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Storage Technology Development and Transfer—Pakistan

Report No. 9

REFRESHER COURSE

ON

FUMIGATION TECHNOLOGY

KARACHI, PAKISTAN

(October 21 - 24, 1991)

KSU
KANSAS STATE UNIVERSITY

FOOD & FEED GRAIN INSTITUTE
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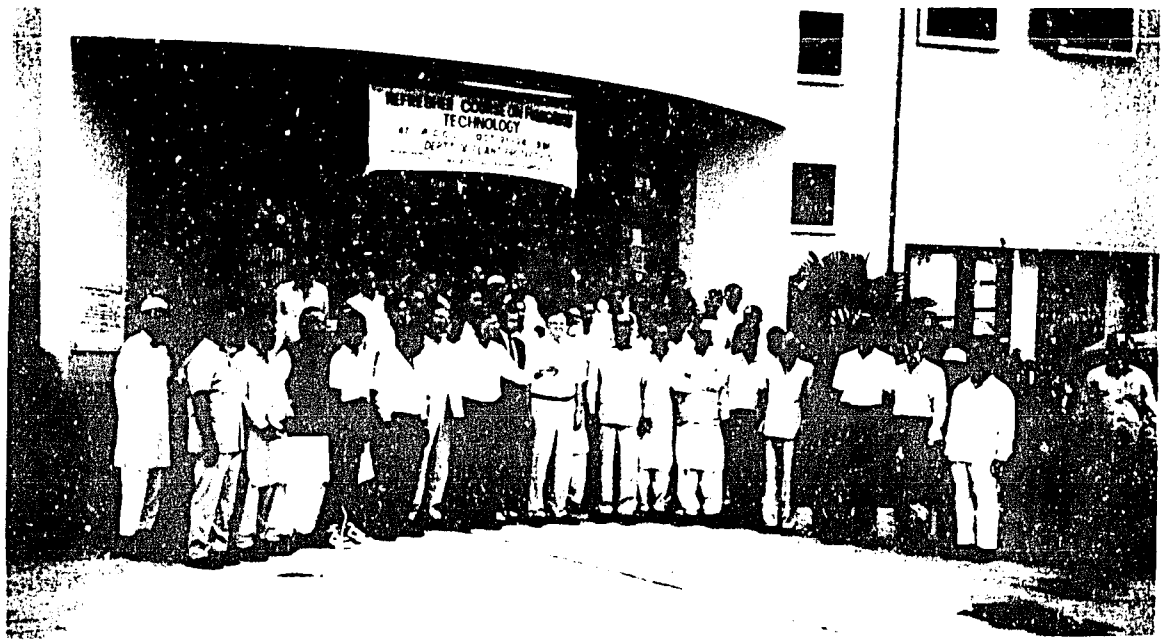

Refresher Course Participants

TABLE OF CONTENTS

	Page
PREFACE	1
OPENING REMARKS	3
CHIEF GUEST	5
LECTURES	
Essentials of Fumigation, Hafiz Ahmed, STDT Research & Training Coordinator, Lahore	13
Principles & Requirements of Methyl Bromide Fumigation, Mubarik Ahmed, GSRL, PARC, Karachi	21
Phosphine Fumigation, Mohammad Sajjad Ahmed & Tariq Mahmood, PARC/STDT, Lahore	35
APPENDICES	
APPENDIX I - List of Commercial Fumigators	59
APPENDIX - II Course Programme	61
APPENDIX - III Names of the Course Participants	63
APPENDIX - IV Deficiencies Observed During Field Visits	65
PHOTOGRAPHS	67

P R E F A C E

Pakistan exports rice and cotton on a large scale, and some other agricultural produce on a small scale, to various parts of the world. All of these commodities are fumigated before export with either methyl bromide or phosphine to obtain a phytosanitary certificate from the Ministry of Food, Agriculture, and Cooperatives (MINFA) Department of Plant Protection (DPP), based at Karachi. Actual fumigations are carried out by the Rice Export Corporation of Pakistan (RECP) and a number of Commercial Fumigators which are "registered" with the DPP for this purpose (Appendix-I). The phytosanitary certificate is issued by the department after "examination" of the fumigated commodity by a plant quarantine inspector of the DPP.

Recent research under the Storage Technology Development and Transfer (STDT) project and in the Pakistan Agricultural Research Corporation (PARC) have shown some storage pest species to have developed high levels of resistance to phosphine at some places in Pakistan. As a result of this development, important changes were "recommended" in stored grain protection procedures involving phosphine, at the "International Conference" held in Lahore, in June 1991 (Proceedings "Bulk Wheat Handling and Storage Conference, Lahore June 17 - 19, 1991." Report No.8, October 1991, FFGI, Kansas State University). Earlier (1987), the Natural Resources Institute (NRI) of UK, in collaboration with PARC, had discovered certain deficiencies in the procedures being followed in methyl bromide fumigation of bag stacks in Pakistan. In light of these developments, it was considered essential to update the knowledge of commercial fumigators and others involved in the export of agricultural produce from Pakistan. For this purpose, a four-day "Refresher Course in Fumigation Technology" was organized jointly by DPP, STDT, and PARC at Karachi from October 21 - 24, 1991 (Appendix-II). A total of 53 persons registered themselves for the course, out of which 31 belonged to private business firms, 14 to DPP, four to RECP, and four to the Grain Storage Research Laboratory of PARC (Appendix-III). The course consisted of lectures and field visits. It was designed to convey the message through talks and demonstration.

The lectures delivered at the course are now being presented in a compiled form for future reference. The deficiencies observed during field visits are also given (Appendix-V). There was some confusion about the recommended dose of methyl bromide. This confusion has now hopefully been removed in the edited version of the lecture presented at the "course".

We wish to record our profound gratitude to the Pakistan Central Cotton Committee (PCCC) for allowing us the use of their excellent facilities for conduct of this "refresher course" on their premises in Karachi.

OPENING REMARKS
REFRESHER COURSE IN FUMIGATION

Richard C. Maxon
Chief of Party
Storage Technology Development and Transfer
Karachi - 21 - 24 October

On behalf of the STDT project of USAID, I want to welcome you to this refresher course on fumigation. This is a cooperative effort with the grain storage laboratory of PARC, and the plant protection department of MINFA.

A remarkable change has taken place with regards to grain storage in the past few years. You now hear open discussions of storage losses even though the government's accounting system does not recognize losses of any kind.

In 1981, a research organization was established to determine the amount of losses and what to do about them. This is the tenth anniversary of the Grain Storage Research Laboratory (GSRL). GSRL and the organization I represent have been working together to carry out that mandate.

At this meeting, we will be demonstrating what has been found and what to do to prevent storage losses. As you will hear many times during coming days, Pakistan has unique combinations of storage problems that require locally developed solutions - and the solutions are changing every day.

In all, it is about time that full recognition is given to the magnitude of the problems - and what is at stake. For instance, do you realize that the amount invested in publicly held wheat inventories of about 5 million tons is equal to the budgets of all union councils, municipalities, and other government units below the provincial level in all of Pakistan?

The replacement cost of all publicly owned wheat storage is probably in excess of Rs 20 billion, excluding the land on which the storage is located. We have talked only of wheat storage. Many other commodities such as rice, maize, oil seeds, pulses, etc., both for domestic use and export, have storage costs and needs as well. The figure shows the amount and type of storage for wheat in use today.

To put it in another manner, the federal and provincial governments spending for wheat procurement and storage each year is about twice the amount spent on all health care, and the same amount as spent on education. Health and education are fundamental matters of concern to all of us. Both are subject to intensive public scrutiny over what is right and wrong with the present system. Wheat has much to do with both of these subjects as well.

In the past five years, over Rs 21 billion have been spent on subsidies for wheat procurement, storage, and distribution. Much of the expenditures have been for imported wheat - wheat replacing domestic wheat that was lost in storage. These funds could have done much to improve the public infrastructure that could provide higher living standards for all.

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What we learn about fumigation in this course will not solve all the nation's problems. But it will set us on the road to thinking about ways and means of improving what we are doing, and the benefits it can bring to the nation.

PLANT QUARANTINE AND ITS IMPORTANCE

By

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Plant quarantine is one of the most important protection techniques laid down under legislative control. In a strict sense, plant quarantine means holding of plants and plant products in isolation until they are proven to be healthy. But in a broader sense, the term of plant quarantine is now used to regulate movement of healthy living plants, parts of living plants, and plant products between politically defined territories or ecologically distinct parts of them. In very simple words, we may say that plant quarantine measures are adopted to prevent introduction and spread of exotic or alien insect pests and diseases in the country, which, if allowed to enter, may establish rapidly, for want of immunity in the host plant and absence of their parasites and predators, and may cause a colossal loss to attached plantation and irreparable loss to the country's economy. Plant quarantine thus acts as a first line defense against exotic pests and diseases.

The terms intermediate quarantine and post entry quarantine are used respectively to denote the detention of plants in Isolation for inspection during transit or after arrival at their final destination.

Some plant pathogens and pests are generally distributed in most parts of the world, but others are more or less restricted in their occurrence. In some cases, this limitation is due to unsuitable environmental conditions or lack of host plants, but in many other cases, the pathogen may be absent as it finds no chance to gain entry into that area.

Almost all the countries desire to prevent or to delay as far as possible the arrival of an exotic pathogen and its spread by introducing legislation and setting up plant quarantine organizations. Plant quarantine legislation is constituted to restrict or prohibit the importation of the pests and pathogens themselves, plant on which they might be living, soil which might be infested, food stuff which may carry them, and packing materials, particularly of plant origin. These legislations vary from country to country, depending on the nature and type of pathogen importation which is to be prohibited. A good legislation must be brief, clear, and at the same time be easy to interpret, give adequate protection without interfering more than is essential with trade, and contain only restrictions which are scientifically justifiable.

Principle For Importation of Plants

In order to reduce the risk of importation of exotic pathogens, certain principles should be followed while importing plants and plant materials:

1. The plants or plant materials should be imported from a country where pathogens to be guarded against are absent. Guidance on the presence or

absence of the pathogens can be obtained form country and regional disease lists and maps. Caution is required in applying this principle, as lack of a record does not necessarily mean its absence, but may indicate that insufficient surveys have been done.

2. Import form a country with an efficient plant quarantine service, so that inspection and treatment of planting material before dispatch will be thorough, thus reducing the likelihood of contaminated plants being received.

3. Obtain an official certificate of freedom from pests and diseases from the exporting country. The value of this will vary with the status of the issuing plant quarantine services, but receipt of such certificate should never be relied upon as a complete guarantee that the consignment is healthy. Treatment of the material in the country of origin may be done and noted on the certificate.

4. Import the smallest quantity of planting material. The smaller the quantity, the less chance of carrying the infection. This will also simplify the inspection and post-entry quarantine procedures.

5. Inspect material very carefully on arrival, and treat (dust, spray, fumigate, heat, or cold treatment) as necessary.

6. Import the safest type of plant material, e.g., seeds are usually safer than vegetative material, unrooted cutting than rooted. The use of exenic cultures of meristem tip tissues (micropropagation) for the international exchange of gemplasm material has outstanding advantages, as such, tissues can be exported free from latent infections by various viruses, M.L.O.'s, etc., as well as other pathogens which are more readily detectable by visual means.

7. If other precautions are not thought to be adequate, the consignment for export should be subject to intermediate or post-entry quarantine. Such quarantine must be carried out at a properly equipped station with suitably trained staff, otherwise it is worse than useless, as it gives a false feeling of security.

Post-Entry and Intermediate Quarantine

Post-entry and intermediate quarantines are two very important tools of plant quarantine, with the help of which we can receive a consignment completely free from exotic pathogens. In doubtful cases, it is advisable to subject plants to a period of growth in isolation, under strict supervision of a procedure normally done in the importing country (post-entry quarantine). The plants are grown at a plant quarantine station located near a research station, where specialists like mycologists, virologists, nematologists, and entomologists are easily available. The station should be easily approachable and have no crop nearby. The station must also possess screened greenhouses, glass houses equipped with air conditioning systems, reception and treatment rooms, a laboratory, soil sterilization and potting sheds, some office and storage places, and an

incinerator. The staff of a quarantine station must possess one experienced horticulturist.

When direct importation of a plant to a country is considered very dangerous, quarantine during transit from the country of origin (intermediate quarantine) may be required. This is often done, for example, for rubber, banana, and cocoa. The requirements for an intermediate station are similar to those for a post-entry station. Intermediate quarantine inspection must always be followed by post-entry quarantine after arrival of the consignment at its final destination.

During post-entry or intermediate quarantine, plants must be kept under close supervision, so that any pest or disease which appears may be immediately detected, and grown under optimum conditions, so that symptoms are not masked by physiological disturbances. Various tests may have to be done to check whether plants are free form infection. Virus diseases are among the most frequently encountered and are the most difficult to guard against.

Inspection, Treatment, and Certification

Inspection of plant material is of primary importance in plant quarantine procedure and may be done both in the exporting country, before issue of a health certificate, and after arrival, as a double check and to detect any pest and disease which may have become evident during transit. The value of inspection is dependent on the skill of the inspecting staff, who must be familiar with planting material of all types, when healthy, as well as being able to recognize the presence of pests and diseases.

Treatment

Treatment used in plant quarantines are generally similar to those used in the general agricultural practice for pest and disease control, and include dusting, spraying, dip treatment with pesticides, subjecting material to heat or low temperature, and fumigation. For plant quarantine purposes, treatments must be completely effective. The level of partial control acceptable for field crops is undoubtedly prohibited.

Certificate

As mentioned earlier, it is the general practice that governments require imported plants to be accompanied by a certificate of freedom from pests and diseases (Health or Phytosanitary Certificate). The form which this document takes varies from country to country, but a model phytosanitary certificate was included at the FAO Plant Protection Convention of 1951. The form was revised at the Plant Protection Convention in 1976 at Rome and approved by FAO in 1979. FAO and all other regional plant protection organizations are striving hard to bring about uniformity in the language and model of the phytosanitary certificate, which must also meet the additional requirements as laid down in the import permit by the importing country.

International Aspects of Plant Quarantine

FAO encouraged action on plant protection work, especially in plant quarantine in 1951, after World War II, with establishment of the International Plant Protection Convention (IPPC). The purpose of the convention was to strengthen the international efforts in combating pests and diseases affecting plants and plant products, and in preventing their introduction and spread across national boundaries. The member states if IPPC agreed to take necessary steps and measures directed towards these ends, including:

1. Reporting existence, outbreaks, spread, and control of pests and diseases.

2. Disseminating information on the control of pests and diseases within the country.

3. Plant quarantine and plant material moving in international traffic.

4. Organizing national plant protection service operating with one another in establishing Regional Plant Protection Organizations.

Besides this world-wide convention, other regional agreements and organizations have been created to safe-guard the interest of the groups of the neighboring countries with similar plant protection problems. Regional action in particularly introduced into any part of the area as its entry into one territory would immediately endanger neighboring countries. For example, Microcylenes ulei, which causes South American leaf blight of rubber is absent from Southeast Asia, its establishment in any one country would endanger all others in the vicinity.

Article VIII of IPPC foresaw the desirability of setting up regional organizations and the following are now in operation:

APPC	-	Asia and Pacific Plant Protection Commission
CPPC	-	Caribbean Plant Protection Commission
COSAVE	-	Comite Regional de Sanidad Vegetal para el Cono sur (South American Plant Health Committee)
EPPO	-	European and Mediterranean Plant Protection Organization
IICA	-	Instituto Interamericano de Cooperacion para la Agricultura
IPPC	-	International Plant Protection Convention
JUNAC	-	Junta del Acuerdo de Cartagena
NAPPO	-	North American Plant Protection Organization
OIRSA	-	Organismo Internacional Regional de Sanidad Agropecuaria (Central American Territories)
RAFR	-	Regional Office for Africa
RNEA	-	Regional Office for the Near East Asia
RLAC	-	Regional Office for Latin America and the Caribbean

The Government of Pakistan (GOP) decided to join IPPC in 1954, and ever since has been regularly participating in IPPC activities. Pakistan is also an active member of APPC.

Legislation

Anyone concerned with the export of plant material should be familiar with the plant import regulations of the recipient countries. In this way, it can be ensured that the consignment is covered by the necessary documents. Almost always, a certificate of freedom from pests and diseases is needed and this may have to have a special declaration for particular plants. Some countries, such as U.S.A., issue special tags to be attached to the consignment. Knowledge of the regulations ensures that only suitable, acceptable material is sent. It is, unfortunately, sometimes difficult to obtain a copy of the original legislation, and is often more difficult to keep it up to date, particularly for territories which depend upon frequent amendments to keep their legislation in good order. Because of this difficulty, certain organizations help by circulating information of new legislation.

