Safety in insecticide usage

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"Safety First, The life You Save May Be Your Own" goes the standard caution is risky or dangerous activities and work situations. Yet daring individuals defy such warning, perhaps out of ignorance, expediency, carelessness and belief in the "macho" ego.

Defiance of these basic safety rule results in death and disability in the farm, industrial plants, on the road and other forms of travel, and even at home. Of particular interest to us is safety in handling pesticides, a toxic material in whatever form. There is no substitute for cure in handling insecticides.

It is important to understand some basic principles related to safe usage of insecticides. The term "safety" means different things to different people and its meaning differs mostly with each situation in which it is used; at best it is a very relative term. For purposes of those of us who deal with insecticidal chemicals, it involves the concept of hazard or risk, i.e. the likelihood of some adverse effect resulting from certain sets of circumstances, including the approved use of a chemical or any possible misuse.

Hazard in the use of pesticides may be defined as the likelihood that injury could result from the use of or exposure to the product, Often, hazard and toxicity are considered by many people to mean one and the same.

Toxicity measures the actual harm which results if the product is absorbed while hazard takes into consideration the likelihood of contact or absorption. In many instances toxic substances are handled for long periods with out any harm simply because precautions have been taken to prevent contact or absorption, hence hazard become negligible.

In order to better appreciate safety of insecticide handling and usage, it is important to consider the following hazards and take the necessary precautions:

A. Acute Hazards

a. Oral intake

1. Eating the substance or contaminated food.
2. Drinking the substance or contaminated food.
3. Eating or drinking from contaminated utensils.
4. Eating or handling food with contaminated hands.
5. Blowing or sucking to clear a blockage in equipment.

b. Dermal Absorption

1. Handling concentrates without protection.
2. Splashing concentrates onto skin.
3. Spillage of concentrates.
4. Contaminated clothing, tools, or work places.
5. Lack of protective clothing.
6. Carelessness in mixing and spraying

c. Inhalation-There is a risk of absorption through the lungs

1. During fumigation
2. Due to insufficient ventilation in work area.
3. During aeration of treated grains
4. During mixing and spraying contact insecticides

B. Chronic Hazards

These can result from faulty practices repeated over extended periods:

1. Familiarity and failure to observe precaution
2. Poor personal hygiene
3. Poor ventilation
4. Inadequate protective clothing
5. Faulty equipment
6. Repeated exposure to spray or dust (particularly organophosphates insecticides)

These are mainly direct hazards affecting men. Hazards to the environment is an important consideration particularly its negative ecological impact. For our purpose we will concentrate on the dangers to man, the applicator and consumers. It does not necessarily mean that insecticides are bad and should not be used - far from that.

Realizing these hapards, let us now consider the corresponding precautionary measures to counteract these risks.

Mammalian Toxicity

Toxicological studies are conducted to determine the threshold limit of a chemical which an animal or human is capable of handling without significant biological effects. The usual beginning in any toxicological evaluation is the assessment of the acute toxicity i.e., the effects of a single dosage of the chemical. The general technique is the determination of the LD50 (the dosage necessary to produce death or reproducible effect in 50% of the animal population tested). The compound is administered on a weight/weight basis (milligram or gram of compound per kgm of body weight of test animals) in a suitable solvent or suspension system. This is evaluated by acute tests, orally (AO) or dermally (AD), chronic oral tests (CO), vapor toxicity tests (VA) and chronic vapor tests (VC) or inhalation tests (IT).

Insecticides can be classified according to their toxicity based on the LD50 values:

1. High toxic

AO LD_{50} = 0-50 mg/kg
AD LD_{50} = 0-200 mg/kg

IT LC_{50} = 0-2000 ug/l

Danger, skull and crossbones and poison on label.

2. Moderately toxic

AO LD_{50} = 51-500 mg/kg
AD LD_{50} = 201-2000 mg/kg
IT LC_{50} = 2,0001-20,000 ug/l

Warning on label.

3. Slightly toxic

AO LD_{50} = 501-5000 mg/kg
AO LD_{50} = 2,000-20,000 mg/kg
IT LC_{50} = more than 20,000 ug/l

4. Relatively nontoxic

AO LD_{50} = 5000 + mg/kg
AD LD_{50} = 20,000 + mg/kg
AD LC_{50} = of some of the common insecticides

Generally, the insecticides used in stored product treatment are of low mammalian toxicity (Table 1) and are in a formulation that is likely to be effective against the species involved, persistent for the required period of time under given storage conditions and will not alter the flavor, color of the stored commodity.

Insecticide Residues

The Joint FAD/WHO Codex Alimantarius Commission was established to implement the Joint FAD/WHO Food Standards Programme. The purpose of the Programme is to elaborate international standards for food aimed at protecting the health of the consumer, ensuring fair practions in the food trade, and by their acceptance by governments resulting in the harmonization of national food legislations, thereby facilitating international trade. The food standards incorporate provisions in respect to food hygiene, food additives, pesticide residues, other contaminants and methods of analyis and sampling. The Codex has a committee which establishes maximum limits for pesticide residues in specific food item or group of food, Table 4 presents both the Codex recommended residues and "guideline [eve". The former is intended to assist administering authorities, eventhough acceptable daily intakes have not been established for the individual products.

Table 1. LD_{50} of some insecticides used for stored product protection'

Insecticide	**LD_{50}, Acute Oral mg/kg body wt. rat)**
Malathion***	885 - 2800
Pirimiphos methyl**	2050 - 2300
Chlorpyrifos methyl**	041 - 2140
Tetrachlorvinphos*	4000 - 5000
Bromophos*	3750 - 7700
Dichlorvos**	25 - 170
Diazinon*	66 - 600
Fenitrothion*	250 - 670
Lindane* *	76 - 200
DDT*	87 - 500
Methoxychlor*	5000- 7000
Carbaryl*	307 - 986

Alletrin**	680 - 1000
Pyrethrine**	200 - 2600

1 From Kenaga and End 1974.
2 Usage summarized from Champ and Dyte 1971.
*** Occasional use**
**** Moderate use**
***** Intensive use**

Guidelines for Safe Pesticide Use

Although the use of insecticides has its undesirable side effects (upset biotic balance, leave harmful residues, and insects develop resistance), its use must go on until a better control method has been found. Thus, there is a need for precautionary measures in its use so that the harmful effects can be minimized.

A. Precautionary Measures

1. Never apply more or less than what the pesticide label specified time of application and rates at the specified time of application and follow safety precautions.

2. Store pesticides under lock and key, away from children, pets, food and anything or anybody who does not understand how dangerous they can be.

3. Never leave pesticides unlabeled or misleadingly labeled. Better still, keep them in their original containers, whenever practicable.

4. Do not smoke or eat while handling pesticides. Protective clothing, gloves and masks are desirable when one works closely with them. Discard contaminated clothing and empty packages and always wash thoroughly after handling such toxic chemicals.

5. Never re-use pesticide containers for purposes such as for storing food or water. No one is ever sure that residues will not

be there.

6. All poison baits should be clearly marked as dangerous. When baits containing acute poisons are laid, everyone should be excluded from the area; and when treatment is finished all uneaten baits should be collected and burnt along with any rodent corpses found during and after treatment.

7. If symptoms of poisoning (nausea, rashes, vomiting), occur, stop working and run, don't walk, to the nearest antidote. The life you save may be your own.

8. In general, repeated and prolonged contact with any insecticide is to be avoided especially if it is in the form of dusts, mists, vapours, or concentrated formulations.

B. Curative Measures

1. Curative measures - Spillage, breakages and other such accident cannot be entirely ruled out in insecticide use. The following therefore are geared towards minimizing poisonous effects:

a. Spilled materials are immediately wiped with rags which are then buried. Do not burn.

b. Thoroughly wash with soap and water skin that has been in contact with pesticides. Contaminated clothing should be washed thorouhly before use or burned depending on the degree of contamination.

c. If pesticide has been swallowed, induce vomiting and immediately seek medical attention.

d. In cases of dizziness or nausea in the use of pesticides, stop work immediately and get medical attention.

C. First Aid in Case of Energency

Call your physician immediately in case of emergency.

1. Group I - Arsenicals, Organochlorines, Fluorines, Nicotine.

Antidote:

a. For ingestion - Induce vomiting by inserting a finger down the throat of the patient or give a tablespoon of salt in a glass of warm water. Repeat until vomit fluid is clear then give two tablespoons of Epson salts or milk of Magnesia in water and plenty of milk or water. Have the victim lie down and keep him quiet. Keep him warm, use external heat (blanket, hot water bottle). If nicotine is involved, artificial respiration may be needed. Phenobarbital should be given by a physician to control convulsions.

b. External - Wash exposed areas with soap and water.

2. Group II - Di Nitro Compounds

Table 3. Estimates of odor threshold and maximum exposures (ppm) safe for human subjects of some fumigants.

Materials	**Major Method of Appl'n[a]**	**Single Exposure**		**Approx. Odor Threshold (ppm)**
		No more than once a week		
		7 hours	**1 hour**	
1. Methyl bromide	1,2,3	100	200	none
2. Phosphine	1	1	25	none
3. Ethylene dibromide	1	50	200	25
4. Ethylene dichloride	1	200	1000	50
5. Ethylene oxide	1	150	500	300 -1500
6. Carbon disulfide	1	100	200	30 - 60
7. Carbon tetrachloride	1, 3	50	300	60 - 70
8. Propylene oxide	1	400	1000	115 - 350

9. Dowfume EB-S[b]	1	75	300	25
10. Serafume[c]	1	50	300	50

a1 - Commodity; 2 - Space; 3 - Structure.
b Mixture of fumigant No. 4, 5 and 7.
c Mixture of fumigant No.6 and 7.

Table 4. The maximum residue limit (ppm) for cereal grains.

Chemical	All Grains	Maize	Rice	Sorghum	Wheat
Bioresmethrin	5 GL	-	-	-	-
Bromophos	10 T	-	-	-	
Carbaryl	-	-	3 T	10 T	5 T
Chlorpyrifos methyl	-	10 T	0.1 T	10 T	10 T
Dichlorvos	2 T				
Fenitrothion	10 T		10 T Hulled	-	-
			& in Husked		
			1 T polished	-	-
Malathion	8 T	-	-	-	-
Methyl Bromide	50 GL				
Piperonyl Butoxide	20 T	-	-	-	-
Pirimiphos methyl	-	7	2 T Hulled		

			10 T in Husked 1 T in Polished		
Pyrethrin	3 T	-	-	-	-

T - Codex Tolerance
GL - Guideline Level

Antidote:

a. For ingestion - Speed is important if body temperature rises, cool with cold presses. Give tablespoon of baking soda in warm water. Repeat until vomit fluid is clear.

b. External - wash with soap and water.

3. Organic Phosphates and Carbamates

Antidote:

a. For ingestion - induce vomiting by inserting finger down throat or by taking tablespoon of salt in glass of warm water. Atropine (0.1 gr.) and oxygen should be administered by a physician. Other agents such as 2-PAM (pyridine-2-aldoxine), DAM (dracetylmonoxime) could be administered by a physician for organophosphate poisoning but never for carbamate poisoning.

b. External Wash with soap and water and swab with ethyl alcohol.

4. Rodenticides

Antidote:

a. In case of poisoning of acute poisons, zinc sulphide, through inhalation or accidental consumption of poison baits, swift action should be taken. Mustard emetic should be immediately administered to induce vomiting. When the vomiting stops, give 6 gms potassium permanganate dissolved in glass of warm water. This will produce insoluble copper sulphide. After that give a purgative - one tablespoon of Epsom salt in water. Call doctor immediately.

b. In case of accidental consumption of this poison, call the physician immediately. Vitamin K administration and blood transfusion are recommended. Never give morphine, baribtuates or tranquilizers. In all cases, do not induce vomiting if patient:

a. **is unconscious or in coma**
b. **is having fits convulsion**
c. **has swallowed a petroleum product**
d. **has swallowed a corrosive acid or alkaline**

Other Measures

All pesticides must be considered in some way potentially harmful to man and should only be used by trained persons.

In particular, concentrated insecticides, rodenticides and fumigants must be handled with extreme caution. Washing water must be available to operators.

Protective clothing should be available. Rubber gauntlet gloves should be worn when handling concentrated insecticides. Face masks must always be worn when insecticide dusts and sprays are mixed or being applied. They should also be worn when rodenticide dusts or concentrates are being used.

For fumigation involving methyl bromide, full face respirators with the appropriate canisters must be used. For phosphine fumigations, respirators with appropriate canisters must be available for all but the smallest trements (e.g. single bags). In all but the smallest fumigation treatments, two operators should be present with one designated as in-charge.

When mixing concentrated insecticides with water or other diluent, a spoon or other implement must be used. Never use the hands to pick-up concentrated insecticide. During this operation, especially if the store room is small, always leave the door open to prevent a build-up of dust or fumes. Lids should be replaced on concentrate concentrate containers immediately after use.

Care must be taken to ensure that correct application of insecticides is undertaken particularly where insecticides are added directly to food commodities.

ALWAYS READ THE LABEL ON THE CONTAINER AND FOLLOW THE MANUFACTURERS INSTRUCTIONS.

Application equipment for sprays and fumigants must be checked before the start of treatment.

Rodenticides must be placed in locations that are not accessible to domestic or farm animals. Use bait boxes where where possible.

All buildings or stacks of products being fumigated must be clearly labelled. Personnel should not continue to work in the building whilst a fumigation is being carried out and should not resume work there until tests have shown it is safe to do so.

All pesticides should be stored in clearly labelled containers in a safe place under lock and key. Storage should not be in the main warehouse where food is stored, but in a separately designated room. Pesticides should not be stored in or adjacent to living quarters. Storekeepers in charge of pesticides must be properly trained. They must not eat, drink or smoke in pesticide stores. All pesticides must be checked into and out of stores and a record with full details kept. Large stocks of pesticides are best avoided since they can deteriorate quickly at high temperatures and humidities. Efforts should be made to ensure that sufficient pesticides for one season only are stored wherever possible.

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1. The Joint FAD/WHO Food Standards Programme and the Codex Alimentarius Commission

The Joint FAD/WHO Codex Alimentarius Commission (the Commission) was established to implement the Joint FAD/WHO Food Standards Programme. Membership of the Commission comprises those Member Nations and Associate Members of FAO and/or WHO which have notified the Organizations of their wish to be considered as Members. By April 1984, 122 countries have become Members of the Commission. Other countries which participate in the work of the Commission or of its subsidiary bodies in an observer capacity are expected to become Members in the near future.

The purpose of the Joint FAD/WHO Food Standards Programme is to protect the health of consumers and to ensure fair practices in the food trade; to promote coordination of all food standards work undertaken by international, governmental and non-governmental organizations; to determine priorities and initiate and guide the preparation of draft standards through and with the aid of appropriate organizations; to finalize standards and following their adoption, publish them in a Codex Alimentarius either as regional or world-wide standards.

For further information concerning the work and procedures of the Commission, readers should refer to the Procedural Manual of the Codex Alimentarius Commission (5th Edition) which also contains definitions of terms for the purpose of the Codex Alimentarius. In addition, Volume I of the Codex Alimentarius (CAC/VOL.I - Ed. 1) includes general information about a wide variety of aspects of the work of the Commission.

2. The Codex Committee on Pesticide Residues

The Codex Committee on Pesticide Residues (CCPR) is an inter-governmental body which advises the Commission on all matters relating to pesticide residues. It meets every year and submits reports ("ALINORM" reports) to the Commission. The CCPR has the responsibility:

(a) to establish maximum limits for pesticide residues in specific food items or in groups of food;

(b) to establish maximum limits for pesticide residues in certain animal feeding stuffs moving in international trade where this is justified for reasons of protection of human health;

(c) to prepare priority lists of pesticides for evaluation by the Joint FAD/WHO Meeting on Pesticide Residues (JMPR);

(d) to consider methods of sampling and analysis for the determination of pesticide residues in food and feed;

(e) to consider other matters in relation to the safety of food and feed containing pesticide residues; and

(f) to establish maximum limits for environmental and industrial contaminants showing chemical or other similarity to pesticides, in specific food items or groups of food.

The CCPR relies on data supplied by Member Governments and on the recommendations and evaluations of the Joint FAD/WHO Meeting on Pesticide Residues (JMPR). The conclusions of the JMPR are submitted to the CCPR for consideration and further elaboration in accordance with the Commission's procedures. After adoption by the Commission, the maximum limits for pesticide residues are submitted to governments for acceptance in accordance with the Procedures for the Acceptance of Codex Maximum Residue Limits laid down by the Commission (see Section 1.7 below).

3. The Joint FAD/WHO Meeting on Pesticide Residues

The Joint FAD/WHO Meeting on Pesticide Residues (JMPR) is composed of expets who serve in a personal capacity. The JMPR evaluates pesticide residues on the basis of all available data supplied by Governments and Industry and, where appropriate, establishes "acceptable daily intakes" (ADls) and recommends maximum limits for pesticide residues in food. The conclusions of the experts are published in joint FAD/WHO reports (Ret: WHO Techn. Rep. Ser. or FAO Plant

Production and Protection Paper Series). Toxicological and residue data are summarized in publications under the series "Evaluations of Some Pesticide Residues in Food" published by FAO. The views and recommendations of the FAD/WHO Experts are taken by the CCPR as the basis for reaching decisions concerning the safety or otherwise of residues of pesticides in food and as the basis on which the CCPR can judge whether such residues are unavoidable in accordance with "Good Agricultural Practice".

4. Procedure for the Elaboration of Codex Maximum Limits for Pesticide Residues

Codex maximum residue limits are elaborated in accordance with a Procedure which affords full participation by Governments and International Organizations, either directly (i.e. at Sessions of the Codex Alimentarius Commission (Steps 5 and 8) or at Sessions of the Codex Committee on Pesticide Residues (Steps 4 and 7)). The Procedure also allows countries to submit to the Commission (at Step 5) a statement in writing on any impact the draft Codex maximum residue limits may have on their economic interests. Furthermore, comments in writing on the draft Codex maximum residue limits are routinely

invited at Steps 3 and 6 of the Procedure. Details of the Codex Procedure are given in the Procedural Manual of the Codex Alimentarius Commission (5th Ed). A summary of the Procedure is given below:

Step	**Action**
1,2	In practice, Steps 1 and 2 are omitted.
3	The maximum residue limits (MRLs recommended by the JMPR - see Section 1.3 - are sent to Governments and International Organizations for comments.
4	The MRLs are considered by the CCPR (see Section 1.2) in the light of written comments received.
5	The MRLs are considered by the Commission (see Section 1.1). Economic Impact Statements may be submitted in writing at this Step.
6	The MRLs are sent to Governments and International Organizations for comments.'
7	The MRLs are considered by the CCPR (see Section 1.2) in the light of written comments received.'
8	The MRLs are considered by the Commission and adopted as Codex MRLs (see Section 1.1). Governments may submit proposals for amendment in writing.

It should be noted that temporary maximum residue limits are no longer adopted by the Commisssion as Codex maximum residue limits. Any existing temporary Codex maximum residue limits are those which were adopted by the Commission previously or maximum residue limits where the "acceptable daily intake" estimated by the JMPR has been converted into a 'temporary acceptable daily intake'.

It should also be noted 'Guideline Levels' (see definitions and Part 3 of the Guide) are not processed beyond Step 4 of the Codex Procedure. Guideline Levels do not constitute Codex recommendations and are published only for the information of Governments, in the expectation that the JMPR will set an 'acceptable daily intake' or 'temporary acceptable daily intake' for the pesticides and their residues concerned.

5. Acceptance of Codex Maximum Limits for Pesticide Residues

Codex maximum residue limits, i.e. those marked "CXL", in the Guide (Part 2) are submitted to all Member Nations and Associate Members of FAO and/or WHO for acceptance in accordance with the Procedure for Acceptance of Codex Maximum Limits for Pesticide Residues contained in paragraph 6 of the General Principles of the Codex Alimentarius, under which the maximum limits may be accepted in one of the three following ways: full acceptance, limited acceptance, target acceptance. The General Principles of the Codex Alimentarius are contained in the Procedural Manual of the Codex Alimentarius Commission (5th Ed).

In interpreting the General Principles of the Codex Alimentarius, it should be recognized that the maximum limits apply to residues of pesticides in food and do not imply recommendations concerning the use of the pesticides. A country accepting a maximum limit for a pesticide residue in any of the ways set forth in paragraph 6 of the General Principles in not thereby prevented from restricting or prohibiting the use of that pesticide, nor is it compelled to permit the use of that pesticide if it is not required in its agriculture or if its use is not desirable for environmental reasons or for other reasons such as the protection of operators.

Letters or instruments of acceptance should specify the type of acceptance in respect of each Codex maximum limit and to indicate all necessary information. To assist Governments in notifying their acceptance or otherwise, a copy of a suitable Acceptance Form relating to the maximum limits is made available.

Governments which are unable to accept a particular Codex maximum residue limit in one of the three ways mentioned above may, nevertheless, be in a position to indicate whether products conforming to that maximum limit may be distributed freely within their territorial jurisdictions, as provided for under paragraph 6.B of the General Principles or may be permitted to be distributed subject to certain specified conditions. Governments are urged to take this possibility into account in cases where full, target or limited acceptance cannot be given.

The Codex Committee on Pesticide Residues is elaborating guidelines on regulatory practices to assist Governments in accepting Codex maximum limits for pesticide residues as soon as completed, the Guidelines will be distributed to Governments.

The Joint Office of the FAD/WHO Food Standards Programme, FAO Headquarters, Rome, will be pleased to provide to the

appropriate authorities in each country any information, explanation or assistance that may be required with respect to the Codex maximum residue limits, to the Codex acceptance procedure or to the activities of the Codex Alimentarius Commission in general.

Up-to-date and full details of acceptances and other responses from Governments as at September 1983, have been published in the Codex Alimentarius, Summary of Acceptances Part II - Codex Maximum Limits for Pesticide Residues.

DEFINITION OF TERMS USED BY THE CODEX

The definitions of terms given below are intended for the purposes of the Codex Alimentarius and other Codex publications, such as the present Guide. Governments may wish to use different definitions. It should be noted that the definitions have been reviewed by the Codex Committee on Pesticide Residues and will be considered by the 16th Session of the Codex Alimentarius Commission.

(a) Animal Feed means harvested fodder crops, by-products of agricultural crops and other products of plant or animal origin which are used for animal feeding and which are not intended for human consumption.

(b) Pesticide means any substance intended for preventing, destroying, attracting, repelling, or controlling any pest including unwanted species of plants or animals during the production, storage, transport, distribution, and processing of food, agricultural commodities, or animal feeds or which may be administered to animals for the control of ectoparasites. The term includes substances intended for use as a plant-growth regulator, defoliant, dessicant, fruit thinning agent, or sprouting inhibitor and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport. The term normally excludes fertilizers, plant and animal nutrients, food additives, and animal drugs.

Explanatory Note: "Agricultural commodities" refers to commodities such as raw cereals, sugar beet, and cottonseed which might not, in the general sense, be considered food.

(c) Pesticide Residue means any specified substances in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities considered to be of toxicological significance.

Explanatory Note: The term "pesticide residue" includes residues from unknown or unavoidable sources (e.g., environmental), as well as known uses of the chemical.

(d) Good Agricultural Practice in the Use of Pesticides (GAP) is the officially recommended or authorized usage of pesticides under practical conditions at any stage of production, storage, transport, distribution and processing of food, agricultural commodities, and animal feed bearing in mind the variations in requirements within and between regions, which takes into account the minimum quantities necessary to achieve adequate control, applied in a manner so as to leave a residue which is the smallest amount practicable and which is toxicologically acceptable.

Explanatory Note: The "officially recommended or authorized usage of pesticides" is that which complies with the procedures, including formulation, dosage rates, frequency of application and preharvest intervals, approved by the national authorities.

(e) Acceptable Daily Intake (ADI) of a chemical is the daily intake which, during an entire lifetime, appears to be without appreciable risk to the health of the consumer on the basis of all the known facts at the time of the evaluation of the chemical by the Joint FAD/WHO Meeting on Pesticide Residues. It is expressed in milligrams of the chemical per kilogram of body weight.

Explanatory Note: For additional information on ADIs relative to pesticide residues refer to the Report of the 1975 Joint FAD/WHO Meeting on Pesticide Residues, FAO Plant Production and Protection Series No. 1 or WHO Technical Report Series No. 592.

(f) Temporary Acceptable Daily Intake (TADI) is an acceptable daily intake established for a specified, limited period to enable additional biochemical, toxicological or other data to be obtained as may be required for estimating an acceptable daily intake.

Explanatory Note: A TADI estimated by the Joint FAD/WHO Meeting on Pesticide Residues normally involves the application of a safety factor larger than that used in estimating an ADI.

(g) Maximum Residue Limit (MRL) is the maximum concentration for a pesticide residue resulting from the use of a pesticide according to good agricultural practice that is recommended by the Codex Alimentarius Commission to be legally permitted or

recognized as acceptable in or on a food, agricultural commodity, or animal feed. The concentration is expressed in milligrams of pesticide residue per kilogram of the commodity.

Explanatory Note: The "recognized as acceptable" is intended to accommodate Member Countries which, under national legislation, do not use MRLs as legal limits. An MRL is principally based on supervised trials carried out under varying conditions of climate and pest control needs.

(h) Extraneous Residue Limit (ERL) refers to a pesticide residue or a contaminant arising from environmental sources (including former agricultural uses) other than the use of a pesticide or contaminant substance directly or indirectly on the commodity. It is the maximum concentration of a pesticide residue or contaminant that is recommended by the Codex Alimentarius Commission to be legally permitted or recognized as acceptable in or on a food, agricultural commodity or animal feed. The concentration is expressed in milligrams of pesticide residue or contaminant per kilogram of the commodity.

Explanatory Note: The term "practical residue limit" has been used for residues in food from unavoidable sources and in food of animal origin arising from residues in animal feed. This term, which had led to much confusion, was abandoned. Residues in food of animal origin that are controllable by farming practices are now covered by MRLs. Residues from unavoidable sources are covered by ERLs which are usally based on residue data from food monitoring programmes.

(i) Temporary MRL (TMRL) or Temporary ERL (TERL) is an MRL or ERL established for a specified, limited period and is recommended under either of the following conditions:

1. where a temporary acceptable daily intake has been estimated by the Joint FAO/WHO Meeting on Pesticide Residues for the pesticide or contaminant of concern; or

2. where, although an acceptable daily intake has been estimated, the good agricultural practice is not sufficiently known or residue data are inadequate for proposing an MRL or ERL by the Joint FAD/WHO Meeting on Pesticide Residues.

Explanatory Note: TMRLs and TERLs are not to be advanced further than Step 7 of the Codex Procedure.

(j) Guideline Level is used to assist authorities in determining the maximum concentration of a pesticide residue resulting from a use reflecting good agricultural practice but where an acceptable daily intake or temporary acceptable daily intake for

the pesticide has not been estimated or has been withdrawn by the Joint FAD/WHO Meeting on Pesticide Residues. The concentration is expressed in milligrams of pesticide residue per kilogram of the commodity.

Explanatory Note: Guideline Levels are not to be advanced further than Step 4 in the Codex Procedure and are to be listed separately from MRLs and TMRLs in Codex documents.

(k) Limit of Determination is the lowest concentration of a pesticide residue or contaminant that can be identified and quantitatively measured in a specified food, agricultural commodity! or animal feed with an acceptable degree of certainty by a regulatory method of analysis.

(l) Regulatory Method of Analysis is a method that has been validated and can be applied using normal laboratory equipment and instrumentation to detect and determine the concentration of a pesticide residue or contaminant in a food, agricultural commodity or animal feed for purposes of determining compliance with a maximum residue limit or extraneous residue limit.

Explanatory Note: for more information on regulatory methods of analysis and their application, refer to Recommendations for Methods of Analysis for Pesticide Residues and Codex Guidelines on Good Analytical Practice.

(m) Intake Study is a study designed to measure or estimate actual dietary exposures of consumers to pesticide residues or contaminants in order to compare such exposures to the acceptable daily intakes for pesticides or contaminants.

Explanatory Note: For more information on intake studies, refer to Guidelines for the Study of Dietary Intakes of Chemical Contaminants prepared by the Joint FAD/WHO Food Contamination Monitoring Programme (WHO-EEPI83.53, FAOESN/M ISC/8312).

GUIDELINES ON GOOD AGRICULTURAL PRACTICE IN THE USE OF PESTICIDES

Introduction

The main purpose of this document is to indicate guidelines on the use of pesticides on a general basis and to encourage the use of more effective and/or less persistent pesticides so as to reduce the amount of residues in food of plant or animal origin, in animal feed, and in the environment. These guidelines are intended for use by administrators, specialists and

advisory agencies. No attempt will be made to elaborate recommendations for the use of individual pesticides and their formulations. It should be emphasized that due to differences in pests, -pest population, commodities, climate and geographical location, it is not possible to propose universal recommendations for the use of specific pesticides against specific pests. It should also be remembered that not all countries have uniform capabilities for the development and implementation of detailed guidelines for the use of pesticides. Therefore, only general guideline practices can be suggested for the use of pesticides, and the details of use will require development of information within the Member countries. The important issue is, however, to try and eliminate disturbing side-effects of certain pesticides or certain applications.

A first basis for general guidelines is provided by the Codex definition of the concept of "good agricultural practice in the use of pesticides", which is as follows:

"Good agricultural practice in the use of pesticides is the officially recommended or authorized usage of pesticides under practical conditions at any stage of production, storage, transport, distribution and processing of food, agricultural commodities and animal feed, bearing in mind the variations in requirements within and between regions, which takes into account the minimum quantities necessary to achieve adequate control applied in a manner so as to leave a residue which is the smallest amount practicable and which is toxicologically acceptable".

Explanatory Note: The "officially recommended or authorized usage of pesticides" is that which complies with the procedures, including formulation, dosage rates, frequency of application and pre-harvest intervals, approved by the national authorities.

1. Noting that the occurrence of unintentional residues in a number of food items and animal feedstuffs is partly a result of environmental contamination, the Meeting recommends that efforts be made to discover the sources of such contamination and, where possible, to eliminate them, in order to reduce the background level of pesticide residues.

2. In view of the concern over the extent of the use of certain persistent pesticides, the Meeting recommends that they be replaced, wherever possible, by pesticides, the residues of which are less undesirable toxicologically.

The emphasis in these recommendations is clearly on the desirability of making a conscious effort to replace certain pesticides by alternative chemicals, which are preferable from the food or environmental health point of view. The importance of reducing residues in animal feed has again been emphasized by a recommendation of the 1969 Joint Meeting (WHO Technical

Report Series No. 458):

"Because some compounds currently in use as seed protectants are highly toxic to humans, and their uses can result in the occurrence of unintentional residues, the need to develop safer substitutes was emphasized. In the meantime, every effort should be made to reduce the contamination of commercial grain and animal feeds to the minimum and to undertake surveys to ensure that directions are being observed by farmers and others concerned with the handling of treated seeds".

Further discussions during the 1972 Joint Meeting have indicated the desirability of recommending limits for pesticide residues in animal feed (WHO Technical Report Series No. 525):

"In recognition of the fact that residues in animal products can result from residues in feed and that such animal feeds enter into commerce, the Meeting felt it would be appropriate to consider data and to make recommendations on residues in such animal feeds".

It must be recognized that the policy with respect to pesticide regulations or control measures has in many countries followed trends similar to those indicated in the FAD/WHO recommendations. As a consequence, restrictions in the use of certain pesticides have been implemented. It would, therefore, seem useful to translate the principles of the recommendations into terms of general guidelines referring to the particular aspects of pesticide usage.

Pesticide Situation

Before attempting to construe general guidelines from existing principles, such as are laid down in the definition of good agricultural practice, and in the various recommendations from the FAD/WHO Joint Meeting on Pesticide Residues, it may be useful to consider briefly the present pesticide situation as background against which further considerations should be judged. Without being exhaustive, the following summary could serve such purpose:

The use of pesticides for agricultural, veterinary, public health, domestic and industrial purposes has:

(a) ensured a better protection of harvest against unpredictable losses caused by plant diseases and pests;

(b) in general improved both the quantity and quality of food;

(c) decreased the extent of vector-borne and other diseases in humans and animals.

