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INSECT PEST MANAGEMENT OF WHEAT STORED IN OPEN BULKHEADS

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INSECT PEST MANAGEMENT OF WHEAT STORED IN OPEN BULKHEADS

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EXECUTIVE SUMMARY

The open bulkhead is a very practical and a relatively cheap storage facility for wheat. It is being used by the Pakistan Agricultural Storage and Services Corporation (PASSCO) and the Punjab Food Department (PFD). In the beginning, open bulkheads were rarely used for short-term storage due to limiting factors. These included non availability of a durable cover, labor intensive loading operations, and the absence of reliable pest control methods. These constraints were eased by the importation of fiber-reinforced plastic sheets to cover the bulkheads and the introduction of portable conveying equipment for loading and unloading purposes. However, the third constraint still prevails, thus leading to this study.

Like other storage structures, fumigation of open bulkheads is a major option in keeping stored grain free from insect infestation. Various methods of fumigation were tested to devise a methodology for a regular phosphine fumigation program. Out of the methods tested, a simple and easy system, is being recommended. In this method, aluminum phosphide (AlP) tablets are inserted in the grain mass with a tablet applicator. The grain mass is covered with fiber-reinforced plastic sheets to hold the gas. All possible leakage points are sealed with PVC tape. With the cover used, the phosphine gas is retained for at least 12 days to ensure complete control of all insect species.

A grain protectant, Reldan, was partially effective as an alternative to fumigation by admixing with grain. At the recommended dose rate, Reldan provides protection against Sitophilus oryzae (rice weevil), Trogoderma granarium (khapra beetle), and Tribolium castaneum (red flour beetle), for a short time. Reldan was ineffective against Rhizopertha dominica (lesser grain borer).

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SECTION I

INTRODUCTION

Public-sector agencies purchase almost 70% of the farmer's marketable surplus of wheat at harvest time in Pakistan. These agencies use various types of wheat storage. The most common storage is the house-type godown for stacking of bags. About two-thirds of all storage in Pakistan is of this kind. Other forms of storage in use are hexagonal bins, bini-shells, vertical silos, and open bulkheads. The storage capacity of each type of facility in-country has been indicated by Ahmad et al., (1991). Except for the house-type godowns and bini-shells, wheat is stored in all other types of storage structures in bulk form; i.e., without using jute bags. Of all these facilities, open bulkheads provide the cheapest method of bulk wheat storage in Pakistan (Coulter, 1991).

PASSCO installed the first open bulkhead in Pakistan at Okara in 1984 with Australian assistance. At present, PASSCO has 21 open bulkheads while PFD has ten such structures. All bulkheads are presently located in central Punjab. Their combined storage capacity is about 150,000 tons of bulk wheat.

The open bulkhead is a simple rectangular structure, made of moveable retaining walls anchored to an asphalt ground base. The retaining walls are made of corrugated iron sheets which are bolted onto inclined steel frame trestles. Most bulkheads in Pakistan measure about 22.25 m x 52.73 m at the base and 23.77 m x 54.25 m at the top ends of the 2.29 m high retaining walls. A fully loaded bulkhead holds a massive heap of over 4,500 tons of bulk wheat.

Originally, portable inclined bucket elevators with a conveying capacity of 18 mt per hour were used to load bulkheads (Figure 1). However, due to their low conveying capacity and some other constraints, the use of these elevators was abandoned. Instead, manual labor was employed for loading and unloading of these facilities. Lack of durable, cheap cover, and the absence of a reliable and practical method of pest control, were other major constraints which limited the use of these facilities.

To cover wheat in bulkheads, PASSCO and PFD are now using imported fiber-reinforced plastic sheets. A portable grain pump having a much higher conveying capacity (Figure 2) has also been introduced by the STDT project to solve the problem of loading the bulkheads. PASSCO uses surface spraying with pesticides and phosphine fumigation to provide protection of wheat from insect infestation with unsatisfactory results. The prime objective of the present studies was to establish an efficient method of phosphine fumigation of bulkheads at PASSCO and PFD.

