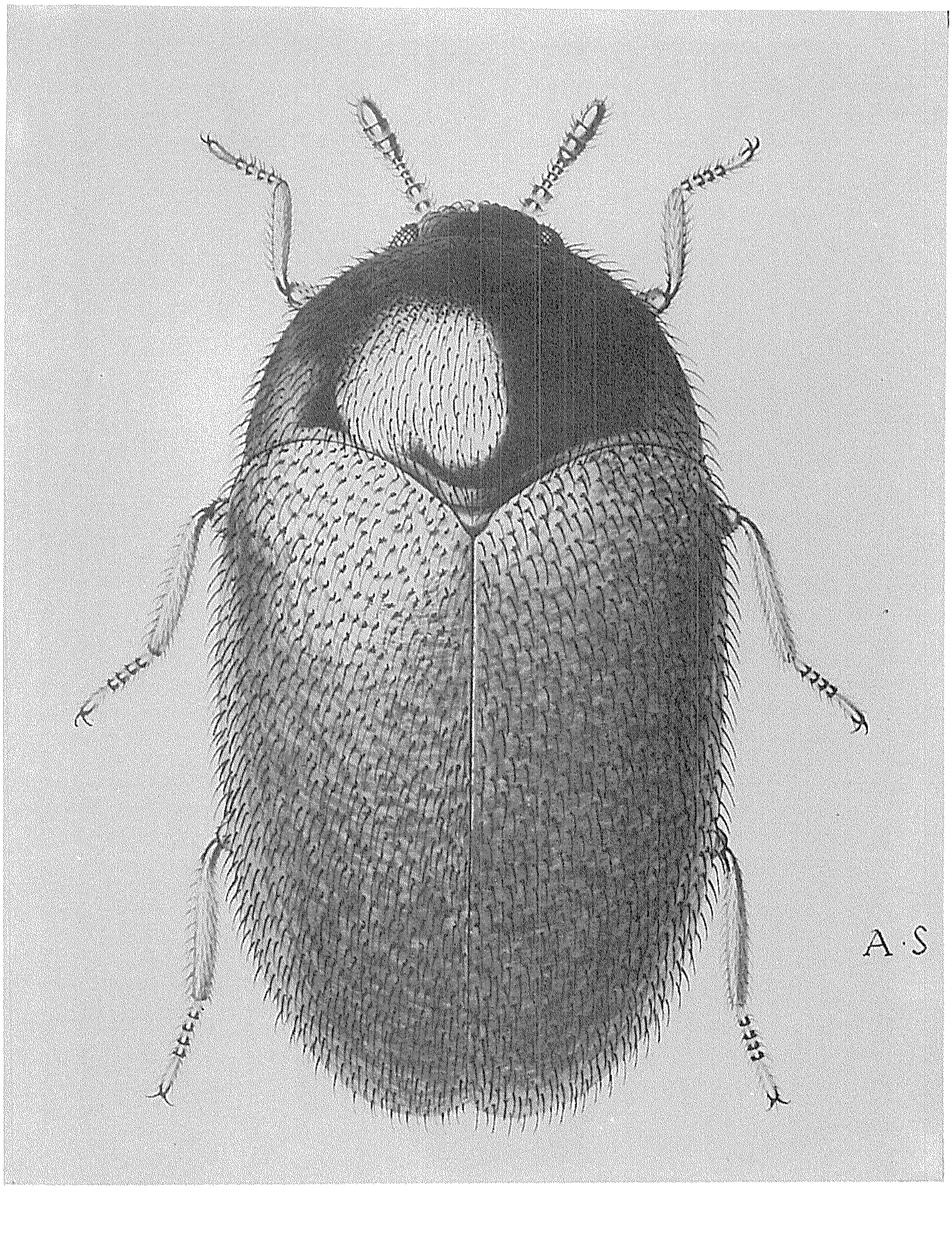


Figure 29. Trogoderma granarium (1.5-3.0 mm).

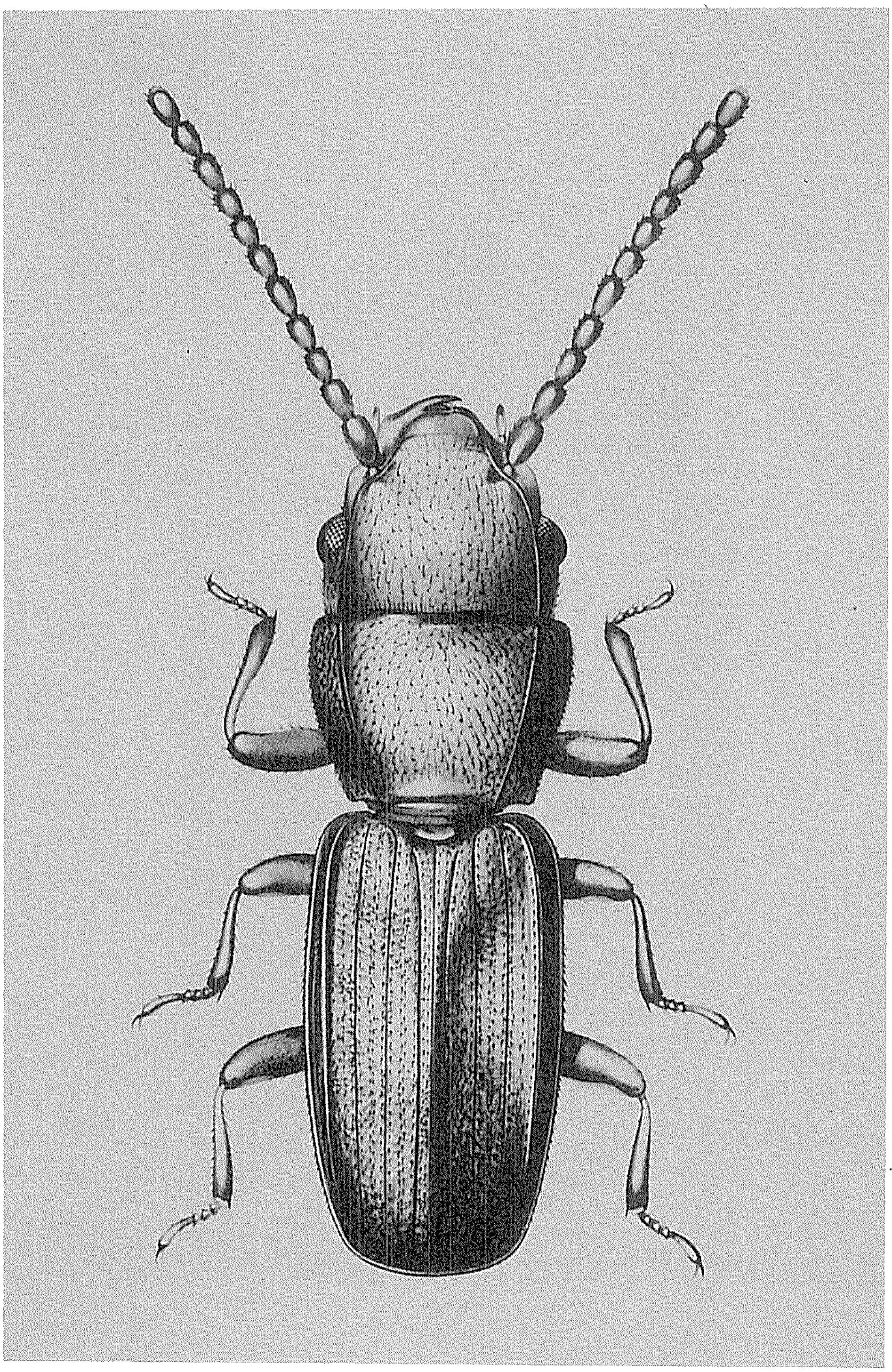


Figure 30. Cryptolestes ferrugineous (1.5-2.0 mm).

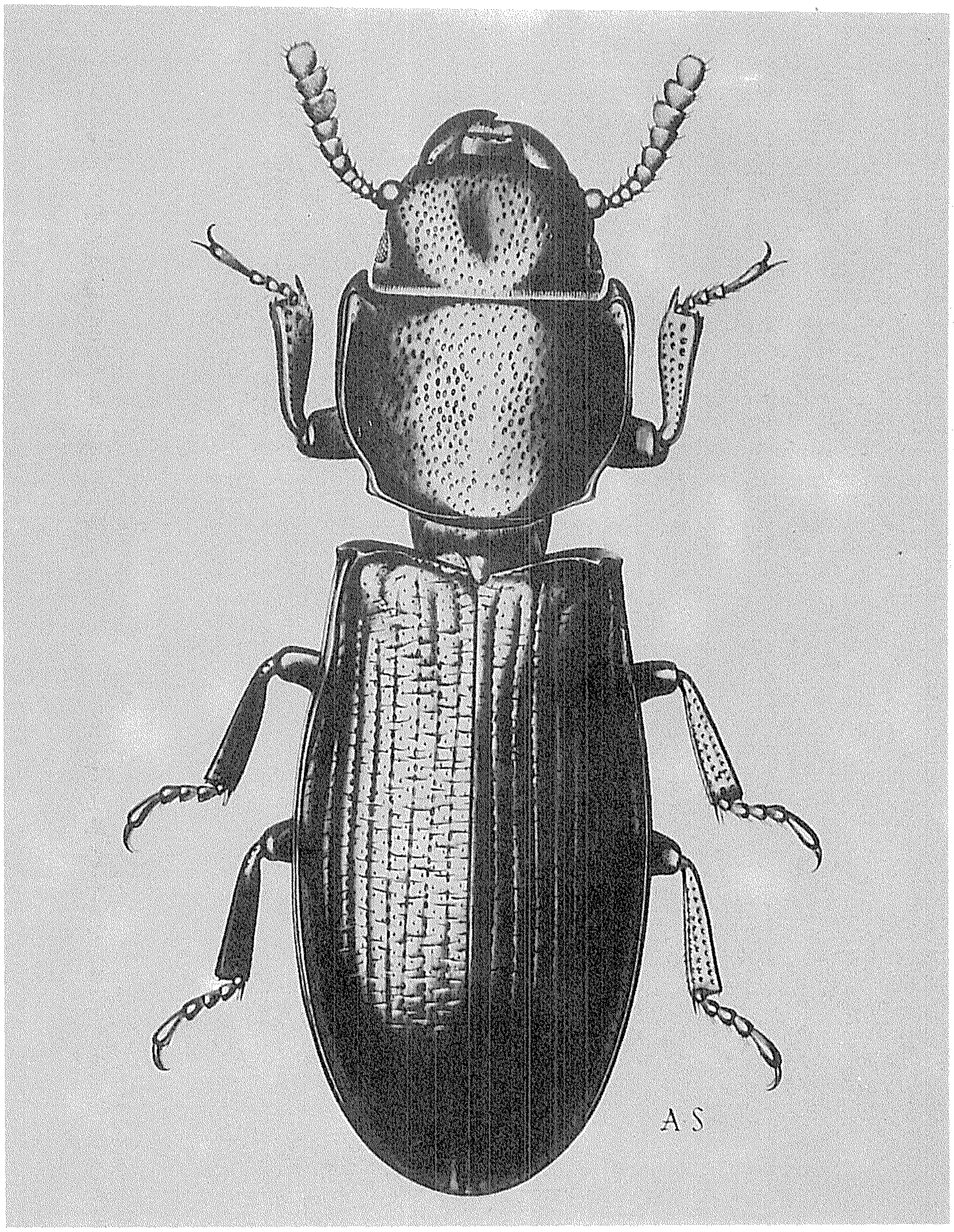


Figure 31. Tenebroides mauritanicus (5-11 mm).

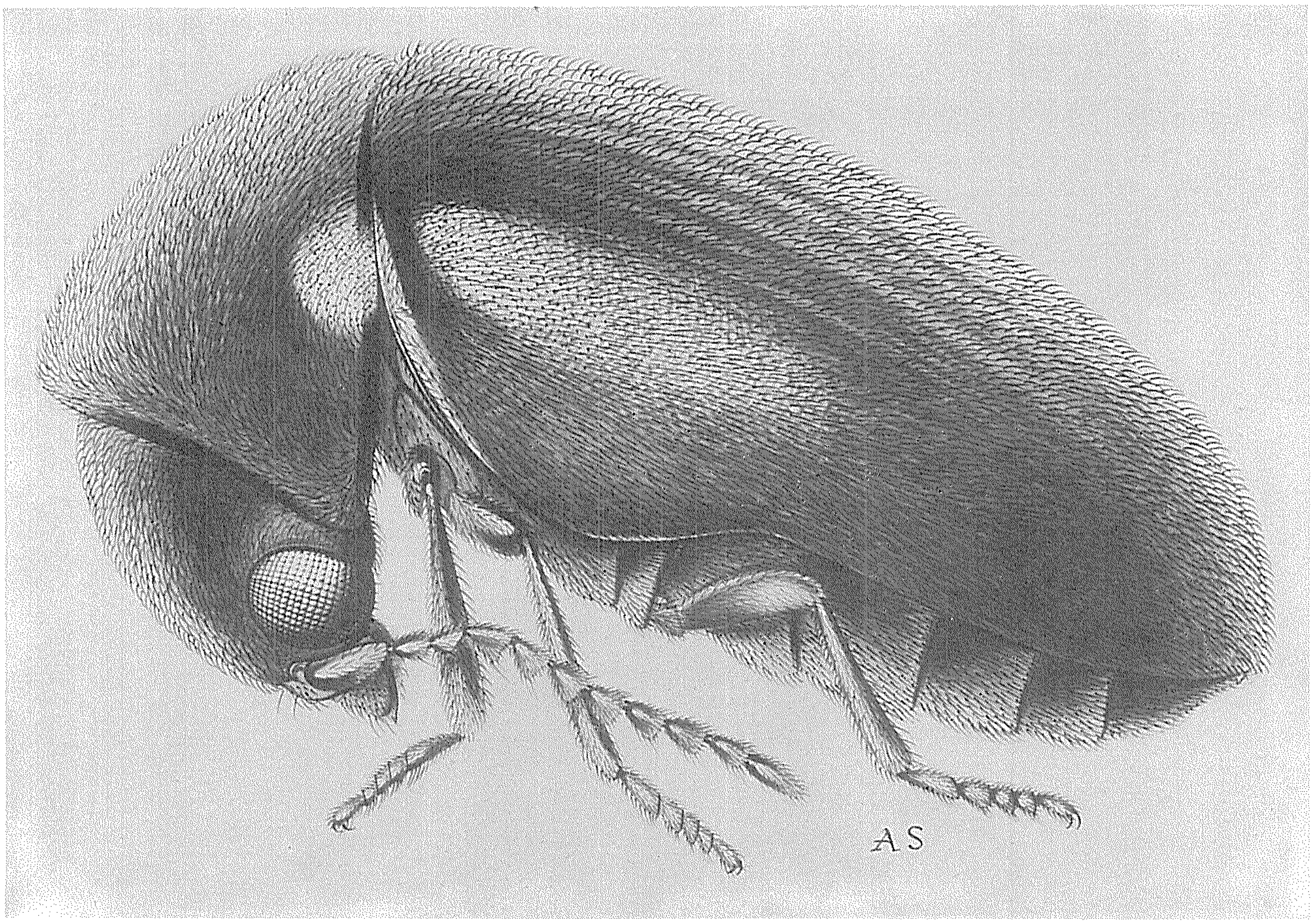


Figure 32. Lasioderma serricorne (2.0-2.5 mm).

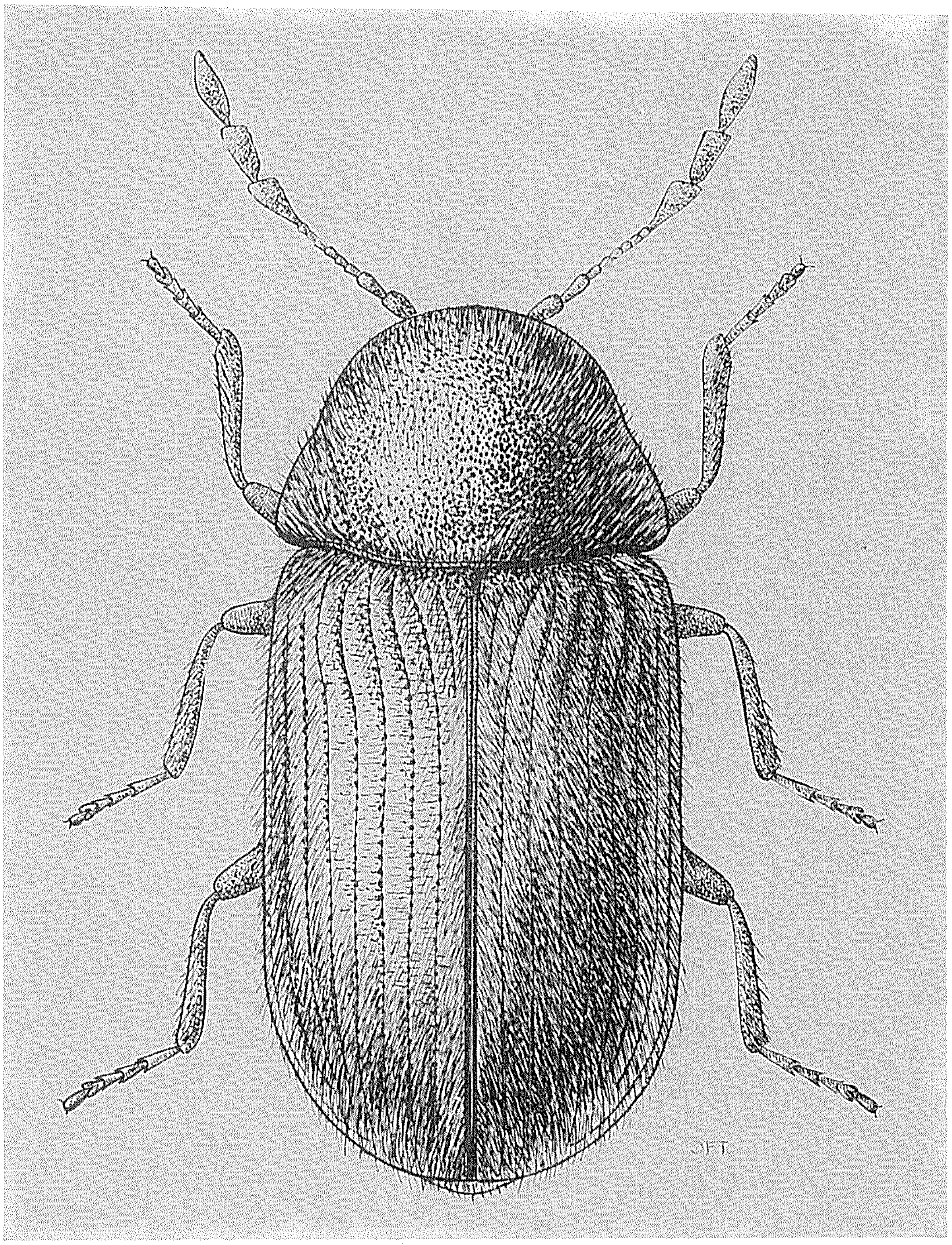


Figure 33. Stegobium paniceum (2-3 mm).

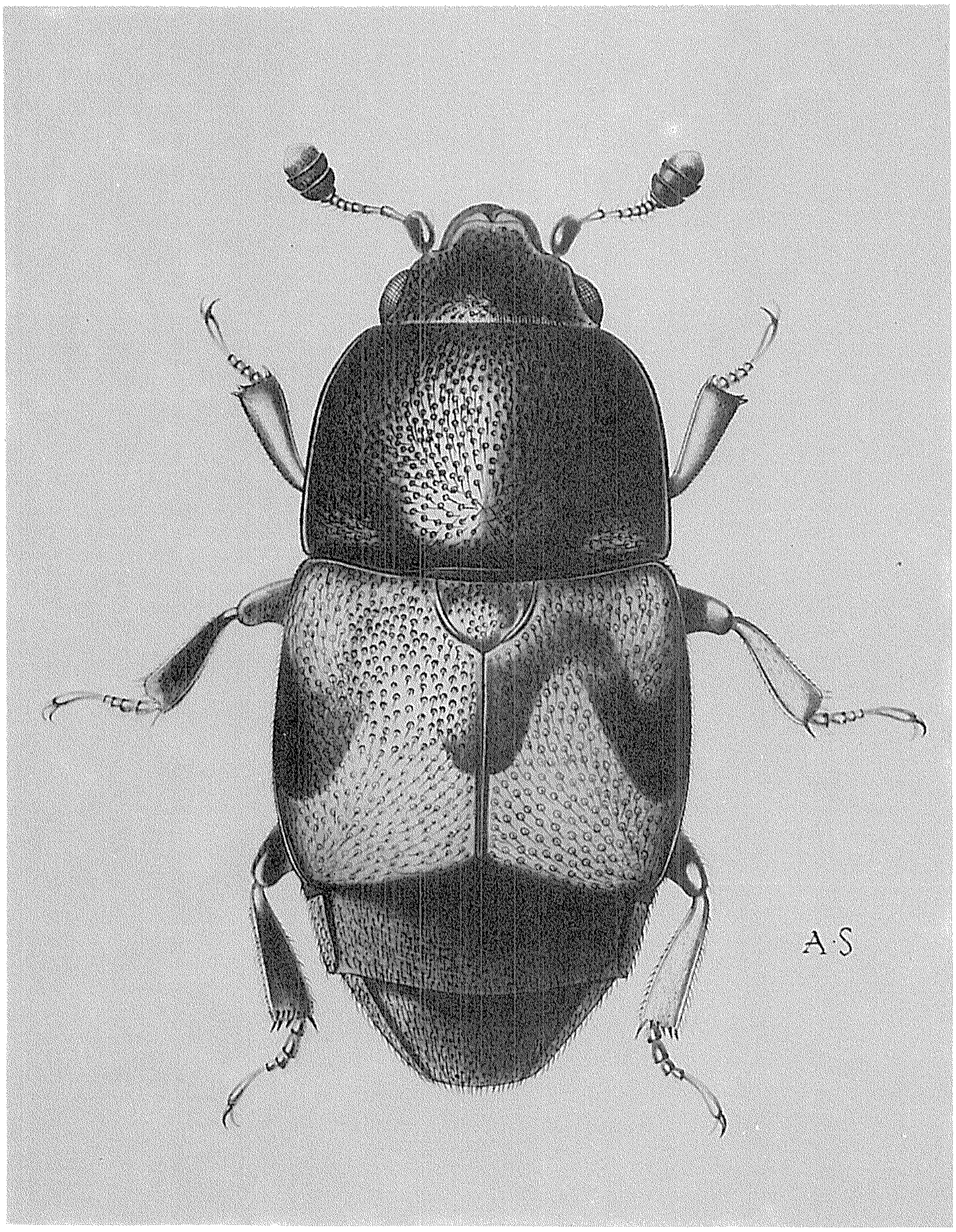


Figure 34. Carpophilus dimidiatus (2.0-3.5 mm).

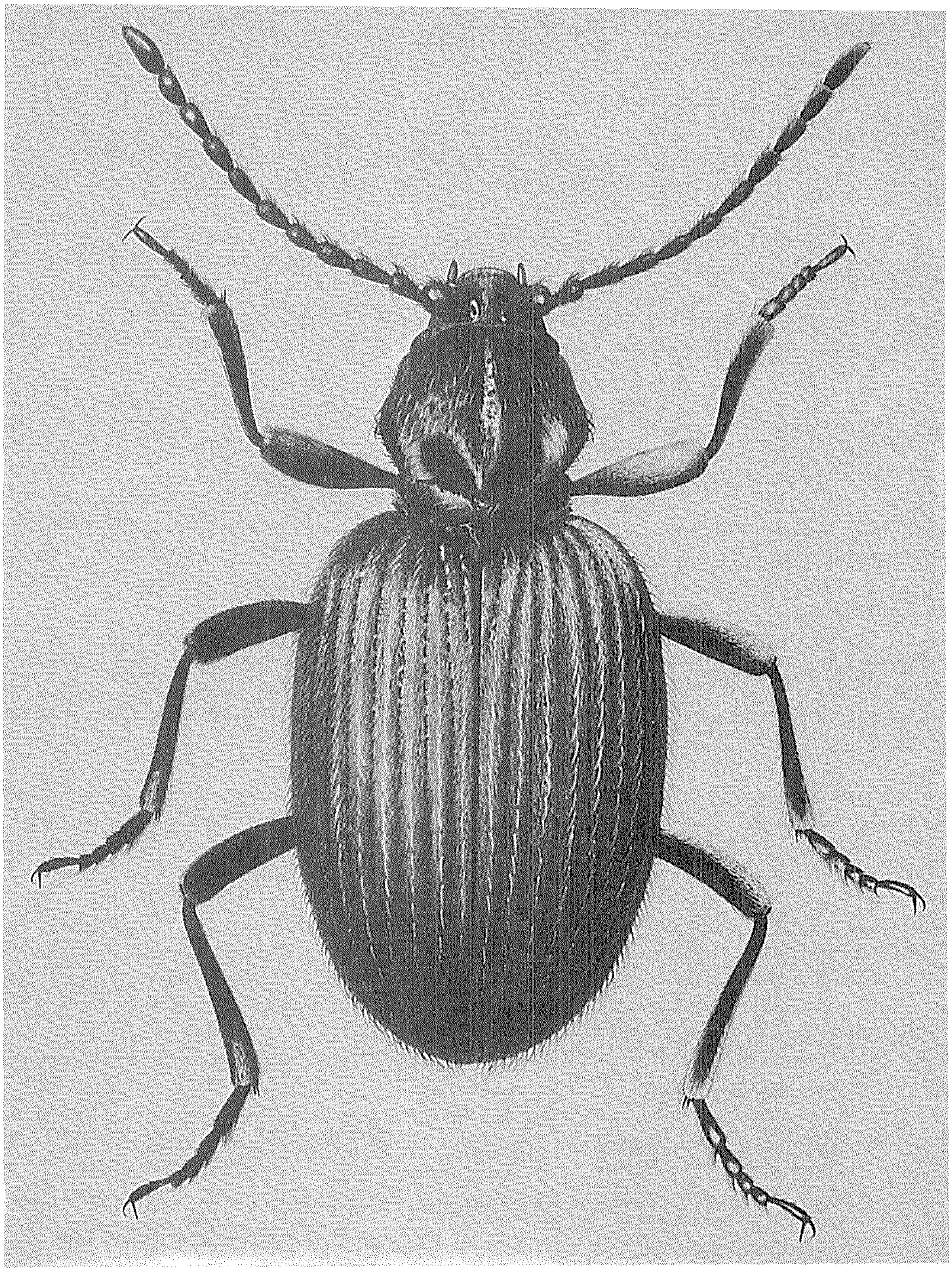


Figure 34. Ptinus tectus (2.5-4.0 mm).

Figure 31. *Tenebroides mauritanicus* (Coleoptera, Trogossitidae). Cadelle beetle. A worldwide pest of cereals and oilseeds and very long lived (adults survive up to two years) with a long development period (ten to 20 weeks). Larvae may remain hidden in wooden bins and structures for long periods and present a serious residual infestation problem.

Figure 32. *Lasioderma serricorne* (Coleoptera, Anobiidae). Cigarette beetle. A widespread and major pest in the tropics of a wide range of commodities, including cereals. The adult is short lived (two to four weeks) and does not feed. The female lays about 100 eggs. The development period is variable but may be about eight weeks.

Figure 33. *Stegobium paniceum* (Coleoptera, Anobiidae). Drugstore beetle. A general feeder similar to *L. serricorne*, commonly found in storage premises.

Figure 34. *Carpophilus dimidiatus* (Coleoptera, Nitidulae). Sap beetle. This species and other *Carpophilus* species are a problem only on damp and mouldy grain and other moist commodities.

Other insects that may become a severe problem, but only in damp and mouldy conditions, are *Ahasverus advena* (foreign grain beetle), *Alphitobius diaperinus* (lesser mealworm beetle) and *Alphitobius laevigatus* (black fungus beetle).

Figure 35. *Ptinus tectus* (Coleoptera, Ptinidae). Australian spider beetle. A worldwide general pest of stored products.

Other insects found infesting stored products are:

Latheticus oryzae (Coleoptera, Tenebrionidae). Long-headed flour beetle. A secondary pest of cereals and cereal products adapted to hot conditions and unable to develop at temperatures below 25°C. Wheat products are more susceptible than rice products and it develops poorly on maize products.

Lophocateres pusillus (Coleoptera, Trogossitidae). A minor pest of several stored products, especially of rice. It is usually found in association with infestations of major pests and rarely found in very large numbers. It is apparently restricted to hot climates but has a widespread distribution within the tropics.

Palorus spp. (Coleoptera, Tenebrionidae). This genus contains several species that are secondary pests (especially of cereals and cereal products). Two of these species, *P. ratzeburgii*, small-eyed flour beetle, and *P. subdepressus*, depressed flour beetle, are quite common pests of cereals and cereal products in most parts of the world and are usually found in association with primary cereal pests and with other tenebrionid secondary pests. In general, however, these species are less important than some other tenebrionid beetles.

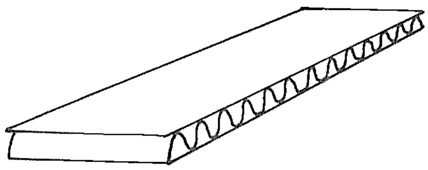
DETECTING INSECT INFESTATION

The detection of insect infestation is primarily a matter of careful inspection and observation based on experience and knowledge of the commodity and the infesting species. The majority of storage insects are inconspicuous and difficult to detect. Some penetrate deeply into a commodity, whereas other, usually larger insects are restricted to the surface. Flying insects, such as moths, are more conspicuous and may be easy to detect in favourable circumstances. Heavy infestations are usually evident, but the detection of light infestations is more difficult and the following techniques should be tried.

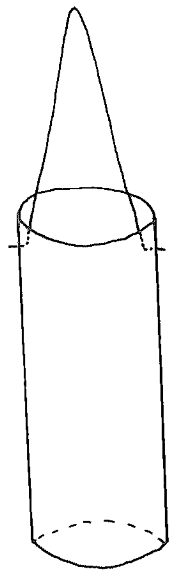
Surface infestation

Use of a torch

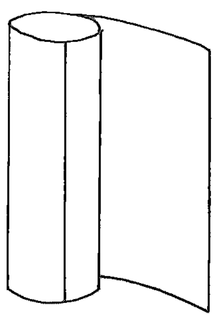
Nearly all storage insects are more active in the dark than in the light. Insects are often conspicuous at dusk, less so at night, and almost completely inconspicuous during the day. Inspection should, therefore, be carried out with a torch when premises are



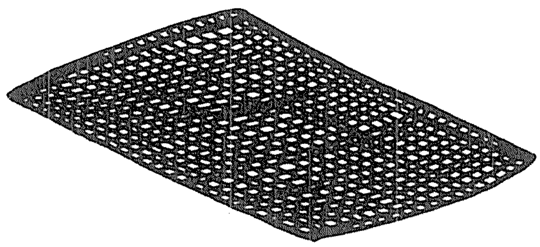
(a) Corrugated cardboard - to collect pupating larvae



(b) Sticky trap - polythene tube faced with sticky paper



(c) Tube trap - rough exterior and smooth interior



(d) Bait trap - attractive foodstuff in a plastic mesh container

Figure 36. Various forms of insect traps.

dark or nearly so. This may be outside normal store working hours.

Uncovering hidden infestation

Most insects will seek out damp spots and areas of favourable temperature. The inspection should include dark areas of the store, the seams and ears of bags and cracks between bags. A few bags at the top of stacks should be raised to see if there are any insects between the bags. Produce with signs of dampness should be specially inspected for signs of infestation.

Agitation of bags

Bags may be agitated violently, several times, and left for about 15 minutes, preferably in a dark or shaded area. Adult *Sitophilus spp.* may walk out onto the bag surface.

Disturbance of the stack surface

Resting adult moths may be disturbed by running a stick over the vertical surfaces of stacks or by simply beating the surfaces.

Trapping

Various methods of trapping insects have been devised (figure 36). They serve as a means of detecting infestation, not as a control measure. Artificial crevices in the form of pieces of corrugated cardboard, about 4 cm wide and 20 cm long, can be placed between bags at the periphery of a stack and left for a time. Insect larvae can be detected as they move into the corrugations to pupate (figure 36a), and the adults of many beetle species will also congregate in these traps.

Pieces of piping about 30 cm long and 10 cm in diameter can be used for making sticky traps. Pieces of grease coated polythene sheet should be wrapped around the pipe and clipped in place with the sticky surface outwards. The traps should be suspended from the roof of the store at various heights to trap flying insects (figure 36b).

A polythene tube wrapped in rough paper, but with the top end open, can be stood upright in a bag or in bulk grain. Many species of insect falling into the tube will be unable to escape because they cannot climb up the smooth surface (figure 36c).

A plastic mesh container with 1.5 mm apertures, heat sealed to form an envelope 20 cm x 10 cm (figure 36d), can be filled with food material and closed with staples. A suitable food material consists of a mixture of equal parts of wheat, broken groundnuts and kibbled carobs. The food mixture should be sterilized, to kill any stray insects, at 60°C for a few hours before use.

These traps are useful for detecting small infestations in empty buildings and in detecting insects on and around grain stacks.

The traps should be placed around the store and left in position for a known period and then examined by shaking them vigorously over a tray. Any insects present will fall through the mesh, which acts as a sieve.

Pheromone traps, some forms of which are commercially available, can be used to attract warehouse moths. There are two basic forms of moth pheromone trap, sticky and funnel, differing in both construction and method used to retain the moths (figure 37).

Infestation within the grain

The inspection and grading of grain before storage should substantially reduce the amount of infestation taken into storage. Nevertheless, the hidden internal stages of insect infestation, when the pre-adult stage are all within individual grains, may be difficult to detect.

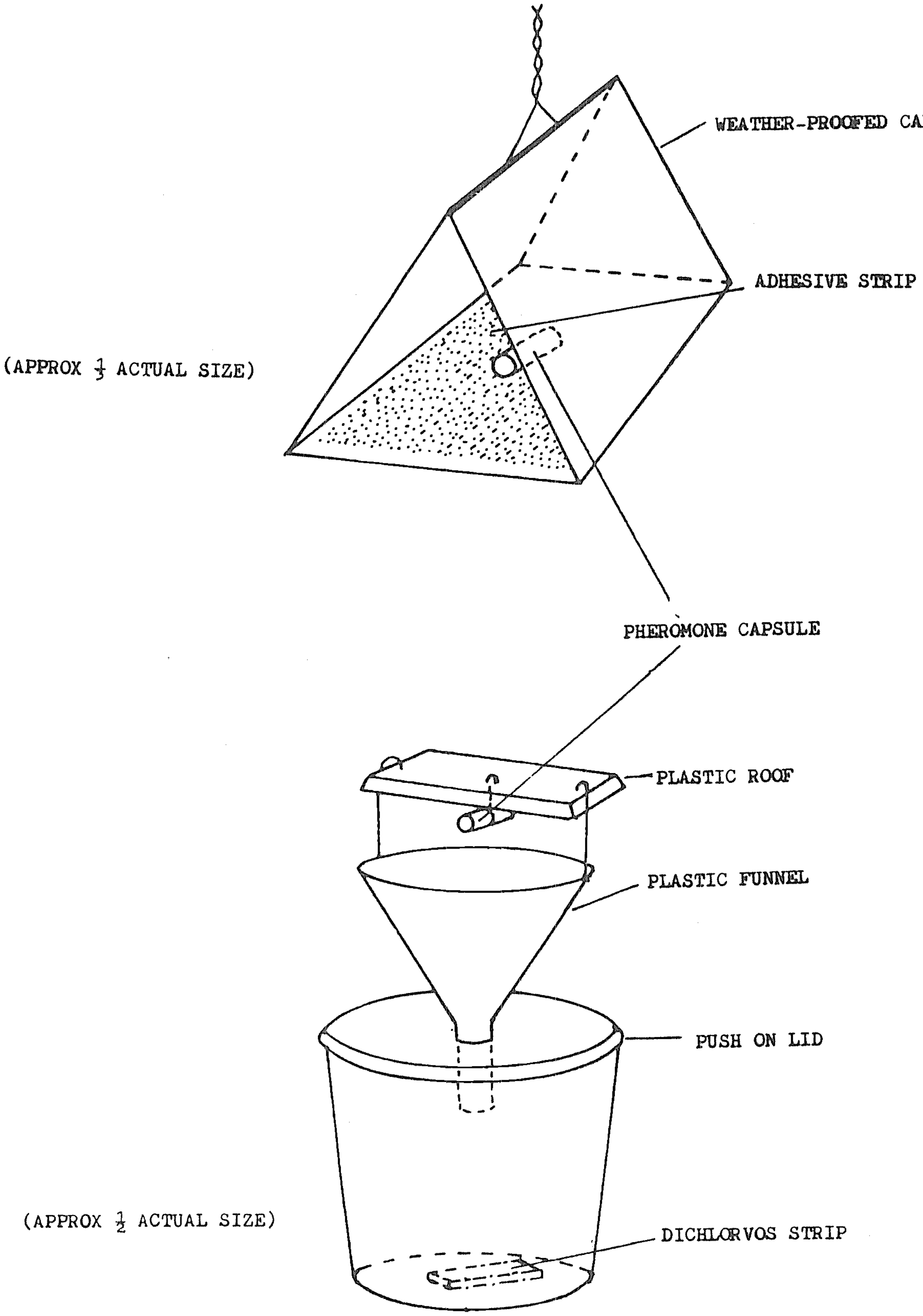


Figure 37. Moth pheromone traps.

Usually, if the grain is infested some adults will be present, but there are situations where there may be a hidden infestation with no adults present. One instance is on newly harvested or cleaned grain when the processing may have killed or separated the adults. Another instance is when grain has been ineffectively fumigated or superficially treated with insecticide, which has killed the adults but not all the pre-adult stages. Effective methods for detecting these hidden stages require sophisticated equipment and laboratory facilities. One of the best methods, where appropriate, is the use of a suitable laboratory x-ray apparatus to photograph large single-layer grain samples. Another is the nin-hydrin technique, developed initially in the USA, but which can be used with a relatively inexpensive apparatus (the Ashman-Simon detector), developed in the UK. This is useful for small grains, especially wheat, but less convenient for large grains, such as maize.

In the absence of equipment for detecting hidden infestation, two alternative approaches are possible, depending on the previous history of the crop and the priority given to absolute control of pests. One alternative is to fumigate all grain going into the long-term storage, whether or not there is evidence of infestation. The other alternative is to retain the samples taken when the grain was being loaded into store and to keep them isolated at normal tropical temperatures for up to six weeks to see if any insects emerge. It is essential that there should be no possibility of re-infestation in that period, but the containers must not be airtight. The samples should be sieved after about five to six weeks. This assessment should be supported by regular and frequent inspections of the stacks or bulk. The presence of insects within a grain bulk may be detected by the use of a sampling spear (see Chapter 2, "Sampling Methods"). Sampling of bags within a stack may be difficult and some shifting of the top layers of bags may be necessary.

Signs of the presence of insects may be easier to detect than the insects themselves. For example, a series of temperature records from thermocouples or thermistors (Annex 3) built into a stack or inserted in a bulk can reveal rises in temperature and may warn of an impending infestation before adult insects become obvious. It is useful to have a thermistor carried on a probe, which can be pushed into the stored produce for on-the-spot checking.

All these techniques should be used together in the routine inspection of stores and commodities described in Chapter 5.

ARACHNIDS

The arachnids found in stores are spiders, pseudoscorpions and mites. Both arachnids and insects have jointed legs but, whereas insects have three pairs of legs, arachnids have four pairs. The life cycle of arachnids is similar to that of some insects; eggs laid by adults hatch into young immature animals, similar to the adults but much smaller. They develop through a number of stages (in which they are known as nymphs), increasing in size each time they moult and generally becoming more and more like the adults in appearance. At the final moult the adult emerges, equipped with full reproductive organs, and the cycle is repeated.

Spiders (Aranea)

Many types of spiders are found in stores, where they are general predators on the insects. They are seldom found in the commodity but may be common on the walls and floors or in residues. They cause no damage to stored produce but they are not economically useful as predators, because they feed indiscriminately on pests and on other beneficial invertebrates, and are not present in sufficient numbers to exert a major control effect.

Pseudoscorpions

Certain species of pseudoscorpions are occasionally found in stored produce, where they prey on other very small invertebrates. They are seldom found in large numbers, except on heavily infested produce.

Mites (Acarina)

Many types of mite are found in stored produce, especially in humid climates, but they are frequently overlooked because of their small size. Some of these mites are pest species, others are beneficial predators. Identification of mites is difficult, partly because of their very small size, but four basic types are often found in stores: astigmatans, cheyletids, gamasines and uropodines. The astigmatans, which are extremely small and difficult to see as they have pale or colourless soft bodies, include most of the pest species that either feed on the produce or on moulds growing on the commodity (figure 38). Although the individual mites are very small, they may, in certain conditions, occur in vast populations. Astigmatan mites can be an important cause of damage, especially in processed cereals (flour) and in the nutritionally important embryo of whole grains, and such mites often cause tainting of the produce.

Uropodine mites are less common than astigmatans and are mainly fungus feeders they are usually only found on commodities that are too moist for safe storage and subject to mould and decay. Cheyletid mites are predators, mainly on astigmatans, and are large emough to be seen during careful examination of a produce sample. Although they are beneficial and do not damage the commodity, the presence of such mites is a strong indication that large numbers of astigmatan mites are also present. Gamasine mites are often found in stores, where they prey on the eggs and immature stages of insect and mite pests. Such mites are generally beneficial in stores, but their presence may indicate that pests are present in large numbers.

DETECTION OF MITES

Most mites are too small to be seen with the naked eye and it is, therefore, extremely difficult to detect an infestation when only a few are present. Detection is far easier when there are large numbers of mites present, because they tend to overflow from the commodity and are visible often as a brownish mobile dust at the base of a stack or on the surfaces of bags. Some mites emit a characteristic odour, sometimes described as "minty", which may give an indication of an infestation. Confirmation of a mite infestation may depend on a microscopic examination of dust samples collected from the base or surfaces of stacks.

The mites infesting stored food commodities generally do not thrive in dry conditions, but moisture often encourages them to breed. Particular attention should be paid to detection of mites when conditions are ideal for their development, that is, at moderately high temperatures and high relative humidities. In such circumstances small sub-samples of produce should be carefully examined with a powerful hand-lens or a low-power microscope. If moisture content is high, mites can breed even at low temperatures of about 5ºC or above. For example, the flour mite *Acarus siro* will breed down to 3ºC

VERTEBRATE PESTS

Rodents

Vertebrates that may be considered as pests in food storage warehouses include rodents, birds and bats. Of these, rodents (mainly rats and mice) are by far the most serious pest group.

Three species of rodent have become worldwide in distribution owing to their association with humans. These are the house mouse, *Mus musculus*, the Norway, common or brown rat, *Rattus norvegicus*, and the roof or ship rat, *Rattus rattus*.

These three rodents are capable of living in a wide range of habitats, possess omnivorous feeding habits and have an immense reproductive capacity. Breeding can occur throughout the year but tends to be seasonal. Under very good conditions a female may produce about 40 offspring in a year. The adult common rat weighs between 100 and 500 g and measures 20 to 27 cm plus 16 to 20 cm for the tail. It is usually brown on the back and grey underneath. The ship rat wieghs 100 to 300 g, is 14 to 20 cm long plus a tail length of up to 25 cm. It is brown or black on the back and either white or grey underneath. The house mouse weighs up to 30 g and is 8 to 10 cm long plus a tail of similar length. It is coloured brown on the back and grey underneath.