The main source of such information is the Food and Agriculture Organization (FAO) of the United Nations, which published a Digest of Plant Quarantine Regulations with two supplements between 1952 and 1956. These are now very much out of date, but a new looseleaf edition is planned. Meanwhile, information is available in the FAO Plant Protection Bulletin in which summaries of new plant quarantine laws are frequently published. As from 1981, particular attention is to be paid in the Bulletin to plant quarantine requirements for seed imports.

FAO also circulates information on new plant quarantine regulations of countries in Southeast Asia and the Pacific from its Bangkok regional office as an information letter of the plant protection committee for the Southeast Asia and Pacific region and in the quarterly newsletter of that committee. EPPO publishes much useful information in its EPPO Bulletin and its series of EPPO publications. IAPSC performs a similar service for its member countries by means of its circular and IAPSC News. Other regional organizations have similar services for their member nations.

FAO also produces a useful list of national plant quarantine services, giving addresses from which information on national quarantine regulations can be obtained.

IMPORTANCE OF PLAN QUARANTINE

1. It is the cheapest method of plant protection.

2. It aims at import of healthy plants and plant materials.

3. Being a part of legislative control method for pests and diseases, it acts as a front line of defense against exotic pests and diseases.

4. Plant quarantine is helpful in guarding entry of new pests and diseases into the country or delays its entry for a considerable period.

5. By preventing entry of new pests and diseases, heavy expenditures are saved which could otherwise have to be made to control new pests and diseases.

LECTURES

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ESSENTIALS OF FUMIGATION

By

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Fumigation is a versatile technique that can be applied in a wide range of situations. It is the preferred method of pest control where insects must be eliminated without moving the infested commodity or where pests are to be removed from the crevices of a structure where spray, mist, or smoke cannot reach. In many cases, fumigation is a mandatory phytosanitary requirement for export of agricultural products. Its greatest use in Pakistan, however, is for infestation control in the large sized foodgrain godowns.

Fumigation is a complex operation that needs considerable skills, careful planning, an understanding of the process, and the associated essential safety measures. It is also essential to keep in mind the purpose for which fumigation is being carried out. If a large sized foodgrain godown is being fumigated, the objective is only to disinfest the commodity so that losses of quality and quantity are avoided or reduced. A little bit of imperfection in such cases is tolerable as long as the results of fumigation do not impinge upon the market value of the commodity. This is because the main purpose here is purely commercial. However, when fumigation is undertaken to meet phytosanitary requirements under plant quarantine laws, its purpose is primarily scientific. The objective here is to prevent the spread of agricultural pests and diseases from one land to the other. As such, survival in the fumigation operations of even a few individuals of the pest population could be critical. The standard of success of the fumigation operations in such cases, therefore, has to be very high indeed.

The purpose of this course is to refresh the knowledge of the participants in some essential aspects of fumigation technology and to update them by bringing to their knowledge some of the recent research findings in this field.

Basic Requirements

The first essential requirement for fumigation is an enclosure capable of retaining the fumigant over the desired exposure period. Barges, shipping containers, and whole warehouses or godowns can be used as enclosures, provided these can be adequately sealed to retain gas. Gastight plastic sheets are commonly used to enclose bagged commodities. Specially manufactured fumigation chambers are used in situations where fumigations are regularly carried out.

Fumigation cannot be undertaken safely and successfully when:

- a trained supervisor is not available;
- enclosure available cannot be sealed to an adequate standard; and

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- workers and other persons cannot be reliably excluded from the enclosure and risk area.

Materials & Equipment

Adequate supplies of appropriate fumigant should be available before commencement of the operations. If plastic sheets are to be used to make enclosures, the required quantity of sheeting material in good and sound condition is to be arranged. In such cases, self-adhesive PVC tape and suitable joining/sealing material such as heat sealers, sand snakes, etc., will also be required.

Equipment required includes:

- personal safety equipment such as gloves, respirators, and their canisters;
- fumigant detection apparatus;
- appropriate fumigant release apparatus such as scales, distribution lines, nozzles, tablet dispensing apparatus, etc.; and
- heat sealing machines and a power source or generator to run these machines in case polyethylene sheeting is to be used.

A high level of supervision is required to ensure that all the equipment is properly used and kept in good working order.

Understanding of the Processes

- Fumigant is a chemical which, at the normal conditions of temperature and atmospheric pressure, will exist in a gaseous state. It differs from aerosols, fogs, mists, and smokes, all of which are suspensions of minute particles of liquids or solids dispersed in the air.

- Fumigation is the process of establishing an environment containing (holding) a fumigant in (an enclosed) space in which the concentration of the fumigant is maintained at a level high enough, and for a period long enough, to be lethal to all the animal pests (mites, insects) and their various developmental stages (eggs, larvae, pupae, and/or adults) and forms (resistant and/or susceptible strains), infesting that space.

- Dose and dosage have somewhat arbitrary distinction. Dose generally refers to the unknown quantity of fumigant which the animal absorbs from its gaseous environment. Dosage, on the other hand, refers to the process in which a measured amount of fumigant is introduced in an enclosure from which a dose is absorbed by the pest progressively over a period of exposure to that environment.

Dosage in fumigation is generally expressed as the product of concentration (C) of the fumigant and the time (t) of exposure or the Ct product. The relationship is presented in its simplest form as:

$$C \times t = K$$

It means that a constant K (say a level of kill) can be achieved by changing either the concentration or the time of exposure. For example, to achieve the Ct product of 166 mg hr/l of methyl bromide (CH_3Br) needed for 99% kill in *Tenebroides mauritanicus*, the following combinations can be used:

Concentration (C) of CH_3Br (mg/l)	Exposure time (t) (in hours)	Ct product (mg.hr/l)
83.0	2	166
55.3	3	166
41.5	4	166
33.2	5	166
23.7	7	166
16.6	10	166

(From FAO's Manual of Fumigation for Insect Control, Monro ,1969)

The above relationships, however, do not hold good for all the fumigants. A more general relationship between concentration and time is of the form:

$$C^n \times t = K$$

where K is again representing a constant level of response such as LD_{99} (lethal dose for 99% of the pest population). The exponent n is the toxicity index that describes the specific toxicity relationship between a fumigant and a pest species and/or the developmental stages of the pest species. The importance of n in practical fumigations lies in knowing the general magnitude of n for the fumigant being used and the pest species being treated. For example, the values of n for phosphine are mostly less than 1 which indicates that exposure time is more important for the outcome of fumigation than concentration. For fumigants for which the value of n is generally greater than 1, as is the case of methyl bromide, it would be more effective to increase the concentration than to increase the time of exposure.

- Selection for resistance to toxic action of fumigants takes place when pests are exposed to its low dosages for generations. This leads to the development of resistant pest strains.

Fumigants in Use in Pakistan

In Pakistan, only two gases, namely phosphine and methyl bromide, are presently being used as fumigants for agricultural products. Their basic physicochemical properties are as follows:

	Phosphine	Methyl bromide
Formula	PH_3	CH_3Br
Molecular weight	34	95
Boiling Point (^oC)	-87.0	3.6
Specific gravity (gas) (air = 1.0)	1.2	3.4
Vapor pressure at 30 ^oC (atm)	42	2.5
Conversion factor g/m^3 to ppm (30 ^oC, 1 atm)	730	260
Flammability limits in air (v/v)	>1.7%	13.5-14.5%
Solubility in water	0.2	3.4

From an operational viewpoint, the two gases have the following main differences:

Phosphine	Methyl Bromide
- Easy to transport as tablets/ pellets/sachets	- Difficult to transport in heavy cylinders
- Readily available	- Not so easily available
- Cheap and simple to apply	- Expensive and difficult to apply through piping
- Leaves almost no residues	- May leave harmful residues
- Not harmful to seed viability	- Harmful to seed viability
- Needs long exposure time for success of fumigation (minimum of 14 days)	- Needs short exposure time for success of fumigation (maximum of 4 days)
- Insect pest strains resistant to phosphine are common and a serious problem	- Resistance in field strains not yet a serious problem

The choice of a fumigant depends on:

- the time available
- the commodity to be fumigated
- the cost and ease of application
- possible reaction with non-target material
- market requirements & residue limits

Factors Affecting Fumigation

Environmental Factors. The following environmental factors can adversely affect results of fumigation by causing excessive leakage of a fumigant from an enclosure:

Wind

Wind causes increased pressure on the windward faces of an enclosure and decreases it over the rest of the enclosure. It will thus force air into the enclosure at a leak and take it out from the other (for rapid gas loss, it is necessary to have at least two holes in the enclosure). The rate of loss of fumigant will be approximately proportional to wind speed. In the case of leaky structures, wind effect can cause fumigation failures.

The Stack or Chimney Effect

When there is a pressure differential across the enclosure walls due to differences in the atmospheric density in and out of the enclosure or wind action, a flow of gases results through leaks in the wall. A tall structure having a vertical distribution of leaks will lose more fumigant than a short one. Such leaks can create 'havens' for the pests, enabling them to survive fumigation action.

Temperature Variation

Thermal expansion of atmosphere in the 'headspace' of a storage structure results in loss of fumigant (contractions do not make a difference as grams of fumigant per cubic meter of enclosure remain unchanged).

Atmospheric Pressure Variations

When a container, such as a railway wagon, is fumigated in transit, atmospheric pressure variation may cause significant loss of fumigant when the wagon ascends to a higher sea-level.

Sorption-Desorption Effects

The rate of loss from sorption is independent of leakage from the enclosure. In fully sealed enclosures, it is the dominant mode of fumigant loss depending upon the ambient temperature, as well as the commodity and the molecular weight and boiling point of the fumigant.

Fumigant that has been taken up (sorbed) by a commodity either reacts to form fixed residues, or is capable of being desorbed again. The rate of desorption is controlled by the diffusion rate of the fumigant within the commodity particle, exposure period and the fumigant concentration external to the particle.

Permeation and Diffusion Losses

The process of permeation involves the transfer of fumigant molecules through an intact material such as a fumigation sheet. No imperfections or leaks are required for this process to occur.

Diffusion is the process of transfer of a fumigant over distance simply through the motion of individual molecules. No bulk movement of gas occurs.

In practice, both permeation and diffusion contribute least to the leakage rate in fumigation compared to other more powerful factors discussed above.

Factors Affecting Local Concentrations of Fumigant Within an Enclosure

In fumigation, it is important not only to achieve a satisfactory average concentration of the fumigant but also to attain its even distribution in the enclosure. A fumigant is generally added to an enclosure in a concentrated form. Its even distribution requires some sort of mixing in the enclosure. Besides, when air enters an enclosure under the influence of 'wind' etc., it dilutes the fumigant in the region close to the entry point. This may create a region in which the fumigant dosage may locally be inadequate. Efficient mixing of the fumigant also reduce chances of such 'havens' where pests may survive.

Mixing of fumigant within the enclosure is determined by four forces: convection, forced mixing, sorption, and diffusion. The last two forces are negligible contributors to overall distribution in large enclosures but may be important in the penetration of caked areas or those containing dust and broken material.

Convection

Temperature differential creates convective air currents within an enclosure and may cause the problem of moisture migration in stored grain. Convective air currents also help in the mixing of a fumigant. The convection pattern may involve a large part of the storage in a single circulation system or be restricted to a small region.

In most sealed conditions, convective mixing will produce an even distribution of the fumigant within a day. However, if the enclosure is leaky, convective mixing may not be rapid enough to cope with the rate of air entry through leaks, and forced mixing will be required to achieve the desired even distribution.

Forced Mixing

Forced mixing is used in situations where natural convection is weak and cannot achieve adequate fumigant distribution. Forced mixing is used particularly for

short exposures as with methyl bromide treatments. It is also used to prevent 'layering', which occurs when a dense fumigant vapor is added to an enclosure without adequate mixing.

Special fans can be used for forced mixing of fumigants. In the case of methyl bromide, gas is released by distributing through pipes at different points at the top of a stack.

Sorption

The rate at which a fumigant moves through the commodity (grain, etc.) is influenced by its sorptive behavior. This is important to achieve a particular level of concentration of a fumigant to achieve insect control as well as for the removal of the fumigant at the end of fumigation to avoid undesirable residues.

Diffusion

Diffusion is a molecular phenomenon. No bulk gas movement occurs. The molecules, which are always in thermal motion, disperse from a concentrated to a more diluted system because of their velocity. Diffusion has a pronounced effect only over distances of less than a few centimeters and is normally insignificant compared to convective mixing. It is important, however, in the penetration of packed commodities.

The rate of diffusion is inversely related to the molecular weight of the fumigant. In a grain bulk, diffusion is about one-third of that in air.

Implications of Forces Affecting Gas Loss & Distribution

Various forces affecting gas losses and distribution have implications for enclosure design, which, in turn, have bearing on the success of fumigation operations. It can be seen that:

- Sealing is required to prevent gas losses from wind and the stack effect. Gas loss can result in lowering fumigant concentrations in localized regions, resulting in sub-lethal dosage and the development of resistant pest strains. Leaky enclosures may also be health hazards.

- To restrict gas losses, temperature changes should be minimized by painting the enclosure white or by shading, insulating, etc.

- Forced mixing may be required with highly sorbed fumigants or when convection currents are too slow to disperse the fumigant throughout the enclosure in a time that is short compared with the planned exposure period.

- Tall enclosures such as silo bins are likely to retain the gas less well than short ones because of the stack effect.

- It is important not to provide a through path between leaks in an enclosure when the gas loss is to be restricted, but useful when gas loss is to be encouraged, such as on venting after an exposure.

- Care must be taken to ensure that the fumigant is fully desorbed after a fumigation.

Safety Considerations

1. The basic safety principle in the conduct of fumigation is that persons should not enter any area containing any significant content of the fumigant. All operations should be planned to meet this requirement. Appropriate modifications may be made to fumigation equipment and enclosures to meet this criterion. This particularly concerns application of the fumigant and subsequent opening of the enclosure for airing. These are the operations during which the greatest risk occurs of accidental exposure to harmful concentrations of fumigant. Because of the risk of accidental exposure, protective equipment must be worn as appropriate and be available for rescue purposes.

2. Fumigation operations must not be carried out by an untrained team. There should be at least one trained and experienced person available at the site who should supervise the operations.

3. There should never be less than two persons present during the introduction and removal of a fumigant whether the operation is a small or a big one.

4. When fumigators are required to enter fumigation enclosures that are difficult to access, safety harnesses and lifelines must be worn. Similarly, when fumigators are required to enter areas where there is the possibility of exposure to high air content of a fumigant, a breathing apparatus of the right type must be worn. Make sure that the canister used with the full face respirator is not out of date (useful life expired) or physically damaged.

5. Fumigation in transit should not be carried out on ships which are not approved for such process by the flag State Administration.

6. Fumigation 'Warning Signs' should be prominently displayed on any building, vessel, or enclosed space under fumigation with the name of the fumigant and date of commencement of fumigation.

PRINCIPLES AND REQUIREMENTS OF METHYL BROMIDE FUMIGATION

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Introduction

Fumigation is the use of insecticidal gases to kill pests through their respiratory system. Fumigants possess the ability to penetrate and diffuse in all parts of an enclosure and are, therefore, potentially lethal to all forms of life in all parts of the enclosure, provided adequate concentrations of the gas are maintained for the required duration. Fumigants generally leave negligible residues in treated materials when used correctly and efficiently. However, indiscreet use and repeated fumigations can cause accumulation of significant residues. Another advantage of fumigation as a pest control tool is the convenience with which an infested commodity can be disinfested without moving it.

Fumigants can be divided into the following three classes:

Solid based fumigants. Hydrogen phosphide (PH_3) or phosphine gas is the well known example of this class. It is produced on the spot from the solid materials aluminum or magnesium phosphides in the presence of moisture in the air which reacts with these materials in the following way:

$$AlP + 3H_2O \text{ ---- } Al(OH)_3 + PH_3$$

$$Mg_3P_2 + 6H_2O \text{ ---- } 3Mg(OH)_2 + 2PH_3$$

Liquid fumigants. Insecticidal chemicals which are liquids at normal temperatures and pressure but vaporize quickly when sprinkled, constitute this class. Liquid fumigants are no longer in use because of their carcinogenic properties. EDCT - a mixture of ethylene dichloride and carbon tetrachloride, can be mentioned as an example of this class used in Pakistan in the mid-fifties. There are other liquid fumigants besides EDCT which have also been used in the past.