In Australia, bulkheads are normally sealed and fumigated with phosphine by placing AlP sachets on the grain surface (Banks, 1986). Trials conducted under the STDT project in hexagonal bins have, however, shown that penetration of phosphine gas from the grain surface into deeper parts of the grain mass was very slow. Gas leakage from the top of the bins exceeded the downward penetration of the gas resulting in the survival of insects present in the bottom sections of the grain mass. The problem was solved in hexagonal bins by inserting AlP

tablets at suitable depths in the grain mass which improved distribution and retention of phosphine gas (Mahmood et al., 1991). A similar method of AlP tablet application was tried for bulkheads as well.

Another possible method for fumigating the massive heap of wheat in bulkheads is the application of AlP tablets through slotted plastic pipes which could be installed prior to, or at the time of, loading a bulkhead. This was suggested in a report by the United States Department of Agriculture (USDA) for on-transit phosphine fumigation of wheat in ship holds (Davis, 1986). This method was tried in the study and the results obtained and the conclusions reached are included in this report.

The direct application of insecticides into the grain has been used successfully in protecting grains from insect infestation (Bengstone et al., 1975 and Desmarcheller et al., 1981). Malathion was the first organophosphorus compound used widely as a grain protectant, but its prolonged use has led to the development of high resistance in storage insect pests (Dyte, 1970; Champ and Dyte, 1976; and Rimes and Sexton, 1977). In Pakistan, field-scale testing of grain protectants was carried out by Ahmad, et al. (1990) in hexagonal bins which showed some encouraging results for short-term storage of wheat. Admixing of insecticides with grain is another way to control the insect infestation in bulk grain. In Pakistan, the application of grain protectants to large volumes of grain is at present difficult to do with manual handling systems. An insecticide, chlorpyrifos methyl (Reldan), described by Rigterink and Kenaga (1966), and introduced by Dow Chemicals Limited, was tested as a grain protectant for possible future application.

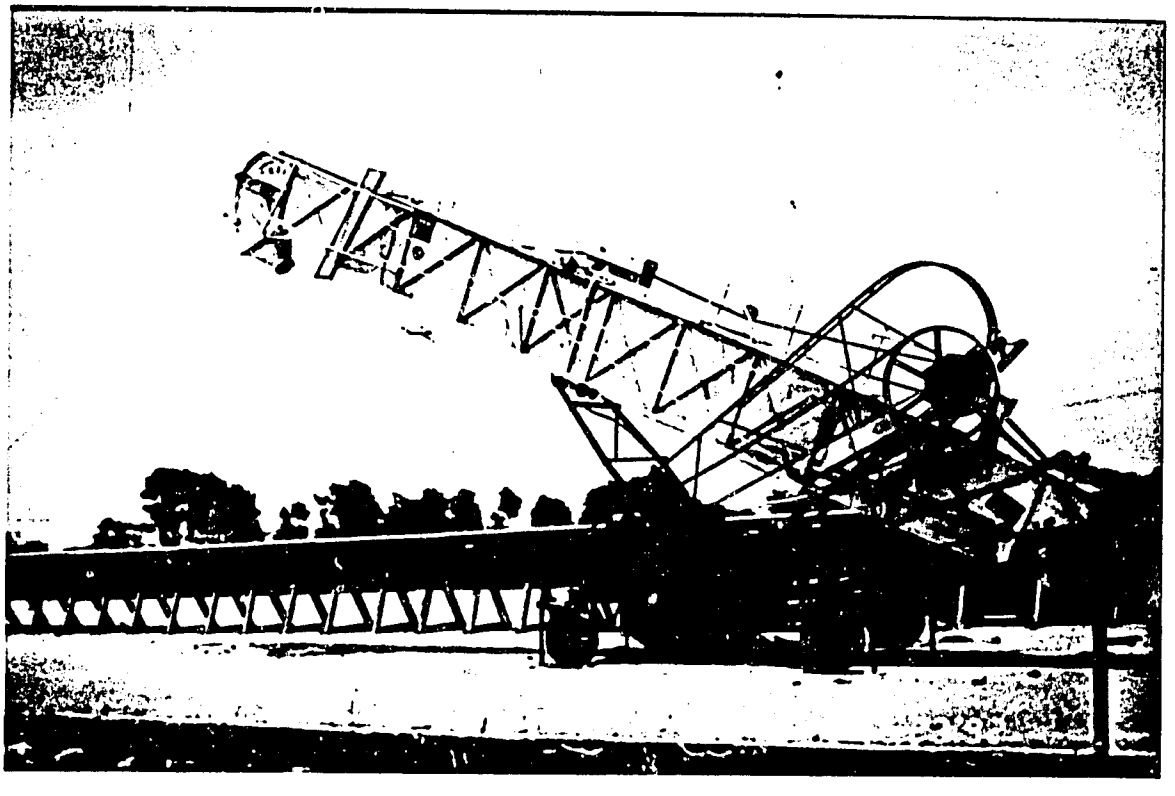

Figure 1. Inclined Australian bucket elevator previously used to load the open bulkhead.