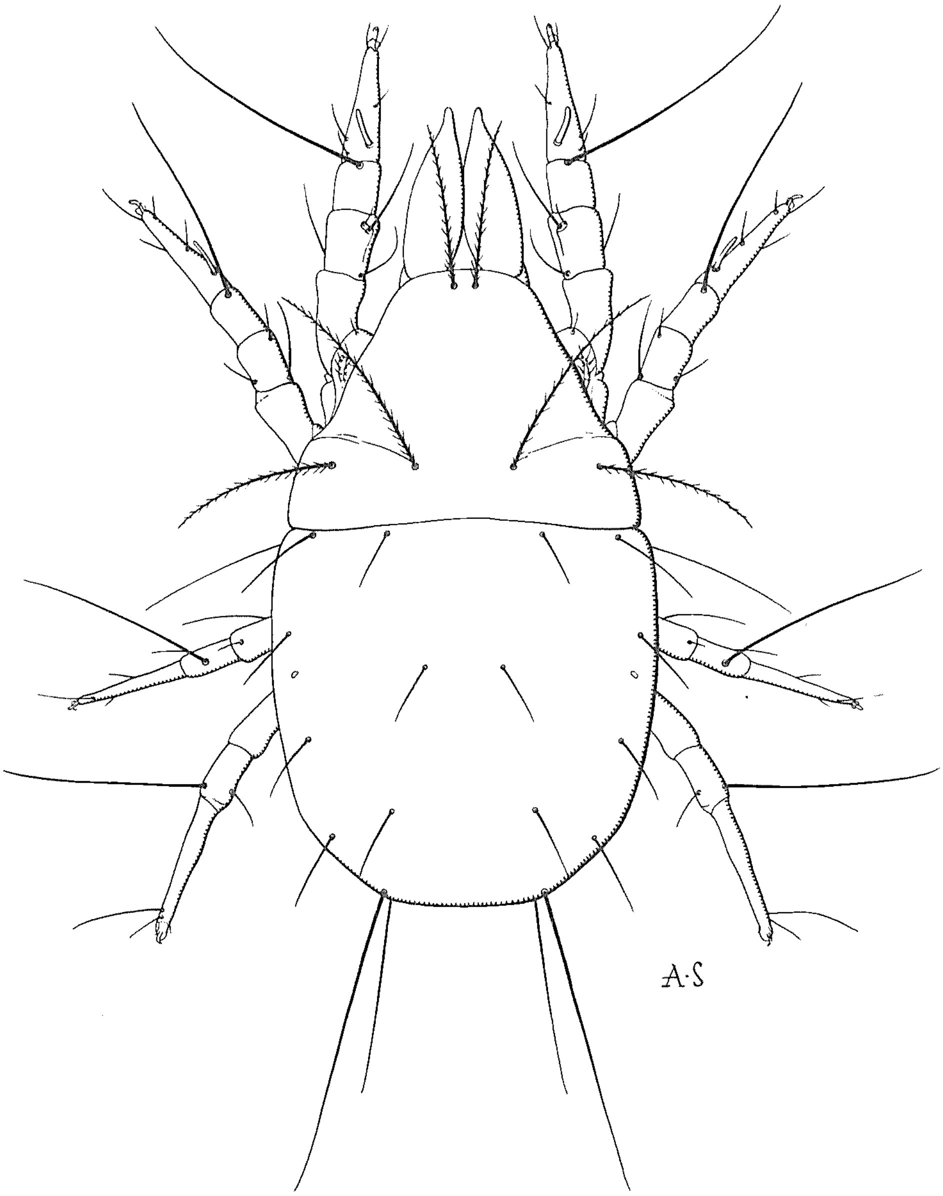


Figure 38. Acarus siro (ca 0.2 mm).

Common rats are more active burrowers but less efficient, although capable, climbers than the other two common rodent species. Rats and mice can climb vertical walls if the surface is rough. Ship rats are more adapted to a climbing way of life and are mainly found at roof height in buildings. They can enter buildings at ground level through small openings or at roof height by climbing rough walls directly or with the aid of unguarded cables and external pipework. Rats and mice are quick to take advantage of cavities in walls, roof spaces and ducts of buildings. In stock piled foods, they frequently nest in crevices between sacks and in the sacks themselves. All three species swim readily and are not hindered by water.

The senses play an important role in the life of rodents, smell and hearing being considerably more important than sight. Taste is very important in discerning the palatability of food. Rodents, although basically grain eaters, will consume a great variety of foodstuffs, including vegetables, meat and fish.

Rats generally need a source of water but mice can exist for very long periods without free water. Rats are more regular than mice in their feeding habits, tend to be nocturnal, follow set runs and feed under cover. Mice are light, erratic feeders and may frequently feed during daylight hours in closed, undisturbed premises.

Where food shelter is adequate, rats and mice tend to have a restricted range of movement and follow regular routes. Rats regard strange objects with suspicion and may take several days to enter traps or bait containers and feed freely. Mice investigate strange objects and food more quickly than rats, but they also lose interest more quickly.

Rodents spread disease and cause fouling and structural damage as well as loss of food.

Bird pests

Birds can be a serious nuisance in food stores and warehouses, where measures may have to be taken to exclude or control them.

Grain spilt by careless handling in and around stores attracts birds and regular spillage quickly leads to the establishment of a permanent population. In addition to whole grains, accumulation of grain dust around processing plants (especially when emitted from dust extraction plants on roofs) will attract birds. Heavy insect infestations on the surface of stacks may also be attractive. Sacks can be badly damaged by pecking. Nesting may result in bird droppings, feathers and bodies contaminating the foodstuffs, packaging and grain-handling facilities. Nests in guttering and down-piping may cause blockages leading to flooding and water damage to commodities.

From a disease point of view, birds are objectionable in food stores. They are hosts for lice and mites, which become occasional pests of humans when the birds nest in buildings. Bird droppings are liable to infection by food-poisoning bacteria (*Salmonella*) and the diseases histoplasmosis, eryptococcosis and aspergillosis are caused by fungal spores contained in bird droppings.

Domesticated poultry are often encouraged by storekeepers, but they should not be allowed in stores, where they may cause many of the problems discussed and they may peck holes in the lower layers of sacks to reach grain. This can cause spillage and, in extreme cases, collapse of the stack.

DETECTION OF RODENTS

A thorough inspection of the stored commodity and the storage buildings should be made to determine whether or not rodents are present. Rats or mice may not be seen, but traces or signs of infestation may be visible, from which the kind of rodent and their habitat may be determined. Some signs of infestation are listed below.

Holes may be apparent in wooden structures. Holes chewed by rats may be about 80 mm diameter and by mice only about 20 mm diameter.

Nests or nesting material may be found, consisting of a variety of shredded material, such as paper, sacking and cotton waste.

Runs and smears are left by rats and mice on routes that are used regularly to travel to and from burrows or nesting sites. Black greasy smears are left on hard surfaces by rodents where their fur comes into contact with walls and doors. When rodents move along the tops of walls or supporting beams in storage buildings, they may have to scramble beneath floor joists or other obstructions that are in their path. When they do this, characteristic loop-shaped smears often develop on the vertical surface below the obstruction. Runs left by mice are usually less obvious but small loop smears may be visible. It may be necessary to decide whether smears are recent or due to an old infestation.

Footprints and tail marks may be seen where rodents have run over dusty surfaces. The presence of rodents in stores may be detected routinely by placing bands of tracking powder around places such as stacks to confirm where animals are moving (see Chapter 5).

Droppings may indicate whether rodents are abundant and where they are moving or feeding. Fresh droppings are shiny, moist and soft, old droppings are dull, hard and dry. Droppings of the common rat are up to 20 mm long and often found in runs. Ship rat droppings are usually up to 15 mm long and curved, while mouse droppings are much smaller.

Damage to stored foodstuffs, spillage and broken sacks may be obvious. Damage to grains by rats can sometimes be distinguished from that due to mice by the size of the teeth marks and because rats often leave half grains mixed with smaller pieces. Mice tend to nibble around the edges of grain, leaving a bitten core and many smaller pieces. In large stacks of bagged grain, mice can remain within the stack for long periods and cause a great deal of damage before any signs become visible on the outside.

Rodent and bird infestation is prevented by proofing buildings (see Chapter 1, "Rodent and Bird Proofing") and by the use of chemical poisons and repellents (see Chapter 4, "Routine Insecticide Treatments in Stores").

4. PEST CONTROL METHODS

This Chapter describes pest control methods that rely mainly on the use of insecticides and fumigants, as these are the only methods generally applicable in all countries. Policies should be aimed at keeping the grain in good condition with the minimum use of pest control chemicals. This requires careful management and close attention to store maintenance (Chapter 1), grain standards (Chapter 2) and inspection and hygiene (Chapters 3 and 5). Alternative methods of insect control, such as hermetic storage, alteration of temperature, inert atmospheres or irradiation, are briefly described in Annex 1.

Non-chemical rodent control methods are described in this Chapter alongside the use of rodenticides in the section on "Routine Insecticide Treatments in Stores". Mould growth must be prevented by keeping grain dry and cool (see Chapter 3 "Moisture Content, Relative Humidity and Temperature in Relation to Infestation and Deterioration") and the use of fungicides has not been recommended, because the levels needed to maintain a fungistatic effect would be unacceptably high for human consumption.

CHOICE OF INSECTICIDES AND FUMIGANTS

The main types of pesticide treatment are shown in Table 7.

TABLE 7. Main types of pesticide treatment in storage.

Treatment	Application	Formulation	Chemicals used
Admixture	On grain moving into storage or on transfer	Insecticide spray or dust	Organophosphorus or pyrethroid insecticide
Fumigation	On bulk or bagged grain in silos or warehouses	Tablets or cylinders	Phosphine or methyl bromide. (Rarely liquid fumigants or inert gases.)
Space	Fogging or misting of warehouses or silos	Oils, cartridges, dispensers	Pyrethroid insecticides, dichlorvos or other organophosphorus insecticides.
Surface	On bags or walls of warehouses or containers	Insecticide spray or dust	Organophosphorus, pyrethroid or carbamate insecticides.
Baiting	Control of rodents	Prepared bait	Acute or anticoagulant rodenticides.

The chief difference between insecticides and fumigants is that the latter are used as gases and are, therefore, self-dispersing and non-persistent. Only two fumigants are widely used and these are fully described in the next section, "Fumigation". Limited use is made of the other fumigants briefly described in Annex 9. The insecticides of proved safety, permitted for use in storage, are comparatively few because of the risk of residues remaining on the grain and of the hazard to operators applying the insecticide in stores.

The control of insects in grain is mainly by fumigation but sometimes the application of insecticides is preferable (see section on "Fumigation of Bagged Grain under Gas-proof Sheets"). The insecticides permitted for use for direct admixture with grain are given in Table 8. The FAO/WHO Joint Committee on Pesticide Residues has proposed maximum residue limits for the insecticides in Table 8, which are consistent with the recommended uses of these insecticides for the post-harvest treatment of grain. These insecticides have fairly general, but not completely universal, acceptance. Until there is a general international agreement, through the FAO Codex Alimentarius Commission, compounds will require approval through country or regional regulation schemes. The insecticides in Table 8 may be used for surface and space treatments as well as for admixture treatments. Other insecticides used in storage for space or surface treatment only, not for direct application to grain, are given in the text and particularly in Annexes 6, 7 and 8, where some of the properties of the insecticides are listed.

TABLE 8. Insecticides with FAO/WHO maximum residue limits for post-harvest grain treatment.

Pesticide Class	Insecticide Common Name/ Trade Name	Acceptable Daily Intake (mg/kg body wt)	Maximum residue limits on raw cereals (ppm)	Suggested Dosage Rate (ppm)
Organophosphorus	Malathion	0.02	8	10 - 12
	Pirmiphos methyl/Actellic	0.01	10	8 - 10
	Chlorphyrifos methyl/Reldan	0.01	10	10
	Bromophos/Nexion	0.04	10	10 - 12
	Fenitrothion	0.005	10	8 - 10
	Dichlorvos/Nuvan/Vapona	0.004	2	5 - 10
Pyrethroid	Pyrethrum	0.04	3	2 - 4
	Bioresmethrin	NONE	5	4
	Phenothrin	0.2	5	8
Carbamate	Carbaryl/Sevin	0.01	5	8
Synergist	Piperonyl butoxide	0.03	20	nil

TREATMENT OF STORE FABRIC

Store preparation

Warehouses must be completely disinfested before intake of stocks.

The buildings should be thoroughly cleaned and brushed out and all loose material in cracks and crevices and behind girders, doors and railings should be removed.

The warehouse should be brought to a good state of repair. To reduce insect and rodent entry cracks and holes in the concrete, brickwork or plaster should be filled in with an appropriate cement mixture. Rodent plates on doors and bird netting on ventilators should be fitted or repaired, if necessary.

The walls and floor should be treated by spraying with an appropriate insecticide (figure 39).

Regular attention to cleanliness and to good repair (see Chapter 1, "Maintenance of Storage Structures") and a regular programme of spraying of surfaces with an appropriate insecticide should be continued after intake of stocks.

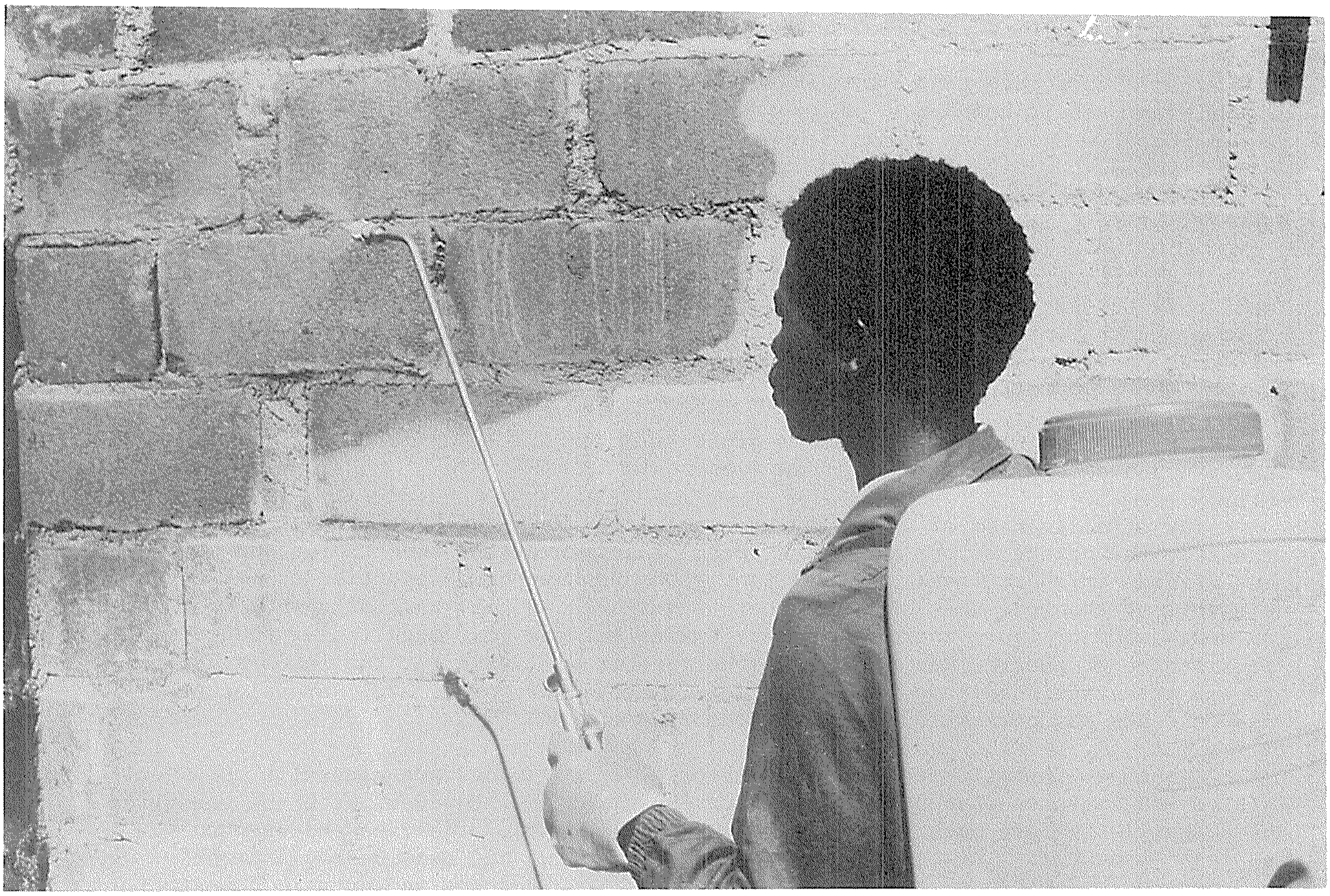


Figure 39. Spraying inside walls of a bag store in Swaizland.

Choice of insecticide

Insecticides commonly used in storage are shown in Table 8 and in Annexes 6, 7 and 8.

The insecticides most commonly used to spray storage structures are fenitrothion, pirimiphos methyl, bromophos, chlorpyrifos methyl, chlorpyrifos, iodofenphos, azamethiphos and carbaryl. Malathion and lindane were formerly the most widely used, but their effectiveness has been diminished by the development of resistance. Since any of these insecticides may be satisfactory if applied at the proper dosage rate, choice may be determined to a large extent by cost and availability.

The acute oral and dermal mammalian toxicity is important to the safety of the people who apply the spray. These toxicities are listed in Annex 7. With the exception of chlorpyrifos all the insecticides listed in the preceding paragraph as suitable for store spraying have acute toxicities beyond the 200 mg/kg body weight level, and most are beyond the 2 000 mg/kg body weight level.

A guide to application rates is given in Annex 8. Insecticides are described in Annex 6 and some properties shown in a table in Annex 7.

The effectiveness of a particular insecticide will depend on the surface to be treated, the nature of the pest, the speed of action of the insecticide and whether the insecticide is short lived or persistent. Organophosphorus insecticides may break down within less than one week on some concrete surfaces and may have very short persistence on rough wood or fibre board. However, the effect may last much longer than the actual persistence of the residue because of the time it will take for the infestation to become re-established. On smooth surfaces, such as plywood, metal, or paintwork, insecticides may persist for several months.

Carbamate insecticides and organochlorine insecticides are generally more persistent on surfaces than organophosphorus insecticides. However, with the exception of carbaryl they are much more toxic to mammals than the organophosphates used in storage (Annex 7). The carbamates dioxacarb, propoxur and bendiocarb, and the organochlorine chlordane are used mainly against cockroaches and ants in domestic premises and are not generally used in storage, but might be used to treat inaccessible parts of stores that are away from all stored foodstuffs.

Formulations

The choice of pesticide formulation depends largely on the nature of the surface to be sprayed. Two formulations are available for mixing with water; the emulsifiable concentrate (ec) and the water-dispersible powder (wdp), also called wettable powder (wp). For porous surfaces a suspension of wettable powder is better but on non-porous surfaces, such as metal or paintwork, an emulsion may be less effective but is generally more convenient to use and is less comspicuous once it has dried. Emulsions are preferred on cardboard boxes. For treating a store by fogging or misting, oil solutions are used. Parts of the store may also be treated by dusting.

Emulsifiable concentrates (ec)

The formulation consists of insecticide, emulsifiers, stabilizers and solvent oils. The concentration of insecticide varies from 20 to 80 percent of the concentrate. Dilution with water produces a stable emulsion in which very small oil droplets containing the insecticide are dispersed throughout the water. Some emulsifiable concentrates can also be diluted with oil (miscible concentrates). Emulsifiable concentrates may be used both for surface applications and for grain treatment.

Water dispersible (wettable) powders

The formulation consists of a mineral powder impregnated with a high concentration of the insecticide, 25 to 80 percent active ingredient, plus emulsifying agents and stabilizers. Dilution with water produces an even, uniform suspension, but the powder slowly settles out and needs to be reagitated continuously or, at least, intermittently. The use of wettable powders is generally recommended for spraying on absorbent surfaces, such as concrete and unpainted wood, brick or fibreboard, while the use of emulsifiable concentrates is recommended for smooth surfaces. In fact, wettable powders may be much more effective on most surfaces. This appears to be particularly true for the synthetic pyrethroid insecticides. However some disadvantages of wettable powders are that they are more difficult to apply evenly, harder on spraying machinery and give a more visible deposit than emulsifiable concentrates.

Oil solutions

These are solutions of insecticide in mineral oil, which may be either concentrates requiring dilution or dilute ready-to-spray formulations. Sprays based on heavy oils, such as technical white oil, need power sprayers, but sprays diluted with odourless kerosene, a light oil, may be applied with hand-operated equipment. Most foggers and mechanical aerosol generators use oil solutions. Care must be taken not to spoil surfaces, such as plastics, which may be attacked by oil, and not to use near naked flames.

Insecticide dusts

Insecticide dusts may be sprinkled around stacks or in corners or puffed into crevices or between bags. Dusts are more easily picked up by insects than sprays and have a long active life. They can be applied by sprinking or by a hand-operated or motorized knapsack duster. For application to bags, only approved insecticide dusts may be used. Dusts usually contain 1 to 5 percent of insecticide active ingredient and should be applied to give the same application rate of insecticide as recommended for spraying (Annex 8).

Application

Pesticide rate

The application rate chosen may depend on the particular pests present and the length of persistence required. The normal application rate of malathion is 1g/m^2 of active ingredient or 0.5 to 1.0g/m^2 of other organophosphates. For other insecticides, carbamates or pyrethroids, the application rate may be less. A table of recommended application rates is given in Annex 8. The label on the product should also be consulted.

Dilution

Emulsifiable concentrates and wettable powders are supplied as concentrates, which must be diluted or mixed with water before use to a suitable application volume. For water-based sprays the volume normally recommended is 5 l/100 m^2 but this should be increased to 10 l/100 m^2 for porous surfaces and reduced to 2.5 l/100 m^2 for very smooth surfaces. The volume applied will also depend on the type of sprayer being used. The aim is to attain complete coverage without excess run-off, and it may sometimes be useful to determine the optimum rate needed to achieve this by a preliminary practice spraying. The concentrations necessary for chosen insecticide and volume application rates are given in Table 9.

The strength of concentrates may vary from 20 percent up to 80 percent of insecticide active ingredient. The strength of the diluted spray will normally be required to be in the range 0.5 percent to 2 percent (Table 9). To determine the amount of concentrate needed for a given volume of dilute spray, the following formula is used:

Number of litres or kilograms of concentrate required =

$$\frac{\text{\% insecticide in diluted spray}}{\text{\% insecticide in concentrate}} \times \text{number of litres of diluted spray required}$$

Examples:

To make 10 litres of 2 percent spray from a 40 percent concentrate
Number of litres of concentrate required = $\frac{2}{40} \times 10 = 0.5$

To make 5 litres of 0.5 percent spray from a 25 percent wettable powder
Number of kilograms of concentrate required = $\frac{0.5}{25} \times 5 = 0.10$ (100 g)

TABLE 9. Concentration of diluted spray needed for a range of volume and application rates.

Volume of spray applied per 100 m²	Application rate required (g/m²)	Concentration of diluted spray required % w/v
2.5 litres	0.25	1
	0.5	2
	1.0	4
5 litres	0.25	0.5
	0.5	1
	1.0	2
10 litres	0.25	0.25
	0.5	0.5
	1.0	1

Although the active ingredient in emulsifiable concentrates is expressed as % w/v (percentage weight in volume) and in wettable powders the insecticide is given as % w/w (percentage weight in weight) the calculation is exactly the same (the wettable powder must be expressed as g or kg whereas the liquid is expressed as ml or l), because 1 kg of 50 percent w/w contains the same amount of insecticide as 1 l of 50 percent w/v. FAO recommends that emulsifiable concentrates are expressed as g/l rather than % w/v to avoid confusion. If, as occasionally happens, the formulation is a liquid expressed as w/w (percentage weight in weight) it is necessary to weigh the concentrate, unless the density is known when the weight can be calculated from the volume.

Spraying equipment

There are four general types of sprayer (figures 40, 41, 42 and 43) for spraying insecticides onto surfaces:

- The hand-operated pneumatic, pressure retaining, knapsack sprayer.
- The hand-operated hydraulic, continuously pumped, knapsack sprayer.
- The motorized knapsack sprayer.
- The spraying pump.

Spinning disc and electrostatic, ultra-low sprayers are not at present suitable for direct coverage of warehouse surfaces.

The choice of sprayer will depend on the size of store and the general situation. A spraying pump or motorized knapsack sprayer may be essential. The pump can soak the the structure and get into crevices and behind girders. The motorized knapsack sprayer can achieve a throw of 6 metres or more upwards but only as a fine mist. However, for routine retreatments in filled warehouses, the motorized knapsack sprayer may be preferable to the spraying pump, as it will cause less splash and run-off onto the commodity and it will also be suitable for bag spraying.

For small stores or for routine spraying, a hand-operated sprayer may be adequate. The pneumatic type does not need to be continuously pumped, after the initial pressurization, but these sprayers, if made of metal, tend to be heavy and may be moved

Figure 40. Pneumatic sprayer.

Figure 41. Hydraulic sprayer.

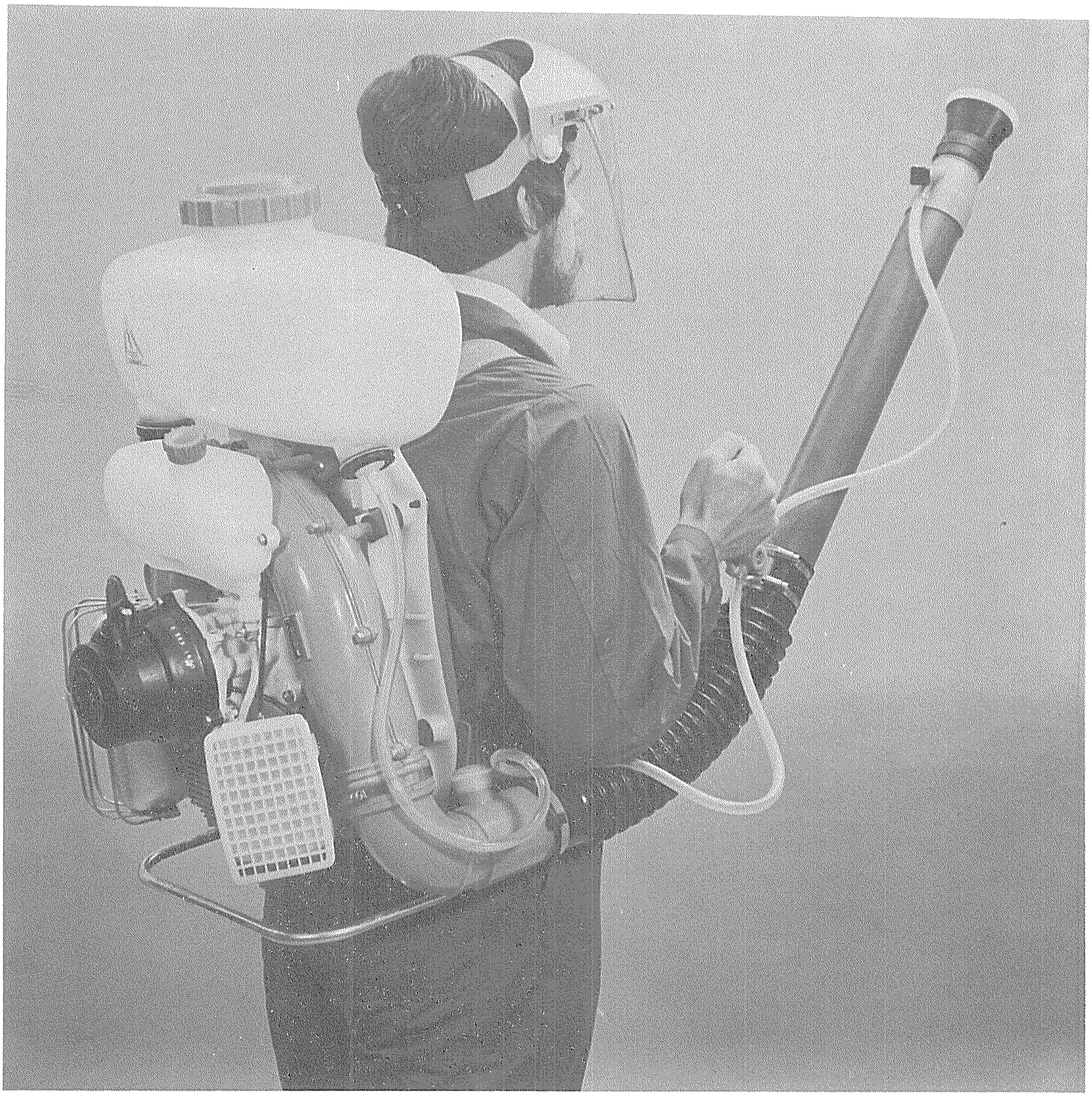


Figure 42. Motorized knapsack sprayer.

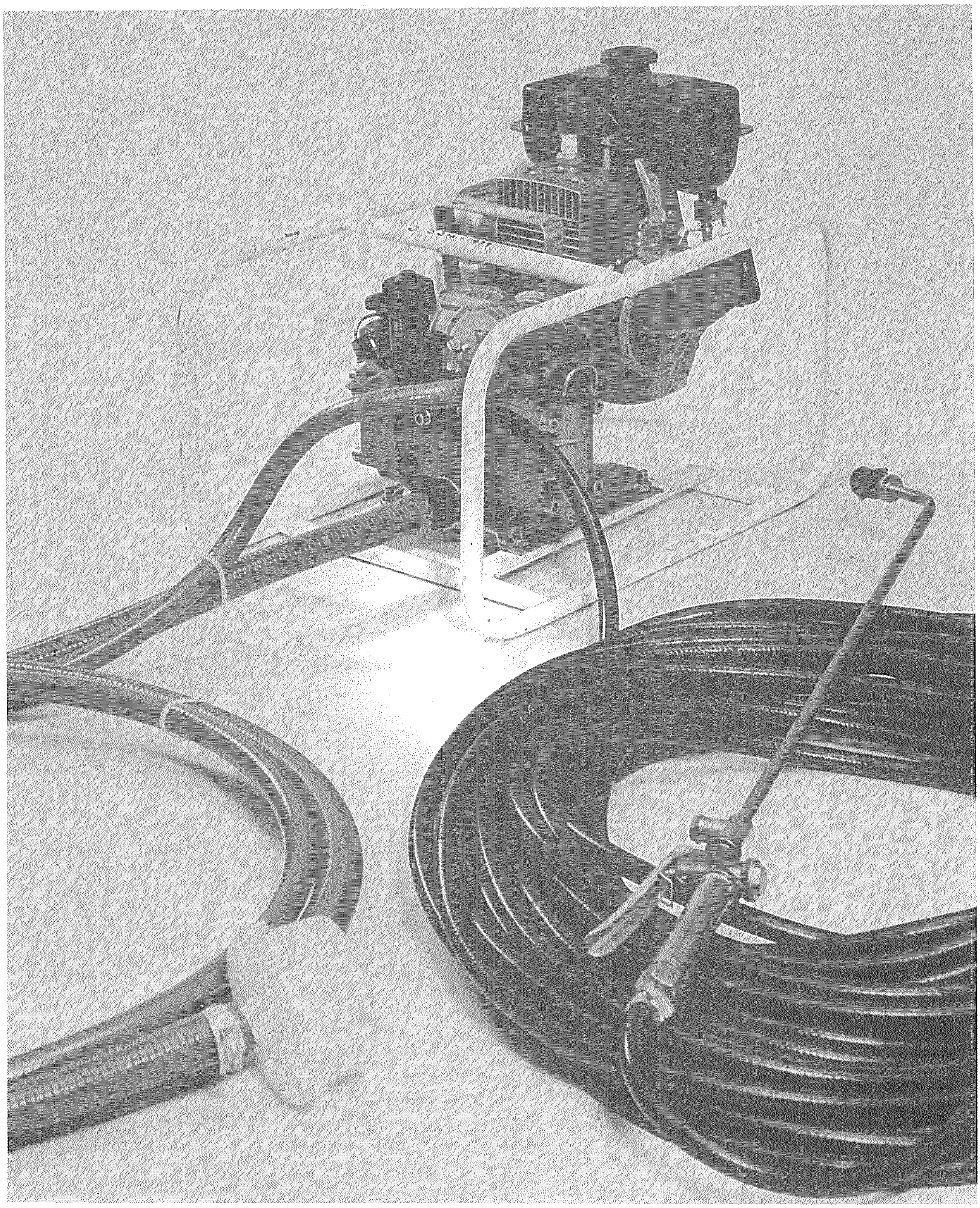


Figure 43, Spraying pump.

around the floor rather than carried on the back. The alternative hydraulic knapsack sprayers need to be carried on the back, as one hand is needed for pumping and the other for holding the spray lance. The hydraulic sprayers may have an advantage when spraying wettable powders because they are more easily kept agitated.

Pneumatic knapsack sprayers

These are generally of 5- to 15-litre capacity. After adding the spray liquid sprayer is pressurized, by a hand pump, enough to complete discharge of the contents. The sprayer should be fitted with a safety valve and a pressure regulating valve. The output of these sprayers varies from 1 l/min down to 300 ml/min when a size 000 fan jet (for emulsions) is fitted.

Hydraulic knapsack sprayers

These are generally up to 20-litre capacity, with outputs up to 2.5 l/min, but probably generally about 0.3 to 1 l/min, depending on the nozzle fitted. The diaphragm pumps are suitable for all suspensions and extension telescopic lances may extend up to 5 metres. The sprayers should be fitted with pressure regulating valves for even spraying.

Nozzles

Hand-operated knapsack sprayers should be fitted with fan spray jets, although a swirl nozzle of similar output can be used. The nozzle should have an output rate of 0.85 l/min at a pressure of 2.1 kg/cm^2 (30 psi). When spraying wettable powders, the filter behind the nozzle should be removed. When applying suspensions, the most suitable ceramic fan jet is size 0 and for emulsions size 000 should be used. This reduces the output at 2.1 kg/cm^2 (30 psi) to 280 ml/min.

Motorized knapsack sprayers

Motorized knapsack sprayers commonly have a 3 hp engine and a capacity of about 10 litres of spray liquid. The ouput may be up to 3 l/min, but this is reduced when the nozzle is raised. The vertical throw is 6 to 8 metres. The sprayers weigh about 12 kg and are worn on the back. The operator has to take care to avoid being burnt when lifting the hot sprayer off the back after use.

Portable spraying pumps

Portable spraying pumps usually have a 3 to 5 hp petrol engine, although they can also be obtained with electric motors, and for convenience and mobility they are usually mounted on a trolley. The output may be 10 to 30 l/min. There may be an integral tank or sunction lines may be run to a convenient tank, such as a 200 litre drum.

Spraying procedure

1) The areas to be sprayed should be cleaned and exposed or susceptible foodstuffs should be covered.

2) Notice should be given to warehouse staff.

3) The area to be sprayed should be calculated and the necessary insecticide, water, sprayers, mixing equipment, protective clothing, washing water and soap should be provided.

4) A chemically resistant, waterproof apron and gauntlet gloves should be worn when insecticide concentrates are handled and any splashes on the skin should be washed off immediately.

Dilution

5) In determining the strength of the dilute spray required, the volume application rate (see previous section) must be considered, and this will depend on the nature of the surface sprayed and on the type of sprayer used. Larger application

volumes will be needed for motorized knapsack sprayers than for the other types of sprayer.

6) Only clean cold water should be used for dilution. The quantity of concentrate should be made up to the required volume, not added to the required volume of water, although the difference is often unimportant in practice.

7) All mixing containers and spray tanks should be absolutely clean (old insecticide from a previous spraying may make the fresh dilution unstable).

8) Emulsifiable concentrate should be diluted on the day of use. The dilute emulsion should normally be stable for several hours, but probably not overnight.

9) Wettable powders should be thoroughly mixed in a small quantity of water to a creamy consistency, and this should then be added to the remainder of the water with vigorous stirring. If the powder is added directly to the main volume of water, it may be difficult to achieve an even dispersion, although some formulations can be mixed directly.

10) As a precaution against blockage, all formulations except wettable powders should be filtered into the sprayer tanks.

Spraying

11) Care should be taken to ensure that all screw threads or unions are tight and free from leakage and that liquid does not seep over the clothing of the operator. Suitable protective clothing should be worn.

12) Diluted wettable powders should be used immediately after preparation, and the sprayer must be shaken at intervals during the spraying to ensure even distribution of the powder throughout the spray fluid and to prevent settling out. The shaking of the sprayer may not be necessary if it is fitted with a constant agitation device.

13) When using hand sprayers, the nozzle should be held about 30 cm from the surface to be sprayed and it should be moved at about 60 cm per second to give the desired output. Successive bands of spray should overlap slightly. Additional lengths of hose and extension tubes may be fitted to hand sprayers so that the reach may be extended. Heavier than normal dosages of spray should be applied to cracks, crevices, holes and other places likely to harbour insects.

14) Care should be taken to avoid hazards such as electrical equipment, dimly lit areas and steep and slippery places. In particular, water-based sprays should not be applied directly to electrical equipment as "shorting" may result. The solvents in some emulsions can damage rubber or plastic or stain boxes or packages.

15) When spraying with a motorized knapsack sprayer, care should be taken not to run the engine faster than is necessary for distributing the spray on surfaces. The engine speed should be varied with the angle of the spray. High engine speed produces excessive airflow, causing spray to bounce off surfaces and possibly contaminate the operation when the spray is directly horizontally against a wall.

16) Great care should be taken when climbing on stacks or up ladders to treat high places, because the weight of a sprayer on the back can upset balance.

17) Motorized knapsack sprayers must be correctly maintained. Particular attention should be paid to ensure that the air filter and sparking plug are regularly cleaned and that only clean petrol and oil mixed in the correct proportions are used for the engine. On completion of spraying, the petrol supply should be switched off and the engine allowed to run until the carburettor is empty. If this is not done the carburettor may become clogged with oil. Spare plugs and nozzles and plug spanner and tools should be kept conveniently to hand.

18) Immediately after spraying is completed, a check should be made to ensure that all areas have been treated and that the correct amount of spray has been applied. Any surplus remaining in the sprayer should be finished on the walls. It is essential not to leave any spray, particularly wettable powder, which may clog the sprayer. The empty sprayer should be washed thoroughly with clean water. Nozzles should be dismantled and cleaned and if necessary blown through by a car

or bicycle pump, but not by mouth. Nozzles should not be poked with wire or pins. Spray tanks, hoses and lances should be drained and dried. A check should be kept for rust, which could cause blockage. All seals, washers and springs should be periodically checked.

19) Empty insecticide containers must be disposed of safely. Partly used containers should be securely closed and all insecticide concentrates kept locked away from foodstuffs.

20) A return visit should be made to confirm that the treatment was effective.

FUMIGATION

Fumigation requires the maintenance of an adequate concentration of the fumigant vapour within the fumigation area for a sufficient period that all the insect pests (at whatever development stage) receive a lethal dose. A suitable dosage must be applied so as to ensure even distribution of gas throughout the fumigation area and to prevent damage and tainting. Precautions must be taken to prevent leakage of gas. Fumigation confers no lasting or residual protection and often needs to be supported by other techniques, such as the spraying of residual insecticides. Fumigation should not be isolated from other supporting measures, e.g. store hygiene and stock mangement, and sources of re-infestation, particularly old stocks or insect harbourages in warehouses, should be dealt with before fumigation is carried out. Phosphine and methyl bromide are the fumigants principally used for the fumigation of cereals and bagged produce under gas-proof sheets and for the fumigation of bulk grain in silos.

Fumigant distribution

Fumigants are pesticides that exert their effect in the gaseous or vapour phase. They penetrate throughout a storage structure, into a commodity and between and within individual cereal grains. Fumigation may sometimes be carried out without disturbing the commodity to be treated, but the distance that a fumigant can move unaided in a bulk of grain is sometimes quite limited and it is often necessary to aid the distribution of the gas. Many fumigant distribution points may be necessary in large bag stacks, while in large bulks of grain there may be a need to recirculate the gas or, with solid fumigants, to turn the grain during application of the fumigant.

Exposure period

The time normally required for fumigation is in the range of one to five days, depending on the fumigant and the temperature. The higher the temperature, the shorter the fumigation period can be.

Gas-tight enclosure

A gas-tight enclosure is required to contain the fumigant in the grain. This can be provided by plastic sheeting or a fumigation chamber, or by concrete or metal bins if they are sufficiently gas tight to contain the gas during the fumigation period. Some loss of gas is inevitable, but this must be reduced to a minimum by searching for leaks and sealing them with tape or plastic sheeting or by permanently repairing and filling in the structure.

Toxicity to insects

The susceptibility of insects to fumigants varies considerably, not only between insect species, but also between different development stages of the same species. Generally speaking, active stages are more susceptible than resting stages. This is because the active stage is living at a higher metabolic rate and respiring more. Adults generally are easily killed (susceptible) whereas pupae are difficult to kill (tolerant). During the time required for fumigation the insects may develop from a tolerant to a susceptible stage.

The fumigation period can be shorter at high temperatures partly because the insect development time is shorter.

Sorption

Fumigants may be strongly sorbed by some commodities, particularly oily ones. Chemisorption, the reaction of gas with the commodity, increases with increasing temperature and is irreversible. The physical sorption of gas to a surface decreases with temperature and is reversible. The purpose of airing periods after fumigation is to allow as much gas as possible to leave the commodity and disperse into the atmosphere. Sorption is generally proportional to boiling point, the higher boiling point fumigants being most strongly sorbed. Sorption removes gas from the space around the commodity, lowering the concentration to a level that may be too low to kill the pests. Therefore, additional fumigant must be used on highly sorptive commodities and dosage schedules for fumigants that are sorbed must vary with the commodity. Sorption also limits the penetration of gases, and this has to be considered when large bulks of grain require fumigation. The reaction products of recommended fumigants with commodities are generally considered to be harmless but taint, changes in texture and loss of viability may occur. This could limit the number of repeat fumigations permissible.

Toxicity to mammals

Fumigants are for the most part extremely poisonous to human beings and frequent exposure even to small concentrations may be harmful. Work with fumigants should not be undertaken unless sufficient training has been received and adequate safety precautions should always be taken.

Phosphine

Phosphine (PH_3, hydrogen phosphide) is a colourless gas with an unpleasant fish or carbide-like odour; molecular weight, 34.0; 1 mg/l = 719 ppm at 25ºC; boiling point, -87ºC; specific gravity of vapour, 1.2 (air = 1.0); almost insoluble in water; highly inflammable and forming explosive mixture with air at concentrations higher than 1.8 percent by volume; attacks metals, such as copper, copper alloys, silver and gold. (Equipment made of copper, particularly electrical apparatus, must be removed or protected from exposure to phosphine by a film of wax).

The fumigant is not supplied as a gas but as tablets, pellets or powders containing aluminium phosphide (55 percent)ammonium carbamate and waxes. Water vapour in the atmosphere reacts with the aluminium phosphide in exposed tablets to produce phosphine. The ammonium carbamate decomposes into the gases carbon dioxide and ammonia, which reduce the possibility of spontaneous ignition of the phosphine. The waxes bind the tablet together and slow the rate of decomposition and evolution of the gas. Some formulations contain magnesium phosphide in place of aluminium phosphide. This is said to decompose more quickly and completely. "Plates" containing this formulation are impregnated in a polyvinyl acetate matrix, which regulates the release of phosphine.

Formulations

In a standard formulation the weight of phosphine produced is approximately one-third of the weight of the solid formulation.

3/g tablets give 1/g phosphine

0.6/g pellets give 0.2/g phosphine

33/g bags give 11/g phosphine

1 magnesium phosphide plate gives 33/g phosphine

Aluminium phosphide tablets are packed in tubes contained in sealed tins. A case of large tins may contain 15 tins x 16 tubes per tin x 30 tablets per tube, totalling 7 200 tablets or 21. 6 kg of formulation. Pellets are packed in resealable flasks containing from 166 up to 2 000 pellets. Bags may be square or rectangular and are packed either 10 or 20 to a tin. The advantage of bags is that recovery of the spent powder is possible (reducing contamination of the cereal). To aid recovery, the bags may be strung together. A set of 100 bags clipped into a plastic sheet is called a "blanket". It permits large quantities to be easily applied and recovered. "Plates" may also be obtained in strips, two of which are equivalent to a "blanket". In situations where recovery of bags would be impossible, tablets should be used.

Dosages

From 1 to 15 g per ton and for three to seven days (Tables 12 and 13).

Toxicity to mammals

Phosphine is extremely toxic. The threshold limit value (TLV)(i.e. the maximum concentration to which a worker may be continuously exposed during working hours) is 0.3 ppm, but 1 ppm has been proposed for short-term exposures. Complete recovery from sub-lethal doses is possible, but 2 000 ppm is rapidly fatal.

Sorption

Phosphine is not strongly sorbed by foodstuffs and residues are usually undetectable.

Detection

Phosphine may be measured by the use of detector tubes or by chemical analysis (see "Measurement of Fumigant Concentrations").

Stability

Preparations of aluminium phosphide are stable in sealed tins but decompose on exposure to water vapour in the air. *Direct contact with water must be avoided as violent decomposition will take place.* Once a hermetically sealed can is opened the preparation must be used within a short period. *Only unopened tins are safe for long-term storage.* Tubes are not effectively sealed and must be kept in sealed tins or dessicators, otherwise the contents may ignite or explode when exposed to air. It is preferable not to keep partly empty tins. It is better to use whole tins in a fumigation rather than have a few tablets remaining, even if this results in a slight change from the recommended dosage.

The preparation can usually be placed safely, without the operator needing a gas mask, provided there are sufficient personnel to complete the application within one to two hours. (This depends on the nature of the enclosure, the temperature and the relative humidity,) The concentration will reach 50 percent of maximum after 20 hours or longer and the maximum concentration may be reached in 45 to 85 hours.