For the foreseeable future agricultural pesticides will continue to be required in the production, transportation and storage of food, feed and fibre. However, most pesticides are derived from, or produced through the use of non-renewable world resources. Wastage in their use should be avoided as part of an overall global effort to conserve these resources, maximize their effectiveness and minimize unnecessary environmental pollution.

Apart from occupational accidents and gross misuse, the regular use of pesticides has resulted in a number of undesirable side-effects, partly attributable to occasional indiscriminate applications, partly due to undoreseen biological effects.

This situation has prompted developments which can be briefly described as follows:

(a) research on alternative methods of pest control, and introduction of these wherever technically possible and economically feasible;

(b) introduction of alternative pesticides with greater safety and suitability;

(c) more adequate legislation or other administrative provisions, coupled with better extension and education facilities in the field of pesticide usage.

At present alternative methods of pest control are not available to the extent that they can be applied on a broad scale as full replacement of pesticides, but they offer possibilities in specific cases, either alone or in combination with selected or selective pesticides.

Research on alternative methods of pest control to be applied in combination with selected or selective pesticides (i.e. integrated pest control) should, therefore, be intensified, and in the meantime emphasis should be placed on a system of supervised control, which aims at a judicious use of pesticides coupled with assessment of economic threshold levels and forecasting systems.

Pesticide legislation or other effective control systems should be introduced and implemented in those countries where they have not yet been established; in other countries with existing legislation or administrative controls, these may need to be

intensified in order to strike a better balance of benefits to agriculture against risks to humans, environment and food.

The extent to which regulations are introduced should, on the other hand, not go beyond reasonable and acceptable limits, in order to ensure that plant health and other pest control requirements as well as availability of adequate pesticides are not jeopardized. Regulations should be accompanied by enlightening and meaningful educational programmes on pesticide use and safety.

Legislation on pesticides deals mainly with two fundamental aspects, which are distinctly different though interrelated, i.e.:

(a) use pattern and handling regulations, pertaining to registration and approval on the basis of criteria for effecacy and for side-effects;

(b) residue regulations, pertaining to the establishment of maximum limits of pesticide residues in food and feed on the basis of "good agricultural practice".

Pesticide residues occur in agricultural commodities as a result of (a) intentional use of pesticides for protection of growing crops or stored products or of animals; (b) unintentional exposure to pesticides such as would occur in crops grown in soil treated previously or contaminated by foliar treatments of other crops grown earlier in the rotation; (c) unintentional accumulation in animals from the ingestion of feeds containing pesticide residues; and (d) contamination of crops or animals exposed to chemicals in the environment.

It has to be recognized that differences exist both between and within countries as to pest incidence, pest control conditions, and types of crops, which may be reflected in the different pesticide use patterns, pesticide demands and requirements regarding maximum residure limits.

The prime target of the Codex Alimentarius Commission is to reach agreement on international maximum limits for pesticide residues in food, in order to avoid trade barriers and to secure good agricultural practice under widely varying conditions.

As maximum residue limits, use pattern and good agricultural practice are interrelated, the Codex Committee on Pesticide Residues has also undertaken to formulate these guidelines for the use of pesticides.

Guidelines

Purpose of the Guidelines

These guidelines indicate principles for the use of pesticides in agriculture, and in the harvesting, marketing, transport and storage of foodstuffs. Taking into account the attainment of the desired degree of control of pests at an economic cost and with a minimum of danger to operators, agricultural workers, consumers, beneficial animals and the environment, the following represents a list of goals which should be aimed at in good practice in the use of pesticides for the above mentioned purposes. It should be understood that the information presented in the guidelines is not intended as a substitute for actual supervised trials under the growing conditions of the area involved.

General

(a) If pesticides reach humans or animals through different routes and thus give rise to additional body loads, the use patterns may have to be adjusted, and if necessary, priority should be given to those uses which are indispensable and for which no adequate alternatives are available.

(b) Maximum residue limits established for products for human consumption are not necessarily acceptable for the same product when this is destined for animal consumption and vice versa, and in such cases this should be indicated as far as possible.

(c) In view of the necessity of preserving a balance between cost, productivity, quality and freedom from residues, the concept of good agricultural practice in relation to pesticide residues embraces all interrelated and essential factors and functions, which ensure that the pests will be controlled effectively, leaving residues that are the smallest amounts practicable and that are toxicologically acceptable.

(d) Therefore, pest control treatments should only be made when necessary. The requirements for pest control should first be established, followed by the application of the preferred method of control.

Choice of Pesticide

(a) All pesticides which are used should be authorized (registered) by appropriate authorities in the country of use. They should only be marketed with labels indicating recommended or approved uses, times, methods and rates of application, and safety precautions for the uses. Such recommended methods of application, should be based on supervised trials and other experimental work, and should take into account such variations in climate, in crop husbandry, and in incidence of pests as may occur under practical conditions from time to time in the various places in which the pesticide may be used (see ALINORM 72/24A, pare 10, and WHO Technical Report series No. 592, page 40, Explanatory Note on Good Agricultural Practice).

(b) Bearing in mind the actual conditions under which the pesticide will be used, the pesticide should be adequately safe to humans and the environment, and at the same time provide adequate pest control.

(c) Where a choice of pesticides is possible, the cost and effectiveness of available pesticides should be weighed against the risks involved, and those which show a more favourable benefit-risk ratio for the particular purpose in question should be preferred.

(d) When pest control is required in the early growing stage of the crop, a pesticide may be needed which has an adequate and acceptable degree of persistence, in order to avoid repeated applications of non-persistent pesticides.

(e) Where plant quarantine and/or phytosanitary requirements make is necessary to apply pesticides close to or after harvest, those which have a short persistence should be preferred (see also 7(a) and 7(b)).

(f) The agricultural use of persistent and/or cumulative pesticides on crops for human consumption should be restricted as much as much as possible, and be limited to the control of pests, weeds and diseases for which at present no suitable alternative chemicals are available.

(g) As a general rule, persistent and/or cumulative pesticides should not be used on fodder crops and not be applied directly to animals for veterinary purposes.

(h) Where post-harvest treatments are required, pesticides which leave residues that are the smallest amounts practicable and that are toxicologically acceptable, do not interact with the food commodity, and/or are readily removed during storage, preparation or cooking, should be preferred.

(i) With respect to post-harvest treatment of stored products (e.g. cereal grains) it is recommended no to use persistent and cumulative pesticides as direct admixture.

(j) The application of adequately durable pesticides to the exterior of packing material for stored products is acceptable, but the use of highly persistent and cumulative pesticides should be avoided as much as possible.

Choice of Formulation

(a) Formulations which combine maximum efficiency of the pesticide with minimum risk should be preferred.

(b) Supplementary adjuvants should be used only if their effects, including toxicological effects, are known and where their use produces a significant improvement in performance.

(c) In general, the use of combined pesticide/ fertilizer formulations should be avoided, However, such practices are recommended by local authorities when they are considered beneficial.

Dosage

(a) The quantity of pesticide applied should not be greater than the minimum required to achieve the desired degree of control.

(b) The number of treatments should be determined by the desired degree of control and by the severity of pest conditions.

Application

(a) The method of application should be selected to ensure optimum pest control with the minimum contamination of the crop and the environment.

(b) Indirect treatment (such as application to the soil, seed dressing, fumigation of empty silo cells, treatment of alternate hosts)'can, in some cases, be used to supplement or replace direct application to food crops.

(c) Application equipment should at all times be maintained and used according to the makers' instructions.

Timing of Treatment

(a) Treatment should preferably be carried out when the pests are at the most vulnerable stage of development, and when climatic conditions and cultural practices will ensure that the optimum effect can be attained from the treatment. In some instances, however, action may be necessary immediately following detection of the pest species.

(b) The interval between last application and harvest (slaughter in the case of veterinary use) should be as long as possible in order to permit the greatest reduction in pesticide residues, bearing in mind the pest incidence, the degree of control required for a maximum utilization of the commodity, and the vulnerability of the treated crop immediately preharvest. To this end official pre-harvest intervals should be established and adhered to.

Post-treatment Practice

(a) Crop rotation should be adjusted in such a manner that unintentional residues in the edible parts of the crop, as a result of previous treatments, will be minimal, particularly if the crop may be used as animal feed, and accumulation in the animal body may lead to undue residues in food products of animal origin.

(b) Seed-grain, treated with pesticides at dosages to provide long-term protection in the soil, must, under no circumstanes, be mixed with commodities destined for human or animal consumption. Sufficient safeguards ought to be provided which would minimize the accident risk of such practices.

(c) Where grain intended for consumption must be protected in storage, only compounds with low chronic toxicity and/or shourt persistence should be used.

(d) In storage practice, the selection of the pesticide for treatment of empty warehouses or ship holds and the subsequent storage arrangements should be such that there is a minimum risk of contaminating feed or food products.

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Related problems to use of insecticides

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Compiled by R. L. Semple

Nature of Resistance

Resistance is an increase in tolerance status of a particular pest species to a toxic substance. The onset of resistance as demonstrated by Parkin (1965), assuming that population has the genetic potential, is dependent on

1. **The life cycle must be relatively short.**
2. **Insecticide stress must be exerting some selection pressure on successive generations.**
3. **Stressed populations must be relatively free from immigration of susceptibles.**

The problem of resistance development is accentuated in bulk grain by the relatively constant and protected microclimate, due to the insulating action of both the storage structure and the grain itself. Insect populations are therefore not subjected to any violent fluctuations in seasonal conditions and breeding is possible throughout the year.

There exists a dynamic variation in tolerance among individuals of any given population, and resistance is therefore initiated by continuous selection of the toxicant of the more resistant individuals in that population. Resistance is due to the selection of hereditary factors and not an adaptation of individual insects to the insecticide. Genes are selected that, alone or in combination, alter the physiology or biochemistry in such a way that progressively higher amounts of insecticide are required to kill them, even up to a point where an insect can tolerate any given dose. Due to economic constraints and potential residue hazards exceeding those maximum residue levels set down internationally, we have for practical purposes a breakdown in control provided alternatives are not available.

The point to remember is resistance will result directly from selection pressure and from this it follows that

1. **Extent of selection is dependent on numbers of insects available for selection, and hence any reduction in the numbers available reduces the genetics variability and therefore the probability of resistance develoment. It is much dependent**

on strict hygiene and cleanliness and good ware housekeeping to reduce the breeding potential and buildup of insect populations.

2. **Controls applied should aim at complete mortality to prevent selection occurring, i.e., the full dose should be available to every individual and assumes that the prescribed rates and concentration is sufficient to kill the most tolerant members of any normal population. Fumigation has been cited as one of the reasons why stored product insects were slow in developing resistance compared to household pests, and to pests of medical and veterinary importance, because mortalities approximating 100% can normally be obtained.**

Fumigation is recommended in case of control breakdown following use of residual insecticides. Why? Because control breakdown maybe the first indication of tolerant members of that endemic population surviving the recommended treatment. His therefore essential to kill them so as to maintain the use and efficacy of the small number of residual contact insecticides registered for use as grain protectants

Mechanism of Resistance

Insect resistand was first discovered in DDTresistant houseflies, Musca domestica in 1946 (Weismann, 1947) and has since become one of the major constraints/concerns in insect pest control.

The most widely used stored-product insecticide during the 1960's to early 70's was the organophosphate Malathion (S-(1,2dicarbethoxyethyl) 0,0-dimethyl dithiophosphate). Malathion was introduced because of its low toxicity to mammals and birds, its low phytotoxicity and its rapid breakdown rate (Yost, Frederick and Migrdichian, 1955).

In Australia, Malathion was applied at the beginning of the storage period when the risk of infestation was highest with normally only one application is used. Work by Minett and Williams (1971) using 150 9 masses of wheat at 25C and 70% RH showed that after 10 weeks about 50% of the malathion still remained after an initial application of 12 ppm. Table 1 depicts the half-life of some grain protectants at the reference temperature and relative humidity of 30C and 50% RH respectively, which are typical of receival conditions for grain in Australia.

Table 1. General rate expressions for 12 protectants plotted to the equation

$$\log t_{1/2} = \log(t_{1/2})_0 - B(T_2 - 30) - \log RH/50$$

where $t_{1/2}$ is the half-life on grain of temperature, T_2 in degrees Celsius and percentage relative humidity RH, and $(t_{1/2})_0$ is a reference half life on grain of 30C and 50% humidity.

Pretectant	**$t_{1/2}$ (weeks)**	**B (degrees^{-1})**
Fenitrothion	14	.036
Bioresmethrin	24	.033
Bioresmethrin*	38	.031
d-Fenothrin	38	.029
d-Fenothrin*	40	.029
Pyrethrum *	55	.022
Methacrifos	8	.055
Malathion	12	.05
Chlorpyrifos-methyl	19	.04
Carbaryl	21	.031
Pirimiphos-methyl	70	small
Pyrethrum	34	-

***plus piperonyl butoxide at 20 mg kg^{-1}**

Source: Desmarchelier and Bengston "Chemical residues of newer grain protectants pp 108115 in Australian contributions to the Symposium on the protection of grain against insect damage during storage, Moscow, 1978.

Malathion acts as a contact poison which is absorbed through the cuticle. Once inside the body it is oxidized to malaoxon I$(CH_3O)_2P(0)SCH\ (CO.OC_2H_5)CH_2CO.OC_2H_5$l, which then acts as a powerful cholinesterase inhibitor. This process of conversion of malathion is known as activation, resulting in a disruption of nerve activity due to acetylcholine accumulation

at the nerve endings which results in excitability, muscular tremors and finally paralysis (O'Brien, 1967).

Acetylcholinesterase (AChe) is the main site of action for the organophosphorous and carbamate group of insecticides. Messages are transmitted across the nerve synapse by the transmitter acetylcholine, and once the impulse is passed acetylcholinesterase acts on acetylcholine to return it to its active ionic state. The organophosphorous insecticides of the -thionate configuration must be oxidised from the P = S to the P = 0 nucleus before they become active, since the P = 0 nucleus has a strong electronic pull on the hydroxyl group of acetylcholinesterase, thus bonding with it and inactivating it once the insecticide penetrates the synapse.

Resistance can be due to various changes, either singly or due to their interaction such as

1. **reduced uptake or penetration of the insecticide**
2. **increased detoxification, storage and excretion**
3. **reduced transportation to the site of action, or**
4. **reduced action by an alteration in the site of action**

In most cases of insecticide resistance, increased detoxification and altered site of action appear to be responsible. This can be brought about by enzymatic changes caused by mutants of single genes. (NB: It is important to realize that insecticides themselves do not perform a mutagenic function, since the genetic variability for resistance already exists in natural populations not previously exposed to insecticides).

Single gene alteration causing a change in the site of action has been demonstrated in spidermites, cattle ticks, leaf hoppers and houseflies where resistance has developed due to an altered cholinesterase displaying a much reduced rate of reaction with the inhibitors (i.e., the insecticide). High degrees of resistance due to single gene alteration resulting in the production of more efficient detoxifying enzymes is known in DDT-dehydrochlovinase and carboxyesterase strains of houseflies degrading DDT and malation respectively. Both resistances are due to the altered properties of the enzyme as well as greater quantities of enzyme produced.

High levels of resistance can also develop through the interaction of more than the resistance gene which may result in decreased penetration as well as detoxification of the insecticide. Resistance to a single insecticide can be due to different causes in various strains of the same species. Malaoxon can be degraded by a carboxyesterase as well as by a microsomal

mixed function oxidase in the housefly. They can be present either singly or together in the same strain eliciting different behavioral responses with applied synergists, such as triphenyl phosphate (TPP).

Malathion is unique in that two distinct metabolic resistance mechanisms are possible.

Malathion non-specific resistance (Mal. nonspec R) is a broad resistance to most organophosphates (i.e. cross resistance). This type of resistance is induced by selection or exposure to any organophosphate compound.

Malathion specific resistance (Mal. spec. R) is restricted almost exclusively to malathion. This type of resistance is due to higher levels of a carboxyesterase in the resistant strain. Although first demonstrated in the mosquito, Culex tarsalis, (Matsumura and Brown, 1961), it has since been demonstrated in a number of other insects. The carboxyesterase attacks the CO.OC2H5 group of the malathion molecule and thus prevents activation.

Genetic studies have shown that high carboxyesterase levels and malation specific resistance are inseparable connected.

Increased mixed function oxidase activity is a very important mechanism since it affects insecticides from practically all chemical groups, whereby crossresistance has been conferred in insect growth regulators (Dyte, 1972; Cert and Georghiou, 1972) with the oxidases being amongst the most likely candidates. Through selective pressures from the use of IGR analogues, high levels of resistance may develop (Plapp and Vinson, 1974), but Amos et. al., (1977) detected no crossresistance to either methoprene or hydroprene in malathion susceptible or resistant strains of Tribolium castaneum or T. confusum.

Figure 1. Malathion metabolism.

There is also evidence that the different forms of the detoxifying enzymes and the aberrant mutants of the cholinesterase are produced by alleles of the structural gene. Work by Devonshire and Sawicki (1978) with the peach potato aphid have shown that they have been placed under extreme insecticidal pressure in greenhouses, and through evolutionary change have duplicated some of their genes. The structural gene continues to produce a functional protein while the duplicate is free to evolve without subjecting the population to long periods of selective disadvantage. They found resistant strains contained more carboxylesterase enzyme than non-resistant strains and that enzyme activity increased exponentially with insecticide resistance brought about by gene doublings. Malathion and parathion resistance in different strains of the housefly Musca domestica as well as altered cholinesterase in resistant spider mites Tetranychus urticae is thought to be alleles of structural

genes.

Truly sublethal exposures to applied insecticides do not induce resistance in known susceptible strains of M. domestica or increase the levels of DDTdehydrochlorinase (DDT-ase) as demonstrated by Moorfield (1958) and Brown (1964). Rather, the cumulative effect of daily sublethal amounts of DDT, gamma BHC, dieldrin or diazinon renders the housefly more susceptible to exposures at the discriminating dose. Bond and Upitis (1972) with sub-lethal treatments of phosphine, found cumulative effects which differed with species when repeatedly applied to insects. For example Tribolium consusum adults recovered from a sublethal treatment in 10 days while Sitophilus granaries adults required 40 days although the tolerance level regained was less than in untreated individuals. Tenebroides mauritanicus larvae showed a varying response after an initial dose that achieved no mortality in the first two weeks; some individuals died slowly, some remained permanently as larvae, some developed into pupae but subsequently died, while some adults that emerged were physically deformed and some appeared morpholigically normal.

These observations on increased susceptibility of insects exposed to sub-lethal doses of phosphine maybe important in terms of economic control if for example, survivors from a treatment where incomplete control is obtained, are more responsive to subsequent treatments applied soon after the first. The normal criterion for effectiveness of a treatment is usually mortality, but various sterilizing effects that inhibit further development of insect populations becomes important in considering combined control strategies.

The mechanism of resistance is by no means clearcut, but certain established criteria enable pest control operators to implement counter measures where suspect resistance occurs.

1. **Development of resistance to one particular pesticide confers on insect populations a measure of resistance to related pesticides, i.e., in same chemical group. Low level resistance to other unrelated series of pesticides may also be developed concurrently.**
2. **Pests in the field maybe exposed to a number of different types of pesticides and, together with introduction of genetic material from other migrating populations or by cross-infestation with strains carrying other types of resistance may result in a complex of unrelated resistances being present in the same strain.**
3. **Where resistance to a particular series of pesticides has been developed, these tolerant populations will develop high levels of resistance to unrelated chemical groups with greater facility than would populations previously unexposed to**

pesticides.

4. **Resistance in field populations maybe lost on segregation of these populations from selection pressure or exposure to pesticides. Rate of loss is dependent on the genetic constitution of the pest and the mode of inheritance of resistance, the intensity of selection for resistance and dilution of the population by individuals of normal suseceptibility from unexposed populations.**

When resistance has been observed, the pesticide in use should be replaced by one of an unrelated chemical groups and attention given to its efficient utilization. With residual pesticides the first indication of resistance is a reduction in the time that residual deposits remain effective; thus a grain protectant that inintially gave 6 months protection may subsequently not control insect populations although residue analyses may indicate no change in the normal decay pattern of the pesticide on the commodity. Early warning indications such as this often go unheeded through mismanagement and it is not until obvious signs of resistance such as large scale buildup of pest populations in or on treated commodities that the problem is recognized. Regular monitoring of the tolerance status is a valuable means of early detection of resistance and can provide unequivocal evidence of the contribution of resistance to control failures.

Breakdown in control measures other than those initiated by insecticide resistance are as follows:

1. Use of pesticides that have deteriorated in storage.

2. Incomplete coverage or application due to faulty equipment or treatment:

- **blocked nozzles leading to underdosing.**
- **incorrect calculations on flow rates overdosing.**

3. Use of unstable preparations: rapid breakdown or disregard of comparability warning on labels.

4. Variation of pest susceptibility with temperature. Dosage levels maybe effective at normal temperature but inadequate in extremely hot or cold weather. Also affects stability, reaction rates of insects and rates of diffusion with chemicals.

5. Also, under conditions of extremely hot weather and light, pesticides maybe decomposed or otherwise lost at abnormally high rates.

Resistance in stored products has advanced from 3 species in 1960 to approximately 17 species of Coleoptera and Lepidoptera in 1979. Resistance to fumigants detected in the field is of major concern because of the global dependence on fumigation both as routine disinfestation and for combating insecticide resistance strains. From the 1972-73 FAO global survey of tolerance status of the major pests of grain, methyl bromide resistance was detected in 23 countries and phosphine resistance in 35 countries, where resistance factors were generally low and in most instances would not have resulted in breakdown of pest control. The species of particular concern were Rhyzopertha dominica Fabricus and Tribolium confusum Jag. du Val.

The emergence of strains of different species may not be a practical problem as yet in the field, but the widespread occurrence of strains surviving discriminating doses which would normally prove fatal to susceptible strains and the case at which this level of tolerance can be increased under laboratory selection, poses a serious threat to international trade.

Most cereal products moving in international trade is almost exclusively in bulk ships and the infestation either originates from the exporting country or, from cross-infestation from residues in previous cargoes or other infested cargoes on board.

Malathion resistance was first detected in Tribolium castaneum in the early 1960's and now can almost be considered to be a normal attribute of a T. castaneum population. The frequency of resistance in other species is still comparatively low and although a much later detected resistance in these species (i.e., Sitophilus oryzae, 1969; R. dominica, 1971) indicates genotypes which were not as conducive to development of resistance.

The movement of resistant strains in trade is providing a mechanism allowing rapid dissemination throughout the world, as well as distributing new resistances as they develop, which is probably happening at present with any new strain acquiring fumigant resistance. Pest control methods now take into account the problems associated with excessive pesticide usage and dependence to obtain control at an economic level.

There exist three very good reasons for reduction in pesticide use:

1. Development of resistance.

2. Cost of pesticides includes development, toxicology and registration

3. Environmental effects

- **destruction of beneficial species (pollinators such as bees)**
- **irreversible effects on birds, fish and animals**
- **long term effects on man himself**

4. Misuse and abuse particularly in home garderners

The application of pesticides since the turn of the century can be classified under 2 broad categories:

1. Utilization of marginally effective inorganic pesticides combined with labour intensive cultural control methods (ca 1900-1945).

This included some extremely deleterious compound such as the mercury based insecticides, arsenicals such as parts green, lead and calcium arsenate and the flouride insecticides. More recently, compounds of botanical origin such as nicotene, pyrethrum and rotenone, have 'had widespread application for field crop, orchard and domestic pest control.

2. Nearly sole reliance upon synthetic organic compounds applied on a calendar or preventative schedule (1945-present).

DDT was the first of these insecticides, first synthesized by Zeidler in 1874, and recognized for its potenial in insect control in 1939 by Mueller against clothes moths. From the synthesis of DDT came a succession of related compounds (methoxychlor, dicofol) followed by the cyclodienes which are chlorinated cyclic hydrocarbons developed in 1945. Next came the organophosphates, carbonates, the synthetic pyrethroids to compounds attempting to mimic naturally occurring insect hormones applied at such a stage as to disrupt their normal life processes.

Both these categories in pesticide development have had associated and related problems such as:

1. **Sub-economic control (inorganic, stage 1)**
2. **Illegal chemical residues (primarily, stage 1)**
3. **Environmental contamination (both stage 1 and 2)**
4. **Pesticide resistance (stage 2)**

5. **Subsequent resurgence of non-target (stage 2) secondary pests**
6. **Destruction of beneficial predators (stage**

Attempts have been made recently to resolve the contradictory demands of society that on the one hand asks for a constant supply o high quality food free of pest damage, but on the other hand is very much concerned with the potential negative side effects of pesticide usage. This approach to pest control has been referred to as integrated pest management (IPM).

The objectives of the system are to utilize an array of suitable control techniques rather than relying on a single disruptive tactic.

It is important to realize that field applications of IPM allow sub-economic pest densities rather than demanding total eradication as the criterion for successful control; for the utilization of biological control agents as a viable tactic depends on residual pest levels to insure the survival of natural enemies.

This is a practical approach which has proved to be an effective and economical control method in growing crop situations with minimum use of pesticides. But the situation is far more dramatic in storage where even the presence of beneficial parasites and predators are not tolerated. The growing crop can also absorb insect damage to a limited extent without any undue exonomic loss, but once a kernel of grain has been attacked, its nutritional value or potential for regeneration is lost forever. The further limitations imposed by some importing countries on levels of acceptable pesticide residues has precipitated the need for higher degrees of management of stocks to meet these constraints.

SUMMARY

Development of resistance is an incremental process which is related to the number of generations under selection pressure as well as the multiplication within each generation (the Net Reproduction Rate, Ro). These factors are largely dependent on the temperature and moisture of the grain in which the selected population is breeding (Heather, 1981) thus modifying the intrinsic rate of natural increase per week or rm.

Temperature and moisture also affect the rate of decay of pesticides during storage, where some are more effective under high temperature regimes (i.e., pirimiphos-methyl, azamethiphos) while the pyrethroids (i.e., permethrin) are more effective at lower temperatures, both groups benefiting from low moistures. Target rates of application of pesticides which are lethal

to all insects in the population is desirable but if infestations do develop, a treatment must be introduced that does not posses any crossresistance correlation of which include fumigation with either methyl bromide or phosphine.

Pest management systems which aim to delay the rapid development of resistance must therefore; aim for complete mortality of target species, since only the survivors can develop resistance. Application techniques, maintenance of spray equipment and correct concentrations and rates of application assume importance.

- **minimize the number of generations that can be selected storing grain in a cool, dry condition retards the rate of development especially under aeration systems.**
- **prevention of carryover of resistant genotypes. Maximize storage management with respect to grain residues, spillage and hygiene as well as other potential sources for supporting the development of insect populations, and**
- **maximize the use of other non-chemical methods, such as controlled atmosphere storage (CA) by manipulating atmospheric gases of bagged commodities under plastic covers with the introduction of carbon diowide. Any method that reduces insect numbers or contamination/damage caused by insects without the reliance on applied pesticides is highly desirable. The potential of thermal disinfestation by application of heat may become an economic alternative to fumigants.**

Low initial populations mean a smaller genetic "pool" from which resistance development can occure, and consequently there will be fewer survivors of any applied pesticide treatment which are much easier and less costly to deal with.

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METHODS OF TESTING CHEMICALS

Several techniques for testing insecticides and other chemicals are discussed extensively by Busvine (1971). This lecture will discuss specifically methods used in the laboratory screening and evaluation of insecticides on stored product insects. The common method used for determining the toxicity of insecticides to stored product insects are: topical application, exposure to residual films, exposure to insecticideimpregnated grains, and; direct spraying of test insects. The compounds found

promising in any of the tests are evaluated in a laboratory-field simulated conditions by sack treatment, admixture with grain and residual treatments.

A. Topical Application

The most commonly employed method of applying contact insecticides to individual insects is by topical application. This offers the precise means of measuring toxicity of known doses of insecticides. Several equipment are used: wire loop, capillary pipettes and microsyringe. The microsyringe with adaptors for regular delivery of small volumes is the one recommended. It can be manually or electrically operated. The syringe size is either 1 ul or 0.25. The small syringe is more sensitive. The syringe should be calibrated individually using mercury. For application work, a 27 gauge hypodermic needle (0.4 mm) is suitable with the tip blunted on a fine abrasive stone. For convenience, the needle may be bent at right angles with the fine wire supplied for cleaning left inside.

This method is commonly used on larger larva or adults of stored product Lepidoptera.

There are three factors which are associated with the delivery of the chemical and thus the toxicity: solvent system, droplet size and site of application.

A-1. Choice of Solvent. - Solvents which tend to destroy or disrupt the waxy epicuticular layer accelerate penetration of the solution to the aqueous region of the exo-and endocuticle. The solvents most commonly used to apply them have been acetone or various oils (mineral or vegetable) or a mixture of acetone with other solvents. A preliminary test to determine the toxicity of the solvent system to the insect before using it as carrier of the insecticide should be conducted. The solvent may or may not be toxic depending upon the method of application and insect species.

A-2. Droplet Size and Insecticide Concentration. - In insects, generally, the smaller amount of droplet size is more toxic than bigger ones. The size of the droplet will vary with the solvent carrier and insecticide. Most often they apply 1 ul of the insecticide of a known dose.

A-3. Size of application. - There is some evidence that effectiveness of application declines with distance from the presumed site of action (the head or CNS). Applications are less effective as they move distally or toward the legs or abdomen.

B. Residual Exposure Methods

Investigations using insecticide films are generally of two types: (1) experiments concerned with the performance in the field, thereby demanding some approximations to practical conditions, or (2) experiments using artificial media, either for simplicity (screening tests) or precision (resistance tests or bioassay). For the first type, residues are sometimes produced by dipping, spraying or painting the substrate. Residues for the second type are often prepared by application by pipette of solutions in volatile solvents.

B-1. Dipping and Spraying. - Insecticide solutions are applied on sacks, concrete or wood to determine the toxicity of stored product insects to the residual films at different storage intervals. This is applied generally by spraying. Sacks could be treated simple by dipping in an insecticidal solution of known concentration, in a formulation to be used in practice.

B-2. Painting. - This method is used to investigate the possibility of incorporating insecticides in ordinary wall treatments such as paints or whitewash. To determine the residual activity, insects are exposed to it at different time intervals.

B-3. Application in Volatile Solvents. - The insecticides are applied in dry or oil solution residues, some workers have urea a very simple method of applying residual insecticides by dissolving them in a volatile solvent (usually acetone), and spreading a measured quantity, as evenly as possible, over a test surface. Among the glass vessels that could be treated are petri dishes, wide conical flasks, wide cylinders and ball jars. The solution is usually spread inside the vessel by tilting or rotating it and evaporation may be accelerated by a stream of compressed air.

Volatile solvents may also be applied in treating paper by applying a small volume from a pipette. However, dry residues from volatile solvents are not so uniform, therefore some workers have used a mixture of volatile and non-volatile (improves the dispersion) solvents to deposit the insecticide. This is the one recommence for treating filter papers for toxicity and resistance tests. The commonly used oils are "Risella" oil and olive oil. The mixture is spread especially over the paper which is mounted on a bed of pins. The concentration is expressed as mg per sq. cm. For resistance studies, Whatman Filter Paper No. 1, 7 cm. diameter is recommended and enclosed in a glass mug or inverted funnel. For insects which crawl up, the glass rings may be smeared with grease or Fluon.

The pick-up and spread of the carrier oil is temperature dependent but if temperature is controlled, uptake of insecticide is a linear funciton of concentration and exposure time. Exposure of insects to impregnated paper can provide a precise and

convenient method of treatment. Insects are not handled individually, anaesthesia is not necessary and the mumber of insects and of samples that can be handled in a convenient time is large.

B-4. Exposure to Treated Grains. - The use of this method is to preliminary screen insecticides that could be used for protectant treatment and to measure the residual toxicity of the insecticides on the grains at different time intervals. This method is not recommended for resistance tests, since the grain particle size and adsorption of insecticide by the grain and grain dust, and in case of OPs, instability associated with enzymatic breakdown (Rowlands, 1967) may all influence the availability of insecticide for toxic action.

D. Direct Spraying of Test Insects

Spray towers, which have been evolved as a precision instrument for laboratory research on toxicological problems, are used for direct spraying of test insects. Two types of spray are available. The direct spray type makes the droplets fall directly from the atomizing nozzle to the target. In the other form, the indirect sprayer, a cloud of particles is blown into a settling chember to form aerosol, and subsequently allowed to settle on the target. The amount applied is measured. Specialized apparatus is required for this method. There are many spray towers used and for detailed information see Busvine (1971).