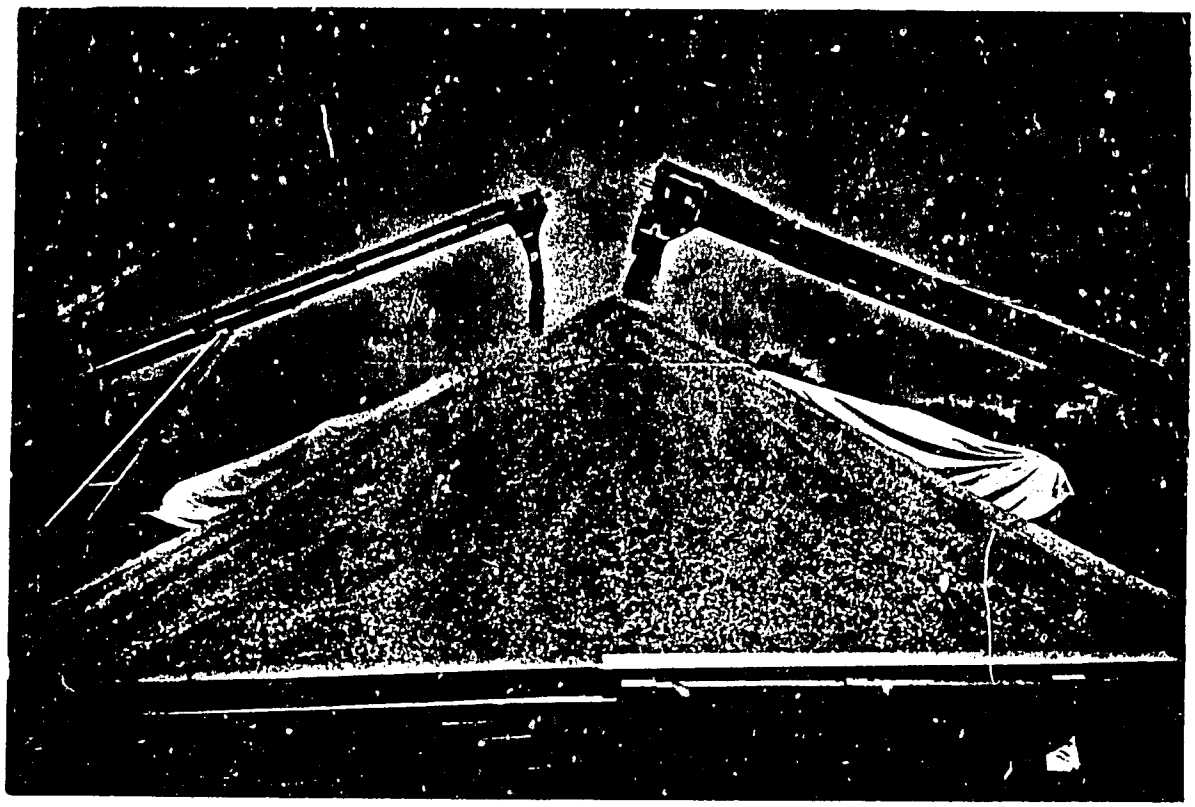

Figure 2. Loading of the open bulkhead with a grain pump (left and a Mass-ter Mover (right).

SECTION II

MATERIALS AND METHODS

Five open bulkheads located at Manga Mandi, Depalpur, and Okara were used for these studies. The bulkheads located at Manga, Okara, and one at Depalpur were 23.77 m wide and 54.24 m long. Each bulkhead had a corrugated galvanized metal wall of 2.44 m high. The other two bulkheads located at Depalpur were 16.76 m wide and 77.42 m long with 1.22 m high retaining walls. The floor of the bulkheads had a brick work base topped with a layer of asphalt for water proofing purposes.