If phosphine fumigations are terminated too early, some of the gas may be wasted and the metal phosphine may still be emitting dangerous quantities of gas.

After an adequate exposure, usually not less than four days, the residue will consist mainly of inert aluminium hydroxide powder but a small amount of undecomposed aluminium phosphide (of the order of 5 percent) may also be present. This phosphine will continue to decompose at a very slow rate until it is wetted, when complete decomposition will take place (see "Fumigation Procedures").

Methyl bromide

Methyl bromide (CH_3Br), also known as bromomethane and under the trade names Embafume, Dowfume and Bromogas, is a colourless gas at normal temperatures; molecular weight, 95; 1 mg/l = 257 ppm (0.026 percent); specific gravity, 3.27 (air = 1). The fumigant is stored and supplied only as a liquid, specific gravity = 1.73 at 0°C, boiling point = 3.6°C.

The liquid attacks rubber, plastics and many other organic materials. It does not corrode steel, copper or brass but as it attacks aluminium, fittings should not be made of this metal. The dilute vapour at fumigation concentrations is not corrosive but may react with organic materials, particularly articles with a high sulphur content, producing a strong odour in, for example, furs and skins.

Methyl bromide has a wide spectrum of action and will destroy insects, mites, nematodes, fungi, bacteria and plants.

Formulation

Methyl bromide is supplied as a liquefied gas under pressure in refillable cylinders. The cylinders vary in size from 18 kg to 100 kg net weight. For small-scale fumigation, 500 g or 1 kg disposable cans are also available. The liquid is usually formulated with 2 percent of chloropicrin as a warning agent.

Dosage

Dosages vary from 15 to over 60 m/l for 24 to 48 hours, according to the commodity and temperature. Recommended dosage schedules are given in "Fumigant Application Rates" (Tables 15 and 16).

Toxicity to mammals

Methyl bromide is very toxic to mammals, both in acute and chronic doses. The threshold limit value (TLV) for continuous working exposure is 15 ppm. Exposure to 100 ppm constitutes a serious health risk and 1 000 ppm for 30 minutes is dangerous to life. Symptoms of poisoning may be delayed for up to 48 hours and there is no antidote. The gas is odourless at normally used concentrations and a warning agent, chloropicrin, is usually added to the formulation, but this is effective only in the initial stages of a fumigation.

Detection

Methyl bromide is easily detected by halide lamp, detector tubes or by a thermal conductivity meter ("Measurement of Fumigant Concentrations").

Sorption

Methyl bromide is strongly sorbed, particularly by materials having a high oil content. This has been taken into account in setting the dosage schedules. However, the gas disperses rapidly after treatment and there may be no detectable residue of methyl bromide within about six hours.

Reaction with the commodity limits the number of repeat fumigations possible with methyl bromide. The reaction products are generally considered harmless although, in addition to taint and bromide residues, there may be change of texture and loss of viability. Bromide residues must not exceed the FAO maximum residue limits (Annex 7). (Phosphine is only slightly sorbed and may, therefore, be used for repeated fumigations.)

Phytotoxicity

Methyl bromide may cause loss of germination, particularly if the seeds are at a high temperature and moisture content. Cool dry seeds are more tolerant.

Use

Methyl bromide is piped as a liquid from cylinders to jets positioned at the points of application, where it evaporates. The vapour is much heavier than air and this density is increased by the cooling produced by the evaporation. The fumigant is applied to the top of a stack or column so that the heavy vapour penetrates downwards into the grain. Grain cannot be fumigated in a silo unless there is a means of circulating the vapour. It is always an advantage to have a means of mixing the gas initially (e.g. a fan in a fumigation chamber) but once an even distribution of methyl bromide in air has been obtained, the fumigant cannot settle out afterwards. The principal use is for fumigation of stacks under gas-proof sheets or in fumigation chambers.

Choice of fumigant

A comparison of the characteristics of phosphine and methyl bromide are given in Table 10. Phosphine will be the normal choice for reserve stocks if time and fumigation sheets are available, particularly for repeat fumigations.

Fumigant application rates

CT production definition

In specifying the dose needed to eliminate an insect infestation by fumigation, it is necessary to record not only the concentration of gas, but also the time during which the gas is acting. This is given as the CT product (concentration x time) and is expressed as mgh/l (mg per litre concentration multiplied by duration of fumigation in hours). For methyl bromide over a wide range of concentrations the CT product needed for a given kill of insects is independent of the time. Short fumigations at high concentration are equivalent to longer fumigations at lower concentrations, having the same concentration x time product (CT). Phosphine fumigations are influenced by other factors and, therefore, the concentration and the time should be stated separately.

Measurement of CT product

If the concentration of gas in a fumigated enclosure is measured at various intervals and the concentration readings are plotted on a graph against the time from the start of fumigation the area under the curve will be the CT product, the total product of concentration x time. The accuracy will depend on the number or readings taken. If only a few readings are taken it may be necessary to estimate the CT product from an estimated average concentration.

To determine the success of a fumigation, it is usually necessary to determine the CT product at several sampling points to show the distribution of the gas.

The amount of gas supplied multiplied by the duration of the fumigation gives the theoretical CT product. The theoretical CT product needs to be divided by a factor of 2 to 4 to obtain an estimate of the CT product that can be achieved in practice.

Toxicity of phosphine to insects

The temperature and exposure period may be extremely critical with phosphine, and the importance of these factors far outweigh small adjustments that might be needed due to differences in the sorption of phosphine by commodities. The effect of temperature is far more marked with phosphine than with other fumigants and at low temperatures it may not be possible to achieve control. Development stages differ greatly in susceptibility, with eggs, pupae and dispausing larvae being generally most tolerant. Longer exposures are much more effective than shorter exposures of equivalent CT product, partly due to the development of insects from tolerant to susceptible stages during the exposure time. Higher temperatures shorten development times and shorter exposures are necessary. Table 11 gives a guide to the concentration of phosphine (mg/l) that must be maintained throughout the given exposure period to achieve 100 percent mortality of all stages at the stated temperature. *Actual dosages must be much higher than this* to compensate for leakage, sorption and the slow build-up of phosphine. There are minimum effective exposure periods, which cannot be reduced by increasing the dosage, as well as lower limits of effective concentration, probably in the region of 0.02 to 0.03 mg/l (15 to 20 ppm).

There is great variation in the toxicity of phophine to insects. *Sitophilus* species are much less susceptible than most other insect species and the pupae of *Sitophilus spp.* are most tolerant stage. On the other hand, with common species of warehouse moths, eggs are by far the most tolerant stage and require a minimum period of four days for fumigation at 25°C. Resistance to phosphine has been noted in the adult and egg stages of *Rhyzopertha dominica*, but the resistant strain should be controlled at recommended dosage levels.

TABLE 10. Comparison of the characteristics of phosphine and methyl bromide

PHOSPHINE	METHYL BROMIDE
Easy to transport	Refillable cylinders are expensive to to transport
Easy to apply	Difficult to apply, requiring special equipment and skill
Good penetration	-
No taint, residues or loss of viability	Sorption occurs and may cause taint, bromide residues and loss of viability
Very toxic to insects but slow acting, particularly at low temperatures and humidities *	*Rapidly toxic and widely effective even at lower temperatures*
Flammable; spontaneous explosive ignition can occur in some circumstances	*Non-flammable*
High acute mammalian toxicity but low chronic toxicity	Dangerous acute and chronic poison with delayed symptoms
Fairly easy to detect	*Very easy to detect*
Rapidly lost by leakage unless fumigation space is well sealed and gas tight	Needs very good sealing

* Not recommended for use at temperatures below 12°C.

TABLE 11. Average concentrations of phosphine (mg/1) required to give 100 percent mortality of all developmental stages of insects underexperimental conditions

Temperature	15°C		25°C			30°C	
Duration of Exposure (days)	4	8	2	4	7	2	4
Sitophilus spp.		>1.50	>3.0	1.65	0.32	>0.36	0.05
Rhyzopertha dominica			1.6	0.18	0.02		
Lasioderma serricorne	0.36	0.04	1.6	0.32	0.15	>0.36	0.17
Trogoderma granarium	>1.30	0.77	0.8	0.32	0.08	>0.36	0.17
Acanthoscelides obtectus			3.0	0.32	0.15	0.36	0.09
Caryedon serratus				0.32	0.20	0.36	0.05
Ephestia elutella		> 1.50	3.0	0.09	0.05	0.15	0.05
Ephestia cautella	>1.30	0.77	1.6	0.03	0.02	0.05	
Ephestia kuhniella	>1.30	0.77	1.6	0.03	0.02	0.05	
Plodia interpunctella	1.30	0.18	1.6	0.03	0.02	0.05	
Tribolium castaneum	0.03		0.16	0.08	0.04	0.02	
Oryzaephilus surinamensis	0.03		0.04			0.05	
Cryptolestes pusillus			0.16	0.08	0.01		
Cryptolestes ferrugineus				>0.08	0.04	0.36	0.05
Ptinus ocellus (= P. tectus)	1.30	0.18	0.40	0.08	0.04		

Source: Ministry of Agriculture, Fisheries and Food, Agricultural Science Service, Slough Laboratory, Slough, U.K.

Phosphine dosage rates

Table 12 gives recommended dosages scaled up from the toxicity data in Table 11.

TABLE 12. Theoretical phosphine dosages, based on Table 11 and a x 4 safety factor to allow for leakage and slow gas emission

Temperature of the fumigated commodity	Duration of fumigation (days)	Dosage
30°C	4	1 g (1 tablet)/m³ all species*
25°C	7	1 g/m³ except for *Sitophilus* spp.
	7	2 g/m³ *Sitophilus* spp.
	4	1.5 g/m³ except *Sitophilus* spp.
	4	5-10 g/m³ *Sitophilus* spp.

* 1g/m³ = 1 mg/l

In the absence of *Sitophilus* spp., *Trogoderma* spp. and *Ephestia* spp., exposures of three days at 25°C and 2g/m³ may also be effective.

For practical purposes, it is usual when fumigating grain not to consider the species to be controlled but to assume that a tolerant species will be present. The recommendations will then depend on the likely duration of exposure, which in turn will depend on the type of structure being fumigated. The recommended rates are given in Table 13 for temperatures of about 25°C.

TABLE 13. Practical dosage rates for phosphine according to type of fumigation

Type of fumigation	Recommended dosage
Long exposure in gas-tight silos	2-4 g/tonne
Grain in bulk under gas-proof sheets	3-6 g/tonne
Bagged grain under gas-proof sheets	5 g/tonne/4 days
	2 g/tonne/7 days
Individual within-bag fumigation	0.2 g (1 pellet)/50 kg
Space fumigation	1 g/m³

The minimum exposure periods for phosphine fumigation must be four to five days at 25°C or a higher temperature. It should be noted, however, that for the control of *Sitophilus* spp., *Trogoderma* spp., and mite species, and at lower temperatures, exposures longer than this minimum will be necessary.

The toxicity of methyl bromide to insects

Compared with phosphine, there is much less variation in the toxicity of methyl bromide with changes in temperature, species or development stage. In addition the CT relationship holds satisfactorily over the range of 3 to 15 mg/l. Below 2 to 3 mg/l the efficiency of fumigation drops so that this may be taken to be the lowest practically effective dose although below 1 mg/l some effect may still be noticeable. Eggs, larval and pupal stages are all susceptible to methyl bromide. However dispausing larvae of moths and of *Trogoderma granarium* and hypopal stages and eggs of mites are much more tolerant and require higher dosages. The following table shows the CT products required for complete control of beetles and moths at various temperatures. A CT product of 180 mgh/l at 20°C is sufficient to control most pests (Table 14). Actual dosages must be much higher to take into account losses and sorption effects.

TABLE 14. Minimum CT products (mgh/l) required for complete control of different groups of storage insects with methyl bromide

Temperature	15–20°C	20–25°C	25–30°C
Beetles	180	150	125
Moths	70	60	55
Trogoderma granarium (in diapause)	200		
Moth larvae in diapause	300	200	180

Methyl bromide dosage rates

Methyl bromide dosage rates are based on the commodity and the temperature and do not take account of the insect species to be controlled, except that higher doses are used against *Trogoderma granarium* and mites. The sorption of methyl bromide is an important factor in deciding the dosage rate. Generally, sorption is higher in oily commodities, such as oilseeds, than in non-oily commodities, such as rice, and this is reflected in the different dosage rates shown in Tables 15 and 16. Table 15 is for use with totally filled volumes, e.g. containers or under gas-proof sheets, while Table 16 is for use where the volume is partly filled, e.g. silos.

Fumigation Safety Equipment

Respirators

Respirator fitted with long tube and back harness.
Respirator canisters: Type P – methyl bromide
Type CC – phosphine
Type C – liquid fumigants

Sealed respirator canisters have a shelf life of up to two years (Type P) and five years (Types C and CC). Open canisters not exposed to fumigant may be kept for one year but must be replaced after exposure (see section on "Routine Insecticide Treatments in Stores").

Gas Detectors

(see "Measurement of Fumigant Concentrations")
Halide leak detector lamp
Spare gas canisters for halide lamp
Separate boxes of detector tubes for methyl bromide, phosphine and other fumigants
Pump for gas-detector tubes
Thermal conductivity meter (methyl bromide) or infra-red absorption meter (phosphine) if accurate measurement essential.

TABLE 15. Dosage schedules for fumigation with methyl bromide where the enclosed volume is filled, e.g. stacks under gas-tight sheets

	Stowage factor (m^3/tonne)	Dosage rate - g/tonne		Dosage rate - g/m^3		Exposure period (hours)
		Temperature (10–20°C)	Temperature (Above 20°C)	Temperature (10–20°C)	Temperature (Above 20°C)	
Rice (milled), peas and dried vine fruits	1.4	36	23	25	16	24
Barley	1.7	40	26	23	16	
Beans	1.8	42	27	23	15	
Paddy rice	1.9	44	28	23	15	
Cocoa beans	2.5	53	34	21	14	
Wheat, lentils	1.4	51	34	36	24	
Maize	1.6	54	36	34	23	
Sorghum, millet and figs	1.4	81	54	58	39	
Dates	1.1	74	55	70	50	
Cased, shelled nuts	2.0	90	60	45	30	
Empty sacks	1.4	81	54	58	39	
Flour	1.5	82	55	55	36	
Oilseeds	1.7	85	57	50	34	
Pollards	1.8	87	58	48	32	48
Groundnut kernels	1.9	88	59	46	31	
Groundnuts in shell	3.1	106	71	34	23	
Oilseed cakes	1.6	144	96	90	60	
Oilseed meals	1.7	145	97	85	57	

NOTES: The dosage rate per tonne can be read directly from the table according to the commodity. Recommended dosages are also given as g/m^3 for situations where the volume, but not the weight, of the commodity is known. The volume dosages have been obtained by dividing the dosage per tonne by the stowage factor. As the stowage factor is only approximate, it is better to use weight dosage; but in some cases, only the volume of a stack can be estimated of measured. The figures are *alternatives* and should *not* be added together. Temperatures refer to that of the commodity. Where *Trogoderma spp*. are present, dosage rates should be increased by 50 percent. Where mites are present dosage rates should be increased by 50 percent. If the exposure period is reduced from 48 to 24 hours the dosage rate should be increased by 50 percent. If the exposure period is increased from 24 to 48 hours the dosage rate can be reduced by 30 percent. Where stacks of less than 30 m^3 (approximately 20 tonnes) are treated under sheets, dosages should be calculated as if the volume were 30 m^3 (20 tonnes).

TABLE 16. Dosage schedules for fumigation with methyl bromide of commodities in chambers, ships, or gas tight warehouses with variable loads

Commodity	Space dosage rates (SD) in g/m^3 and commodity dosage rates (CD) in g/tonne				Exposure period (hours)
	Temperature ($10-20^oC$)		Temperature (above 20^oC)		
	SD	CD	SD	CD	
Rice (milled or paddy), peas, beans, barley, dried vine fruits, cocoa beans	15	15	10	9	24
Wheat, maize, lentils	15	30	10	20	24
Sorghum, millet, nuts, dates, figs	15	60	10	40	24
Flour, pollards, groundnuts (kernels and in shell), oilseeds, empty sacks	15	60	10	40	48
Oilseed cakes and meals	15	120	10	80	48

NOTES: This table is employed where the ratio of load to volume is variable, e.g. in chambers, ships, barges or gas-tight warehouses. To calculate the dose required the total volume to be treated is multiplied by the space dosage (SD) found in the table (either 10 or 15 g/m^3). To this is added the commodity dose (CD) given in the table for the particular type of commodity multiplied by the weight being fumigated.

Amount of methyl bromide (g) needed = Volume (m^3) x SD + Quantity (tonnes) x CD.

Temperatures refer to that of the commodity. Where *Trogoderma* spp. are present, dosage rates should be increased by 50 percent.

Where mites are present, dosage rates should be increased by 50 percent.

If the exposure period is reduced from 48 to 24 hours, the dosage rate should be increased by 50 percent.

If the exposure period is increased from 24 to 48 hours, the dosage rate can be reduced by 30 percent.

Where stacks of less than 30 m^3 (approximately 20 tonnes) are treated under sheets, dosages should be calculated as if the volume were 30 m^3 (20 tonnes).

Other safety equipment

Warning notices
Overalls and gloves
First aid kit
Resuscitation kit and oxygen cylinder

General equipment for fumigation under gas-proof sheets

For gas-proof sheets

- Repair kits
- Masking and sealing tape
- Mastic or joining compound
- Paste and paper
- Spring clamps for rolled joints
- Readymix mortar or concrete
- Sandsnakes - discarded fire hose
  - layflat polythene tubing (250 micron), 12 cm (5 inch) diameter
- Measuring tape
- Nylon rope
- Tools - assorted spanners - lockable tool box
- Cleaning equipment - broom/bucket/shovel
- Trolley
- Fumigation register/card index
- Sampling kit - spears
  - sample bags
  - sample sieves
  - probe thermometers

Methyl bromide application

- Methyl bromide application equipment supplied complete or as separate items - nylon tubing 10 mm o.d., 6.7 mm i.d., crosses, tees, end connectors, ferrules and washers
- Cylinder fittings - on/off valve, pressure gauge, Schrader valve, filter couplings
- Gas jets, e.g. Bray 235/00
- Heavy duty foot-pump
- Scale and tripod or platform scales to 120 kg capacity
- Nylon capillary gas sampling line (2 mm i.d.)
- Methyl bromide vapourizer with manifold and hose

Description of fumigation sheets

Fumigation sheets must be gas proof, i.e. impermeable to fumigant gases. Ordinary water-proofed tarpaulins of the canvas type are unsuitable, but a variety of plastic materials are sufficiently impermeable and the choice would depend on handling properties, strength, durability, price and availability. A list of some of the possible alternatives for fumigation sheets are given below.

Neoprene coated nylon. Light (340 g/m^2), resistant to heat and ultra-violet radiation, easily handled, flexible, very expensive, difficult to obtain, fairly easily torn.

PVC or terylene-coated nylon cloth. Strong and durable, impermeable. Moderately expensive, often very heavy (500 to 600 g/m^2), difficult to handle. Might be suitable if weighing less than 450 g/m^2.

PVC laminated on a nylon mesh. Flexible, easily handled, medium weight (420 g/m^2), medium cost, good tear strength. Damaged by liquid methyl bromide, but otherwise good.

Woven high density polythene or polypropylene coated with polythene. Very light (200 g/m^2), very inexpensive, excellent tear resistance, unaffected by methyl bromide, does not fold well, shows tendency to pinhole and to deteriorate in the tropics.

Unsupported PVC (250 micron). Fairly light and inexpensive, low tear resistance, tends to harden and crack in tropical use, attacked by liquid method bromide.

Polythene film (125 micron). Very inexpensive, poor handling characteristics and extremely poor tear resistance. Can only be used a few times before being discarded.

None of the sheet materials are ideal. PVC fabrics tend to crack after long exposure to UV light and are damaged if liquid methyl bromide is spilt on them. Polythene sheets fold badly and tear easily. Coated nylon fabrics are heavy if tear resistant. Neoprene coated nylon is very expensive and tears faily easily. Ideally, the weight should not be greater than 450 g/m^2 (13.5 oz/yd^2) and preferably less than 400 g/m^2 (12 oz/yd^2). The tear strength should be not less than 15 kg; and the permeability (K) should allow a rate of loss not greater than 3 $mg/h/m^2$ of surface per mg/l concentration of methyl bromide at 20°C. A standard fumigation sheet measuring 18m x 12m (216 m^2) with a density of 500 g/m^2 weighs 108 kg.

Fumigation sheets chosen for mainly outdoor use should be heavier and more tear resistant than sheets intended mainly for internal use, should not be made of unsupported PVC or polythene, and should not be translucent but should be black, or better still, a light colour incorporating UV inhibitors. Black sheets are resistant to UV damage but get very hot and suffer heat damage if made of PVC. White sheets remain cooler but may be subject to damage by UV. A light colour with added UV inhibitors may be preferred.

Measurement of Fumigant Concentrations

Methyl Bromide

The halide lamp leak detector (figure 44a) is an essential piece of equipment for methyl bromide fumigation to indicate leaks and show whether gas masks need to be worn.

The lamp has a burner attached to a cartridge of butane or propane gas and the flame makes a contact with a replaceable copper ring. Traces of organic halide vapour entering the flame react with the copper to produce a distinctly coloured green to blue flame. The approximate colour reaction of methyl bromide, shown below, may be used to judge the amount of methyl bromide in the atmosphere.

Methyl bromide (ppm)	Colour of flame
0	No reaction
10	Very faint green at edges
30	Light green flames
60	Moderate green flame
100	Green flame
200	Intense green, blue at edges
500	Blue-green flame
1 000	Intense blue flame

Only a rough guide to the concentration can be obtained but the lamp will give a positive indication at the TLV (i.e. the maximum concentration to which a worker may be continuously exposed during working hours) of 15 ppm. At the other end of the scale an intense blue flame would indicate a substantial and very dangerous leak.

When the lamp is lit, air is drawn to the flame through a flexible metal tube. The open end of this tube is placed at the suspected leak or point being checked. If methyl bromide vapour is present it will be drawn up the tube and will colour the flame. The lamp gives a continuous indication and this is a major advantage when searching for leaks. The lamp should always give a flame free from green colour when burning in air that does not contain halide vapours. It should not be used where a naked flame would be hazardous.

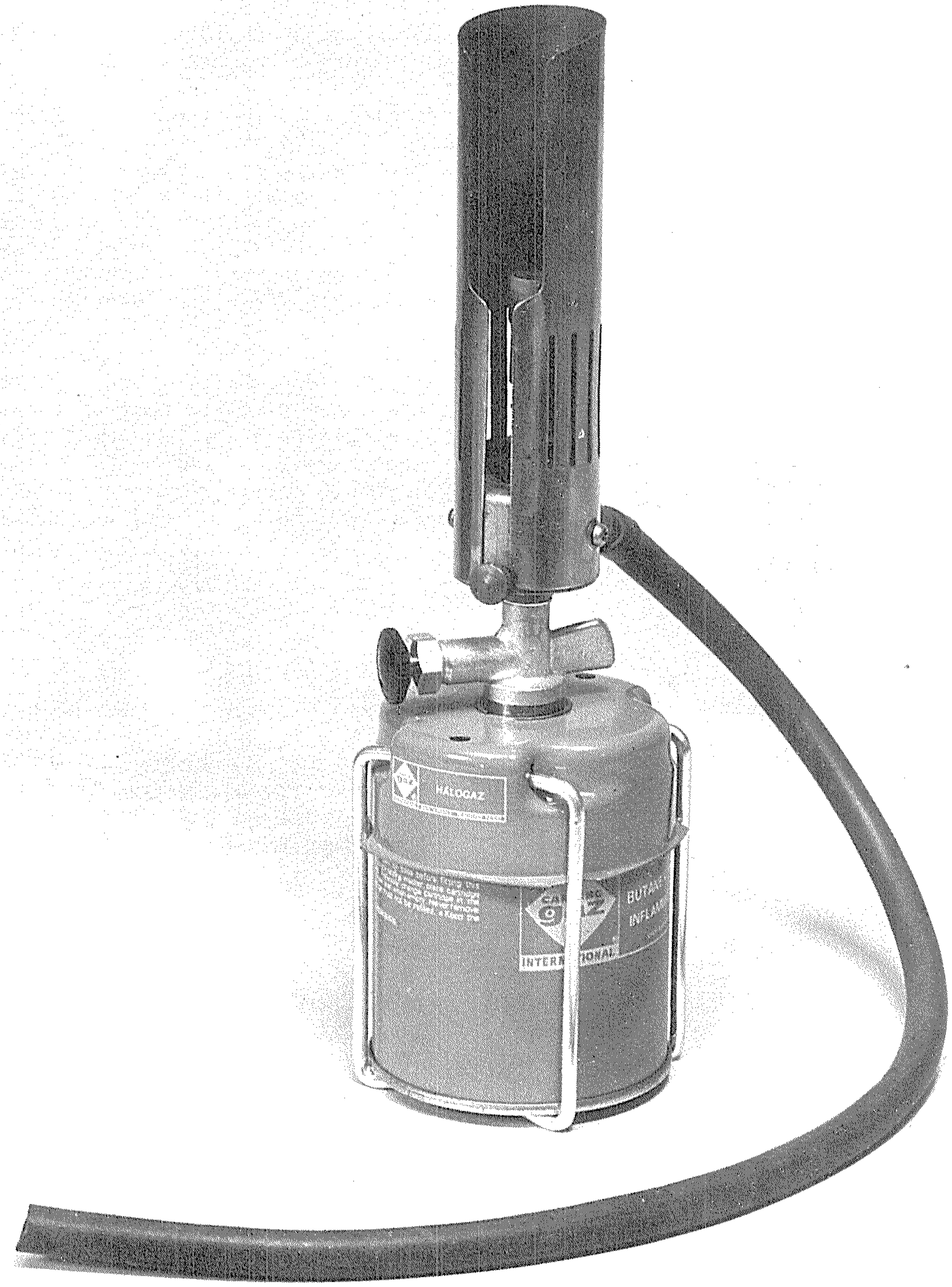
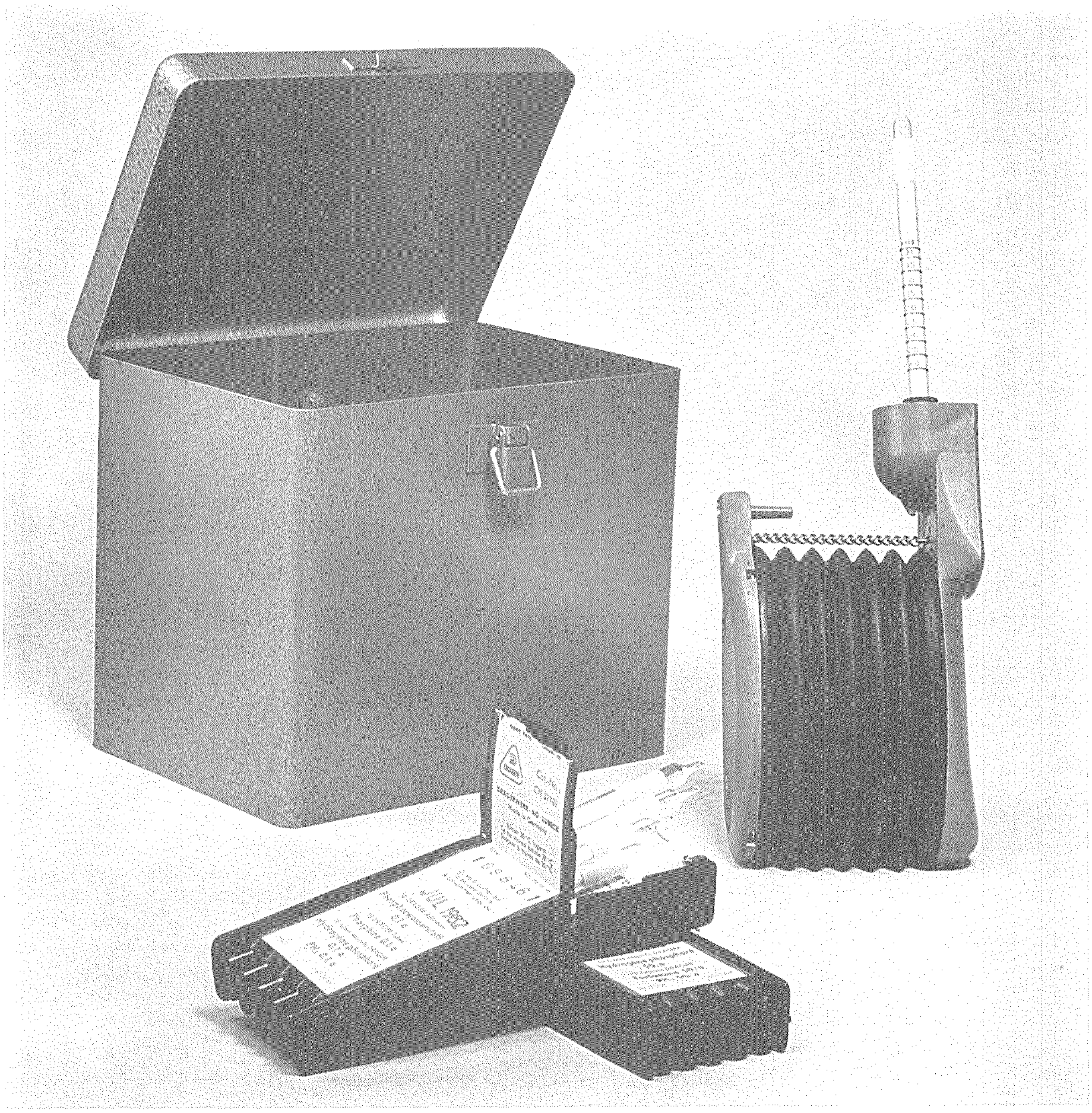


Figure 44a. Halide lamp for detecting methyl bromide leaks.



44b. Detector tubes for detecting methyl bromide leaks.

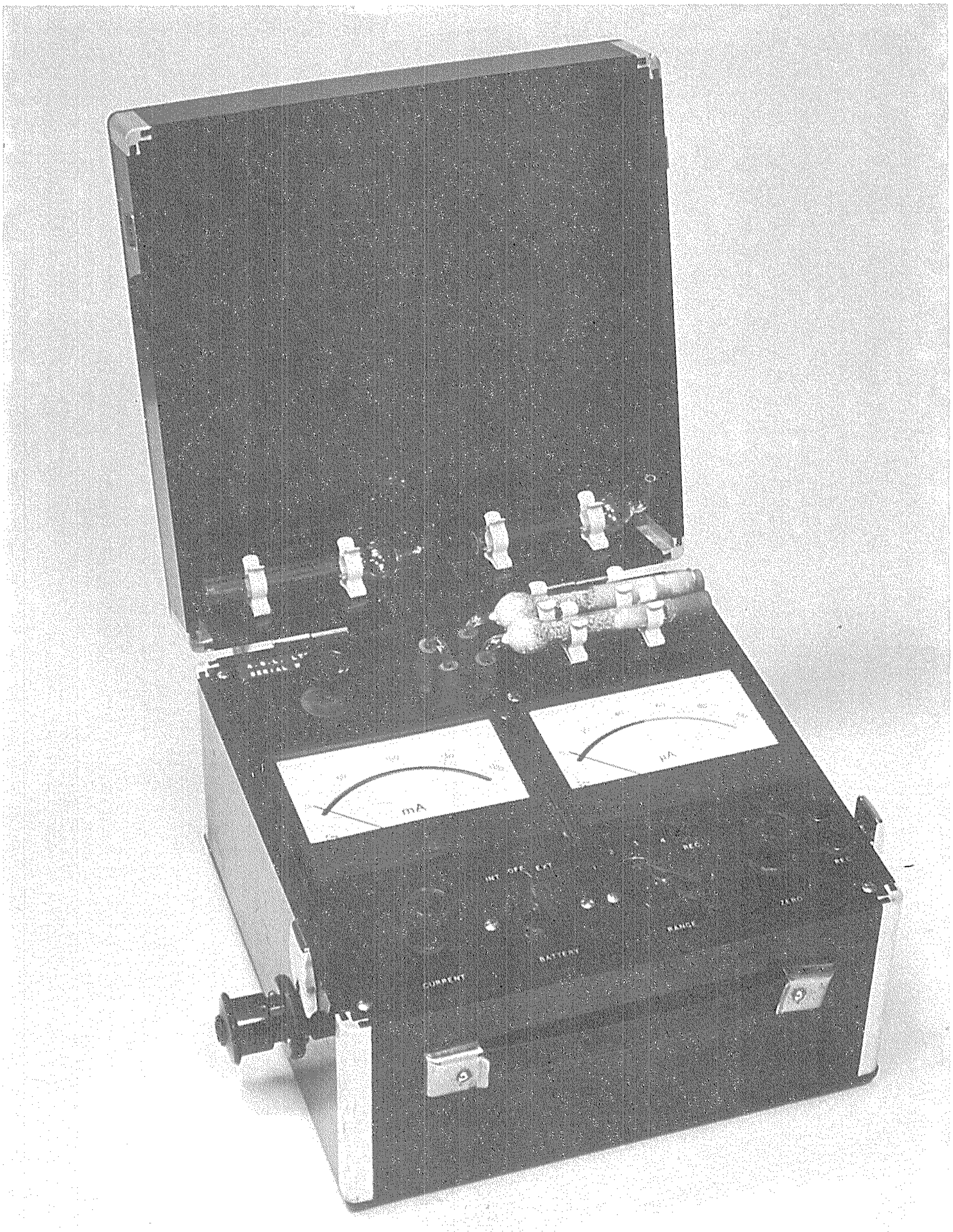


Figure 44c. Thermal conductivity meter for measuring methyl bromide.

Other halide fumigants, such as carbon tetrachloride, ethylene dichloride and ethylene dibromide and halides used in aerosols, also give a positive reaction.

Detector tubes (figure 44b) give rapid more precise measurement of low concentrations of methyl bromide. The detector tube consists of a column of chemical reagents in a graduated glass tube sealed at both ends. To sample the air, both ends of the glass tube are broken and a measured sample of air is drawn through the tube by means of a standard hand pump. If methyl bromide is present the chemicals change colour. For a standard volume of air the length of the coloured band is proportional to the fumigant concentration and the tubes are calibrated directly in ppm of fumigant in air. The tubes are calibrated to detect a range of 5 to 50 ppm of methyl bromide. Detector tubes for other fumigants have different ranges. The tubes are primarily used to determine if an area is safe. The use of tubes is fairly expensive since a fresh tube is needed for each determination. Tubes are packed in boxes of ten with instructions on the number of pump strokes required.

Thermal conductivity meters (TC) (figure 44c) are used to measure methyl bromide for research purposes rather than for routine fumigation practice. Nevertheless a TC meter may be used at any time in preference to detector tubes. The TC meter consists of a pump, thermal conductivity cell, battery and meter. In the cell, a wire filament heated by an electric current reaches an equilibrium temperature in air. When a gas of different thermal conductivity is drawn through the cell the equilibrium temperature of the wire changes. This will cause a change in resistance that is measured on the meter, which may be calibrated to read fumigant concentration directly or by conversion from an arbitrary scale. Sampling takes place through 2 mm i.d. nylon tubing at a flow rate of 0.5 litres per minute. A steady reading must be held for about 30 seconds. Meters are calibrated at source but the calibration needs to be checked periodically against other instruments or against a known concentration. Methyl bromide may also be measured with an infra-red absorption meter or by titration or gas chromatographic methods.

Phosphine

Neither the halide detector lamp nor the thermal conductivity meter can be used for phosphine, but there are detector tubes covering the ranges 0.1 to 40 ppm (type 0.1/a) and 50 to 1 000 ppm (50/a). The low range is used for safety measurements and the high range for measuring the effectiveness of a fumigation.

For research work, phosphine may be measured with a portable infra-red absorption meter (figure 45) but these meters are very expensive.

Monitoring the effectiveness of a fumigation

Complete mortality

Fumigation should achieve 100 percent insect mortality. Survival of insects indicates some fault in the fumigation technique that needs to be remedied. Checks should be made to ensure that fumigation is effective.

Visual assessment

The first examination of the stack should take place as soon as possible after removal of the sheets, allowing for aeration. The exposed surfaces of sacks, and particularly the folded edges of sacks and crevices between adjacent sacks, should be carefully examined. It may be useful to dislodge dust on to a card or sheet of paper for more careful scrutiny. The presence of live adult insects at this time will indicate some gross failure in the fumigation, unless it is due to re-infestation. For most insects the larvae and pupae are much more resistant than adults and are often hidden within the grain. Survivors are likely to be at inaccessible parts of the stack. Therefore, the apparent absence of live adults does not confirm that the fumigation has been a complete success.

Sampling and Incubation

Samples of the grain should be taken after the fumigation and kept isolated at a suitable temperature and moisture content to see if there is any subsequent emergence of surviving insects. Samples need to be taken at different heights and different distances

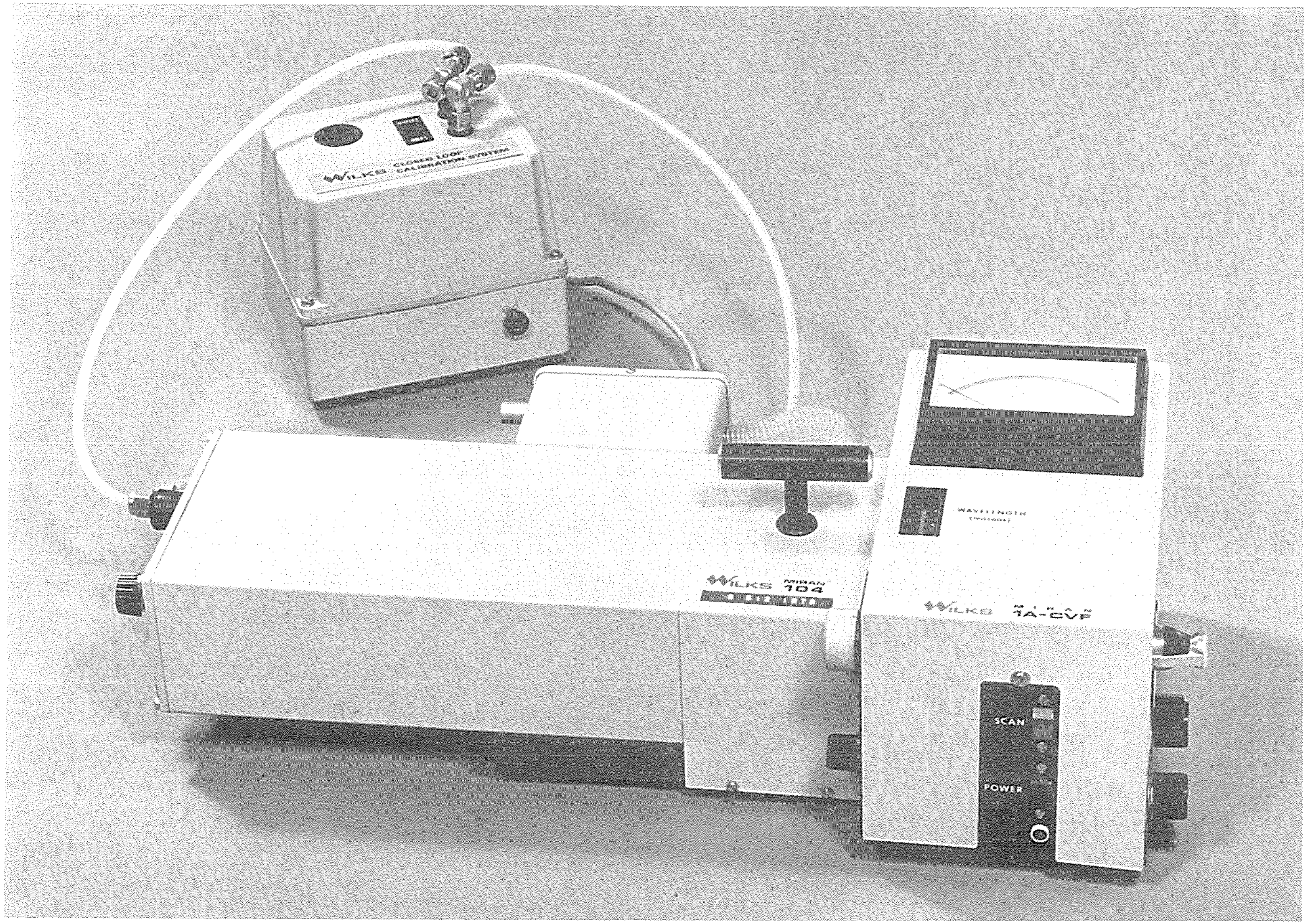


Figure 45. Infra-red absorption meter for measuring phosphine.

from the fumigant application points and some should be selected from the remote parts of the stack. Samples should be taken with a spear sampler and should be of about 0.5 kg. The samples should be kept in a cotton bag or in an open container securely covered with muslin that is placed in an incubator or on a bench at normal atmospheric conditions and kept isolated from extremes of cold or heat and from containers of insecticide or fumigant. The samples should be kept from 30 to 40 days and then sieved through a 10 mesh sieve. No live adults should emerge if the fumigation has been effective.

Test insects

When it is particularly important to check the effectiveness of a fumigation and the natural infestation is light, samples of previously infested grain may be placed on the stack before the fumigation and recovered immediately afterwards. A tolerant species, for example *Sitophilus spp.* for phosphine, should be used. The samples should be incubated and sieved after a suitable interval. Surviving pupae may emerge in one week, larvae in two to four weeks, but these intervals will vary with the species and the conditions. An immediate check of adult mortality can be obtained using fine mesh tubes of insects (figure 46).

Gas concentration measurement

Chemical measurements of samples of air drawn from the fumigated enclosure can show the distribution and persistence of the gas and give an early indication ofthe effectiveness of the fumigation techniques. This is particularly useful for the fumigation of grain in silos or flat bulk warehouses, where there may be some doubt about the gas tightness of the structure or the depth to which the gas can penetrate. Areas to be sampled need gas sampling lines to be inserted before the fumigation starts; this is done by laying down nylon capillary tubing of 2 to 3 mm internal diameter from the points to be monitored to places outside the fumigated area where measurement can be conveniently carried out. An aspirator bulb or pump is used to draw air through these capillary tubes. Sufficient air must be drawn through the tube to give an accurate sample of the gas at the sampling point. Methyl bromide concentrations can be measured with a thermal conductivity meter, described previously. For phosphine, detector tubes measuring in the range of 50 to 100 ppm (1.4 mg/1) or an expensive meter can be used. (See "Measurement of Fumigant Concentrations".)

Fumigation safety

Methyl bromide and phosphine are very dangerous to human life and approved procedures must be followed to ensure complete safety in all fumigation work.

1. All fumigators must be properly trained. This is especially important for methyl bromide fumigation.

2. At least two operators must be present, of which one must be fully experienced and trained in first aid.

3. Suitable respirators and other protective clothing must be available (see Section on "Maintenance of Safety") for all personnel actively involved in the application of the fumigant. In methyl bromide fumigation, a respirator must be worn. In phosphine fumigation a respirator is required only in emergencies or in difficult types of application, but must be available. It should be worn if a smell of phosphine is noted and concentrations greater than the TLV are detected. Where dust including the residues of aluminium phosphide left from the use of pellets or tablets is a hazard, workers may need to wear respirators with dust filters. Dust masks alone would not be sufficient, as dust trapped on the filter might cause phosphine to be breathed.

   Plastic or rubber gloves should be worn when handling aluminium phosphine but not methyl bromide. Hands need frequent and thorough washing and any other exposed part, notably hair, should be washed if necessary.

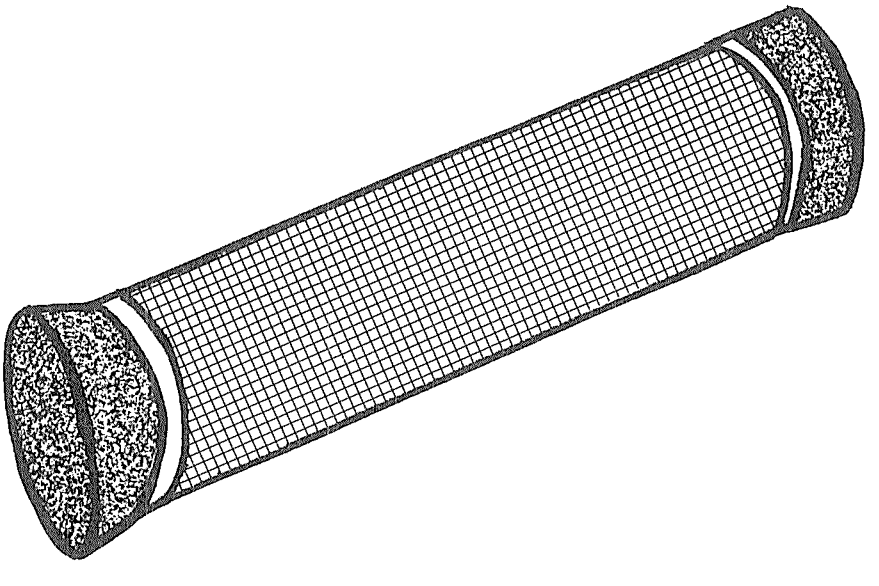


Figure 46. Bioassay tube of fine mesh with cork bungs in each end.