E. Evaluation Methods

The promising compounds found in the screening tests are further evaluated in field experiments. Sack treatment either by dipping or spraying, direct treatment of grain or combination of these methods are used for evaluation. The experimental samples are kept in laboratory-field simulated conditions for a certain period, i.e. 6-12 months. Damage, number and kind of insects, dead and alive are noted before treatment and at different time intervals after treatment, e.g. 1, 3, 6, 9 and 12 months after treatment.

TOXICOLOGICAL STATISTICS

A. Importance of Ouantal Response Assessment

A great deal of research on insecticides involves either comparison of the potencies of different compounds or comparison of the susceptibility of different species or strains of insects. In either case, the most useful method of comparison is on the basis

of equitoxic doses. There are three general ways of assaying poisons 6Finney, 1952) to find these critical doses: (1) to direct assay, or by indirect assay (2) quantitative response or (3) quantal response.

In insects, the indirect assay based on quantal response is most feasible, precise and practical assay. In tests based on quantal response, the data required are the proportions of each batch reacting in a particular way. The object of the method is to estimate the magnitude of the dose which is sufficient to produce death or knockdown within a given proportion of population of insects. Comparisons may then be made on the basis of this critical dose.

For statistical reasons, it is easiest to estimate the median (50%) response level of a population rather than the most susceptible as tolerant. The median lethal dose is commonly expressed as LD50 for the 50% lethal dose; and correspondingly LD90 or LD95 for other equitoxic levels. Equivalent expressions for other dosage parameters are used. LC50 for lethal concentrations, LT50 for lethal exposure time, KD50 for knock-down dosage, and ED50 for effective dose.

The median lethal dose and similar data are quantitative expressions of the tolerance of a particular species (or strain) of insects under certain conditions. The same data as expressed as the tolerance of an insect, provides a measure of the toxicity of the insecticide used. The higher the LD50 the lower will be the toxicity.

In all the above evaluation, the criteria of toxic action is death or knockdown at a certain time (i.e. 24 or 48 hrs). This measures the acute toxicity of a compound. For those with side effects, the onset of paralysis or knockdown is often used as a criterion of toxic action. In most cases, knockdown and death are just lumped together in obtaining data.

B. Obtaining Date for Quantal Response

It is necessary to expose batches of insects to a range of doses of a toxicant. Both test insects and environmental conditions need to be standardized. The number required for each batch is governed largely be practical considerations. With stored product beetle which can be reared without difficulty in large numbers, more insects should be used per replicate per dose. The larger the number per batch, the greater the accuracy; but there is generally little advantage in exceeding 30 or 50 per batch per replicate.

In selecting doses or concentrations for testing, it is desirable to space them evenly over the mortality range. since toxic effect is more conveniently realted to the logarithm of the dose than to the dose itself, the doses chosen should be a geometric

series.

In choosing for the time of assessment of mortality, it is desirable to make preliminary observations, for any insect/poison, on the reactions displayed at different periods of dosing. If an insecticide with rapid action, which allows some individuals to recover from paralysis, is being compared with a slow-acting irreversible poison, the conclusions reached will vary greatly according to the time chosen to assess their effects. Changes are more pronounced at high doses. the most common practrice is to assess at 24 and 48 furs.

C Statistical Procedures Correction for Control Mortality

The data collected should be corrected for the control mortality, which if appreciable, may affect the precision of the results. This is corrected by Abbott's formula:

$$PT = \frac{PO - PC}{100 - PC} \times 100$$

where PT = corrected mortality; PO = observed mortality in treated and PC = control mortality (all%). Rejection of expriments is recommended with control mortalities of 10 to 20%.

The Use of the Probit/Log Dosage Transformation The most usual way of interpreting quantal response is from the regression line (either plotted graphically or computed) relating the log dosage to a transformed percentage response. This will correct for the sigmoid form of curve when the percentages per se are plotted against the dose in ordinary graph paper.

The use of probits and log doses to obtain estimates of critical dosage levels and their limits of accuracy can be done in three ways with different degrees of precision. these are (1) simple arithmetical and graphical methods (2) standard method of computation using desk calculator and (3) using a computer programme.

In graphical method (Appendix A), the critical doses or susceptibility can be estimated with sufficient accuracy from a probit/log-concentration graph. The two transformed variables are also plotted on plain paper of the original data (% kill and dose) can be plotted on logarithmic/probability paper. A straight line is fitted by eye (a celluloid ruler is useful) and the critical doses determined by inspection.

For the calculations of the regression line relating probits and dose consult Finney (1952a & b).

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International code of conduct on the distribution and use of pesticides

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Introduction

The action by FAO to develop, in consultation with appropriate United Nations agencies and other organizations, an International Code of Conduct on the Distribution and Use of Pesticides follows and accompanies many other events, some going back 25 years. All these events were designed to benefit the international community and to serve to increase international confidence in the availability, regulation, marketing and use of pesticides for the improvement of agriculture, public health and personal comfort.

One of the basic functions of the Code, which is voluntary in nature, is to serve as a point of reference, particularly until such time as countries have established adequate regulatory infrastructures for pesticides.

The Director-General of FAO in 1981 suggested that such a Code could help to overcome a number of difficulties associated with pesticides. The FAO Panel of Experts on Pesticide Specifications, Registration Requirements and Application Standards, at its meeting in 1982, agreed that activities involving the export and import of pesticides, and thereby their safe use, might be best dealt with through the adoption of a Code of Conduct. To that end a working paper was prepared for the FAO Second Government consultation on International Harmonization of Pesticide Registration Requirements, Rome, 11-15 October 1982. The formal decision to develop the Code was taken at that Consultation, which recommended that FAO, in consultation with the appropriate United Nations organizations and bodies and international organizations outside the United Nations system, should draft a Code (1). The Code itself was adopted by the FAO Conference at its Twenty-third Session in 1985 by way of

Resolution 10185, which appears as an Annex to the present publication.

A number of governments and organizations have expressed concern about the propriety of supplying pesticides to countries which do not have infrastructures to register pesticides and thereby to ensure their safe and effective use. It should be noted that the development of national regulatory programmes is the first priority of FAO activities in this field. There has also been concern over the possibility that residues of certain pesticides, not needed or not permitted in particular countries, are present in imported agricultural commodities produced in other countries where the use of such pesticides is not restricted. While recognizing that it is impossible to eliminate all such occurrences, because of diverging pest control needs, it is none the less essential that every effort be made to apply pesticides only in accordance with good and recognized practices. It is at the same time important for industrially developed countries to recognize, in their regulatory activities concerning residues, the pest control needs of developing countries, particularly the needs of countries in tropical regions.

In the absence of an effective pesticide registration process and of a governmental infrastructure for controlling the availability of pesticides, some countries importing must heavily rely on the pesticide industry to promote the safe and proper distribution and use of pesticides. In these circumstances foreign manufacturers, exporters and importers, as well as local formulators, distributors, repackers, advisers and users, must accept a share of the responsibility for safety and efficiency in distribution and use.

The role of the exporting country needs to be considered. Much emphasis has been given recently to the desirability of regulating the export of pesticides from producing countries. It is generally accepted that no company should trade in pesticides without a proper and thorough evaluation of the pesticide, including any risks. However, the fact that a product is not used or registered in a particular exporting country is not necessarily a valid reason for prohibiting the export of that pesticide. Developing countries are mostly situated in tropical and semi-tropical regions. Their climatic, ecological, agronomic, social, economic and environmental conditions and therefore their pest problems are usually quite different from those prevailing in countries in which pesticides are manufactured and exported. The government of the exporting country, therefore, is in no position to judge the suitability, efficacy, safety or fate of the pesticide under the conditions in the country where it may ultimately be used. Such a judgement must, therefore, be made by the responsible authority in the importing country in consultation with industry and other government authorities in the light of the scientific evaluation that has been made and a detailed knowledge of the conditions prevailing in the country of proposed use.

The export to developing countries of pesticides which have been banned in one or more other countries or whose use has been severely restricted in some industrialized countries has been a subject of public concern which has led to intensive discussions on whether the exporting country should assume responsibility for the marketing and use of such products in the importing country. In this respect it is essential to note that when pesticides are banned, the reasons are toxicological, environmental or social. Valid and adequate toxicological reasons justifying banning a product are of concern, though not necessarily of equal importance, to most countries. Consequently, such products should not be exported or imported without careful consideration of the toxicological implications for those likely to be exposed.

While a Code of Conduct may not solve all problems, nevertheless it should go a long way toward defining and clarifying the responsibilities of the various parties involved in the development, distribution and use of pesticides, and it should be of particular value in countries which do not yet have control procedures. Where there is a pesticide regulatory process in a country, the need for a Code of Conduct will obviously be less than where there is no such scheme in operation.

The Code of Conduct is not a short or simple document, mainly because the nature, properties, uses and effects of pesticides are diverse and therefore require comprehensive consideration. Furthermore, the strong public pressure for banning or restricting the use of some effective and much needed pesticides often stems from a lack of understanding of the many important issues involved. This document is designed, therefore, also to provide the general public with some basic guidance on these issues.

Text of the Code

Article 1. Objectives of the Code

1.1. The objectives of this Code are to set forth responsibilities and establish voluntary standards of conduct for all public and private entities engaged in or affecting the distribution and use of pesticides, particularly where there is no or an inadequate national law to regulate pesticides.

1.2 The Code describes the shared responsibility of many segments of society, including governments, individually or in regional groupings, industry, trade and international institutions, to work together so that the benefits to be derived from the

necessary and acceptable use of pesticides are achieved without significant adverse effects on people or the environment. To this end, all references in this Code to a government or governments shall be deemed to apply equally to regional groupings of governments for matters falling within their areas of competence.

1.3 The Code addresses the need for a cooperative effort between governments of exporting and importing countries to promote practices which ensure efficient and safe use while minimizing health and environmental concerns due to improper handling or use.

1.4 The entities which are addressed by this Code include international organizations; governments of exporting and importing countries; industry, including manufacturers, trade associations, formulators and distributors; users; and public sector organizations such as environmental groups, consumer groups and trade unions.

1.5 The standards of conduct set forth by this Code:

1.5.1 encourage responsible and generally accepted trade practices;

1.5.2 assist countries which have not yet established controls designed to regulate the quality and suitability of pesticide products needed in that country and to address the safe handling and use of such products;

1.5.3 promote practices which encourage the safe and efficient use of pesticides, including minimizing adverse effects on humans and the environment and preventing accidental poisoning from improper handling;

1.5.4 ensure that pesticides are used effectively for the improvement of agricultural production and of human, animal and plant health.

1.6 The Code is designed to be used, within the context of national law, as a basis whereby government authorities, pesticide manufacturers, those engaged in trade and any citizens concerned may jidge whether their proposed actions and the actions of others constitute acceptable practices.

Article 2. Definitions

For the purpose of this Code:

Active ingredient means the biologically active part of the pesticide present in a formulation.

Advertising means the promotion of the sale and use of pesticides by print and electronic media, signs, displays, gift, demonstration or word of mouth.

Banned means a pesticide for which all registered uses have been prohibited by final government regulatory action, or for which all requests for registration or equivalent action for all uses have, for health or environmental reasons, not been granted.

Common name means the name assigned to a pesticide active ingredient by the International Standards Organization or adopted by national standards authorities to be used as a generic or nonproprietary name for that particular active ingredient only.

Distinguishing name means the name under which the pesticide is labelled, registered and promoted by the manufacturer and which, if protected under national legislation, can be used exclusively by the manufacturer to distinguish the product from other pesticides containing the same active ingredient.

Distribution means the process by which pesticides are supplied through trade channels on local or international markets.

Environment means surroundings, including water, air, soil and their interrelationship as well as all relationships between them and any living organisms.

Extension service means those entities in the country concerned responsible for the transfer of information and advice to farmers regarding the improvement of agricultural practices, including production, handling, storage and marketing.

Formulation means the combination of various ingredients designed to render the product useful and effective for the purpose claimed; the form of the pesticide as purchased by users.

Hazard means the likelihood that a pesticide will cause an adverse effect (injury) under the conditions in which it is used.

Integrated pest management means a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economically unacceptable damage or loss.

Label means the written, printed or graphic matter on, or attached to, the pesticide; or the immediate container thereof and the outside container or wrapper of the retail package of the pesticide.

Manufacturer means a corporation or other entity in the public or private sector or any individual engaged in the business or function (whether directly or through an agent or through an entity controlled by or under contract with it) of manufacturing a pesticide active ingredient or preparing its formulation or product

Marketing means the overall process of product promotion, including advertising, product public relations and information services as well as distribution and selling on local or international markets.

Maximum residue limit (MRL) means the maximum concentration of a residue that is legally permitted or recognized as acceptable in or on a food, agricultural commodity or animal feedstuff.

Packaging means the container together with the protective wrapping used to carry pesticide products via wholesale or retail distribution to users.

Pesticide means any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant-growth regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport.

Pesticide industry means all those organizations and individuals engaged in manufacturing, formulating or marketing

pesticides and pesticide products.

Pesticide legislation means any laws or regulations introduced to regulate the manufacture, marketing, storage, labelling, packaging and use of pesticides in their qualitative, quantitative and environmental aspects.

Poison means a substance that can cause disturbance of structure or function, leading to injury or death when absorbed in relatively small amounts by human beings, plants or animals.

Poisoning means occurrence of damage or disturbance caused by a poison, and includes intoxication.

Product means the pesticide in the form in which it is packaged and sold; it usually contains an active ingredient plus adjuvants and may require dilution prior to use.

Protective clothing means any clothes, materials or devices thet are designed to provide protection from pesticides when they are handled or applied.

Public-sector groups means (but is not limited to) scientifice associations; farmer groups; citizens' organizations; environmental, consumer and health organizations; and labour unions.

Registration means the process whereby the responsible national government authority approves the sale and use of a pesticide following the evaluation of comprehensive scientific data demonstrating that the product is effective for the purposes intended and not unduly hazardous to human or animal health or the environment.

Repackaging means the transfer of pesticide from any commercial package into any other, usually smaller, container for subsequent sale.

Residue means any specified substances in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities considered to be of toxicological significance. The term "pesticide residue" includes residues from unknown or unavoidable sources (e.g. environmental) as well as known uses of the chemical.

Responsible authority means the government agency or agencies responsible for regulating the manufacture, distribution or use of pesticides and more generally for implementing pesticide legislation.

Risk means the expected frequency of undesirable effects of exposure to the pesticide.

Severely restricted - a limited ban - means a pesticide for which virtually all registered uses have been prohibited by final government regulatory action but certain specific registered use or uses remain authorized.

Toxicity means a physiological or biological property which determines the capacity of a chemical to do harm or produce injury to a living organism by other than mechanical means.

Trader means anyone engaged in trade, including export, import, formulation and domestic distribution.

Use pattern embodies the combination of all factors involved in the use of a pesticide, including the concentration of active ingredient in the preparation being applied, rate of application, time of treatment, number of treatments, use of adjuvants and methods and sites of application which determine the quantity applied, timing of treatment and interval before harvest, etc.

Article 3. Pesticide management

3.1 Governments have the overall responsibility and should take the specific powers to regulate the distribution and use of pesticides in their countries.

3.2 The pesticide industry should adhere to the provisions of this Code as a standard for the manufacture, distribution and advertising of pesticides, particularly in countries lacking appropriate legislation and advisory services.

3.3 Governments of exporting countries should help to the extent possible, directly or through their pesticide industries, to:

3.3.1 provide technical assistance to other countries, especially those with shortages of technical expertise, in the assessment of the relevant data on pesticides, including those provided by industry (see also Article 4);

3.3.2 ensure that good trading practices are followed in the export of pesticides, especially to those countries with no or

limited regulatory schemes (see also Articles 8 and 9).

3.4 Manufacturers and traders should observe the following practices in pesticide management, especially in countries without legislation or means of implementing regulations:

3.4.1 supply only pesticides of adequate quality, packaged and labelled as appropriate for each specific market;

3.4.2 pay special attention to formulations, presentation, packaging and labelling in order to reduce hazard to users, to the maximum extent possible consistent with the effective functioning of the pesticide in the particular circumstances in which it is to be used;

3.4.3 provide, with each package of pesticide, information and instructions in a form and language adequate to ensure safe and effective use;

3.4.4 retain an active interest in following their products to the ultimate consumer, keeping track of major uses and the occurrence of any problems arising in the actual use of their products as a basis for determining the need for changes in labelling, directions for use, packaging, formulation or product availability.

3.5 Pesticides whose handling and application require the use of uncomfortable and expensive protective clothing and equipment should be avoided, especially in the case of small-scale users in tropical climates.

3.6 National and international organizations, governments, and pesticide industries should take action in coordinated efforts to disseminate eductional materials of all types to pesticide users, farmers, farmers" organizations, agricultural workers, unions and other interested parties. Similarly, affected parties should seek and understand educational materials before using pesticides and should follow proper procedures.

3.7 Governments should allocate high priority and adequate resources to the task of effectively managing the availability, distribution and use of pesticides in their countries.

3.8 Concerted efforts should' be made by governments and pesticide industries to develop and promote integrated pest management systems and the use of safe, efficient, cost-effective application methods. Public-sector groups and international

organizations should actively support such activities.

3.9 International organizations should provide information on specific pesticides and give guidance on methods of analysis through the provision of criteria documents, fact sheets, training sessions, etc.

3.10 It is recognized that the development of resistance of pests to pesticides can be a major problem. Therefore, governments, industry, national institutions, international organizations and public sector groups should collaborate in developing strategies which will prolong the useful life of valuable pesticides and reduce the adverse effects of the development of resistant species.

Article 4. Testing of pesticides

4.1 Pesticide manufacturers are expected to:

4.1.1 ensure that each pesticide and pesticide product is adequately and effectively tested by wellrecognized procedures and test methods so evaluate as to fully evaluate its safety, efficacy (2) and fate (3) with regard to the various anticipated conditions in regions or countries of use:

4.1.2 ensure that such tests are conducted in accordance with sound scientific procedures and good laboratory practice (4)- the data produced by such tests, when evaluated by competent experts, must be capable of showing whether the product can be handled and used safely without unacceptable hazard to human health, plants, animals, wildlife and the environment (3);

4.1.3 make available copies or summaries of the original reports of such tests for assessment by responsible government authorities in all countries where the pesticide is to be offered for sale. Evaluation of the data should be referred to qualified experts;

4.1.4 take care to see that the proposed use pattern, label claims and directions, packages, technical literature and advertising truly reflect the outcome of these scientific tests and assessments;

4.1.5 provide, at the request of a country, advice on methods for the analysis of any active ingredient of formulation that they

manufacture, and provide the necessary analytical standards;

4.1.6 provide advice and assistance for training technical staff in relevant analytical work. Formulators should actively support this effort;

4.1.7 conduct residue trials prior to marketing in accourdance with FAO guidelines on good analytical practice (5) and on crop residue data (6, 7) in order to provide a basis for establishing appropriate maximum residue limits (MRLs).

4.2 Each country should possess or have access to facilities to verify and exercise control over the quality of pesticides offered for sale, to establish the quantity of the active ingredient or ingredients and the suitability of their formulation (8)

4.3 International organizations and other interested bodies should, within available resources, consider assisting in the establishment of analytical laboratories in pesticide-importing countries, either on a country or on a multilateral regional basis; these laboratories should be capable of carrying out product and residue analysis and should have adequate supplies of analytical standards, solvents and reagents.

4.4 Exporting governments and international organizations must play an active role in assisting developing countries in training personnel in the interpretation and evaluation of test data.

4.5 Industry and governments should collaborate in conducting post-registration surveillance or monitoring studies to determine the fate and environmental effect of pesticides under field conditions (3).

Article 5. Reducing health hazards

5.1 Governments which have not already done so should:

5.1 Implement a pesticide registration and control scheme along the lines set out in Article 6;

5.1.2 Decide, and from time to time review, the pesticides to be marketed in their country, their acceptable uses and their availability to each segment of the public;

5.1.3 provide guidance and instructions for the treatment of suspected pesticide poisoning for their basic health workers, physicians and hospital staff;

5.1.4 establish national or regional poisoning information and control centres at strategic locations to provide immediate guidance on first aid and medical treatment, accessible at all times by telephone or radio. Governments should collect reliable information about the health aspects of pesticides. Suitably trained people with adequate resources must be made available to ensure that accurate information is collected;

5.1.5 keep extension and advisory services, as well as farmers' organizations, adequately informed about the range of pesticide products available for use in each area;

5.1.6 ensure, with the cooperation of industry, that where pesticides are available through outlets which also deal in food, medicines, other products for internal consumption or topical application, or clothing, they are physically segregated from other merchandise, so as to avoid any possibility of contamination or of mistaken identity. Where appropriate, they should be clearly marked as hazardous materials. Every effort should be made to publicize the dangers of storing foodstuffs and pesticides together.

5.2 Even where a control scheme is in operation, industry should:

5.2.1 cooperate in the periodic reassessment of the pesticides which are marketed and in providing the poison control centres and other medical practitioners with information about hazards;

5.2.2 make every reasonable effort to reduce hazard by:

5.2.2.1 making less toxic formulations available;

5.2.2.2 introducing products in readyto-use packages and otherwise developing safer and more efficient methods of application;

5.2.2.3 using containers that are not attractive for subsequent reuse and promoting programmes to discourage their reuse;

5.2.2.4 using containers that are safe (e.g. not attractive to or easily opened by children), particularly for the more toxic homeuse products;

5.2.2.5 using clear and concise labelling;

5.2.3 halt sale, and recall products, when safe use does not seem possible under any use directions or restrictions.

5.3 Government and industry should further reduce hazards by making provision for safe storage and disposal of pesticides and containers at both warehouse and farm level, and through proper siting and control of wastes from formulating plants.

5.4 To avoid unjustified confusion and alarm among the public, public-sector groups should consider all available facts and try to distinguish between major differences in levels of risk among pesticides and uses.

5.5 In establishing production facilities in developing countries, manufacturers and governments shoud cooperate to:

5.5.1 adopt engineering standards and safe operating practices appropriate to the nature of the manufacturing operations and the hazards involved;

5.5.2 take all necessary precautions to protect the health and safety of operatives, bystanders and the environment;

5.5.3 maintain quality-assurance procedures to ensure that the products manufactured comply to the relevant standards of purity, performance, stability and safety.

Article 6. Regulatory and technical requirements

6.1 Governments should:

6.1.1 take action to introduce the necessary legislation for the regulation, including registration, of pesticides and make provisions for its effective enforcement, including the establishment of appropriate educational, advisory, extension and health care services; the FAO guidelines for the registration and control of pesticides (9) should be followed, as far as

possible, taking full accuount of local needs, social and economic conditions, levels of literacy, climatic conditions and availability of pesticide application equipment;

6.1.2 strive to establish pesticide registration schemes and infrastructures under which products can be registered prior to domestic use and, accordingly, ensure that each pesticide product is registered under the laws or regulations of the country of use before it can be made available there;

6.1.3 protect the proprietary rights to use of data;

6.1.4 collect and record data on the actual import, formulation and use of pesticides in each country In order to assess the extent of any possible effects on human health or the environment, and to follow trends in use levels for economic and other purposes.

6.2 The pesticides industry should:

6.2.1 provide an objective appraisal together with the necessary supporting data on each product;

6.2.2 ensure that the active ingredient and other ingredients of pesticide preparations marketed correspond in identity, quality, purity and composition to the substances tested, evaluated and cleared for toxicological and environmental acceptability;

6.2.3 ensure that active ingredients and formulated products for pesticides for which international specifications have heen developed conform with the specifications of FAO (8), where intended for use in agriculture; and with WHO pesticide specifications (10), where intended for use in public health;

6.2.4 verify the quality and purity of the pesticides offered for sale;

6.2.5 when problems occur, voluntarily take corrective action, and when requested by governments, help find solutions to difficulties.

Article 7. Availability and use

7.1 Responsible authorities should give special attention to drafting rules and regulations on the availability of pesticides. These should be compatible with existing levels of training and expertise in handling pesticides on the part of the intended users. The parameters on which such decisions are based vary widely and must be left to the discretion of each government, bearing in mind the situation prevailing in the country.

7.2 In addition, governments should take note of and, where appropriate, follow the WHO classifications of pesticides by hazard (ll) and associate the hazard class with well-recognized hazard symbols as the basis for their own regulatory measures. In any event, the type of formulation and method of application should be taken into account in determining the risk and degree of restriction appropriate to the product.

7.3 Two methods of restricting availability can be exercised by the responsible authority: not registering a product; or, as a condition of registration, restricting the availability to certain groups of users in accordance with national assessments of hazards involved in the use of the product in the particular country.

7.4 All pesticides made available to the general public should be packaged and labelled in a manner which is consistent with the FAO guidelines on packaging (12) and labelling (13) and with appropriate national regulations.

7.5 Prohibition of the importation, sale and purchase of an extremely toxic product may be desirable if control measures or good marketing practices are insufficient to ensure that the product can be used safely. However, this is a matter for decision in the light of national circumstances.

Article 8. Distribution and trade

8.1 Industry should:

8.1.1 test all pesticide products to evaluate safety with regard to human health and the environment prior to marketing, as provided in Article 4, and ensure that all pesticide products are likewise adequately tested for efficacy and stability and crop tolerance, under procedures that will predict performance under the conditions prevailing in the region where the product is to be used, before they are offered there for sale;

8.1.2 submit the results of all such tests to the local responsible authority for independent evaluation and approval before

the products enter trade channels in that country;

8.1.3 take all necessary steps to ensure that pesticides entering international trade conform to relevant FAO, (8), WHO (10) or equivalent specifications for composition and quality (where such specifications have been developed) and to the principles embodied in pertinent FAO guidelines, and in rules and regulations on classification and packaging, marketing, labelling and documentation laid down by international organizations concerned with modes of transport (ICAO, IMO, RID and IATA in particular);

8.1.4 undertake to see that pesticides which are manufactured for export are subject to the same quality requirements and standards as those applied by the manufacturer to comparable domestic products;

8.1.5 ensure that pesticides manufactured or formulated by a subsidiary company meet appropriate quality requirements and standards which should be consistent with the requirements of the host country and of the parent company;

8.1.6 encourage importing agencies, national or regional formulators, and their respective trade organizations to cooperate in order to achieve fair practices and safe marketing and distribution practices and to collaborate with authorities in stamping out any malpractices within the industry;

8.1.7 recognize that the recall of a pesticide by a manufacturer and distributor may be desirable when faced with a pesticide which represents an unacceptable hazard to human and animal health and the environment when used as recommended, and cooperate accordingly;

8.1.8 endeavour to ensure that pesticides are traded by and purchased from reputable traders, who should preferably be members of a recognized trade organization;

8.1.9 see that persons involved in the sale of any pesticide are trained adequately to ensure that they are capable of providing the buyer with advice on safe and efficient use;

8.1.10 provide a range of pack sizes and types which are appropriate for the needs of small-scale farmers and other local users to avoid handling hazards and the risk that resellers will repackage products into unlabelled or inappropriate containers.

8.2 Governments and responsible authorities should take the necessary regulatory measures to prohibit the repackaging, decanting or dispensing of any pesticide in food or beverage containers and should rigidly enforce punitive measures that effectively deter such practices.

8.3 Governments of countries importing food an agricultural commodities should recognize good agricultural practices in countries with which they trade and, in accordance with recommendations of the Codex Alimentarius Commission, should establish a legal basis for the acceptance of pesticide residues resulting from such good agricultural practices (7, 14).

Article 9. Information exchange

9.1 The government of a pesticide-exporting country which takes action to ban or severely restrict the use or handling of a pesticide in order to protect health or the environment domestically should notify, directly or indirectly, the designated national authorities in other countries of the action it has taken (15).

9.2 The purpose of the notification regarding control action is to give competent authorities in other countries the opportunity to assess the risks associated with the pesticide, and to make timely and informed decisions as to the importation and use of the pesticides concerned, after taking into account local, public-health, economic, environmental and administrative conditions. The minimum information to be provided for this purpose should be:

9.2.1 the identity (common name, distinguishing name and chemical name);

9.2.2 a summary of the control action taken and of the reasons for it - if the control action bans or restricts certain uses but allows other uses, such information should be included;

9.2.3 the fact that additional information is availabe, and the name and address of the contact point in the country of export to which a request for further information should be addressed.

9.3 If export of a banned or severely restricted pesticide occurs, the country of export should ensure that necessary steps are taken to provide the designated national authority of the country of import with relevant information.

9.4 The purpose of information regarding exports is to remind the country of import of the original notification regarding

control action and to alert it to the fact that an export is expected or is about to occur. The minimum information to be provided for this purpose should be:

9.4.1 a copy of, or reference to, the information provided at the time of the notification of control action;

9.4.2 indication that an export of the chemical concerned is expected or is about to occure.

9.5 Notification of control action should be provided as soon as practicable after the control action is taken. For pesticides banned or severely restricted before the implementation of the Code, an inventory of prior control action should be provided to the International Register of Potentially Toxic Chemicals (IRPTC), unless such information has already been provided.

9.6 Provision of information regarding exports should take place at the time of the first export following the control action, and should recur in the case of any significant development of new information or condition surrounding the control action. It is the intention that the infomation should be provided prior to export.

9.7 The provision of such information by the exporting country must take into account protection of the confidentiality of data in the importing country.

9.8 Governments of importing countries should:

9.8.1 establish internal procedures for the receipt and handling of such information from the exporting country;

9.8.2 ensure that such information received is not used in any manner which would be inconsistent with the provisions of the General Agreement on Tariffs and Trade (GATT).

Article 10. Labelling, packaging, storage and disposal

10.1 All pesticide containers should be clearly labelled in accordance with applicable international guidelines, such as the FAO guidelines on good labelling practice (13).

10.2 Industry should use labels that:

10.2.1 include recommendations consistent with those of the recognized research and advisory agencies in the country of sale;

10.2.2 include appropriate symbols and pictograms whenever possible, in addition to written instructions, warnings and precautions;

10.2.3 in international trade, clearly show appropriate WHO hazard classification of the contents (11) or, if this is inappropriate or inconsistent with national regulations, use the relevant classification;

10.2.4 include, in the appropriate language or languages, a warning against the reuse of containers, and instructions for the safe disposal or decontamination of empty containers;

10.2.5 identify each lot or batch of the product in numbers or letters that can be read, transcribed and communicated by anyone without the need for codes or other means of deciphering;

10.2.6 are marked with the date (month and year) of formulation of the lot or batch and with relevant information on the storage stability of the product.

10.3 Industry should ensure that:

10.3.1 packaging, storage and disposal of pesticides conform in principle to the FAO guidelines for packaging and storage (12), the FAO guidelines for the disposal of waste pesticides and containers (16), and WHO specifications for pesticides used in public health (10);

10.3.2 in cooperation with governments, packaging or repackaging is carried out only on licensed premises where the responsible authority is convinced that staff are adequately protected against toxic hazares, that the resulting product will be properly packaged and labelled, and that the content will conform to the relevant quality standards.

10.4 Governments should take the necessary regulatory measures to prohibit the repacking, decanting or dispensing of any pesticide into food or beverage containers in trade channels and rigidly enforce punitive measures that effectively deter such practices.