The PARC/STDT team tested the following six different procedures for pest management in these bulkheads:

1. Use of 'Reldan' as a grain protectant (P-1).

2. Application of AlP tablets within horizontal perforated pipes (P-2).

3. Application of AlP tablets within vertical perforated pipes (P-3).

4. Fumigation by the PASSCO procedure (P-4).

5. Insertion of AlP tablets with tablet applicator (P-5).

6. Fumigation as prescribed in P-5 and covering the bulkhead with a tarpaulin instead of a fiber-reinforced plastic sheet (P-6).

Detailed Procedure

At Manga Mandi, the bulkhead was divided into four compartments with partitions made of bags filled with grain. Each compartment was 15.24 m wide and 17.82 m in length. The width of each bag wall was 1.71 m and polyethylene sheet-lined on one side to isolate one compartment from another and to minimize cross-compartment effects. Wheat treated with Reldan was filled in the bags that comprised the wall separating the first and second compartments. Grain in other bag walls remained untreated because the last three compartments were used for the fumigation procedures. Bulk grain was filled mechanically by using a grain pump as described by Ahmad and Mahmood (1992). A Mass-ter Mover 50 with chain and plastic paddles (Hutchinson Wil-Rich Manufacturing Company, Kansas, USA) was used to load the bulkheads at Depalpur. However, the bulkhead at Okara was filled manually. Immediately after applying the fumigant, the entire bulkhead was covered with fiber-reinforced plastic sheets. Concentrations of phosphine gas were monitored with the use of a "Cititox" meter (Harris and Cox, 1990). Nylon capillary tubes were used to draw inter-granular air samples from various parts of the bulkhead. These tubes were inserted from the grain surface with a long steel rod. Figure 3 schematically shows the location of these tubes in the grain mass. The phosphine gas concentration at each point was monitored after each 24-hour period from the day of application of the fumigant and was recorded until it fell below 150 ppm.

Further procedural details are given below for each method of pest control tested in these experiments:

P-1. Use of a Grain Protectant. Reldan 25 EC was applied at the dosage of 21.6 ml/liter of water/ton of grain which corresponds to the recommended 6 ppm by the manufacturers. A Reldan-water solution was prepared in a clean plastic drum. A power sprayer mounted on the inlet hopper of the drag conveyor (grain pump) was used to spray the insecticide directly on the moving grain (Figures 4 and 5). The conveyor had a feeder auger that helped mix the grain with the insecticide during loading. The floor and walls of the compartment were also sprayed with the Reldan solution before filling with grain.

P-2. Application of AlP Tablets Within Horizontal Perforated Pipes. This procedure was tested in compartment No. 2. In this procedure, three pipes of 13 cm diameter having slotted perforations, were laid down horizontally in the grain mass. Each pipe was spaced 4.46 m from each other and 1.5 m above ground level (Figure 6). Six-foot long flexible tubes were attached at both ends of the pipes to facilitate insertion of the fumigant. In the absence of the required AlP sachets, tablets were packed in small polyethylene envelopes as a substitute system. Each envelope contained ten tablets. Forty-six such envelopes were tied to a sufficiently long rope for each pipe. Before application, small incisions were made in each envelope for the gas to leak out. These ropes were then inserted into the entire length of each dosing pipe with a stiff wire.

P-3. Application of AlP Tablets Within Vertical Perforated Pipes. This procedure was used in compartment No.3. Five perforated PVC pipes, as shown in Figure 5, were placed vertically in the grain pile at the time of loading. To fumigate this compartment, the total required number of AlP tablets was divided equally into five portions. One portion of tablets was placed in each pipe mixed with wheat in layers as described in Figure 7. Three such layers were established in the central pipe while four peripheral pipes had only two such layers. The top end of each pipe was capped with a piece of polyethylene sheet.

P-4. Fumigation by the PASSCO Procedure. The fourth compartment was fumigated by PASSCO personnel according to their existing method and served as the control. In this procedure, the total number of tablets was inserted haphazardly by hand on the entire heap about 1-2 ft below the surface of the grain.