4. The operator in charge must be responsible for all safety precautions, including the posting of warning notices and testing for the presence of dangerous concentrations in any area near the fumigation enclosure to which fumigation staff, or other persons and animals, may have access. Detector tubes should be used to test the safety of these areas. Normally, workmen may remain in a warehouse where stacks are under phosphine fumigation, provided that the doors are kept open and there is adequate ventilation. Fumigation should not be carried out in buildings in which people are sleeping.

FUMIGATION OF BAGGED GRAIN UNDER GAS-PROOF SHEETS

Warehouses for the long-term storage of grain stocks in bag stacks are rarely gas tight and the stacks need to be fumigated under gas-proof sheeting (figures 47 through 54). Phosphine is the fumigant generally used, although methyl bromide may occasionally be preferable, particularly if the fumigation must be completed quickly.

Type of stack suitable for fumigation

Stacks should be flat topped and rectangular. To allow complete covering with fumigation sheets, there must be complete and easy access to the sides and top and a clear gangway along each side of the stack at least one metre wide. The stack must be clear of any pillars or beams supporting the roof, with adequate space on top for workers to stand when they are pulling on the sheet. The stack must be placed on concrete or flooring impermeable to gas. If the ground surface is bare earth, cracked cement or wooden decking, the stack must be built on an underlay of polythene or similar gas-proof sheet.

Stack dimensions

As the height increases, it becomes increasingly difficult to achieve an even distribution of methyl bromide gas. However, the ideal stacking height will depend on the commodity, the method of stacking, whether mechanically or by hand, and the need to make efficient use of the warehouse space. The maximum size of stack that can be fumigated depends on the number and size of sheets and, in the case of methyl bromide, on the quantities of piping and fittings available. To cover large stacks, a number of sheets can be joined with rolled joints. For the most economical use of sheets, there are certain dimensions of stack that are suited to a particular size of sheet. Experience has shown that a sheet 18 m x 12 m is the most useful size and is generally preferable on grounds of cost, ease of handling and transportation. The sizes of stacks that can be used with this sheet size to achieve the best effect are given in annex 10. An 18 m x 12 m sheet is generally more suitable than a 20 m x 10 m sheet. However, it may be preferable to order fumigation sheets of a special size to fit a standard stack size. Sheets measuring 20 m x 15 m can be considered for large stacks, but they may be difficult to handle.

Sheeting of stacks

Stacks should be covered completely with a fumigation sheet with about a 1 m margin laid flat on the floor on all sides. Large stacks can be covered with a number of sheets, which must be properly joined as described later in this section. The cover must be complete and must make a gas-tight enclosure. The following technique should be used in folding a fumigation sheet:

1. Open out flat on a smooth surface.

2. Note centre line (figure 55 a).

3. Fold in a 1 m strip from one side. About five workers are required to give a neatly folded sheet, with all personnel working in unison.

4. Keep folding the 1 m strip over and over until the central line is reached. Fold in the other side similarly (figure 55 b).

5. Fold one roll on to the other roll (figure 55 c).

Figure 47. Methyl bromide fumigation under gas-proof sheets: making pits in top of stack.

Figure 48. Methyl bromide fumigation under gas-proof sheets: laying out gas lines and jets.

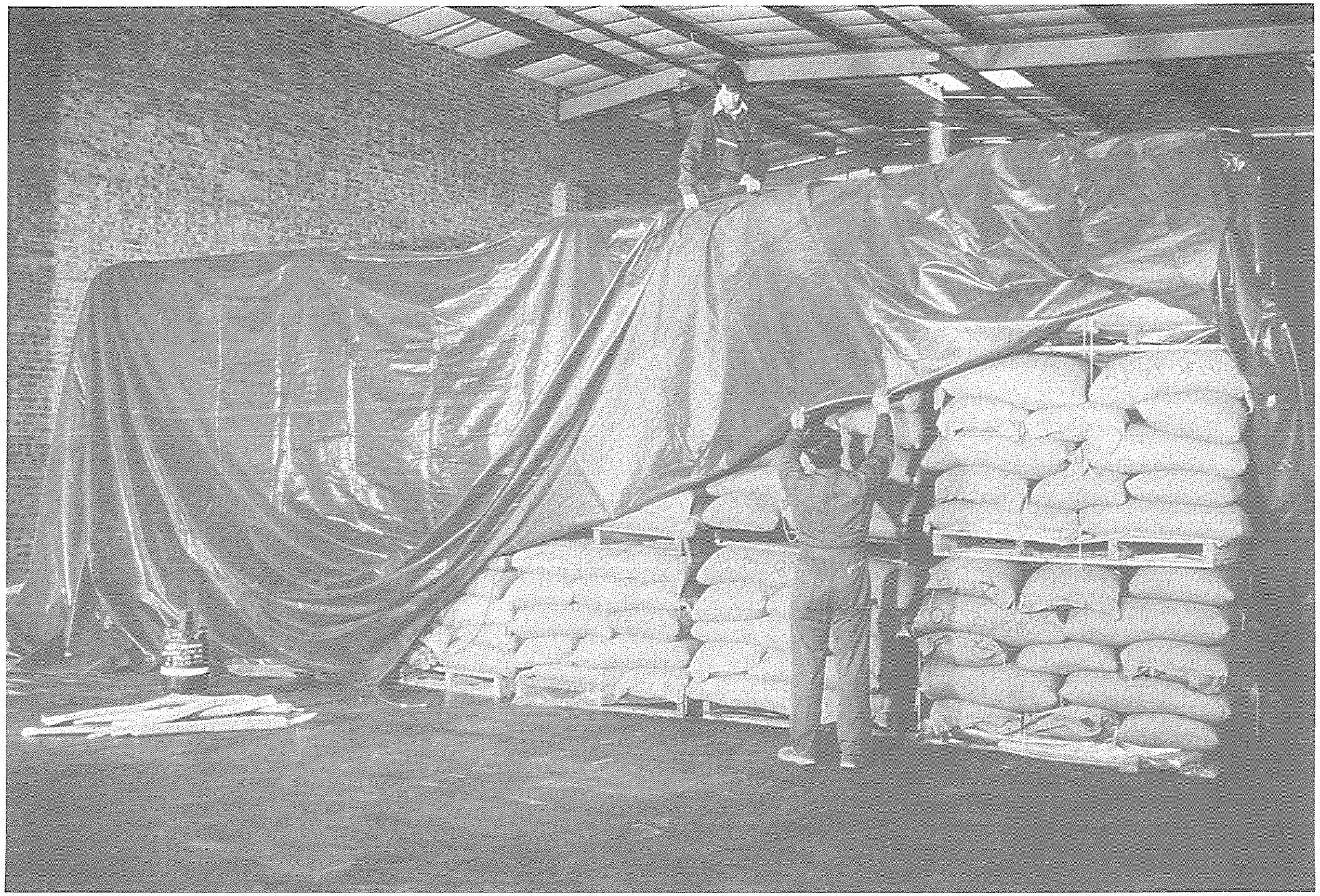


Figure 49. Methyl bromide fumigation under gas-proof sheets: sheeting the stack.

Figure 50. Methyl bromide fumigation under gas-proof sheets: putting sandsnakes in place.

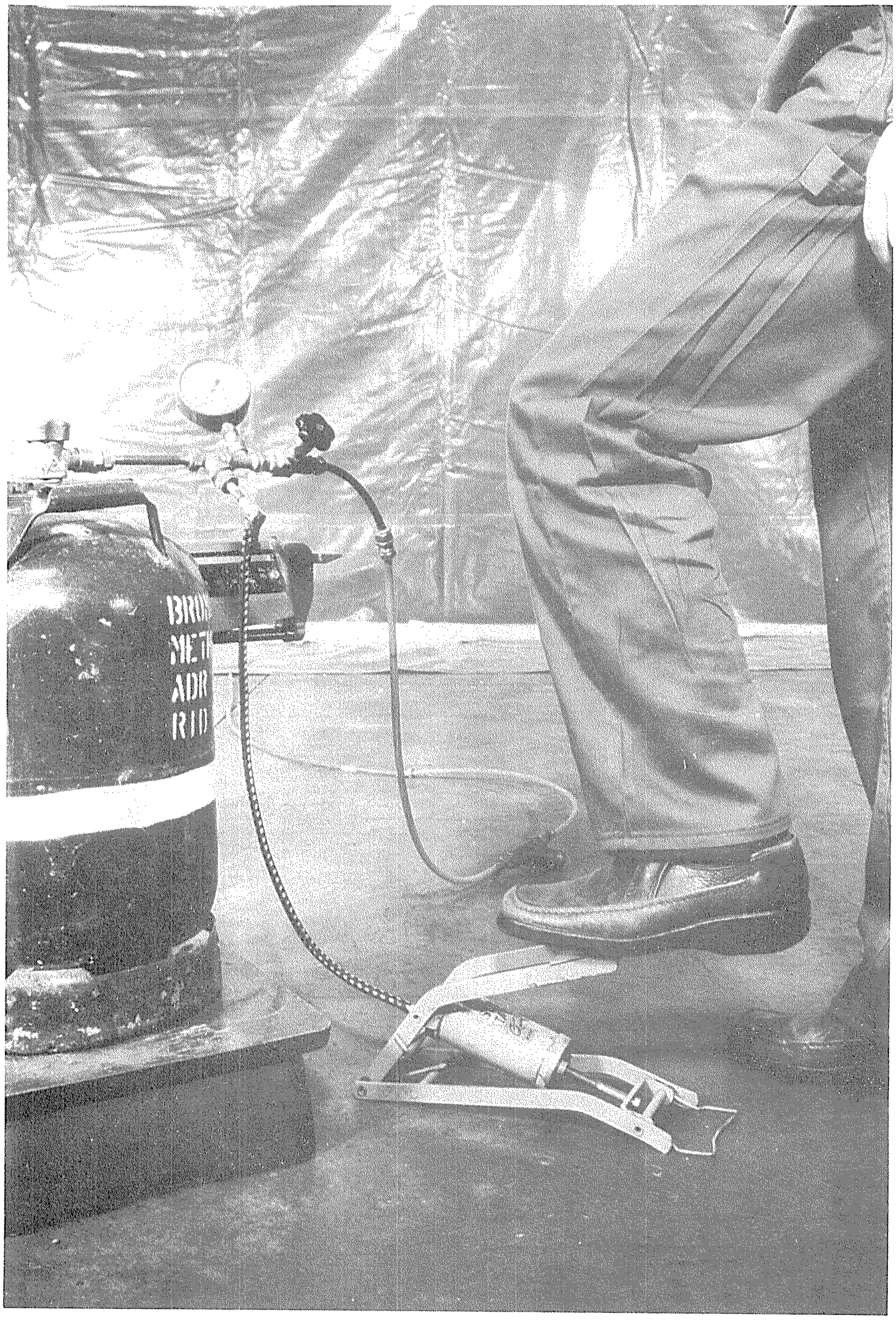


Figure 51. Methyl bromide fumigation under gas-proof sheets: pressurizing the cylinder.

Figure 52. Methyl bromide fumigation under gas-proof sheets: opening the cylinder.

Figure 53. Methyl bromide fumigation under gas-proof sheets: checking for leaks with a halide lamp.

Figure 54. Methyl bromide fumigation under gas-proof sheets: putting up warning notices.

6. For transporation or storage, take one end of the roll to the further end (figure 55 d) and roll the sheet starting at the folded centre (figure 55 e).

It is important that the folded sheet should be placed in the correct position on the stack to give the right overlap on the floor and for jointing when it is unrolled. Sheets can be placed on the stack rolled up, or the long strip can be opened out to its full length (figure 55 c), passed up the sides of the stack across the top and one end passed down the other side until a 1 metre length is on the floor. As sheets are usually rectangular, not square, it is important to remember whether the sheet has been folded on the long or the short axis.

The sheet should be opened out one section at a time across the top of the stack, working towards the edge where the folded sheet is pushed over and the weight of the sheet carries it down to floor level. The sheet is then opened out to its full extent and the final straightening and laying smoothly on the floor is done.

Choosing the right position for placing the sheet initially is very important, as once the sheet is opened it is difficult to reposition it. It should not be necessary to drag or move an opened sheet on a stack, as this can lead to damage of the sheet or collapse of the stack. In many fumigations excess sheet needs to be folded away either on the top of the stack or on the floor, where it is best to use the side that has most space, as it is difficult to fold excess sheet neatly in a one metre gap between a stack and a wall.

Sealing on the sheet to the floor

Two operators, standing at adjacent corners, should each place one hand high on the sheet close to the stack and the other hand on the edge of the sheet. By pulling against each other the wrinkles are straightened out in the sheet on the floor. When the sheet is taut, sand snakes made of 12 cm fire hose or flat plastic tubing filled with sand should be placed up close to the stack on this side. This operation should then be repeated on the next, adjacent side.

The corner junction between these two sides is then folded neatly on the vertical sides. One operator should kneel on the sheet at the corner, place his hands flat on the sheet and push it until there is a section of flat sheet from the first side around the corner. Leaving one hand holding that section in position, the other hand should work the sheet from the second side back over the top of the sheet from the first side. This folding should be continued concertina fashion, over and back, until all the sheet forms a neat, tight fold. Sand snakes should be placed in position around the corner, and the third side should then be smoothed out and weighted with sand snakes. A concertina fold at the corner of the second and third sides should then be completed. Finally, the fourth side and remaining corners should be completed in the same way.

When the stack is covered by sheets joined with rolled joints, the procedure is similar, but operators should be positioned on top of the rolled joints to prevent them being pulled apart by the people at the corners. Multiple-sheeted stacks with more than two rolled joints on a side should be straightened from the central rolled joints to the corners.

Rolled joints

When a stack needs more than one sheet, the sheets must be joined with a rolled joint. This joint should be made in the following manner. The first sheet should be placed in position and the leading edge folded back 1 m along its entire length. The second sheet should be laid to overlap the first by 1 m so that the edges lie together. These edges should then be folded until the overlap is taken up. The fumigation team should spread along the fold so that, working together, the overlap is taken up by rolling as tightly as possible. The rolled joint shall then be clamped with spring clamps at 1 to 2 m intervals and weighted with sand snakes. Indoors it may be possible to manage with clamps on the sides only, but outdoors clamps are needed on the sides and on the top.

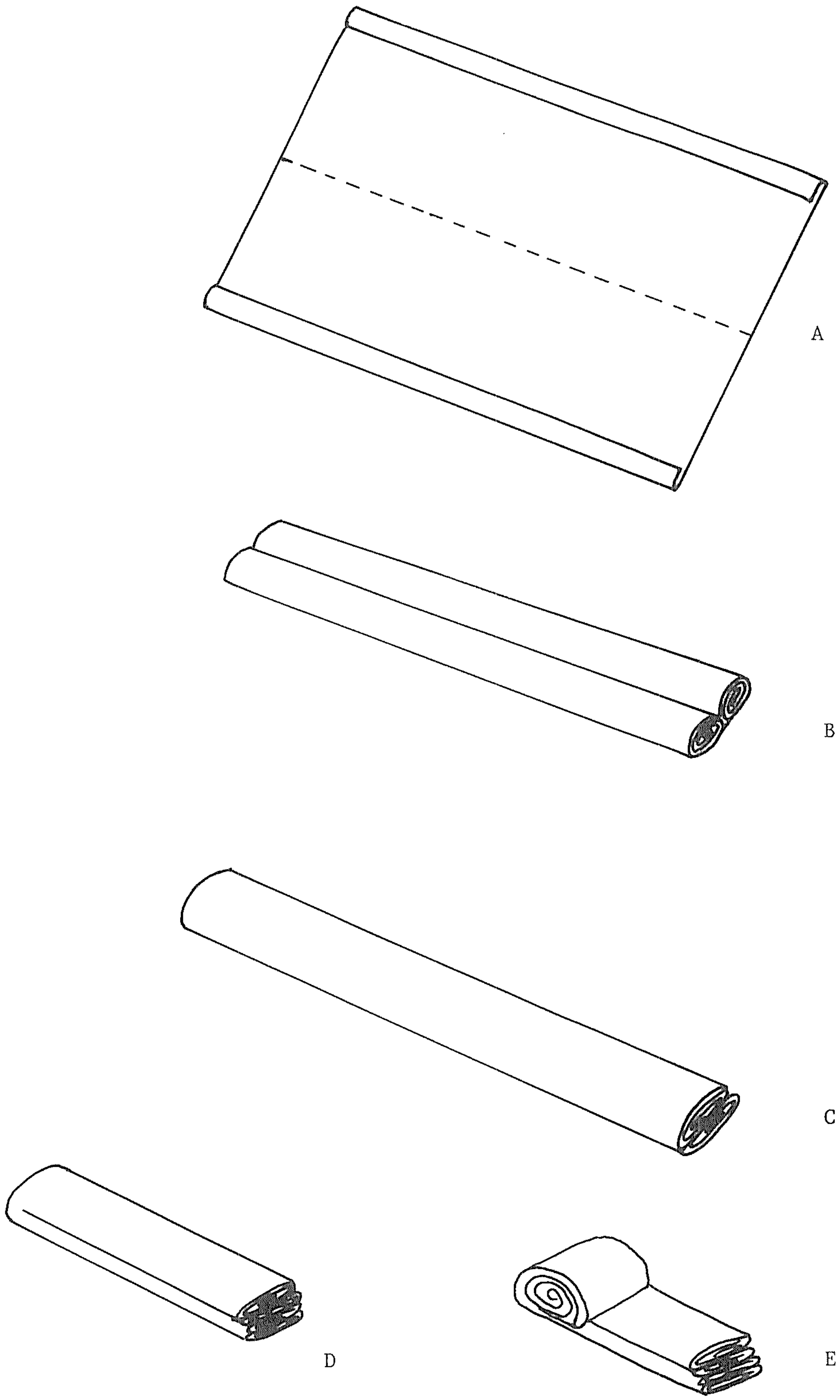


Figure 55. Folding a fumigation sheet.

Rolled joints should always run vertically on the side of a stack from top to bottom, never horizontally or at an angle.

Folding away excess sheet

If a sheet is larger than is required to cover the stack, or a multiple sheeted stack is left with a quantity of excess sheeting material, this excess must be folded correctly to leave a good seal. If there is sufficient space to operate, more than the minimum 1 m gap between stack and wall, the excess sheet can be opened fully, pulled straight and, after sand snakes have been put in position, folded back over itself.

Greater excess lengths, particularly in narrow gaps, should be retained on top of the stack. This will require a different technique of folding the sheet. For example, on a three-sheet stack, the two sheets covering the ends should first be put in place and folded back for the rolled joint.

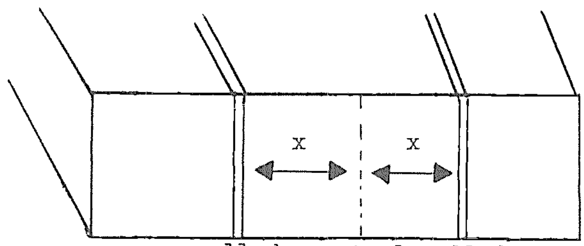


Figure 56. Folding the middle sheet of three joined sheets

The third sheet should be folded in the following manner to ensure that when it is opened out it exactly fills the gap between the end sheets (figure 56). The sheet is first folded in half and rolled, starting from the folded edge until a measured distance (x in figure 56) from the edge is reached. The doubled sheet is opened out on both sides of this folded centre and both sides are folded from the edges to the centre as usual. When the sheet is placed on top of a stack it can be opened, leaving the centre fold closed, and the edges of the sheet should then be in the correct position.

It is not sufficient to cover a gap with overlapping sheets without rolled joints. Sand snakes could be laid across the top and on the junction with the floor but this would not make a satisfactory gas-tight seal unless the vertical sides were taped.

Multiple-sheeted stacks

When covering a large stack with several sheets, joints may have to be made in two directions. It is essential that the order of placing the sheets in position and of rolling the joints is carefully planned.

An indication of the way to do this is given in figure 57. The order of placing sheets and making rolled joints is as follows: Sheet 1, 2-joint A; 3-B, 4,5-C; 6-D,E; 7,8-F; 9-G,H. When placing the sheets on the stack it is important to ensure that the rolled joints A and C (figure 57) do not overlap but are separated by at least 1 m to avoid the problem of rolling a joint that has two other rolled joints on top of each other.

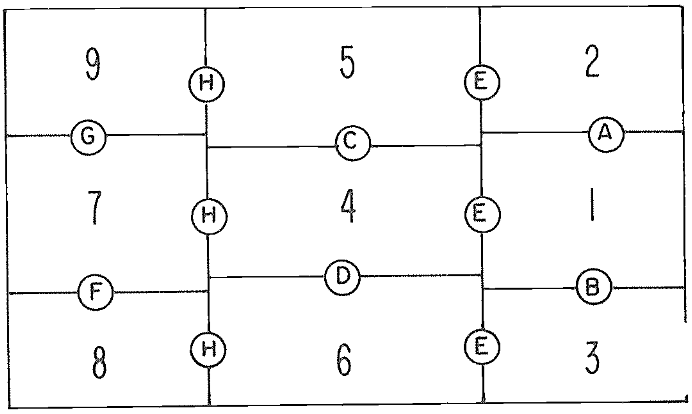


Figure 57. Layout for a multiple sheet fumigation

When sheeting a large stack in this way, particularly out of doors, it may be necessary to weigh down the sheets with bargs or similar heavy objects while the sheets are being put into place. It is easier to carry out an operation if the sheets are folded correctly initially and taken up onto the stack and laid out in the correct position. Various types of fumigation sheets are described in the section on "Fumigation".

Application of Methyl Bromide

Piping and jets

Methyl bromide is delivered as a liquid from a pressurized cylinder to the top of the stack in a system of branched piping ending in jets or nozzles. The piping is laid out in the stack before the fumigation sheets are put on. The piping is usually nylon or black polythene plastic, 7 mm l.d. and 10 mm o.d. Jets are normally of a gas jet type (e.g. Bray No 235/00) and are similar to jets in gas boilers. Special adapters to take these jets are available or the jets can be screwed directly into holes bored in the plastic tubing. Sections of piping are joined by compression couplings to T pieces and X pieces.

Layout of piping

Space must be made on the top of the stack to accommodate the spray jets through which the methyl bromide is delivered. This space is needed to allow adequate vaporization of the methyl bromide and to prevent excessive wetting of the commodity or the sheet with liquid fumigant. The space is created either by leaving channels along the stack top or by removing bags to make pits three bags deepy under each jet. The bags removed to make the pits are placed around the pits and over the piping (figure 58).

This effectively deepens the pits and keeps jets well away from the sheet, which is very important as many types of PVC sheets are damaged by liquid methyl bromide. It also holds the piping near the jets firmly in place so that they are not displaced during the placing of the sheet. It does not matter whether the jets point upwards or downwards, provided there is at least 0.5 m free space on the deliver side of the jets. Therefore, a jet in piping lying along a channel must point upwards, while a jet suspended over a pit must be pointed downwards. Jets must of course be kept clean, otherwise blockages may cause dangerous leaks elsewhere in the pipeline.

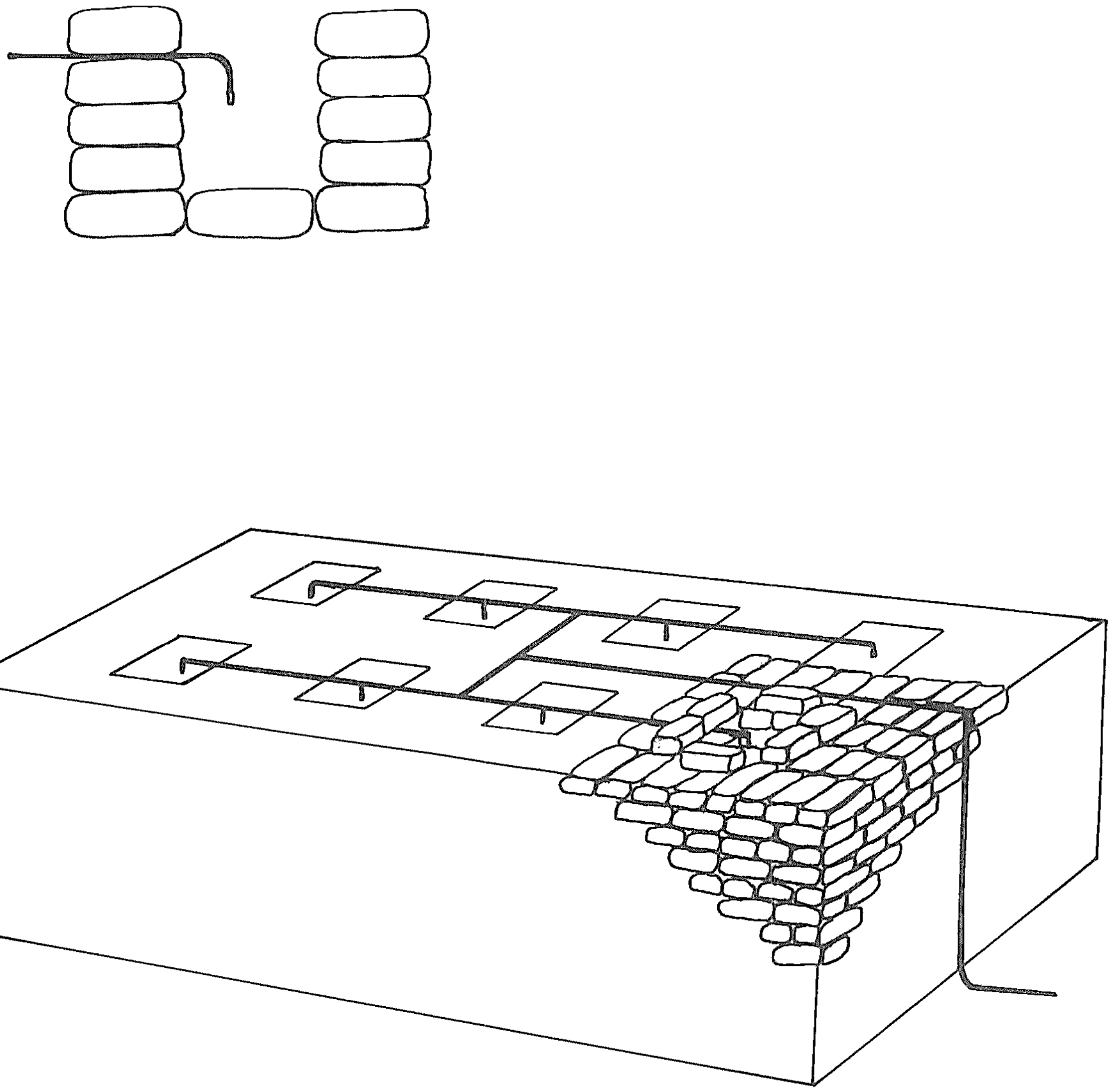


Figure 58. Layout of methyl bromide jets

The purpose of the system of jets is to obtain an even distribution of methyl bromide. If all the jets were arranged in a straight line from the cylinder, the pressure at each jet would decrease with increasing separation from the cylinder and a very uneven distribution would result. The jets further from the cylinder might not deliver any methyl bromide at all. Therefore, for any system requiring more than a few jets, a branched system is necessary. A large number of jets are most commonly arranged in a form of an H (figure 59).

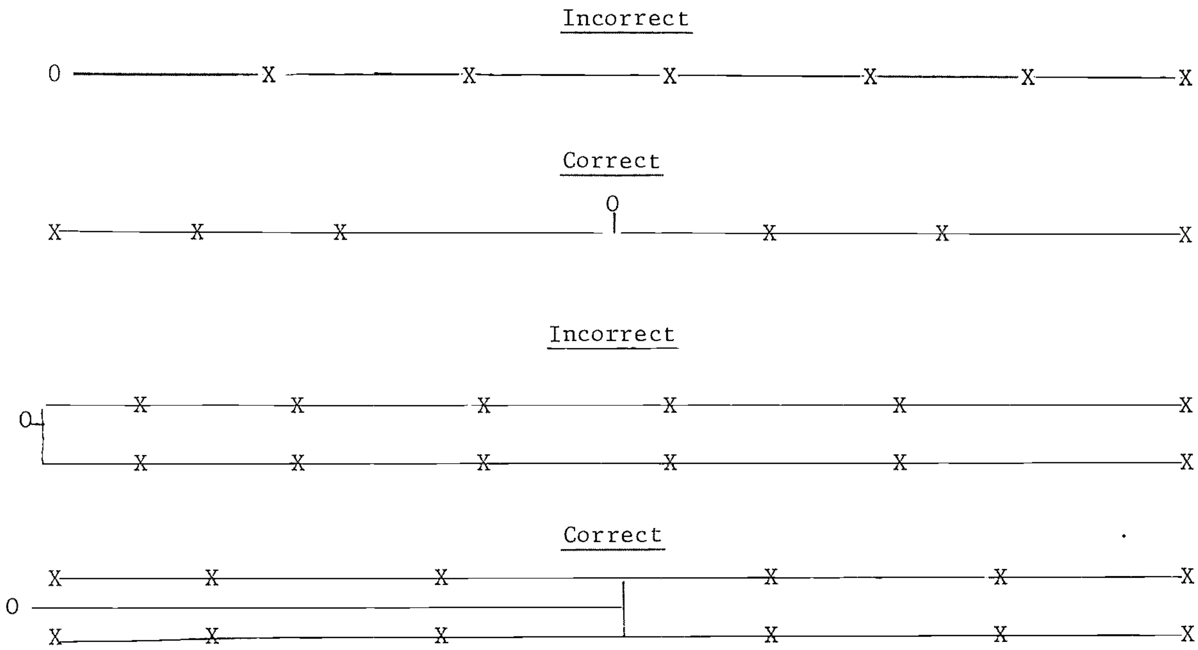


Figure 59. Correct and incorrect ways of connecting jets.
X = jets; 0 = cylinder

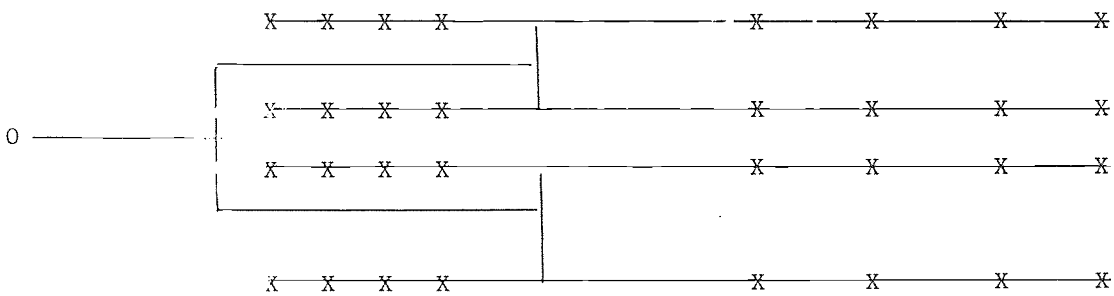


Figure 60. Piping layout for a very large stack.
X = jets; 0 = cylinder

A larger stack may need a double-H arrangement, as shown in figure 60. One jet is required for every 9 to 10 m^2. The number of jets should be calculated from the stack dimensions, rounded up to an even number and the layout determined. Jets should be situated 3 m apart and there should be not more than four or five jets in each arm. At the sides and ends the jets should be 2 m from the edge of the stack. There will always be an initially high concentration at the bottom of the stack, as the heavy vapour will flow over the top and down the sides, but the gas should distribute itself satisfactorily in the course of the fumigation if it has been evenly applied.

Fumigant cylinders

Methyl bromide is delivered from cylinders ranging in content from 18 to 100 kg of the fumigant. The cylinder valves should be checked with a halide lamp when taking the cylinder out of store. The amount of methyl bromide applied should be determined by weighing the cylinder before and after application. The cylinder should be placed on a portable platform scale capable of weighing at least 150 kg or it may be suspended from a spring balance attached to a tripod. Alternatively, the exact amount of methyl bromide required may be transferred by weighing from a large cylinder to a small cylinder. The small cylinder can then be taken to the stack. This avoids moving the balance, but the small cylinder must be pressurized to ensure effective delivery.

Cylinders may have a single outlet closed by a wheel valve (A in figure 61a), with a dip tube to the bottom of the cylinder, or two outlets (figure 61b), of which one outlet has no dip tube and is used for pressurization of the cylinder. The other outlet is for delivery, has a key valve, B, and a dip tube to the bottom of the cylinder. As shown in figure 56, the cylinders need a delivery fitting that incorporates a Schrader valve, C, a gauge, D, a wheel valve, E, additional to the wheel or key valve on the cylinder, and a filter, F. The filter contains glass wool to prevent dirt and rust from getting to the nozzles. The size of the connecting joint varies with the manufacturer and the fitting must have an adapter suitable for the cylinder. (Some cylinders have a 3/8 inch (1 cm) male thread.) However, apart from the special connection to the cylinder, the rest of the line couplings should be a standard 10 mm.

To assist in applying the fumigant, the pressure should be raised to 80 to 100 p.s.i. (550 - 690 kN/m^2). This may be achieved by means of a heavy duty car foot pump, although it is preferable to use a compressor. Cylinders with a single outlet can be pressurized through the delivery valve, but not while delivery is taking place. With cylinders having two outlets, the pressure can be kept at a constant level throughout the entire application. The pressure should not be allowed to fall below 40 psi. (275 kN/m^2.)

The opening of the valves should be carried out by two persons wearing respirators (See section on "Maintenance of Safety") and using a halide lamp to detect leakage (See section on "Fumigation"). All other personnel should stand at a distance. A rapid release of large quantities of methyl bromide can take place if valves are faulty or joints are loose. In this case, the valves must be closed tightly and the sources of leakage attended to. With valve E closed (figure 61), valve A or B should be opened and the pressure checked and increased if necessary. Valve E should then be opened cautiously and a small amount of methyl bromide (about 10 percent of the dose) introduced into the stack. Valve E should be then closed and the whole system checked for leaks. Joints should be tightened, if necessary, and any leakage around the stack sealed off.

In the event of an emergency where gross leakage occurs due to breakage or disconnection of a delivery pipe, the main cylinder valve should be turned off and the team should withdraw. After a period of ventilation, an operator, wearing a respirator, should check that the area is clear with a halide lamp or detector tubes before carrying out the necessary repairs.

Methyl bromide leaking from under a gas-proof sheet leads to much higher concentrations at floor level than at the level of the operator's face. This is an added safety factor. When a high concentration is detected at ground level with the halide lamp, there may be enough time to put on the respirator without serious exposure having occurred.

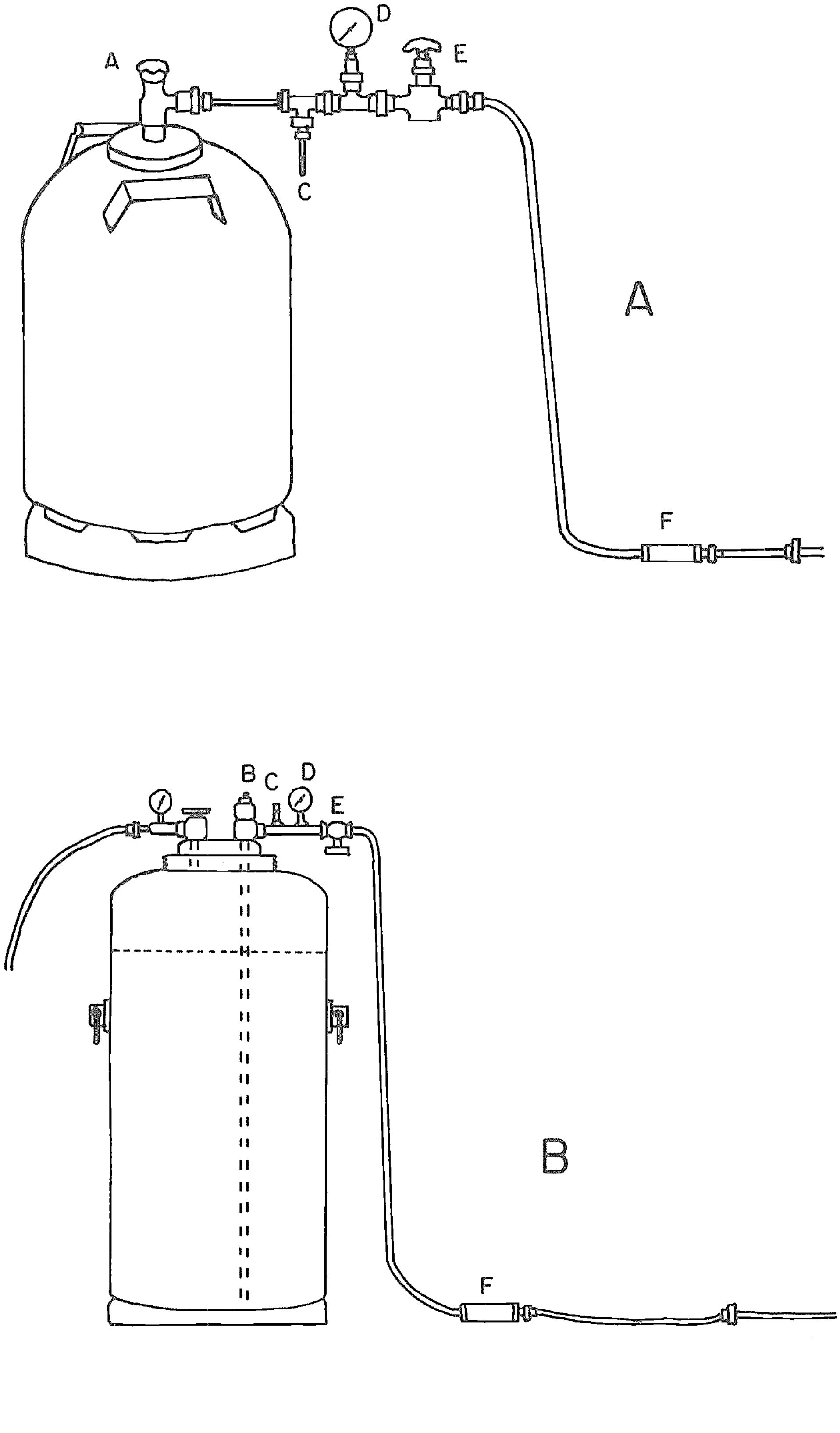


Figure 61. Methyl bromide cylinders and fittings.

When the gas tightness is satisfactory, the remainder of the dose should be applied. After closing valve A or B, the lines should be cleared by applying compressed air through the side valve, C, and the cylinder should then be disconnected.

On termination of the fumigation, removal of the sheets is carried out step wise. The corners should first be opened, but the sheets should not be completely removed until some hours later. Respirators and halide lamp or detector tubes must be used and all non-essential personnel kept clear.

Application of phosphine

Correct sheeting of stacks (See "Sheeting of stacks") is necessary. Containers of aluminium phosphide (figure 62) should be opened outside or in a well-ventilated area very shortly before use. Plastic gloves should be worn. The whole contents of non-resealable tins should be used in one operation. The dose of aluminium phosphide preparation should be distributed over the surface or around the stack before closing the fumigation sheets. If the stack is on dunnage, some fumigant should be placed under the stack. Tablets or pellets should be placed on trays to enable spent material to be removed after the fumigation. Bags should be placed in any convenient position. A set of bags can be hung from the side of the stack by the strings provided.

Phosphine is evolved slowly at first and, if the fumigant can be distributed within one to two hours, it should not be necessary to wear a respirator. Within four hours gas may be given off rapidly, but long before that time the sheets should be sealed down, a safety barrier erected and warning notices displayed. In clearing up it should be ensured that no tablets are left in apparently empty tins. No water should be allowed to touch fresh aluminium phosphide preparation. Leaks in a sheet should be detected by inspection and sealed with tape. These can be detected by detector tubes, but owing to the slow release of phosphine, leakage cannot be detected immediately and, in general, reliance must be placed on ensuring that stacks are properly sheeted.

On termination of the fumigation the sheets should be removed in steps by opening up the corners of the sheets first and removing the sheets entirely some hours later.

Disposal of spent formulation

Residues of pellets or tablets may be scattered on waste ground if amounts are small. Otherwise, they should be stirred into buckets containing warm water and detergent (30-60g of detergent in 10-25 l of water (figure 63). When no further bubbles can be seen in the liquid, the buckets should be emptied on waste ground. Containers should be immersed in the liquid and then buried. Bags of aluminium phosphide should be buried. A gas mask should be worn or care taken not to inhale the fumes during disposal. Residues from tablets, pellets and bags must not be heaped together, otherwise there is a risk of fire or explosion.

Fumigation procedures

Initial preparations

1. Check all items of equipment required, including:

   (a) Safety equipment - respirators and canisters, halide leak, detector lamp, detector tubes, gas concentration monitoring equipment, warning signs, rubber gloves (See section on "Fumigation" and "Maintenance of Safety").

   (b) Fumigation equipment - sheets and sand snakes, clamps for rolled joints, sealing materials, lines, jets, filters, scales, applicator tubes or liquid fumigant spray pump.

   (c) Fumigant and insecticide - check that adequate quantities are available.

2. Choose the most suitable time to begin operations and issue instructions for any rebuilding of stacks and cleaning up that is necessary.

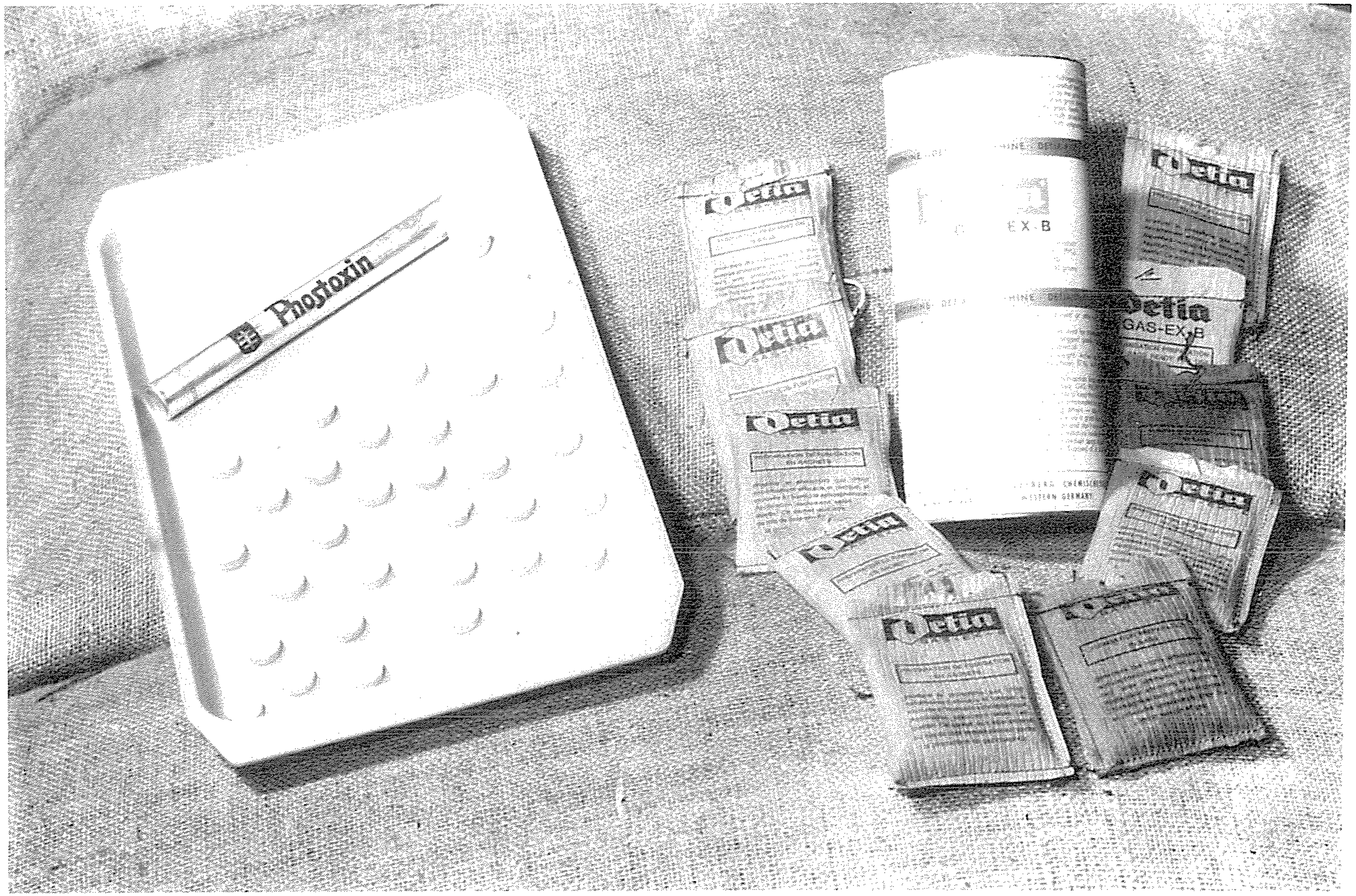


Figure 62. Aluminium phosphide preparations.