Low boiling point fumigants. Low boiling point fumigants are marketed as liquids under pressure in cylinders or cans. The well known example of this class is methyl bromide which is also the topic of discussion here.

Methyl Bromide Fumigation

Methyl bromide is one of the two most common fumigants presently being used for insect pest control in agricultural commodities (the other one being phosphine). The following factors are of particular importance in determining its effectiveness:

- Proper sealing leading to good retention of gas;
- Even mixing of gas within the enclosure;
- Appropriate periods of exposure to gas.

Physical properties of methyl bromide. Physical properties of methyl bromide are summarized below:

Chemical formula		CH_3Br
Boiling point		3.6 degrees centigrade
Molecular weight		94.94
Specific gravity :		
	Gas	3.27 at 0^oC (Air = 1)
	Liquid	1.73 at 0^oC (Water at 4^oC =1)
Threshold Limit Value (TLV)		15 ppm
Conversion factor, g/m^3 to ppm (30^oC)		260

Methyl bromide is a powerful organic solvent, particularly for natural rubber. It is odorless at fumigation concentrations. That is why it is usually marketed mixed with 2% chloropicrin which acts primarily as a warning gas.

Availability of methyl bromide. Methyl bromide is marketed in containers and is released from them in the following manners:

a) cans : by use of the special applicator,

b) cylinders: discharged by the pressure inside the cylinder through filter and to a system of piping,

c) vaporizer: discharged by pressure from the cylinder through a vaporizer of sufficient size.

To ensure vaporization at less than 80^oC, the pressure in the cylinder is important. During use however, as the liquid methyl bromide is released, pressure in the cylinder decreases, thus slowing down the discharge rate of methyl bromide. This, in turn, reduces the efficiency of vaporization at the jets. The cylinder must therefore be pressurized prior to release of methyl bromide or, alternatively, pressure must be maintained during discharge using a compressor (Figure 4). In case the pressure in the cylinder drops below 40 psi (2.8 kg/cm^2), delivery should be stopped and the cylinder re-pressurized.

Since methyl bromide gas is more than three times heavier than air, its density increases by cooling which occurs during vaporization. The gas will thus tend to sink down to the bottom of the enclosure. This can be avoided by using any of the following methods:

a) By releasing the gas at the top using a system of piping and jets so that gas sinks downward, passing through the commodity (See Figure 1);

b) Application through a vaporizer;

c) The use of a recirculation or fan system so as to improve distribution and penetration.

Important Considerations. The various situations in which methyl bromide might be used and the important considerations, which must be kept in view in each case, are summarized below:

	Situations	Consideration
a)	Stacks under gasproof sheets	- Piping layout and jets - Walls or channels - Sheeting and sealing
b)	Space or "whole-godown" fumigation	- Adequate distribution - Retention of gas and sealing
c)	Chamber-type fumigation i) Atmospheric fumigation ii) Vacuum fumigation	- Correct loading - Dosing and circulation - Aeration
d)	Silos	- Forced circulation - Leakage
e)	Ships	- Adequate distribution - Retention of gas in treated areas - Hazards to crew - Delay and costs
f)	Flour and other finely divided commodities.	- Vaporization of fumigant - Residues

Fumigation of bag stacks. One of the common applications of methyl bromide is for the fumigation of bag stacks after covering them with gasproof sheets. These stacks should be properly built on an impermeable floor, leaving appropriate gangways on all sides. The top of the stack should be flat. The stack should preferably be in a rectangular shape. More than one gasproof sheet could be used, if required, to cover the stack by using the "rolled joint" technique. Methyl bromide is applied from the top of the stack using an appropriate system of pipes and jets (see Figure 1). Each jet should be positioned to discharge into a pit or channel, with sufficient distance between jet and bag to avoid wetting of the commodity in bags with methyl bromide (Figure 2). For application of methyl bromide, the gas cylinder is placed on a platform scale with one side connected to a compressor and the other side to the piping system. The entire stack is covered with gasproof sheets with free ends duly secured to the floor under the weight of sand snakes. The whole system of application is shown in

Figure 4. It is desirable to first apply about 10% of the dose to detect leakage, if any.

GSRL, in collaboration with NRI of UK, conducted some trials at RECP's Bins Qasim Complex near Karachi on methyl bromide fumigation of bagged rice. For this purpose, methyl bromide was applied by two methods on each of the two stacks of bagged rice, each containing 200 tons of milled rice in 95 kg jute bags. Dimensions of each stack were 34 x 25 x 12 ft, giving a stack a volume of 10,200 cu ft (289 m^3). The piping system for application of methyl bromide was laid as shown in Figure 1C. The sampling points for monitoring the concentration of gas during bag stack fumigation are shown in Figure 3. For this purpose, nylon capillary tubing was used. All the sampling points were in free space outside the bags except for one at the bottom of the stack side (position 4) in which the tubing was pushed inside the bag. Gas was monitored by thermal conductivity meter.

Two methods of applying methyl bromide were used. In the first, (Fumigation I) 10 lbs (4.54 kg) of methyl bromide was applied to the top of the stack using a piping arrangement as shown in Figure 1C. In the second, (Fumigation 2) 20 lbs (9.08 kg) of methyl bromide was applied by inserting pipe from the cylinder directly into the stack at mid point on all four sides at a height of about five bags from the floor. In Fumigation I, the liquid fumigant was vaporized through jets at eight points. No attempt was made to vaporize methyl bromide in Fumigation 2. Prior to the application of fumigant, the stacks were covered with gas-proof sheets duly secured to the floor of the godown with overlapping sand snakes.

Concentration x time (Ct) products for methyl bromide at seven sampling points in Fumigations 1 and 2 are shown in Figure 3.

It is evident that in Fumigation 1, good distribution of gas was achieved at both the bottom and top of the stack (Figure 3a). However, in Fumigation 2, there was a large difference in concentration of gas between bottom and top levels. The bottom received a massive initial dose in one case exceeding 100 mg per liter while the top received only a little gas (Figures 3b and 3c). This is due to the fact that methyl bromide, being heavier than air, sinks to the bottom of the stack from where it either leaks or diffuses out.

In Fumigation 1, a Ct product of 235 to 445 mg hour/liter over a period of 24 hours was achieved. This is well in excess of 150 mg hours/liter requirement to kill insect pests at 25°C. On the contrary, in Fumigation 2, all the sampling points, other than bottom layers, showed an inadequate Ct product over 24 hours despite the application of a two times higher dose than the dose used for Fumigation 1. Even after 48 hours, the top parts of the stack had received 135 mg hour/liter dosage which is not quite sufficient to kill all the beetle pests.

<u>Fumigation in Chambers at Atmospheric Pressure</u>. Chambers are normally used to fumigate products which require only short exposure to methyl bromide. Such products get damaged if exposed to methyl bromide for long periods. The chambers should be of sound construction having walls, floor, roof, and doors impermeable to methyl bromide. Fans will be required to achieve even mixing of

the gas while treating the commodity and for removing the fumigants after treatment.

Fumigation in Large Silos. The only way to achieve adequate mixing/distribution of methyl bromide within a large silo is through forced circulation.

Ship Fumigation. Ship holds can be fumigated with methyl bromide, though it is a difficult and hazardous operation. The uniform distribution of gas can only be achieved by using a circulation fan. An efficient exhaust system is also required for the removal of gas after fumigation. It is necessary that the crew not be permitted on board during the course of fumigation until the entire fumigant has been removed.

Dosages of Methyl Bromide

For normal fumigation, the amount of fumigant and exposure times should be worked out to yield a Ct product (see Appendix IV) of at least 150 g hours/m^3 at temperatures of 25°-29^oC. In cases where ambient temperature is 30^oC or above, the required Ct product should be at least 100 g hours/m^3.

For quarantine purposes, the requirements of Ct products are generally greater than those for normal commercial storage. For quarantine against *Trogoderma granarium*, for example, a Ct product of more than 400 g hours/m^3 will be required.

Methyl bromide is sorbed considerably by different commodities. Therefore, allowance must be made for this factor as well, while calculating the quantity required to achieve the desired Ct product.

The quantity of methyl bromide needed (in grams) for a given situation of fumigation operation is worked out by combining both the space dose (S) and the commodity dose (M). For this, the following formula is used:

Methyl bromide needed (g) = S x total volume of enclosure (m^3) +
M x tonnage of commodity

where S and M are the prescribed doses (in grams) per cubic meter and per ton respectively (see the table below).

Given below are the dosage parameters for methyl bromide application to various commodities for insect pest control. These values are given as guides and should be adjusted in light of experience, based on results of monitoring fumigation and the Ct products achieved (see Annexure) under actual field conditions.

Commodity	S (g/m^3)	+ M (g/tonne)	Exposure time (hours)
Rice, paddy and barley	10	0	24
Wheat, oats, maize, & pulses	10	20	24

Sorghum	10	40	24
Flour, nuts, oilseeds, and rice bran*	10	60	48
Oilseed cakes and meals*	10	120	48

* These commodities sorb methyl bromide heavily and should not, therefore, be fumigated with this gas unless required by contractual obligations or quarantine reasons. Phosphine gas is preferred for fumigation of these commodities.

Monitoring Concentration of Methyl Bromide. Monitoring the gas concentrations at intervals is necessary to know its distribution/mixing in the enclosure and to work out the Ct product achieved during the fumigation. An adequate number of readings are required to determine Ct product achieved at various points which indicate the effectiveness of fumigation. Such monitoring of gas is extremely important in cases of space/ship and silo fumigations.

Methyl bromide gas concentration is usually measured by thermal conductivity meters, infrared gas analyzers, and interferometers. There are other specialized meters which have only recently been developed.

Safety Measures

Since methyl bromide is a highly toxic substance, it should only be handled by persons who have received proper training in its safe and correct use. While using this gas, the following items of safety should be available at each fumigation site:

a) Respirator fitted with appropriate canister for methyl bromide;

b) Halide leak detector lamp; and

c) Gas detector meter

The fumigation site should be away from the living quarters and working places. At the time of fumigation, the persons involved in fumigation must have a respirator which must be worn unless tests indicate that it is safe to remove it. During fumigation, a halide detector lamp should be used to detect leakage, if any. The lamp can indicate the concentration of methyl bromide in the working place by changes in the color of flame. The flame color at 10 ppm concentration is a very faint green, at 30 ppm it is a light green, at 60 ppm it is a moderate green, at 100 ppm it is a strong green, at 240 ppm it is a strong greenish blue, and at 500 ppm it is a strong bluish green.

During aeration, respirators should again be worn for safety reasons as the methyl bromide gas is toxic to humans at even very low concentrations. The threshold limit value (TLV) for methyl bromide is 15 ppm. Exposure to 100-400 ppm for few hours can lead to death. The gas can burn skin on contact and can accumulate fluid in lungs on inhalation. It can also damage the nervous system.

Other main poisoning symptoms include nausea, vomiting, dizziness, headache, abdominal pain, mental confusion, convulsions, etc. If contacted accidentally, the contaminated part should be washed immediately with water and the effected person should immediately be taken to a hospital for medical aid.

There is no known antidote for methyl bromide. Poisoning symptoms may be delayed up to 48 hours after exposure.

A C K N O W L E D G E M E N T S

In preparation of this article necessary help has been obtained from the following books/reports. Their authors/publishers are gratefully acknowledged.

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FIGURE 1

PIPING LAYOUTS FOR APPLICATION OF METHYL BROMIDE IN BAG STACKS OF A COMMODITY TO BE FUMIGATED

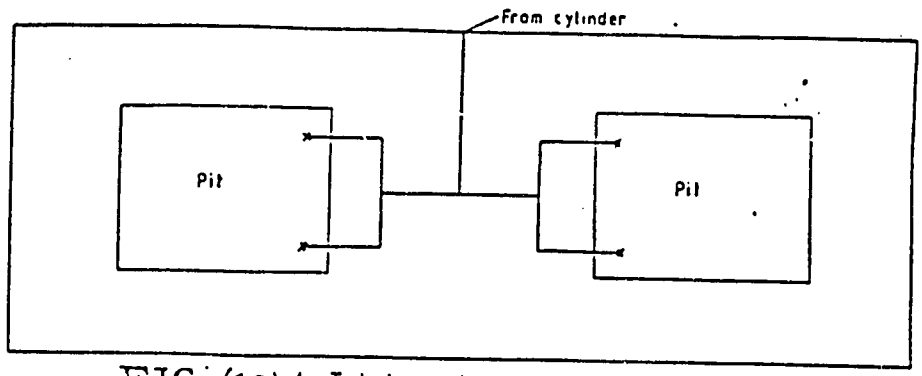


FIG. (1a) 4-Jet Layout

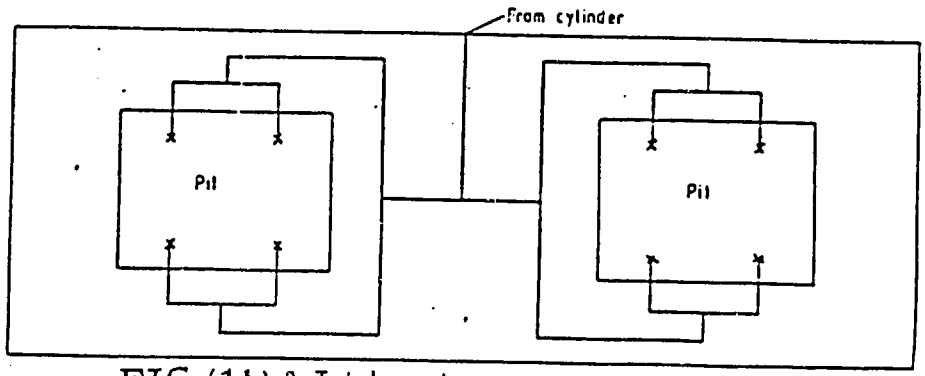


FIG.(1b) 8-Jet Layout

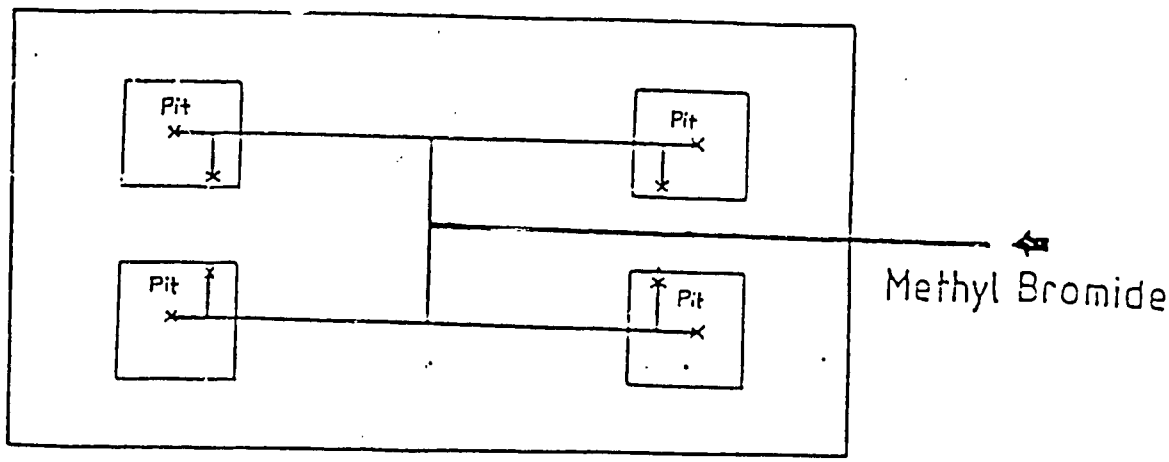
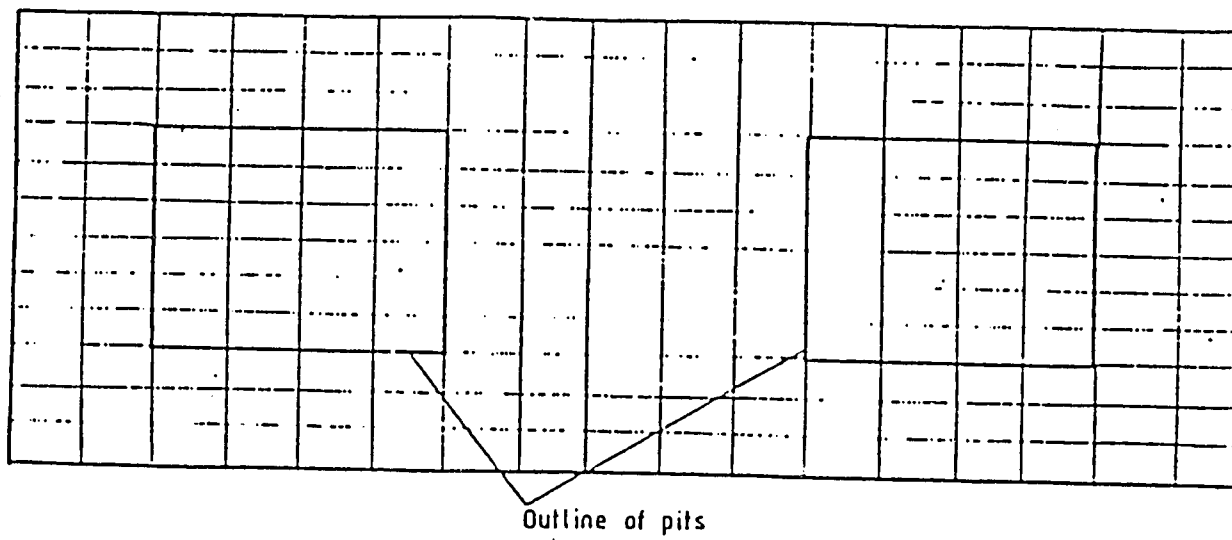