P-5. Fumigation With the Help of a Tablet Applicator. This procedure was tested in three bulkheads located at Depalpur and Okara. The grain surface was exposed by removing the plastic sheets (Figure 8). The surface area was determined and 400 AlP tablet insertion points were calculated each approximately 2 m apart. At each point, about 20 tablets were deposited half way down the entire grain depth with the use of an AlP tablet applicator (Figure 9). A total of 8,000 AlP tablets was used at the dosage of two tablets/ton of wheat. Each bulkhead was covered with five overlapping fiber-reinforced plastic sheets which were held down with sand-filled bags (Figure 10). The loose ends of these sheets, hanging on

the ground, were held down with loose earth placed all around the bulkhead (Figure 11). Other possible leakage points were sealed with PVC self-adhesive tape.

P-6. Fumigation Method as Prescribed in P-5 But With a Tarpaulin Covering. This procedure was tested in a bulkhead located at Depalpur. The main objective was to test the phosphine gas retention characteristics of waterproof tarpaulins. The AlP tablets were deposited in the grain mass in the same way as described in P-5 and the bulkhead was covered by a tarpaulin instead of fiber-reinforced plastic sheets. Tarpaulins were stitched tightly together to cover the entire bulkhead. Loose ends of the tarpaulins were clamped on the retaining walls. The joints between the retaining walls and floor were sealed with mud plaster.

Grain Sampling

Grain samples were taken from the bulkhead at Manga to determine the density of live and dead insects at the time of loading. This was done in all compartments immediately after loading by using a negative pressure grain probe (Cargill's Probe-A-Vac). The four partitioned compartments were considered as independent units. Each unit was further divided into three arbitrary zones; namely, top, middle, and bottom. The depth of each zone depended on its distance from the surface of the grain pile (Figure 3). Twelve primary samples were drawn at pre-selected points in each zone. The samples were thoroughly mixed and divided with a Boerner divider to obtain three representative samples for determining the presence of insects. The insects were separated from the grain with a Dockage tester (Carter-Day Company, Minneapolis, USA) having sieves of 0.089 T and 5/64 R meshes and a riddle of No. 2. The live and dead insects were collected, identified, and counted. The same procedure of sampling was followed at the termination of the experiment.

A monthly sampling schedule was followed in P-1 to determine the effectiveness of the grain protectant (Reldan) against different insect species. Monthly sampling was done only from accessible points of the compartment because of the difficulty of uncovering the entire bulkhead. The enormous size and weight of the plastic sheets prevented more frequent grain sampling from the entire bulkhead.

Temperature Monitoring

The grain temperature was recorded daily from P-1 and P-3 of the bulkhead at Manga. For temperature monitoring, thermocouple wires were inserted into different vertical and horizontal zones of the grain mass (Figure 12). The temperature was monitored with the use of a digital "Hot Spot" meter (George A. Rolfes Company, USA) by connecting it to each thermocouple wire inserted into the grain mass.

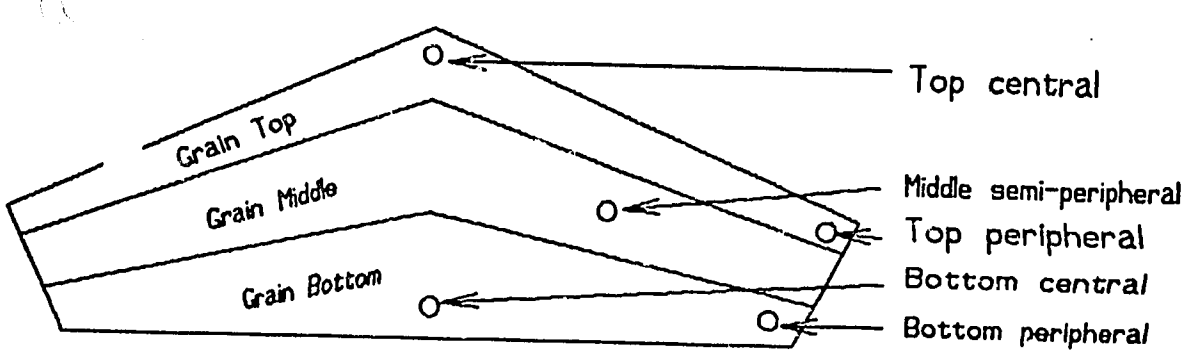

Figure 3. Cross-section of an open bulkhead showing the hypothetical grain depths and phosphine gas monitoring points.