Article 11. Advertising

11.1 Industry should ensure that:

11.1.1 all statements used in advertising are capable of technical substantiation;

11.1.2 advertisements do not contain any statement or visual presentation which, directly or by implication, omission, ambiguity or exaggerated claim, is likely to mislead the buyer, in particular with regard to the safety of the product, its nature, composition, or suitablility for use, or official recognition or approval;

11.1.3 pesticides which are legally restricted to use by registered operators are not publicly advertised through journals other than those catering for such operations, unless the restricted availability is clearly and prominently shown;

11.1.4 no firm or individual in any one country simultaneously markets different pesticide active ingredients or combinations of ingredients under a single distinguishing name;

11.1.5 advertising does not encourage uses other than those specified on the approvel label;

11.1:6 promotional material does not include use recommendations at variance with those of the recognized research and advisory agencies;

11.1.7 advertisements do not misuse research results or quotations from technical and scientific literature; and scientific jargon and irrelevances are not used to make claims appear to have a scientific basis they do not possess;

11.1.8 claims as to safety, including statements such as "safe", "non-poisonous", "harmless", "nontoxic", are not made, with or without a qualifying phrase such as "when used as directed";

11.1.9 statements comparing the safety of different products are not made;

11.1.10 misleading statements are not made concerning the effectiveness of the product;

11.1.11 no guarantees or implied guarantees e.g. "more profits with...", "guarantees high yields" are given unless definite

evidence to substantiate such claims is available;

11.1.12 advertisements do not contain any visual representation of potentially dangerous practices, such as mixing or application without sufficient protective clothing, use near food, or use by or near children;

11.1.13 advertising or promotional material draws attention to the appropriate warning phrases and symbols as laid down in the labelling guidelines (13);

11.1.14 technical literature provides adequate information on correct practices, including the observance of recommended rates, frequency of applications, and safe pre-harvest intervals;

11.1.15 false or misleading comparisons with other pesticides are not made;

11.1.16 all staff involved in sales promotion are adequately trained and possess sufficient technical knowledge to present complete, accurate and valid information on the products sold;

11.1.17 advertisements encourage purchasers and users to read the label carefully, or have label read to them if they cannot read.

11.2 International organizations and public sector groups should call attention to departures from this Article.

11.3 Governments are encouraged to work with manufacturers to take advantage of their marketing skills and infrastructure, in order to provide publicservice advertising regarding the safe and effective use of pesticides. This advertising could focus on such factors as proper maintenance and use of equipment, special precautions for children and pregnant women, the danger of reusing containers, and the importance of following label directions.

Article 12. Monitoring the observance of the Code

12.1 The Code should be published and should be observed through collaborative action on the part of governments, individually or in regional groups, appropriate organizations and bodies of the United Nations system, international governmental organizations and the pesticide industry.

12.2 The code should be brought to the attention of all concerned in the manufacture, marketing and use of pesticides and in the control of such activities, so that governments, individually or in regional groupings, industry and international institutions understand their shared responsibilities in working together to ensure that the objectives of the Code are achieved.

12.3 All parties addressed by this Code should observe this Code and should promote the principles and ethics expressed by the Code, irrespective of other parties' ability to observe the Code. The pesticide industry should cooperate fully in the observance of the Code and promote the principles and ethics expressed by the Code, irrespective of a government's ability to observe the Code.

12.4 Independently of any measures taken with respect to the observance of this Code, all relevant legal rules, whether legislative, administrative, judicial or customary, dealing with liability, consumer protection, conservation, pollution control and other related subjects should be strictly applied.

12.5 FAO and other competent international organizations should give full support to the observance of the Code, as adopted.

12.6 Governments should monitor the observance of the Code and report on progress made to the Director-General of FAO.

12.7 Governing Bodies should periodically review the relevance and effectiveness of the Code. The Code should be considered a dynamic text which must be brought up to date as required, taking into account technical, economic and social progress.

Annex

FAO Conference Resolution 10/85: International Code of Conduct on the Distribution and Use of Pesticides

THE CONFERENCE

Recognizing that increased food production is a high priority need in many parts of the world and that this need cannot be

met without the use of indispensable agricultural inputs such as pesticides,

Noting that FAO's study entitled Agriculture: toward 2000 foresees a steady increase in the worldwide use of pesticides,

Convinced that such growth in pesticide use is likely to take place in spite of necessary intensive parallel efforts to introduce biological and integrated pest control systems,

Acknowledging that pesticides can be hazardous to humans and the environment and that immediate action must be taken by all concerned, including governments, manufacturers, traders and users, to eliminate, as far as possible and within the scope of their responsibility, unreasonable risks, not only in the country of origin but also in the countries to which pesticides may be exported,

Being aware that the requirements for safe and proper use of pesticides in some developed countiries have led to the adoption of complex systems of regulations and of enforcement mechanisms, but that many other countries have neither such mechanisms nor the necessary legislation, regulations or infrastructures to control the import, sale or use of pesticides,

Convinced that additional efforts are needed to enable such countries to control pesticides more effectively and to assess the hazards which could result from their use or misuse,

Recognizing that a voluntary International Code of Conduct, based on internationally agreed technical guidelines, would provide a practical framework for the control of pesticides, especially in countries that do not have adequate pesticide registration and control schemes,

Noting that such a draft Code was reviewed by the Committee on Agriculture at its Eighth Session, and endorsed by the Council at its Eighty-eighth Session,

Having further noted the conclusions and recommendations of these bodies,

1. **Hereby adopts a voluntary International Code of Conduct on the Distribution and Use of Pesticides as given in the annex to this Resolution;**
2. **Recommends that all FAO Member Nations promote the use of this Code in the interests of safer and more efficient use**

of pesticides and of increased food production;

3. **Requests governments to monitor the observance of the Code, in collaboration with the Director-General who will report periodically to the Committee on agriculture;**
4. **Invites other United Nations agencies and other international organizations to collaborate in this endeavour within their respective spheres of competence.**

(Adopted 28 November 1985)

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FAO plant protection paper 21. "Recommended methods for measurement of pest resistance to pesticide"

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J. R. Busvine, 1980.

Statistical Principles of the Detection and Measurement of Resistance Correction for Control Mortality

It should be noted that the mortality observed in bioassay tests may not all be due to the pesticide, since handling and holding operations may also be lethal to some of the arthropods. This can be checked by using batches of controls, which are treated in the same way, except for use of pesticide. If it is assumed that deaths from handling and from the pesticide are quite independent and uncorrelated, then a correction for control mortality can be made by the use of Abbott's formula, as follows:

$$\text{Corrected \% mortality} = \frac{\text{Test \% mortality} - \text{control \% mortality}}{100 - \text{control \% mortality}} \times 100$$

Two comments on this correction may be of interest. Firstly, the change effected by its use is greatest at low mortalities and becomes very small near 99% mortality; secondly, the correction is virtually negligible when control mortalities are below 5%.

Dose-kill Relations

As has been stated, resistance can only be determined by comparison with a reference strain, which provides base-line data. These are obtained by exposing batches of this strain to a series of dosages and recording the mortality produced. The dosage may be the actual dose applied (e.g. in milligrams per arthropod, or per gram weight); or it can be the concentration used, or even the exposure time, since these are normally simple functions of the dose. Since the lethal effects of pesticides (like other poisons) are related to the logarithm of the dose, the dosages used should be in a logarithmic series, or else converted to logarithms for comparison with the kills.

The lethal effects, expressed as percentages killed, are related to the normal distribution of sensitivity in any homogeneous population. Because most susceptibility values are close to the average, there will be bigger changes in percentages killed by a given dose increment in this region than at extremes of high or low susceptibility. Therefore, to obtain a linear relation with log dosage, the percentages must be transformed, which can be done by using a table of "probits". Alternatively, the results may be plotted directly on to logarithmic probability graph paper (as shown in Figure 1). With results plotted on this paper, a straight line may be drawn to the results; and from it, the median lethal dose and other statistics may be estimated graphically with reasonable accuracy. If high accuracy is required, the log doses and probits may be used to compute the position of the line.

Various stages may best be explained by a hypothetical case, illustrated by Figure 1.

Base-line Data. In this hypothetical example, batches of the reference strain have been exposed to doses of 0.25, 0.5, 0.75 and 1.0 dose units, and the resulting percentages killed are plotted as open circles. The kill obtained by 1.0 units was 100%, which cannot be represented on a probability scale; so this point is represented by an arrow. The regression line "A" is drawn to fit these points as closely as possible. From it can be read the best (graphically determined) estimate of the kill to be expected from any dosage. Thus, 0.47 units corresponds to 50% kill, which is known as the median lethal dose, or LD50. If concentration were used for dosage, the expression would be LC50; and LT50 would correspond to a median lethal time of exposure. Similarly, other doses corresponding to 90% (LD90), 99% (LD99), etc., can be estimated.

As has been pointed out, the susceptibility of the reference strain may vary with different intrinsic or extrinsic factors. Therefore, base-line "A" will only be relevant for pests of defined status and conditions. With different status or conditions, the line could be displaced, to "B" for example. It will, however, be assumed that the resistant strain will be directly comparable to base-line "A".

Monitoring for Resistance. For routine monitoring to detect resistance, it is necessary to use a "diagnostic dose". This is chosen with reference to the regression line "A", using it to select a dosage with a high probability of killing all of a sample of normal pests. There is no absolute criterion of the number of individuals to be used in such a sample, nor of the dosage to be employed. The larger the number of pests in the sample, the better the chance of detecting resistance when only a small proportion of the population is affected. Generally a sample of at least 100 should be used, if possible.

With regard to the dosage chosen, it will be clear that one expected to give 99% kill will theoretically allow the survival of one normal individual in 100% that corresponding to 99.9% kill should spare only one in 1000. The lower level will occasionally give false indications of resistance, while the higher one will sometimes miss genuine, but low-level, resistance. Which ever dosage is chosen, the test should be repeated when survivors appear; and if they continue to appear every time, resistance should be suspected.

Detection of Resistance. In the hypothetical example, with pest status and conditions that produced line "a", a diagnostic dose expected to kill 99.9% would be 2.0 units. If conditions or pest status had changed to those which would have given line "f", the dose of 2.0 units would allow about 5% survival. Thus, monitoring with different conditions or status (e.g. lower temperature or insects entering diapause) could give false indications in incipient resistance.

Let it be assumed, however, that conditions and status are constant and that about 20% survivors have been repeatedly found at the 2.0 unit dose. This constitutes a warning signal, indicating a strong possibility of resistance. Additional tests are now done over a wider range of doses, the results of which are indicated by crosses in Figure 1. It will be seen that, above the diagnostic dose, there is little increase in kill over a large increase in dosage. The regression line of the suspected population ("c") forms a plateau, corresponding to about 80% kill, up to the point where resistant forms begin to be killed. This is consistent with the existence of 20% of resistant pests in the population.

It may be noted that, if changed conditions or status had been responsible for survivors at the diagnostic dose, there would have been no plateau, because increased doses would have soon cause a complete kill.

Measurement of Resistance. It is clearly impossible to draw a straight line to the results of tests with the suspected population, nor can one logically determine its LD50, as can be done with a homogeneous population (though some workers have tried to assess resistance levels of field populations by doing so). It should be noted that the dose to kill 50% of the suspect population has not changed much.

To measure the resistance level, it is necessary to obtain a homogeneous resistant strain, by appropriate breeding and selection in the laboratory. In the hypothetical example, a very high resistance has been postulated, as indicated by the results of tests which gave line "d" 1. Because of technical limitations in the test method, it was not possible to get kills higher than about 50%. If the resistance had been at a lower level, corresponding to line "d2", tests with the suspected field population would have begun to kill some of the resistant individuals in the population at the higher doses, diving line "c2".

Cross-resistance Tests. When the existence of resistance has been confirmed, it is clearly desirable to investigate its crossresistance characteristics by tests with other pesticides. This work, which would involve laboratory studies, should help to select an alternative pesticide.

Dosage units

EVALUATION OF INSECTICIDES FOR GRAIN TREATMENT, THE PRACTICAL DETAILS FOR DETERMINING EFFICACY

During the last 10 years work on the development of insecticides for grain treatment in Australia has concentrated on the control of malathion resistant strains. Samples of live insects were collected from storages throughout Australia and typical resistant strains are now maintained under continuous selection with insecticides in laboratory culture.

LABORATORY TRIALS

initial testing of candidate compounds in the laboratory involves modifications of the standard FAO resistance tests with impregnated papers. This provides a rapid assessment and is valid for comparison of compounds within one chemical group. It is not valid for use with highly volatile compounds.

Promising compounds are then bioassayed in treated grain. With wheat, desired quantity of insecticide is pipetted into bottles of grain at 11 % moisture content in sufficient volume of water to increase the moisture content to 12%. Grain is mixed by tumbling on a mechanical tumbler for 10 minutes. In general each bioassay involves six doses of an insecticide plus and untreated control. At each dose reacts there are 3 replicates of 50 parent insects in 83 9 of wheat for Sitophilus oryzae or Rhyzopertha dominica or in 167 9 for Tribolium castaneum. For Ephstia cantella 100 eggs are added to 167 9 of grain. The test insects are added 16 hours after treatment.

Initial assessments of mortality are made on parent insects after 3 days using as a criterion of response the inability to stand and walk.

All insects are returned to the treated grain and mortality again assessed at 26 days when all parent insects are removed. Most tests are conducted at 25C and 55% RH but at this time those involving Rhyzopertha and Tribolium are transferred to 30C and 55 RH for progeny development. The numbers of F1 progeny developing at 10 weeks are recorded and also the number of arbitrary F2 progeny at 16 weeks.

The efficacy of residues of highly promising compounds is determined after storage at 25C for 0,112,3,4 - 1/2,6,9 and 12 months after treatment.

Data are analysed using probit analysis and compounds are compared with standards using relative potency analyses.

The rate of decay of residues is determined by chemical analysis of samples at the same time.

FIELD TRIALS

Silo scale experiments are carried out in commercial silos using standard industry equipment. The candidate insecticides are applied by spraying into the grainstream, 11 per tonne, during unloading of grain into storage. Silos larger than 500 tonnes are preferred since in smaller grain masses temperatures approximate ambient conditions which are often at lower temperatures than grain in large silos.

Grain samples are taken at 12 points each 2 m below the grain surface using a vacuum sampler. Samples are bulked, subsampled and sealed into sample tins before leaving the treated bin. Significant losses of residue have occurred from newly treated grain during subsampling using more conventional techniques.

Bioassays and chemical assays are carried out on samples of treated grain in the laboratory as already described.

Necessary records for silo scale experiments include grain quality, grain moisture and grain temperature. The presence of any naturally occuring infestations are determined by sieving samples collected either with the vacuum sampling probe from the grain surface or directly from the grain stream during turning. The presence of such infestations indicates a failure but the

absence does not necessarily indicate success. The species could simply be absent.

Supplementary observations are made on the stability of insecticide formulations, the effect of insecticide on grain conveyor belts, the concentration of insecticide in grain dust and the reaction of workmen to the treatment.

Residues are determined in appropriate pro-. ducts manufactured from treated grain e.g., bran, germ, wholemeal flour, white flour, wholemeal bread and white bread. Additional laboratory studies are made of the rate of breakdown of residues on treated grain of different moisture contents at different temperatures. These data then enable the prediction of breakdown of residues under any given temperature or moisture conditions.

The final stage of testing involves Pilot Usage Trials at a minimum of 20 sites throughout the major grain producing areas of Australia. During this stage scientific staff are involved only with residue analyses and bioassays. All of the treatment operations are carried out by industry personnel.

The participation of industry personnel both at the administrative and operational levels is considered an essential aspect of the field testing programme.

Recommended Methods for the Detection and measurement of Resistance of Agricultural Pests to Pesticides

Tentative method for adults of some major pest species of stored cereals, with methyl bromide and phosphine FAO Method No. 16

Synopsis

A test method is described for detecting and measuring resistance to the fumigants methyl bromide and phosphine in Sitophilus oryzae, S. zeamais, S. granarius, Rhyzopertha dominica, Tribolium castaneum, T. confusum, Oryzaephilus surinamensis and O. mercator.

The method is based on exposure of adult insects to discrete atmospheres containing fumigant. Exposure periods are 5 hours for methyl bromide and 20 hours for phosphine. Responses are determined 14 days following termination of the exposure.

Base-line data are established with reference strains of known susceptibility from which it is possible to select discriminating doses that may be used to monitor samples of beetles for resistance. Survival in such tests is indicative of resistance, following which extensive testing should be carried out to determine the degree of resistance present.

Equipment and materials

Insectary. Facilities should be available for rearing insects at both 25 and 30C at approximately 70 percent relative humidity. A large incubator can be used, in which case the humidity can be adjusted by introducing an open tray filled with a saturated solution of sodium nitrate or strontium chloride.

Breeding materials. A summary of the breeding media and appropriate temperatures for the different species is given in Appendix 1. The media should be disinfested by heating in a sealed container at 60C for one hour after this temperature is reached throughout the medium. For breeding containers, small jars or wide-mouthed bottles sealed with filter paper (Whatman No. 29, black) and paraffin wax (to restrict movement of mites) are suitable.

Containers held in the incubator should be placed on trays containing paraffin oil as a further precaution to prevent contamination by mites.

All grain pests are subject to disease in laboratory culture. Tribolium species are particularly susceptible to the protozoan parasite Farinocystis tribolii. All equipment used for handling insects and media should be sterilized in a hot-air oven at 110 to 120C between each use and when not in use should be stored in this oven. At least one-half to one hour exposure at this temperature is necessary to ensure the destruction of the protozoan spores. all plastic ware used should be polypropylene, nylon or polycarbonate which is not affected by this temperature.

A supply of Fluon GP1 (an aqueous dispersion of polytetrafluoroethylene, obtainable from Imperial Chemical Industries Ltd.) must be available to assist in restraining all species other than Tribolium spp. and R. dominica. A film of this material is applied to the top 2 cm of the inside wall of breeding containers to prevent insects congregating on the filter paper seals and boring out. All handling containers must be treated similarly.

Test area. A room with normal illumination maintained at 25C is required. Should this room have a controlled humidity of 70 percent it will also serve to condition the atmosphere of fumigation chambers before commencing tests; however,

preconditioning of fumigant chamber atmospheres may be carried out in a breeding room.

Funigants. Pure methyl bromide (excluding chloropicrin) is recommended. Suitable sources include commercially available ampoules and cans. Aluminium phosphide formulations available commercially provide a suitable source of phosphine. Glassware, etc.

1. Fumigation chambers. Desiccators, 20 cm (8 in.) in diameter, fitted with a plate of stainless steel or other chemically inert material, and with lids containing ground sockets of a standard glass joint size make suitable fumigation chambers. Cone/screw thread adapters (e.g. Quickfit) should be fitted to the sockets of desiccator lids. A pure gum-rubber septum (or other rubber with good resealing properties when pierced with a syringe needle) is placed under the screw cap. Septa for this purpose are conveniently obtained from sheet rubber 3.2 mm (0.12 in.) thick with a wad punch.

Ground surfaces of desiccator flanges and cone/screw thread adapters should be lightly coated with silicone grease. (The use of cone/screw thread adapters is not essential. Any method providing in the lid of desiccators a septum that ensures both a gastight seal and chemically inert surfaces will be satisfactory.)

2 Fumigation cages Glass rigs 30 mm diameter and 25 mm high attached to filter papers (35 mm or 42.5 mm diameter) or small flat-bottom evaporating dishes are recommended as containers in which to confine insects during exposure to fumigant. Stainless steel gauze discs should be placed over fumigation cages when dosing species that may fly.

3. Gas-tight syringes. A range of gas-tight syringes (e.g. Hamilton gas-tight syringes) is required. The range chosen will be influenced by the volumes of the fumigation chambers but would probably include 50, 100 and 250 microlitre syringes together with 1-, 2.5- and 10- millilitre syringes. (It is not good practice to dispense small volumes from a large volume syringe.)

4. Magnetic strirrer. A magnetic stirrer is recommended for stirring gas mixtures within fumigation chambers. For this purpose a 45-mm PYCcoated follower with a rim is placed in the bottom of each fumigation chamber. Where necessary a magnetic stirrer may be made by fitting a suitable magnet to the shaft of a small electric motor. Speed control is not necessary.

5. Fumigant storage vessels. A 25- or 35-ml vial fitted with a screw cap and a Mininert valve provides a satisfactory method for storing methyl bromide (Figure 1). From this vessel, dose volumes of methyl bromide vapour may be obtained with a gas-tight

syringe. Alternatively a tube fitted with a septum and side-arm with stopcock, as shown in Figure 1, may be used as a means of providing a source of methyl bromide vapour.

For phosphine, a glass tube fitted with a septum together with a gas jar or measuring cylinder is required. A diagram of this apparatus together with accessory items is shown in Figure 2.

Collection of specimens and rearing

For identification of the various species see Appendix 2. The correct identification of species is particularly important and the tests have been designed to permit workers to identify species after discriminating tests have been conducted. It is essential that all identifications be checked at this time, particularly of survivors, and if there is any doubt as to the identity of specimens these should be submitted to an appropriate expert.

Figure 1. Methyl bromide storage/dose-source vessels.

Preparation of gas sources

Methyl bromide. All handling of methyl bromide should be carried out in a fume cupboard or well ventilated area. The Maximum Allowable Concentration (MAC)4 for methyl bromide is 20 ppm.

The container of methyl bromide, the storage vessel (dose-source vessel, see Figure 1) and a small glass funnel should be cooled to about 0C beforehand. Liquid methyl bromide is then transferred to the storage vessel until it is about three-quarters full, following which the cap of the storage vessel is firmly replaced to ensure a gastight seal.

Generally, sufficient methyl bromide will be vaporized during transfer to the storage vessel to flush out most of the air. To expel remaining air from the space above the liquid, the septum should be removed from the Mininert valve when the liquid is at room temperature and the valve opened for a short time allowing gas to escape. If the alternative storage vessel is used, the stopcock in the side-arm is opened for a short time. When not in use, both vessels should be stored in a refrigerator or cool place or in a fume cuphoard. Although both vessels should be completely gas-tight the possibility of leakage should not be overlooked.

Phosphine. All handling of phosphine should be carried out in a fume cuphoard. The MAC value for phosphine is 0.3 ppm.

Phosphine is conveniently obtained for laboratory dosing purposes from aluminium phosphide according to the equation:

A1P + 3HOH - $A1(OH)_3 + PH_3$

Some commercially available aluminium phosphide formulations contain ammonium carbamate as well, which also reacts with water liberating ammonia carbon dioxide.

Figure 2. Apparatus for generating phosphine from aluminium phosphide pellets. The collection vessel for phosphine gas mixture is shown inside the gas jar.

Commercially available pellets containing a phosphine equivalent of approximately 0.2 9 are recommended as the most suitable source of phosphine for the present method.

The apparatus (Figure 2) for generating phosphine is prepared by filling the gas jar, collection tube and rinsing tube with water. All air must be removed from the collection tube and rinsing tube. Approximately half the water in the gas jar is siphoned out and replaced by 10 percent (v/v) aqueous sulphuric acid solution. The contents of the gas jar and collection tube should be thoroughly stirred. Mixing within the collection tube may be achieved by forcing a jet of liquid through the rinsing tube and repeating this procedure a few times. A pellet containing aluminium phosphide is then placed in the gas jar with the aid of the stainless steel wire, the funnel is lifted slightly and placed over the pellet. Liberation of phosphine commences almost immediately.

As the reaction proceeds, the liquid disphlaced from the collection vessel is removed by means of the siphon, thus maintaining the level in the gas jar more or less constant. Throughout the procedure the liquid level in the gas jar should be maintained above that in the collection tube thus exerting slight positive pressure on the gas collected.

When the collection tube has been filled with gas, the walls of the tube may be rinsed with the "rinsing tube" to remove adhering pellet residue. This step is not absolutely necessary. However, frequently liquid remains in the neck of the collection tube and this may be displaced by a jet of liquid from the rinsing tube.

The gas mixture obtained in this manner from a "fresh" pellet contains approximately 86 percent phosphine (1.195 hg/ul) and is sufficient to provide a source of phosphine for dosing purposes over several weeks. The inclusion of sulphuric acid in the liquid contents of the gas jar and collection tube is primarily to absorb ammonia but it should also prevent the production of diphosphine (P2H4) which is spontaneously inflammable.

Measuring volume of desiccator

The volume of each desiccator must be determined so that dose volumes may be calculated. Thus each desiccator should be fully assembled to simulate operating conditions and then completely filled with water. The weight of water, corrected for the temperature of the water, provides a satisfactory estimate of volume. At 25C 1 gramme of water occupies 1.003 cc.

Prefumigation procedures

The following procedures are carried out on the day prior to dosing.

Preparation of insect cages. Filter-paper circles are fixed to the bottom of glass rings with a water soluble adhesive (a film of adhesive in a petri dish facilitates this operation) and the adhesive allowed to dry, preferably in an oven. If the flatbot tomed dishes are used, a filterpaper circle of suitable size should be placed in the bottom of the dish so that insects may walk normally.

When testing species that are able to climb a vertical glass surface, rings or dishes should be dipped in liquid Fluon to produce a film approximately 5 mm wide on the upper portion of the inner surface. With dishes it is necessary to provide a ventilation tube to permit displacement of air from inside the inverted dish.

Preparation of insects. A complete test comprises two replicates of 50 insects for each of five concentrations puls two control replicates, i.e. 600 insects in 12 glass rings for each strain tested. Adult beetles are counted in 12 batches of 50 into small vials or directly into the glass rings, progressively placing a maximum of ten insects in each vial or ring until each has the required number. The 12 batches are then assigned at random to the six desiccators, i.e. five treatments plus one control.

When testing species that are inclined to fly, the rings or dishes are covered with a square of stainless steel mesh. The squares of mesh are held in place by pushing down and banding the four corners over the ring or dish.

The insects thus prepared are held overnight in the desiccators, with lids removed, in a controlled temperature environment at 25C and 70 percent relative humidity.

Determination of dose volumes. The five concentrations to be used in the test should be selected. The data of Appendixes 3 and 5 are intended as a guide to likely dose ranges of susceptible strains. A dose equal to the discriminating dose should be selected as the highest dose of the test.

Having selected the concentrations, the required dose volumes (i.e. gas volumes) are determined (see Appendix 4).

Fumigation procedures

Preparation of chambers. Replace the lids on desiccators within the controlled temperature environment in which the desiccators and insects were held ovemight. The atmosphere of the chambers is thus conditioned at atmospheric pressure to 70 percent relative humidity at 25C. Transfer the desiccators to the dosing area.

Dosing chambers with methyl bromide. If the storage vessel (dose-sorec vessel) has been stored in a refrigerator, remove the vessel well before dosing is to commence to allow vessel and contents to reach ambient temperature.

Withdraw required gas volumes from the dose source vessel with the appropriate gasligkt syringe. Flush the syringe, before taking the first dose, by withdrawing small volumes of gas and expelling syringe contents into the fume cupboard. Do not allow heat from the hands to warm the contents of the syringe. Inject the dose into the desiccator and record the time of dosing. Immediately stir the atmosphere of the desiccator ith a magnetic stirrer for one to two minutes.

Following dosing, the desiccators should be held at a temperature of 25C throughout the exposure period. The exposure period required is five hours. This period hould be adhered to strictly in normal testing experiments.

Dosing chambers with phosphine. It is advisable to flush syringes to be used for dispensing phosphine doses in a stream of oxygen-freenitrogen immediately before use.

Before taking the first dose with a particular syringe, flush the syringe with small quantities of the phosphine source by withdrawing small volumes of gas and expelling these into the fume cuphoard. When drawing phosphine into the syringe

move the plunger slowly at all times. A sudden reduction in pressure within the syringe may ignite the phosphine spontaneously. As a further precaution ensure that at all times the liquid level in the gas jar is above that in the collection vessel thus exerting slight pressure on the phosphine gas mixture.

Withdraw the required dose volumes and inject these into the appropriate desiccator. recording the time when each dose is applied. Immediately stir the atmosphere of the desiccator with a magnetic stirrer for one to two minutes. Do not allow heat from the hands to warm the contents of the syringe during the dosing procedure. Between doses syringe needles should be capped with a rubber plug.

Following dosing, the desiccators should be held at a temperature of 25C throughout the exposure period. The exposure period required for hosphine tests is 20 hours. This period should be adhered to exactly in normal testing experiments.

Post-fumigaticn procedures

Termination of exposure. At the end of the required exposure period the lids of desiccators are removed, insect cages extracted and the desiccators ventilated. All insects are transferred to a small quantity of medium in a suitable container and held at 25C and 70 percent relative humidity.

Mortality assessment. Mortality should be assessed 14 days from the end of the exposure period. This post-treatment holding period allows time for end-point mortalities to be reached for both fumigants.

Numbers responding, i.e. dead, should be taken to include those insects that are in fact dead together with those showing only slight twitching of appendages when prodded. If death is recorded in the controls, the percentage responding to all test levels should be corrected by Abbott's formual. Results should be discarede and the test repeated if the percentage allected in controls is greater than 10.

Interpretation, calculation and reporting

The mortality figures are plotted on logarithmicprobability paper and the dosage-mortality relationship fitted by eye or by appropriate calculations. The LD50 and LD99.9 values are then determined from these lines. Values are expressed in concentration of fumigant (mg/l) or as concentration x time products (c x t) expressed in milligramme hours per litre (mg h/l).

when reporting these values both methods of expression should be prefaced (e.g. in table headings) be a statement of the exposure period since this is the fixed variable of dosage in the tests described.

The above procedures serve to establish baseline data for susceptible reference strains of beetles. Some results obtained by this method are referred to in Appendix 3. Testing of field strains may also be carried out in the foregoing manner. However, when testing field strains a full series of replicates of the susceptible reference strain should be included. Thus chemical estimation of gas concentrations is not necessary. Abnormal gas concentrations during tests will be revealed by the abnormal response of the reference strain. Nevertheless, a detailed evaluation of strains showing increased tolerance may require gasconcentration measurements.

Testing resistant strains

Procedures similar to the above allow the determination of LD50 and LD99.9 values for resistant strains. It will be necessary to increase dosages to obtain an equivalent range of response. When testing strains resistant to methyl bromide, dosages may be increased by increasing either the concentration or the exposure time. Strains resistant to phosphine, however, should be tested by increasing the fixed period of exposure, e.g. from 20 to 48 hours, and using the same range of concentrations. Small increases in concentrations can be made. At high concentrations of phosphine, however, insects become narcotized, the effect of which is to produce nonlinear probit lines, apparent resistance in susceptible strains and exaggerated resistance factors in resistant strains.

LD50 and LD99.9 Values obtained for resistant strains may be compared with those obtained for the susceptible reference strain and resistance factors calculated.

Monitoring for resistance

For routine monitoring to detect the inintial appearance of resistance in wild populations of stored product beetles, it is convenient to use a discriminating dose which is expected to kill all susceptible specimens. The dose chosen is that corresponding to slightly above the LD99.9 obtained from the regression line for susceptible beetles allowing for, in the case of phosphine, what appears to be inherent variability of response. Some discriminating concentrations are given in Appendix 1 Susceptible reference strains must always be included in discriminating tests.

When using a discriminating test with fumigants it is advisable always to make provision for abnormal concentrations. If a concentration is obtained that is less than the discriminating concentration this will be revealed by abnormal survival in the susceptible reference strain. Abnormally high concentrations may be revealed by the inclusion in the tests of a reference strain (or species) with slightly greater tolerance to the fumigant than the susceptible reference strain on which the discriminating dose is based, approximately x 1.5 for methyl bromide tests and x 2.5 for phosphine tests. An alternative approach to this is to use three concentrations, one at the discriminating concentration, one at the approximate LC90 level and the other at an equivalent level above the discriminating concentration.

In regular monitoring for resistance, it is desirable that it may be detected when only a small proportion of resistant individuals is present. For such purposes a minimum of 100 insects in two batches of 50 should used per sample.

Limited numbers of insects may not be sufficient to detect low levels of resistance. There-fore, additional samples should be obtained if possible. If, however, there is suspicion of serious resistance (e.g. from failure of treatments) a test with small numbers (10 to 20) may provide early valuable indication.

The insects are exposed to the discriminating dose for the appropriate period, in the usual way. If all of them are dead at the end of the post-treatment holding period, the sample can be classified as "no resistance detectable", and the medium in which they were held is put into a hot-air oven to destroy the culture. On the other hand, the presence of unaffected insects at the end of the test should be regarded as prima facie evidence of resistance, requiring further investigation.

Confirming resistance when a few Insects are unaffected

The appearance of unaffected insects in a discriminating test could be due to the presence of unusually tolerant individuals from a normal population. Provided that the conditions of exposure, the physiological state of the insects and the dosages are consistent, the probability of a single insect in a batch of 100 being unaffected due to chance is less than 0.1 (i.e. less than once in ten tests). It is important to determine whether incomplete response is due to such causes or to genuine resistance. This can be checked in the following manner:

1. By repeating the test, using further samples from the same field population. The chances of adventitious failure to respond by a single individual in each of successive tests decline progressively (less than 0.01, 0.001, 0.0001 and so on). Survival of two or more individuals throughout is even less likely. Therefore, the continued appearance of a proportion of unaffected

individuals can be considered as proof of resistance.