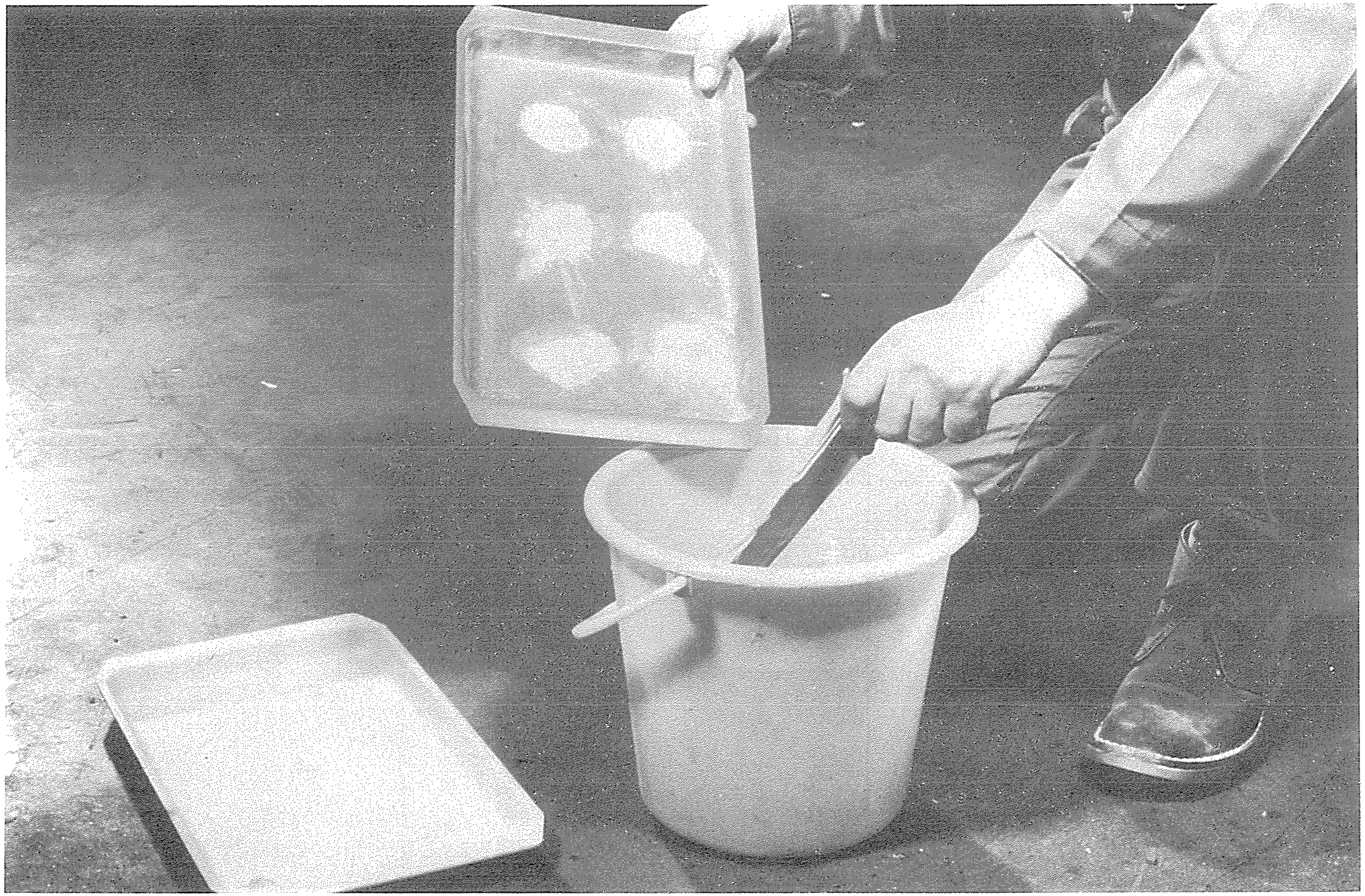


Figure 63. Disposal of spent aluminium phosphide powder.

3. Check the previous history and future storage of the produce in question so that the appropriate treatmet can be given. Take into account the other commodities that may be adjacent or coming into the store.

Preparation of the area to be fumigated

1. Check stack or store for suitability for fumigation. The top surfaces of stacks should be level and there should be a 1 m gap on all sides and ample clearance on the top for operators to handle the sheet.

2. Clean up any spills in the area to be treated and dispose of the sweepings.

3. Carry out recommended insecticidal protective spray treatment, if this is necessary (See sections on "Treatment of Store Fabric"and "Routine Insecticide Treatments in Stores").

4. Take account of possible hazards to neighbouring work areas or living quarters, which may be in use throughout the fumigation period, and provide adequate warning.

Methyl bromide

1. Measure the stack temperature, estimate the volume or weight to be fumigated and calculate the dosage to be applied at the dosage rate appropriate for the commodity and the temperature (Table 15). Ensure that there is sufficient methyl bromide in the cylinder.

2. Prepare the stack for fumigation and make channels or pits in the top of the stacks for placing nozzles (figure 46).

3. Calculate the number of jets required and choose a suitable piping layout (figures 55 and 56).

4. Place the piping, arrange the jets and connect up to the filter, cylinder fittings and cylinder (figure 60).

5. Cover the stack with sheets, join up, fold the corners and place the sand snakes in position (See "Sheeting of Stacks").

6. Check sheeting, sand snakes and pipe couplings and repair sheets with plastic tape if necessary.

7. Make final thorough check on the area around for possible hazards.

8. Send away all onlookers from the fumigation area.

9. Light halide lamps and put respirators on. Rubber gloves should not be worn.

10. Pressurize the cylinder to 80 to 100 psi (550 to 690 kN/m^2) with a footpump or compressor.

11. Record the weight of the cylinder.

12. Open the cylinder valve and check for any leaks. Introduce a small quantity of methyl bromide, about 10 percent of the full dose, by opening the side valve for a short period.

13. Check and seal off any leaks around the stack. The halide lamp will indicate whether there is any need for a respirator to be worn.

14. Re-open the side valve and introduce the methyl bromide until the scales indicate that the full dose has been given.

15. Repeat the check for leaks.

16. Uncouple the cylinder after blowing out the lines with the pump.

17. Put up warning notices, inform management and others concerned and issue appropriate instructions.

18. Leave for not less than 24 or 48 hours.

19. If it is desired to measure the concentration achieved, a thermal conductivity meter and gas sampling lines are needed (See section on "Fumigation). Such measurement is not a normal part of a routine fumigation.

On termination of the methyl bromide fumigation:

1. Open all doors and windows.

2. Wearing a respirator, remove the sand snakes open up the stack at the corners and at the rolled joints on the vertical sides and quickly leave the area.

3. Return 30 minutes to one hour later, still wearing the respirator, and open up the sheet still further.

4. One to two hours later return with a halide lamp, wearing the respirator if necessary, remove the sheet from the stack, take away and fold for the next fumigation.

5. Leave for several hours or overnight.

6. Check with the halide lamp or detector tubes and leave for further ventilation, if necessary.

7. When the area is clear of gas, remove the piping and jets.

8. Remove the warning notices.

9. Check the effectiveness of the fumigation (see section on "Fumigation").

10. Check all items for damage and repair before storing or using again.

11. Complete a written record of the fumigation and attach the record to the stack.

Phosphine

1. Measure the stack temperature, estimate the weight or volume of the commodity and calculate the dosage to be applied at the appropriate rate (Tables 12 and 13).

2. Partly cover the stack with the fumigation sheets (See "Sheeting of Stacks").

3. Open the appropriate number of tins of aluminium phosphide preparation. Wearing rubber or plastic gloves, insert the calculated dosage of aluminium phosphide. Distribute bags evenly over the top of the stack. Tablets or pellets should be put out on trays to allow recovery of the residues.

4. Close the sheeting, seal the joints and corners and put the sand snakes in position.

5. Erect a safety barrier and put out warning notices.

6. Check and dispose of the empty containers. The entire contents of non-resealable tins or tubes should be used.

7. Clean the gloves in detergent solution.

8. After four hours check for leaks by odour or with detector tubes. Seal off any leaks.

9. Inform appropriate staff and leave for a minimum of four to five days (depending on temperature), preferably longer.

The following description of termination of the phosphine fumigation presumes that the sheets are required for another fumigation. If they are not required, and if the grain is thoroughly dry, the sheets may be left in position. If the stack has been a long time under sheets it may be safe to assume that no gas remains.

1. Place a respirator around the neck.

2. Open all doors and windows.

3. Check the phosphine concentration using detector tubes and put on the respirator if the concentration is unsafe.

4. Remove the sand snakes, raise the corners of the sheets, the rolled joints on the vertical sides and quickly leave the area.

5. Leave for 30 minutes to one hour.

6. Return to open the sheet still further and again leave for a similar period.

7. Check on the safety of the area with detector tubes.

8. Remove the sheets, take away and fold for the next fumigation.

9. After a period of at least one hour, but preferably overnight, remove the spent residues and dispose of them in the recommended manner (See "Disposal of Spent Formulation").

10. Check the success of the fumigation (See "Monitoring the Effectiveness of a Fumigation").

11. Remove the warning notices.

12. Complete a written record of the fumigation in a log book and attach a record to the stack.

INSECT CONTROL IN BULK GRAIN

Alternative treatments

Grain taken into long-term storage in silos or flat-bulk warehouses must be disinfested by fumigation or insecticide admixture. Unless the grain has recently been disinfested this treatment should be applied routinely, as the grain is taken into storage irrespective of whether or not it appears to be actively infested. The choice between fumigation and insecticide admixture will depend on the type of installation and on other factors, such as local regulations regarding the use of insecticides and fumigants. If the structure is gas tight, fumigation may be more immediately effective but, in structures that are not gas tight insecticides admixture may be preferred. Admixed insecticides give residual protection, but only those with permitted maximum residue limits may be used.

Phosphine would generally be the preferred fumigant but methyl bromide might be useful in installations with a recirculation system. In cool climates, or to achieve greater penetration in a fixed bulk, liquid fumigants could be used (Annex 9), but these are not favoured because of high cost, and high chronic mammalian toxicity.

Fumigation in unsealed flat-bulk warehouses

Phosphine

1. For this type of storage the grain is fumigated by insertion of a solid phosphide preparation into it. The calculated dose of tablets, pellets or packets must be inserted at various points over the surface of the grain and at different depths at each point. The recommended procedure for tablets is to make one insertion per square metre. The calculated dose should be divided by the number of insertions and the dose for each insertion distributed at various depths. The surface of the grain should be flattened and boards should be used to make it easier to stand on and cross over the surface. Strings marked at 1 m intervals should be laid out to help achieve a uniform distribution.

2. The recommended dosage is given in Table 13. For a dosage of about five tablets/tonne, tablets should be introduced with a probe, making one insertion/square metre and placing three tablets/metre depth at each insertion, starting at the lowest depth and ending with the top tablet 30 cm below the surface. Three tablets/metre depth are then equivalent to three tablets/cubic metre or approximately four tablets/tonne. For larger or smaller dosages, the number of tablets/metre depth should be increased or reduced.

3. The tablets can be applied by means of a probe directly from the tubes in which they are packed by means of a counter that records the number of tablets delivered. The length of the probe can be varied by screwing on a number of sections; the bottom section is fitted with a hinged flap to prevent grain from running up the probe on insertion. It is possible to probe to a depth of 10 m, but probing to any depth greater than 5 to 6 m is very hard work. The gas will penetrate a few metres below the lowest tablets. Alternatively, simple metal tubes can be inserted into the grain at intervals and the tablets dropped down the tubes by hand as they are pulled up through the grain. The tubes must be at least 25 mm in diameter to avoid jamming of the tablets. In practice the grain may not come up the tube to any extent and a flap may not be necessary. Considerable effort is required with a team of well-trained operators to fumigate a large bulk of grain.

4. Bags of aluminium phosphide may be used instead of tablets. Bags being larger than tablets are inserted much further apart in the grain.

5. After the fumigant has been applied, the surface of the grain should be covered with sheets of plastic film or other suitable gas-proof material. The sheets should be rolled out progressively, as the probing continues, to reduce the amount of gas released to the atmosphere. It is not sufficient to lay sheets soosely over the top of the grain. The edges must be weighted down with sand snakes and sheets joined together with rolled joints. All windows and ventilators should be open during treatment, which must be completed in the least possible time and certainly not more than 2 hours in temperatures above 20°C. The number of workers and probes should be sufficient to ensure this.

6. The grain should be left under gas for at least one week and preferably longer. Removal of sheets should be carried out in stages with as much ventilation as possible, preferably by forced draught.

7. When using bags of aluminium phosphide, if strings have been attached during application, it may be possible to retrieve the bags from shallow grain. However, it is not possible to recover the bags from greater depths and they must be left until the grain is moved. The bags are then removed manually or by sieving and are buried in waste ground.

8. The effectiveness of the fumigation should be monitored as described in the section on "Fumigation".

Methyl Bromide

1. Grain in sealable flat bulk warehouses may be fumigated with methyl bromide by gravity penetration, single pass distribution or recirculation; however, phosphine is generally preferable for flat bulks.

2. In application by gravity penetration, the required dose is vapourized above the grain from suspended jets. The number of jets should be large to obtain an even distribution in the head space, but this may be difficult because of the practical problems of suspending the piping and jets. Methyl bromide can penetrate to 6 m depth but the distribution may be very uneven and insects may survive even in the upper layers of grain.

3. Further distribution of methyl bromide should be assisted by the use of one or more fans. Fan switches should be on the outside and they should be switched off after about 30 minutes. Buildings frequently used as methyl bromide fumigation chambers, e.g. for bagged or boxed goods, should have piping and jets fixed to the walls.

4. In single pass distribution, the fumigant may be distributed in an air stream passed through the aeration ducts. A more rapid distribution is achieved than with gravity penetration, but uniform distribution may be difficult to obtain because air passes at different rates through different parts of the grain. To avoid wasting fumigant by venting it away with the excess air, either the time taken for passage of air through the grain should be known or the fumigant concentration must be measured. Complete recirculation of methyl bromide maybe difficult to achieve in horizontal warehouses.

5. The dosage of methyl bromide depends on the commodity and the temperature. Dosages are given in Tables 14 and 15. For situations where heavy gas losses are likely, such as single pass distribution, the dose should be increased by 50 percent. Full safety procedures and equipment are needed for all methyl bromide applications (See section on "Fumigation"). In stores that are not gas tight, where fumigation sheets must be laid over the grain, phosphine should be used.

Fumigation in sealed horizontal stores ("flat" warehouses)

Phosphine

1. The essence of good fumigation is gas tightness. Structures to be used regularly for fumigation should have permanent sealing and should satisfy a gas tightness test, e.g. a decay time from an excess internal pressure of 500 Pa to 250 Pa in not less than five minutes. To achieve this standard, the store must be of sound construction with a concrete floor. Stores used for total store fumigation often have brick or concrete walls and a solid roof. Rough brickwork must be faced with hard cement plaster and hollow concrete blocks must be faced on both sides with a hard, smooth cement finish. The plaster should be painted with two coats of polyurethane paint, bitumen emulsion or chlorinated-rubber based paint. A false ceiling of painted hardboard may improve the gas tightness and cut down the dead volume. There should not be any eaves or roof gap. Warehouses with cladding walls and roof can also be sealed for fumigation. All eaves and other openings, joints, bolt holes and intersections must be sealed with plastic, fibreglass or aluminium foil tape and with bitumastic or silicone sealants and paints. It must be noted that ordinary decorative emulsion paints do not provide a satisfactory gas-proof coating.

   All gaps, ventilators, windows and doors must be sealed. This sealing can be done by taping, by filling gaps with solid foam strips or cloth, by pasting on several layers of sheets of paper or by covering the whole door, window or eaves with sheets of polythene taped at the edges. Difficulties may be experienced with large sliding doors and it it often advisable to tape sheets of polythene over the difficult spots or to cover the whole doorway, if the polythene film is available. Wind can be a problem with outside sealing of paper or polythene. Sealing should be completed inside the building as much as possible, leaving only the final door to be sealed from the outside. Well-sealed stores should have a pressure relief valve. They should be painted white. Before every fumigation the gas tightness should be checked and leaks eliminated.

2. Stores should be reasonably fully loaded to avoid wastage of fumigant in the free space. Aluminium phosphide may be probed into bulk grain as described in the previous section. However, in a properly sealed store it is probably sufficient to lay the formulation on the grain surface in the form of blankets or plates (See paragraph below). Dosages are given in Table 13 and and extra space dosage of 1 to 1.5 g/cubic metre of free space should be added.

3. If the store is part of a building complex, adjoining rooms or stores should be kept well ventilated and unoccupied. Heating, and sources of ignition should be put out of operation. Articles of copper or brass should be protected from attack by phosphine, with a coating of wax.

4. In very well-sealed storages, e.g. plastic covered bunkers, the dosage rate may be cut to about 1 g phosphine/tonne. The aluminium or magnesium phosphide is best applied in the form of "blankets", which are strong tissue paper rolls containing 100 sachets of aluminium phosphide, each blanket being shipped in a sealed tin. One blanket releases 1 100 g of phosphine and is enough for 1 000 tonnes of grain. Alternatively, sealed strips of magnesium phosphide plates can be used; each strip contains 16 plates (528 g of phosphine). Blankets are laid on the grain surface and are recoverable intact. Blankets may be up to 30 m apart. The success of this fumigation depends onexcellent gas tightness, since long exposure periods (up to 28 days) should be obtained and points most distant from a blanket may not reach maximum concentration in much less than ten days.

Condensation problems

The lack of ventilation in warehouses designed and sealed for fumigation can result in moisture condensation problems, especially if the grain is insufficiently dry or only marginally well dried. This risk must be kept in mind and appropriate measures should be taken to minimize it or to deal with the problem promptly after the fumigation treatment.

Fumigation in silos

1. Silo bins must be checked for gas tightness before fumigation of grain. (A suitable standard is 500 to 250 Pa in 5 minutes or more). The walls of concrete bins may need sealing. Unless metal bins are of the welded type, all plates and bolt holes must be sealed with tapes and fillers. Eaves must be sealed with padding, foam and impermeable coatings on open-eaved, uncapped bins. Alternatively, gas-proof sheets can be sealed down on top of the grain or over the top of the silo. Outlets must be temporarily sealed with plastic film or tape. A pressure test should be used. It may be useful to have a manometer permanently linked to the bins. Sealed bins must have a pressure-relief valve to prevent structural stress.

2. Methyl bromide fumigation of silos requires closed recirculation. Bins of any depth may then be fumigated. The atmosphere is circulated after introduction of the fumigant until about three complete air changes have occurred. The recirculation system is then stopped. The fans and ducting must be part of the tested gas-tight sealed system to prevent dilution of the fumigant. The recirculation system is also used to aerate the bin after fumigation.

3. Dosages of methyl bromide are given in Tables 14 and 15.

4. Phosphine formulations are generally either probed-in or added to the grain during loading. The former is only suitable for small bins as probing to any depth greater than 5 to 6 m is very difficult. The probing needs to be completed within about one hour and gas masks should be available. In unsealed bins, the top of the grain or the top of the bin must be covered with gas-proof sheet. To fumigate grain with phosphine in deep silo bins, the fumigant must be added to the grain stream as the bin is filled. If grain in a bin is found to be infested it must be turned from one bin to another so that the fumigant can be admixed with it. The calculated dose (Table 13) should be added proportionately to the grain stream until the bin is full. Fumigant preparations can be applied by dropping them through the inspection cover at the top of the bin, or, preferably, onto the moving grain stream on the conveyor belt immediately before it enters the bin. Pellets or tablets can be delivered by an electrically driven automatic dispenser, which is adjusted so that the rate of application matches the rate of flow of the grain, and so that delivery of the pellets stops with the grain flow. The air displaced from the bin during filling will contain some phosphine and it is advisable to test concentrations in the working spaces above the bins and to exclude workers other than those carrying out the treatment, who should be provided with suitable gas masks and instructed in their use. Good ventilation of the working space is essential. It is preferable to complete the fumigation of a bin in one uninterrupted operation.

5. Bins 20 m deep have been effectively fumigated with formulations, such as magnesium phosphide plates, placed on the surface of the grain. The advantages of this procedure are that the formulation can be applied after the bin has been filled, it is less hazardous to apply and the spent formulation is recoverable. The use of low air-flow rates to assist distribution of phosphine have also been described. The safety of these techniques is still being evaluated. Application of the formulation to the surface of grain in bins requires: (a) a very well-sealed bin so that the gas reaches all parts without leakage; (b) a long exposure time (at least 20 days); (c) a headspace sufficient to allow all the phosphine to accumulate without reaching explosive levels; (d) *a low dosage rate (not more than 1 g per tonne)*; (e) a dry commodity and (f) a white exterior to keep temperatures low and reduce moisture migration. *It must be emphasized that despite the advantages of adding the formulation to the grain surface the technique must be used with extreme caution and only by personnel capable of ensuring that the grain and silo are properly dry and filled only to a safe level.*

6. When a bin has been treated, all manholes and openings should be sealed and, preferably, locked and warning notices should be placed near the outlet slide and on top of the bin. At the end of the fumigation period the grain may be run off immediately, if required, but a watch should be kept on any hazard due to phosphine or aluminium phosphide dust in the working spaces. If the grain is left in the bin, most of the

phosphine will disappear in 20-30 days. The effectiveness of the fumigation should be monitored as described in the section on "Fumigation".

Treatment with insecticide

1. When bins and bulk warehouses cannot be made gas tight, fumigation is difficult and the admixture of a suitable contact insecticide may be the most effective means of control. The insecticide can be evenly distributed and measured exactly to correlate with the amount of grain needing treatment. Unlike application of a fumigant, it does not matter if the bin is only partly filled or if filling is slow. Insecticides can also provide persistent protection, although persistent insecticides can only be used where the resultant residues are permitted on the cereal grain.

2. The condition of the grain will determine the length of time than an insecticidal treatment remains effective. Insecticide will persist much longer on cool, dry, clean grain than on warm, moist or dirty grain.

3. The insecticides approved for admixture with grain are given in Table 8. When using these chemicals it is important that only formulations labelled for grain protection be used. One of the following organophosphorus insecticides, malathion, pirimiphos methyl, clorpyrifos methyl, bromophos or fenitrothion, is normally used and may be mixed with pyrethrum or a synthetic pyrethroid where control of tolerant insects, such as *Rhyzopertha dominica* is necessary. Organophosphorus insecticides should be applied at the rate given on the label but, as a general rule, the application rate should be not more than 10 mg/kg. Pyrethroids are applied at a rate of 1 - 3 mg/kg. A table of application rates is given in Annex 8.

4. Dust or spray formulations labelled for grain protection are available, but sprays are easier to apply and generally preferable. Dust application is more difficult, is a greater risk to health and safety and alters the grain bulk density.

5. Dilute dusts containing 1 percent insecticide are the least stable formulations and should not be kept long before use. A well-formulated dust from a reliable manufacturer may be fully active for two years, but poorly formulated dusts may become inactive within a few weeks. Dusts should be added to the grain by means of a powder feeder, usually an electrically operated vibrator, at a rate of 500 g per tonne for 2 percent malathion or at the appropriate rate for an alternative insecticide. The output of the feeder must be adjusted to suit the grain-conveying rate. Dust vibrators are not suitable for conveying rates of less than five tonnes per hour.

6. The normal application rate for organophosphorus sprays is 0.5 - 1 litre of 2 percen or 1 percent spray per tonne. The application of this volume of water does not significantly alter the moisture content of the grain.

7. Grain sprayers should be set up to give a continuously measured spray of insecticide to all grain passing into the bin or flat-bulk storage. A commercial grain sprayer consists of a pump, suction hose and filter to be placed in a tank or drum of dilute insecticide emulsion, by-pass hose to provide agitation in the tank, spray hose leading to a pressure regulator, pressure gauge, lance and nozzle. A reserve insecticide tank is needed to allow for continuous use. The sprayer should be fixed to the conveyor as close as possible to the point where the grain is discharged into the bin or bulk warehouse. The grain should be treated after drying and cleaning but not while it is still warm from the drier. The equipment must be placed where it can be easily inspected and serviced. Considerable quantities of water may be needed and the water source should be close to the spray tank. If there is only one sprayer for several bins, it must be portable. The nozzle should be mounted about 20 cm above the grain band. The sprayer should be connected and controlled to start spraying when the grain begins to flow and, equally important, to stop spraying when the conveyor stops. The application rate should be set according to the grain flow rate and adjusted if the grain flow is changed. It is, therefore, necessary to know the rate of flow of the grain, which may be up to 400 tonnes per hour, and from this to calculate the required rate of spray flow. The required rate of flow for insecticide spray is obtained by choosing appropriate nozzles and spraying pressures, which should be given in the manufacturer's instructions.

8. Frequent checks are necessary to maintain the tank of dilute insecticide emulsion, to adjust the spraying pressure when necessary, to obtain the correct application rate, and to maintain nozzles and filters clean and undamaged. Constant attention may be needed to prevent blockage when treating dusty grain and, in any case the sprayer should be checked and filters cleaned daily.

ROUTINE INSECTICIDE TREATMENTS IN STORES

Wall spraying

The technique of fabric spraying has been described in the section on "Treatment of Store Fabric". This spraying should be carried out in an empty store before it is filled. Respraying may be necessary at intervals, depending on the surface treated, the insecticide used and the degree of re-infestation that occurs. In some circumstances monthly spraying may be necessary, whereas in other circumstances spraying once or twice a year may be sufficient. Application rates are given in Annex 8.

Protection of stacks

Fumigation confers no long-term protection and fumigated stacks are immediately open to re-infestation when the fumigation sheets are removed. To protect stacks against re-infestation, certain procedures may be followed:

- The fumigation sheets may be kept permanently in place.
- The outside of the stacks may be sprayed with insecticide.
- The stacks may be covered with cotton or hessian cloth and sprayed with insecticide.
- The store may be regularly disinfested by misting or spraying.

The system adoptem may be one or a combination of these procedures, depending on the availability of materials, the local regulations governing the use of insecticides on bags, the state of the store and the type of re-infestation likely to occur. Whichever procedure is followed, it must be monitored by careful and regular inspection (Chapter 5) and changes made, if necessary. It must also be a fundamental principle governing the pest control system that newly fumigated stacks should not be exposed to infestation from adjacent infested stacks awaiting fumigation.

Retention of fumigation sheets

Good protection may be obtained by keeping fumigation sheets on the stacks, but this technique will only be possible in certain limited circumstances, following phosphine fumigation, when plenty of inexpensive sheeting, probably polythene film, is available and if the commodity is very dry. If this method of protection is followed, care must be taken that moisture migration in the stack and sweating inside the sheet does not cause deterioration at the edges of the stack.

Stack surface spraying

A commom method of protecting against re-infestation is by spraying the outside of the stack with insecticide (figure 64). The first spraying should be applied just before fumigation with a motorized or hand knapsack sprayer (See section on "Treatment of Store Fabric"). The top and the sides of the stack must be well sprayed. A wettable powder formulation is preferable, but an oil solution or an emulsifiable concentrate may also be used. A guide to application rates is given in Annex 8. The insecticides pirimiphos methyl, fenitrothion, bromophos and chlorpyrifos methyl are recommended generally at an application rate of 0.5 or 1 g/square metre. The synthetic pyrethroid permethrin may also have potential value for this type of use. The spraying of either jute or woven polypropylene bags leaves insecticide residues in the commodity, but the overall residue is likely to be fairly low. Nevertheless, high residues could occur near bag surfaces and,

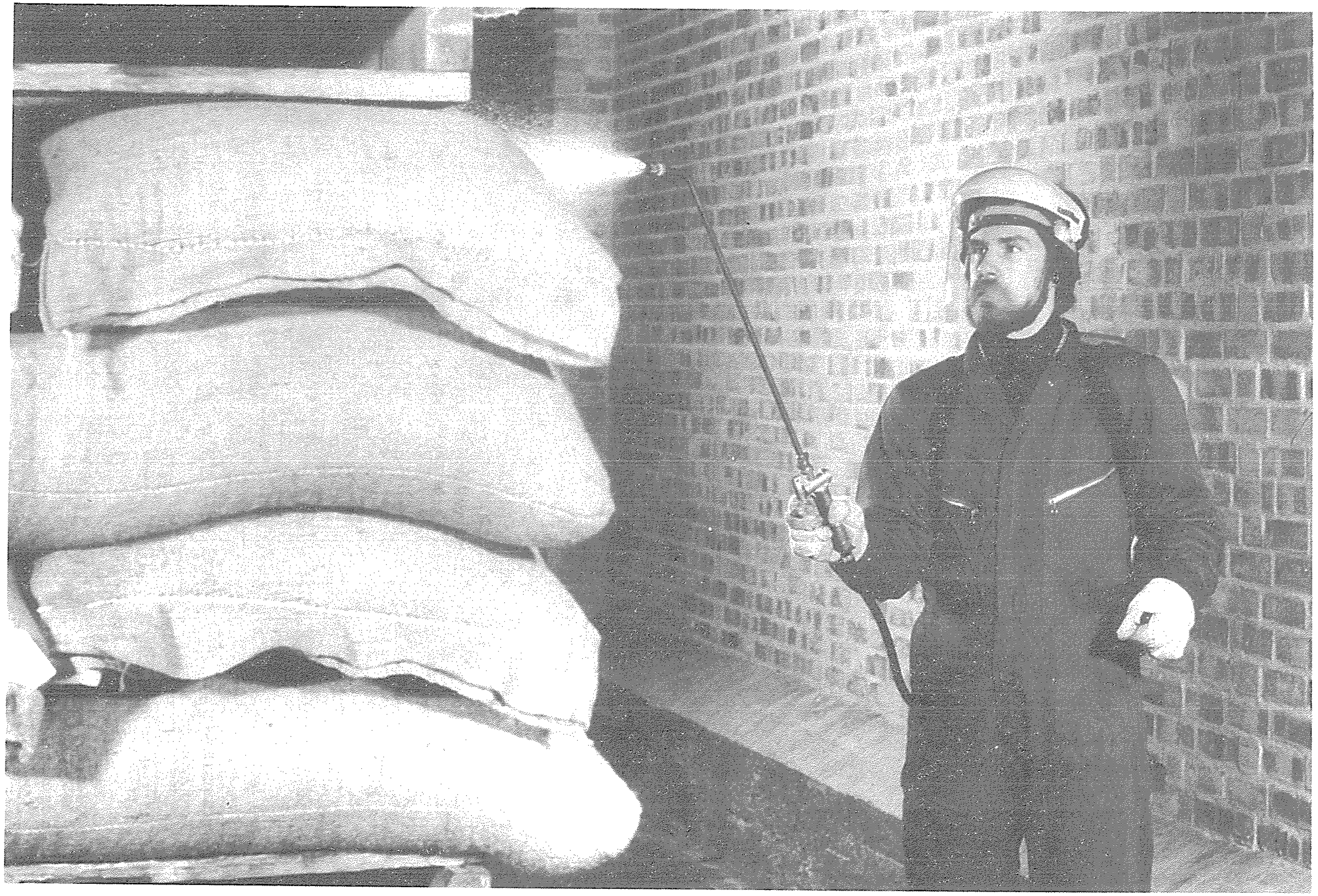


Figure 64. Stack spraying.

therefore, only approved insecticides should be used (Table 8). Some authorities do not permit the use of any insecticide sprays on bags of grain.

Instructions on the use of sprayers and on dilution and application rates are given in the section on "Treatment of Store Fabric". The length of effective protection is difficult to predict but cannot be expected to be more than a few weeks. However, frequency of re-spraying must take into account the accumulation of residues and spraying should not be more frequent than once every three months.

Sprayed stack covers

Increased protection is obtained, with smaller residues on the grain, if the stacks are covered with sheets of muslin, cotton baft or light hession cloth and the insecticide is sprayed on the outside of these covers rather than on the stack itself. The cloth must completely cover the stack, with an overlap on the floor, to be reasonably effective against beetles, but even an unsprayed cover may give some protection against moths. The main disadvantage is the extra cost and effort in making and handling the covers. There is also the possibility that the covers may themselves harbour dirt and infestation if they are not properly maintained.

Space treatments

It has been generally found that spraying stacks with organophosphorus insecticides does not give complete protection, particularly against moths, and usually needs to be backed up by some treatment of the store space. In space treatment, the pesticide is dispersed in air either as a vapour or as a mist, fog or smoke. A sound, well-closed structure is required and windows, doors and eaves should be closed, but the store does not need to be gas tight as it would for total store fumigation. (Space treatment is sometimes erroneously called "fumigation", but this term should not be used as the treatment is quite different to fumigation in the storage sense. In structures that are gas tight and fumigable, insecticide space treatments are unlikely to be required.) Space treatments are particularly effective against flying insects, such as moths, and regular space treatments should be carried out where such insects are a problem. Moths are most active at dusk and this is the best time for the treatment to be applied. Treatments may be applied daily, twice weekly, weekly or at longer intervals, depending on the nature of the treatment, the rate of application and the degree of control required. Some alternative treatments are given in Table 17. Low application rates applied frequently are obviously preferable for protecting stacks from re-infestation by flying insect pests, but greater frequency may mean higher cost for both personnel and machinery. Space treatments are not a substitute for surface spraying and may not leave an active deposit. However, space treatments may enable inaccessible surfaces to be reached and, if the application rate is increased when using smokes or if the droplets of fogs are altered to produce the so-called "wet" fogs, a surface deposit may be obtained.

Mists

Mists are produced by the shearing effect of an air blast on a liquid or by dispersion of the liqued from a high-speed spinning disc. Mist blowers may be either electrically driven or powered by petrol or diesel engines and may be regulated to give different droplet sizes and different output rates. In a fine mist the diameter of the droplets is in the range of 20 to 50 µm and in a coarse mist droplet diameters are mainly in the 50 to 100 µm range. The liquid output of mist blowers may vary from 3 to 60 l/h and the volume treated from 150 to 350 cubic metre/minute. Ready to use formulations of insecticide in light oil (e.g. odourless kerosene) are normally used, but water-based formulations can also be used in some types of mist blower.

The frequent application of small quantities of insecticide may be the most effectiv method of preventing infestation by flying insects. This is most easily achieved by coupling a mistblower with a timer (figure 65) to control the release of a small dose at a certain time every day. Early evening may be the best time to catch insects in flight. The treatment should continue unaided except for refilling the insecticide reservoir, checking that the clock gives the right time and occasional maintenance. A well-closed store, with closed eaves, is needed to prevent rapid loss of the small dose. The recommended daily application rate for dichlorvos insecticides is given in Table 17.

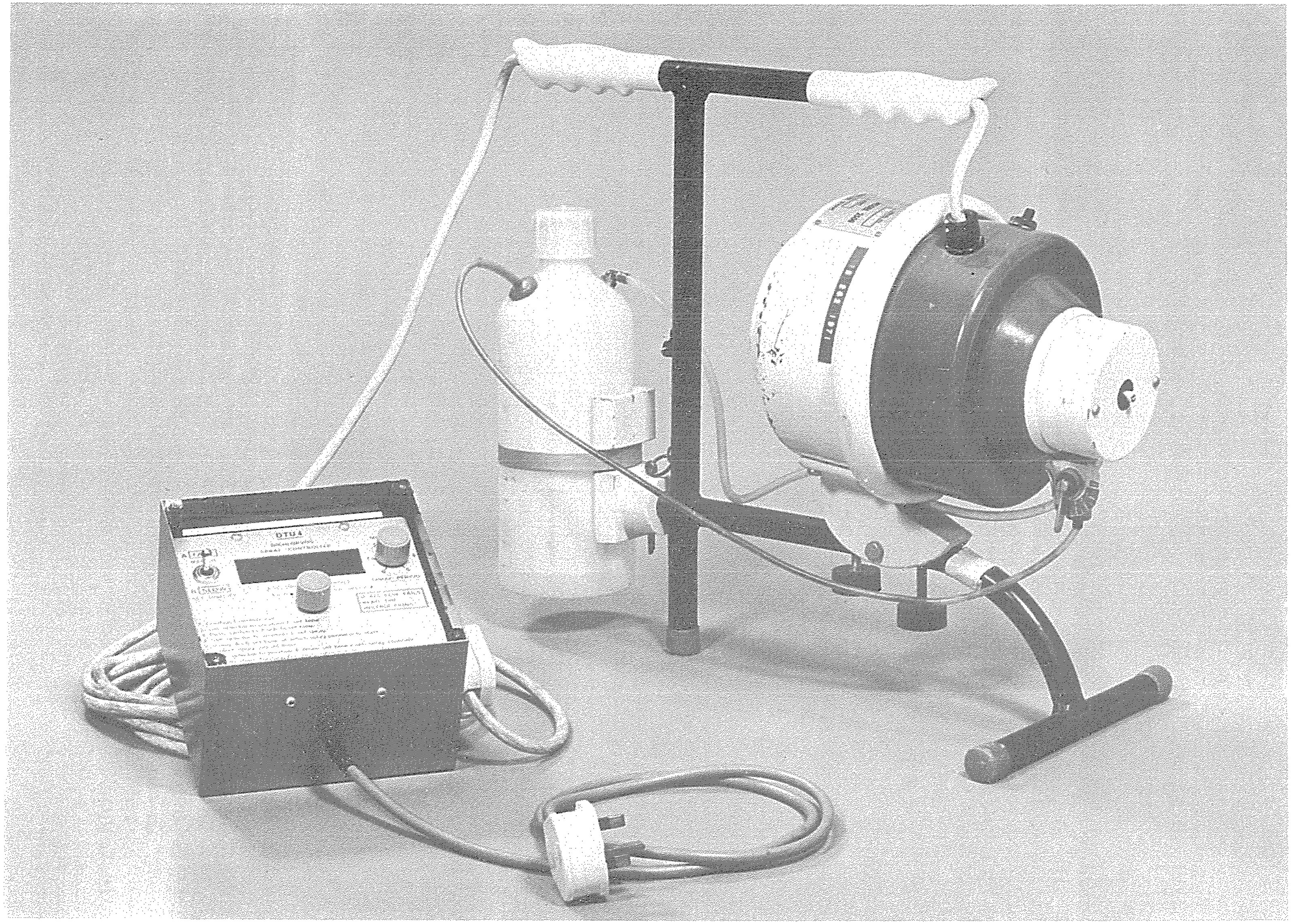


Figure 65. Automatic mist blower.

TABLE 17. Application rates for space treatments

Insecticide	Type of Treatment	Recommended Application Rate (active ingredient)
Dichlorvos*	Single or occasional misting	35 to 70 mg/^{3}
	Weekly or twice-weekly misting	15 to 30/mg/^{3}
	Daily misting	5 to 10 mg/m^3
	Strip dispenser	1 per 30 m^3 space
Pirimiphos methyl (Actellic)	Fogging	50 to 100 mg/m^3
	Misting every 2 weeks	20 mg/m^3
	Smoke (every few weeks)	35-40 mg/m^3
Pyrethrins synergised with piperonyl butoxide (1:5)	Occasional misting or fogging	1.5 to 3 mg/m^3 applied as 1 litre of 0.3% to 1 000 to 3 000 m^3
	Daily application by automatic misting	1 mg/m^3
	Treatment to obtain a residual deposit	25 - 45 mg/m^3 applied as 15 litres of 0.3% to 1 000 m^3
Bioresmethrin or synthetic pyrethroid mixtures	Misting	0.5 to 1 mg/m^3
Lindane	Smoke for residual protection against beetles	100 mg/m^3
	Smoke for immediate effect on moths and flies	25 mg/m^3

* Formulation obtainable as 7 percent w/v to 100 percent w/v solution for direct application without dilution.

Vapour dispensers

The volatile insecticide dichlorvos may be formulated in plastic or resin strips, from which the insecticide slowly vapourizes over a period up to three months, maintaining a continuous low concentration in enclosed spaces. Dichlorvos strips should be used in confined spaces (figure 66) such as the head space of bins or in small enclosed stores. They may not be effective in large warehouses or well-ventilated stores.

Fogs

Fogging solutions are insecticides dissolved in heavy oil, such as technical white oil. Thermal foggers (figure 67) are petrol engines producing a blast of hot air into which the insecticide in oil solution is injected. When this hot air blast meets the cooler surrounding air, a fog is formed. Fogs suitable for the control of flying insects have particle diameters generally below 10 µm. A cooler, wetter fog (particle size 10 to 50 µm) can be produced if the oil is partly replaced by water; this may be used at a higher application rate to form a deposit against crawling pests. The fog generators may be hand held or trolley mounted. The output of the large, trolley-mounted foggers varies from 25 to 400 l/h and the volume treated in the region of 200 to 500 cubic metre/minute. The hand-held fogger has an output of 10 to 30 l/h. The higher output produces a coarser fog. The fogger can treat 250 cubic metre/minute.

Smoke generators

Smoke generators contain insecticide mixed with chemicals that can be ignited to burn and produce large volumes of dense, white smoke. These formulations should be used as a substitute for fogging in small and confined premises against moths and other flying insects. A limited effect may be obtained against crawling insects if higher dosage rates are used (Table 17).

When to treat

Space and surface treatments should be used to back up fumigation and prevent re-infestation. No definite, pre-determined treatment schedule can be given, as the need for insecticide treatment varies so widely with climate, location and type of store.

Simple inspection procedures (See section on "Routine Storage Procedures") should be used to determine when to apply treatments and subsequently to record how effective they have been. After some experience, regular routine treatments may be found to have advantages compared to intermittent treatment only in response to need. One obvious advantage is that a regular treatment is less likely to be overlooked. However, the routine treatment must be kept constantly under review and changed if it fails to meet the need.

Surface treatments are mainly used to control beetles and smokes are mainly used against moths but may also have a useful effect against crawling pests. Insecticides that can be used for stack surface spraying are given in Table 8 and the recommended application rate is given in Annex 8. The technique of surface spraying is described in the section on "Treatment of Store Fabric". In applying sprays to bags, the danger of residue accumulation must be kept in mind.

Space treatments, such as fogging and misting, are mainly used to control moths, e.g. *Ephestia* spp., *Corcyra cephalonica* and *Plodia interpunctella*.