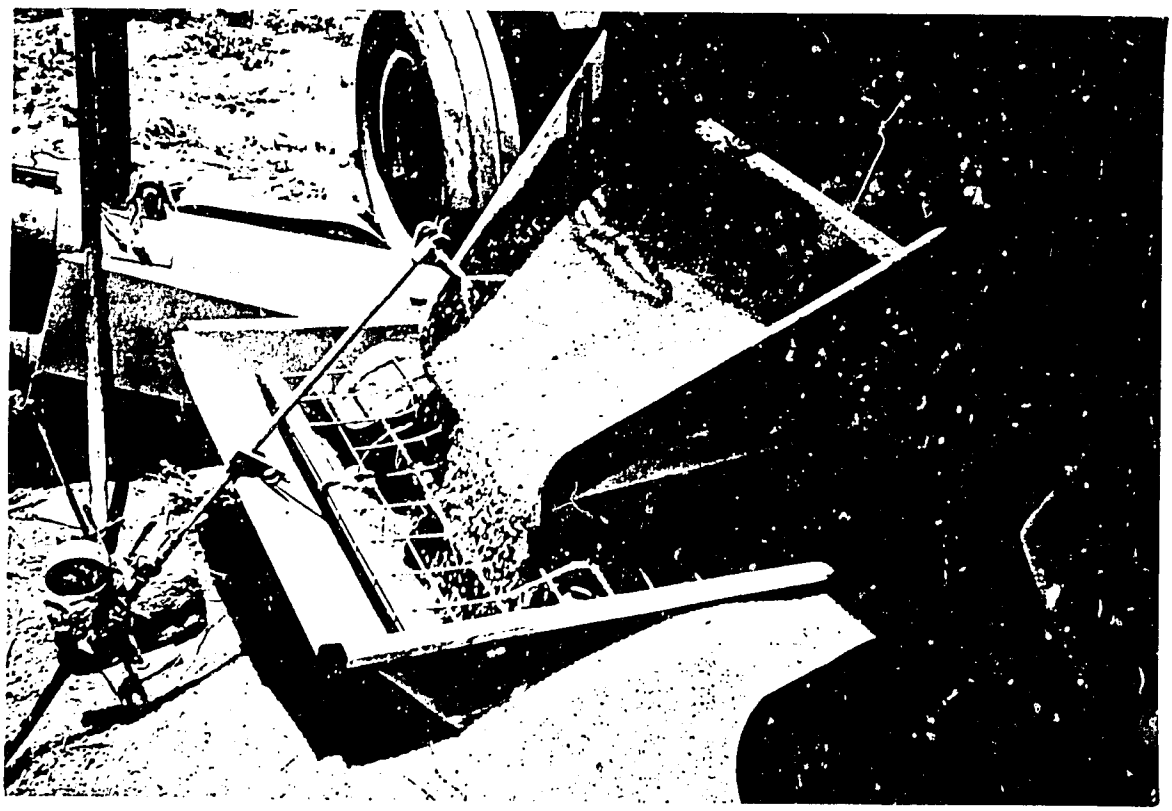

Figure 4 and 5. Spraying of Seldan solution on the moving grain.

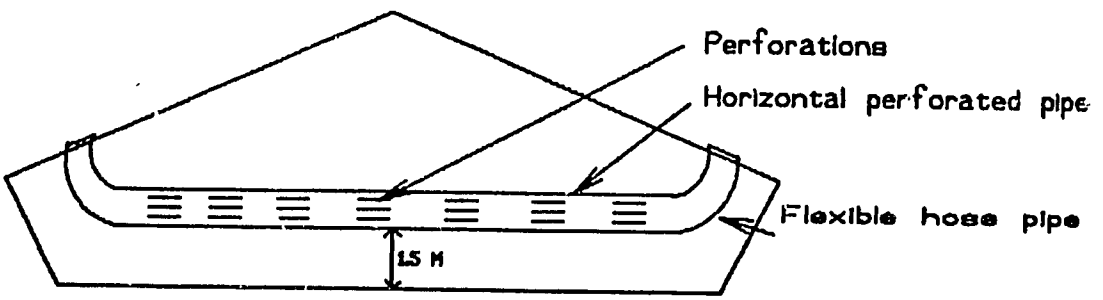

Figure 6. Cross-section of a compartment of the bulkhead showing the horizontal perforated pipe.