2. Alternatively, the insects which were unaffected in the discriminating test may be kept and used for breeding a further generation. should their reaction be truly due to resistance, it will be found that a substantially larger proportion of their progeny will fail to respond to the discriminating concentration.

Appendix 1 Some normal susceptibility data obtained for methyl bromide and phosphine together with discriminating concentrations

	LC_{50}	**$LC_{99.9}$**	**Discriminating concentration**
	mg/l		
Methyl bromide			
(Exposure period 5 hours)			
Sitophilus oryzae	3.6	4.8	6
S. zeamais	3.2	5.4	6
S. granarius	5.1	7.5	9
Rhyzopertha dominica	4.0	7.4	7
Tribolium castanceum	8.4	11.7	12
T. confusum	8.6	11.2	13
Oryzaephilus surinamensis	5.8	8.5	9
O. mercator	5.8	8.5	9
Phoshpine			
(Exposure period 20 hours			
Sitophilus oryzae	0.011	0.039	0.04

S. zeamais	0.007	0.013	0.04
S. granarius	0.013	0.041	0.07
rhyzopertha dominica	0.008	0.028	0.03
Tribolium castaneum	0.009	0.028	0.04
T. confusun	0.011	0.029	0.05
Oryzaephilus surinamensis	0.012	0.036	0.05
O. mercator	0.011	0.034	0.05

Appendix 2 Calculations of dose volumes and concentrations

The method requires the selection of concentrations, following which dose volumes of gas are determined. The following examples show the calculations and steps required to determine dose volumes and actual concentrations for a temperature of 25C (298K).

Example 1. Methyl bromide

Step 1. Determine the volume, d_1(ml) of methyl bromide vapour at 25C required to obtain a concentration of x_1(mg/l) in a desiccator of volume V_1(l)

$$\frac{298 \times x_1(\text{mg/l}) \times V_1(\text{l}) \times 22.414 \times 1000}{273 \times 1000 \times 94.939\ (\text{GMW methyl bromide})} = d_1(\text{ml})$$

i.e. x_1(mg/l) x V_1(l) x 0.2577 = d_1(ml)

Step 2. Select nearest whole division on appropriate syringe to give actual dose volume D_1(ml) of vapour and recalculate concentration, i.e. concentration X_1(mg/l) actually applied.

$$\frac{D_1(ml) \times 273 \times 94.939 \times 1000}{298 \times V_1(l) \times 22.414 \times 1000} = X_1(mg/l)$$

$$i\,e = \frac{D_1(ml) \times 3.8804}{V_1(l)} = X_1(mg/l)$$

Example 2. Phosphine

Step 1. Determine the volume d_1(ul) of the 86% phosphine gas source at 25C required to obtain a concentration of x_1(mg/l) in a desiccator of volume V_1(l).

$$\frac{298 \times x_1(mg/l) \times V_1(l) \times 22.414 \times 1000 \times 1000 \times 100}{273 \times 1000 \times 33.9977\ (\text{GMW phosphine}) \times 86} = d_1(ul)$$

$$\text{i.e. } x_1(mg/l) \times V_1(l) \times 836.81 = d_1(ul)$$

Step 2. Select nearest whole division on appropriate syringe to give actual dose volume D_1(ul) of the 86% phosphine source and recalculate concentration, i.e. concentration X_1(mg/l) actually applied.

$$\frac{D_1(ul) \times 273 \times 1000 \times 33.9977 \times 86}{298 \times V_1(l) \times 22.414 \times 1000 \times 1000 \times 100} = X_1(mg/l)$$

$$\text{i.e. } \frac{D_1(ul) \times 0.001195}{V_1(l)} = X_1(mg/l)$$

An 86% phosphine source is equivalent to a concentration of 1.195 ug/ul. Thus if concentration is expressed in terms of (ug/l) the equivalent of steps 1 and 2 in the foregoing is given by

Step 1 $$\frac{x_1(ug/l)\times V_1(l)}{1.195(ug/ul)} = d_1(ul)$$

Step 2 $$\frac{D_1(ul)\times 1.195}{V_1(l)} = X_1(ug/l)$$

Appendix 3 Suggested concentration ranges for tests on susceptible beetles

Table 1. Optimal Temperature Ranges of some common stored products insects.

Insect Species	**Common Name**	**Optimum Range (C)**
1. Species thriving at moderate grain temperatures:		
Acaros siro	Flour mite	21 - 27
Ptinus tectus	Australian spider beetle	23 - 25
Sitophilus granarius (L.)	Granary weevil	26 - 30
2. Species requiring moderate - warm temperatures:		
Sitophilus oryzae (L.)	Rice weevil	27 - 31
Acanthoscelides obtectus (Say)	Bean weevil	27 - 31
Sitotroga cerealella (L.)	Angoumois grain moth	26 - 30
3. Species fequiring high temperatures:		
Tribolium confusum Duv.	Confused door beetle	30 - 33
Zabrotes subfasciatus (Boh.)	Tropical bean weevil	29 - 33

Oryazephilus surinamensis (L.)	Saw-Toothed grain beetle	31 - 34
4. Species thriving in a hot climate:		
Rhyzopertha dominica (Fab.)	Lesser grain borer	32 - 35
Tribolium castaneum (Herbs".)	Rost-red door beetle	32 - 35
Trogoderma granarium Everts	Khapra beetle	33 - 37
		(max 41C)

Source: Howe (1965).

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Test method for determining resistance to insecticide in the rust red flour beetle, tribolium castaneum (HERBST)

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The test method has three phases.

1. **Establishment of base response data from known susceptible strains.**
2. **Use of discriminating concentrations to screen samples for resistance.**
3. **Complete definition of resistance by comparison of graded series of concentration mortality responses of susceptible and resistant strains.**

Type of Test

The type of test used is continuous exposure of adults, without food, to filter paper impregnated with insecticide. Insecticides are dissolved in a 3:1:1 mixture (by volume) of petroleum other (60-80C b.p.), acetone and Risella 17 oil to which 2 parts of dibutyl phthalate is added in the case of carbaryl. Aliquots of 0.5 ml of the solutions are spread with a pipette on Whatman No. 1,7 cm filter papers. For convenience, depostits are referred to as concentrations of solution rather than as dose/unit area of filter paper. Impregnated papers are allowed to stand overnight on sheets of plate glass. Glass rings, 5 cm dia. and 2.5 cm high are used to confine test insects on the treated surface. The criterion of response used is knockdown, defined as inability of insects to stand and walk. A gentle push forward with forceps is usually sufficient to determine in which category an individual is to be classed.

Papers are labelled with pencil before impregnation. To prevent loss of the insecticide to the substrate during application, papers are supported on 3 fine points or on small glass rings. They are allowed to dry for approximately one minute and then transferred to the plate glass sheet.

The 0.5 ml aliquots of insecticide solution are spread on the filter paper circles with 1 ml pipettes using a progressively decreasing circular pattern to ensure even distribution. Care should be taken to select pipettes with fine points and suitably sized outlets.

To prevent any change in concentration from evaporation of the volatile solvents, never take aliquots of solution for application to papers from the test solution flasks if the solutions are to be retained for later use. Always transfer twice the required voluem to a separate narrow-neck flask and pipette from this, discarding the remainder. The outside of the pipette should be wiped with a tissue after each paper is prepared.

Fresh test papers should be made daily and unused papers discarded. The test solutions should be kept in a refrigerator and under such conditions can have a storage life of several years (this should be checked periodically be chemical analysis). solutions should be allowed to come to room temperature before using.

Collection of Samples

A sample of insects, preferably adults, should be collected from each different commodity or habitat where infestations are detected. Samples must be kept separate and labelled. In general, a sample of 100 insects will be adequate - otherwise as many as possible. Plastic vials, approximately 3 cm diameter and 8 cm high with a perforated lid are convenient containers.)

Insects are collected by:

1. **Sieving of the commodity.**
2. **Brushing from floor, walls or surfaces of bags.**
3. **Selectively taking small quantities of the commodity or residue in a spoon.**
4. **Using an aspirator.**

If the insects are substantially separated from the commodity a small quantity of flour should be added to the container. Samples should not be allowed to stand in the sun or be otherwise exposed to extreme conditions and should be despatched as soon as possible to the testing centre.

Receipt of Samples

On receipt in the laboratory, the insects should be separated from any commodity or medium and placed in breeding containers in a medium of flour + yeast. A minimum of 2 9 of medium should be allowed per insect. Samples are placed in an incubator at 30C and 70 percent relative classified "no resistance detectable" and the

Preliminary Discriminating Tests

A minimum of 80 insects in two batches of 40 are used per sample if sufficient material is available. Otherwise all available insects are used. The test insects are removed from the breeding media which is then replaced in the incubator. The insects are counted into vials and held for 1 hour without food at 25C and approximately 70 percent relative humidity. They are then transferred to the filter papers impregnated with insecticide at the discriminating concentration (Appendix 4) and the time of commencement of exposure recorded. After the exact exposure period, the response and total number number of insects used is recorded on the resistance testing data sheet (Appendix 5) and the collector advised.

If there are no survivors, the sample can be classified "no resistance detectable" and the medium in which the test insects were held placed in a hot air oven to destroy the culture. If survivors are recorded beyond the exoposure period, comparisons must be made of the responses to a graded of doses, of the suspect strain and a known susceptible strain using laboratory standardised material. This is done either at the laboratory carrying out preliminary tests or at a central laboratory. Additionally if a low proportion only of insects survive the discriminating dose, the insects not knocked down are removed

immediately from the test filter papers and placed in media to breed. Their progeny are tested at the discriminating concentration. If the surviving insects represent the upper range of normal susceptibilitty, all progeny can be expected to respond at the discriminating dose. If, however, they represent true resistant phenotypes, a lower proportion of the progeny will be knocked down than responded in the original sample. This test provides valuable confirmation of resistance in doubtful cases.

Where tests are being made for malathion resistance, it is useful to determine whether the resistance detected is malathion-specific or of a more general type. Extra batches of insects are exposed to papers impregnated with the 1:20 malathion:synergist mixture at the discriminating concentrations of 0.5 percent malathion, 2 percent triphenyl phosphate. If limited material only is available (80 adults) one half of the test insects are exposed at the discriminating concentrations of malathion and triphenyl phosphate to determine whether the resistance is suppressible. Thus if malation resistance is present, an immediate statement can be made of the type of resistance probably present.

Breeding Laboratory Standardised Material

Sufficient insects must be produced to allow a graded concentration-response test to be conducted. Each test requires a minimum of 4 concentrations (+ control) and 3 replications with 40 insects per batch. If the original sample contained 100 insects then the holding period of 4 days will have allowed ample egg production but if the sample contained less than 40 insects the required 600 test insects will not be available and the stock must be increased for a further generation. In general, adult insects are allowed to oviposit for 1 week in media (maximum density 100 insects/200 9 medium) after which they are removed by sieving. The first progeny will appear after approximately 23 days with the peak emergence over the 26-30 day period. All progeny are removed from the culture after 40 days and held for a further 2 weeks in flour before use. The bulk of the progeny will then be 3-5 weeks old adults and for practical purposes individuals with all development times will be represented.

Graded-concentration Response Tests

Test insects are removed from the holding medium one hour before use and counted into 15 (treatment x replications) batches of 40 insects. The batches are assigned to concentrations and replications by overall randomisation. A parallel test with a known susceptible strain should also be included.

With resistant strains the range of higher concentrations must be extended to give a more complete concentration-response curve. The response at the discriminating concentration will assist in determining the range required - alternatively a preliminary assay may be carried out using one replication and full range of concentrations to determine the range required.

A provisional LC50 is assigned by plotting percentage responses, corrected by Abbott's formula, on log-probability paper and eye-fitting a concentrationresponse regression line. Results are expressed on a basis of percentage concentration of solution used to impregnate the filter paper circles.

The response data and particulars of the test should be recorded on the Resistance Testing Data Sheet (Appendix 6).

Information That Should be Recorded When Collecting Samples of Beetles for Resistance Tests

A. General

1. **sample number**
2. **date**
3. **collector's name**

B. Location

1. **state (country)**
2. **town (nearest post-office)**
3. **latitude and longitude**

C. Details of site

1. **structure of building (floor, walls, ceiling)**
2. **other storage use**
3. **insecticide treatment**
4. **general infestation level**

D. Commodity

1. **variety**
2. **origin**
3. **time of storage (weeks)**
4. **aeration**
5. **drying**
6. **moisture content**
7. **temperature**
8. **contamination**
9. **insecticide treatment**

E. Infestation

For each pest present

1. **species**
2. **degree of infestation**

Appendix 1 Rearing Temperatures, Media and Approximate Times of Development for the Test Species Rearing times

Insect	Rearing temperature	Rearing medium	Rearing times		
			First emergence	Peak emergence	Progeny removed
Days					
Sitophilus oryzae	25C	Wheat	35	36-43	63
S. zeamais	25C	Wheat	35	36-43	63

S. granarius	25C	Wheat	34	36-43	63
Rhyzopertha	30C	Wheat + broken wheat	35	36-43	63
dominica		(3 1)			
Tribolium	30C	Whole wheat flour + yeast	23	26-30	42
castaneum		(12 1)			
T. confusum	30C	Whole wheat flour + yeast	27	29-32	42
		(12: 1)			
Oryzaephilus	25C	Broken wheat + rolled	26	28-32	42
surinamensis		oats + yeast (5: 5: 1)			
O. mercator	25C	Broken wheat + rolled	26	28-32	42
		oats + yeast (5 : 5 : 1)			

Some Response Data From Susceptible Beetles and Suggested Discriminating Concentrations for Detecting Resistance

	Exposure period	Effective concentrations			Discrimi-nating concentrations
		KD_{50}	KD_{99}	$KD_{99.9}$	
	Hours				
MALATHION					
Sitophilus oryzae	6	0.89	1.38	1.60	1.5

S. zeamais	6	0.35	0.69	0.85	1.5
S. granarius	6	0.63	1.25	1.57	1.5
Rhyzopertha dominica	24	0.41	1.42	2.15	2.5
Tribolium castaneum	5	0.15	0.32	0.41	0.5
T. confusum	6	0.24	0.43	0.52	0.5
Oryzaephilus surinamensis	5	0.28	0.62	0.80	1.0
O. mercator	5	0.10	0.66	1.20	1.0

REPORT FORM FOR MONITORING TESTS FOR RESISTANCE OF STORED PRODUCT PESTS TO PESTICIDES FORM 1

REPORT FORM FOR MULTIPLE-DOSE TESTS FOR RESISTANCE OF STORED PRODUCT PESTS TO PESTICIDES FORM 2 (i.e., for basic susceptibility data or for investigations of suspected resistance)

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Section 9 - Chemical control methods fumigation technology

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Gas monitoring and detection systems

Fumigation technology in developing countres - Report of discussions and recommendations

BACKGROUND AND OBJECTIVE OF SEMINAR

Phosphine is applied to commodities as a solid formulation containing aluminium or magpoisons. This means that they must be applied as gases or as liquids which readily vaporise to produce toxice gas. This is in contrast to contact or stomach insecticides which poison insects through direct contact or ingestion in the liquid or solid state. Fumigants play a major worldwide role in the protection of stored grain from insect pests, but are particularly important in tropical and subtropical regions where conditions are most favourable for insect development. They have the particular advantage over other insecticides in that they can penetrate to all parts of a bulk or bag stack and, if used properly, can produce a complete kill of all stages of insect pests.

Fumigants which are applied in the gaseous state, such as hydrogen cyanide or methyl bromide, have used for many years in the developed countries. Certain fumigants applied as volatile liquids, e.g. ethylene dichloride, ethylene dibromide, carbon tetrachloride and carbon disulphide, have also been commonly used as grain fumigants, often as mixtures. It was only about 30 years ago that fumigation, mostly with methyl bromide or ethylene dichloride/carbon tetrachloride, began to be carried out in developing countries. The introduction of phosphine, generated by exposing solid formulations containing aluminium or magnesium phosphide to air, greatly simplified application procedures so enabling fumigation to be used more readily in developing countries. Unfortunately the expansion in the use of phosphine was not always accompantied by appropriate training in the techniques of application needed to ensure a total kill of the insect infestation.

Recently there has been increasing evidence showing the development of resistance by certain major pests to phosphine. Levels of resistance in some strains of certain species have increased to such an extent that it is difficult to achieve succesful results using a recommended dosage rate and fumigation procedure. There is much evidence to suggest that such resistance is associated with the use of poor fumigation techniques over many years. These difficulties with phosphine have been accompanied by a gradual withdrawal of the older alternatives which are either much less convenient to use or are now suspected of having carcinogenic properties. The scope for the introduction of completely new fumigants which might be used

as phosphine replacements is necessarily very limited due to the small number of chemicals possessing the necessary properties, and the high cost of producing all pre-registration data now required by pesticide registration authorities.

The objective of the seminar was to discuss the present situation and to identify ways in which the organisations represented by GASGA and other bodies throughout the world might respond to it. The role of phosphine as a fumigant is crucial to developing countries and if its continued effectiveness were to become doubtful, without the existence of suitable alternatives a grave situation would be created.

PHOSPHINE FORMULATIONS AND FUMIGATION PRACTICE

Phosphine is applied to commodities as a solid formulation containing aluminium or magnesium phosphide which reacts with atmospheric moisture to liberate phosphine. Formulations based on magnesium phosphide generate phosphine more rapidly than those containing aluminium phosphide. Phosphine is also liberated more rapidly from both types of formulation under ambient conditions of high relative humidity and temperature. The manufactured products contain ingredients which retard this reaction or produce carbon dioxide which prevents spontaneous combustion of phosphine.

Four main types of formulation are currently available for the generation of phosphine; (1) flat or round tablets generating 1 g of phosphine, (2) flat of round pellets generating 0.2 g of phosphine, (3) sachets generating 11 g of phosphine and (4) 'plates' generating 33 g of phosphine. Of these only the fiat tablets and pellets are manufactured in developing countries. Each of these has particular characteristics in relation to the rate of generation of gas. Pest control organisations in developing countries need to consider which type is most suitable for local conditions, including also ease of application and safety, packaging and storability and cost when deciding which formulation to use (Halliday, page 19). If tablets are produced locally there may be no choice and cost will generally be the most important factor.

Techniques have been developed by the United States Department of Agriculture (USDA) for the fumigation of bulk grain in tankers and bulk dry cargo vessels using phosphine. These techniques are claimed to be both safe and effective under the prevailing circumstances. The margins for safety and efficacy are very narrow, however, and the techniques should only be used under favourable conditions. Such fumigations may be carried ourt while the vessel is at sea thus reducing the need to delay shipments. In-transit fumigation of grain has proved particularly valuable to US grain exproters and is now also being carried out on shipments of bulk grain from France, the Federal Republic of Germany and Argentina. The procedure developed by the USDA has been endorsed by the International Maritime Organisation (IMO). The possibility of some survival

of insects during such fumigations was recognised but it has to be accepted that the current inspection and handling procedures often permit no alternative to in-transit ship-board. fumigation when cargoes were found to be infested. Ship-board fumigations should be confined to bulk grain in tankers and bulk dry cargo vessels. No techniques have yet been developed for the safe and efficient fumigation of cargo types of ships, break bulk cargoes and 'tween deckers and fumigation in these vessels should not be attempted.

There are three methods by which flat bulks of grain are treated with phosphine

(1) Probing phosphine formulations throughout the bulk with or without covering with gas-proof sheets.

(2) Placing the fumigations on the surface of the grain: fumigation of bulk grain in this way is only satisfactory if carried out at temperatures exceeding 15C and it is essential that adequate dosages be applied. There is great concern at the low dosages that are now being recomended for use in developing countries. Dosing at levels substantially above the theoretical minimum is needed for full control, especially where there is difficulty in obtaining the high standards of sealing necessary to enable the exposure periods to phosphine required for control.

(3) 'Spot' fumigation, in which only limited portions of the grain bulk are fumigated by probing formulations into areas which are identified as being infested was deplored. Spot fumigation with phosphine has only a 50% chance of success at the first attempt and could lead to a gradual build up of resistance.

Experiments in Togo demonstrated the successful phosphine fumigation of small rural storage structures containing sorghum grain, despite considerable leakage of gas, with application rates of 6 g phosphine/m. It was considered that phosphine could be used for the disinfestation of grain developing countries at village or small trader level in appropriate circumstances. The need to ensure safety was emphasised, however, especially as storage installations are often intermingled with living accommodation. This can only be achieved with good sealing which is necessary in any case if efficacy is to be achieved and the danger of build-up of resistance to phosphine is to be avoided. Also there is a need for small packs of phosphine formulations so as to avoid the danger of traders breaking large packs and retailing tablets in unsealed containers.

MEASUREMENT OF FUMIGANT CONCENTRATIONS

Sensitive, accurate, reliable, rapid and protable methods of analysis are needed for monitoring concentrations of fumigations

in the field. This is necessary both for assurance that adequate concentration - time products are obtained and to avoid exposure of personnel to hazardous concentations.

The most common method used in the field for the rapid determination of phosphine and methyl bromide concentrations is that of detector tubes. These contain cotton wool impregnated with a chemical reagent which changes colour as a gas sample is drawn through the tube. A measure of the concentration of fumigant is indicated by the length of the decolourised cotton wool. Detector tubes are calibrated directly for this purpose and can be used to give approximate indications of fumigant concentrations within a period of 5 min or so. Detector tubes are not sufficiently accurate for the determination of phosphine concentrations in experimental programmes.

Other methods for monitoring fumigant concentrations depend on their physical rather than their chemical properties. A meter measuring methyl bromide concentrations by thermal conductivity has been in use for 30 years. Portable infra-red gas analysers for the determination of both phosphine and methyl bromide have been used for 10 years or more, while instruments based on sonic analysis or interferometry have also been developed. None of these, however, has found any widespread application except for research purposes.

The most accurate method of analysis for both methyl bromide and phosphine remains that of gas liquid chromatography (glc). It is difficult to use this technique in the field, however, except in mobile laboratories. Such facilities are generally only available to sophisticated research organisations.

Two methods for phosphine analysis which have recently been developed were demonstrated. They combine the accuracy of glc with the other requisites of field test equipment. They have significant potential, not only for research purposes but also as a more accurate replacement for detector tubes. The first of these, developed by the Tropical development and Research Institute (TDRI), is based on the reaction of phosphine with mercuric chloride in a modified cell connected to a conductivity meter which provides a direct digital reading of phosphine in parts per million (Harris, page 56). The method is simple to operate and has been successfully used in a wide range of field conditions in Africa and Asia. Accuracy, determined by comparison with glc, is about 5%, including sampling errors. The equipment may be assembled from standard components, it is cheap and can be carried in a small camera case.

The other method developed at Laboratoire Denres Stockes in France uses the reducing activity of phosphine in an electrochemical cell. When gas containing phosphine is admitted to the cell an oxydoreduction reaction is induced and

produces electric current in proportion to the concentration of phosphine present. This can be converted into a direct reading of phosphine in parts per million on a digital meter. The method has been tested in field trials in France and has provided a reliable method of measuring phosphine concentrations over a range of conditions. It may be possible to adapt it to give a continuous recording of phosphine concentrations.

TOXICITY OF PHOSPHINE TO INSECTS, MODE OF ACTION AND RESISTANCE MECHANISMS

Many aspects of phosphine toxicity to insects are still incompletely understood but it is known that oxygen is needed for the gas to be effective and different species, and developmental stages of the same species of insects, vary enormously in their susceptibility. Some stages are so tolerant that they are able to continue normal development in the presence of quite high concentrations of gas. In so doing they pass from the tolerant stage to one of greater susceptibility. If the fumigation area is adequately sealed death of these stages occurs shortly after a susceptible stage is reached. Obviously, with an actively increasing population comprising adults and immature stages, there is much to be gained if the exposure pelod can be increased to span the tolerant stages in the life cycle. The length of the exposure required is temperature dependent because it is governed by the rate of insect development. Increasing concentration of gas over shorter periods is unlikely to improve control in these circumstances.

In tests on adults or diapausing larvae where there is little or no progressive development, the period of exposure to phosphine is still more important concentration. For larvae in diapause there is much variation in the minimum time of exposure required for death among individuals in tests at high concentrations. Minimum periods to achieve 50 or 90% kills are relatively long compared with other stages. For this reason, efficacy of phosphine, unlike other fumigants is not determined by the product of concentration and period of exposure. Formulae equating concentration of phosphine and exposure periods cannot, therefore, be expressed in terms of the product product producing a constant mortality (as for other fumigants such as methyl bromide). They must also take account of minimum gas concentration and exposure period needed to achieve required levels of mortality.

Superimposed upon the basic toxicity pattern is a narcotic threshold, encountered at higher concentrations; this is a state assumed by insects in which they become dormant and are not killed by phosphine. The concentration range over which this effect is observed may increase at higher temperatures. At concentrations inducing narcosis some insects survive for longer periods than at lower concentrations, but the protection conferred is temporary. Unexpected survival after relatively long

exposures is also encountered when insects experience a gradual rise in gas concentration from zero (Reichmuth, page 88). This occurs in practice as gas is released from a proprietary formulation. This effect may also be linked with narcosis because, when concentrations rise to 1 or 2 mg/l in about a day, narcotic levels are encountered within a few hours of dosing. At present phosphine toxicity data has largely been obtained using constant concentrations and more work is required on changing levels.

The mode action of phosphine is still uncertain, however, some interesting results have been obtained from uptake studies comparing resistant and susceptible strains. Examples of phosphine resistance so far studied have not been associated with narcosis but physical activity and respiration have appeared unaffected for a substantial initial period of the exposure. Clear evidence has been obtained in Rhyzopertha dominica for a mechanism which actively excludes the gas and which greatly delays the accumulation of poison in the tissues. Four other species have a similar mechanism. Investigations are underway to determine if exposure conditions can be manipulated to overcome this mechanism.

Resistance to phosphine has been detected in insects from a number of developing countries. Tests on immature stages have shown that some resistant strains of several species now require doses as high as the naturally tolerant Sitophilus spp. for control. Resistance has been detected in strains of six species of beetle collected in the UK. It was observed that no discriminating dose test has yet been developed for species of moth infesting stored products.

Work in Australia has shown that resistance can be induced in most strains of insect species by exposure to phosphine in the laboratory. The relative importance of time of exposure and concentration level varied in different strains, although time of exposure was always the more important factor. The minimum level of concentration required for the fumigation to be effective was raised in resistant strains, indicating a greater ability for detoxication. The narcotic threshold was also higher in resistant strains.

No instance has so far been detected in which resistance to phosphine has developed to the extent that infestation cannot be controlled by recommended procedures. However, it is vital that fumigations with phosphine only be carried out where exposure to lethal concentrations can be guaranteed for adequate periods. This implies either good conditions of sealing or the use of novel procedures in which multiple application of fumigant can be carried out. There is also a need to update information on the incidence of resistance in countries where. phosphine is used.

GEOGRAPHICAL DISTRIBUTION AND CAUSES OF RESISTANCE

The FAO global survey or insecticide resistance carried out in 1972-73 by Champ and Dyte (1976)* showed evidence of phosphine resistance by a number of important species of insect pests of stored products, and pointed out the potential for further development of resistance to phosphine.

The first positive confirmation of fumigation failure due to phosphine resistance occurred in Bangladesh in 1981. This could be related to poor fumigation practice in which leaky godowns had been fumigated with inadequate doses of phosphine over many years. Substantial levels or resistance were noted in R. dominica, Cryptolestes ferrugineus and Tribolium castanceum. Highly resistant strains of C. ferrugineus have been found on commodities imported into the UK from the Indian subcontinent, suggesting that the resistance noted in Bangladesh was not an isolated occurrence.

TDRI is now carrying out a survey of the current geographical incidence of resistance to phosphine. Resistance has been observed in strains of insects from Pakistan, Nepal, Bhutan, Sri Lanka, Botswana, Mali and Tunisia. Strains from Ethiopia, Liberia, Nigeria, Zimbabwe, USA, Burma, St. Lucia and Thailand were found to be non-resistant. Evidence was presented to suggest that some of the resistant strains had originated in other countries and had been transferred on imports. This and similar work to update current knowledge of resistance to phosphine is most valuable and should be continued and strongly encouraged.

The causes of resistance development have been examined in detail. The area where resistance appears to be most prominent is in the Indian subcontinent where the fumigation of whole stores without proper sealing is commonly practiced. This is the same cause as the observed resistance in Bangladesh, and fumigation procedures similar to those used in Bangladesh are widely practiced in India, Pakistan and Nepal. Such practices result in repeated underdosing and inadequate exposure periods which cause a gradual increase in the proportion of the total population showing resistance.

It was recognised that fumigation of whole stores is likely to continue because the simplicity and cost of the technique made it attractive. Fumigation of such stores can be improved without any great increase in cost or technical complexity by better sealing, the use of a phosphine formulation which releases gas more slowly and by multiple application of formulation. The need for further research into the development of suitable fumigation techniques, taking more account of meteorological factors such as temperature variation and wind was recognised. The importance of developing such techniques for whole-store fumigation is paramount.

ALTERNATIVES TO PHOSPHINE

The use of carbon dioxide as a fumigant for grain stored in large bulks has been demonstrated in the USA, Australia and other countries. Such treatment is effective if concentrations of about 90% are maintained. For this reason it is likely to be economic only where carbon dioxide is available at very low prices. Interest in this technique is being shown by countries in Southeast Asia where cheap carbon dioxide is available.

The use of carbon dioxide mixed with small quantities of phosphine or methyl bromide was described. Such techniques have been shown to be effective and were likely to be of most use for the fumigation of bulk grain in silos and containers.

The use of oxygen-free ('inert') atmospheres to control infestation of bulk grain was described. The atmospheres may be produced by combustion and feeding the exhaust gas into the structure. They have the advantage over carbon dioxide in that they can be readily produced on site and are thus independent of industrial production of gases. The effective use of inert atmospheres requires a high degree of airtightness as the presence of even very low concentrations of oxygen will allow insects to survive. Such air tightness is most easily obtained in flexible plastic enclosures. Whilst there is potential for such systems there may be difficulties in applying them in most developing countries.

Liquid fumigants might be reconsidered to a limited degree as a replacement for phosphine. Potentially they are of particular use for the fumigation of small quantities of bulk grain, spot fumigation in large bulks and the localised fumigation of milling equipment. Most traditional liquid grain fumigants, e.g. ethylene dibromide or ethylene dichloride administered with carbon tetrachloride, are suspected of possible carcinogenicity and other toxic effects. A new mixture (80% trichloroethane, 20% methyl bromide) was discussed and it was hoped it would meet the new, more stringent, requirements for mammalian toxicity and still be as effective as the former fumigants.

Hydrogen cyanide was at one time extensively used for the fumigation of grain and other commodities but has been almost completely superseded by methyl bromide or phosphine. There might be some scope for the reintroduction of hydrogen cyanide in particular circumstances where phosphine or methyl bromide cannot be used.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. Specifications for Phosphine Formulations

Notional regulatory authorities which operate pesticide registration schemes should require suppliers of phosphine

formulations to provide information, with supporting experimental data, on the total yield and rate of release of phosphine under specified conditions of temperature and relative humidity which approximate to those that might be expected during use.

The authorities should also require that the standard of packaging of phosphine formulations should be such as to ensure that unopened containers can be safely stored without deterioration for at least 2 years. The size of packages should be appropriate to the local pattern of use.

On the basis of most currently recommended dosage reates and methods of application for phosphine-generating products, and in the light of current knowledge, exposure periods of less than 5 days should be discouraged in recommendations on labels or in product information sheets supplied by manufacturers or their agents. Labels on phosphinegenerating products should not contain any information that suggests that phosphine is suitable for use in fumigation enclosures that are of a lower standard of gas tightness than that required for other fumigants.

2. Fumigation on Ships

Grain exporters and shippers should note that techniques and safeguards have been developed for the in-transit fumigation of bulk grain in tankers and bulk dry cargo vessels. However, it is recognised that margins for safety and efficacy are too narrow for this technique to be widely recommended and it should be confined to those situations where good results can be assured. In particular, in-transit fumigation in ships' holds cannot yet be recommended as a suitable approach to disinfesting grain or similar commodities for developing countries. No such techniques have been developed for break bulk cargoes and 'tween deck ships and it is strongly recommended that intransit fumigation of such cargoes or in such vessels should not be attempted at all pending further research and the development of a safe and effective methodology. Guidelines have been published by the IMO on this subject.