Pyrethrum, synthetic pyrethroids, dichlorvos and pirimiphos methyl are the insecticides normally used for space treatments in stores. Recommended application rates are given in Table 17. Dichlorvos is considerably more volatile than the other insecticides and, for that reason is suitable for dispensing as a vapour from automatic or strip dispensers. It is effective even at concentrations below 1 mg/l. Pirimiphos methyl has moderate volatility suitable for mists and fogs. The pyrethroids have low volatility, but they are active against flies and moths when applied in the form of aerosols, mists and fogs. Most pyrethroids do not persist on stack surfaces, because they are unstable to light, but recently developed photostable synthetic pyrethroids may persist and provide a useful residual contact effect. Doses applied frequently may be most effective against

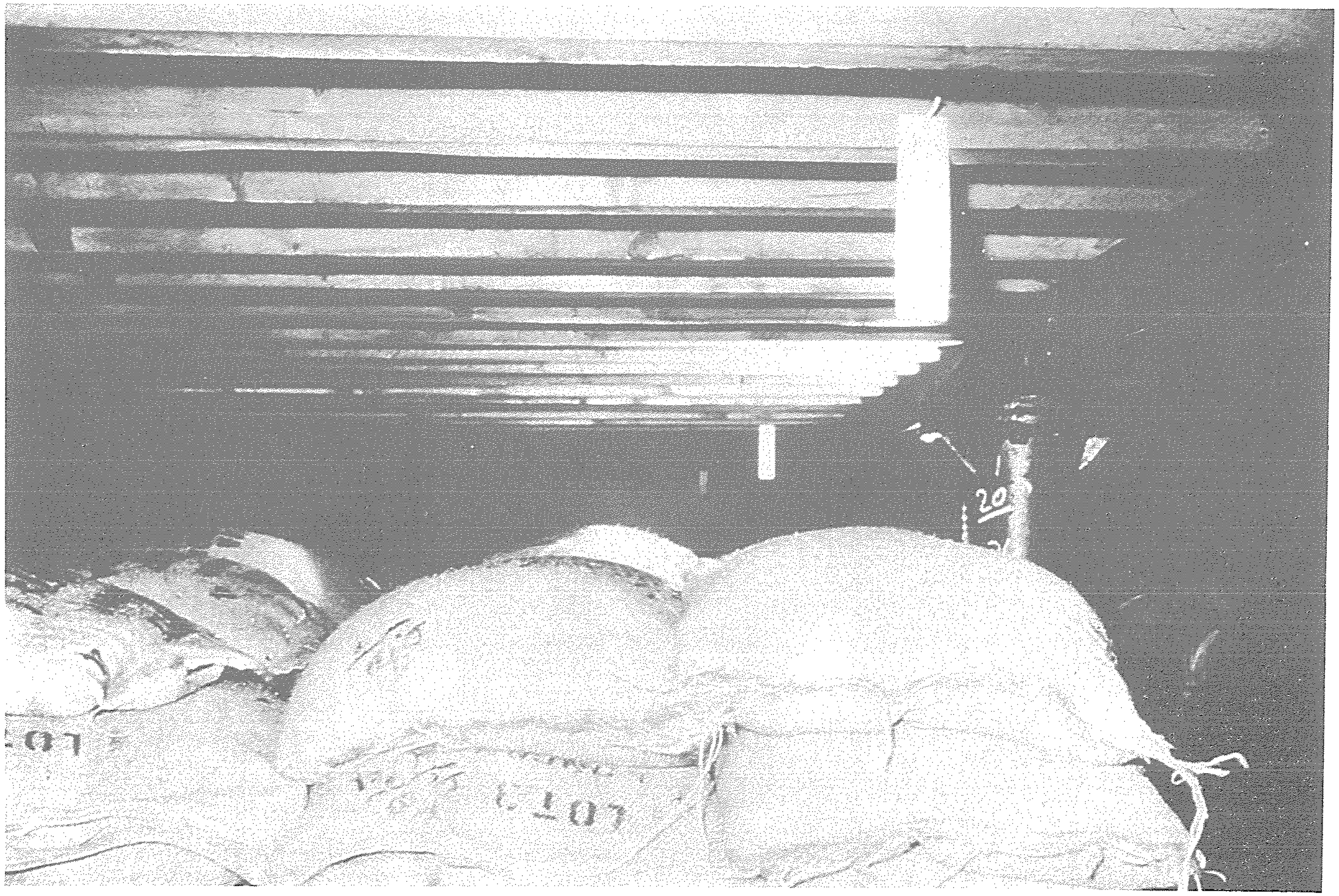


Figure 66. Dichlorvos dispensers used in a confined store.

Figure 67 a. Thermal fogger.

Figure 67 b. Protective clothing for space treatments.

moths and the automatic daily misting is the most frequent form of treatment. However, if a store is not very well closed, a less frequent, more thorough space treatment may be more effective.

Treatment technique

- Space treatment should be carried out in fairly well-closed premises, preferably with closed doors and eaves.
- Treatments should be carried out at the time of maximum insect flight activity and least wind speeds, normally at dusk or dawn.
- Stores must first be thoroughly cleaned and debris removed.
- Protective clothing, particularly rubber gloves and respirators, must be used (See section on "Maintenance of Safety"). (figure 67 b)
- Foggers must be handled with care, particularly to prevent anyone standing in front of the machine while it is being started. The correct oil must be used. Electrical apparatus must be turned off and naked flames extinguished. (Insurance could be invalidated if foggers and smoke generators are improperly used.)
- Care should be taken that the oil does not spoil plastic surface or cause slippery deposits on floors.
- Treatment should be made from outside, if possible. If not, the operator should move from the closed end towards the exit and the treatment should be finished from outside. Similarly, smoke generators should be lit starting with the furthest from the exit and progressing to the exit. Care should be taken to distribute the devices evenly on the floor of the store before any are lit.
- The store should be closed, with warning notices displayed, and left unoccupied for 24 hours. Ventilation may be necessary before normal work can be resumed.

CONTROL OF VERTEBRATE PESTS

Rodents

Rodent prevention should begin with strict attention to environmental hygiene, rubbish disposal inside and outside of the store, maintenance of a vegetation free area around the store and rodent proofing of the store structure (See Chapter 1, "Rodent and Bird Proofing"). Frequent inspections (See Chapter 3, "The Detection of Rodents" and Chapter 5, "Measures During Storage") should be carried out followed, if necessary, by the control methods described here.

Anticoagulants

Rodent infestations may be controlled either by poisoning or trapping with the former being generally more effective. Two kinds of poisons, the multiple dose poisons and the single dose acute poisons, are used. The multiple dose poisons are safe and effective and are mostly anticoagulants, which act by preventing blood from clotting, thus leading to death from internal haemorrhages. The poison acts slowly and may need to be taken in repeated doses over several days, although the most recently developed anticoagulants can be effective after a single feeding. A lethal dose has generally been taken before the rodent becomes too ill to feed and other rodents do not, therefore, become shy of the treated food. Anticoagulants are applied by addition to food baits and differences in effectiveness are often due to differences in the acceptability of the bait.

The common anticoagulant rodenticides are listed in Table 18. Warfarin is the most widely known and used. The ship rat and the house mouse are both more tolerant to warfarin than the common rat and require a dose two to four times greater. Resistance to warfarin is fairly widespread in all three species, but control by other anticoagulants is more difficult in the ship rat and the mouse than it is in the common rat. Chlorophacinone and diphacinone have limited effectiveness against resistant rodent populations, but difenacoum and brodifacoum are effective against rats and mice resistnat to other anticoagulants. Most of the newer compoinds are more toxic and are used at 0.005 percent (50ppm) compared to 0.025 percent for warfarin. A single dose may be sufficient in the case of brodifacoum, which could be a great advantage particularly for mouse control, as this rodent may frequently vary its feeding site. Calciferol (Vitamin D_2), either alone or in combination with warfarin, may be effective against anticoagulant resistant rodents.

TABLE 18. Common anticoagulant rodenticides

Common name	Single dose (a.i.) Acute Oral LD_{50} *Rattus norvegicus* (mg/kg body weight)	Concentrate (percent)	Ready to use bait (percent)
Warfarin	60 - 186	0.5 to 1.0	0.025-0.100
Coumatetralyl	16	0.75	0.038
Chlorophacinone	20	0.25	0.005*
Diphacinone	3	0.1	0.005
Coumachlor	900	0.5 to 1.0	0.025
Calciferol + Warfarin	-	-	0.1 + 0.025
Difenacoum	1.8	0.1	0.005
Brodifacoum	0.26		0.005

* 0.005 percent is equivalent to 50 ppm.

Baits and baiting

Anticoagulants are obtained either as ready to use baits, at concentrations varying from 0.005 percent (50 ppm) up to 0.100 percent(Table 18), or as concentrates containing 0.1 to 1 percent of rodenticide. These concentrates usually require dilution before use at the rate of one part of concentrate to 19 parts of bait. The ready to use baits are more convenient, but generally more expensive and do not permit the variation in bait that may be necessary in some circumstances. The manufacturer's instructions for dilution of the concentrate should be closely followed. A large number of possible ingredients can be used successfully in bait, including barley meal, maize meal, wheat meal, cut wheat and whole wheat and it may be worthwhile to try out new combinations of locally available materials. The continued use of a preparation should be reviewed according to the success obtained. Ground cereals can be directly mixed with most rodenticide concentrates. Dry medium ground or crumbled cereal is often successful and should be tried first. Damp baits are generally more attractive than dry baits and should be tried if dry bait proves unattractive. However, they tend to dry or mould and so have to be replaced frequently, which is inconvenient when the poisons need to be left for long periods. Preservations may be used in damp situations, for example 2.5 g paranitrophenol or 1 g dehydroacetic acid per kg of bait, but these preservatives may lower the palatability of the bait and should not be used at greater than the recommended concentration (paranitrophenol is itself a dangerous poison and should not be inhaled or spilt on the skin). Ready to use baits have a preservative already added. Whole or coarsely ground cereals are attractive but need a little water or oil to get the concentrate to stick to the bait. If a vegetable oil is used, the initial attractiveness of the bait is increased but the oil may turn rancid and reduce the palatability of the bait.

Alternatively, whole grain wheat can be soaked in water overnight and mixed with the concentrate after excess water has been drained off. Some rodenticides may be available as water soluble preparations, which may be added in solution to whole or coarsely ground cereals.

For mixing baits, buckets with close fitting lids should be used to prevent accidental poisoning. A balance is needed, although it may be easier to measure volumes instead of weights by improvising measures to hold known weights of bait or poison.

The most important principle in anticoagulant baiting is to keep plenty of bait available until the rats stop feeding on it. Baits should be placed in piles, on rodent runs or near entrance holes, as close as 1 m apart in a heavy infestation, on a tin lid or board, if necessary, to protect them from damp ground. Baits should be covered to keep out other animals and provide protection and seclusion (figure 68). About 100 to 200 g for rats and 25 g for mice should be placed at each point and a careful record kept. Baits should be inspected twice per week and replenished as necessary. If most of the bait is being taken, the amount should be increased to at least twice the former amount.

After about a week of baiting, the consumption of bait should rapidly decline as animals begin to die, and ultimately feeding on the bait should stop altogether. Cessation of feeding might occur within three weeks for common rats, four weeks for ship rats and five weeks for house mice, but this would depend very much on the situation and the material used. A few days after feeding has stopped, a fresh survey should be made. If the evidence shows that some rodents have not been killed, a different bait or a different poison might be tried, the number of bait and drinking points might be increased or the need for using or extending the use of a contact rodenticidal dust might be considered.

In dry warehouses it may be difficult to attract rats to baits and it might be more effective to poison the drinking water with water-soluble warfarin or diphacinone. All alternative water sources should be eliminated. Chick founts make good containers for the poisoned water and keep it clean and fresh. Some anticoagulants are obtainable as tracking powders that are formulated to adhere to rodent's fur and these may be effective if baiting fails.

In some circumstances bait may continue to be taken by rodents long after the periods given above. This may happen because there is continuous re-infestation of the site, as shown by evidence of variable levels of rodent activity and newly-poisoned animals continuing to be found on the site, together with evidence of neighbouring infestations on adjacent sites. If the site is particularly susceptible to re-infestation, even though all practicable hygiene and proofing measures have been taken, bait containers should be installed at appropriate places and baiting continued indefinitely as a preventive measure. Bait boxes, pipes or drums can be used. Anticoagulant bait, 1 to 2 kg, should be put down and inspected monthly. In humid climates a mould inhibitor may be needed. However, if bait consumption and other rodent activity continues at a fairly steady or gradually increasing level and there is evidence that rodents are not being killed, it is likely that they are resistant to the anticoagulant poison and the circumstances should be reported to the appropriate authority. The survivors should be treated with an acute poison using the anticoagulant as a "pre-bait".

Acute poisons

Acute poisons act rapidly and usually kill rodents after a single feed. They may be used where speed is essential. When inattention to control has led to the build-up of large rodent populations, acute poisons may quickly prevent further damage.

The acute poison treatment should be rapidly followed up with anticoagulants to dispose of any survivors. Acute poisons may also be used in situations where resistance to anticoagulants is suspected. These, like anticoagulants, are mainly used mixed with bait, but they differ from anticoagulants in that best results are generally obtained if unpoisoned

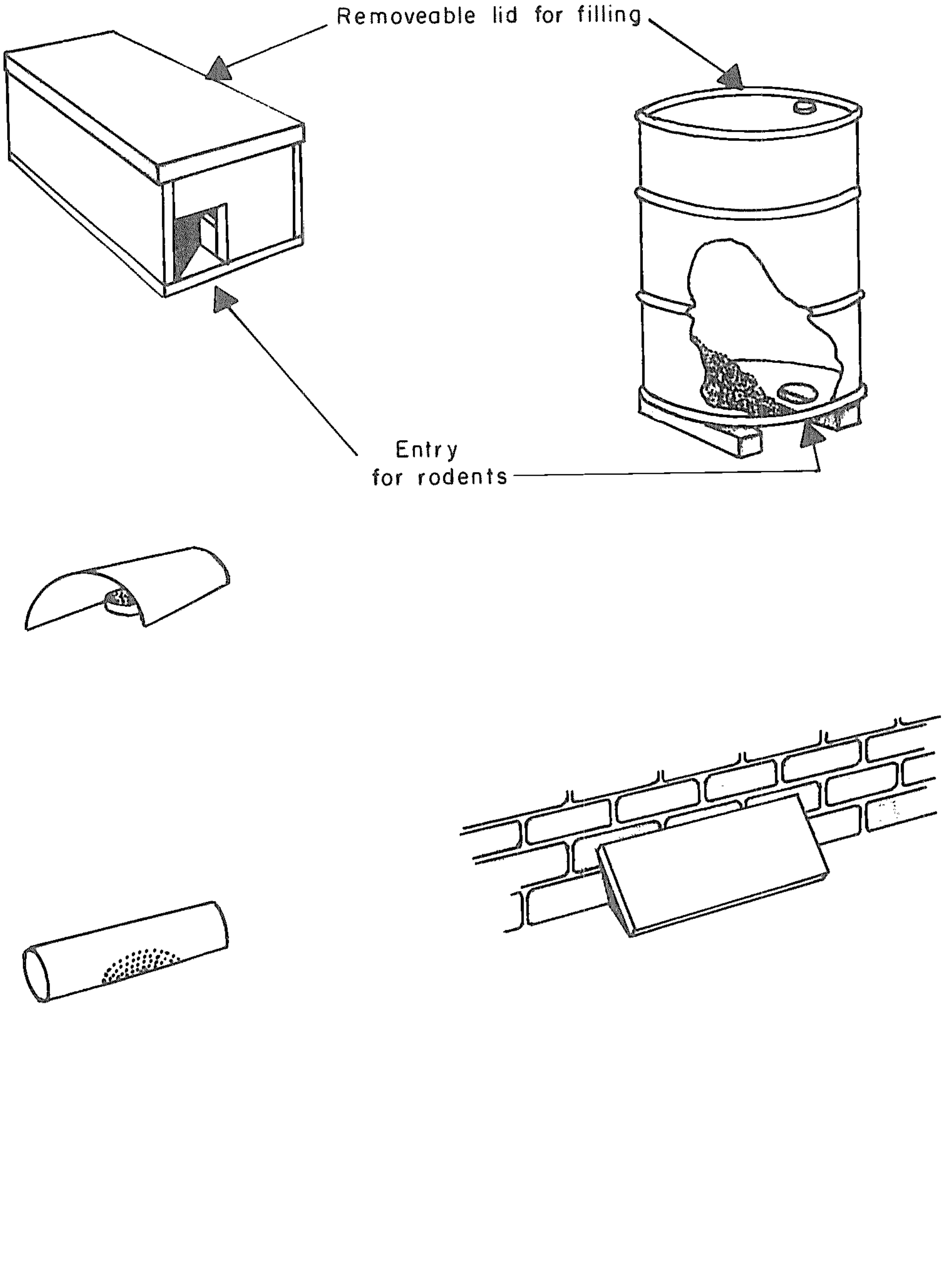


Figure 68. Simple containers and covers for rodent bait.

baits are first laid for four to eight days. When the rodents are judged to be freely taking the bait, poison bait should be put out for the next one or two nights. This technique, known as pre-baiting, allows the rodents to become accustomed to feeding at a particular place and on a particular bait, so that when poison is laid they are likely to feed on it readily and rapidly. Rapid feeding is also likely to be encouraged if the bait is damp and if disturbance in the treated area is kept to a minimum during the critical period when the poisoned bait is laid.

A list of the most useful acute poisons, together with the concentrations at which they should be used against different rodent species, is given in Table 19. Some of the compounds listed are banned in some countries due to hazard or cruelty. Only officially approved compounds should be used. Formulations may be either ready to use baits or concentrates requiring dilution. Dilution of the purchased products should follow the manufacturers' instructions.

Acute poisons should be made available to rodents for only one or two nights, particularly after pre-baiting. After the poison has been removed, a few days should be allowed for any animals that have taken sub-lethal doses to become active again. The area should then be re-surveyed and baits of a different type laid where rodents might still be present. When "takes" of the new bait have occurred, poison bait should again be laid using a different poison. This process of pre-baiting and poisoning should go on, if possible, until no rodents are left.

TABLE 19 Acute rodenticides

Name	Percent by weight used in bait	Use
Zinc phosphide	1 - 5	All species
Arsenious oxide	3 - 10	Rats only
Norbormide	0.5 - 1	Rats only
Red Squill	10	Norway rat
Sodium fluoracetate (1080)	0.25	All species
Fluoracetamide	2	All species
Thallium sulphate	0.5 - 1.5	All species
Antu	1 - 3	Norway rat only
Alpha-chloralose	4	Mice only, below 18°C
RH 787	2	All species

Tracking powders

In situations where food is plentiful, bait may not be taken and it may be easier to kill rodents by the use of tracking powders. These are powder formulations containing a high concentration of poisonous active ingredient, such as lindane or DDT at 20-50 percent strength or anticoagulants at 1 percent. The powders should be scattered on surfaces where rodents walk to be picked up on the feet and fur and later ingested during grooming. The powders should be laid along runs in patches about 0.5 metres long and about 2-3 mm deep, or blown into the burrows with hand-operated dusters. Great care must be taken to ensure that tracking powders do not come into contact with foodstuffs in any way and are not laid where other animals can come in contact with them.

Trapping

Traps are unlikely to be an effective means of rodent control when used alone in large food stores. However, they can be useful to catch survivors of a poisoning treatment. Traps should be located against walls and where rodents run near cover rather than in open areas. The treadles of breakback traps should lie across "rodent runs". For control of rats, baited but unset traps should be laid for several days in order to prevent development of trap shyness. For mice, traps can be baited and set immediately. The bait may have to be varied until a type is found that will successfully attract the local rodent population. Grain, nuts or fruit (mango) may prove suitable alternatives.

Miscellaneous methods

Gassing powders containing sodium cyanide or metallic phosphides are very effective in rat burrows. However, because of the dangers of persistence of the toxic gases hydrogen cyanide and phosphine, these powders are not used in stores.

Rodents are sensitive to ultrasonic waves and ultrasonic generators are marketed, which are claimed to be effective in repelling rodents from stores. These have proved ineffective in tests owing to the lack of penetration and dispersal of the ultra sound.

Domestic pets can generally not be relied on for control of serious rodent infestation.

Special procedures and chemicals for mouse control

Mice tend to be more difficult to kill than rats because they may live for long periods in the interior of stacks of bagged food commodities and may not, therefore, succumb as easily to poisoned baits as rats. They may survive without drinking for long periods, so that water may not attract mice even in a dry store.

Mice prefer to feed by sampling at many points rather than at one location and small amounts (25 - 50g) of anticoagulant bait should be placed at several sites, about two metres apart, and replenished daily for several weeks.

Mice are less easily killed by anticoagulants than rats and acute poisons such as zinc phosphide may be used with more success. At temperatures below 18°C alpha-chloralose is an effective acute poison for control of mice but the temperature requirement limits its use in tropical areas.

Poisoned tracking powders can be useful in mouse control if baiting is nto effective.

Calciferol in combination with warfarin or alone on canary seed has been found to be especially effective in mice resistant to anticoagulants.

Reasons for control failure

If rodents are not killed by a poisoning treatment, a number of factors must be examined in order to determine the reason for failure.

1) Is the bait being taken at all? If not, the choice of bait may be incorrect and further investigation is required by test-baiting with unpoisoned food to find an acceptable material. This applies to bait used for anticoagulant or acute poisons.

2) If anticoagulant bait is taken but no control is achieved, there are several possibilities:

   a) The period that bait is exposed is too short.

   b) Insufficient bait is being given, with none remaining from one baiting to the next replenishment.

c) Baiting points are too few and too far apart.

d) The rodent population is resistant to the anticoagulant employed and expert assistance must be sought.

3) If anticoagulant baits are taken sparingly it may be for one of several reasons:

a) The bait itself may be a poor choice or improperly formulated.

b) The bait may be badly sited.

c) Too many alternative and palatable food sources are available to the rodents.

d) The bait is old or mouldy, rancid or insect infested, is unpalatable and needs frequent renewal.

e) The quality of the anticoagulant is poor or it arouses suspicion.

4) If acute poisoned baits are taken but control is not achieved, the prebaiting technique should be employed with a different unpoisoned bait for about a week before poison is introduced into the new bait.

Other vertebrate pests

Food stores may become infested and damaged by birds and bats, but they are minor pests compared to rodents. Control measures are usually aimed at exclusion rather than killing. Use of wire screens over ventilators and other openings will prevent entry. Bats cause a considerable amount of contamination on the tops of stacks of bagged or bulk grain. They can be driven out with lindane smokes. Electronic bird scarers, which emit the sounds of predators, are alleged to keep storage buildings free of bird pests.

Poisoning should be used only when other methods fail. As there is a risk that poisoned birds may be eaten by other animals, the poison must be carefully selected and its use strictly controlled. Strychnine is effective in small dosages but is highly toxic. Sodium fluoride may also be used on grain and meal baits. Other more specific acute, repellent or sterilizing poisons may be used as available. Usually a period of pre-baiting with non-toxic bait will improve the effectiveness of the treatment.

Safety in vertebrate control measures

Safety precautions are a necessity during all stages of vertebrate control. Operators carrying out the work are at risk in a number of ways and must be made aware of the dangers involved.

1) Only experienced personnel should be permitted to handle, mix and apply acute poisons or gassing powders. Fluoracetamide, sodium fluoracetate thallium sulphate and other rodenticides are extremely toxic chemicals and can be very dangerous in unskilled hands.

2) All operators should be provided with face masks, since many of the dusts used in rodenticidal baits are poisonous if inhaled. Face masks give no protection against phosphine, which is released as a gas from zinc phosphide and must be mixed in the open unless respirators are worn.

3) Poisons should not come into contact with the skin or the mouth and plastic or rubber gloves that can be washed before removal must be worn when mixing poisons. Water must be available for washing when poisons are prepared. All utensils for mixing should be well washed as soon as possible after use.

4) Smoking and eating where rodenticides are prepared or stored must be forbidden.

5) All poison baits and concentrates must be securely held in a locked store in the original labelled container and only made accessible under proper authority.

6) When baits are laid in a store, they should be clearly labelled and marked dangerous. They should not be allowed to come in contact with human or animal food.

7) When a poisoning treatment is complete or baits become stale, they should be removed and burnt or buried together with any dead rodents recovered. Burial should be sufficiently deep to prevent access to dogs or cats.

8) Operators must wear gloves hen handling dead rodents as these can carry insects and mites capable of transmitting disease from rodents to humans.

MAINTENANCE OF SAFETY

All insecticides, fumigants and rodenticides are, in varying degrees, toxic and potentially hazardous to human beings. The maintenance of adequate safety standards is an essential part of efficient pesticide usage. Accidents may occur even in apparently safe conditions and compounds considered safe may produce toxic effects from long-term exposure to small doses. Measures should, therefore, be taken to prevent accidents, to avoid regular exposure of personnel to small doses of pesticides because of poor technique and to be prepared for any emergency that may arise.

Protective clothing

Overalls

Overalls of durable cotton fabric are necessary to protect against sprays and dusts. These must be regularly washed, otherwise they can accumulate pesticide and lead to contamination of the wearer.

Gloves

Gloves made of neoprene of PVC and long enough to protect the wrists should be worn for the handling of pesticides, particularly for the dilution of concentrates or weighing of dusts. They should be frequently rinsed to prevent contamination. Gloves should not be worn for methyl bromide fumigation, because there is a danger that the harmful caustic vapour may be trapped against the skin.

Respirators

Although it should be the practice during fumigation not to enter a toxic atmosphere, whether wearing a respirator or not, sutiable respirators should be held by all persons taking part. In the event of an accident, or more frequently a leak, a respirator is vitally important. A respirator consists of a rubber face piece fitted with a glass window for vision and connected to a canister by a flexible rubber tube (figure 52). The canister contains a small quantity of absorbent to remove the fumigant from the inhaled air. An appropriate canister must be fitted for each gas.

The following classification is sometimes used:

Methyl bromide	Type P
Phosphine	Type CC
Liquid fumigant	Type C

Respirators are only effective at low gas concentrations. At about 2 percent methyl bromide and 1 percent phosphine, the normal canister has a life of about 10 minutes. Some fumigant passes through at higher concentrations while at lower concentrations the canister should have a proportionately longer life. No indication is given when canisters are partially exhausted or about to fail and they must, therefore, be replaced in good time so that complete operator protection is maintained.

When not in use, the seal on the canister must be replaced. Sealed canisters have a shelf life of two to five years. Canisters that have been opened but not exposed to fumigant may last for one year. After exposure to high concentration of gas, a canister should be replaced at once. Respirators must be kept in good condition and regularly checked for defects.

It is preferable to use a respirator fitted with a long tube so that the canister can be worn on the back. It is then easier to move around narrow spaces and, when the wearer is bending over the cylinder or piping, the opening in the canister is further away from possible leakage points.

It is most important that the respirator should fit properly. Each time a respirator is put on, a check must be carried out to ensure that the rubber face piece is giving a good seal on the face. This is easily done by pinching the hose. If the respirator fits properly the wearer will not be able to breathe and the mask will collapse against the face.

It is generally most unpleasant to wear a respirator for more than a few minutes in high temperatures. The face will quickly become sore where the skin is in contact with the rubber and perspiration will collect in the valve. Therefore, the time for which a respirator must be worn should be kept as short as possible.

For prolonged exposure, for instance if rescue procedures have to be undertaken after an accident, remote breathing apparatus should be used. The simplest form is a flexible tube of about 25 mm internal diameter connected to a mask on the wearer's face and opening in clean air. For distances greater than nine metres the tube will be too long for natural breathing and air will need to be blown along the tube or fed in from a compressed air cylinder.

Face masks

For dusting, spraying or misting with insecticides, a cartridge respirator, dust mask or face shield should be worn. Cartridge respirators are usually half-face masks covering the nose and mouth. They can be combined with goggles or obtained as a whole-face mask to protect the eyes. One or two cartridges containing an absorbent and a filter are attached to the face piece by a clamp or holder. Different cartridges are available for dusts, sprays and organic vapours. They may give protection for a short time against low concentrations of phosphine (less than 1 mg/l) and against aluminium phosphide dust, but they must be discarded before the aluminium phosphide breaks down. They should be changed after eight hours use or more frequently if any smell of pesticide is able to penetrate. Cartridges should be removed from the masks and kept in a tight container when not in use. The mask should be washed and left to dry.

The simplest form of face mask is a pad covering the mouth and nose. The gauze in these dust masks should be changed every time the mask is worn. The head should also be protected with a hat or helmet. When there is not much likelihood of spray dust or vapour being breathed in, but there is a need to guard against splashes of insecticide, a face shield or visor is preferable. It is better if this is attached to a light-weight helmet with a detachable cape to cover the neck and shoulders. A face shield is generally preferable to goggles because there is less chance of blurred vision; a larger part of the face is covered and there is no chance of harmful substances being trapped close to the eyes. However, goggles may be needed if lachrymatory materials are being handled.

Storage and disposal of pesticides

1) Pesticides should be kept in a securely locked store that is cool, dry and adequately ventilated when in use. Windows should be barred or secured. The following items should be held in the store:

- A record book detailing all stock stored, used or disposed of.
- A work bench and a sink with tap water.
- First aid equipment (including an eyewash bottle).
- A chart giving basic first aid instruction and the address or phone number of the nearest medical assistance.
- Unbreakable, washable, mixing containers and spoons.

2) All chemicals should be kept in containers that are clearly and correctly labelled with the name of the active ingredient, the concentration and directions for use. Chemicals must not be transferred to unlabelled containers or to containers with a different labelling.

3) Heavy containers should be stored on or near to the ground but bags of chemicals should be kept off the floor to prevent spoilage through damp. Insecticides and solvents should be kept apart from rodenticide baits to prevent taint.

4) Stocks of pesticides should be carefully managed on a first-in first-out principle to avoid prolonged storage of any batch. The contents of broken, damaged or corroded containers should be used as soon as possible or disposed of, as they become . increasingly hazardous if left. It is especially important not to store damaged or corroding cans of methyl bromide or packages of aluminium phosphide, as these can be extremely dangerous. In most cases, normal but careful use as soon as possible will be the safest means of disposal.

It is difficult to dispose of large quantities of concentrated pesticides and preferable to use the materials for their intended purpose. Where this is impossible, pesticides should be poured onto gravel soakaways or waste dumps in clay soils. Great care should be taken to avoid contaminating drains, ditches, streams, rivers or agricultural land. Containers should be emptied, punctured, crushed and buried. In some circumstances it may be possible to wash out containers with detergent and water, or most residues can be destroyed by standing overnight with a rinse of 5 percent aqueous sodium hydroxide solution. The container needs to be well rinsed with water first and care should be taken with sodium hydroxide,which is caustic. Incineration may be dangerous and should only be used with great caution.

The precautions necessary in the handling and application of pesticides have been described in the sections on "Treatment of Store Fabric", "Fumigation", "Routine Insecticide Treatments in Stores" and "Control of Vertebrate Pests".

Accidental contamination of food grain

Despite precautions, grain may be come contaminated with pesticide, either through spillage or accidental overdosing or because the grain is put into contaminated sacks or containers. Each case must be dealt with according to the particular circumstances *but in no case should any incident of this kind be ignored*. If there is gross contamination of a small amount, the grain should be separated and buried or burnt. If the contamination is spread to an extent where disposal is economically or practically difficult, widely taken and representative samples of grain should be sent to a chemical laboratory for analysis of pesticide residues. Further action following from the results of the residue analysis should be decided by an appropriate authority. Steps should be taken to prevent recurrence of the accident. In particular, if a non-approved pesticide has been used, this must be removed so that it cannot be accidentally used again. Under no circumstances must seed grain dressed with insecticide/fungicide be allowed to be mixed or come near to grain for human consumption.

Accidental poisoning - symptoms and treatment

Everyone working with pesticides should be physically and mentally fit for work. Any cuts or abrasions should be cleaned and covered with a waterproof dressing before pesticides are handled. A first aid kit and illustrated first aid charts should be available. Some knowledge of first aid on the part of one or more staff is desirable.

In case of accidents or accidental exposure to pesticides, the most urgent measures are to remove the exposed person to fresh air and to cut off the source of exposure, e.g. by turning off the gas cylinder or sprayer. Other workers and a supervisor should be notified. If pesticide has been spilled on skin or clothing, the contaminated clothing must be removed and the skin washed with large quantities of water. Depending on the exposure, it may be necessary to flush the eyes with large quantities of water, induce vomiting or apply artificial respiration. Artificial respiration should take precedence over the first aid procedures and the use of oxygen will often be beneficial (figure 69). The patient should generally be kept warm, comfortable and quiet.

In all but the slightest of accidents, a doctor should be called at once or the patient should be taken to hospital. The address or phone number of the nearest medical aid should be prominently displayed where pesticides are kept. The doctor should be informed of the source of poisoning and shown the medical advice normally given on the product label.

Phosphine

The main routes of poisoning are by ingestion, inhalation and absorption through the skin. In the case of phosphine, only inhalation is of serious importance. Phosphine causes paralysis of the central respiratory system and disturbance of liver and kidney functions. Slight poisoning is recognized by nausea, vomiting, chest pains and tiredness. The patient should lie down in a warm place, be given rest and fresh air, as well as assistance with breathing, mouth to mouth resuscitation or oxygen, if necessary. If the patient recovers within one to two hours, there will probably be no after-effect and the patient may be able to return to work after a day's rest. In more serious cases, displaying symptoms of nausea, respiratory difficulties, giddiness, muscular dysfunction or anoxia, urgent medical care is necessary. There is no specific antidote and treatment is symptomatic. Treatment of convulsions (with sedatives) and of pulmonary oedema may be necessary.

Methyl bromide

Liquid methyl bromide can cause burns by contact with the skin and inhalation of the vapour can lead to lung, brain and nerve damage.

Methyl bromide is particularly dangerous, because signs of poisoning may be delayed for several hours after exposure to the gas. Continued or repeated exposure to low doses, as well as a short exposure to a high dose, can produce harmful effects. Any concentration above the threshold limit value (15 ppm) is potentially dangerous.

Symptoms may range from headache, fatigue, nausea and vomiting, dizziness, los of vision, blurred speech and lack of coordination to massive accumulation of fluid in the lungs (pulmonary oedema), brain and kidney damage, coma and death. The patient must be removed from exposure to the gas and put in a semi-recumbent position to assist breathing. Oxygen may be used to assist respiration and antiemetic drugs to combat vomiting and nausea. Contaminated clothing must be removed and contaminated skin well washed. There is no specific antidote and the symptoms of convulsion, pulmonary oedema or renal failure must be treated appropriately. Blood bromide levels may give an indication of the seriousness of the poisoning. The normal level is less than 1 mg/100 ml; up to 5 mg/100 ml is not dangerous but greater than 15 mg/100 ml is serious. Even in slight cases of exposure, the patient should be kept under observation for 48 hours in case symptoms develop. In severe cases of exposure, recovery may take several months or more.

If you think a person has stopped breathing, don't delay. Give first aid immediately. Ask someone else to get medical help.

Is the person breathing?

To find out if the person is breathing, place him flat on his back and put your ear close to his mouth. If he is breathing, you will feel his breath and see his chest rise and fall.

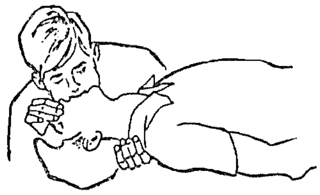
Open the airway

If the person has stopped breathing lift up his neck with one hand and push down on his forehead with the other. This opens the airway and the person may start to breathe. If he doesn't, begin resuscitation at once.

Resuscitation

Keep one hand under the person's neck so that his head is tilted backward with his chin up.

Pinch his nostrils shut with the fingers of your other hand.



Take a deep breath and cover his mouth completely with yours. Blow air into his mouth. When his chest moves up, take your mouth away and let his chest go down by itself.

Repeat this procedure every five seconds. Do not stop until the person starts breathing or medical help comes.

Figure 69. Mouth to mouth resuscitation.

Organophosphorus and carbamate insecticides

The acute toxic action of these insecticides is by reduction of the cholinesterase activity, which results in loss of muscular activity and paralysis of the chest and leads to collapse and death. The most serious risk of poisoning is by absorption through the skin, because insecticide absorbed in this way can immediately affect the neuromuscular sites, whereas swallowed insecticide may be partly detoxified in the stomach. Symptoms vary from headache, tiredness, irritation, nausea, sweating and diarrhoea to vomiting, blurred vision, lack of muscular control, convulsions and severe breathing difficulties. Any accidental spillage must be immediately washed off and clothing removed. If insecticide has been swallowed, vomiting must be induced and the stomach emptied. Expert medical attention should be given if symptoms of organophosphorus or carbamate insecticide poisoning are evident. If atropine sulphate tablets are part of the first aid kit, they must be given immediately but the patient must then be rushed to expert care. Full recovery is possible through the use of atropine and specific antidotes. The antidotes are specific to certain types of compound and a general recommendation cannot be given. Without expert medical attention, there may be unnecessary loss of life. As the long-term effect of small doses of insecticide is uncertain, exposure should be kept to a minimum. It may be considered appropriate for persons working regularly with toxic pesticides to have periodic cholinesterase level checks and physical examinations.

5. ROUTINE STORAGE PROCEDURES

The treatments recommended in this chapter apply mainly to bagged grain in warehouses, although a section relating to silos and bulk warehouses has been included. Most of the treatments have been described in greater detail in other parts of the Manual and references to these descriptions are given in brackets. The chapter is intended to be a guide for the store manager or inspector.

STORE PREPARATION

1) The structure should be repaired and proofed (Chapter 1, "Rodent and Bird Proofing").

2) The walls, floors, doors and roof beams should be brushed or washed down. Rubbish and old stocks should be cleared away.

3) The walls should be whitewashed or painted with white or lightcoloured emulsion paint.

4) All surfaces should be sprayed with insecticide (Chapter 4, "Treatment of Store Fabric).

5) Lines marking stack bases should be painted on the floor.

BEGINNING OF STORAGE

1) The grain should be sampled and graded (Chapter 2, "Quality Standard"). Moisture content and temperature should be checked. Sub-standard, damaged or wet grain should be set aside for drying, cleaning, sorting, rebagging or rejection. All grain should be in clean sound bags.

2) Accepted bagged grain should be stacked on dunnage. Avoid damage with hooks or by dragging. Allow ample access to each stack for loading, unloading, inspection and pest control. (At least 1 m clear of all obstructions around and on top and at least 1 m clear of the wall.)

3) The stock should be recorded and record cards attached to each stack.

4) The stacks should be fumigated (Chapter 4, "Fumigation of Bagged Grain Under Gas-Proof Sheets"), unless proper fumigation has recently been carried out, in which case samples should be bred out to check that there is no hidden infestation (Chapter 3, "Detection of Insert Infestation"). The fumigation should take place outside the warehouse if there is a danger of infesting already clean stacks. If possible, fumigation sheets should remain in place until all stacks have been treated.

5) It is advisable that phosphine be used in the store and methyl bromide be used for greater speed outside the store. After the fumigation sheets are removed, one of the following protective treatments should be immediately applied (Chapter 4).

   - The outside of the stacks should be sprayed or dusted, using an insecticide of proven effectiveness under local conditions.
   - The stacks should be covered with cloth that is sprayed with an effective insecticide or which provides an effective mechanical barrier to insects.
   - Automatic misting should be started and continued regularly, using an insecticidal treatment of proven effectiveness.
   - the situation may be judged sufficiently clean for no further insecticide treatment (other than wall spraying) to be necessary: subject to regular review.

6) Rodent baits, rodent tracking powders (Chapter 4, "Control of Vertebrate Pests") and insecticide barrier dusts (Chapter 4, "Treatment of Store Fabric") should be put down as necessary.

7) A temperature recorder should be set up (Annex 3).

8) The store should be tightly closed. If the store has closable ventilation this may be opened if necessary for aeration but not in conditions that would raise the in-store humidity.

MEASURES DURING STORAGE

Inspection

The frequency of inspection and remedial action must depend on the circumstances and on the judgement of the storekeeper. It is suggested that:

1) There should be a visual inspection weekly, fortnightly or monthly and a sampling inspection monthly or three-monthly to look for

   - live insects or rodents
   - damage caused by insects or rodents
   - wet or mouldy grain
   - general heating and hot spots
   - structural damage.

2) The basic insect inspection should be mainly a visual one. Alternative methods such as X-rays, flotation, staining, UV fluorescence, CO_2 measurement and breeding out, are valuable where possible but do not replace visual inspection. As insects mostly move at dusk, it is better to inspect for live pests in dim light in the evening with a torch, but damage should be looked for in good daylight. The aids to detection given in Chapter 3, "The Detection of Insects", should be used.

3) The sampling inspection should include:

   - spear sampling of bags
   - sievings of whole sacks (if considered necessary)
   - a detailed examination of dust and crevices
   - turning over bags to look for heating or infestation underneath
   - use of grain thermometer and probe moisture meter to check for unexpected changes in grain temperature and moisture content (Annex 3)
   - a check of the records or readings of instruments installed to monitor temperature and R.H.
   - a note of structural damage
   - observation of rodent damage or marks of rodent movements (Chapter 3, Detection of Rodents")
   - setting aside samples to detect hidden infestation (Chapter 3, "Detection of Insects").

Actions resulting from inspection

1) A record should be kept.

2) No action may be needed if there is no evidence of live pests or poor grain condition, or if there are only a few (5 or less) serious pest insects per bag.

3) Action maybe needed if there are more than 20 serious pest insects (other than mites or psocids) per bag. However, if the grain is in a store where it is always likely to suffer fairly prompt re-infestation, it may be necessary to space the re-fumigation treatments. For reasons of cost and convenience, fumigation may have to be delayed if the store manager deems it safe to do so.

4) If warehouse moths are present, misting or fogging should be carried out (Chapter 4, "Routine Insecticide Treatments in Stores").

5) An obvious source of re-infestation should be dealt with, for example by generous dusting with insecticide in corners or crevices.

6) Store fabric or stack surfaces should be resprayed with insecticide if necessary. The intervals between treatments must depend on the circumstances and the need. About once every six months for spraying of stacks, once every three to six months for spraying of walls and weekly misting might be suitable.

7) Poor grain condition should be dealt with according to the cause (e.g. rain water leakage). It may be necessary to aerate the grain or move it to a different store.

8) If there is evidence of rodent infestation the cause should be sought. It may be necessary to make a thorough survey of the whole area, including adjoining property, to determine the species involved, its habitats, sources of food and drink and pathways. Action should then be taken to seal off the routes of entry into the store and to put poison baits or rodenticidal powders in the path of the rodents or to destroy the rodents in their habitat or poison their water supply.

Store hygiene and maintenance

1) After inspection, the floor should be swept and the sweepings burnt. There should be little spillage in the reserve store and it should be possible to keep the building tidy and to leave tracking dusts and insecticidal dust barriers undisturbed. Occasionally, walls, floors, ledges, beams, doors and door frames should be given a good brush out. Trouble spots should be noted while cleaning up.

   Rubbish, empty sacks and damaged or infested goods should be discarded or promptly treated. The area outside the store should be kept clear.

2) Full records should be kept of stock in, stock out, inspections carried out, infestation detected, treatments applied and quantities of pesticide used. Cards recording this information should be attached to stacks.

3) There should be a periodic check on the roof, guttering, ventilators and state of walls, floors and doors and the necessary repairs made (Chapter 1, "Maintenance of Storage Structures").

4) Attention should always be paid to the proper storage of pesticides (Chapter 4, "Maintenance of Safety") and to re-ordering stocks in advance of requirements. (away from foodstuffs)

Control of rodents

Tracking dust should be laid as a continuous smooth band, approximately 100 cm wide, around stacks to detect the presence and movement of rodents in a store. Tracking powders may also be rodenticidal but these are not suitable for banding stacks due to the possibility of contamination of the grain. They may, however, be used on runs, burrows or places where contamination of grain is unlikely. The application of toxic baits was discussed in Chapter 4, "Control of Vertebrate Pests".

Baits of 100 to 200 g should be laid at intervals of 1 to 2.5 metres, in covered places, and inspected twice weekly. The number of points and amount of bait should be increased if most of it is being taken. Baiting should continue until there are no more takes or signs of infestation.

Alternatively, in permanent prophylactic baiting, large quantities (1-2 kg) of anti-coagulant bait should be left concealed in bait where they can be taken by rodents but not by larger animals. They should be inspected and renewed every one to two months.

Treatment for silos or flat bulk storage

1) Grain being put into silos should be fumigated with phosphine or treated with insecticide (Chapter 4,"Insect Control in Bulk Grain"). Silos or flat storages that are open or prone to reinfestation with insects are not suitable for long-term grain storage.

2) Thereafter, the main problems may be concerned with temperature and moisture migration, which should be corrected by aeration (Chapter 2, "Quality Standards").

3) Meters recording temperature and humidity should be installed to assist the checking of grain conditions.

4) Dichlorvos strips may be hung in silos or misting or fogging in stores may be used to control flying pests.

5) Samples should be taken monthly to assess the grain conditions and check for infestation. If there is an infestation problem, it may be necessary to transfer the grain from one bin to another to achieve successful treatment, unless methyl bromide can be circulated through the grain (Chapter 4, "Insect Control in Bulk Grain").

A N N E X 1

CONTROL TECHNIQUES ALTERNATIVE TO PESTICIDE USE

The Manual has described the use of fumigants and contact insecticides as the primary methods of control because these are the only techniques widely available for long-term storage, particularly for bagged grain. The following paragraphs draw attention to alternative techniques that are being developed. The spread of resistance to pesticides in storage insects may increase the need for these alternative control methods. The main techniques described are hermetic storage, use of inert atmospheres, cooling or heating and irradiation.

Hermetic storage

Hermetic storage requires specially designed structures such as the Cyprus Bins, A 1.1., (figure 70), inflatable butyl silos or underground pits. The supression of insect development requires a low oxygen concentration (less than 2 percent) usually assisted by increased carbon dioxide levels. The rate of depletion of oxygen depends on the rate of respiration and the infestation present. In circumstances where oxygen levels are rapidly depleted, for example in grain with a high moisture content or a heavy infestation, moisture migration problems are likely and peripheral mould damage may occur.

Inert atmospheres

Inert atmospheres of nitrogen or carbon dioxide can be used to replace the normal atmosphere of grain. The production of a controlled atmosphere using nitrogen is carried out in two phases:

purging - during which the atmosphere is created by introducing the gas; and

maintenance - the addition of further gas to maintain the required atmosphere against leakage.