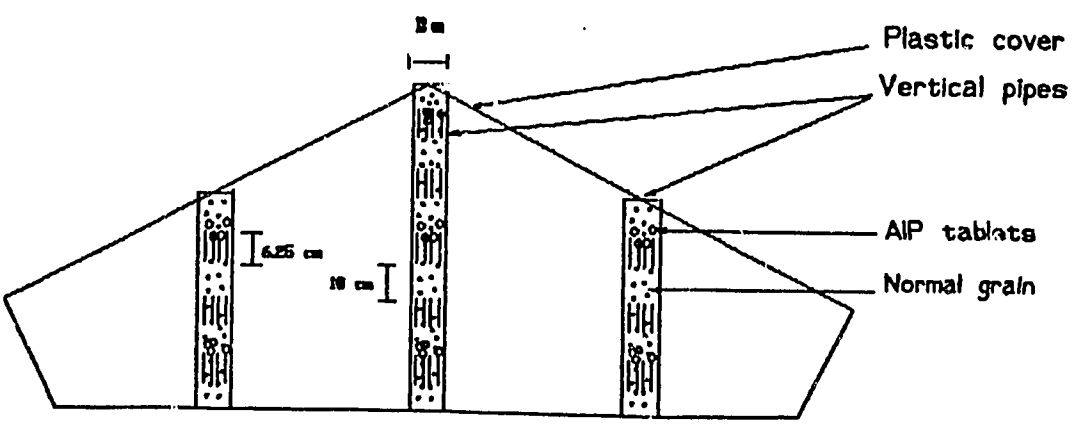

Figure 7. Cross-section of a compartment of the bulkhead showing the vertical perforated pipes.