3. Fumigation of Large Bulks of Grain

Organisations storing large quantities of grain in bulk should undertake fumigations only under good conditions of sealing. Phosphine fumiga ions of bulk stores should be attempted only on the total bulk, and not in localised areas of it, so as to ensure full control of insect infestation and to avoid the development of resistance.

4. Resistance of Insects to Phosphine

The Group noted the scientific studies on the toxicity of phosphine, its mode of action and the mechanisms of resistance in progress at several centres in developed countries. These studies are vital for a thorough understanding of problems of resistance which have occurred in practical fumigation. It is most strongly recommended that these studies be continued and increased and, additionally, extended to cover the higher temperatures prevailing in the tropics.

The Group recognised the value of the FAO worldwide survey of insecticide resistance carried out in 1972-73 by Champ and Dyte which clearly indicated the potential for a phosphine resistance problem. This has now been shown to exist in many geographic areas. It is considered of the greatest importance and most urgent that the current status of the degree and geographical extent of resistance to phosphine be assessed. It is further recommended that donor agencies:

(1) consider this programme a project of high priority;

(2) consider how they might contribute to the identification of countries, regions and situations where insecticide resistance, particularly fumigant resistance, is serious and increasing;

(3) implement programmes to improve fumigation technology where these are most urgently required.

5. Application Technology

Government departments, parastatal organisations, commercial pest control operators and all those with responsibility for stored grains should note that the primary cause of control failures leading to the development of resistance is poor fumigation techniques. These are exemplified by inadequate dosage, insufficient exposure time, poor and improper sealing and failure to recognise and understand the significance of prevailing ambient conditions.

The Group recognised that the most effective method of ensuring satisfactory standards of control of infestation in bagged grains and flat bulks in nonfumigable warehouses is by fumigating under undamaged gas-proof sheets. Developing countries need to be advised on specifications for fumigation sheets, and their proper maintenance and repair and storage when not in use.

The Group also recognised that fumigation of whole stores will continue to be carried out but that many of the observed practices in the sealing of the building and application of the fumigant are inadequate. Specifications need to be provided for the adequate sealing of stores to be constructed, having regard to the cost and availability of local materials and skills.

Studies are also needed on the feasibility and cost of sealing existing buildings. Where it is not possible to realise an effective total seal means should be developed to measure the effectiveness of the attainable seal and application techniques be developed appropriate to the condition of the store.

The need for adequate training and a proper status for pest control operational personnel, at all levels, should be recognised by senior management if the work is to be given its proper priority and good results are to be obtained.

6. Detection and Monitoring of Fumigant Concentrations

New and relatively inexpensive methods of measuring phosphine are now available. Pest control operators, marketing boards other responsible authorities should be actively encouraged to use these methods to monitor fumigations for which they are responsible. Detector tubes are now available to monitor concentrations of many industrial gases but the limitations of accuracy of those used to measure fumigant concentrations should be recognised.

It is a matter of concern that recently accepted threshold levels of methyl bromide cannot be detected using an halide lamp and new wethods for detection in the field at these concentrations are urgently needed.

7. Alternative Fumigants

The Group recognised the danger of there being only two widely used fumigants, phosphine and methyl bromide. It also recognised a need for the development of alternatives and took note of carbon dioxide, used exclusively or as a mixture with other gases, methyl chloroform/ methyl bromide mixtures and nitrogen. It was considered, however, that the complexities of logistical support and application needed would, at present, inhibit acceptance of these alternatives in developing countries. Nevertheless additional research in this area would be most beneficial in the long term. It should be noted that there may still be a role for hydrogen cyanide in some situations.

8. Fumigation on Farms

Fumigation in farms and small village stores should not be encouraged unless safe and effective treatments can be ensured. This will entail the provision of fumigant in packs of appropriate size and good sealing of structures and commodities being fumigated. Such conditions can rarely be achieved under present circumstances.

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Storage pests and their control manual

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by JOSEFINA M HILARIO

This paper is a summary of pest control procedures currently being followed by the National Food Authority of the Philippines in accordance with internationally-accepted practices. No attempt is made here to present a detailed discussion of the basic concepts and principles of pest control as the author presumes that the participants has already obtained these information elsewhere. The exercises described here are intended merely to complement previous lectures on the subject and thus familiarize the participants with the manner in which the different pest control techniques are carried out in practice.

EXERCISE I FUMIGATION

A. Materials and Equipment:

1. Phosphine fumigation

Fumigating sheets
Sand bags
Phostrays
Phostoxin tablets

Warning signs
Masking tape
Protective clothing
Gas maske
Hand gloves
Phosphine gas detector

2. Methyl bromide fumigation

Fumigating sheets
Sand bags
Jiffy applicators
Evaporating pan
Methvl bromide, 1.5 lb. tin cans
Halide detectors
Alcohol
Match
Warning signs
Masking tape
Protective clothing
Gas mask
Gas extraction machine

B. Computations:

For phosphine fumigation:

Number of tablets = total volume or weight of pile x dosage

For methyl bromide fumigation:

Number of tin cans @ 1.5 lb. = Total volume of weight of pile.

$$\frac{\times \text{ dosage (lb)}}{1.5}$$

C. Procedure:

Fumigation is the application of a chemical which, at a required temperature and pressure, can exist as a gas in sufficient concentration to be lethal to a given pest organism. This treatment is resorted to as a remedial measure to control internal infestation. Fumigants, in contrast to other pesticides, are capable of diffusing and penetrating tightly-packed materials and can reach pests even inside grain kernels. They are effective against insects in all stages of development egg, larvae, pupa and adult.

Fumigation may be carried out under gasproof sheets or in lightly sealed enclosures. Fumigation under sheets:

The goods most often fumigated under sheets are cereals and other plant products in bags and the principal fumigants used are methyl bromide and phosphine. Gasproof sheets which retain fumigant vapors for a sufficient time when placed over infested materials may provide a safe and effective method of fumigation. This technique makes it possible to treat infested materials in situation, e.g. without moving them from their usual trade channels.

1) Preparation of stock: a. Prepare the stock by sealing all openings that would lead to the downward leakage of the fumigant during treatment. Inspect the fumigating sheets and repair rips and holes with masking tape to prevent leakage of gas. b. Hoist the sheets to the top of the stack leaving the ends hanging at the side with three feet extra sheeting for sealing edges to the floor. If sheets are not large enough, two or more may be joined by rolling together about three feet of the edges of each of the adjoining sheets.

2) Application of Fumigants:

a. If methyl bromide is to be used-in small piles, form a"dome" by propping bags against each other. In large stacks, a long space two bags deep and two bags wide should be made by lifting adjoining bags to form a trench. Lay a pan or can to receive

the liquid discharging from the end of the outlet tube. Spread the sheets to completely cover the entire stack leaving the punching mechanism of the jiffy applicators outside the sheets on the floor. Seal the edges of the sheets to the floor by using sand bags. Apply the fumigant using the necessary protective devices.

b) If aluminum phosphide is to be used - the tablets, pellets, or sachets may be applied by evenly distributing them into phostrays and placing in strategic locations around the base of the stack. Sachets may be bound in lots of ten and dropped over or in the sides of the stacks in evenly-spaced positions prior to sheeting. Rubber gloves should be warm when directly handling tablets, pellets or sachets. Spread the sheets to completely cover the entire stack. Seal the edges of the sheets to the floor by using sand bags.

3) Leakage

a) When using methyl bromide, a careful check should be made with the leak detector around the base of the stack immediately.

b) Bolled junctions should also be tested.

4) Aeration

a) Operators must wear gas masks during the process of airing until dangerous concentrations of the fumigant have diffused.

b) Open all doors and windows and run exhaust fans.

c) Aeration should begun by, quickly lifting several sheets of each corner of the stack, in cases where gas extraction machine is not available, more sheets maybe lifted after a time interval.

EXERCISE II - PROTECTIVE SPRAYING

A. Materials:	Equipment:
Pail	Water
Stirrer	Regular grade gasoline

Graduated Cylinder	**Protective clothing**
Motorized knapsack' sprayer	**Respirator**

Emulsifiable concentrate Hand gloves insecticide

B. Computations: Volume of solution = Total surface area x rate of application

$$\text{Number of loadings} = \frac{\text{Volume of solution}}{\text{Capacity of solution tank}}$$

$$\text{For a single loading} = \frac{\text{Volume of solution tank} \times \text{dosage}}{\text{\% active ingredient in commercial formulation}}$$

C. Procedure:

Protective or surface spraying is applied on the external surfaces of stacked commodities to prevent insect attack and control existing infestation, if any. This consists of a spray application on the four sides and the top surface of the bag stack. Protective spraying must be done after receipt of stack and after fumigation on a regular basis. Before spraying, thorough cleaning of the stack be carried out to achieve effective control.

Fill the pail with the required volume of water and add the necessary amount of insecticide measured by a graduated cylinder. Stir the solution thoroughly and pour into the solution tank of the sprayer. Supply on the exposed surfaces of the stack and the surrounding areas taking care not to drench the bags. Refill as may be necessary. Use protective devices in preparing and applying the spray.

EXERCISE III - RESIDUAL SPRAYING

A. Materials and Equipment:

Drum	**Water**
Pail	**Gasoline**
Stirrer	**Protective clothing**
Compressurized power sprayer	**Respirator**
Weetable powder insecticide	**Hand gloves**

B. Computations:

Volume of solution = Total surface area x rate of application

$$\text{Weight of insecticide} = \frac{\text{Volume of solution x dosage}}{\text{n / active ingredient in commercial formulation}}$$

C. Procedure:

Residual or fabric spraying is applied in the structure of an empty warehouse or portion of a warehouse about to receive commodities for storage. Before spraying, thorough cleaning of the warehouse should be carried out. Residues from previous warehouse operations should be removed, burned or properly treated since they serve as a good source of reinfestation.

Weigh the required amount of insecticide, place it in a pail and add just enough water to produce a cream. Pour the creamy solution to the drum and fill up with water to produce the required volume of solution. Stir to ensure complete dispersion of the powder. Spray the deluted solution on ail internal surfaces including floors, post, trusses and ceiling. Use protective devices in preparing and applying the spray.

EXERCISE IV-FOGGING

Thermal fogger	**Diesel oil**
Pail	**Gasoline**
Stirrer	**Protective clothing**

Graduated cylinder	**Respirator**
Stainer	**Hand gloves**

B. Computations:

Volume of solution = Total volume of wareouse rate of application

$$\text{Number of loadings} = \frac{\text{Volume of solution}}{\text{\% active ingredient of commercial formulation}}$$

Volume of diesel oil = Capacity of solution tank - volume of insecticide

C. Procedure:

Fogging is the application of smoke or fog containing insecticide in an enclosed warehouse. This is done to control infestations of flying or migratory insects or those not controlled by residual treatment. Fogging should be applied at a time of day when insects are most active, generally at dusk. In order to achieve effective control, the treatment should be repeated at frequent intervals. When fogging, make sure that all openings of the warehouse are properly sealed.

Fill the pail, with the required volume of diesel and add the necessary amount of insecticide measured by a graduated cylinder. Stir the solution thoroughly and pour into the solution tank of the fogger using a strainer. Dispense the fog making sure that it is evenly distributed throughout the warehouse. Refill as be necessary. Use protective devices when preparing and applying the fogging solution.

EXERCISE V - RODENT BAITING

A. Materials and Equipment:

Sample pan	**Rodenticides**
Bait stations	**Hand gloves**

Bait material	Beam balance

B. Computations:

Number of baiting stations = Length (m) + I x Width (m) + I

Weight of bait - Number of baiting stations x 100 gm.

Weight of rodenticide = Weight of baidt x 1/36

Weight of bait material= Weight of bait-weight of rodenticide

C. Procedure:

Rodent baiting makes use of single dose (acute) poisons and multiple-dose (chronic) poisons mixed with a suitable material or as ready-bait preparation. The use of acute poisons is being restricted because of the hazards of secondary poisoning and the development of bait-shyness among rodents. In the case of chronic poisons, rodents die after a few days of feeding and less possibility of developing bait shyness. Success of poisoning depends largely upon the choice and skillful placing of bait. Baits should be more attractive to rodents than their usual diet and should be stationed in strategic places. Baiting stations may be made of discarded oil cans or fabricated from wood materials.

Initially, only a few bait stations may be used to determine the rate of bait consumption. If baits are found to be consumed regularly and in large amounts, the number of bait stations may be gradually increased until the point of saturation is reached. Pre-baiting for two or three days is usually necessary when using chronic poisons. In pre-baiting, only the bait material is being offered minus the rodenticide. Sustained poisoned baiting then follows for a period of seven to ten days. Each bait station should contain about 100 gms of bait consisting of one part rodenticide for every thirth-five parts of bait material (for Tomorin or Ratoxin brands). Mix the bait thoroughly, considering contaminations with the skin. Place the bait in the stations and replenish as often as maybe necessary. Dispose the dead rats recovered by dumping or burning.

NATIONAL FOOD AUTHORITY

Quezon City

Recommended Pesticides/Fumigants and Their Application

	: RECOMMENDED :PESTICIDE/FUMIGANTS	:FREQUENCY OF :APPLICATION	:DOSAGE :%	:RATE OF :APPLICATION
1. Protective Spraying				
Equipment Used:				
a. Motorized	Malathion 57 EC	Every 2 weeks	1	1 li/40m
Knapsack	Actellic 25 EC	-do-	0.5	-do
(Stihl SG-17)	Coopex 25 WP	Every 3 weeks	0.1	1 li/30
2. Residual Spraying				
Equipment Used:				
a. Compressurized	Gardona 75 WP	Every 3 months	1	li/30m
Power Sprayer		Every 3 months	2	4 li/20m
(marunaka)				
b. Motorized				
Knapsack	Coopex 25 WP	Every 3 months	0.2	1 li/30m
(stihl SG-17)				

3. Thermal Fogging				
Equipment Used:				
a. Fogging Machine	Malathion 95%	As necessary	2	400 ml/500m
(Swing fog,	Nuvan 93% Tech.	As necessary	2	400 ml/500m
Dynafog)	DDVP 93%	As necessary	2	400 ml/500m
4. Ultra low-volume				
Nomthermal Aerosol				
Equipment Used:				
a. ULV Aerosol	Bioresmethrin	As necessary	0.2	150 ml/500m
Generator 0.2%				
(microgen, Leco				
Mini)				
Fumigation	Phostoxin (Exposure	As necessary		Bagged grains:
	as necessary tine is			15-45 tablets
	3 to 5 days)			per 1,000 cu. fit.
				Bulk storage:
				2-5 tablets
				per metric ton
				Space treatment:

				15-20 tablets
				per 1,000 cu. ft.
	Dowfume MC-2 or Methyl	As necessary		Bagged grains:
	Bromide (exposure time			1-4.5 lbs. per
	is 2 to 3 day.)			1,000 cu. ft.
	Detia Gas Ex-B	As necessary		Bagged grains:
				3-5 bags per
				1,000 cu. ft.
				Bulk storage:
				1 bag per 1 to
				3 metric tons
				Space treatment:
				2-3 bags per
				1,000 cu. ft.
6 Rodent Sustained				
Baiting				
(Use of chronic Ratoxin		Monthly	0.029(1:35)	
poisons or anti-Tomorin		Monthly	0.029(1:35)	

coagulant) Ratak	(ready mix)		0.005	

Types of Canisters Used with Respirators Recommended For Respiratory Protection Against Certain Fumigants*

FUMIGANT	DESIGNATION OF CANISTER TYPE	USUAL CONTENTS OF CANISTERS
Acrylonitrile, carbon disulfide		
carbon tetrachloride, ethylene		
chlorobromide, ethylene dibromide,		
ethylene dichloride, methyl	Organic vapors	Activated charcoal
bromide, naphthalene, trichloroethylene.		
(Also any mixture of these with a		
total concentration not exceeding 2%		
by volume in air)		
Chloropicrin, ethylene oxide, phosphine	Organic vapors,	Activated charcoal
(maximum PH3 concentration 0.5 %	acid gases	and soda lime or other
		alkaline granules
Hydrogen cyanide (HCN)**,	Acid gases (a special	Soda lime caustic
Sulfur dioxide	canister is usually	pumice or a sodium

	marketed for NCH)	hydroxide preparation and
		activated charcoal
HCN**, chloropicrin	Organic vapors,	Activated charcoal
	acid gases (a special	and soda lime or other
	canister is usually marketed	alkaline granules.
	for HCN and chloropicrin**	

*** Canisters will not give protection when the total concentration exceeds 2 per cent by volume in air.**
**** Certain fumigants, such as HCN, may be absorbed in toxic amounts through the skin**
***** Chloropicrin is sometimes added in small proportions to HCN and methyl bromide to serve as warning agent.**

SOMD/RRG/JMH/naa

TYPES OF FUMIGATION ENCLOSURE AND FUMIGATION PROCESS USED.

Type of enclosure	**Situation to betreated**	**Fumigant and application process appropriate**
Sealed permanent	Fumigation chambers	Methyl bromide (direct application), Phosphine (as a phosphide), hydrogen cyanide (direct application)
	Large silo bins (greater than 300 tonne capacity)	Methyl bromide (recirculation), phosphine (as phosphide into grain stream, onto surface for squat bins), hydrogen cyanide (as Ca(CN)2 into grain stream).

	Small silo bins (less than 300 tonne capacity)	Phosphine (as phosphide into grain stream, by probe or direct onto surface), methyl bromide (direct application), carbon disulphide (direct application).
	Storage sheds with bulk grain	Phosphine (surface application or by probe), methyl bromide (recirculation).
	Storage sheds empty or with grain.	Phosphine (as phosphide, distributed around store), methyl bromide (distributed by fan), hydrogen cyanide (distributed by fan).
Sealed movable enclosuresa	Road and rail vehicles, freight containers	Methyl bromide (direct application), phosphine (as phosphide, on surface of stow).
	Barges and ships	Methyl bromide (gravity penetration or by recirculation), phosphine (as phosphide, on surface of stow)
Temporary enclosures	Under gasproof sheets	Methyl bromide (direct application, sometimes with fan distribution), phosphine (as phosphide), carbon disulphide and chloropicrin (direct application, small quantities of grain only)
	Spot fumigation	Chloropicrin (inserted by probe), phosphine (as phosphide, by probe)

a Fumigation in transit is subject to strict control and may not be permitted with some fumigants and situations.

Rearing Temperatures, Media and Approximate Times of Development for the Test Species

Insect	Rearing temperature	Rearing medium	Rearing times		
			First emergence (days)	Peak emergence (days)	Progeny removed (days)
Sitophilus oryzae	25C	Wheat	35	36-43 63	
S. zeamais					
Temporary enclosures	Under gasproof sheets	Methyl bromide (direct application, sometimes with fan distribution), phosphine (as phosphide), carbon disulphide and chloropicrin (direct application, small quantities of grain only)			
	Spot fumigation	Chloropicrin (inserted by probe), phosphine (as phosphide, by probe)			

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			emergence (days)	emergence (days)	removed (days)
Sitophilus oryzae	25C	Wheat	35	36-43 63	
S. zeamais	25C	Wheat	35	36-43 63	
S. granarius	25C	Wheat	34	36-43 63	
Rhyzopertha	30C	Wheat + broken wheat			
dominica		(3: 1)	35	36-43 63	
Tribolium	30C	Whole wheat flour + yeast			
castaneum		(12 1)	23	26-30 42	

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Fumigation for the control of insect pests in storage

Contents - Previous - Next

Rolando Tiongson

INTRODUCTION

The earliest use of fumigants dates back to about 1000 years B.C. w were used to disinfect ancient homes. However, it was only in 1854 disulphude and hydrogen cyanide for disinfestation was acknowled; these chemicals gave rise to the modern concept of fumigation. To (one of the most effective control measures against varieties of store

Fumigation is generally defined as a chemical which at a required te pressure, can exist in the gaseous state in sufficient concentration t pest organism. Fumigants may be applied as gas (hydrogen cyamide a solid which will evelve as a gas (aluminum phosphide which evolv phosphide, calcium cyanide which evolves hydrogen cyanide) or liqu dibromide, carbon tetrachloride, ethylene dicholire and carbon disu

Fumigation as a control technique may be described simply as the e athmosphere containing a lethal gas in the environment of an insec high enough and an exposure period long enough to kill the insect.

This briefly discusses some important principles governing the use a fumigants. Properties of some commonly used fumigants are also pı emphasis is given on phosphine, being the fumigant now widely use especially in the developing countries.

CONCENTRATION AND TIME RELATIONSHIP

The effectiveness of fumigation largely depends on the quantity of f an insect from its gaseous environment over a certain period of tim clearly understandable that the dose absorbed by an insect is a fun and time of exposure. As an illustration, 33.2 milligrams per liter of be maintained for 5 hours in order to kill 99 percent of larvae of Teı mauritanicus (c). Monro and Bond 1961). The product 33.2 milligran 166 milligrams per liter per hour is known on the concentration x tiı kill 99 percent of this insect (table 1) It can be abbreviated and refeı product.

If the-dose is a function of concentration and time, it follows that b
time can be varied within a certain limit, provided that the combine
same. Hence, the same effect may be produced by a low concentrat
high concentration for a short time.

FACTORS AFFECTING THE TOXICITY OF FUMIGANTS

1. Temperature

Temperature greatly affects the toxicity of fumigants to insect. At a
15C, stored product insects are not as active as at higher temperatu
absorb less fumigant over a given period of time. Chemical reactivit
of fumigants are also reduced by lowering the temperature. From 1(
concentration of a fumigation required to kill a given stage of an ins
with the rise in temperature.

**Table 1 Required concentration x time (cf) products to obtain 99% r
Tenebroides mauritanicus (Monro, 1969)**

Concentration methyl bromide	Exposure hours	Ct
83	2	16
55.3	3	16
41.5	4	16
33.2	5	16
23.7	7	16
16.6	10	16

2. Adsorption/Desorption

Adsorption is the most important physical factor modifying the pen Physical sorption of the fumigant by the material containing the ins the temperature increases and proportionately highed concentratic needed to kill the insects.

As the temperature is lowered, the amount of gas physically adsorb necessary to add more fumigant in order to sustain concentrations insects. Also, at low temperatures, diffusion of the gas into porous and there is a corresponding decrease in the rate of desorption afte

Chemical reaction of the fumigant with some of the fumigated mate temperature is raised. If the residue formed is significant, it is advisa treatment at as low temperature as permissible.

3. Relative Humidity

Variation in response at certain humidities have been observed not different species subjected to different fumigants, but also betweer species exposed to a single fumigant.

4. Carbon Dioxide

Cotton et al (1939) Jones. (1938) and Bond et al (1978) have demon addition of CO2 to some of the fumigants may increase or accolerat the gas by simulating the respiratory movements and opening of th However, excessive amount may tend to anaesthesize the insects th action of the fumigants.

5. Narcosis

At high concentrations phosphine acts as a narcotic and the toleran increased. In adults of a susceptible strain of T. castaneum a sevent tolerance at the LD99 level occurs when they are exposed to a conc compared with that of 0.5 mg/l. Although narcosis is symptomatic c it does not appear to be the neehanesm to resistance.

TYPES OF FUMIGATION ENCLOSURE

The choice of fumigant and its method of application are largely det situation and type of enclosures in which the treatment is to be un enclosures for grain may be clasified as follows:

1. Sealed fixed enclosures

- **fumigation chambers**
- **silo bins**
- **storage sheds or godown**

2. Sealed movable enclosures

- **road and rail vehicle**
- **barges and ship**
- **freight container**

3. Temporary enclosures

- **under gas proof sheet**
- **spot fumigation**

Table 2 provides an outline of the types of situations where fumiga
and the appropriate process of fumigation.

PROPERTIES OF SOME COMMONLY USED FUMIGANTS AND THEIR M

A. Phospine (PH3).

Phosphine is now probably the most widely used fumigant in the w
reached this position because it has most of the properties desirabl
commercially available in easy-toapply solid formulation.

Properties

Phosphine is a highly toxic colorless gas. It has a boiling point of 87.
weight of 34.04. It is highly flammable and slightly soluble in water.
prolonged exposure is 0.3 ppm in air or 0.4 milligram/cubic meter o
slightly heavier than air (20%)

Mode of Action

Aluminum phosphide is available in a number of different forms inc
blanket and sacket. All contain a mixture of aluminum phosphide a
On contact with water vapour in the air these preparations liberate
phosphine and other gases which act to lower the combustibility of
allow fine grinding of the aluminum phosphide which results in qui
complete decomposition of the preparations. Ammonium carbamat
formulations and liberates ammonia and carbon dioxide which inhi
diluting the hydrogen phosphide formed during subsequent hydrol
ammonia performs the important dual of function acting as warmin
the pungent odour) and once this is noticeable the decomposition
phosphide has already commenced releasing hydrogen phosphide w

increase in the carbide like odour.

Manufacturers of phosphine tablets have claimed that there is a de
hour before phosphine is freely evolved. However, laboratory trials
since the delay period has never been observed. Gas was evolved a
were exposed to humid air and evolution continued in almost linea

Commencement of the process involving the evolution of hydrogen
(phosphine) is accompanied by a change in external appearance of
The shiny gray-green surface turns matte rough and whitish and fin
bloom. Grey white dust appears on the surface, the structure becor
the tablets and pellets increase finally resulting in the pile of grayisl
aluminum oxide hydrate, a constituent of clay) 5 times the original
or pellet. This process takes 3-4 days for complete decomposition o
(although depending on the temperature and humidity once the tal
the athmosphere, decomposition may take 48-72 hours or in the ca
hours).

Most of the gas will be developed between the 4 th and 12th hour.
that 3 gram tablets have a "peak off" or maximum release of phosp
Even during the period of maximum gas release, the tablet remains
generated by the hydrolys is of aluminum phosphide is used in the
unstable carbonate.

Methods of Application

Aluminum phosphide tablets and pellets can be applied directly to
loaded into a sealed silo bin or flat storage either by an automatic
Natural gas movement will then distribute the gas throughout the s
taken to ensure that no tablets or pellets touch each other in order
localized heating, explosion or spontaneous combustion.

In shallow grain bulk, tablets may be probed into the surface at int
purpose may be obtained from the manufacturer's agent. For a sma
simple hollow tube of appropriate internal diameter may be used.
withdrawn tablets may be placed singly at selected depths within t

Alternatively, tablets or pellets can be placed on trays that will facil
residues at the completion of fumigation and ventilation. With this
must be taken to avoid piling of tablets or pellets on the trays, i.e. i
in a single layer. This mode of application is particularly applicable
stacks under sheet covers. Likewise, it is extremely important that t
to be used will provide sufficient gas tightness to ensure maximum
vapours and for safety reasons. Sheeting materials

Ventilation After Completion of Exposure period

There are the minimum ventilation periods for the following structu
commodities.

1. With throughflow and forced drought (flashproof fan) operate
   hours off in period of 12-24 hours, depending on the size of th
2. With throughflow and natural draught (wind) for structure of 3
   capacity for a period of 2-5 days; depending on size, for structu
   tonnes capacity, ventilation period is 5 days.

For well-sealed, plastic covered, bunker storages of not less than 10
ventilation period is 2 hours, after removal of covering.

For Empty Buildings

1. With throughflow and forced draught (flash proof fan) operate
   hours off for a period of 1 to 2 days, depending on the size of s

2. With throughflow and natural draught (wind) for structures of capacity not less than 2 days depending on structure size, oper speed; for structures of less than 300 tonnes capacity ventilati

Withholding Period

Allow a period of 2 days after completion of ventilation before usin commodities for human consumption or for stock feed. Treated con safely transported after completion of the recommended ventilatio

Criteria for Successful Phosphine Fumigation

Bank and Annis (1983) have proposed certain criteria that will resul phosphine fumigation. These are:

1. The grain bulk must be free of live insects at the completion of by conventional sampling methods.
2. The average maximum concentration should not be less than 5 concentration based on the applied dosage and total gas volur
3. The average concentration should remain above the minimum concentration against insects at the end of the exposure perio
4. The ratio of minimum to maximum phosphine concentrations s than 0.25 (1:4) after 25% of the total exposure period has beer remain higher than this level throughout the fumigation.

In most cases unsuccessful fumigation can be atributed to the follo

1. Excessive loss of fumigants
2. Inadequate dosage in localized regions
3. Excessive delay between application and the fumigant reachin in shorter exposure periods than expected

4. **Excessive loss rate combined with slow dispersion**

Safety Precautions

Exposure to phosphine is reported of cause depression of the centr impairment of the respiratory function. Inhalation of phosphine ma following symptoms:

* Nausea	* headache
*Vomiting	*chest pain
*Diarrhea	*abdominal pain
*Shock	*intense thirst

The current Threshold Limit Value for phosphine in the air is 0.3 pp concentration at which, it is believed, men may be repeatedly expo: day, five days per week without adverse effect on the general healt

A full face mask equipped with the correct phosphine-absorbing ca during fumigation. Also, gloves should be worn when the phosphin pellets are handled.

B. METHYL BROMIDE (CH3 Br)

The insecticidal value of methyl bromide was first reported by Le G since been used for the fumigation of a very wide range of commod grains.

Properties

Methyl bromide is a colorless liquid with a boiling point of 3.5C. He

pressure it exist as gas at normal temperature. At a concentration n
fumigation purposes, methyl bromide vapour is odorless. This is the
chloropicrin is added as a lachrymatory warning agent. At high conc
bromide is said to posses a musty or sticky sweet odour. Methyl bro
heavier than air.

Formulations Available and Dosage Rates

Methyl bromide is packaged in cans, cylinders and ampules and is a
material or a mixture containing 2% chloropicrin (CC13 NO2) as a w
normal fumigation purposes cans or cylinders are used which conta
bromide under pressure. Pack sizes range from cans containing 700
kg (220 lbs) cylinders.

For almost all species of stored product insects, a dosage of 200 g/h
can be expected to produce a complete kill at temperatures greater

Under local Philippine conditions, methyl bromide is used for the tr
grains at the rate of 1-4.5 lb per 1000 cu ft.

Methods of Application

Because methyl bromide is heavier then air and due to its vapor de
introduced at the top of the fumigation enclosure via an appropriat
distribution piping and outlet nozzles. In small fumigations, a single
center of the top of the enclosure may be adequate. Methyl bromic
into the fumigation enclosure as a gas or as a liquid.

a) To introduce the fumigant as a gas, the can should be attached t
attachment with the piercing tube uppermost. The liquid will progr
the can and can be expelled into the fumigation enclosure. After th

connected to the fumigation enclosure and attached to the piercing be placed in warm water not exceeding 77 C. This is necessary beca effect vaporization. No attempt should be made to warm cans befo the piping via the piercing attachment.

b) To introduce the fumigant as a liquid, a shallow metal evaporati should be Iorated within the fumigation enclosure under the outlet The pipe should be sufficiently large to hold more than the full liqu addition, the outlet nozzle should be loosely wrapped by towel or l prevent splashing of the liquid, i.e. liquid should be prevented from commodity. With this method the can should be attached to the pi attachment and then inverted so that the liquid is expelled by the v methyl bromide within the can.

Ventilation Requirements

Following fumigation with methyl bromide, structures or commodit thoroughly ventilated. Methyl bromide is more difficult to ventilate than phosphine since it is more strongly sorbed. Desorption from c limiting factor in methyl bromide ventilation not the amount or vel through a commodity. To ventilate methyl bromide it is necessary t throughflow of air and where possible a fan of suitable capacity sh provide force drought.

Safety Precautions

Methyl bromide is highly toxic to all forms of animal and human life to inhale the vapour and to allow the liquid or concentrated vapou with the skin. The effect of a single inhalation depends on the conc period of exposure. The new Threshold Limit Value (TLV) for the me at 5 ppm is 1981 from 20 ppm in 1964, this is the maximum limit th

continuous exposure 8 hr/day at 40 working hr/week., The effect o cumulative. It is important to note that symptoms of poisoning are may take several days to a few weeks or months.

For protection against occasional exposure to low concentrations, u fitted with exhaust value and special methyl bromide filter or canist operator is protected by a gas mask his total exposure to methyl br not exceed 15 minutes per day.

C. HYDROGEN CYANIDE (HCN)

Hydrogen cyanide has been used to control insect in stored grains a generated in practice by the action of moisture on sodium or calciu dispensing of gaseous HCN from a cylinder or by release of HCN abs material HCN was first used extensively in the late 1800's against sc trees in California.