The actual exposure time depends on whether the method is to be used for disinfestation or for holding grain in a protective atmosphere for a long period. Disinfestation usually takes longer with controlled atmospheres than with chemical fumigants and it may be more difficult to provide the quantities of inert gases that are needed than to provide the much smaller quantities of fumigants that would be required. Tanker supplies of inert gases are generally needed for large storages.

Control by cooling or heating

Most storage insects will only breed within the range of 15°C to 35°C. Temperatures outside these limits progressively impede reproduction and development and in extreme conditions lead to death, especially at high temperatures.

Many storage insects quickly adapt to survival at a slow metabolic rate at temperatures below 15°C and several weeks exposure to temperatures below 5°C may be needed to kill some species. In cold climates, stored grain usually cools to temperatures well below those at which insects reproduce and develop, and in bulk grain this cooling can be assisted by forced aeration with ambient air to render it safe from insect attack. Cooling the grain by this method to temperatures of between 4°C and 15°C is a useful measure for retarding infestations because, even if insects are not killed, they cease to breed. Grain below 12.5 percent moisture content can be stored safely for long periods in grain bins equipped with ventilation systems when the grain temperatures are reduced to 10°C to 14°C.

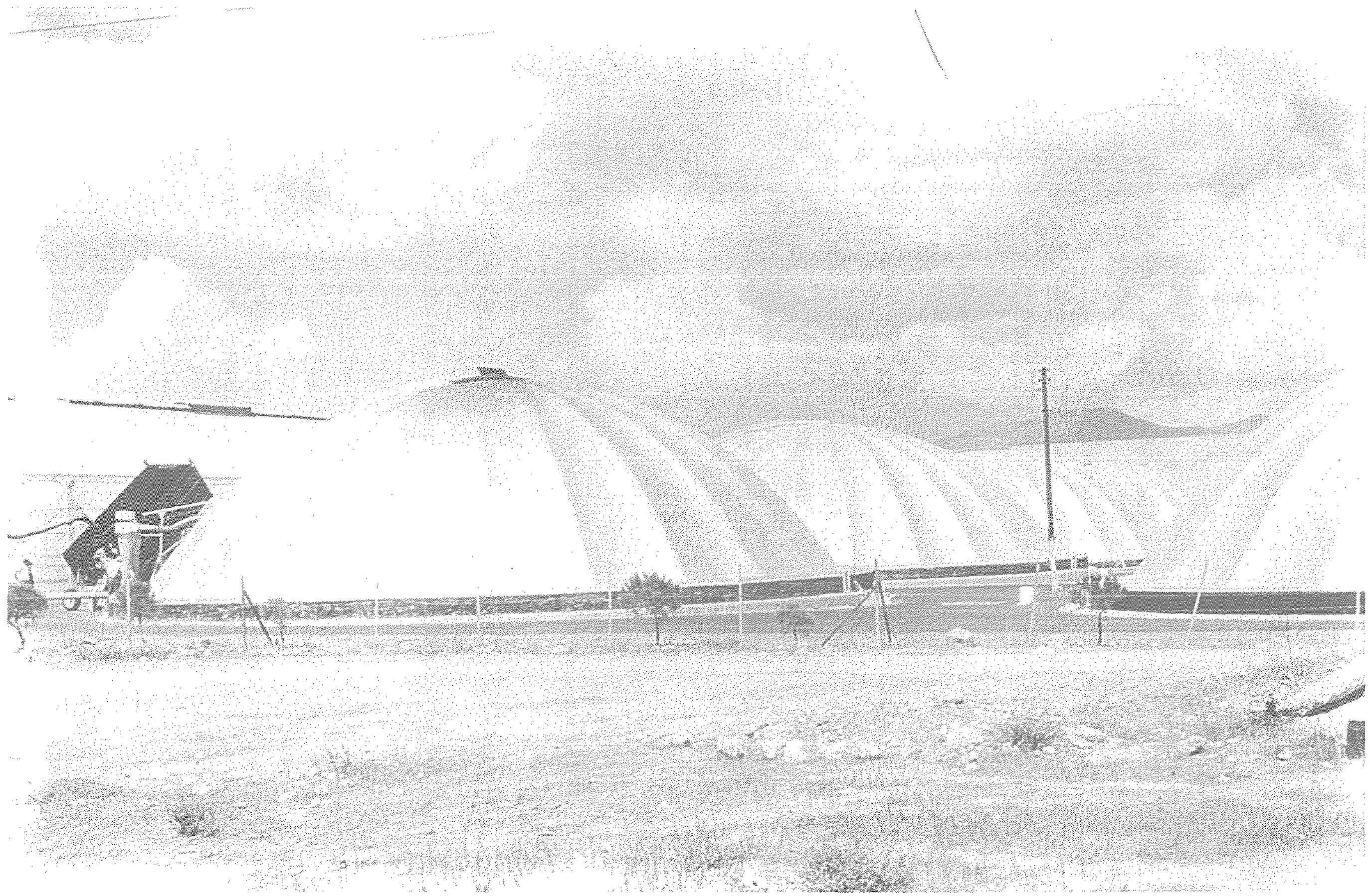


Figure 70. Cyprus bins for hermetic storage.

Grain can normally be aerated only when the relative humidity of the air is less than 75 percent and this usually restricts aeration to limited times of the day. In the tropics, the use of aeration to cool a bulk of grain is not usually possible because ambient daytime temperatures are too high and at night, when the air is cooler, the relative humidity may be very high. This does not necessarily rule out aeration at night but careful consideration of the actual psychrometric conditions, with particular regard to the water vapour content of the air, is essential.

Refrigeration units may be employed to chill grain and temperatures 15°C to 20°C below ambient air temperature have been achieved. The rate of chilling is faster in damp grain and the method in temperate countries is primarily used to prevent the development of moulds in damp stored grain. Mites will only be controlled if the temperature is below 5°C. The capital costs of refrigerated cooling are high.

Insects and mites are generally killed more quickly by heating than by cooling. Most storage species are killed by short exposures to temperatures above 60°C and some are quickly killed at temperatures above 50°C.

Continuous flow (fluidized bed) high-temperature disinfestation of wheat has reached the commercial stage of development. The wheat is heated to 65°C by fluidizing it for three minutes in directly heated air. After the heat treatment the grain is restored to ambient temperature by spraying water onto the surface. The water evaporates and is carried away by the fluidizing air. Extensive tests have shown that this heat treatment has no effect on the milling and baking qualities of wheat. It is not yet known if this method can be adapted to all kinds of cereal grains, since some are more susceptible than wheat to heat damage, but further investigations are likely.

Microwave radiation

Microwaves are electro-magnetic waves, of very high frequencies, which produce dielectric heating in poor conductors placed in the electro-magnetic field. The heat generated is directly related to the moisture content of the exposed object, so that if the moisture content of insects is higher than that of infested grain it may be possible to kill the insects without affecting the grain. In tests with *Sitotroga cerealella*, *Sitophilus oryzae* and *Rhyzopertha dominica* the older larvae and pupae have been found to be more resistant to microwave energy than young larvae and eggs. However, most insects that feed internally in grains can be controlled at temperature of 65°C produced by microwaves.

Infra-red radiation

Infra-red radiation penetrates slowly and is mostly used only where surface heating is required. Nevertheless, experiments with infra-red batch heaters and continuous flow heaters have shown that shallow layers or falling streams of grain can be disinfested rapidly (in less than 60 seconds) by raising the grain temperature to 65-68°C.

Other forms of radiation

Gamma radiation, X-rays and accelerated electrons have been used to kill insects or to cause sterility. Difficulties exist, particularly for bagged grain, in finding ways to pass the grain continuously and uniformly through the irradiator. The major disadvantage of irradiation is the high capital cost, but gamma ratiation from radioactive materials, such as cobalt 60, has been shown to be effective against a wide range of insect species. However, the time interval between treatment and death has also been considered to be a disadvantage of the method. Death may occur from one day to several weeks after exposure, depending on the dose applied, but threshold doses, below those which cause immediate death, may produce immediate and generally irreversible sterility.

The susceptibility of insect pests of stored products varies widely. Dosages of up to 50 Krad are considered economic but at these dosages long periods between treatment and death must be expected. Lepidoptera appear to be more resistant to irradiation than Coleoptera, especially when the sterilization dose is used as the basis for comparison.

Extensive tests have demonstrated the safety of the consumption of irradiated wheat and wheat flour treated with ionizing radiation in the range of 5 to 50 Krad.

ANNEX 2

DETAILED DESIGN OF WAREHOUSES

Floors

Floors should be water-vapour proof.

Walls

Masonry walls are preferable to metal walls because they reduce the temperature variation in the store. The walls should rise to the eaves or ventilators, and should be independent of the structural framework, so that if a stack collapses the walls can give way without damaging the framework. Damp-proof courses should be provided.

Cladding materials for walls and roofs should be of readily-available types. Excessive deflection and movement of roof or wall cladding caused by wind loads, temperature stress, or movement of maintenance staff on roofs or walls should be avoided by correct spacing of purlins and sheeting rails with matched fastenings. Hook bolts should be used to fasten the roof and wall cladding to the purlins and sheeting rails.

Roofs

Roofs should be pitched at about a 20^{o} angle and be of simple construction. An overhang at the eaves gables is essential. Roofs should be of bright reflective metals or painted white. Roof cladding should be of galvanized steel, or aluminium. No roof lighting sheets should be employed in reserve grain stores, as light stimulates insect and bird activity in store, and poor fixing or distortion can result in leaks.

Drainage

The danger of roof leaks should be minimized by avoiding the use of shallow-angle roofs, using adequate end and side overlaps on cladding, using sealing compound on joints and sealing washers on hook bolt connectors. The use of rainwater gutters and downpipes should be avoided in heavy rainfall areas by the use of large roof overhangs without gutters. Gutters should be used only over loading doors that are not provided by the use of single-span buildings. Otherwise, valleys created by joining roofs should have wide gutters, with downpipes (and gutters) placed at both ends of the valley gutter and not entering the warehouse. Valley gutters should discharge so that any overflow spills away from the walls onto dished hardcore or correctly sloped concrete open drains approximately 1 metre wide. These drains should be situated on both sides of the building, along its length, and should take all the rainwater coming off the roof away from the site. Opposite the doors, these drains should be covered by a small culvert to enable lorries to drive over them without damage.

Lighting

The illumination should be sufficient to ensure that all parts of the building are safe for personnel to work in. Lighting should preferably be artificial (fluorescent tube type) and explosion-proof. Translucent plastic roof sheets should be avoided. If natural lighting is necessary, eaves-height windows of translucent plastic, wired glass or translucent glass fibre corrugated sheets, should be used, but these should be fixed, to reduce risk of damage. The windows should be shaded from direct sunlight. The simplest eaves ventilation, may also provide light, at little cost.

Electrical installations

All electrical installations, including lighting, should be dust tight, insect proof and rodent proof to a satisfactory standard suitable for use in atmospheres containing grain dust.

Doors

The main doors should be simple sliding doors, supported at the top and fitting closely against the outer wall. Special door operating gear or roller shutter doors should be avoided. Steel doors are best, but wooden doors protected with galvanized steel sheeting may be used. A reserve grain store requires fewer doors than a commercial warehouse; two double doors 4 x 4 metres facing each other, plus one personnel access door are often sufficient. Canopies, platforms and vehicle access doors should suit local vehicles and loading gauges in local use. Adequate and renewable bumping bars and posts for vehicles should be provided at loading platforms and doors.

Ventilation

The ventilation required depends on the climate. In humid climates, controllable ventilation is necessary (figure 9). A simple rope and pulley method on a slotted board should be used to open and close ventilators rather than a complicated mechanical system. Padlock staples should be fitted to low-level ventilator controls. In very dry climates, the cheapest fixed eaves ventilation may be acceptable. The simplest eaves ventilation is preferable to ridge ventilation. Ventilation at floor level should be avoided.

Maintenance and access

Access ladders, crawling boards and platforms should be provided for the roof and for equipment requiring regular inspection and maintenance. Suitably reinforcec beams should be provided over entry points for machinery requiring maintenance.

Access panels, manholes, rodding eyes and removable sections should be provided on items liable to blockage and requiring cleaning, such as drains, process conveyors, elevators and spouting.

Adequate clearance should be provided around all equipment, including electrical switchgear, and space provided for removing access doors and parts of equipment.

Access ways should be provided to pits for intake hoppers, elevators and weighbridges. All such pits should be waterproofed against ingress of ground water, and equipment (especially elevator boots) should be raised on a plinth above base level. The base should slope to a large sump area. Ramps should be provided where necessary. Canopies should be fitted over pits situated outside the main building.

A N N E X 3

MEASUREMENT OF RELATIVE HUMIDITY, MOISTURE CONTENT AND TEMPERATURE

Relative humidity (RH) is an expression of the degree of saturation of air with water vapour, being defined as the ratio of the mass of water vapour in a fixed volume of air to the mass of water vapour in the same volume when completely saturated at the same temperature. The amount of water vapour in the air is small (of the order of 0.01 g/1) and difficult to measure accurately. Moisture content, the ratio of the amount of water in the sample to the total weight of the sample, is easier to measure.

Relative humidity

Relative humidity (RH) is measured with a hygrometer. The wet and dry bulb hygrometer can be used to measure the RH in a warehouse, but not in a grain mass. The measurement of RH depends on the difference in temperature between the two bulbs caused by evaporation from the wet bulb. In one version, the whirling hygrometer, evaporation is assisted by spinning in the hand (figure 71), whereas the Assman hygrometer has a fan to assist evaporation.

Certain animal hairs and synthetic organic fibres change in length according to the RH. This principle is used in the hydrograph, which records RH as a trace on a drum recorder (figure 72). Some probe meters can be used to measure RH up to about 1 metre deep in grain (figure 73). These simple and inexpensive meters are calibrated to give a direct reading of grain moisture content by conversion from the RH, and have separate calibrations for different types of grain. They need frequent checks on the accuracy of the calibration, however, and can give misleading results if the temperature of measurement is very different from the scale calibration temperatures.

Other instruments work on the principle of a change of capacitance or resistance with changing humidity.

Grain moisture content

The moisture content deep inside a grain bulk can be measured with the Reethorpe moisture monitor, illustrated in figure 74. The sensor is filled with grain, which reaches equilibrium with the surrounding grain. The moisture content of the grain is calculated from the electrical resistance. A number of suitable moisture meters, such as the one shown in figure 75, are used to measure the moisture content of small grain samples taken by the sampling procedures described in Chapter 2. The meters measure electrical resistance or capacitance. At depots measuring a large number of samples per year, meters with print-out or digital read-out and automatic weighing and temperature compensation can be used.

Accuracy of measurement

In the moisture range of 11 to 15 percent (the safe storage moisture content for maize for long-term storage is not greater than 12 percent), the typical accuracy is $\pm$ 0.5 percent. Outside, but close, to this range the accuracy may be $\pm$ 1 percent.

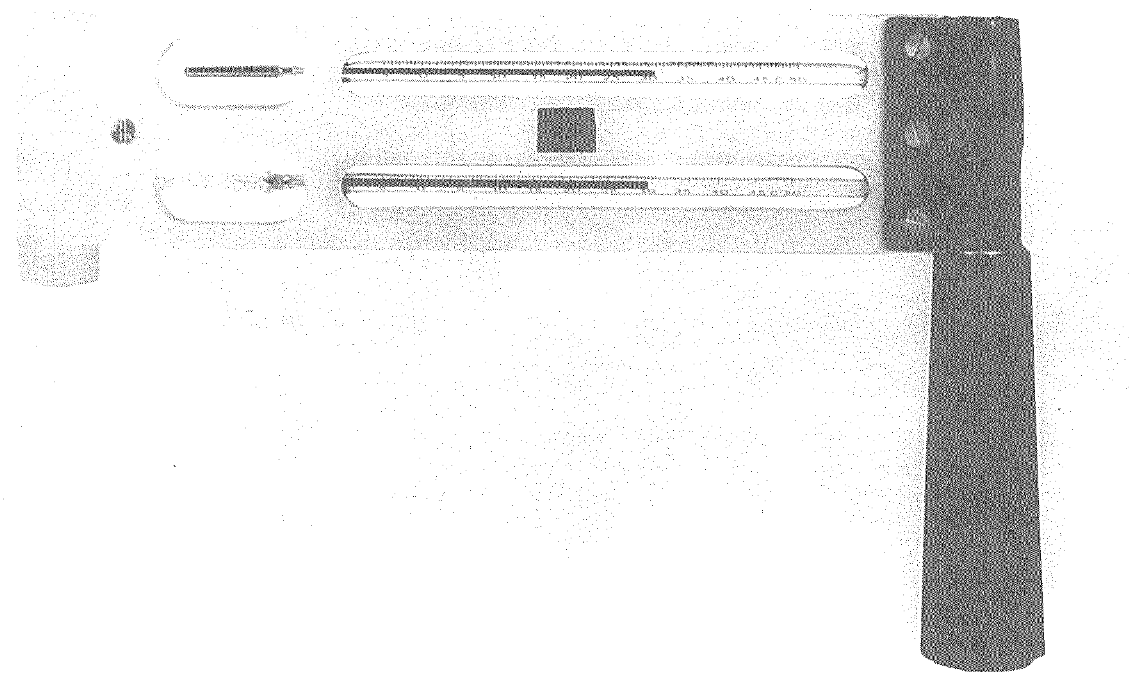


Figure 71. Whirling hygrometer.

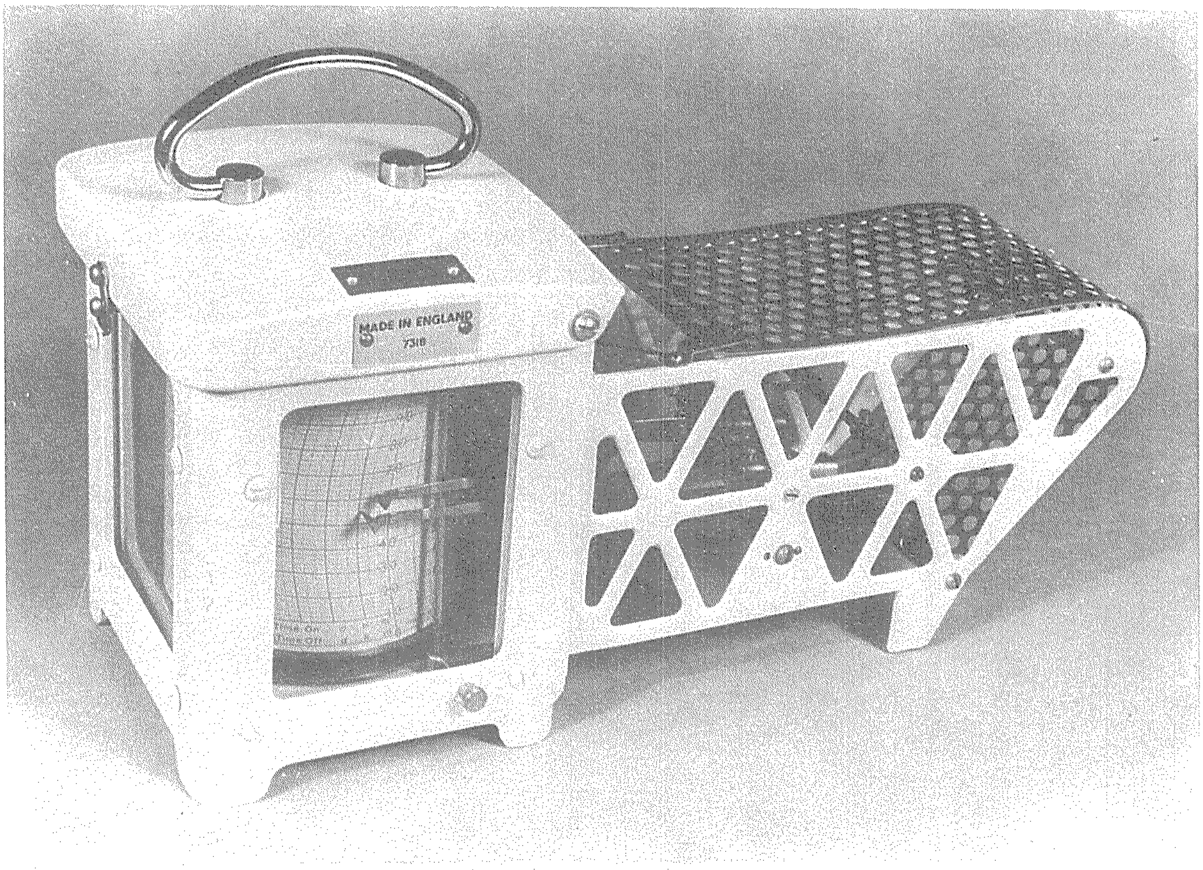


Figure 72. Drum hydrograph.

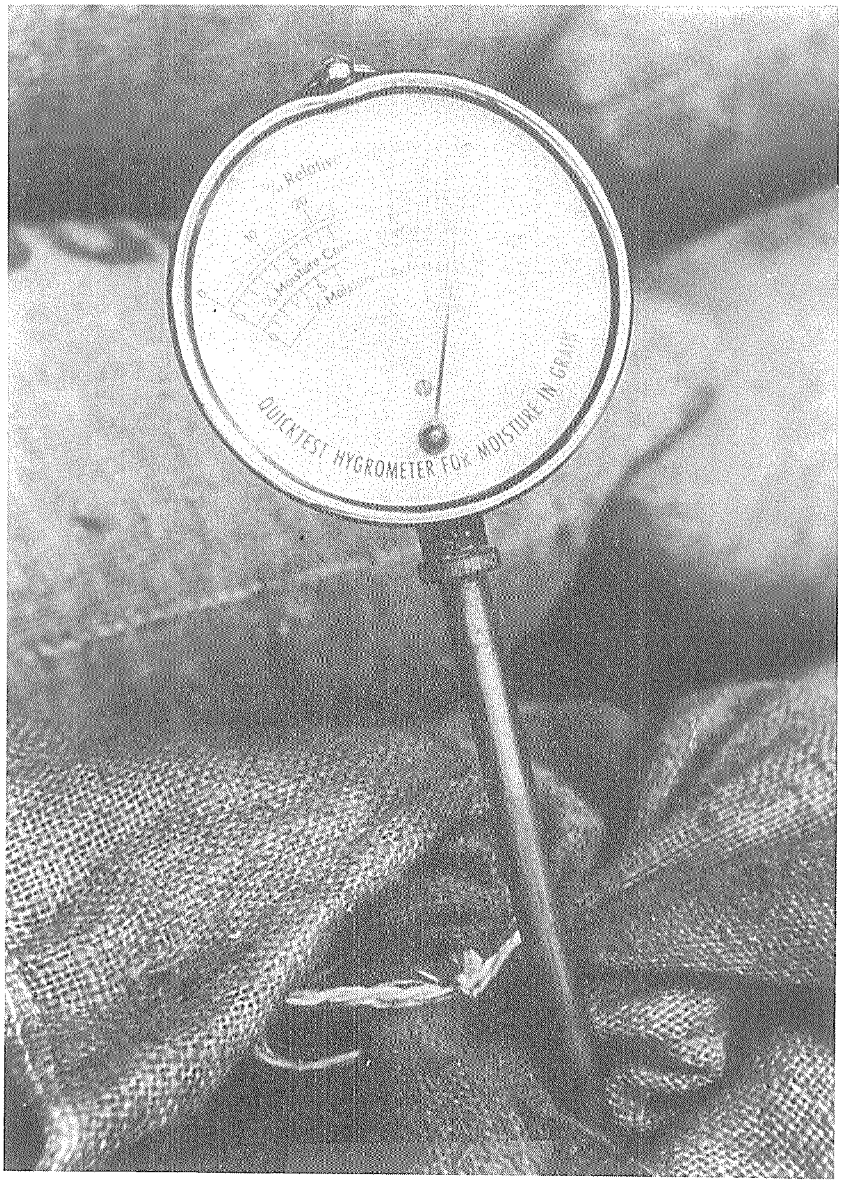


Figure 73. Meter for measuring moisture in grain.

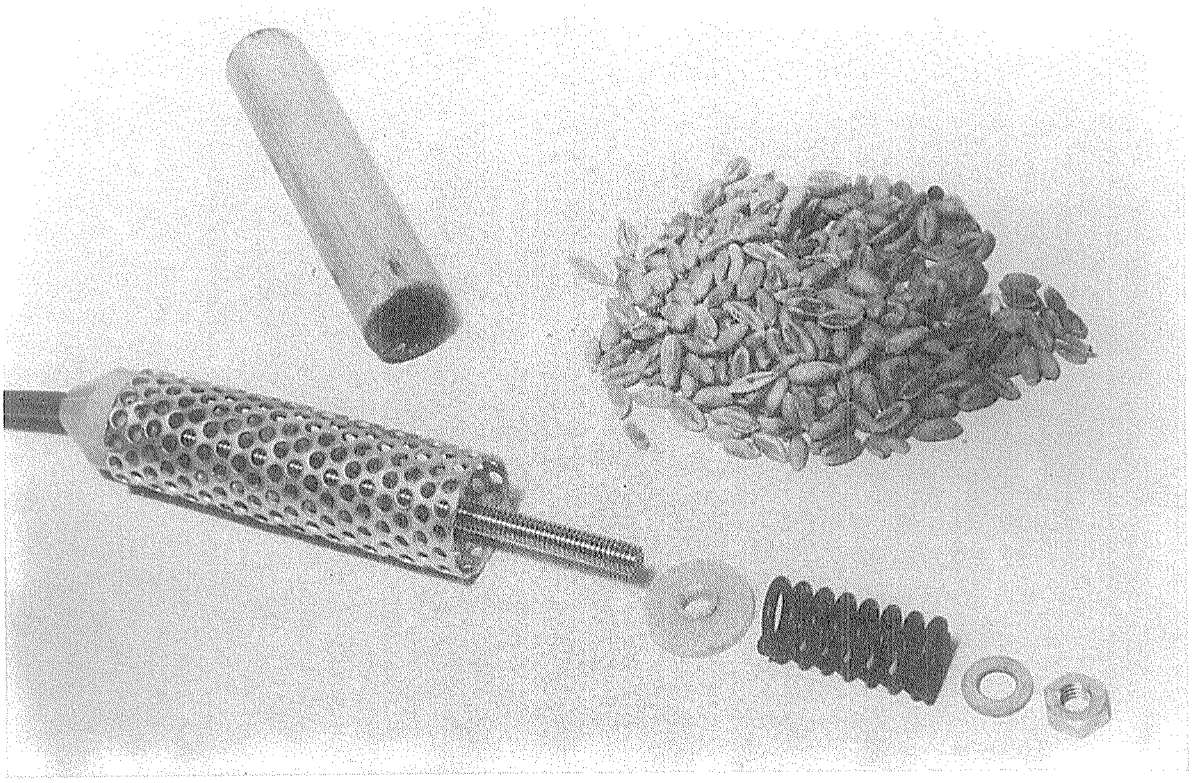


Figure 74. Reethorpe meter for measuring moisture deep inside a grain bulk.

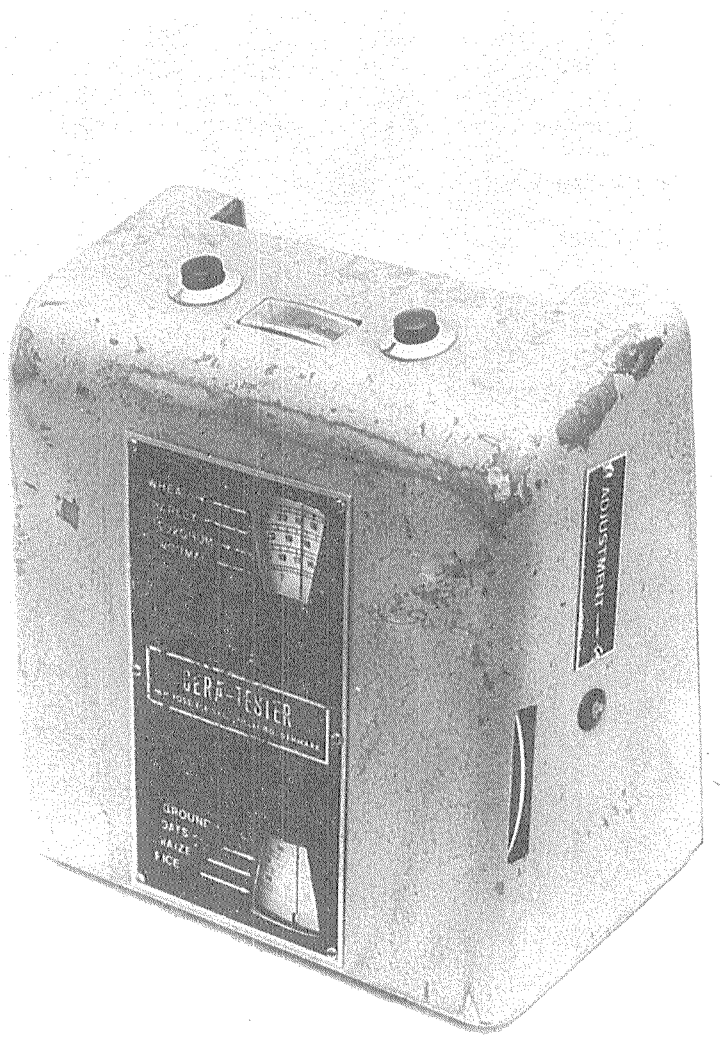


Figure 75. Cera tester for measuring moisture content of small grain samples.

Sources of possible error are:

- human error in measurement
- variation in the density of packing of the cereal into the meter
- different varieties needing different standardization
- temperature differences not being properly compensated
- manufacturer and user using different reference methods.

Factors to be considered in the choice of a meter are cost, suitability for a particular commodity, portability, robustness, availability for batteries or power source and degree of operating skill required.

Air temperature

An ordinary mercury-in-glass thermometer is adequate for measurement of air temperature in a store. A combined maximum-minimum thermometer is the most suitable type, as it will indicate extremes. It must not be placed in direct sunlight. For a continuous record of store temperature (and RH), a thermohydrograph is generally used. This gives an unattended record of store conditions, although charts must be replaced periodically. A direct reading thermistor system (see below) may be used to obtain a quick and accurate reading when inspecting a store or a silo.

Grain temperature

Wide variations in temperature can occur within a bulk of grain and measurements should be assumed to be related only to a small area near the point of measurement. Changes in temperature are more important than the absolute temperature level, and temperature measuring equipment should be able to determine temperatures within $\pm$ 0.1°C. The various types of thermometers are given below.

Expansion thermometers

Mercury-in-glass thermometers - must be placed inside a metal probe for protection.

Mercury-in-steel thermometers - can be pushed well into grain, but tend to give an average rather than a spot temperature.

Bimetallic strips - can have stems for dipping into grain to take spot checks in stacked produce, but tend to have a slow response.

Electrical thermometers

These are more accurate, have a quicker response and are less cumbersome than the expansion thermometers. Types of electrical thermometers include:

Platinum resistance thermometers - may be used to give a recording on a chart and as a permanent installation in a bin. Disadvantages are the relatively high resistance of the leads and the small change of resistance with temperature.

Thermistors - are transistor junctions with an enormous change or resistance with temperature. They are ideal for field use, robust and chemically resistant and are preferred for permanent installation in bins, either buried in the grain for taking surface temperatures on silo walls.

Thermocouples - measure the potential difference at a junction between two metals and relate the voltage to the temperature. Their advantages over thermistors are cheapness and independence of the length of the leads, so that there is no problem with remote reading. However, they are not suitable for automatic recording and require frequent checking against a standard.

Choice of method for temperature measurement

For measurement of the temperature of grain in bags, a bimetallic thermometer can be used but it is slow and measures an average of temperature over a large proportion of the stem. A thermocouple or thermistor system incorporated in a metallic spear is preferable for bags or for taking spot measurements in bulk grain at depths up to five metres.

Monitoring of the temperature within a grain bulk over a long period is best carried out with either a thermistor or thermocouple system. In both cases the leads should be placed *in situ* before the silo is filled with grain. If monitoring at a small number of points is required, then the thermistor system is most suitable, and thermistors are essential if long-term monitoring by automatic recording is required. Thermocouples are cheap and convenient to use where large numbers of points are to be monitored.

Monitoring systems requiring many sensors also need a switching device, which should be located, if possible in an air-conditioned room. Otherwise, in hot humid climates, they may fail.

Temperature gradients near the surfaces of a bulk of grain can be severe in tropical and sub-tropical climates. Such gradients are best measured with thermocouple or thermistor systems, because their sensing heads can be made small enough to take meaningful measurements of temperatures at points in close proximity to each other.

ANNEX 4

SAMPLING INSPECTION OF BAGGED CEREAL

Count the number of bags in the consignment and determine the number of bags from which primary samples will be taken.

Remove the bags to be sampled, using a set of random numbers as a guide.

Record the weights of the sample bags and, if necessary, calculate the total net weight of the consignment.

Use the sampling spear to obtain primary samples weighing not less than 200 g from top, middle and bottom positions in each sample bag and accumulate a Bulk Sample, weighing at least 2 kg, to represent the consignment.

Mix the sample and pass it through a divider to obtain a submitted sample weighing at least 1 kg weighed to 0.1 g.

Sieve to extract large foreign matter. Sieve to extract small foreign matter.

Examine both the large and small foreign matter and record whether it is infested or not. Also record any unusual features of the foreign matter.

Combine the large and small foreign matter, weigh it to the nearest 0.1 g and express it as a percentage of the Submitted Sample weight. (If the calculated percentage exceeds determined limits, stop the assessment and reject the consignment.)

Thoroughly mix the Submitted Sample, then pass it through large and small multiple slot sample dividers, as appropriate, to obtain a Working Sample of at least 200 g.

Thoroughly mix the Working Sample and take a sample for the determination of the percentage Moisture Content. Return the grain used for percentage moisture content determination to the remainder of the Working Sample and mix it thoroughly. Use the small multiple slot sample divider to obtain a sub-Working Sample weighing not less than 50 g.

Weigh the sub-Working Sample to the nearest 0.1 g. Then separate out foreign matter and all other fractions.

Weigh each fraction to the nearest 0.1 g and express the results as percentages of the sub-Working Sample Weight. Combine the percentage foreign matter obtained here with the percentage foreign matter obtained earlier to give the total percentage foreign matter. Reject the consignment if any of the percentages exceed the maximum permitted percentages prescribed by the Standard.

Assess the quality and take appropriate action. The submitted sample should be retained for assessment of internal infestation (See Chapter 4, "Fumigation"). A guideline record form is shown below. (Source: D.L. Proctor, 1978, Instruction Manual on Grain Quality Control in Iran. Report No. TA 9/10 - 6/IRA/01/T., FAO, Rome.)

Number of Bags in Consignment ________

Number of Sample Bags ________

Net weight of Sample Bags ________ kg

Average weight of Sample Bags ________ kg

Net weight of Consignment ________ kg

Weight of Submitted Sample ________ kg

Foreign matter in Submitted Sample, weevily/not weevily

" " " " " , net weight ________ g

" " " " " , percentage ________ %

Percentage moisture content ________ %

Sub-Working Sample, net weight ________ g

Foreign matter in sub-Working Sample, net weight ________ g

" " " " " " , percentage ________ %

Total percentage foreign matter ________ %

Other cereals, net weight ________ g

" " , percentage ________ %

Broken grain, net weight ________ g

" " , percentage ________ %

Diseased grain, net weight ________ g

" " , percentage ________ %

ANNEX 5

SIEVES

Hand-held sieves

Hand-held sieves are commonly used for assessing the foreign matter content of small samples of grain. Round-framed sieves with a diameter of 300 to 310 mm are preferred, although square-framed sieves with sides 300 to 310 mm long may be used. Each set of sieves should be provided with a bottom pan (receiver), for the collection of material passing through the screens, and a lid to prevent spillage during the sieving.

Comparability of the results of using hand-held sieves depends primarily on uniformity in their manufacture and it is essential to use sieves made by a factory whose products are approved by a standards organization.

Hand-held sieves should be used in a uniform manner if comparability of results is to be maintained. Firstly, the sieve should be held level in both hands directly in front of the body, with the elbows tucked in to the waist. Secondly, using a steady motion, the sieve should be moved approximately 25 cm to the left and back through the centre position, smoothly 25 cm to the right and returned to the centre position. This sieving operation should be repeated exactly 30 times, taking about 30 seconds to do so. No forwards and backwards or up and down movements are permitted, although a final gentle tap of the sieve will help to clear it of any material hanging from the perforations before the bottom pan is removed. When sieves with slotted screens are being used, it is important to ensure that the long sides of the slots are parallel with the movement of the sieve.

Sack sieves

The foreign matter content of grain is more accurately assessed when the contents of whole sacks are screened, although this is obviously more time consuming than the hand-sieving of small samples.

A sack sieve should possess two essential features a hopper for feeding grain gradually on to the screen and a screen that moves during the sieving operation. The slope of a moving screen should ensure that the grain is kept in motion towards the discharge end. Lateral movement of the screen, as in a rotary type of sieve, is more efficient in separating out foreign matter than the end-to-end movement of other kinds of mechanical sieve.

Sizes

TABLE 20. Some standard sieve sizes for cereal grains

Grain Type	Shape		Diameter (mm)	Breath x Length (mm)	Arrangement	US
Maize	Round	(C)	14.0	-	Staggered	4.8
"	"	(F)	5.0	-	"	
Sorghum	"	(C)	6.5	-	"	1.0
"	"	(F)	2.5	-	"	
Bulrush millet	"	(C)	4.0	-	"	
" "	"	(F)	1.0	-	"	
Wheat	Slot	(C)	-	4.5 x 25.0	End Staggered	1.6 x 9.5
"	"	(F)	-	2.4 x 20.0	" "	2.1 (round)
Paddy Rice	"	(C)	-	4.5 x 20.0	" "	1.5 x 12.7
" "	"	(F)	-	2.5 x 20.0	" "	3.6 (round)

(C) - Coarse Screen, for removing material larger than the grain.

(F) - Fine Screen, for removing material smaller than the grain.

Locally produced varieties of grain may require sieves to have screens with specifications significantly different from those indicated in Table 20. Samples of grain should be checked against standard sieves of different specifications before quantities of sieves are purchased for grain quality assessment.

Care and maintenance

Sieves of standard quality are precision instruments, that should be used and handled with care, and always kept clean and dry. A proper sieve brush should be used for removing dust and other material from a sieve after it has been used. Pieces of material stuck in the perforations should never be pushed through from the top surface of the screen. This can distort the holes and affect the accuracy of the sieve. Instead, the screen should be turned upside down and tapped sharply or the material should be pushed out of blocked perforations with the finger tip.

Newly manufactured sieves are often coated with a thin film of oil or wax. This must be removed with warm water and detergent before the sieves are used.

If a sieve is not going to be used for some time, it should be thoroughly cleaned and coated with oil before storage to prevent possible deterioration. It must be cleaned before reuse.

Sieves are subject to wear and tear despite due care and attention and they should be checked periodically for accuracy, by comparing them with standard sieves. This is normally the responsibility of a national standards organization or central laboratory in control of all grain quality matters.

ANNEX 6

DESCRIPTIONS OF INSECTICIDES USED IN STORAGE

Insecticide groups

The four main groups of insecticides are organochlorine compounds, pyrethroids, organophosphosphorus compounds and carbamates.

Storage insecticides are described briefly within these groups. Essential properties, which are grouped in tabular form in Annexes 7 and 8, are Acute Mammalian Toxicity, Maximum Residue Limits, Molecular Weights, Melting Points and Vapour Pressures, Comparative Effectiveness and Recommended Application Rates.

Organochlorines

Lindane (gamma HCH, gammexane)

Lindane, also known as gamma HCH and gammexane, is the gamma isomer of 1, 2, 3, 4, 5, 6-hexachlorocyclohexane. It is the only organochlorine insecticide extensively used in grain storage and is available formulated as dust, e.c., w.p., oil, rodent tracking powder or smoke generator. Technical HCH, which contains only 14 percent lindane, should not be used. Lindane has been effective against a wide range of pests, including moths and mites, but, owing to the widespread development of resistance and concern about the possibility of persistent toxicity, its use has largely been discontinued.

Organophosphosphorus insecticides

In this group, many insecticides are highly toxic to mammals, but a few compounds with moderately low toxicity are approved for storage use. These include malathion, pirimiphos methyl, bromophos, chlorpyrifos methyl and fenitrothion for general storage. Other insecticides, such as iodofenphos and tetrachlorvinphos, are used for surface spraying only. The volatile insecticide, dichlorvos, is used for space treatments.

Malathion

Malathion, S-1, 2-di (ethoxycarbonyl) ethyl 0,0-dimethyl phosphorodithoate, is the most widely known and cheapest of the organophosphorus insecticides used in storage. It may be admixed with grain as a dust or spray. Malathion is unstable on moist grain and concrete surfaces and is not very effective against some stored product species, particularly moths and mites. Only premium deodorized grade should be used.

Pirimiphos methyl

This insecticide, 0-2-diethylamino-6-methyl pytimidin-4yl-0,0-dimethyl phosphorothioate (Actellic), has a wide spectrum of activity against beetles, moths and mites. It is generally more persistent and more effective than malathion.

Bromophos

Bromophos, 0-(4-bromo-2,5-dichlorophenyl) 0,0 dimethyl phosphorothioate (Nexion), has been reported to be more persistent than malathion on concrete and on warm moist grain, but it is slow acting and oviposition may take place before kill.

Chlorpyrifos methyl (Reldan)

This insecticide, 0,0 dimethyl 0-3,5,6-trichloro-2-pyridyl phosphorothioate (Reldan), has a low toxicity to mammals and is effective against a wide range of stored product pests. It is said to have marked vapour toxicity.

Fenitrothion

This insecticide, 0,0 dimethyl 0-(3-methyl-4-nitro-phenyl) phosphorothioate, (Sumithion, Folithion, Accothion), is very effective against a wide range of insect pests and is more persistent than malathion on most types of surfaces. The toxicity to mammals is greater than most other insecticides used on raw grain (Annex 7).

The above organophosphorus insecticides can be admixed with grain. The FAO/WHO Joint Meeting on Pesticide Residues has approved a maximum residue limit of 10 ppm on raw cereals for each one, except malathion (8 ppm). All are available as emulsifiable concentrate formulations and some as wettable powders, oil solutions, dusts, granules or smokes.

Dichlorvos

Dichlorvos, - 2,2 dichlorovinyl dimethyl phosphate (Vapona, Nuvan, Dedevap, DDVP), is a toxic and corrosive insecticide requiring particular care in the storage and handling of concentrated formulations. The concentrated liquid attacks mild steel and penetrates PVC. The insecticide is very active against a wide range of insect pests but, owing to its high vapour pressure, it is especially effective against moths and flies. It is, therefore, used for space treatment dispensed either from misters, thermal vaporizers or from dichlorvos strips. The latter are effective for about three months in reasonably well-closed, unventilated areas. Dichlorvos persists in a treated atmosphere for only a few hours after application owing to rapid adsorption on surfaces and ready decomposition. Dichlorvos is also used as a spray applied to grain, but usually only to grain in transit where a quick disinfestation followed by rapid breakdown of the insecticide is required.

Others

Other insecticides in this group include iodofenphos (Nuvanol N), a non-volatile persistent insecticide used for surface application; methacrifos, an insecticide with moderately high volatility, and etrimfos both not yet fully evaluated; phoxim, an effective insecticide used for spraying surfaces and chlorpyrifos (dursban), restricted to wall spraying because of its comparatively high toxicity.

Carbamates

Insecticides in this group, with the exception of carbaryl, are generally too toxic to humans to be considered for widespread storage use.

Carbaryl

1 - naphthyl methyl carbamate (Sevin). The mammalian toxicity of this compound is much lower than that of other carbamates. It is generally used as a wettable powder for spraying surfaces or as a dusting powder against crawling insects. It is also used to control *Rhyzopertha dominica* in grain, because it is more effective than the organophosphorus insecticides against these species and cheaper than the effective pyrethroids.

The following insecticides are fairly toxic to mammals and are used only for surface application. They generally give good persistence against cockroaches and ants.

Bendiocarb

2,2-dimethylbenzo-1,3 dioxol-4yl methyl carbamate (Ficam).

Propoxur

2-isopropoxyphenyl methyl carbamate (Baygon, Blattanex, Aprocarb).

Dioxacarb

2-(1,3 - dioxolan-2-yl) phenyl methyl carbamate (Famid).