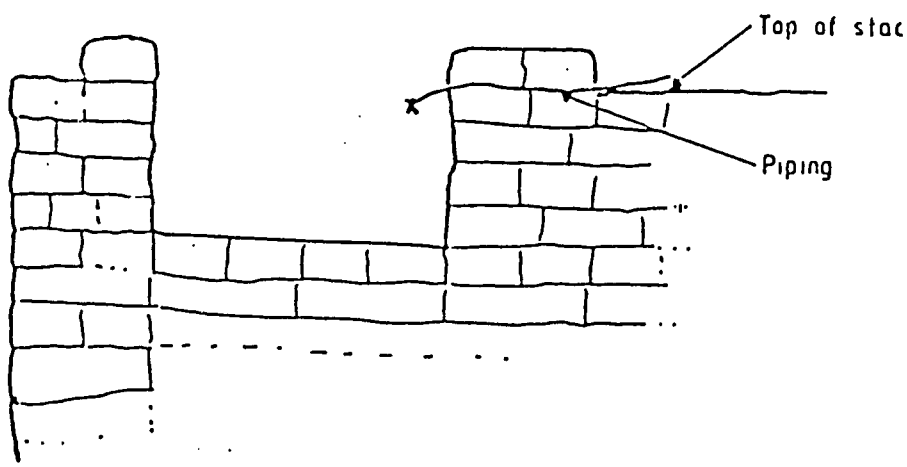
FIG.(1c) 8-Jet Layout

FIGURE 2

POSITIONS AND A CROSS SECTION OF PITS MADE AT THE TOP OF A BAG STACK FOR VAPORIZATION OF METHYL BROMIDE



Top Layer of Stack



Cross Section of Pits

FIGURE 3

CT PRODUCT (MG HOURS/LITER) ACHIEVED IN EXPERIMENTAL FUMIGATIONS WHERE GAS WAS INTRODUCED AT THE TOP THROUGH PIPING (FUMIGATION-1) AND FROM SIDES AT MID STACK HEIGHT (FUMIGATIONS 2 & 3).

FIG. 3a

C X T PRODUCT AFTER 24 HOURS IN FUMIGATION 1

(DOSAGE APPLIED = 10 lbs)

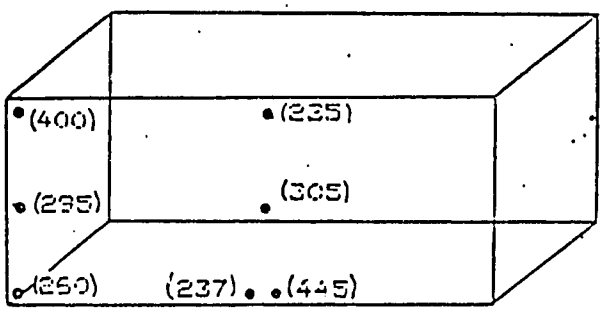


FIG. 3b

C X T PRODUCT AFTER 24 HOURS IN FUMIGATION 2

(DOSAGE APPLIED = 20 lbs)

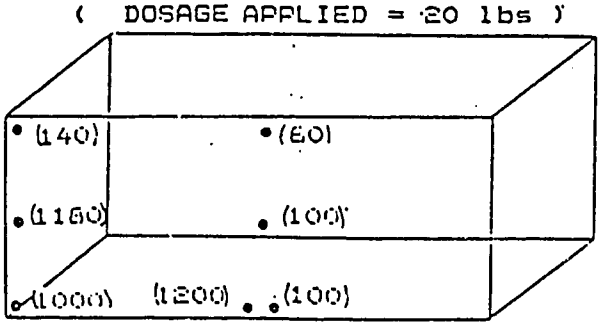


FIG. 3c

C X T PRODUCT AFTER 48 HOURS IN FUMIGATION 3

(DOSAGE APPLIED = 20 lbs)

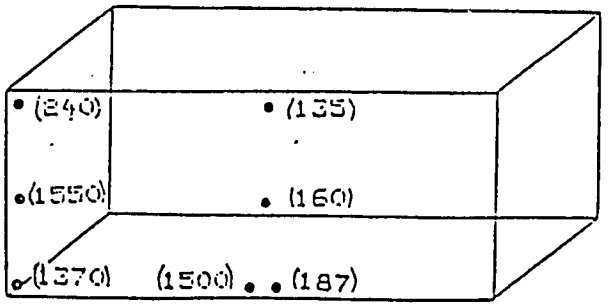
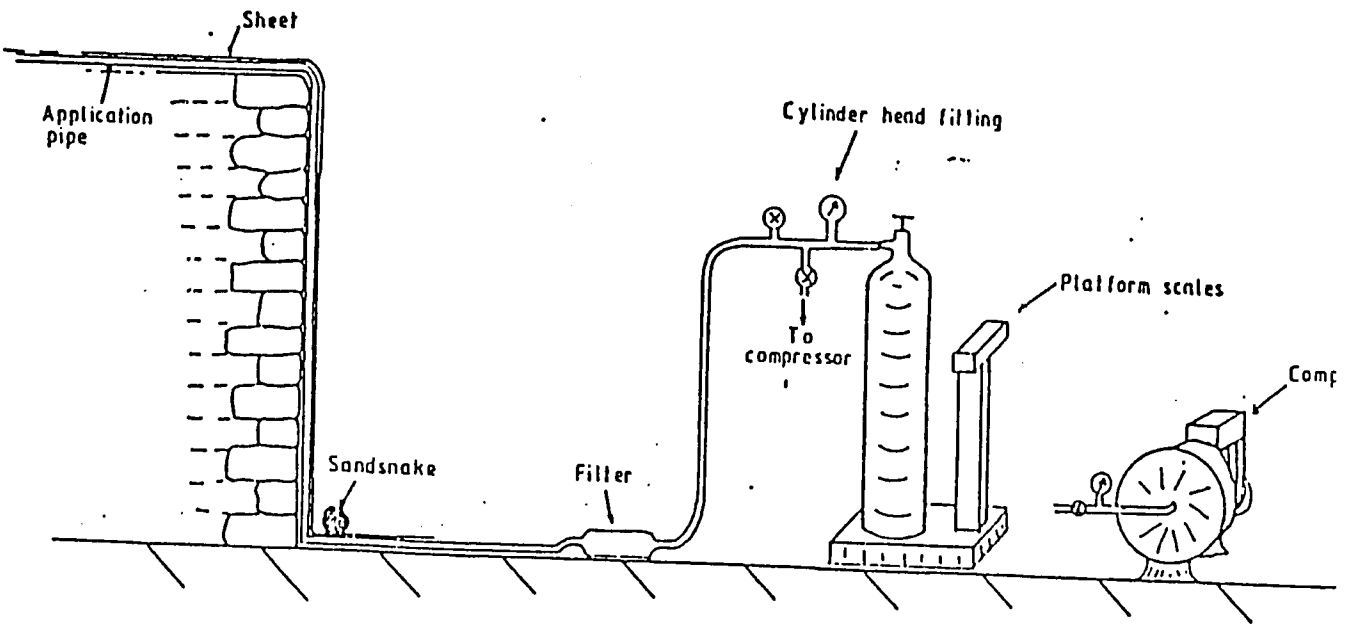


FIGURE 4

THE SETUP OF A PROPER METHYL BROMIDE SYSTEM FOR ITS INTRODUCTION IN A BAG STACK.



Annexure

METHOD FOR THE DETERMINATION OF CT PRODUCT IN METHYL BROMIDE FUMIGATION

Effective fumigation with methyl bromide can be ensured only if the recommended Ct product has been achieved. The Ct product is calculated by multiplying the concentration of fumigant observed in grams per cubic meter (g/m^3) by the time in hours (h) for which the gas remains in the enclosure. The Ct product is thus recorded in grams multiplied by hours per cubic meter (grams h/m^3).

In actual fumigation operations, gas concentrations in the enclosure vary with time. A Ct product as achieved is, therefore, calculated by adding the component Ct products and multiplying by the time interval between them. *The best approximation of true Ct product is obtained with a large number of concentration observations in an exposure.* Due to practical constraints only a limited number of observations can be made but it should be measured after 2, 4, 12, 24, 36, and 48 hours after dosing. To calculate a Ct product, at least two measurements must be present and the first reading should be taken after gas mixing is completed (eg. at least 2 hours after dosing a bag stack).

In fumigation under gas-proof sheeting, the Ct product can be calculated by using the following formula:

$$Ct_{n,n+1} = (T_{n+1} - T_n) \times C_n \times C_{n+1} \quad (g.h/m^3)$$

where

T_n	= Time when the first reading was taken in hours
T_{n+1}	= Time when the second reading was taken in hours
C_n	= Concentration reading at T_n in g/m^3
C_{n+1}	= Concentration reading at T_{n+1} in g/m^3
$Ct_{n,n+1}$	= Calculated Ct product between T_n and T_{n+1} in $g.h/m^3$

The Ct product obtained from a series of sequential readings is then added to calculate the cumulative Ct product for the whole exposure period. The final value is the actual value which indicates the success or failure of a fumigation. Observations containing a zero or unquantifiably low concentration cannot be used in such calculations.

Example of Ct Product Calculation

Most commercial fumigators use under-sheet method of fumigation for which the calculations could be as follows:

Time (hours)	Time step (hours)	Conc. (g/m^3)	Ct product ($g\ h/m^3$)	Cumulative Ct	Comments
0.0	-	-	-	-	End of gassing
2.0	2.0	20.0	*	0.0	Ct cannot be calculated
4.0	2.0	15.5	35.2	35.2	
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 cannot be calculated
48.0	12.0	0.0	**	155.9	Ct cannot be calculated

* Ct product cannot be calculated as the first reading is nil.

** Ct for this time period cannot be calculated as final value is less than a quantifiable concentration.

Example of Calculation

Using above formula for the time period from 2 to 4 hours,

Ct product = (4.0 - 2.0) x (20.0 x 15.5)

= 2.0 x 310.0

= 2.0 x 17.6

= 35.2 gram h/m^3

That is, the Ct for the period between the observations = the time between the observation x the square root of the product of the concentrations at the two observation times.

PHOSPHINE FUMIGATION

By

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Introduction

Phosphine is considered to be an ideal gas for use as a fumigant to control insects in many stored grain products. Safety in application, easy transportation, high toxicity against insect pests, and easy mixing are the major factors which support the use of phosphine throughout the world. Almost no equipment is required in its application. Ready availability of this gas is also important in its increasing use as a fumigant. This overall easiness has, unfortunately, led in some countries, to the adoption of some undesirable practices while undertaking phosphine fumigation. These include:

1. Inadequate sealing;
2. Sub-lethal dosage;
3. Short exposure period;
4. Inexperienced and untrained personnel.

These unsatisfactory practices result in repeated exposure of the pest species to sub-lethal dosage of phosphine which leads to insect resistance and consequently an increase in fumigation cost. The South-Asian sub-continent is known as the area where phosphine resistance has become a most important factor affecting the use of this gas as a fumigant.

At present, we have only two or three compounds which can be recommended as fumigants for food grains. This very limited number of fumigants makes it imperative that we retain effectiveness of those compounds to achieve benefits for as long as possible. This should be the main objective of any fumigation program.

Chemical Nature and Formulation of Phosphine

Phosphine is obtained from the reaction of metal phosphide (aluminum, calcium, magnesium, and zinc) with water. Only aluminum (Al) and magnesium (Mg) phosphide are recommended for direct use with grain under tropical conditions. Aluminum phosphide is preferred over magnesium phosphide because of a relatively slow release of phosphine.

Pure phosphine has no smell but some other chemicals are added in formulation to give out a warning smell and to decrease the rate of gas release, as well as to prevent fire hazards. Normally ammonium carbonate (NH_2COONH_4) and some waxes are added for this purpose. These chemicals, on exposure, release ammonia and carbon dioxide gases which give phosphine a garlic or carbide-like smell.

Phosphine is available under different trade names, like Agtoxin, Fumitoxin, Gastoxin, Detia, Delicia, Gas-EX-B, Celphos, etc. Despite different trade names the active ingredient present in all these products is similar.

Different forms of phosphine are available for fumigation purposes. The details are as follows:

i- **Tablets:** Each tablet weighs 3 g. Commonly an AlP tablet is 18 mm in diameter and 6 mm in thickness. On exposure to moisture in the air, each tablet releases 1 g of phosphine. Tablets are normally packed in gas-tight aluminum tubes or flasks. The number of tablets per pack varies from 10-480.

ii- **Pellets:** A pellet weighs 0.6 g, is 9 mm in diameter, and 7 mm in thickness, and on exposure to air, can liberate 0.2 g of phosphine gas (one-fifth of the yield of a tablet). The pellets are normally packed in aluminum flasks and each flask contains 166-1660 pellets.

iii- **Sachets:** Sachets are made of porous paper. Each weighs 34 g and can liberate 11 g of phosphine. They are normally packed in gas-tight tins which cannot be resealed after opening. Each tin contains 10-20 sachets depending upon its size.

<u>Dosage For Phosphine Fumigation</u>

Dosage is expressed as the product of concentration (C) of fumigant and the exposure time (t) or simply the Ct product. This relationship is simply presented as:

$$C \times t = K$$

Where "K" is the constant for level of response or mortality. This relationship showed that to increase the response (K), either or both values, C or t, have to be changed. This relationship may be good for other fumigants but not for phosphine. A more general relationship however, seems to be more practical for phosphine presented as:

$$C^n \times t = K$$

The exponent n is the toxicity index and its value for phosphine is less than one. Any change in 'n' will have less effect on 'K' or level of response. It means for increased mortality, the role of 't' or exposure period assumes higher importance.

To determine optimal exposure period for phosphine fumigation the following important factors are to be considered:

i- Species;
ii- Development stages; and
iii- Resistance level.

i-Species. The exposure time varies considerably for different species because each species responds differently to phosphine gas. The variable response may be due to different levels of natural or acquired tolerance against phosphine. The study conducted to determine optimum exposure time for control of resistant insects in Pakistan exhibited that Trogoderma granarium usually required a longer exposure period as compared to Tribolium castaneum and Rhizopertha dominica (Table-1).

ii-Development stages. It is known that different insect species and different stages (egg, larva, pupa, and adult) of the same species show a very wide range of tolerance. Egg and pupal stages are generally more tolerant than the larval and adult stages (Figure 1). Insects continue their development in the presence of gas. As such, their tolerance changes with time. Death results after a susceptible stage is reached, provided an adequate concentration of gas is maintained for a long period. This will enable a tolerant stage to enter a more susceptible stage. For example, for eggs to reach late egg stage or hatch, or for pupae to reach late pupal stage, or mould to adult.

iii-Resistance level. The major drawback in the use of phosphine is that insects can develop resistance to it. Resistance to phosphine has been detected in a number of developing countries. The major cause of development of phosphine resistance is under-dosing, which commonly takes place by fumigation in leaky godowns and by using inadequate doses by untrained personnel.