In disinfestation of grains hydrogen cyanide is used in the form of p cylinders or as a liquid absorbed into special cardboard disks. It ma situ from calcium cyanide which produces HCN on contact with wat acid to sodium cyanide.

Monro (1969) recommends a rate of 40/9 tonne with a 24 hour exp cyanide alpplied with recirculation to bulk grain or 160 g/tonne of c applied to the grain stream with a 7 day holding period.

D. CARBON DISULPHIDE

Carbon disulphide is a liquid fumigant. It is sprinkled from a spraye the surface of bagged or bulk grain within an enclosure. The heavy v to percolate through the commodity by gravity. Carbon disulphide i

and explosive when mixed with air. It can be used in combination v liquid, typically carbon tetrachloride to reduce this hazard.

Carbon disulphide should be applied only to small grain bulks (e.g. rates of 75/g/m 3 (60 ml/m3) and 150g/m) should be used at greate 21 C respectively (Willian et al 1980)

E. CHLOROPICRIN

Chloropicrin is a relatively non-volatile liquid fumigant often used i localised infestations. The use of this fumigant is not so reliable anc except under conditions where no other process is available. Chlor probing pieces of rag soaked in the correct dosage of the fumigant i infestation so the the whole infestation region is treated. After app surface above the infestation is sheeted. Where local regulations pe be used to fumigate bag stacks of grain, by sprinkling the liquid ove and then sheeting it.

Chloropicrin applied as spot treatment should be used at a rate of 8 exposure period of 7 days.

F. DICHLORVOS

Dichlorvos is being used as a space fumigant by suspending inpregn the grain in sufficient quantity to produce a vapour concentration l Ephestia cautella. Dichlorvos is also applied as a spray to grain and action is that of a fumigant.

ACKNOWLEDGEMENT

Much of the information contained in this lecture material has beer

compilation on "Insect Pests of Stored Grain and Their control, Vol. and Sealing Requirements" by R. L. Semple and from the Proceeding Development Assistance Course on the Preservation of Stored Cere Champ and E. Highley.

DOSAGE RATES AND EXPOSURE TIMES FOR PHOSPHINE

(according to Degesch, GMBH, Frankfurt, West Germany)

The effective results obtained with any fumigation strategy depend and the exposure time required to reach and maintain a lethal atm extent with Phostoxin and Magtoxin formulations generating phosp exists between concentration and time (Ct product), but the factors time cannot be interchanged at extreme values with the time eleme important than applied dosage.

The dosage of Phostoxin or Magtoxin tablets, pellets, prepacks, plat on;

- **Type of storage (gastightness requirements)**
- **pests to be controlled**
- **prevailing temperature inside the commodity.**

The following tables indicate the manufacturers recommendations dosage:

NO:

- **When applying pellets by using the automatic dispenser, the d third of that applied manually in the grain stream because of t distribution. An automatic dispenser is now available for Phost**

with a hopper capacity of 6 kg (= 2000 tablets) and with a disp maximum of 20 holes, 1150 tons of grain can be treated.

- **Silos made of wood or loosely constructed metal or not very ga consequently even a considerable increase in dosage will not a containers need to be sealed or a polyethylene film can be use envelop the container, which results in a considerable saving i**

For resistant insects such as T. granarium and S. granarius, the high dosage for each storage situation should be used.

For more susceptible insects, such as. Tribolium spp., or any type of dosage should be sufficient.

For mite control, the highest recommended dosage for each respect should be increased by 20%

At temperatures of greater than 25Crespective inside the commodit lower range of the respective storage situation can be used.

STORAGE	TABLETS	PELLETS
Silo, Bins		
1. Welded steel or well constructed	2-5 per ton (60-150 per 1000	4-12 per ton*
concrete bins (sufficiently gaslight)	bushels)	bushels)
2. Bottled steel bins or Butler Bins	3-6 perton (90-180 per 1000	10-30perton*
that are only reasonably gaslight	bushels)	bushels)

Loosely piled grain in warehouses		
1. Under plastic sheets	3-6 per ton (90-180 per 1000	15-30 per ton
	bushels)	bushels)
Packed commodities (in bags)		
1. Under plastic sheets	0.5-1.5 per m (15-45 per	2.5-7.5 per m
	1000 ft) = 0.5-1.5 g.m^{-3}	ft) = 0.5-1.5 g.
2. Tobacco	1 per m maximum; (30	5 per m maxi
(150	per	
	per 1000 ft)	1000 ft)
Space fumigation (floor mills; ware-	0.5-0.75 per m (15-20 per	
houses)	1000 ft)	= 0.5 - 0.75 g.

Table 2. Recommended dosages when using Degesch plates and stri

SITUATION	DOSAGES	
	: Plates	: Strip
Loosely piled grain	1 plate per 35-45 tons	1 strip
Bagged commodities	1 plate per 15-30 m	1 strip
Leaf tobacco in bales cases, hogsheeds	1 plate per 30-60 m	1 strip

Space fumigation	1 plate per 10-15 m	1 strip

Notes on Table 2.

*** Degesch plates and Strips are magnesium phosphide based formu contain ammonium carbamate, and therefore do not liberate amm dioxide (CO2) on the evolution of phosphine upon exposure to atm Fumigation of fruits and vegetables (1 plate per 2040 m or 1 strip pe therefore be carried out without any adverse phytotoxic effects.**

The active ingredients are embedded in an inert, plastic matrix and of a semi-rigid plate covered on both sides with a moisture-permea plate or strip being sealed in gaslight foil pouches.

Once removed from the foil, hydrogen phosphide is evolved after a around 112-1 hour. (unlike tablets and pellets, the plate or strip for dependent on temperature and moisture (RH) for evolution of PH3, OC and 10% RH.

Degesch plates weigh 206 9, are 280 x 170 x 5 mm in size, each tin c plates (3 tins per wooden case), and evolve 33 9 of PH3 per plate.

Degesch strips weigh approximately 3.2 kg, are 4,480 x 170 x 5 mm i of 16 plates, come sealed in tins (2 strips per tin, 3 tins per wooden 9 of PH3 per strip.

The advantages of plates and strips when compared to tablets and

- **easy and quick application to large volumes**
- **simple collection after fumigation**
- **conveniently disposable and no contamination**

- conveniently disposable and no contamination of treated comı

EXPOSURE PERIODS:

The required exposure time for an effective fumigation using phosp formulations is dependent on;

- **temperature inside the commodity**
- **humidity**
- **types of commodity being treated**
- **pest species to be controlled**

The determining factor in each case is the MINIMUM COMMODITY

Under no circumstances should the recommended minimum exposı reduced, and under normal operating conditions, extended exposuı prescribed in Table 3, is considered advantageous in achieving more phosphine-generating formulations.

Very dry grain or densely packed commodities (such as tobacco in c requires longer exposures. For the control of Sitophilus spp., exposı extended to 10-14 days, while for mite infested grain, the grain sho be left under gas for up to 10 days.

The following table gives approximate guidelines for the necessary commodity disinfestation.

Table 3

Notes on Table 3:

A

- **Phostoxin tablets, round tables and pellets are composed of 5(phosphide; 26% ammonium carbamate (approx); 3% edible pa (18%) inert materials. The release of ammonia in the proprieta phytotoxin.**
- **Decomposition of tablets and pellets in air leaves approximate AIP residues in dust (calculated as PH3). Maximum concentrati after 48-72 hours with tablets, and 12-48 hours with pellets (b surface area).**
- **At 60% RH and 20C, AIP containing products have released onl content in 24 hours.**

B:

- **Magtoxin tablets, round tablets and pellets are similar in comp phytotoxic) except that aluminium is replaced by magnesium ii formulation.**
- **Decomposition is almost complete (99.9%) and therefore only (0.1 %) remains in the dust residue.**
- **In both cases, the trace amounts of PH3 decomposes almost co grain is moved. For grain and similar products, there is an estal 0.1 ml.m^{-3} (0.1 ppm) expressed as PH3, by the FAD/WHO Code Committee.**
- **At 60% RH, 20C, almost 75% of the total PH3 content of Magto been released in 24 hours. The maximum concentrations of PH hours, therefore exposure times can be reduced. Under best ga depending on the pests to be controlled, the application can b minimum of 2 days.**

C:

- **Round tablets, because of their spheroid shape, have an extre that of Phostoxin and Magtoxin pellets (crumbling and dusting reduced to 0.3% minimum). This allows packaging in resealabl sizes of 100 tablets (300 g. nett) and 500 tablets (1500 g. nett) f tablets (210 g. nett) and 350 tablets (1050 g. nett) for Magtoxin**

D:

- **Degesch Plates and Strips do not contain ammonium carbonat safe to use on fruits and vegetables.**
- **The release of PH3 is less dependent on temperature and relat Phostoxin and Magtoxin formulations.**
- **Maximum gas readings are normally achieved within the first 2 minimum exposure periods can be significantly reduced, if dee**

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Code of practice for storage and fumigation of bagged gr

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by Vern Watter

Proper storage practices permit good fumigation and help maintain that prolongs the time between fumigations. They help pin-point th infestation and try to eliminate sources of insect breeding.

Proper sanitation requires proper placement of stacks so that swee pesticide treatment can take place. The following should be observ

- **Stacks should be no more than 6 meters high**
- **Minimum gap between stacks and wall or columns should be 1**
- **Minimum gap between stacks for gang ways should be 2 meter**

Before bags are stored in any area, it should be cleaned of all debri sweepings should be fumigated or immediately destroyed to avoid infestation. Floor cracks should be filled with cement or hard filler. with a good residual pesticide to discourage insect migration for sto dry before any material is placed in the area.

Walls should be checked for holes or cracks that could retain old gr and old grain should be brushed clean and all holes and cracks shou cement. Wall spraying with residual pesticides, of or appropriate ty could be considered when practical to do so.

Overhead areas should be cleaned of dust and moth webbing and s insecticides.

Storage should be segregated:
Old and new stock
Good and bad stock
Different moisture levels
Different grains or varieties

Incoming grain should be checked for insect infestation and treated programme of inspection maintenance and sanitation should be im

Sanitation requirements for stored bagged grain.

All grain should be inspected on arrival and fumigated if infested.

Insects will live in spilled grain next to bags and along walls. This mu and fumigated or destroyed.

Insects can live in grain dust on ledges and ceiling beams. These mu enough to discourage this infestation.

Tailings and siftings from equipment will contain many live insects. fumigated or destroyed each day.

Weekly inspections should be made to locate possible infestations longer in good condition.

Where market demands permit, the oldest stock should always be

Applications of residual insecticides should be made to the walls ar ares at least once per month.

If the storage area can be sealed enough for effective treatment, sp Dichlorovos should be made twice per month.

All used bags should be fumigated before reuse.

All cleaning and bagging equipment should be fumigated once per

Stock that can no longer be sold at regular prices and is more of an a value, should be disposed of at the least possible loss. Destructio profitable than keeping the material and increasing treatment costs

Broken bags should be repaired and spills cleaned up as soon as fo

A rodent trapping or poisoning program should be maintained whe problem.

Bird infestation in the godowns should be discouraged through use doorways and other mechnaical deterrents.

Floor drains should be kept clean and treated to discourage cockroa can affect the odor and flavor of rice.

Code of Practice for Fumigation techniques

1. Preparation of area to be fumigated.

Check to be sure there is enough room on all sides and at the top t close to walls or posts, the fumigation should not be attempted un and effectively.

Have the area around the stack swept clean so that a good floor se

Measure the length width and height of the stack and calculate the fumigated.

Inspect to determine the type of insects causing infestation.

Calculate the dosage based on volume and species to be controlled

Consider potential reinfestation and include nearby stacks in fumig

Consider safety of potentially exposed workers. Will there be other during the fumigation? Can the fumigation be done at another time

cross ventilation to provide a level of safety? Is gas monitoring equi workers must be nearby? All safety feretions should be very safety t workers reservation.

Choose the proper fumigants.

Choose Methyl bromide if:

Less than 4 days are available

There is a heavy infestation of grain mites

Nearby electrical equipment could be damaged

Odor of chloropicrin is needed for safety reasons.

The price is advantageous

Choose Phosphine if:

Four or more days are available

Deep penetration is needed

Product may have high level of bromine from previous fumigations.

Damage to germination is a concern

The price is advantageous

Be sure that all needess equipment is on hand for sealing closing, le safety equipment, ventilation

2. Equipment needed for fumigation of bagged grain.

Measuring tape to determine volume
Broom to clean floor
Ladder if stack is hard to climb
Polymer vinyl sheets or other gas proof sheets
Mending tape for sheets
Warning signs
Respirators
Leak detectors
Instruments to measure concentration
Gloves if required
Adequate amount of fumigant
Label and labelling for fumigant or other instructions.
Clamps for rolled joints
Sandsnakes
Thermometer
Trays if phosphine is used
Scales if methyl bromide is used Fans if methyl bromide is used
Hoses if methyl bromide is used.

3. Proper placement of gas-proof sheets (tarps)

Most gas-proof sheets can be easily torn and must be handled with

The first step is to prefold the sheets so that they can be unrolled o
Many fumigators prefer to lay the sheet flat in a large open area an
each side of the short direction of the sheet. Working together, the
the sheet about 1/4 of the way from the middle and bring it to the
sections are folded on top in accordian style until there is a stack o

midpoint. The two sides are folded on top of each other and then c area that is now about 1/2 meter1 meter wide is pulled on top for a 2/3 of the lenghth of the lower section. The sheet is then rolled tigh folded end to the open ends so that air will be worked out. This tig then easy to transport and to lift on top of stacks.

The rolled sheet is placed on top of the stack and unrolled along th the stack. The end of the folded sheet is pulled down so that is tou overlaps by at least 1.0 m. One side is then, pulled down until it toc overlaps by 1 m. If this sheet is even on the floor it will facilitate oth can then be used to anchor this area.

Next, pull the other edge down until it too touches the floor with a is surplus sheet, it is better to gather it on the top in folds and hold snakes. Surplus sheet on the floor makes sealing more difficult.

The corners are the hardest part to seal correctly since if they are n will be too many folds on the floor and gas may leak. The corner is triangle of material. Some try to roll this triangle and this has advar there are strong winds. However inside, the rolled corners will alwa the floor.

The best way is to anchor one edge of the corner with a sand snake surplus back along the other edge with an inside fold. This can be a snake and the sheet will then fold back down with two folded corn the corner. Along the floor there will be only large smooth sections with the sand snakes.

The major leaking point will be at the floor level snakes. The sand s pieced in a double row so that the second row will overlap the join snakes in the first row. At the corners, sand snakes should go arour

than meet at the corner.

Floor level leakage also occurs when there is a floor joint, a crack, o
areas should be avoided when preparing for a fumigation but the p
partially Overcome by taping over these openings.

If a single gas proof sheet will not cover the stack, it will be necessa
sheets together. Just overlapping the sheets will not retain the gas
sheets can be joined together and be reasonably gas tight by taking
edge of each sheet and rolling the two together into a tight seam. T
clamped with steel spring clamps every 1 meter or less. The rolled j
for sealing at the bottom. The seam should be flattened and extra s
get a better seal.

This is still not a strong seam. If it was placed horizontally the weig
pull the seam apart after a few hours. The seams must run verticall
top of the stack and weighted with sand snakes so that there is no

If "Hanging seam" must be used such as when tall buildings are cov
procedure is used. The two sheet edges are placed between two lo
combination is then rolled together several times and retained with
meters.

If two sheets are not enough and only a small amount of additional
should be placed in the middle. It is important of fold the middle sh
combined sheets fit evenly and tightly. Lay the middle sheet on the
half. If the gap to be filled is 4 meters plus a meter on each side to
meter sheet. Roll the folded side of the sheet until within 3 meters
open up to be a 6 meter wide sheet with a false seam down the ce
false seam and then place the middle sheet in place and join with t

Clamps on rolled joints help prevent leakage Of gas during fumigati

Many sheets

When many sheets are joined together, there could be a problem w seams meet at a horizontal seam. The seams must be staggered as s illustration to avoid this.

4. SUGGESTED DOSASE PER BAGGED GRAIN UNDER GAS PROOF SHE

Phoshine

4 Days 5g/ton

5g/ton = 5g/1.6 m Maize = 3.125 g/m
5g/ton = 5g/1.9 m Paddy = 2.631 g/m
7 Days 2g/tonne
2g/ton = 29/1.6 m maize = 1.25g/m = 35.49/1000 cu. ft. maize
2g/ton = 2g/1.9 m paddy = 1.05 g/m

Methyl bromide

24 Hours
9 lbs/100 ton = 28.8g/m = 1.81b/1000cu. = 28.8 oz/1000 cu. ft.
9 lbs/100 ton = 9 lb/5000 cu. ft. = 1.8 lb/100 cu. ft. = 140 OZ/62.5 m

Conversion factors

g/m phosphine x 658.8 = ppm
ppm3 10,000 = % by volume in air
g/m methyl bromide x 235.9 = ppm

oz/1000 cu.ft. = g/m = mg/liter (approximately)
Ib/1000 U9 bu x 12.87 = g/m
1 g/m phosphine = 659 ppm3 = 28.59/1000
cu. ft. 339/1165. n = .0077 m/sec
1 ft/hr = 28 m/hr = .47m/min = .0077 m/sec
1 picul = 60 kg
1 quintal = 100 kg
2.5 rai = 1 acre

4.1 Fumigation application - Phosphine

After the cubic content and/or the weight of the material to be fum the chart will give the rate in grams per unit. Various forms of phos different amount of gas;

1 tablet = 1 gram
5 pellets = 1 gram 33 9 bags = 11 grams
1 mg PH3 Plate = 33 grams

The success of the fumigation depends on maintaining a sufficient c long enough periode of time. Aluminum phosphide releases gas slo phosphide and bags of aluminum phosphide release gas slower tha release gas slower than pellets. Proper phosphine fumigations are f days. It may be advantageous to use a combination of slow and fas or, if it can be done safely, to add part of the dosage after two days the period of moderate concentration.

When tablets or pellets are used in fumigation of bagged grain, the container so that the final dust can be disposed of safely. The conta enough so that tablets are not piled on top of each other. Piled tab sealing themselves so that the concentration in the center of the st

point of combustion. When spread out in a container this is not a p

Bags can be hung in a series on the side of a stack to help distrubut shou never be used touching each other.

Plates should be left standing on end on the floor with both sides c against the stack of bags or the pallets.

Gloves should be worn even though phosphine cannot be sorbed tl will be small amount of extremely toxic phosphis on the hands whi edwhen eating or smoking after the fumigation if hand washing is r

Even though phosphine formulations are not supposed to normally amount of gas in the first hour, it is safer to cover the stack complet phosphine produce materials are opened and applied. Release dep moisture, and formulations. Magnesium phosphide formulations ha give of over 20 ppm in less than 30 minutes in mill fumigations. The suggests respiratory protection for any concentration over .1 ppm.

Respiratory protection should either be worn or readily available ar order depending on the like hood of its need.

After the gas releasing raterial has been put in place and gas-proof warning signs should be placed on all sides of the area where some final check for leaks should then be made.

The following description of termination of the phosphine fumigati sheets are required for another fumigation. If they are not required thoroughly dry, the sheets may be left in position. If the stack has b 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 the concentration is unsafe. If more than 0.1 ppm, send unprotecte area

4. Remove the sand snakes, raise the corner of the sheets, the rolle 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 simila

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 overninght, re residues and dispose of them in the recommended manner (Set "Di Formulation")

10. Check tife success of the fumigation

11. Remove the warning notices.

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

Disposal of spent formulation

Residues of pellets or tablets may be scattered on waste ground if a otherwise, they should be stirred into buckets containing warm wa 6Og of detergent in 10-25) of water. When no further bubbles can b the buckets should be emptied on waste ground. Containers shoul liquid and then buried. Bags of aluminium phosphide should be bu should be worn or care taken not to inhale the fumes during dispo tablets, pellets and bags must not be heaped together, otherwise t explosion.

4.2 Methyl bromide fumigateer

Over the stack with sheets, join up, fold the corners and place the s position.

Cheek sheeting, sand snakes and repair sheets with plastic tape if n

Inert hose throgh tarp into expansion chamber.

Make final thorough check of the area around for possible hazards.

Send away all onlookers from the fumigation area.

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

Record the weight of the cylinder. Or select the proper number of c

Open the cylinder valve and check for any leaks. Introduce a small c bromide, about 10 percent of the full dose, by opening the side valv

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

Re-open the side valve and introduce the methyl bromide until the the full dose has been given. Or add remaining cans of methyl brom

5. Code of Practice on the Fumigation Techniques for Containers

The success of fumigations depends on many small details being do the fumigator, other possibly exposed persons and cargo need to b

It is not enough to put the correct dosage into a container and shut does not reach the insects in all parts of the container, they will not to reach the insects either through leakage or through poor circulat methyl bromide.

5.1 Examine the container carefully for any possible leaks around d These must be sealed before the fumigantion is complete.

5.2 Check the commodity and note whether suggested fumigant is a example methyl bromide will not penetrate plastic bags. Chloropicr processed food going to the United States. Phosphine should not b vegetables like potatoes. Phosphine could also hurt copper, gold or not likely to be in a container that needed to be fumigated. If the g shipper should be contacted.

5.3 If methyl bromide is to be used, the tube should be taped to th the container so that the gas will be discharged into the open space will mix with the air before filtering down through the cargo. The h through a corner of a door and the door carefully closed without n hose.

5.4 Check the listed size of the container. Normally the cu. cap. is th figure since the entire space will be fumigated regardless of how ful

5.5 Calculate the dosage from the cubic capacity a volume, the net v or from a chart considering both items. Put the required amount of container.

5.6 Several forms of phosphine can be used. Grain that has not bee bulk maize could be probed wish tablets. Rice in bulk or in bags cou Phostoxin prepac, Detia Bags FumiCel plates or similar brands. Plate dropped into processed foods such as polished rice since the plates during release. They can be put in cotton bags and suspended from never be placed between bags or stacked on top of each other as a

5.7 Methyl bromide is often used froms 1 1/2 lb cans instead of cyli small dose. If the gas is released into the head space it will probably fumigator can be injured utilizing these small containers. There is so puncture point any time that the can is used. The leaks are worse if is punctured or if the gasket is old. Proper precautions are needed.

- **Do not wear gloves, rings, or bandages on the hands**
- **Protect the eyes with at least goggles.**
- **Puncture can quickly but carefully being sure to miss any seam**
- **Change the ruber gasket regularly.**
- **Set the can down and stand back while it is discharging to avoi**
- **Pick can up for last discharge and hold away from body. Keep i to release last amount.**
- **Take clamp off the can when all gas seems to be discharged bu there is probably a little bit left and can may "spit" Place empt fumigation is done. Do not step on it as this could force gas ou**
- **Proceed with next can or if this is the last, pull tube out throug carefully and drain the hose by holding it up. Many injurys occu the small amount of gas left in the hose being flipped onto sor**

- **If methyl bromide gets on shoes or clothing, remove them imm possible embarassment and do not put clothes back on till the An extra set of clothes should be carried in the truck. Shoes ma aeration.**
- **Fumigant cans and packages should be aerated thoroughly anc waste containers. They should not be carried inside the truck u aerated.**
- **Warning signs should be placed at least on two sides to warn t fumigated containers below the deck.**
- **Racks should be built on the roof or the sides of the truck for h used for fumigation. They should not be carried inside a closed**
- **Check seal around entire container with leak detector and seal leaving**
- **Record work and gas used.**

6. Code of Practice on the Fumigation Techniques of river Barges

6.1 Phosphine tablets.

Phosphine has the best chance of giving a good kill of all insects in l at least 4 days and a very good seal to maintain a lethal concentrati exposures may be necessary for resistant or tolerant species, or life

Ideally the phosphine producing tablets should be added as the gra barge if mechanical equipment is available so that the barge can be hours. In most cases tablets will have to be probed into the grain m loaded.

If a four day exposure is contemplated, a dosage of 5 9. per tonne is expensive fumigant can be reduced to only 3 9. per tonne if a 7 day

For a four day exposure, it is best to probe the tablets to 3/4 of the Longer exposures can permit shorter probes which can be done wit

In a typical barge a minimum of 30 places would need to be probed would be used per probe but these should added a few each time t a few feet. Proper sealing is very important.

Any openings from the hold to the rope locker or other areas shoul the hold side before loading and on the other side to minimize the

No one should be on the barge during the fumigation except possib concentration readings.

After the fumigation, the tarps can be pulled back and the area sho from people until the concentration is below 13 ppm.

6. FumiCel and Fumistrips

The FumiCel and FumiStrip formulations of magnesium phosphide a way of applying phosphine gas. These like the magnesium phoshide gas faster than the older aluminum phosphide tablets but the kill m quicker. Some insects must be exposed to the gas for a period of tir least one growth stage or molt before they succumb to the gas.

The FumiStrips can be used more effectively if they are fastened to rods so that they will be suspended in the air space instead of just l surface. They must never be used where two plates are touching ea

The FumiCel plates release 33 g. of phosphine gas and the strips rel phosphine gas. A combination of the two can permit right dosage a tonne is suggested for a four day exposure. The manufacturer sugge

fumigation with the barge at anchor during this time.

As with any fumigantion, the quality of seal is very important. The t Thailand can, according to our tests, hold phosphine very well if the adequately patched. It is important for the fumigator to carefully ex and patch any obvious holes and it is important that they also mon they can spot small hard to see holes or tears.

Compartment doors from the hold are best sealed with a section of the doorway. The door can then be shut on the sheet and the edge bulkhead. It can also be taped directly to the bulkhead over the do would be too many wrinkles in the tarp which could allow gas to es

Warning signs must be posted at all potential entrance points to th should be on the barge during fumigantion unless readings show th than 0.3 ppm.

Aeration with the tarps off should continue until gas readings are b the bottom of the hold and in the rope locker and other areas whe On warm windy days this should occur within a few hours but meas safest way of knowing that the area is safe.

7. SHIP FUMIGATIONS

Fumigations are done either at anchor or innecessary because of pr poorly cleaned hold but is needed more often due to infestation in loaded.

Fumigations are done either at anchor or intransit. The high cost of ships are held at anchor makes the in-transit fumigantion attractive problems

**Small leaks of gas can contaminate crews quarters, paint lockers an
have resulted in some deaths. Intransit fumigation should only be c
person has examined the ship and certified that a fumigation can b
risk. A trained person then must accompany the ship and take gas r
the fumigation so that any leakage will be discovered and appropri
taken.**

**Fumigation of bulk grain is very difficult because it is difficult to get
the gas. It is almost impossible to get good penetration of bulk grai
and penetration with phosphine can take from 7-14 days dependin
hold. In some tests conducted by USDA, adequate gas penetration v
the bottom of the hold unless ducts were installed prior to loading.**

**Fumigation in-transit is a valuable technique since there is no later
reinfestation.**

7.1 Methyl bromide.

**Although methyl bromide does not have the penetraling and dispe
phosphine, it can kill insects in 24 hours if the gas reaches all areas.**

**Obviously the problem with methly bromide is due to the fact that
weight of air and moves very slowly if there are no fans to circulate**

**If the gas is released at only one point at the center of the barge as
will probably be failure to kill all of the insects. If the gas is release
many different points, it will slowly drift down through the carge a
distribution. Fans are still advised for recirculation of methyl bromi
we believe this technique will work, research is needed to establish
and other details.**

T. confusum	30C	Whole wheat flour + yeast			**On some ship fumigations, methyl bromide is dispersed through tul notches cut along the length. Unfortunately most of the gas will be openings and only a little gas will come out of the last openings.'** **A "H" configuration as shown below can solve this problem. The ma a 3 meter section of hose with a brass "T". Then perforated hoses a center with more brass "T" s. About four of these harnesses would average barge and if they are made from a good quality plastic, the times. This would require releasing the gas into four hoses at four p one spot but this would not take much longer. The dispersion of th improved if the harness is supported above the bags by fastening it ribs of the barge.** **The use of a fan under the tarp for at least one hour after the intro greatly increase the dispersion of the gas.** **It is inexpensive to check for gas leaks of methyl bromide with a hal this should be done on each treatment so that additional sealing ca** **Since there can still be small undiscovered leaks, no one should be the fumigation unless equiped with a gas mask. Signs should be pla persons to stay away during the fumigation period.** **After 24 hours, the tarps can be removed and aeration can start but in lower areas and these areas should be checked before workers e** **Figure** **7.2 Ship fumigation while evacuated by personnel and crew.** **If there is a possibility that gas can leak from the holds to an occupi**

occupied area, fumigations should only be done after the crew and
left the ship. The only persons remaining on the ship should be fum
are equipped with respiratory protection and gas measurment devi

Before the gas is introduced, the fumigator in charge should plan h
aerated to a safe level. This may mean placing fans in some areas if
or can be made available with protable generators.

If two days or less are available, only methyl bromide should be use
could not give an adequate kill in a short time.

Bulk grain cannot be adequately fumigated with methyl bromide ur
are inserted deep into the grain in many areas to aid to distributior
procedure that should only be attempted by trained personner wea
respiratory protection equipment. Bulk grain should normally only
phosphine and with an exposure time of at least 4 days.

Bagged grain can be easily fumigated with methyl bromide if a serie
used such as the "H" harness discussed in the barge fumigation sec
still dependent on air circulation to in sure the gas stays evenly dis
readly evacuated. Fans must be used for at least one hour after gas
mean gaining power through a portable generator.

After the gas been released at many points and the fans have run f
the fans can be shut off and the seal can be checked for leaks. All le
by persons wearing respiratory equipment. Exposure time should b
After the exposure time is achieved, it is helpful if a new gas readin
excessive leakage has occured. Tarps can be pulled back and aerati
near the bottom of the hold during loading can be started and will
time. Aeration is complete when the gas concentration in all areas i
methyl bromide or .3 ppm with phosphine.

7.3 Ship Fumigatiom-Bulk grain treated with Phosphine.

The only practical fumigant to penetrate large amounts of bulk grai do an excellent job if the gas penetrates to all areas in sufficient co Penertration is obtained through long exposures or through placing throughout the grain mass with probes.

Although many factors can influence the time required for phosphi throughout a hold, some rough guidelines are:

Barges - Allow at least 4 days
Small freighters - Allow at least 7 days
Large ships - Allow 14 days and use ducts if possible

The large amount of phosphine required (58./tonne) should never j of the grain. Particularly if the grain was loaded during wet weathe gas into the head space can be much faster than its penetration int standard dosage could give over 1000 ppm if the gas was evenly dis not be dangerous. However, a fast release could cause gas readings over 17,900 ppm which could a fire or explosion. If the tablets are e grain mass, there should not be a problem.

For even distribution by probing, try to probe once per square mete possible, about 2-3 meters. Apply 4-5 tablets per meter is recomme practical under ship fumigation procedures. The purpose of placing each time the probe is withdrawn a little is not only to disperse the distribution but also to seperate the tablets to avoid high concentr tablets should be at least 30 cm. under the surface of the grain.

After the probing, the hatch cover should be replaced and covered. used can provide a reasonably good seal if they are in good conditi

additional sealing will be necessary. A trained person with gas mea: respiratory equipment must accompany the ship and the Captain m take whatever precaution is necessary to protect the health of peo|

Monitoring of the gas level should include areas adjacent to the hol occupied or rarely occupied area and be dangerous.

7.4 Safety practice in intrainsit ship fumigation

The first step in any intransit ship fumigation is to examine the ship designated ships officer to establish if the ship's holds can be safely

The holds should be examined for obvious points of leakage but un must be considered. There may be cross connections from the bilge or other areas. Gas has been known to follow this path.

Smoke detectors draw air from the hold to a sampling point at the This could bring gas from the hold to the bridge and at least one fat occured from this. It may not be safe to discontinue the use of the s additional safeguards would be indicated.

Some crews like radios in their quarters and will rig elaborate anter known to drill through a common wall between a hold and their qu the antenna wire to a distant point. This can permit gas leakage int

Doorways to the crews quarters are often left open even when they fumigated hold. Again leakage can occur.

Other areas are occasionally occupied by the crew and have been k concentrations. Paint lockers and rope lockers may have hatches to fumigated. We measured a very high concentration due to this on o

Crews will sometimes sit on the hatch covers or sleep on the hatch overcome by very small amounts of gas leakage.