Pyrethroids

Pyrethrum

The natural insecticide, pyrethrum, is extracted from the flowers of *Crysanthemum cinerariaefolium*. This insecticide combines irritancy, repellency, rapid knockdown and kill in a manner unequalled by any other. The mammalian toxicity is low. Natural pyrethrum extract contains a mixture of six esters, the pyrethrins, together with a great deal of non-insecticidal plant extractives, e.g. fatty acids, sterols and terpenes. Pure pyrethrins are not isolated from the extract for commercial use, as the product would be unstable. Pyrethrum is mainly used as a space spray and gives rapid knockdown of flies or moths. It may be applied as an admixture treatment and is effective against bruchids on pulses and against *Rhyzopertha dominica* on grain. However, it is less effective than the organophosphates against *Sitophilus and tribolium spp*. on grain. Pyrethrum is rapidly broken down by sunlight and, therefore, is not used as a residual spray on walls. Pyrethum is usually formulated with a synergist (Piperonyl butoxide) at a 1:2, 1:5 or 1:10 ratio. This increases the potency and reduces the dosage needed by blocking the insect detoxification mechanism. The most suitable ratio of synergist to pyrethrum depends on the insect to be controlled.

The principal formulation is a 0.3% pyrethrins, 3.0% piperonyl butoxide solution in odourless kerosene or technical white oil for fogging or misting. Other formulations include dusts, aerosols, sprays and mosquito coils.

Synthetic pyrethroids

Many synthetic substitutes for pyrethum have been made, of which bioresmethrin, bioallethrin, tetramethrin and resmethrin are among the most widely used in storage. The compounds tend to be active either as knockdown agents or for kill, and they are therefore frequently blended for optimum effect. They are most suitable for use in mists and aerosols. Synergist may be added for some applications. The compounds are rapidly broken down by sunlight and are generally expensive compared to other classes of insecticide (Table 21).

Bioresmethrin

5 benzyl-3 furyl methyl (+)-trans-chrysanthemate. Bioresmethrin is the most active of these pyrethroids against *T. castaneum and S. oryzae* (Table 21) and is effective against organophosphorous-tolerant *R. dominica*. It is more stable than malathion on moist grain. A mixture of bioresmethrin 2 ppm, piperonyl butoxide 2 ppm and fenitrothion 4 ppm, has been used to control pests in wheat.

Resmethrin

5 benzyl-3 furylmethyl-($\pm$)-cis, trans-chrysanthemate. Resmethrin is an isomeric mixture that is cheaper but less effective than bioresmethrin.

Bioallethrin

($\pm$)-3-allyl-2-methyl-4-oxocyclopent-2-enyl($\pm$) trans-chrysanthemate. Bioallethrin has good knockdown properties but generally produces less kill than pyrethrum.

S-biol

(±)-3-allyl-2-methyl-4-oxocyclopent-2 enyl(±)-trans-chrysanthemate. S-biol is an isomer of bioallethrin and is generally more active.

Tetramethrin

3, 4, 5, 6 tetrahydrophthalimidomethyl (+)-cis, trans-chrysanthemate (Neopynamin). This compound is a less effective and cheaper than bioresmethrin.

TABLE 21. Comparative toxicity of pyrethrins dusted on wheat (LC_{95} in ppm).

	Oryzaephilus surinamensis	*Sitophilus granarius*	*Sitophilus oryzae*	*Tribolium castaneum*
Bioresmethrin	1.6	2.9	5.5	2.0
Bioresmethrin: piperonyl butoxide(1:5)	0.3	0.8	1.1	0.9
Pyrethrum	16.7	22.2	6.9	60.1
Pyrethrum: piperonyl butoxide (1:5)	1.3	2.1	3.0	6.5
Tetramethrin: piperonyl butoxide	0.5	3.1	2.8	8.7
Malathion	0.4	1.7	4.2	1.1
Fenitrothion	0.14	1.6	1.0	0.34

Photostable synthetic pyrethroids

The photostable synthetic pyrethroids listed below are persistent in light and have very high toxicity to flies and storage insects. They generally have higher mammalian toxicity than other insecticides used in storage and the potential use of this type of compound for storage protection is still being evaluated.

Permethrin

3-phenoxybenzyl(+)*cis*, trans-2, 2-dimethyl-3-(2,2-dichlorovinyl) cyclopropane-1-carboxylate.

Cypermethrin

(IR, IS)-*cis*, *trans*-3-(2,2 dichlorovinyl)-2,2-dimethyl cyclopropanecarboxylate.

Deltamethrin

(S)-cyano-3-phenoxybenzyl (IR, 3R)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylate.

Fenvalerate

(R,S)-2-cyano-3 phenoxybemzyl (R,S)-2-(4-chlorophenyl)-3-methyl butyrate.

A N N E X 7

TABLES OF INSECTICIDE PROPERTIES

TABLE 22. Acute mammalian toxicity (LD_{50} - mg/kg body weight)

Insecticide	Rat (oral)	Dermal	Hen (oral
Bromophos	4 000-8 000	2 000	9 700
Chlorpyrifos	135- 155	202	32
Chlorpyrifos methyl	950-1 100	>2 000	> 2 000
Dichlorvos	56- 108	75-110	15
Fenitrothion	250- 500	3 000	35*
Iodofenphos	2 100	> 2 000	> 2 000
Malathion	1 000-1 400	4 100	-
Methacrifos	700	3 100	-
Pirimiphos methyl	2 050	2 000	30-60
Tetrachlorvinphos	4 000-5 000	> 2 500	2 500
Chlordane	450- 600	700-850	-
Lindane	90	1 000	30-60
DDT	110	2 500	
Bendiocarb	34- 48	600- 1 000	-
Carbaryl	500- 850	4 000	2 000*
Dioxacarb	60- 80	1 950 (3 000)	-
Propoxur	90- 130	800- 1 000	20*
Bioallethrin	500- 860	3 000- 5 000	-
S-Biol	800-1 500	1 500	-
Bioresmethrin	7 000	10 000	10 000
Resmethrin	1 400	3 000	-
Piperonyl butoxide	10 000		
Pyrethrum	580- 900	2 000	
Tetramethrin	4 600-6 500	>4 000	5 000
Cypermethrin	250	>1 600	
Deltamethrin	130- 140	>2 000	
Fenvalerate	450	>4 300	
Permethrin	1 500-4 700	>4 000	
Phenothrin	> 10 000	>5 000	

Note: The figures for oral toxicity are for rats or as specified. Dermal figures are for rats, rabbits or unspecified.

* Pheasants

TABLE 23. Maximum residue limits (mg/kg) recommended by the FAO/WHO Joint Meeting on Pesticide Residues (as at January 1985)

Insecticides	Grain	Rice in Husk	Bran (Raw)
Dichlorvos	2	2	–
Malathion	8	–	20
Bromophos	10	–	20
Chlorpyrifos methyl	10	–	20
Fenitrothion	10	–	20
Pirimiphos methyl	10	–	20
Carbaryl	5–10	5	20
Lindane	0.5	0.5	–
Pyrethrins	3	–	–
Bioresmethrin	5	–	–
Piperonyl Butoxide	20	–	–
Phenothrin	5	–	15
Fenvalerate*	5	–	10
Permethrin	2	–	10

Fumigants	Raw Cereals	Milled Cereals	Cooked Cereals
Methyl bromide	5	1	0.01
Carbon tetrachloride	50	10	0.01
Ethylene dichloride	50	10	0.1
Ethylene dibromide	20	5	0.01
Carbon disulphide	10	2	0.5
Inorganic bromide	50	50	–
Phosphine	0.1	0.01	–

* Provisional

TABLE 24. Molecular weights, melting points and vapour pressures

Insecticide	Molecular Weight	Melting Point ^{o}C	Vapour Pressure as mm Hg* (Temperature - ^{o}C in brackets)
Dichlorvos	221	L **	1.2×10^{-2} (20^{o}), 5×10^{-2} (35)
Methacrifos	240	-	8.3×10^{-4} (20^{o}),
Bromophos	336	51	1.3×10^{-4} (20^{o}), 4.2×10^{-4} (30^{o})
Pirimiphos methyl	305	15-18	1×10^{-4} (30^{o})
Chlorpyrifos methyl	323	46	4.2×10^{-5}(25^{o}), 1.8×10^{-4} (35^{o})
Malathion	330	L	4×10^{-5} (30^{o})
Fenitrothion	277	L	6×10^{-6} (20^{o})
Iodofenphos	413	76	8×10^{-7} (20^{o}), 8×10^{-5} (50^{o})
Tetrachlorvinphos	366	96	4.2×10^{-8} (20^{o}), 1.5×10^{-6} (25^{o})
Lindane	291	113	3×10^{-2} (20^{o})
Chlordane	410	103-105	1×10^{-5} (25^{o})
DDT	355	109	1.9×10^{-7} (20^{o})
Carbaryl	201	142	4×10^{-5} (25^{o})
Propoxur	209	85	1×10^{-5} (120^{o})
Bendiocarb	233	130	5×10^{-6} (25^{o})
Dioxacarb	223	115	3×10^{-7} (20^{o}), 5×10^{-6} (40^{o})
Bioallethrin	302	L	-
Bioresmethrin	338	35	1×10^{-2} (180^{o})
Piperonyl butoxide	338	L	-
Pyrethrum	350	L	1×10^{-1} (170^{o})
Tetramethrin	331	65-80	3.5×10^{-8} (20^{o})
Phenothrin	350	L	
Cypermethrin	416	L	1.2×10^{-4}(80^{o})
Deltamethrin	505	98-101	-
Fenvalerate	480	L	2.8×10^{-7} (25^{o})
Permethrin	391	34-39	3.4×10^{-7} (25^{o})

* 1 mm (Hg) is equivalent to 131.00 N/m^2

** L - Liquid at normal temperature.

TABLE 25. Comparative toxicity of insecticides

The following table gives a general guide to the comparative toxicity of insecticide groups to different species.

	Malathion	Other Organo-phosphates	Lindane	Pyrethroids
Sitophilus spp.	X	X	0	0
Oryzaephilus spp.	X	X	0	0
Tribolium spp.	X	X	0	0
Callosobruchus spp.	–	X	X	X
Ephestia spp.	–	0	0	X
Trogoderma granarium	X	X	X	
Rhyzopertha dominica	–	–	X	X
Lasioderma serricorne	X	X	X	X
Stegobium paniceum	X	X	X	
Cryptolestes ferrugineus	X	X	X	
Carpophilus hemipterus	–	X	X	
Dermestes maculatus	–	X	X	
Ptinus tectus	–	0	X	
Mite spp.	–	0	X	

Key: X = effective; 0 = moderate; – = ineffective.

A N N E X 8

INSECTICIDE APPLICATION RATES

Table 26 gives a guide to insecticide application rates. The effectiveness and persistence of insecticide treatments depends very much on circumstances, particularly on the nature of the treated surface. Most organophosphorus insecticides completely break down within one week on fresh concrete surfaces but persistence may be greater on older concrete. On metal, wood or paintwork the effectiveness may last for three to four months or longer. When insecticides are sprayed on to the surfaces of bags, much of the initial insecticidal effect disappears within one month after spraying. Some of this insecticide migrates onto the commodity, where it may continue to have a protective effect.

The organophosphorus and carbamate insecticides are quite stable on dry, cool grain and applied at 10 ppm may remain effective for up to one year. Dichlorvos is less persistent, lasting only a few weeks. On moist, warm grain, however, organophosphorus insecticides are readily broken down. Pyrethrum and synthetic pyrethroids are more persistent than organophosphates on grain provided they are not exposed to direct sun-light, which causes the rapid breakdown of many pyrethroids.

TABLE 26. Recommended insecticide application rates

Insecticide	Dust Admixture with Cereals (ppm)	Surface Treatments (g/m^2) Walls	Surface Treatments (g/m^2) Bags	Space Treatment (mg/m^3)
Malathion	8-12	1-2	1-2	-
Pirimiphos methyl	4-10	0.5	0.5 (3 months)	50 - 100 at 1 ml/m^3 (fog) 35 - 40 (smoke)
Fenitrothion	4-12	0.5	0.5 - 1	-
Bromophos	6-12	0.5-1	0.5 - 1	-
Chlorpyrifos methyl	4-10	0.5-1	0.5 - 1	-
Dichlorvos	2-20*	0.5		Simple fogging or aerosol 35-70 mg. Daily fogging or aerosol 10 mg. Strip changed every 2-3 months 1 - per 30^3.
Methacrifos	5-15	0.2 - 0.4 *		50 - 150
Iodofenphos	-	1-2	-	-
Tetrachlorvinphos	-	1-2	1 - 2	-
Lindane	1-2.5	0.5		40 - 80 (fog), 25 smoke
Pyrethrin/piperonyl butoxide (1:5)	3	-	0.075 - 0.1	1 - 2 (applied at 1 ml 0.3% for 1.5 to 3 m^3)
Bioresmethrin (Resmethrin)	2	-		0.5 - 1
Phenothrin	5	-		-
Permethrin	-	0.5-0.10	0.5-0.10	-
Garbaryl	5-10	1-2	-	-
Bendiocarb	-	0.1-0.2	-	-
Dioxacarb	-	0.4-0.8	-	-
Propoxur	-	0.5	-	-

* Short persistence
\- Generally signifies that the compound is not used in that type of treatment.

ANNEX 9

PROPERTIES OF LIQUID FUMIGANTS

1. Liquid fumigants are used when temperatures are too low for the use of phosphine or for other special reasons, for example, to achieve penetration in a deep bin. Essential data on liquid fumigants are given in Table 27.

2. The currently used liquid fumigants vary considerably in mammalian toxicity, but most are toxic to some extent and some sountries ban their use. Liver, kidneys and the respiratory system are most likely to be affected. Symptoms of poisoning include irritation of the nose, eyes and throat, headaches, nausea, vomiting, diarrhoea, coma and respiratory failure. Illness can result from long-term exposure to small doses or from a single exposure to large doses. Exposure to acute doses may be especially dangerous since the onset of symptoms may be delayed for several hours or days. Threshold limit values (TLVs) and maximum allowable concentrations for short exposures (MACs) are given in Table 27.

3. The alkyl halide liquid fumigants, carbon tetrachloride, ethylene dichloride, ethylene dibromide, trichloroethane and methallyl chloride, may be detected with the halide lamp. There are also detector tubes (Chapter 4, section on "Fumigation") to measure concentrations of carbon tetrachloride, ethylene dichloride, and ethylene dibromide.

4. Liquid fumigants are supplied in 25, 50 or 200 litre drums. The choice of fumigant depends mainly on the depth of grain to be fumigated. The application rates are given in Table 27.

5. Liquid fumigants should be applied with an electrical or engine-driven pump equipped wi.h a discharge hose pipe and coarse jet nozzle. PVC and rubber pipes are unsuitable.

6. The vapour is harmful and the fumigant should be applied from a well-ventilated area. Canister respirators (Siebe Gorman type C or type 0) should be worn. Respirators are not suitable for high concentrations or for prolonged exposure, for which remote or self-contained breathing apparatus is essential (Chapter 4, section on "Maintenance of Safety"). Heavy plastic or synthetic rubber gloves may be worn. Smoking must be prohibited. (Some fumigants are decomposed by lighted cigarettes and the very toxic gas phosgene, is formed.)

7. After application, the grain surface or bag stacks should be covered with polythene film or orther gas-proof sheeting. The grain should remain covered for at least seven days and be aired for at least a further seven days.

General description of individual fumigants

Carbon tetrachloride (CTC)

Many countries have banned the use of carbon tetrachloride because of its high mammalian toxicity. It is a colourless, non-flammable liquid with a sweet smell, a high chronic mammalian toxicity and a rather low toxicity to insects. Low levels of residues may persist for several months. Carbon tetrachloride has been used for treating deep grain bins, at 300 ml per tonne for 7-14 days in bins up to 30 metres deep, or as a mixture with other fumigants to assist penetration and reduce flammability.

Ethylene dichloride (EDC)

Many countries are banning the use of ethylene dichloride because it is a suspected carcinogen. Ethylene dichloride (1, 2, dichloroethane) is a colourless liquid with a sweet smell, a high mammalian toxicity and a moderate toxicity to insects. It is flammable, with a flash point of 12-15°C at 6-16%V/V. It penetrates fairly well, although not as well as carbon tetrachloride, and is used as mixtures of 3:1 EDC:CTC in grain up to 2 metres deep and of 1:1 EDC:CTC in grain 2 to 6 metres deep at the high rate of 900 ml per ton.

Ethylene dibromide (EDB)

Ethylene dibromide (1:2 dibromoethane) is a confirmed carcinogen and widely banned for use on grain. It is corrosive liquid that is very toxic to both mammals and insects. Grain treated with ethylene dibromide must not be fed to chickens without processing. It is highly absorbed penetrating only a few cm into grain, and is used as a mixture with CTC and EDC containing 2.5% to 5% of EDB.

Trichloroethane

1, 1, 1 Trichloroethane (methyl chloroform) is a possible substitute for carbon tetrachloride. The liquid is safer to humans than carbon tetrachloride but, like carbon tetrachloride, its toxicity to insects is low. It is non-flammable.

Carbon disulphide (CS_2)

Many countries have banned the use of carbon disulphide as a grain fumigant because of its high mammalian toxicity. It is moderately toxic to insects and has good penetrating power. The high flammability and wide explosive limits (30 to 1500 g/m^3) makes it necessary to mix carbon disulphide with a non-flammable solvent (usually carbon tetrachloride at 4:1 CTC:CS_2).

Methallyl chloride

Methallyl chloride (3 chloro-2-methyl propene-1) is a colourless liquid with a sharp unpleasant smell. The compound is flammable and explosive in air between the limits of 3.2% to 8.1% V/V at 23°C. It is very irritating to the eyes, throat and skin. Its use as a grain fumigant is likely to be restricted because of its mammalian toxicity.

TABLE 27. Properties of liquid fumigants

		Carbon tetra-chloride	Methyl chloro-form	Ethylene dichloride	Methallyl chloride	Ethylene dibromide	Methyl bromide
Molecular weight		154	133	99	91	188	95
Conversion 1 mg per litre, expressed as ppm		145	184	224	247	120 ?	236
Boiling point (^oC)		77	74	84	73	132	4
Specific gravity liquid at 20^oC		1.60	1.34(25^oC)	1.26	0.93	2.17	1.73
Specific gravity gas (air = 1)		5.32	4.62	3.42	3.12	6.49	3.27
Mammalian toxicity	LD_{50} acute oral rats mg/kg body weight	5 000-9 000	10 000	770	580	146	
	TLV (ppm) 8 hour day	10	350	50	(1)	25	15
	Maximum allowable concentration (ppm) short exposure	20	2 000	75	-	25	15
	Concentration fatal in 30 mins (mg/1)		$>$100	240	45-90	65	16
	Nasal detection threshold	70	100	6	-	-	-
FAO tolerances for unchanged fumigant	Raw cereal	50	-	50	-	20	50
	Milled cereal	10	-	10	-	5	10
Toxicity to insects	Required CT products LD_{95} at 25^oC Adults	2 500	-	1 100	250	15	45
	(Mean of 5 species) Pre-adults	13 000	4 700	4 700	300	50	65
Application	Commodity dose per ton	400 ml/ 14 days	900 ml	* 900 ml/ 7 days	50 to 70 g	-	34 g
	Space dose (mg per litre)	-	-	-	50 to 100	25-50	10-15

* Mixed with carbon tetrachloride

A N N E X 10

FITTING SHEETS TO STACKS

It is advantageous to build stacks of a standard dimension to make maximum use of the sheets. Table 28 shows the maximum stack sizes coverable by sheets 18 metres x 12 metres. A 1 m overlap all round the base of the stack and a 1 m overlap for a rolled joint between two sheets has been allowed in the preparation of this table. For comparison, Table 29 shows the maximum stack sizes coverable by sheets 20 m x 10 m. More efficient coverage is obtained with the standard 18 m x 12 m sheets.

TABLE 28. Stack sizes covered by 18 m x 12 m fumigation

Number and Layout of Sheets	Stack height											
	4 m			5 m			6 m			7 m		
	L x W x H	Volume m^3 approx.	Tonnes*	L x W x H	Volume m^3 approx.	Tonnes*	L x W x H	Volume m^3 approx.	Tonnes*	L x W x H	Volume m^3 approx.	Tonnes *
2 2 x 1	12 x 8 x 4	380	230	10 x 6 x 5	300	180	8 x 4 x 6	190	110			
3 3 x 1	22 x 8 x 4	700	400	20 x 6 x 5	600	350	18 x 4 x 6	430	250			
4 4 x 1	32 x 8 x 4	1 000	600	30 x 6 x 5	900	550	28 x 4 x 6	670	400			
5 5 x 1	42 x 8 x 4	1 300	800	40 x 6 x 5	1 200	700	38 x 4 x 6	900	500			
6 6 x 1	52 x 8 x 4	1 600	1 000	50 x 6 x 5	1 500	900	48 x 4 x 6	1 100	650			
4 2 x 2	24 x12 x 4	1 100	700	22 x10 x 5	1 100	650	21 x 8 x 6	960	500	18 x 6 x 7	750	450
6 2 x 3	40 x12 x 4	1 900	1 100	38 x10 x 5	1 900	1 100	36 x 8 x 6	1 700	1 000	34 x 6 x 7	1 400	850
6 3 x 2	24 x22 x 4	2 100	1 200	22 x20 x 5	2 200	1 300	20 x18 x 6	2 100	1 300	18 x16 x 7	2 100	1 200
8 2 x 4	56 x12 x 4	2 600	1 600	54 x10 x 5	2 700	1 600	52 x 8 x 6	2 400	1 500	50 x 6 x 7	2 100	1 200
8 4 x 2	32 x24 x 4	3 000	1 800	30 x22 x 5	3 300	2 000	28 x20 x 6	3 300	2 000	26 x18 x 7	3 200	1 900
10 2 x 5	72 x12 x 4	3 400	2 000	70 x10 x 5	3 500	2 100	68 x 8 x 6	3 200	1 900	60 x 6 x 7	2 700	1 600
10 5 x 2	42 x24 x 4	4 000	2 400	40 x22 x 5	4 400	2 600	38 x20 x 6	4 500	2 700	36 x18 x 7	4 500	2 700
12 2 x 6	88 x12 x 4	4 200	2 500	86 x10 x 5	4 300	2 600	84 x 8 x 6	4 000	2 400	82 x 6 x 7	3 400	2 000
9 3 x 3	40 x22 x 4	3 500	2 100	38 x20 x 5	3 800	2 300	36 x18 x 6	3 800	2 300	34 x16 x 7	3 800	2 300

* Rough calculation assuming 1.65 m^3/tonne.

TABLE 29. Stack sizes covered by 20 m x 10 m fumigation sheets

Number and Layout of Sheets	Stack height 4 m: L x W x H	4 m: Volume m^3 approx.	4 m: Tonnes*	5 m: L x W x H	5 m: Volume m^3 approx.	5 m: Tonnes*	6 m: L x W x H	6 m: Volume m^3 approx.	6 m: Tonnes*	7 m: L x W x H	7 m: Volume m^3 approx.	7 m: Tonnes*
2 2 x 1	7 x10 x 4	280	170	5 x 8 x 5	200	120	6 x 3 x 6	108	65			
3 3 x 1	14 x10 x 4	560	340	12 x 8 x 5	480	290	10 x 6 x 6	360	210	8 x 4 x 7	224	135
4 4 x 1	21 x10 x 4	840	500	19 x 8 x 5	760	460	17 x 6 x 6	612	370	15 x 4 x 7	420	250
5 5 x 1	28 x10 x 4	1 120	640	26 x 8 x 5	1 040	630	24 x 6 x 6	864	520	22 x 4 x 7	616	370
6 6 x 1	35 x1C x 4	1 400	840	33 x 8 x 5	1 300	800	31 x 6 x 6	1 100	670	29 x 4 x 7	812	490
4 2 x 2	27 x 7 x 4	750	450	25 x 5 x 5	625	370						
6 2 x 3	27 x14 x 4	1 500	900	25 x12 x 5	1 500	900	23 x10 x 6	1 300	830	21 x 8 x 7	1 100	640
6 3 x 2	44 x 7 x 4	1 200	740	42 x 5 x 5	1 050	630						
8 2 x 4	27 x21 x 4	2 260	1 350	25 x19 x 5	2 300	1 400	13 x17 x 6	2 300	1 400	21 x15 x 7	2 200	1 300
8 4 x 2	61 x 7 x 4	1 700	1 000	59 x 5 x 5	1 450	890						
10 2 x 5	28 x27 x 4	3 000	1 800	26 x25 x 5	3 250	1 900	24 x23 x 6	3 300	2 000	22 x21 x 7	3 200	1 900
10 5 x 2	78 x 7 x 4	2 100	1 300	76 x 5 x 5	1 900	1 150						
12 2 x 6	35 x27 x 4	3 700	2 200	33 x25 x 5	4 100	2 500	31 x23 x 6	4 200	2 500	29 x21 x 7	4 200	2 500
12 6 x 2	95 x 7 x 4	2 600	1 600	93 x 5 x 5	2 300	1 400						
9 3 x 3	44 x14 x 4	2 400	1 400	42 x12 x 5	2 500	1 500	40 x10 x 6	2 400	1 400	38 x 8 x 7	2 100	1 200

* Rough calculation assuming 1.65 m^3/tonne.

A N N E X 11

STORAGE VOLUMES

Commodity	Bulk	Bag
	-------m^3/tonne---------	
Wheat	1.30	1.49
Maize	1.42	1.65
Paddy	1.76	1.92
Rice milled	1.35	1.36
Barley	1.44	1.56
Millet	1.59	1.36
Rye	1.44	
Beans	1.42	1.87
Peas	1.30	1.42
Groundnuts (shelled)		1.84
Groundnuts (unshelled)	3.05	
Cocoa	1.76	2.54
Coffee	1.56	1.81

Sources: E.T. O'Dowd (unpublished data); H.H. Bridger and O.M. Watts, 1930. Practical Cargo Stowage, London.

ANNEX 12

GLOSSARY OF TERMS FOR PESTICIDE USE

Adjuvant	An ingredient that improves the properties of a pesticide formulation. Includes wetting agents, emulsifiers and stickers.
Broad spectrum insecticide	Non-selective, having about the same toxicity to most insects.
Carbamate insecticide	One of a class of insecticides derived from carbamic acid.
Carrier	An inert material that serves as a diluent or vehicle for the active ingredient or toxicant.
Compatability	When two materials can be mixed together with neither affecting the action of the other.
Concentrate	A formulation containing a pesticide at a higher level than is normally used, but in a form suitable for dilution.
Concentration	Content of a pesticide in a liquid or dust, for example g/1 or percentage by weight.
CT product	Concentration X time product. The measured amount of a fumigant over a certain period of time (mg h/1).
Dermal toxicity	Toxicity of a material as tested on the skin.
Diluent	Component of a dust or spray that dilutes the active ingredient (e.g., kaolin, talc, water, kerosene).
Dose, dosage	The amount of toxicant (active ingredient) per insect, unit area or volume
Emulsifiable concentrate	Pesticide formulation that readily mixes with water to form a stable emulsion.
Emulsifier	Surface active substances used to stabilize suspensions of one liquid in another, for example, oil in water.
Emulsion	Suspension of small droplets of one liquid in another.
Formulation	The type of preparation in which a pesticide is sold for use.
Fumigant	A volatile pesticide that exerts a toxic action in the gaseous or vapour phase.

Inorganic insecticide	An insecticide of mineral origin, most often used as a dust or bait (e.g., boric acid powder).
Insecticide	Poison specifically for killing insects.
LD_{50}	A lethal dose for 50 percent of the test organisms. The dose of a toxicant producing 50 percent mortality in a population. A value used in presenting mammalian toxicity, usually oral toxicity, expressed as mg of toxicant per kg og body weight.
LT_{50}	The time required for a toxic substance to kill 50 percent of a test population.
Oral toxicity	Toxicity of a compound when given by mouth. Usually expressed as the number of mg of chemical per kg of body weight of animal when given orally in s single dose that kills 50 percent of the animals. The smaller the number, the greater the toxicity.
Organochlorine insecticide	Class of insecticides with multiple chlorine atoms.
Organophosphorus insecticide	Insecticide with an active phosphorus group.
Persistence	The quality of an insecticide to persist as an effective residue due to its low volatility and chemical stability.
Pesticide	General term for substances used for controlling any pest. The term covers insecticides, rodenticides, fumigants and fungicides.
Repellent	Substance used to repel or deter insects.
Residue	The amount (often a trace) of pesticide and its metabolites left in food crop after treatment.
Residual deposit	Amount of insecticide remaining on a surface after application.
Resistance (insecticide)	Ability of an ornanism to tolerate the poisonous effect of a toxicant.
Selective insecticide	One that kills selected insects but spares many or most of the other organisms, including beneficial species, either through differential toxic action or the manner in which insecticide is used.
Suspension	Finely divided solid particles dispersed in a liquid (water dispersible powder in water).
Synergism	Increased activity resulting from the effect of one chemical on another.
Maximum residue limit	Amount of pesticide residue permitted to remain in a food. Expressed as parts per million (ppm).
Wettable powder	Pesticide formulation of toxicant mixed with inert dust and a wetting agent, which mixes readily with water and forms a suspension.

A N N E X 13

SYMBOLS AND ABBREVIATIONS USED

m	metre
cm	centimetre (10^{-2}m)
mm	millimetre (10^{-3}m)
µm	micron (10^{-6}m)
l	litre
ml	millilitre (10^{-3}l)
t	tonne
kg	kilogram
g	gram (10^{-3}kg)
mg	milligram (10^{-6}kg)
kN	kilonewton
psi	pounds per square inch
s	second
min	minute
h	hour
^{o}C	degrees celsius
ai	active ingredient
ID	internal diameter
%/w/w	percentage weight/weight
%/w/v	percentage weight/volume
hp	horse power

INDEX

Accidental contamination of grain, 147

Acute rodenticides, 140-1

Anticoagulants, 138-39

Arachnids, 64-5

Baiting (rodents), 139-40, 154-5

Bird pests
    control, 144
    description of, 67
    proofing, 13

Bulk density of commodities, 189

Cause of loss, 2-3

Cooling as means of disinfestation, 156-7

Disposal of old pesticide stocks, 147

Drying of grain, 16

Dunnage, 19

Face masks, 146

Fumigation equipment
    detector tubes, 89, 93-7
    gas lines, 92, 113
    halide lamp, 93
    jets, 92, 113
    respirators, 89, 145-6
    sheets, 92-3, 186-8
    thermal conductivity meter, 97

Fumigation procedures
  application
    methyl bromide under sheets, 116, 121-2
    phosphine under sheets, 118, 122-3
  bulk grain treatment
    methyl bromide in flat warehouses, 125
    phosphine in flat warehouses, 124-5
    silos, 127
  disposal of spent phosphide, 118
  in-store, 126-7
  measurement
    CT product, 85
    methyl bromide, 93-7, 99
    phosphine, 97, 99
  monitoring effectiveness, 97-9
    incubation, 97-9
  operation of methyl bromide cylinders, 116
  piping and jet layout for methyl bromide, 113-7
  preparation of area for fumigation, 121
  rolled joints, 110-11
  safety, 99-101, 111
  sandsnakes for sheet sealing, 110
  sealing of stores, 126-7
  sheet fumigation, 101-24
    folding of sheets, 101
    joining of sheets, 110-12
    of stacks, 101-13

Fumigation procedures (cont.)
  stack size, 101
  stack sheet sizes, 186-8
  termination of fumigation
    methyl bromide, 122
    phosphine, 123
  under-sheet fumigation stepwise, 118-23
  use of test insects for assessing fumigation, 99
  visual assessment of fumigation efficiency, 97

Fumigants
  CT product definition, 85
  distribution, 81
  liquid fumigants
    carbon disulphide, 184
    carbon tetrachloride, 183
    ethylene dibromide, 184
    ethylene dichloride, 184
    methallyl chloride, 184
    trichloroethane, 184
  methyl bromide
    detector tubes, 97
    dosage schedules, 89-91
    formulations, 84
    measurement of, 93-7, 99
    poisoning, 148
    properties of, 83, 86
    sorption, 84
    toxicity of insects, 88-9
    usage, 84
  phosphine
    dosage schedules, 88, 126
    formulations, 82
    poisoning, 148
    properties of, 82-3, 86
    stability, 83
    toxicity to insects, 85
  sorption, 82
  toxicity, 81, 82

Gloves, 145

Grain
  damage, 22
  heating, 38
  infestation, 22, 37
  quality standards, 21-4
    equipment for, 24-6
    examples of standards, 23
    foreign matter, 22
    measurement of, 24, 26

Heat disinfestation, 156-7

Hermetic storage, 156

Hot spots, 38

Inert atmosphere storage, 156

Insecticides
  acute mammalian toxicities, 177
  application rates, 181-2
  carbamates
    bendiocarb, 174

Insecticides (cont.)
carbaryl, 174
dioxacarb, 175
propoxur, 175
maximum residue limits, 178
melting points, 179
molecular weights, 179
organochlorines
lindane, 173
organophosphates
bromophos, 173
chlorpyrifos methyl, 174
dichlorvos, 174
fenitrothion, 174
malathion, 173
pirmiphos methyl, 173
pyrethroids
bioallethrin, 175
bioresmethrin, 175
cypermethrin, 176
deltamethrin, 176
fenvalerate, 176
permethrin, 176
pyrethrins, 176
resmethrin, 175
S-tiol, 176
tetramethrin, 176
pyrethrum, 175
toxicity to insects, 180
vapour pressures, 179

Insecticide formulations, 72
emulsifiable concentrates, 72
oil solutions, 73
smoke generators, 134
wettable powders, 72-3

Insecticide sprayers, 74-9
automatic misters, 131
grain sprayers, 128
hydraulic knapsack, 79
motorized knapsack, 79
pneumatic knapsack, 79
portable spraying pump, 79
spraying nozzles, 79
vapour dispensers, 134

Insecticide treatments
approved for storage use, 70, 181-2
dilution of formulations, 73-4, 79-80
dusting grain, 128
dusting surfaces, 73
fogging, 134
frequency of space treatments, 131
grain spraying, 128-9
misting, 131
rates for application
bulk grain treatment, 128, 181-2
space treatment, 131, 133, 181-2
stack surface treatment, 129-30, 181-2
store surfaces, 72-3, 129, 181-2
recommended treatments
grain, 128

Insecticide treatments (cont.)
- recommended spaces, 131, 133
- recommended store structures, 70-2
- routine grain treatment, 155
- space treatment vs. fumigation, 131
- space treatments, 131-8
- techniques, 133-8
- stack cover spraying, 131
- stack spraying, 129-31
- storage surface treatment procedure, 70-81
- surface spraying technique, 80
- wall spraying, 70-1, 129

Insects
- control in bulk grain, 124-9
- descriptions, 43-60
- detection, 60-4
- inspection for, 153
- orders, 40, 43
- predatory hymenoptera, 41
- primary pests, 43
- secondary pests, 43
- *Acanthoscelides obtectus*, 46
- *Alphitobius diaperinus*, 60
- *A. laevigatus*, 60
- *Ahasverus advena*, 60
- Australian spider beetle, 60
- angoumois grain moth, 46
- cadelle beetle, 60
- *Callosobruchus chinensis*, 46
- *C. maculatus*, 46
- *C. rhodesianus*, 46
- *Carpophilus dimidiatus*, 60
- cigarette beetle, 60
- *Corcyra cephalonica*, 49
- *Cryptolestes ferrugineus*, 49
- *C. pusillus*, 49
- *C. pusilloides*, 49
- dried bean beetle, 46
- drugstore beetle, 60
- *Ephestia* spp., 49
- *E. calidella*, 49
- *E. cautella*, 49
- *E. elutella*, 49
- *E. figulella*, 49
- *E. kuhniella*, 49
- granary weevil, 46
- Khapra beetle, 49
- larger grain borer, 49
- *Lasioderma serricorne*, 60
- *Latheticus oryzae*, 60
- lesser grain borer, 49
- lesser meal worm, 60
- long-headed flour beetle, 60
- *Lophocateres pusillus*, 60
- maize weevil, 46
- *Oryzaephilus mercator*, 60
- *O. surinamensis*, 60
- *Palorus ratzeburgii*, 60
- *P. subdepressus*, 60
- *Plodia interpunctella*, 49
- *Prostephanus truncatus*, 49
- *Ptinus tectus*, 60
- *Pyralis farinalis*, 49

Insects (cont.)
  Rhizopertha dominica, 49
  rice weevil, 46
  rust red flour beetle, 49
  rusty grain beetle, 49
  Sitophilus granarius, 46
  S. oryzae, 46
  S. zeamais, 46
  Sitotroga cerealella, 46
  Stegobium paniceum, 60
  Tenebroides mauritanicus, 60
  trapping, 62
  Tribolium castaneum, 49
  T. confusum, 49
  Trogoderma granarium, 49
  warehouse moths, 49
  Zabrotes subfasciatus, 46

Inspection, 60-4, 138-9
  follow-up procedures, 154

Maintenance, 13-4

Mice control, 44

Mites
  description, 65
  detection, 65

Moisture content, 22, 159
  adsorption isotherm, 37-8
  definition, 37-8
  measurement, 161
  relative humidity definition, 37-8
  relative humidity measurement, 161
  safe level, 38

Moulds
  detection and control, 39-40

Mycotoxins, 39

Overalls, 145

Pest control methods, 69-144
  in silos, 9
  in warehouses, 8

Poisoning
  carbamates, 150
  methyl bromide, 148
  organophosphates, 150
  phosphine, 148
  resuscitation, 150
  symptoms, 148
  treatments, 148-50

Protective clothing, 145-6

Pseudoscorpions, 64

Radiation disinfestation, 158

Receipt of grain (procedures), 152-3

Respirators, 145-6

Rodents
  acute rodenticides, 140-2
  anticoagulants, 138-9
  baffles, 13
  barrier, 10
  baiting, 139-40, 155
  control, 138-44, 154-5
  description, 65-7
  detection, 67-8
  gassing, 143
  kicking plates, 13
  mouse control, 143
  Mus musculus, 65
  proofing
    materials, 13
    doors, 10, 13
    eaves, 13
    stores, 10
    ventilators, 13
  Rattus norvegicus, 65
  Rattus rattus, 65
  safety precaution for control, 144-5
  tracking powders, 143
  trapping, 143

Routine storage procedures, 152

Safety
  equipment, 89, 92
  precautions
    fumigation, 99-100, 118
    rodent control, 144-5
    space treatment, 134, 138
  protective clothing, 145-6

Sampling
  Boerner divider, 36
  coning and quartering, 33
  dividers, 33-36
  equipment, 28-36
  methods, 27-8, 169-70
  primary, 28
  produce flow sampler, 33
  random number tables, 28, 31
  riffler, 36
  sub-sampling, 33-6

Sieves and sieving, 171-2

Silos
  aeration, 9, 19
  capacity, 9
  design, 9
  gas-tightness, 10
  pest control features, 9

Spiders, 64

Stack
  covers, 129
  heights, 19, 101

Stacking, 18, 19

Storage
  of pesticides, 147
  procedures (routine), 152
  volumes, 189

Store
  hygiene, 154
  maintenance, 154
  preparation, 152
  siting, 5

Structural maintenance, 13, 16, 159

Temperature
  measurement of air, 167
  of grain, 167

Thermometers, 167-8

Warehouse
  capacity, 5
  design, 5, 159-60
  doors, 160
  drainage, 159
  floors, 8, 159
  gas tightness, 8
  lighting, 159
  maintenance, 13, 16, 160
  pest control features, 8
  rodent proofing, 10, 13
  roofs, 8, 159
  wall cladding, 159

Ventilation, 19, 160

Vertebrate pests
  control, 138-44
  description, 65-7
  detection, 67-8

FAO TECHNICAL PAPERS

FAO PLANT PRODUCTION AND PROTECTION PAPERS:

1. Horticulture: a select bibliography, 1976 (E*)
2. Cotton specialists and research insitutions in selected countries, 1976 (E*)
3. Food legumes: distribution, adaptability and biology of yield, 1977 (E* F* S*)
4. Soybean production in the tropics, 1977 (C* E* F* S*)

4 Rev. Soybean production in the tropics, First revision, 1982 (E*)

5. Les systèmes pastoraux sahéliens, 1977 (F*)
6. Pest resistance to pesticides and crop loss assessment — 1, 1977 (E* F* S*)
   Pest resistance to pesticides and crop loss assessment — 2, 1979 (E* F* S*)
   Pest resistance to pesticides and crop loss assessment — 3, 1981 (E* F* S*)
7. Rodent pest biology and control — Bibliography 1970-74, 1977 (E*)
8. Tropical pasture seed production, 1978 (E* F*** S***)
9. Improvement and production of food legume crops, 1977 (E*)

10 Rev. Pesticide residues in food 1977 — Report, 1978 (E* F* S*)

10 Sup. Pesticide residues in food 1977 — Evaluations, 1978 (E*)

11. Pesticide residues in food 1965-78 — Index and summary, 1978 (E* F* S*)
12. Crop calendars, 1978 (E/F/S*)
13. The use of FAO specifications for plant protection products, 1979 (E* F*)
14. Guidelines for integrated control of rice insect pests, 1979 (C* E* F* S*)
15. Pesticide residues in food 1978 — Report, 1979 (E* F* S*)

15 Sup. Pesticide residues in food 1978 — Evaluations, 1979 (E*)

16. Rodenticides: analyses, specifications, formulations, 1979 (E*)
17. Agrometeorological crop monitoring and forecasting, 1979 (C* E* F* S*)
18. Guidelines for integrated control of maize pests, 1980 (E*)
19. Elements of integrated control of sorghum pests, 1980 (E* F* S*)
20. Pesticide residues in food 1979 - Report, 1980 (E* F* S*)

20 Sup. Pesticide residues in food 1979 - Evaluations, 1980 (E*)

21. Recommended methods for measurement of pest resistance to pesticides, 1980 (E* F*)
22. China: multiple cropping and related crop production technology, 1980 (E*)
23. China: development of olive production, 1980 (E*)
24. Improvement and production of maize, sorghum and millet - Vol. 1, 1980 (E*)
    Improvement and production of maize, sorghum and millet - Vol. 2, 1980 (E*)
25. *Prosopis tamarugo*: fodder tree for arid zones, 1981 (E* F* S*)
26. Pesticide residues in food 1980 - Report, 1981 (E* F* S*)

26 Sup. Pesticide residues in food 1980 - Evaluations, 1981 (E*)

27. Small-scale cash crop farming in South Asia, 1981 (E*)
28. Second expert consultation on environmental criteria for registration of pesticides, 1981 (E* F* S*)
29. Sesame: status and improvement, 1981 (E*)
30. Palm tissue culture, 1981 (E*)
31. Eco-climate classification of inter-tropical Africa, 1981 (E*)
32. Weeds in tropical crops: selected abstracts, 1981 (E*)

32 Sup. Weeds in tropical crops: review of abstracts, 1982 (E*)

33. Plant collecting and herbarium development, 1981 (E*)
34. Improvement of nutritional quality of food crops, 1982 (E*)
35. Date production and protection, 1982 (E*)
36. El cultivo y la utilización del tarwi (*Lupinus mutabilis* Sweet) 1982 (S*)
37. Pesticide residues in food 1981 - Report, 1982 (E*)
38. Winged bean production in the tropics, 1982 (E*)
39. Seeds, 1982 (E/F/S*)
40. Rodent control in agriculture, 1982 (E*)
41. Rice development and rainfed rice production, 1982 (E*)
42. Pesticide residues in food 1981 - Evaluations, 1982 (E*)
43. Manual of mushroom cultivation, 1983 (E*)
44. Improving weed management, 1983 (E*)
45. Pocket computers in agrometeorology, 1983 (E*)
46. Pesticide residues in food 1982 - Report, 1983 (E*)
47. The sago palm, 1983 (E*)
48. Guidelines for integrated control of cotton pests, 1983 (E*)
49. Pesticide residues in food 1982 - Evaluations, 1983 (E*)
50. International plant quarantine treatment manual, 1983 (E*)
51. Handbook on jute, 1983 (E*)
52. The palmyrah palm: potential and perspectives, 1983 (E*)
53. Selected medicinal plants, Vol. I, 1984 (E*)
54. Manual of fumigation for insect control, 1984 (E*)
55. Breeding for durable disease and pest resistance, 1984 (E*)
56. Pesticide residues in food 1983 - Report, 1984 (E*)
57. Coconut, tree of life, 1984 (E*)
58. Economic guidelines for crop pest control, 1984 (E*)
59. Micropropagation of selected rootcrops, palms, citrus and ornamentals, 1984 (E*)
60. Minimum requirements for receiving and maintaining tissue culture propagating material, 1984 (E*)
61. Pesticide residues in food 1983 - Evaluations, 1985 (E*)
62. Pesticide residues in food 1984 - Report, 1985 (E*)
63. Manual of pest control for food security reserve grain stocks, 1985 (E*)

Availability: March 1985

C	—	Chinese	* Available
E	—	English	** Out of print
F	—	French	*** In preparation
S	—	Spanish	

The FAO Technical Papers can be purchased locally through FAO Sales Agents or directly from Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy.

M-66
ISBN 92-5-102235-6