The first positive confirmation of fumigation failure due to phosphine resistance occurred in Bangladesh in 1981. Rhizopertha dominica, Cryptolestes ferrugineous, and Tribolium castaneum were noted to be highly resistant species. In Pakistan, studies were initiated by PARC to determine the resistance level in stored insects against phosphine. It was demonstrated that most of the common insect pests collected from different localities have become resistant to phosphine. The intensity of the resistance can easily be understood by the table on the following page.

To control the resistant insects, a comparatively longer exposure period than for the susceptible strains is essential. In order to determine the optimum exposure period for the control of resistant insects, a study is being conducted at Lahore. Under this study, insects from different localities were collected and exposed to a lethal concentration of phosphine for various numbers of days (3-15). The mortalities were noted for these exposure periods. It was observed that 100% mortalities were achieved in Trogoderma granarium, Rhizopertha dominica, and Tribolium castaneum after 5-14 days (Tables 2 and 3).

The exposure period recommended for phosphine has varied widely. In the past, a 3-7 day period was considered sufficient to obtain complete kill, but now there has been a trend of extending the exposure period while lowering the concentration. The minimum lethal concentration of phosphine maintained for long periods are now recognized as comparatively more effective than the high concentration held briefly, because it is known that a high concentration of phosphine for a short period of time induces narcosis in insects. This results in reduced phosphine uptake due to a low respiration and metabolic rate. Furthermore, some developmental stages are known to be very tolerant of high phosphine concentration. So keeping in view the present resistance level, and in light of recent

Species	Locality	Site	Resistance level (Times)
Tribolium castaneum	Karachi	Bin Qasim, RECP*, SGFG**.	2-67
	Lahore	Lahore, Manga	10-14
	Multan	Multan	8
	Mansehra	NWFP food godown	34-81
Rhizopertha dominica	Karachi	SGFG	3-80
	Hyderabad	SGFG	8-79
	Lahore	Pb. Food Dept.	3-6
	Sargodha	"	80
	Peshawar	NWFP Food Dept.	4.50
	Mansehra	"	5-72
Trogoderma granarium	Karachi	SGFG	11-18
	Multan	Pb. Food Dept.	15
	Muzafargarh	"	15-35

* Rice Export Corporation of Pakistan
** Sindh Government Food Godowns

studies, it is recommended that an exposure of 15-20 days to phosphine is essential for the achievement of complete control of both resistant and susceptible strains.

Dosage Rate.

In practice, the requisite number of AlP tablets is calculated on the basis of internal volume of the structure to be fumigated, including the head space (empty space over and above the space occupied by the commodity). However, in cases where head space is not involved, as under plastic sheets, the requirement of AlP is determined in relation to the quantity of the commodity.

Dose rate for phosphine fumigation is expressed in terms of grams of phosphine per cubic meter of space (g/m^3) or gram per metric ton of the commodity (g/mt). In space fumigation, the dose rate will be the same whether the store is filled completely, partially, or empty. Addition of extra tablets in a leaky structure will not compensate the loss rate.

The recommended dosage rate under Pakistan conditions is one tab/cubic meter when fumigation is being carried out in a structure having head space. The dose rate recommended according to quantity to be fumigated is two tablets per metric ton.

Note: One AlP tablet weighs one gram and gives off one gram of phosphine gas. Also note that 1 tablet = 5 pellets = 1/11 sachet.

Commodities Which Can be Fumigated With Phosphine.

Phosphine can be used to fumigate most agricultural commodities, animal feed, processed food, and other non food items, the details of which are given below:

a. Agricultural Commodities and Animal Feed

- Wheat, barley, rice, corn, seeds, sunflower, sorghum, millet, dates, almonds, cotton seeds, vegetable seeds, pulses, nuts, soybean

b. Processed Foods

- Cereal flour and bakery mixes, cereal foods (cookies, crackers, noodles, snack food, etc.)

- Cheese and its byproducts, dried and processed meat products, dried milk, non dairy creamers

- Dried or dehydrated fruits, processed nuts, processed tea, dried and dehydrated vegetables, yeast

c. Non Food Commodities

- Processed or unprocessed cotton, wool and other natural fibers or cloth, clothing, feathers, human hair, rubberized hair, leather products, animal hides and furs, tires, tobacco, wood and wood products, paper and paper products, dried plants and flowers, straw, and hay

Note: Under no condition shall any processed food, tobacco, and certain other of the non food commodities be allowed to come in contact with AlP tablets, pellets, or residual dust.

Procedures For Phosphine Fumigation

A. Fumigation of Bagged Commodities

a. Whole Store Fumigation

In this method, a commodity is stored in bag or bulk inside a structure, and the whole structure is fumigated. This is the most common practice of our food handling agencies. The normal step-wise procedure is as follows:

1. Clean the interior of the building by sweeping the floor, walls, and roof, and all the sweepings should be taken out and buried.

2. Any cracks in walls, floor, and roof should be repaired permanently with cement. If possible, the store's interior should be painted white.

3. All doors, windows, and ventilators should be checked carefully, and re-paired, if needed.

4. Calculate the volume of the godown by multiplying the length, width, and height in meters.

5. Arrange the number of tablets required at the dosage rate of one tablet/m^3.

6. Close all the ventilators, windows, and doors except the last one. Apply mud plaster to further supplement the gas tightness. The last door will be closed and sealed after spreading the tablets.

7. Spread all the tablets on the floor and top of the stack or put the tablets on some trays/craft paper and place them under the dunnage, if present. Care should be taken not to pile up the tablets on the floor or on the trays, this will mask the tablets present in the lower layer, and they will not have contact with air moisture and the gas will not be liberated.

8. Close and seal the last door.

9. The store should remain sealed for 15-20 days for better results.

Whole godown fumigation method requires a high degree of gas tightness for complete kill of insects. This practice should only be tried in well sealed structures and where the resistance level is very low. In scrutiny of this technique, it was observed that gas was leaked out within three days from a well-built godown at a PASSCO storage center (Figure 2), while another godown in the same complex having similar shape could hold the gas for six days (Figure 3), Addition of 2.5 times more AlP tablets in two successive doses could prolong the exposure period to some extent but the difference was not proportionate to the increase in the number of tablets applied. The whole store fumigation results showed the failure of this practice especially at those sites where insects have attained high tolerance against phosphine. At such places, continuation of this practice would not only increase the resistance problem, but also add up the cost incurred to disinfest the commodities. So whole godown fumigation should be abandoned, and commodities should be fumigated under polyethylene or plastic sheets to kill all forms of insects.

b. Under-sheet Phosphine Fumigation:

This is an effective and practical method for a successful fumigation. It is effective for small and large stocks. In this method, polyethylene sheets, PVC sheets, or other gas-tight plastic sheets are used to cover the commodities. The normal procedure for better retention of phosphine gas is described as under:

1. Spread a low density polyethylene sheet having a thickness of 0.2 mm on the clean and smooth floor.

2. Stack the bagged commodity on the pre-spread sheet in such a way that the sheet should be free about 2-3 feet from all sides.

3. Cover the commodity with similar sheets and roll up the peripheral ends with the underlay sheet and put some weight like sand snakes or bricks on the fold.

4. If more than one sheet is being used, the overlapping should be sealed with self adhesive tape or by using a heat sealing machine.

5. Calculate the number of AlP tablets according to the quantity of the commodity to be fumigated. The dosage rate should be two tablets/mt.

6. Total number of tablets should be divided into two halves and one portion should be thrown inside the enclosure by giving four incisions (one on each side) with the help of a blade or sharp knife. Then close these incisions with self adhesive tape.

7. After seven days from first application, open the previously made incisions, throw in the other portion of the tablets, and close the inlets.

8. Uncover the sheets after 15-20 days or when required afterward.

By using this method, the required lethal concentration of phosphine gas can be retained for more than 17 days (Figure 4).

B. Fumigation of Bulk Commodities

a. Fumigation of Horizontal or Flat Bulk Storage

Bulk commodities are sometimes stored and fumigated in flat storage, either in the form of open or covered. Open bulkhead is a typical example of horizontal storage. To fumigate such type of storage, the following procedures should be adopted:

1. Treatment of these types of storage may require considerable efforts, therefore, sufficient manpower should be available to

complete the work rapidly enough to prevent excessive exposure to phosphine.

2. Open the tablet containers outside in the case of indoor bulk storage.

3. Conduct fumigation during the cooler period of the day.

4. Plug all gaps between the floor and the side walls by placing polyethylene at the time of loading or by mud plastering from outside.

5. Find out the total weight of grain stored in the bulkhead. Arrange the number of tablets at the rate of two tablets/ tonne.

6. Uncover the grain by folding the gas-tight covers without actually pulling them down on the ground. This will save labor and enable the fumigators to re-spread the covers immediately after inserting the AlP tablets into the grain. If the grain has not yet been covered, the gas-proof sheets should be placed in position to cover the grain immediately after application of tablets.

7. Measure the top surface area of grain in the bulk-head, and calculate the points for insertion of AlP tablets. The tablets are to be inserted in the grain, about ten (or more) at a point, equidistant from each other. Insert the tablets with the help of an AlP tablet applicator (Figure 5). Insert tablets at depths ranging from about 1.0 meter in the periphery to 2.5 meters towards the center of the bulk-head (Figure 6).

8. Cover the grain surface with gas-proof sheets as soon as application of the AlP tablets is completed. Join the sheets by overlapping them at the ends and folding the ends together. Keep the folded ends under weight, such as that of sand snakes, etc.

9. Make the bulkhead as gas-tight as possible. If done properly, this method will hold phosphine concentration of above 200 ppm in all parts of the bulkhead for about 12 days (Figure 7).

10. Tarpaulin sheets should not be used to cover the bulkhead for fumigation because it cannot hold the phosphine gas (Figure 8).

b. Fumigation of Containers, Trucks, and Rail cars

Containers, trucks, or other transport vehicles can be fumigated before moving over public roads or railway tracks. The fumigation procedure is the same as in the flat storage facility. All leaks should be sealed before fumigation. The

AlP tablets may be spread over the surface in case of bagged commodity, or probed below the grain surface in case of bulk. The dosage should be calculated according to the internal volume of the container. After fumigation, the facility should be sealed, labelled, and responsible personnel notified.

c. Fumigation of Vertical Storage

Various kinds of vertical silos and hexagonal bins are important vertical bulk storage facilities in the country. Special attention should be given to the fumigating of these structures because many environmental factors affect the distribution and retention of phosphine gas. To fumigate a small bin or a hexagonal bin, the following procedures should be adopted:

1. Clean the bins before loading, if possible.

2. Each hex bin can hold 34-36 tons of grain. The number of AlP tablets should be 72 at the rate of two tablets per ton. The number of tablets will remain the same for a full or partially filled bin.

3. Fumigate the bin as soon as loading operation is completed.

4. AlP tablets should be applied by inserting in the grain and not by placing on the surface of the grain. Total tablets should divide into two equal portions and insert one portion at a depth of about 5 meters in the grain with the help of an AlP tablet applicator. Insert the second portion in the same way, at a depth of 1 meter in the grain mass.

By the application of this method, phosphine gas can be retained in all parts of the bin for about 12 days (Fig. 9). To increase this retention period, multiple dosing can be done. To do multiple dosing, divide the total number of tablets into four equal portions, and insert two portions at the said two depths. The other two portions will be inserted in a similar way after seven to eight days. For the insertion of the second dose, open the lid of the bin and insert the tablets at the said depths very quickly.

Detection and Measurement of Phosphine Gas

Detection and measurement of phosphine gas in an environment sometimes becomes very necessary, especially before entering a fumigated enclosure. Different methods and devices are being used to determine the concentration of phosphine in a particular environment.

i- Detector Tubes. These tubes contain a material that stains when air containing phosphine is passed through it. These tubes vary in sensitivity and accuracy. One tube is used for a single test and therefore, is expensive to use for monitoring a large scale fumigation.

ii- Haris Phosphine Meter. This meter was developed by TDRI, England. In this meter, phosphine gas is passed through the mercuric chloride

solution, which produces hydrogen and chloride ions which greatly increase the conductivity. This increase in conductivity is measured with a conductivity meter. The conductivity meter is so adjusted that one microsiemen is equal to one ppm (parts per million) of phosphine. This gives a direct and accurate reading.

iii- Cititox Phosphine meter. This meter was developed recently by Citi Technology Ltd., England. In this meter, phosphine gas is passed over a sensitive membrane fitted inside the gas receiving chamber. The phosphine gas molecules strike against this membrane and the number of striking molecules correspond to ppm of gas present in the enclosure from where the gas sample was drawn out.

iv- EC 80 Phosphine Monitor. This meter was developed by Bedfont Technical Instruments Ltd., England. It works on the same principal as the Cititox Meter. It is provided with a suction pump which can be connected directly to the gas sampling tube coming out of the enclosure where phosphine fumigation was done.

Safety Recommendations

1. Never fumigate alone. At least two persons trained in the use of phosphine must be present during fumigation, one must be the in-charge among them. Never allow an uninstructed person to handle phosphine formulations.

2. Wear dry gloves of cotton or other material if in contact with AlP tablets or dust. Aerate the gloves or contaminated cloths in a well ventilated area prior to laundering.

3. Open the AlP container in open air only. Never open in a flammable atmosphere.

4. Do not allow AlP tablets to contact liquid water.

5. Do not use phosphine when temperature is below 15°C.

6. Piling of AlP tablets or pellets, or addition of water may speed up the reaction, cause a temperature increase, and confine the gas so that ignition could occur.

7. Protect unused AlP tablets from excessive exposure to atmospheric moisture during application and tightly reseal the flasks after use.

8. Fumigated areas must be aerated to 0.3 ppm phosphine or less prior to reentry by unprotected workers.

9. Phosphine gas may react with certain metals to produce corrosion. This gas is corrosive to copper, copper alloy, and precious metals such as silver and gold. Sensitive equipment and items containing these elements should be removed or protected prior to fumigation.

10. Do not allow AlP tablets or their residual dust to come in contact with processed food.

11. Phosphine gas at normal dosages appears to have virtually no effect on the germination of seeds held at safe moisture content, but there is some evidence that it may reduce germinability if applied to high moisture grain.

12. Phosphine gas is highly toxic to humans, exposure to even small amounts should be avoided. Poisoning can result from inhalation of the gas or ingestion of tablets or pellets, but this gas is not absorbed through the skin. Inhalation of phosphine may produce symptoms including nausea, vomiting, diarrhoea, headache, and chest pain which can precede death due to massive accumulation of fluid in the lungs (pulmonary oedema). Very brief exposures to a concentration of 2.8 mg/L i.e 2000 ppm in air are lethal to humans. The hygienic standard is usually set at an average concentration of 0.3 ppm for a normal eight-hour working day.

13. Respiratory protection equipment must be available when AlP tablets are to be applied from within the structure to be fumigated.

14. A full-face gas mask with hydrogen phosphide (phosphine) canister may be used at levels up to 15 ppm. Above this level or in situations where the phosphine concentration is unknown, a self-contained breathing apparatus or its equivalent must be used.

TABLE 1

EXPOSURE PERIOD (DAYS) REQUIRED FOR ACHIEVING COMPLETE KILL IN VARIOUS SPECIES OF STORED GRAIN PESTS COLLECTED FROM DIFFERENT LOCALITIES

No.	Localities	Name of Species*				
		T.g.	R.d.	T.c.	S.o.	C.f.
1	Bahawalpur	7	-	-	-	-
2	Jhalarian	11	-	-	-	-
3	Hasilpur	9	11	12	-	-
4	Dunyapur	14	-	6	-	-
5	Manga (4)	11	5	14	-	3
6	Manga (9)	12	3	7	-	-
7	Badami Bagh	5	-	-	-	-
8	Murdekey	6	3	3	3	-
9	Islamabad-1	4	4	3	-	-
10	Islamabad-2	3	3	3	-	-
11	Sehala	3	-	-	-	-
12	Jhelum	3	3	3	-	-
13	Rawalpindi	6	3	3	-	-
14	Sargodha	5	3	3	-	-
15	Quaidabad	5	4	3	-	-
16	Jhang	3	3	3	-	-
17	Faisalabad	8	3	3	-	-

*
T.g. - Trogoderma granarium
R.d. - Rhizopertha dominica
T.c. - Tribolium castaneum
S.o. - Sitophilus oryzae
C.f. - Cryptolestes ferrugenius

TABLE 2

EXPOSURE PERIODS AND PERCENT MORTALITY IN DIFFERENT STRAINS OF TROGODERMA GRANARIUM AT PHOSPHINE CONCENTRATION ABOVE 240 PPM (0.33 MG/1)

Localities	Exposure period (days)											
	3	4	5	6	7	8	9	10	11	12	13	14
Bahawalpur	98	99.4	99.2	99.4	100							
Jhalarian	27	66	88	92	99	99.8	99.8	99.9	100			
Hasilpur	28	78	93	97	99.5	99.9	100					
Dunyapur	29	54	64	91	95	97	98	99.5	99.7	99.8	99.9	100
Manga (4)	89	78	82	88	97	99	99.9	99.9	100			
Manga (9)	13	21	43	66	76	92	95	93	95	100		
Murdekey	70	80	98	100								
Rawalpindi	88	95	99	100								
Faisalabad	60	72	87	95	99	100						

TABLE 3

EXPOSURE PERIODS AND PERCENT MORTALITY IN DIFFERENT STRAINS OF TRIBOLIUM CASEANEUM AND RHIZOPERTHA DOMINICA AT PHOSPHINE CONCENTRATIONS ABOVE 240 PPM.