All holds have vents and even though these may be well sealed at t seals may deteriorate later.

A trained person must be on board the ship to measure the concen unusual problems. He may be a ships officer or may be part of the f key thing is sufficient training and equipment.

8. Flat Grain Storage Fumigations

Flat grain storage structures can be built quickly and at a low cost p they have several problems. Even with aeration ducts and the fans difficult to maintain uniform moisture in the grain.

Fumigation is even more difficult and most fumigators will agree th difficult type of fumigation to achieve 100% control. This is due to t amount of surface compared to the total amount of grain. The cont fumigations where there is only a limited surface at the top compar mass. It is the large surface area where the gas is lost on most fumi gas loss through the metal walls as the gas can leak between the co they overlap.

The problem is compounded by poor storage practice. The grain is r covering it with a tarp is difficult.

There apparently has been a tendecy in the past to take some shor procedures. The grain wasn't leveled first and the tablets were "wa probed deeply into the grain. The grain was probably not covered w gas within the grain mass. Some tablets were placed within the aer

fans were run for for about 15 min. Unfortunately all of these pract could even be dangerous or could contribute to resistant insects.

The natural air currents in the grain would probably be up-ward so gas would go below the point of application. It is very easy for the g the roof vents and at the roof wall juncture.

The fans would have very little effect on the phosphine in the first 1 would not reach its peak of release for 24-48 hours and the release

Flat grain fumigations are done in many countries and can be reaso there is no substiture for the hard work it takes to do a good job.

8.1 Flat Grain Fumigation Techniques

The fumigation should be started by preparing the grain and the str fumigation.

Two crews of workers should be selected. One will be the applicato spread a plastic sheet over the grain and tuck it in at the edges and successive sheets.

There should be enough people on the application crew so that the the width of the grain and have no more than a meter between eac applicators can then move across the grain probing phosphine into This will give good horizontal coverage even if the tablets are probe meters deep.

The other crew will follow the applicators spreading out the plastic overlapping and pinning with bamboo pegs. The two crews should enough to move through the area before appreciable gas has been

measurements are still adviseable.

After the tablets have been probed and the grain covered, gas loss (by sealing any roof vents with plastic bags and sealing doors and wi sheets or tape at the joints.

At least 7 days exposure should be used but the plastic should be r weeks or sooner if the grain has a high moisture content. Sweating otherwise.

The people removing the plastic should be protected with gas mask is above .3 ppm. The gas level can often be reduced below this at th fumigation by merely leaving the doors and vents open for a day be removal.

9. TRAINING NEEDS:

Basic training

Groups to receive training
Subjects to be covered with each group and why
Suggested training techniques
Training materials available
How to prepare additional training material

Subjects to Study

Economic loss due to insects and molds
Important Insect species
Insect control through Integrated Pest Management
Non-chemical controls

Pesticides

- **Principles of Fumigation**
- **Fumigants available in Thailand**
- **Sealing techniques for fumigation**
- **Monitoring techniques Respiratory protection**
- **Insect resistance problems**
- **Use of residual pesticides and grain protectants**
- **Safety in use of pesticides**

Vertebrate pests and their control
Mycotoxins and their control
Warehouse practices and Sanitation
Government regulations

9.1 Training - Fumigation Detail

Commercial Pest Control Operators

Present Problems

Commodity pricing can cause fumigators to take some short cuts an can be eliminated.

The gas-proof sheets are patched many times before they are repla cracks is narrow 2" rather than 3". Insufficient time is spent in prop the floor to get the best possible seal.

At least on export grain fumigations, an officer of the Dept. of Agr. r so that the correct amount will be applied. We can only speculate c fumigations. The accent seems to be on the dosage rather than the

throughout the exposure. Fumigators do not return every few hour

Leak detectors are not used even though this would not add substa Small leaks in the seal are probably often missed.

Fumigators sometimes do not have access to the many training mee many other countries. Training is often in-house and may not be su

Most books and periodicals on fumigation are written in languages language. This makes home study impossible for many fumigators.

Most pesticides, equipment and safety materials must be imported Instructions will usually be in English and require explanation by in

Exporters and others often specify the type of fumigant to use. The the limitations or safety problems of that choice.

Godown managers do not realize the importance of storage practic sealing impossible.

Ships and barges are often in poor condition making safe and effect time consuming and generally difficult.

Minimum standards for various types of fumigation should be print Plant Quarantine should refuse to issue certificates for fumigations officers to be possibly dangerous or ineffective.

Training sessions should be held in the local language.

Godown personnel should be trained to store properly

Exporters should be informed about the limitations of each fumigar

Equipment should be developed that would permit recirculation of barges or similar areas.

Leak detectors should be used on all fumigations and enforcement a government officer is required to witness a fumigation.

Establish an import requirement that all pesticides, equipment and be accompanied by adequate instructions in the local language.

Give government officers the right and duty to disapprove vessels tl might create a safety hazard for in-transit fumigation.

Stress to exporters and other purchasers of fumigation the high cos port of arrival compared with a modest increase in fumigation cost acording to new standards.

Encourage fumigators to sell additional services with the fumigatior space treatments, and even inspection services can be cost effective

Set up a certification program for fumigation supervisors with writt recertification by exam or attendance at training sessions.

Restrict sale of dangerous fumigants to persons that have passed th

Sponsor attendance by key Dept of Agr. Officers at fumigation train countries.

Key subjects for commercial fumigators

Principles of fumigation. Gas movement, sorption, desorption, and

Principal fumigants and their advantages and limitations.

Safety in the use of fumigants

Respiratory equipment with practice in using each.

Gas leak devices with practical use on the job site or laboratory.

Gas monitoring equipment. Care and use. Calibration.

Techniques in fumigation under gas-proof sheets.

Techniques of container fumigation.

Techniques of barge fumigation with methyl bromide and with pho

Techniques of ship fumigation in-transit or at anchor.

Use of fans to improve circulation of gas.

Information needed to pass written exams for fumigation superviso

Laws concerning fumigation in Thailand and Maritime regulations.

First Aid instructions for fumigant injuries.

How to handle fumigation requests that would be ineffective or da

Business aspects of fumigation including cost accounting.

Dosage calculation based on temperature, commodity, fumigant, ti
How to vary dosage and still obtain correct time/concentration.

Time/Concentration calculations in fumigation.

Fumigation techniques for flat grain storage.

Fumigation of perishable fruits, vegetables, and flowers.

Insect resistance and why past techniques won't work in the future

Suggested Training Techniques

Lectures with slide series

Integrated pest management for stored grain

Inspection techniques

Principles of fumigation

Bagged grain fumigation

Barge fumigation

Shipping container fumigation

Rodents and their control

Demonstrations

Techniques of tarp fumigation

Dosage calculations and concentration importance

Choosing the proper fumigant

Preparing the stack for methyl bromide

Sealing techniques and leak detection

Safety and respiratory equipment

Proper storage practices

Observation of sanitation

Sources of reinfestation

Other pests and inspection techniques

Dosage vs Concentration

Importance of expansion chamber for methyl bromide

Importance of a good seal

Concentration time graphs and charts

CT factors for 100% kill of Sitophilus species chart

Monitoring tests of typical fumigations

How to use the fumiscope

How to use the leak detector

How to put on gas mask and check. its function

Calculations important in fumigation

9.2 Training - Fumigation Detail

Warehouse - Godown - Bag Storage

Present Problems

Many facilities have serious insect problems particularly in old stocl grain residue in used bags, equipment, holes in the walls and other

Residual pesticides are often rarely used and fumigation is used pri sale. Loss in the meantime is probably close to 1% per month by we serious losses in quality occur.

Fumigations occasionally of only a few stacks of bags is probably w reinfestation sometimes occurs even before the gas-proof sheet is r

Fumigations are often done by either the godown personnel or eve fumigators with a less than effective floor seal. This translates into fumigation.

Removal of infested floor sweepings is offer not done to eliminate t of reinfestation even though floor sweepers are employed. Educati step can improve grain quality at a very low cost by limiting reinfest grain.

Training subjects for Godown and Warehouse Personnel

Importance of proper storage practices in fumigation and insect cor

Importance of sanitation in insect control to avoid reinfestation.

Inspection, isolation, and treatment of arriving grain.

Importance of an Integrated Pest Management program.

How to obtain initial control in an infested warehouse.

Fumigation specifications that will permit informed bidding.

Techniques of do-it-yourself fumigation.

Safety considerations in fumigations under gasproof sheets.

Residual insect control applications that can be profitable.

Space treatments - when and how they can be done profitably.

Use of gas leak detectors and monitoring equipment.

Advantages and limitations of various fumigation sites. Godown, ba

Warehouse inspection techniques and their value. Economic advant with much reduced insect infestation.

10. PROPOSED FIELD TESTS OF FUMIGATION PRACTICES

Determine efficacy of present barge fumigations with monitoring lir hours on a Fumiscope or other device. Test insects will help evaluat there will probably be a good natural infestation. This test could th making minor changes such as using pallets on the bottom and a hi chamber on with multiple release points for the gas.

We can only speculate about present hazards. Gas testing for comp

Threshold Limit Values should be done on the following:

Intransit barge fumigations

Intransit ship fumigations

Godown tarp fumigations with nearby workers

Fumigated containers that may be stored below deck without aerat

Tobacco sample room fumigations next to offices.

A demonstration godown should be selected and given the entire p including fumigation of all stacks at one time and application of res space treatment. Godown personnel would also be taught how to i the control. This would then be visited by other interested parties t possible.

Try to obtain the total weight of grain bought per year by one godo the total weight sold. An attempt then should be made to determir loss and evaluate the significance to a good pest control program.

The efficacy of various tarp treatments should be made by samplin typical fumigations as:

Fumigation tarp bunched at the bottom permitting leaks

Fumigation tarp held down with bags instead of sand snakes

Fumigation tarp not sealed to floor near walls or posts

Fumigation tarps properly sealed to smooth out tarp held with ove

RECIRCULATION OF METHYL BROMIDE ON A BARGE

Export grain must arrive insect free at the port of destination to rec Fumigations inside godowns are subject to reinfestation. Ship fumig be hazardous and may not be effective due to the depth of the hol

Barges are often used to transport grain from the godowns to the s sealable area isolated from probable reinfestation but there have b obtaining insect control during barge fumigations.

The 24 hour holding period of the barge at the dock is not long eno fumigation with phosphine and there is strong reluctance to pay fo The tightly packed bags placed directly on the floor of the hold, imp circulation. There is no use of fans and only limited expansion cham Although we saw multiple release points used in ships holds, we ne one release point used on barges. This type of fumigation can be ex perfect.

Recognizing the success of recirculation of Methyl bromide in instal Controlled Circulation Chamber for Orchids, we propose to test a m barge fumigation procedure.

Instead of placing the first layer of bags on the bottom of the hold, be placed with all 2 x 4 runners lined up with the ship so that air ch to aft.

The rope locker would be used as one plenum chamber. The door f rope locker would be left open. A board would be sealed to the hat in the board would be connected to a gas powered air pump. The a ducted to the top of the hold and the tarp would be sealed around around the entire perimeter. The gas would be injected into the air

would mix with air in the plenum created by the gas proof sheet he pipe hoops. The gas/air mixture would settle through the bags both pull of the blower drawing air from the hold into the rope locker. T the entire 24 hours and then again during aeration after the tarp ha will provide better safety for workers that must enter the hold to u hand.

The pipe hoops may need to be lengthened to form,a larger expans exists and to allow for the loss of space taken up the pal lets.

Test lines should be placed at the top, middle, and bottom at the fr as well as the rope locker and crews aren to evaluate the concentra should be used for the readings.

The crew should not be allowed on board during the fumigation bu if air sampling is done. There is always a hazard to the crew if they s being fumigated but even a small leak will be serious during recircu

The size of the blower must be kept small enough to not put too m of the tarp put should be enough to assure proper circulation of the

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Gas monitoring and detection systems

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Detection of gaseous concentrations is an essential prerequisite for

safety reasons when any fumigation is attempted.

The requirements are the determination of excessive leaks from the (sheeted stack) or building, the concentrations achieved during the fumigation, the concentration reduction during aeration, and prote from potential hazards associated with the fumigant. The threshold have been revised with respect to the common grain fumigants in p emphasizes the need for more accurate detection of environmental operator safety.

Detection equipment must be used in preference to odour, even th can be detected (not accurately;) this way. Phosphine possesses a g odour (due to probably diphosphine, since pure phosphine is odou apparent due to preferential sorption on grain. Methyl bromide is c concentrations, and most formulations contain chloropicrin as a wa atmospheres containing methyl bromide may not be apparent to th different sorptive characteristics of chloropicrin (BP 112C) as compa (BP 3.6C).

Detector Tubes

These are sealed glass tubes which, after the tips are removed, are and air is drawn through the tube. The fumigant then reacts chemic coated granular filler and the color change is measured directly on t calibration chart.

There are various types of pumps, such as Drager, Auer, Kitagawa a

Detector tubes are available for phosphine, methyl bromide, carbon disulfide, hydrocyanic peid, (acrylonitrile, ethylene oxide, carbon di dibromide, ethylene dichloride, oxygen, and other environmental c

1. Drager Multi Gas Detector

The pump consists of a simply designed, extremely strong bellows v practically no maintenance. The pump is easily operated by one hai 100 cm (100 ml) of gas per stroke, and measures the gas sample at t same bellows pump is used for the dust sampler to suck in the air s of dust concentrations.

The Drager tube is a glass tube fused at both ends and is chemically condition with a normal shelf life of approximately 2 years.

Operation

Both ends of the Drager tube are opened in the ampoule breaker e breaking motion", the eyelet being located next to the loop which r chain. The break off husk can also be used to open the ampoule. It splinters from falling, and is provided in the carrying bag of the Gas should be emptied from time to time.

The open tube is then inserted into the pump head so that the arrc towards the pump and the writing surface towards the air inlet. Th firmly and tightly in the pump head so that no bypass air can be dra

During the test, the pump body is gripped by the working hand so t which carries the pump head and takes the form of a recessed hanc against the palm and the ball of the hand. The pump is held betwe base of the forefingers. The four fingers rest loosely on the front pl operated by compressing the rubber bellows as far as the stop and

When the pump is compressed, the air escapes form the bellows th in the front panel and not through the tube, because this has a mu

resistance than the outlet valve. The suction of the pump begins wi
four fingers which previously rested on the front panel. The fingers
released from the panel, but the pump will still be firmly located be
the base of the forefingers. The compression springs within the bell
tensioned when the bellows are compressed, expand and the outle
vacuum created in the bellows. The air then flows into the bellows,
while the bellows expands to its original volume. The air volume dr
is determined by the dimensions and the stroke of the bellows. The
movement is reached when the arrestor chain is fully tensioned. Th
tube, which is decisive for the accuracy of measurements, is thus de
the spring force and the resistance of the Drager tube charge, which
manufacture. The number of strokes prescribed for the various Dra
observed at each test (See Table 1).

2. Auer Gas-Detector(R), Auergesellschaft, GMBH, FRG

The Auer Gas-Detector(R) consists basically of a suction ball bulb ar
which the detector tube is inserted. When the suction ball is compr
pressure is produced which draws the air to be sampled through th
chemical composition of the indicating material being specifically de
and vapours being monitored showing a characteristic discolouratic

In most cases, a specific sample volume is drawn through the detect
concentration of the substance to be detected is read from a scale a
of the stain or is evaluated by means of a table. Some detector tube
short discolouration (annular indication). In these cases, the sample
obtain the discolouration is equivalent to the concentration. Detect
developed for specific gases and vapours, or for broad spectrum ap
of gases.

Table 1.

GAS AND VAPOURS	**DRAGER TUBE USED**	**ORDER CODE (1 pack)**	**MEASUREMENT RANGE (20C; 1013mbar):**
Perchloroethylene	Perchloroethylene 51a	6.7 26699	5-50 ppm
(Tetrachloroethylene)	" 10/b CH 30701		10-500 ppm
	" 0.1%1a 67 28021		0.1-1.4% vol.
1,1,1-Trichloroethane	Trichloroethane 50/C	CH 21101	50-600 ppm
(methyl chloroform)			
Phosphine	Phosphine 0.11a	CH 31101 0	.1-4 ppm
	Phosphine 501a	CH 21201	50-1000 ppm
			15-300 ppm
			150-3000 ppm
Phosphoric acid	Phosphoric acid	67 2846 0.02	ppm DDVP
esters	esters 0.021a		

The Auer Gas-Detector is simple with only 10 parts (locking screw; c washer; spring pin; spring; pump body; bushing; tube breaker; valv aspirator bulb for model 69), and can be taken apart and reassemb use of plastic and rubber makes the device largely resistant to corro vapours; and combined with sturdy construction, virtually no maint Where AUER Toximeter (TX), an electronically operated automatic p tubes is recommended.

OPERATING INSTRUCTION

Break off both tips of the detector tube in the tube breaker on the Auer Gas Tester with a rotating movement.

Insert detector tube tightly into the pump body in the direction of t the tube (unless otherwise specified in the special instructions). Set to the number given in the instructions for use of the detector tube

One hand operated, hold neck of suction ball between the tips of tl fingers, apply thumb broadly to the operating ring at the bottom of Compress suction ball firmly in the direction of the pump body up t to squeeze out the residual air contained in the sides of the suction

Take off thumb and allow suction ball to expand keeping the detec seconds in the sampling area (unless otherwise specified). Repeat sa often as indicated in the instructions for use of the detector tube. M device one by one digit before every stroke. The disc counting devic engage at 0, which shows the user that the test is completed. Some off acid vapours during testing. Although the device is extremely res vapours, it is advisable to flush it after each use with a few blind str

detector tube reading as described in the instructions for use.

Phosphine Detector Tubes

PH3-0.1: Used for detecting phosphine in air or technical gases over ppm. For concentrations greater than 50 ppm and for checking TLV.

PH3-50: Used for detecting phosphine in a range from 50-2000 ppm

The detector tubes have two scales, or calibrated for use with AUEF pump (G.T.), the other calibrated for use with the AUER Toximeter (

Principle of Operation:

Reaction of phosphine with a silver compound and the formation o indicator layer (white) is progressively discoloured zone for zone to of phosphine.

The concentration indicated only applies for the selected location, a moment in time the measurement was taken. Changes in concentra leakage, formation of vapour clouds, etc) must be taken into consid

Accuracy:

Length of stain, more than 10 mm:t 10 to 15% standard deviation
Length of stain, less than 10 mm:+ 15 to 25% standard deviation

Measurement

TUBE TYPE PUMP TYPE	: PH_3-0.1		PI

	:Gas tester (GT):	**Toximeter (TX):**	**Gas Tester (GT):**	**T**
Connecting	Arrow points to-	Arrow pointing	Arrow in detector	I
detector tube	wards pump	away from pump	tube indicates	t
			flow direction	n
			(towards pump)	
				A
				fl
				(
Range of	10 strokes :0.1	Switch position	1 stroke (1 H)	S
measurement	to 10 ppm	10: 0.1-10	50 to 2000 ppm	1
	Take reading on	ppm	For evaluation	p
	10 stroke scale	Switch position	use GT scale	F
	(GT)	1: 1 to 100		u
	1 stroke: 1 to	ppm		
	100 ppm			
	Take reading on			
	10 stroke scale			
	and multiply by			

	10. (GT)			
Suction time	20 seconds per	Switch position	Approx. 25 sees.	S
	stroke includ-	1: approx. 25	per stroke	1
	ing waiting time	seconds		s
		Switch position		
		10: approx. 2.50		
		seconds		

	GAS DETECTION EQUIPMENT
Phosphine	Detector Tubes
Methyl bromide	Detector Tubes
	Halide Gas Detector
	Thermal Conductivity Analyzer
	Interference Refractometer
Carbon tetrachloride	Detector Tubes
	Halide Detector
	Thermal Conductivity Analyzer
	Interference Refractometer
Carbon disulfide	Detector Tubes

	Thermal Conductivity Analyzer
Hydrocyanic acid	Detector Tubes
	Color Indicator
Sulfuryl fluoride	Thermal Conductivity Analyzer

Appendix

Fumigants can affect the commodity; or the nature of the commodi efficiency of a fumigant. Methyl bromide and phosphine may reduc methyl bromide can taint some products. Sorption of methyl bromi other high oil content materials can reduce or even stop penetratio bulk. A similar problem exists where hydrogen cyanide is used to fu content grains and other products.

Where economic advantage can be gained by marketing a product c free the choice of fumigant will be limited to carbon dioxide or pho dioxide is the only fumigant that is acepted by the biodynamic and phosphine fumigation is considered to be a chemical treatment whi carbon dioxide is not.

The following three 'decision-trees' provide a pathway that allows r choice of fumigant.

FUMIGATION DECISION TREE NO. 1

FUMIGATION DECISION TREE NO. 2

FUMIGATION DECISION TREE NO. 3

Is the fumication enclosure close to occupied dwellings that cannot be vacated for the duration of the treatment?

Is the fumigation very close to a work area in use?
Will the commodity be needed in less than 15 days,
Has carbon dioxide an economic advantage?
Use Phosphine
Use Carbon Dioxide

Are Trogoderma spp. present?
Will market accept phosphine-treated commodity?
Has phosphine an economic
Use either Phosphine or Carbon Dioxide

When and when not to use methyl bromide as a fumigant

Methyl bromide should be used:

- **when a treatment must be completed within 4 days or less**
- **for most quarantine treatments**

Methyl bromide use should be avoided:.

- **on seed required for planting or malting**
- **on very absorbent materials, such as expeller cake or oilseeds**
- **in areas immediately adjacent to workspaces or habitations**
- **on materials previously fumigated with methyl bromide more t**
- **where there is no trained, qualified, and properly protected fu**
- **in unsealed enclosures**
- **There may, however, be occasions when methyl bromide must quarantine or contractual obligations, where it would not othe of choice.**

When and where not to use hydrogen cyanide as a fumigant

Hydrogen cyanide is the fumigant of choice for

- **vertebrate pest control in enclosures, such as buildings ships**
- **where a rapid treatment is required and germination must be**
- **where a rapid treatment is required and the equilibrium relati commodity is less than 60% and methyl bromide may lead to t residues.**

Hydrogen cyanide should not be used:

- **where there is a risk of leakage into work spaces or habitation**
- **where there are no properly trained, qualified, and protected f**
- **where there are moist commodities or free water within the fu**
- **at ambient or commodity temperatures lower than 26C.**

When and when not to use phosphine as a fumigant

Phosphine is the fumigant of choice:

- **when a commodity is required in not less than 7 days**
- **when Trogoderma granarium is present and use of methyl bro**
- **when oilseeds*, expeller cake, and meals must be treated**
- **where germination is important**
- **where commodities have been treated previously with methyl**
- **where taint may be a problem if methyl bromide is used. e.g.. (**

Phosphine should not be used:

- **where resistance is known to exist in an insect population**
- **in unsealed enclosures**
- **at temperatures below 15C**
- **where a rapid treatment is required, i.e. less than 7 days**
- **in areas immediately adjacent to workspaces and habitations**
- **where there is no trained, qualified, and properly protected fu**
- **Residue data not vet available**

Dosage rates for hydrogen cyanide treatment of grain and empty st

Situation	Dosage	Exposure Per

Empty warehouses, ships and barges, for control of residual insects	8 g/m	24 hours, wit
Empty warehouses, ships and barges for control of rodents	2 g/m	2 hours, with
Bulk grain with liquid HCN from cylinders, for insect control	50 g/t	24 hours, wit
Bulk grain with calcium cyanide, as Ca(CN)2, for insect control	80 g/t	5 days
Bagged grain under gas-proof for insect sheets, for insect control	50 g/t	24 hours, wit distribution

Dosage parameters for methyl bromide applications to various com insect pests.

Commodity	**S (g/m) plus**	**M (g/tonne)**
Paddy, brown and milled rice, barley	10	0
Wheat, oats, maize, pulses	10	20
Sorghum	10	40
Flour, nuts, oilseeds, rice bran*	10	60
Oilseed cakes and meals*	10	120

***These commodities should not be fumigated with methyl bromide contractual obligations or for quarantine reasons. Other fumigants**

When and when not to use carbon dioxide as a fumigant

Carbon dioxide is the fumigant of choice:

- **where long-term storage is planned, i.e. more than 15 days**
- **where freedom from residues is of value**
- **where phosphine, methyl bromide, and hydrogen, and hydrog are not accepted by markets**
- **where a rapid kill of rodents is desirable and hydrogen cyanide**
- **where treatments must be undertaken close to workspaces an**

Carbon dioxide should not be used:

- **where a treatment must be completed in less than 15 days**
- **where Trogoderma granarium is present**
- **where seed viability and germination may be affected**

The aim with a carbon dioxide fumigation is to expose any insects p concentration of carbon dioxide above 35% for longer than 15 days to achieve this will depend on:

- **the initial concentration achieved**
- **the leakage rate of the enclosure**
- **the displacement volume of the commodity**
- **the amount sorbed by the commodity**
- **the efficiency of purging.**

As these factors will vary vastly between enclosures, a set dosage p can be only a rough guide to the required dosage. A more economic is to observe the concentration within the enclosure and to stop ad average concentration (or the concentration at the top of the enclo

carbon dioxide. In a correctly sealed enclosure, this will give a conce than 34% at 15 days after treatment.

In a sealed enclosure meeting the pressure test standard, a concent 75% carbon dioxide should require no more than 1.7 kg of carbon d of total storage space. The amount less than 1.7 kg/m3 will depend attributed to 1-5 above. In a full storage with effectively zero heads achieve greater than 75% has been observed to be about 1.2 kg of c tonne.

Dosage rates for phosphine

Temperature (C)	**Dosage rate (g/m)**	**Equivalent commodity dosage* (g/tonne)**	**Minimum exposure peric (days) Admixture & recirculation**
Above 25	1.5	2	7
15-25	1.5	2	10

*** Rate appropriate for raw, whole cereal grains. Commodity dosage only when structures are full or have little no head remaining.**

Calculation of Ct products

Effective fumigation with methyl bromide can ensured only if the re product has been reached or exceeded. The Ct product is calculatec concentration of fumigant observed in grams per cubic metre (g/m) (h) that the concentration has been present, and is recorded in grar metre (9 h/m). If the gas concentration within the enclosure were t

Ct product could be estimated simply by multiplying the concentrat However, in any real fumigation the gas concentration always chan; product then has to be calculated by adding together the compone obtained from the average concentration of sequential observation the time interval between them. The best approximation of true to obtained with a large number of concentration observations it an e practical constraints often limit the number of observations that ca Concentrations should be measured at about 2, 4, 12, and 24 hours hour exposure is used, readings at about 36 and 48 hours should al product cannot be calculated on fewer than two concentration mea readings are possible the first must be taken after gas mixing is con must indicate a quantifiable concentration (that is, more than zero

In fumigations under gas-proof sheeting where gas loss rates are ve is best calculated by using the geometric mean. This is done by mul observed gas concentrations (as grams per cubic metre), taken one multiplying the square root of this number by the time interval (in I two readings. This can be expressed as the equation:

$$Ct_{n.n+1} = (T_{n+1} - T_n) \times \sqrt{C_n \times C_{n+1}} (gh/m^3)(1)$$

where

T_n is the time the reading was taken in hours
T_{n+1} is the time the second reading was taken in hours
C_n is the concentration reading at T_n in g/m
C_{n+1} is the concentration reading at T_{n+1} in g/m
$Ct_{n,n+1}$ is the calculated Ct product between T_n and T_{n+1} in g h/m

The Ct products obtained from a series of readings may then be adc cumulative Ct product for the whole exposure period (see examples Appendix). It is this value that is used to indicate the success or failı The calculation is easily carried out on a simple electronic calculatoı function.

In well sealed enclosures that have passed a pressure where gas los product may be calculated by using the arithmetic mean. This is doı two observed gas concentrations (as grams per cubic metre), taken and multiplying half of this number by the time interval (in hours) b readings. This can be expressed as the equation:

$$Ct_{n,n+1} = \frac{(T_{n+1} - T_n) \times (C_n + C_{n+1})}{2.0} (gh/m^3) (3)$$

where:

T_n is the time the first reading was taken in hours
T_{n+1} is the time the second reading was taken in hours
C_n is the concentration reading at Tn in g/m
C_{n+1} in g/m
$Ct_{n,n+1}$ is the calculated Ct product between T_n and T_{n+1}, in g h/m

The Ct products obtained from a series of readings may then be adc cumulative Ct product for the fumigation (see example 3). It is this v indicate the success or failure of a fumigation.

It is possible to add gas during the course of an exposure to mainta concentration and so achieve a prescribed or statutory Ct product.

Note: whichever method of calculating the Ct product is used, it is i within the enclosure is well mixed and the concentrations have bec even by the time the first concentration reading used in the calculat bag stack) have been taken. Pairs of observations containing a zero (e.g. trace) concentration cannot be used to obtain a valid contribut cumulative Ct product.

Worked examples of Ct calculation

The following examples (based on hypothetical methyl bromide fun illustrate the steps needed to calculate Ct products using either equ

Example I

A fumigation under gas-proof sheets with a high loss rate, where th calculated on the basis of equation 1. This is the type of result that many commercial fumigations or where the commodity is very sorb

Example of calculation

Using equation 1 for the period form 2 to 4 hours

$$Ct_{2,4} = (4.0-2.0)\ (20.0 \times 15.5)^{1/2} = 2.0\ (310.0)^{1/2} = 2.0\ 17.6 = 35.2$$

That is, the Ct for the period between the obserations = the time b observation x the square root of the product of the concentrations observation times.

Readings:

	Time				

Time (hours)	step (hours)	Concentration (g/m)	Ct product (g h/m)	Cumulative Ct (g h/m)	Co
0.0	-	-	-	-	En
2.0	2.0	20.0	+	0.0	Ct
4.0	2.0	15.5	35.2	35.0	
12.0	8.0	6.2	78.4	113.6	
24.0	12.0	2.0	42.3	155.9	
36.0	12.0	trace	*	155.9	Ct
48.0	12.0	0.0	*	155.9	Ct

+ No contribution to Ct as most probably not mixed by this time an representative of concentrations as a whole.
***Ct for this time period cannot be calculated as final value is less th concentration.**

Example 2

A fumigation with a very high loss rate where top up gas is added t required Ct product is achieved. Here the Ct product is calculated u the type of result that can be expected from a poorly sealed fumiga sheets, or a fumigation of a very sorbtive commodity where a contr target dose (either Ct or minimum concentration over a set time) ha

Readings:

Time (hours)	Time step (hours)	Concentration (g/m)	Ct product (g h/m)	Cumulative Ct (g h/m)	Co

0.0	-	-	-	-	En
2.0	2.0	20.00	+	0.0	Ct
4.0	2.0	15.5	35.2	35.2	
7.0	3.0	10.0	37.3	72.5	To
8.0	1.0	19.5	14.0	86.5	To
15.0	7.0	10.0	97.7	184.2	To
16.0	1.0	15.5	12.4	196.6	To
24.0	8.0	4.0	63.0	259.6	
36.0	12.0	trace	*	259.6	Ct
48.0	12.0	0.0	*	259.6	Ct

+ No contribution to Ct as gas most probably not mixed by this time be representative of concentrations as a whole.

***Ct for this time period connot be calculated as final value is less th concentration.**

Example 3

A fumigation in a well sealed enclosure that has passed the pressur gas loss rate is low. Here the Ct product is calculated using equatio fumigation is only likely to occur in an extremely well sealed enclos nonsorbtive comodity.

Readings:

Time (hours)	Time step (hours)	Concentration (g/m)	Ct product (g h/m)	Cumulative Ct (g h/m)

0.0	-	-	-	-
2.0	2.0	19.8	+	0.0
4.0	2.0	19.7	39.5	39.5
12.0	8.0	19.0	154.8	194.3
24.02.0	18.1	222.6	416.9	
36.0	12.0	17.2	211.8	628.6
48.0	12.0	16.4	201.6	830.2

+ No contribution to Ct as gas most probably not mixed by this time be representative of concentrations as a whole.

Example equation 2 for the period from 2 to 4 hours

$$Ct_{2.4} = \frac{(2-4)\times(19.8+19.7)}{2.0} = \frac{2\times 39.5}{2.0} = 39.5$$

That is the Ct for the period between the observations = the time b observation the sum of the concentrations at the two observation t

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