Localities	Exposure period (days)											
	3	4	5	6	7	8	9	10	11	12	13	14
Tribolium castaneum												
Hasilpur	50	61	73	92	95	98	99	99	99.5	100		
Dunyapur	60	64	81	100								
Manga (4)	35	70	94	94	94	94	95	95	96	96	96.5	100
Manga (9)	42	50	60	75	100							
Rhizopertha dominica												
Hasilpur	52	78	83	91	95	97	98.5	100				
Manga (4)	98	99.5	100									

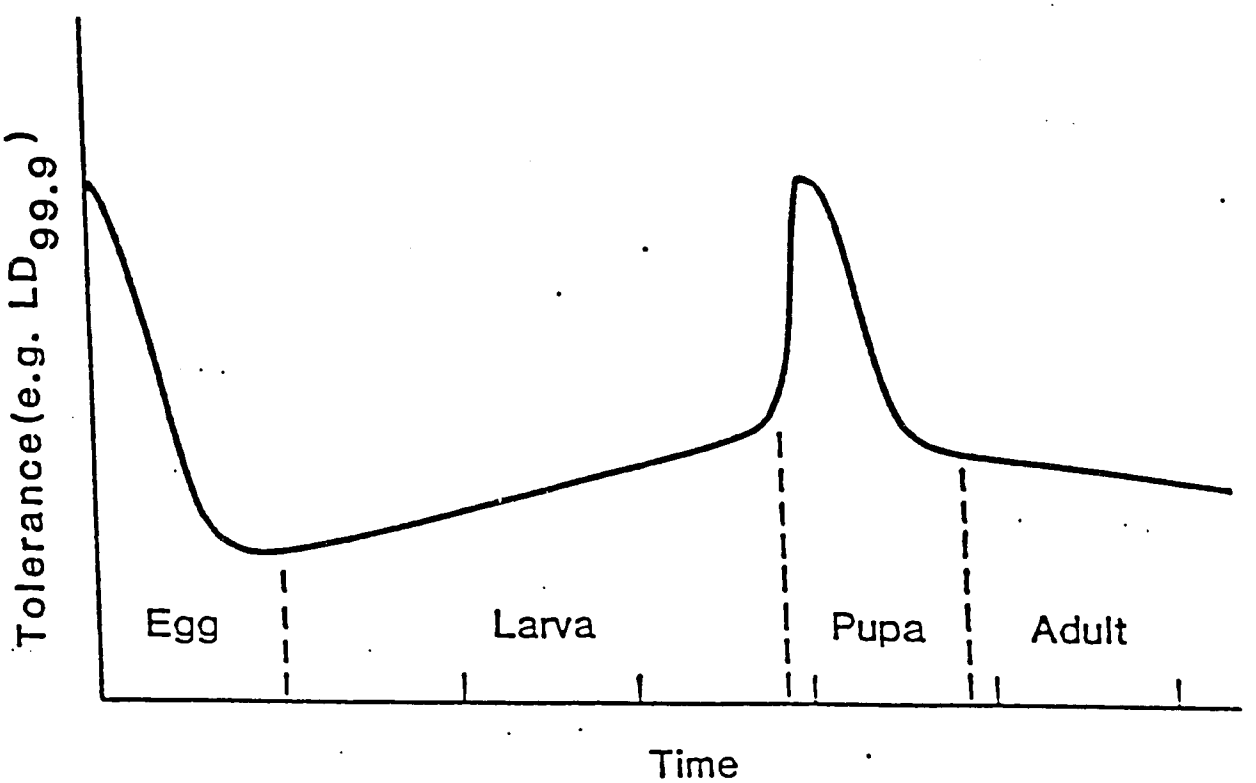

Figure 1. Schematic representation of the change in tolerance to phosphine of the different stages of stored product insects with time (from Winks, 1986).

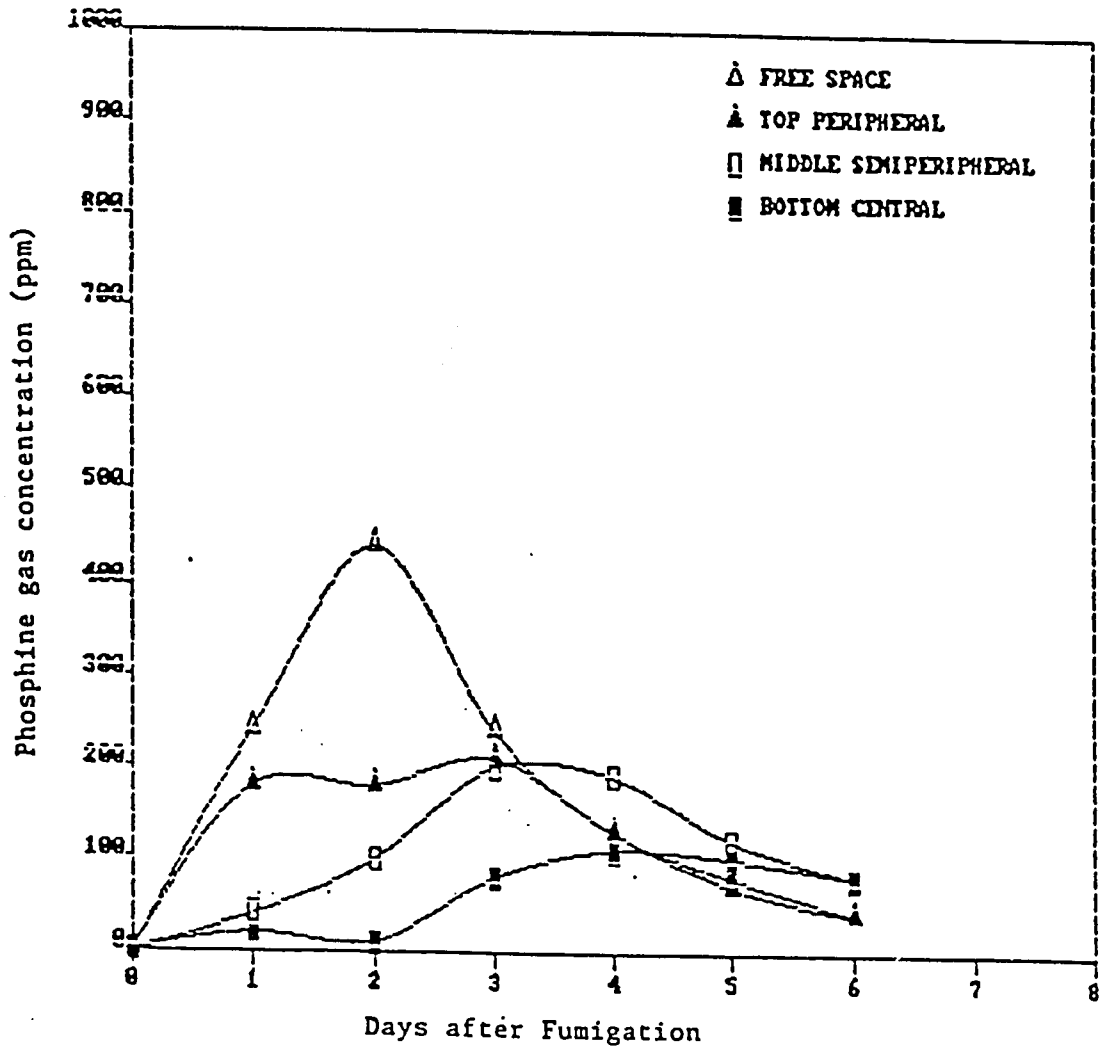

Figure 2. Phosphine gas concentration at various positions by using single dose of Alp tablets in house-type godown No. 4.

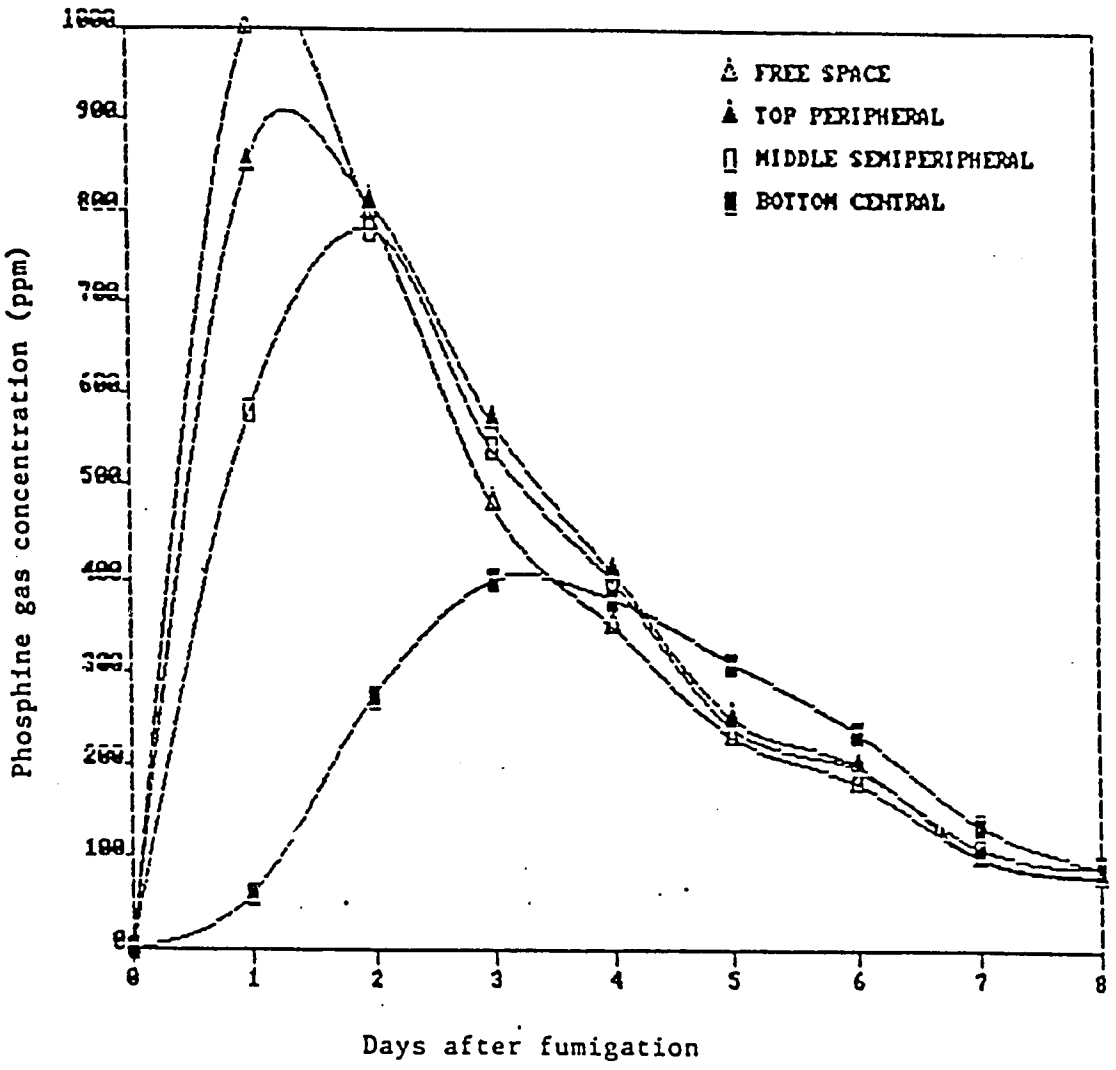

Figure 3. Phosphine gas concentration at various positions by using single dose AlP tablets in house-type godown No. 14.

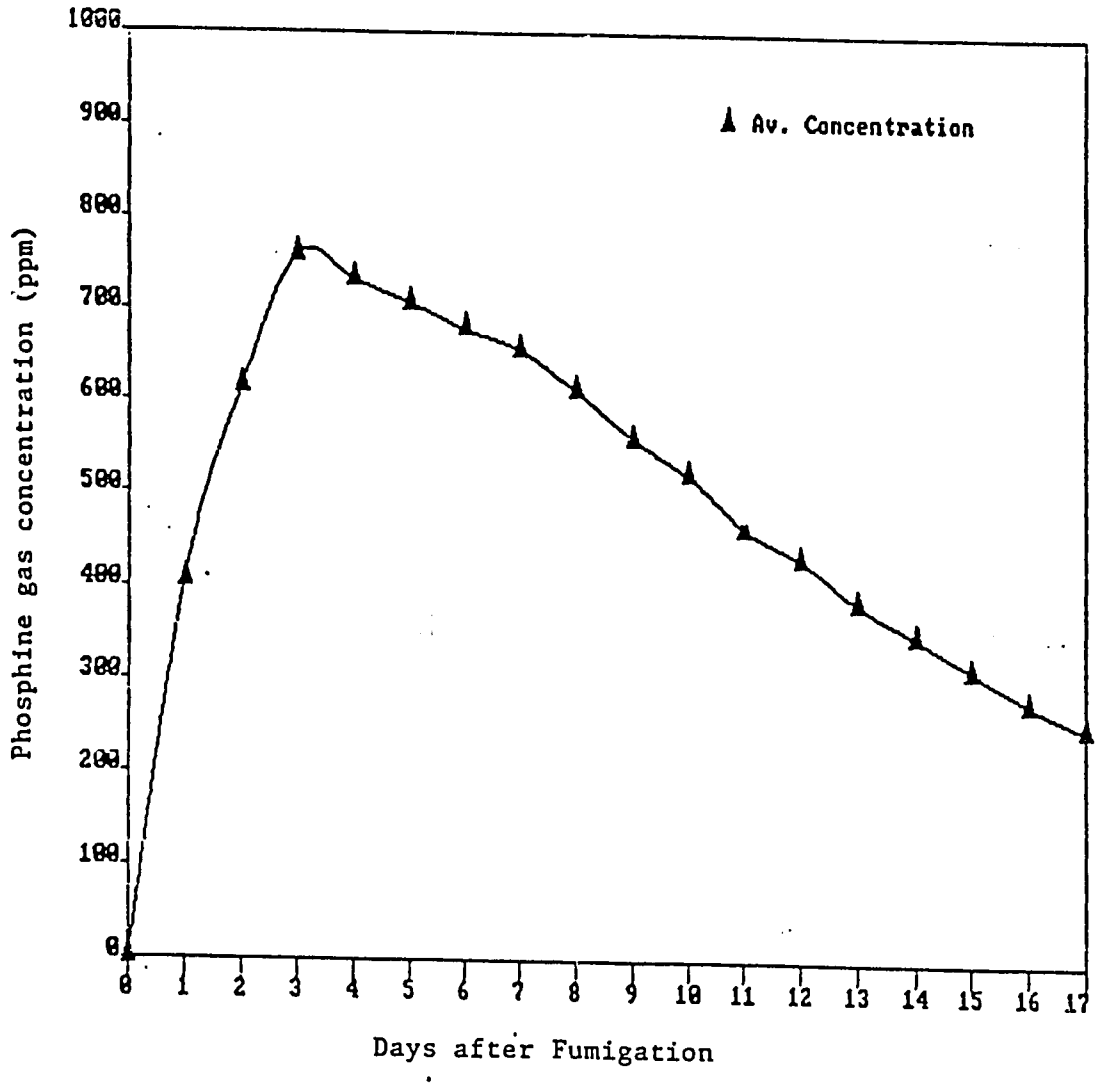

Figure 4. Concentration of phosphine in a stack fumigated under polyethylene sheets.

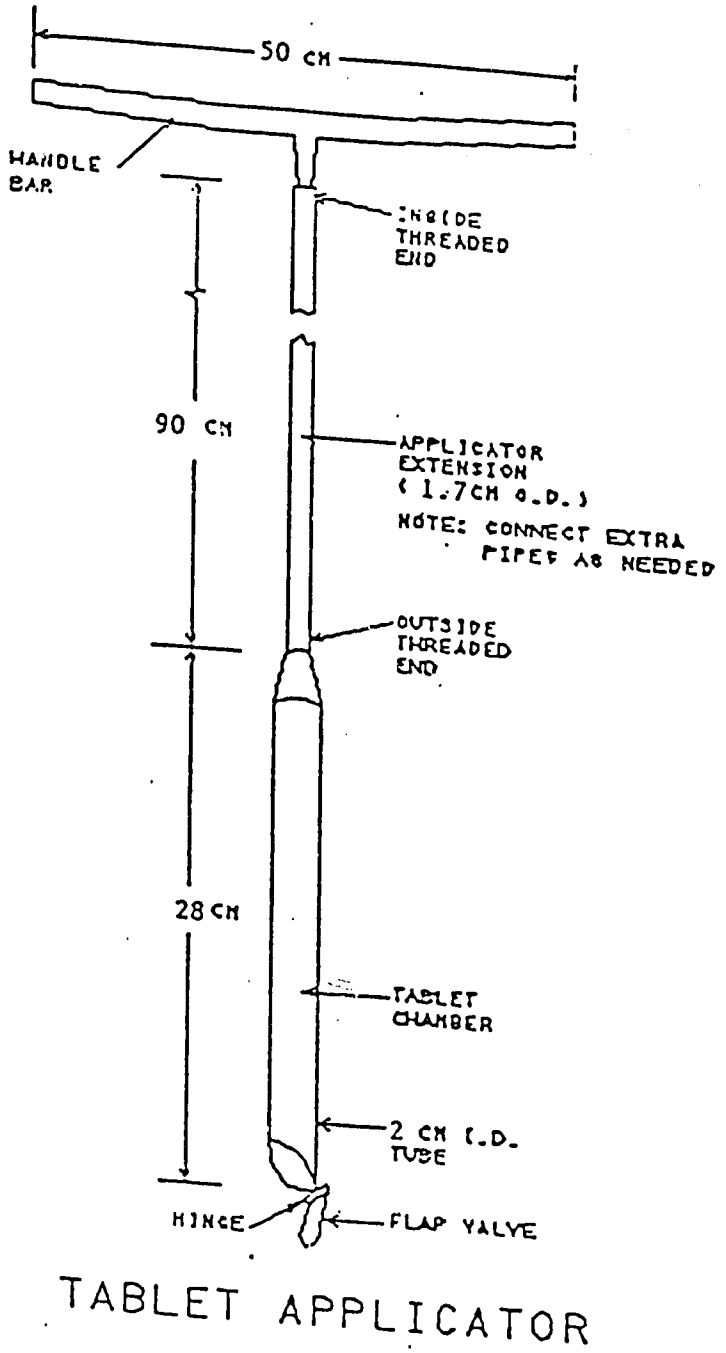

Figure 5. Measurements of AlP tablet applicator drawn to help its local manufacturing.

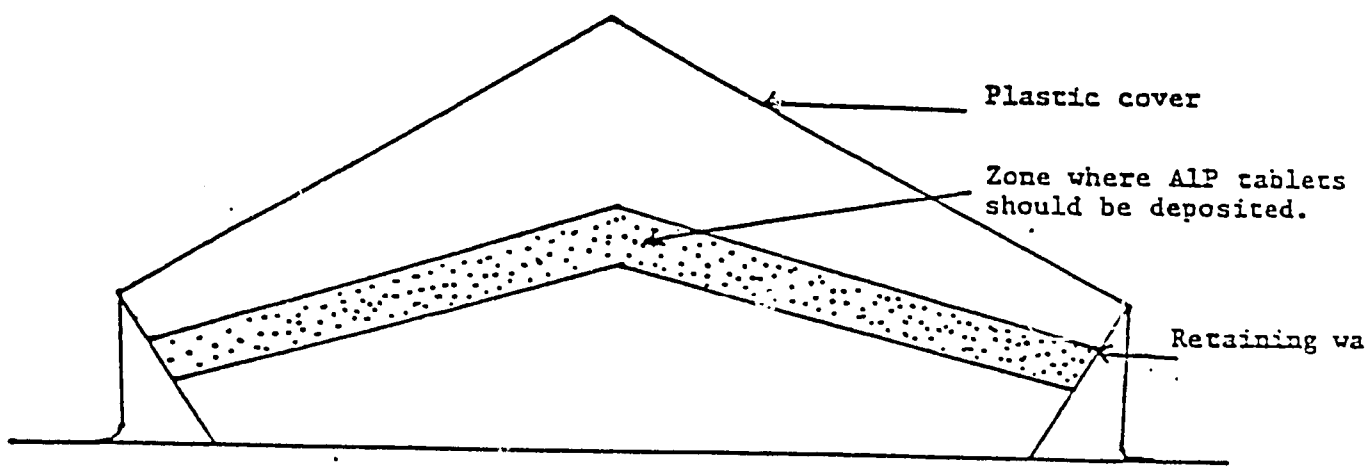

Figure 6. Cross section of open bulkhead showing the zone where AlP tablets were deposited.

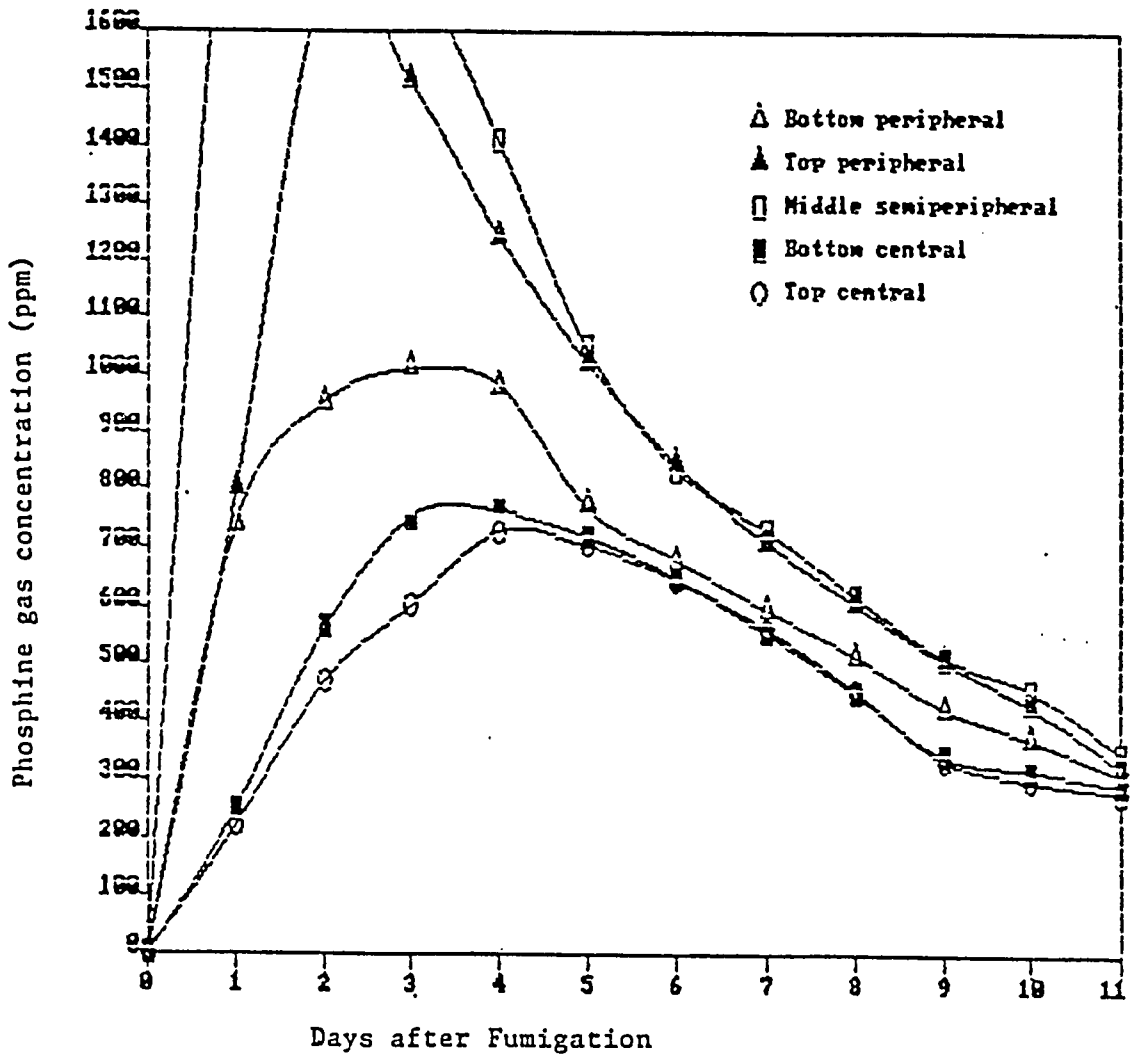

Figure 7. Phosphine gas concentration in bulk wheat loaded open bulkhead at Depalpur (No. 2).

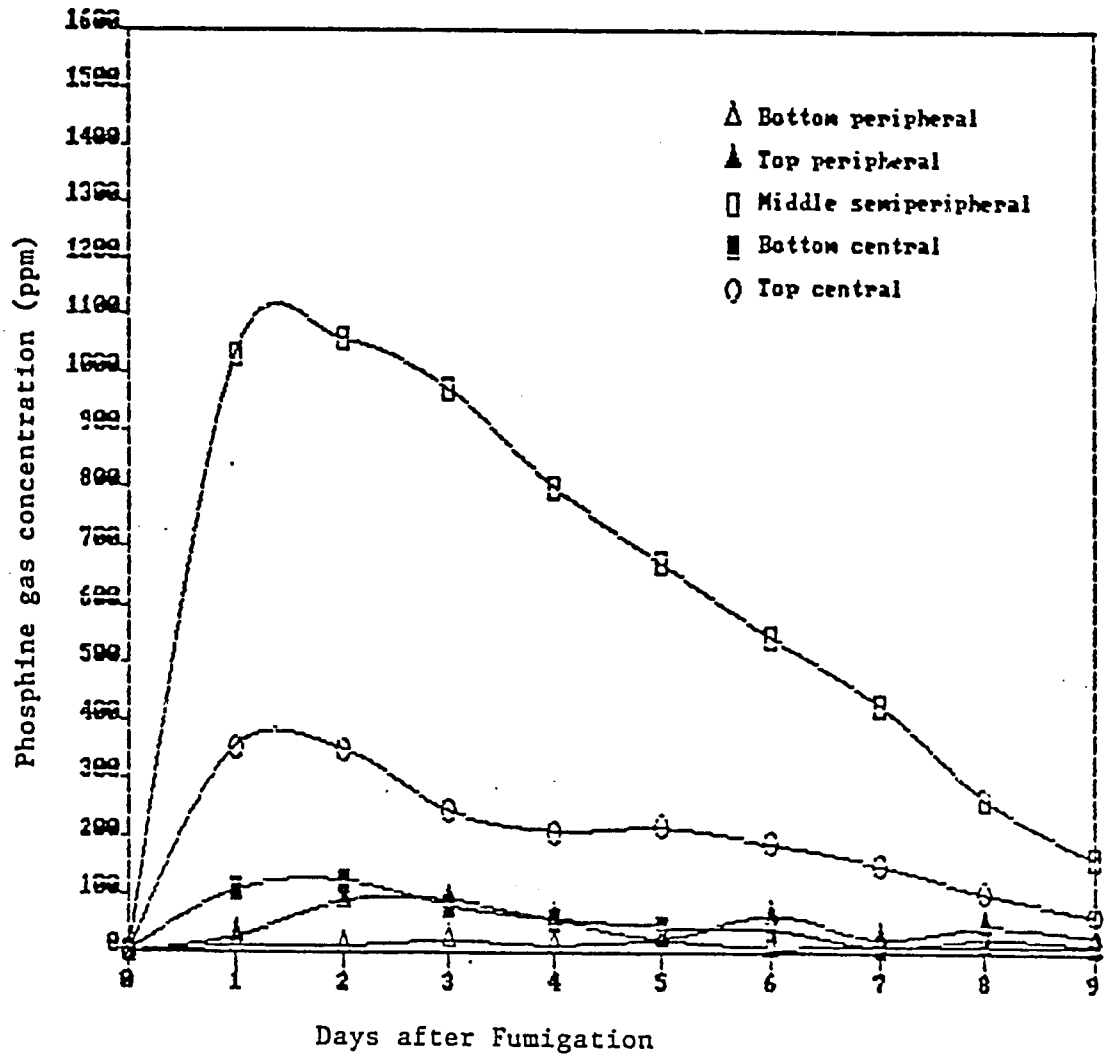

Figure 8. Phosphine gas concentration in bulk wheat loaded open bulkhead (control, i.e. covered with tarpaulin) at Depalpur.

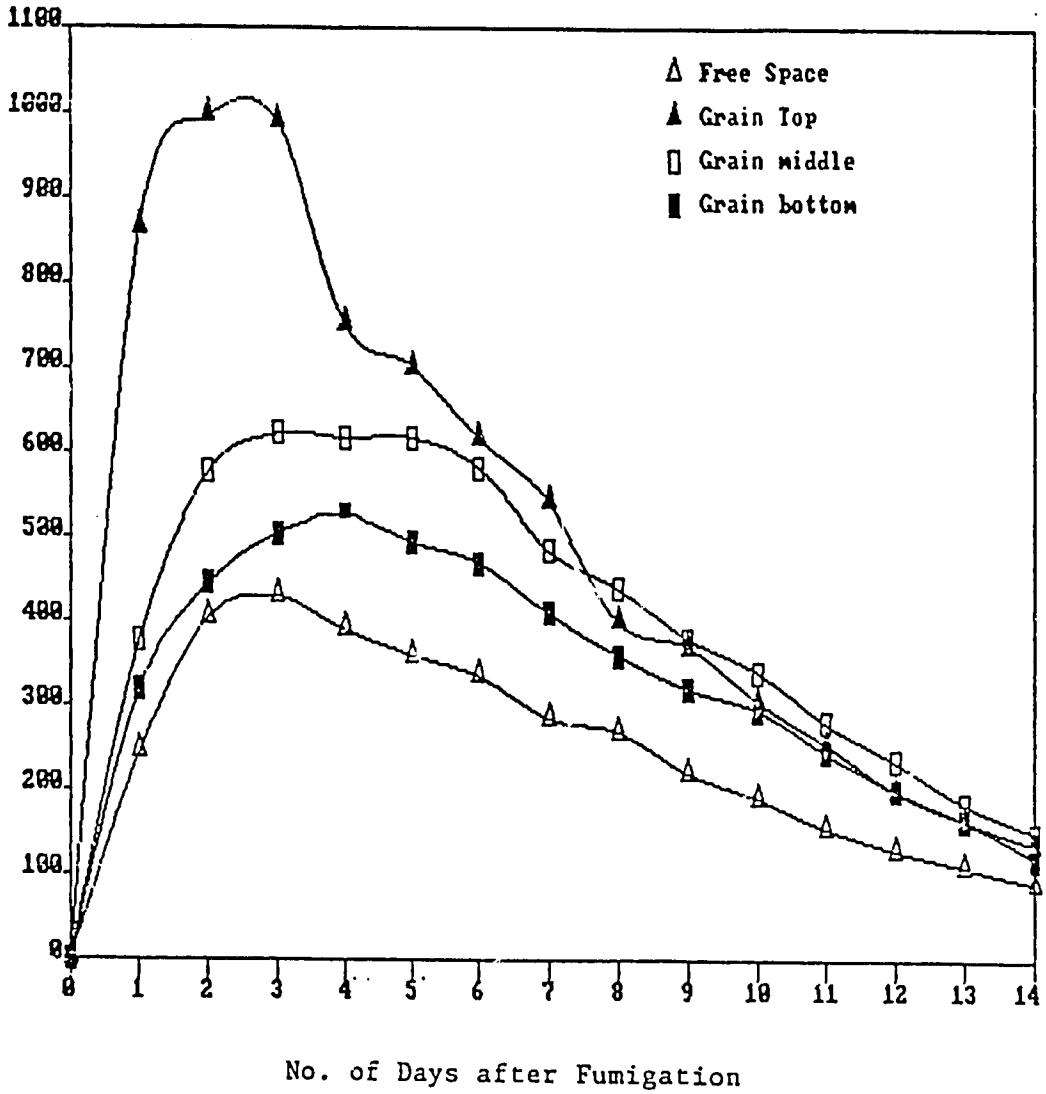

Figure 9. Concentration of phosphine gas in different parts of a wheat loaded hexagonal bin.

APPENDICES

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APPENDIX I

LIST OF COMMERCIAL FUMIGATORS REGISTERED WITH
THE DEPARTMENT OF PLANT PROTECTION
GOVERNMENT OF PAKISTAN
MALIR HALT
KARACHI

Serial Number	Name and Address of the Fumigators	Telephone Number	Registration Expires on
1	Delta Pest Control Service, Habib Bank Building, 3rd Floor, Abdullah Haroon Road, KARACHI	(021)-727351	01-17-1993
2	IMA Services, 191, Altaf Hussain Road, New Challi, P.O. Box 10296, KARACHI	(021)-439616	01-13-1993
3	Mahmood & Sons, 191- Altaf Hussain Road, Near Millat Press, KARACHI	(021)-224823	01-22-1993
4	National Fumigator Corp., Sharah-e-Liaquat, KARACHI	(021)-215440 -218002	02-10-1993
5	Progressive Fumigator Corp., 2/14 Fatima Zohra Building, New Challi, KARACHI	(021)-220869	01-08-1992
6	Pakistan Fumigator Corp., 609-611, Muhammadi House, I.I. Chundrigar Road, KARACHI	(021)-236961 -223642	12-26-1992
7	Pakistan Pest Control, 65-Noor Chambers, 4th. Floor, Opposite Allahwala Market, Robson Road, KARACHI	(021)-218113	04-21-1993
8	Prince Pest Control Services, 21-B, 3rd Floor, Writers Chambers, Dunolly Rd. off I.I. Chundrigar Rd., KARACHI	(021)-2416082	06-14-1991

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9	Star Industries, 72, Wazir Mansion, Nicol Road, KARACHI	(021)-233932	07-04-1991
10	Unique Services, 191, Altaf Hussain Road, New Challi, KARACHI	(021)-226623	02-11-1993
11	Asian Inspection and Pest Control Services, 250-251, Hotel Metropole, KARACHI	(021)-515478	10-29-1991
12	Superb Pest Control Services, Arkay Square Extension, 5th. Floor, Room No. 518, Sharah-e-Liaquat, New Challi, KARACHI		04-10-1991
13	Pesticon, 124, Baber Block, New Garden Town, LAHORE-16	(042)-851845	03-20-1993
14	Technocon, 40-A, Poonch House, Sultan Road, LAHORE		01-19-1992
15	Argrow, 306-Gul Plaza, 15, Civic Centre, New Garden Town, LAHORE	(042)-855457	03-05-1993
16	Saljoqi Traders, Syed Jamaluddin Afgahani Road, 63-E, Ata Turk Lane, University Town, PESHAWAR		09-13-1991
17	Iqbal Chemical Works, Kansi Lodge, Killi Deebe, Near Municipal Water Tank, QUETTA	(081)-733321	03-08-1992

APPENDIX II

REFRESHER COURSE ON FUMIGATION TECHNOLOGY
(Organized jointly by DPP, STDT & PARC)

PROGRAMME

October 21, 1991

0900 Hours — Inaugural Session

- Recitation from Holy Quran
- Introduction to the course
  Dr. Mohammad Shafi, Plant Protection Advisor and Director, Department of Plant Protection
- Introduction to the STDT project
  Dr. Richard C. Maxon, Chief-of-Party, STDT, Kansas State University, Food & Feed Grains Institute
- Inaugural Remarks
  Chief Guest
- Tea Break

1030 Hours — First Session

- Essentials of Fumigation
  Dr. Hafiz Ahmed, Training & Res. Coordinator, STDT Project, Lahore
- Importance of Plant Quarantine
  Mufti Zaffar Ullal Khan Tariq, Dy. Director, Department of Plant Protection

October 22, 1991

0800 Hours — Second Session

- Methyl Bromide Fumigation
  Mr. Mubarik Ahmed, Senior Scientific Officer, Pakistan Agricultural Research Council
- Visit the Karachi Sea Port to monitor & discuss the actual operations of commercial fumigators

October 23, 1991

0800 Hours Third Session

- Phosphine Fumigation
  Mr. M. Sajjad Ahmad, Sr. Scientific Officer, Pakistan Agricultural Research Council

- Visit the Karachi Sea Port to monitor & discuss the actual operations of commercial fumigators

October 24, 1991

0800 Hours Fourth Session

- Visit the RECP storage Complex Bin Qasim/Landhi to see demonstrations of methyl bromide and phosphine fumigations
  Mr. Akhlaq Ahmed and Tariq Mahmood, Pakistan Agricultural Research Council

- Final discussions and award of certificates

APPENDIX III

NAMES OF THE COURSE PARTICIPANTS & THEIR FIRMS/ORGANIZATIONS

Serial No.	Name of participants	Name of Firm/Organization
1	M. A. Anjum	Unique Services
2	Syed Kalimullah	
3	Khalid Anwar	Pakistan Pest Control
4	S.T.H. Naqvi	
5	Hayat-uz-Zafar	National Fumigation Corporation
6	Shahid Ahmad	
7	Alim Ahmad	Star Industries
8	Mohammad Ahmad Khan	
9	Salim Ahmad	
10	Dr. M. Maqsud Nasir	IMA Services
11	Mohammad Ali	Mahmood and Sons
12	Jawed A. Aziz	
13	Khawja Amin Usmani	Pakistan Fumigation Corporation
14	Haji Abdul Karim	
15	M. Iqbal A. Latif	
16	Aziz Ahmad Khan	Prince Pest Control Services
17	Lutafuddin A. Jafar	
18	Syed Zia-ul-Hasan	Delta Pest Control Services
19	Anwer Shah	
20	M.S. Qureshi	Ali Farms, Fumigation, and Pest Control Services
21	Qazi Anisuddin Ahmad	
22	Rafiq Zaki	
23	Mrs. Ale Zehra	
24	S.A.H. Zaidi	
25	Sakhi Mohammad	
26	Mohammad Aslam Khan	Iqbal Chemical Works
27	S.M. Tahir	Progressive Fumigation Corporation
28	Qazi Ahtesham-ul-Haq	
29	Mustafa Akbar	Asian Inspection and Pest Control
30	Arshad Munir	

31	Haider Zaidi	S and S Pakistan
32	Mirza Ilyas Baig	Department of Plant Protection
33	S.M. Rafi Zaidi	
34	Shahab-ud-din	
35	Abdul Wahid	
36	Mashkoor Hasan Khan	
37	M. Ibrahim Bhatti	
38	Hamid Ali	
39	Gauhar Ali	
40	Shahid Abdullah	
41	Niaz Wali	
42	Mrs. Raees Fatima	
43	Rasool Bakhsh Dars	
44	Safdar Ali	
45	Abdul Qadeer	
46	Akhtar Hussain	Rice Export Corporation of Pakistan
47	Manzoor Mustajab Ahmad	
48	Qaseem Abbas	
49	Syed Amanullah Bukhari	
50	Shamim Iqbal	Grain Storage Research Laboratory
51	Syed Asim Rehan Kazmi	
52	Akhlaq Ahmad	
53	Jamshed Khan	

APPENDIX IV

DEFICIENCIES OBSERVED DURING FIELD VISITS

1. The polyethylene sheets being used by "Commercial Fumigators" to cover stacks for fumigation were of low quality. In some cases, the sheets were in tatters and incapable of holding gas for any appreciable time. This was a serious deficiency which the firms concerned will hopefully remove immediately to ensure success of fumigations.

2. Fumigations were being carried out on porous floors without using gasproof underlays. Fumigation enclosures made in this fashion are not likely to hold gas for long periods of exposure. As such, fumigation with phosphine gas, which requires a long exposure time, is not likely to be successful in such enclosures.

3. In some cases, bags of the commodity to be fumigated were found stacked along the wall, and the gasproof sheet covering the stack was attached to the wall using adhesive tape to make an enclosure for fumigation. Fumigant gas, particularly phosphine, is likely to leak out through the porous wall, resulting in unsuccessful fumigation.

4. Polyethylene sheets were observed to have been joined together using adhesive tape. Such joints are likely to give way after some time. In fact, one such separation of sheets was actually observed at one place where rice was being fumigated with phosphine. Polyethylene sheets can be joined together easily by using heat sealers. Even folding of sheets at ends and then holding them together under some sort of weight would be a more reliable way of joining sheets.

5. Cotton bales sealed in shipping containers are regularly fumigated before their loading on the ships. This could yield very good results provided the fumigators have a full understanding of the process, and knowledge of the ambient conditions which can affect the final outcome process of the fumigation operations. The fumigation monitored by the group on the field visit was, however, unsuccessful because the aeration vents of the container were not closed by the fumigators before introducing methyl bromide gas. The container, being made of steel, must have generated strong convection air currents in the enclosure which carried methyl bromide gas out of the container through the open vents.

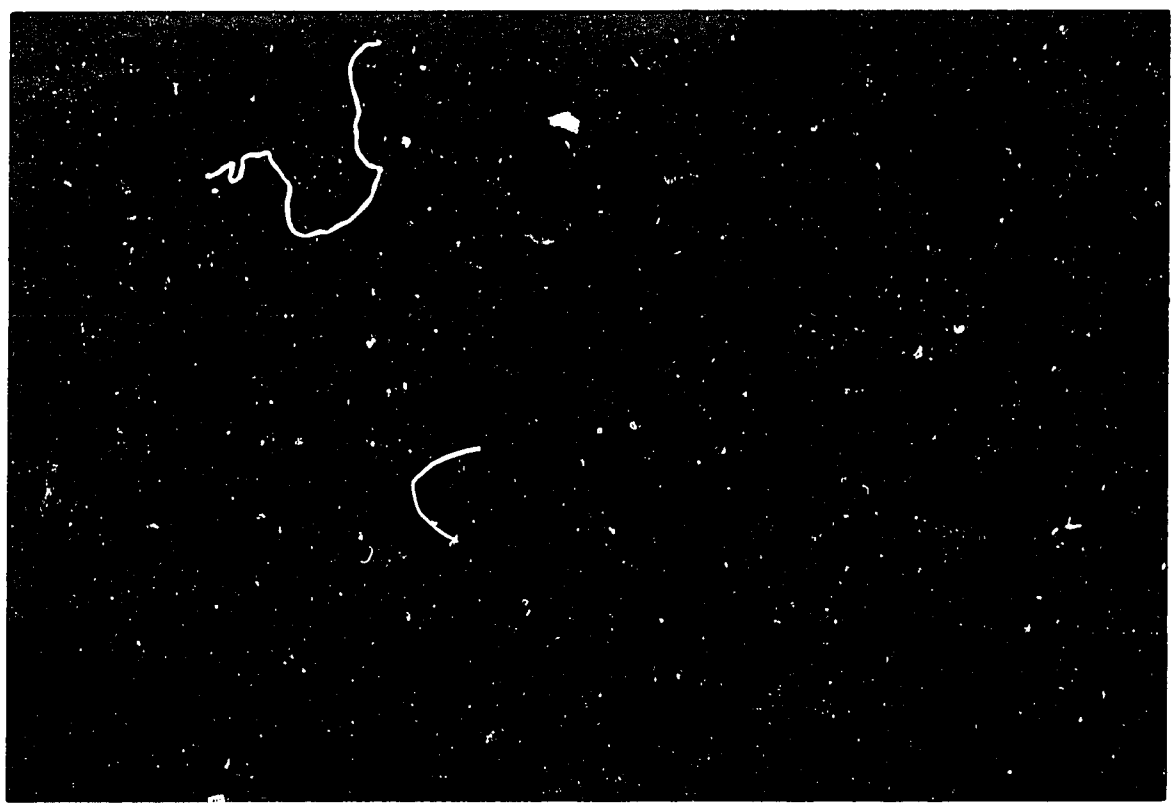
6. None of the private commercial fumigators or the government and public agencies involved in the export trade of agricultural produce possessed the phosphine and methyl bromide meters. Such meters could prove to be of great value in determining the success or failure of fumigation operations which are undertaken to obtain a phytosanitary certificate. This is because the commercial availability of such meters is only a recent phenomenon. These meters are shown in the photographs. The STDT project purchased these gadgets from M/S BEDFONT Technical Instruments Ltd., Sittingbourne, Kent, ME9 7HN, England.

7. Direct body contact with methyl bromide liquids could cause serious burns. One of the labourers suffering from such burns was noticed during field visits (see photographs). Probably the man had burned his finger while opening or closing methyl bromide cylinders, and his ear while testing leakage from such cylinders.

8. Export quality rice was found to be heavily infested with insects at some (not all) places (see photographs). It could well be due to the presence of resistant strains of insects at the rice storage/processing site. Control of such strains through fumigation is highly demanding on the proficiency of the fumigator.

PHOTOGRAPHS

Infested rice prior to fumigation



Insects on bags

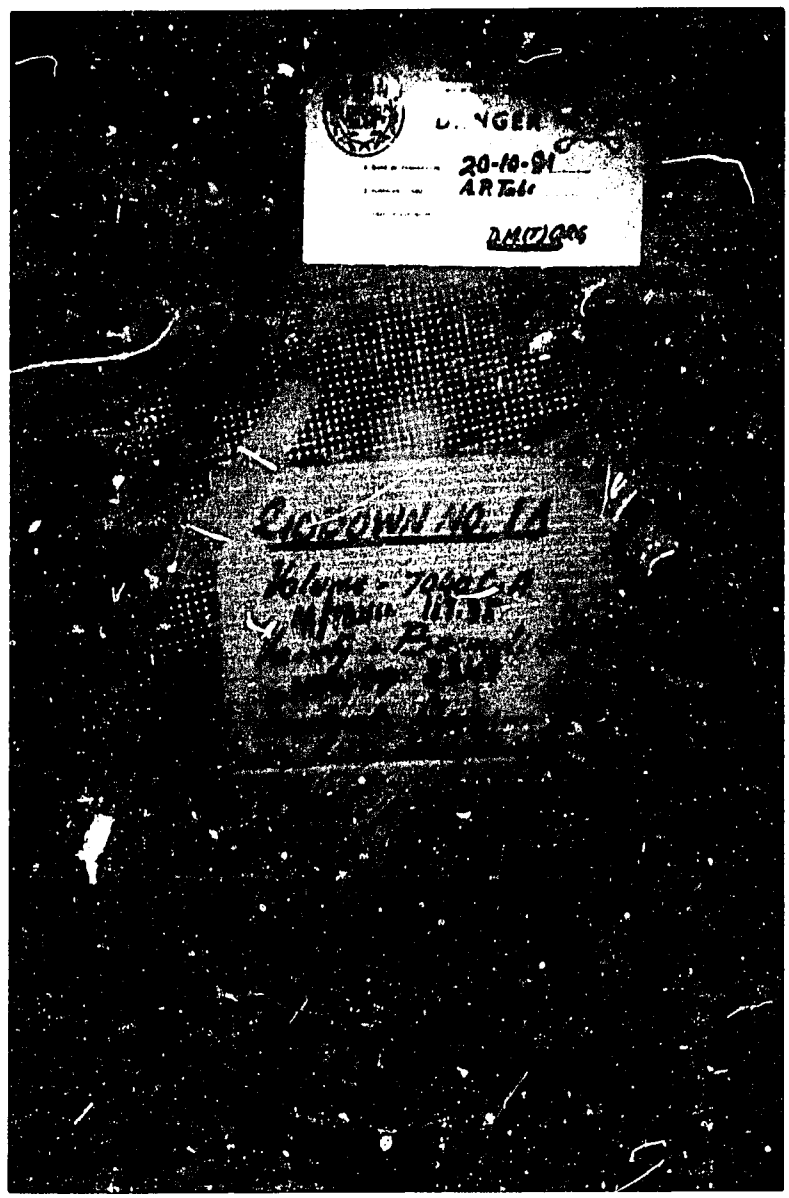
Applying the fumigant methyl bromide

Private Sector Fumigation

Checking results with methyl bromide meter

Explaining the fumigation procedures

Fumigation under the plastic cover



Fumigation warning labels and information

Injuries to ear and hands through improper handling of methyl bromide fumigation

Monitoring fumigation of export containers