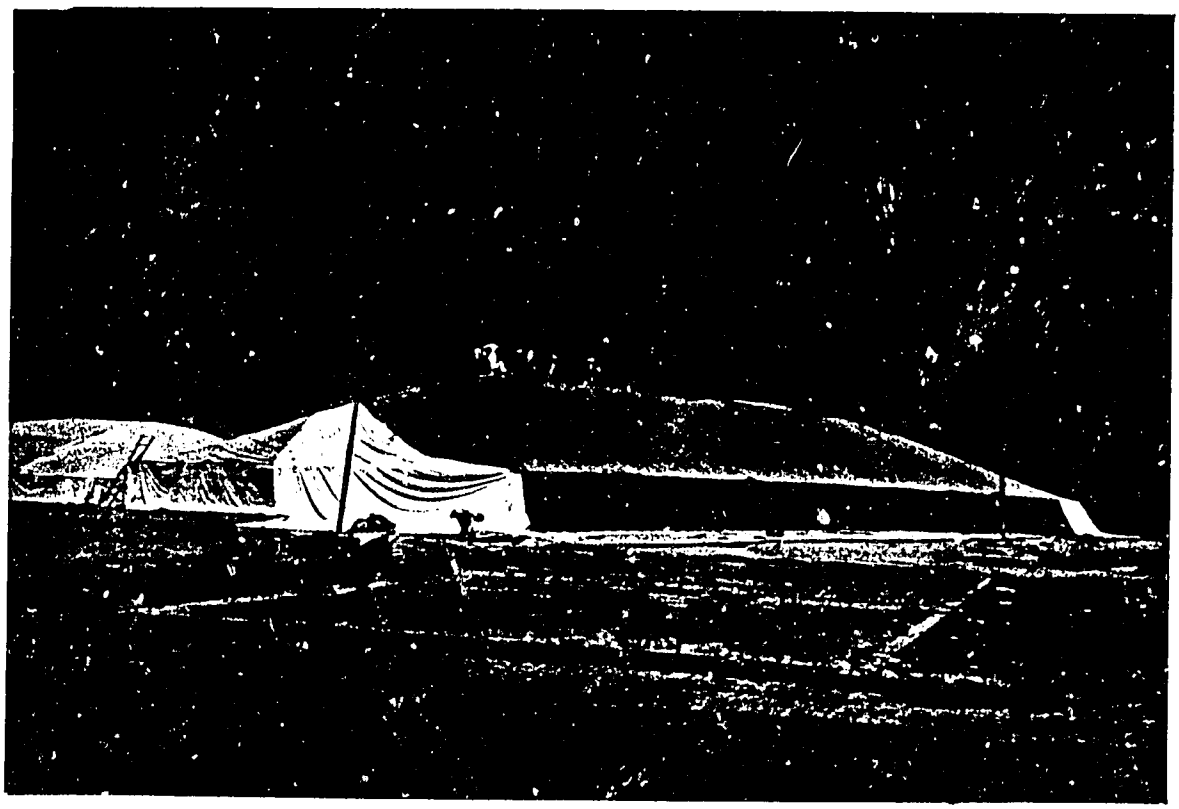

Figure 8. Uncovered grain surface before the application of Aluminum phosphide (AlP) tablets.

Figure 9. Use of a tablet applicator for the insertion of AlP tablets in the grain mass.

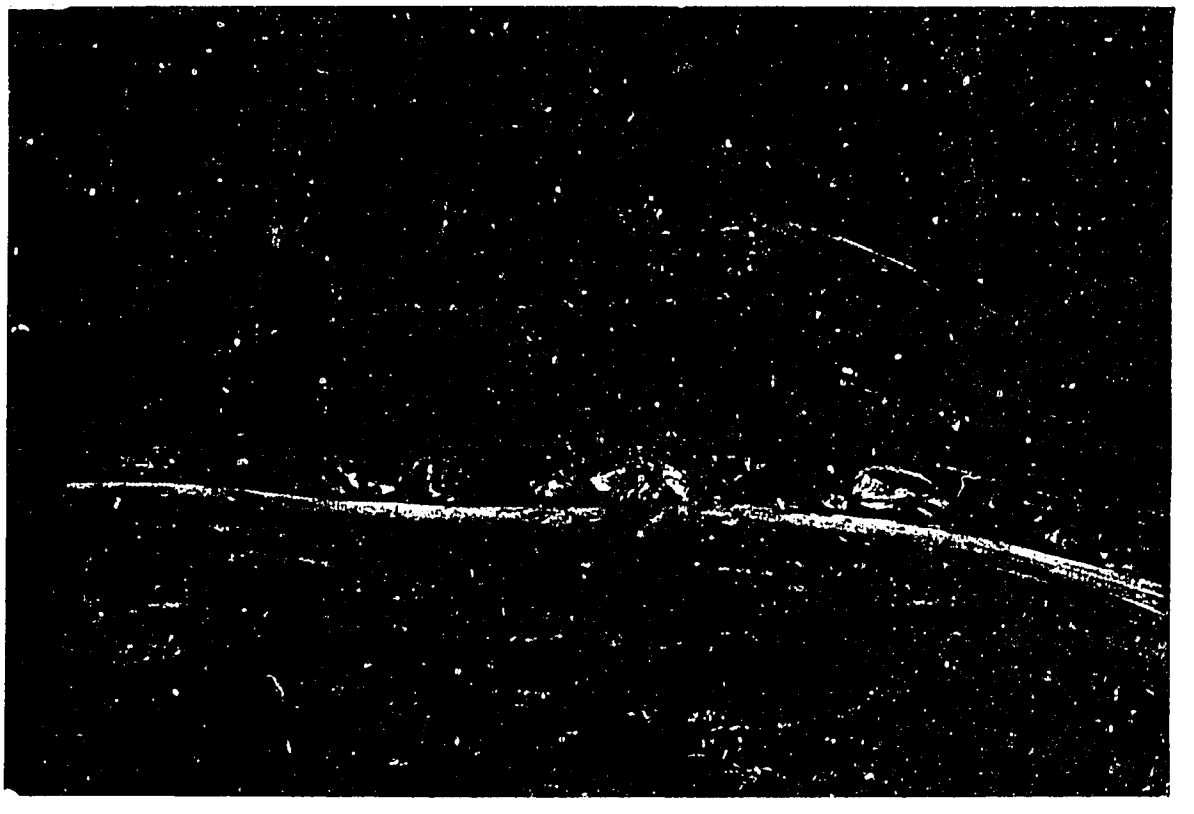

Figure 10. Sand-filled bags placed on the overlapped region of the plastic sheets.

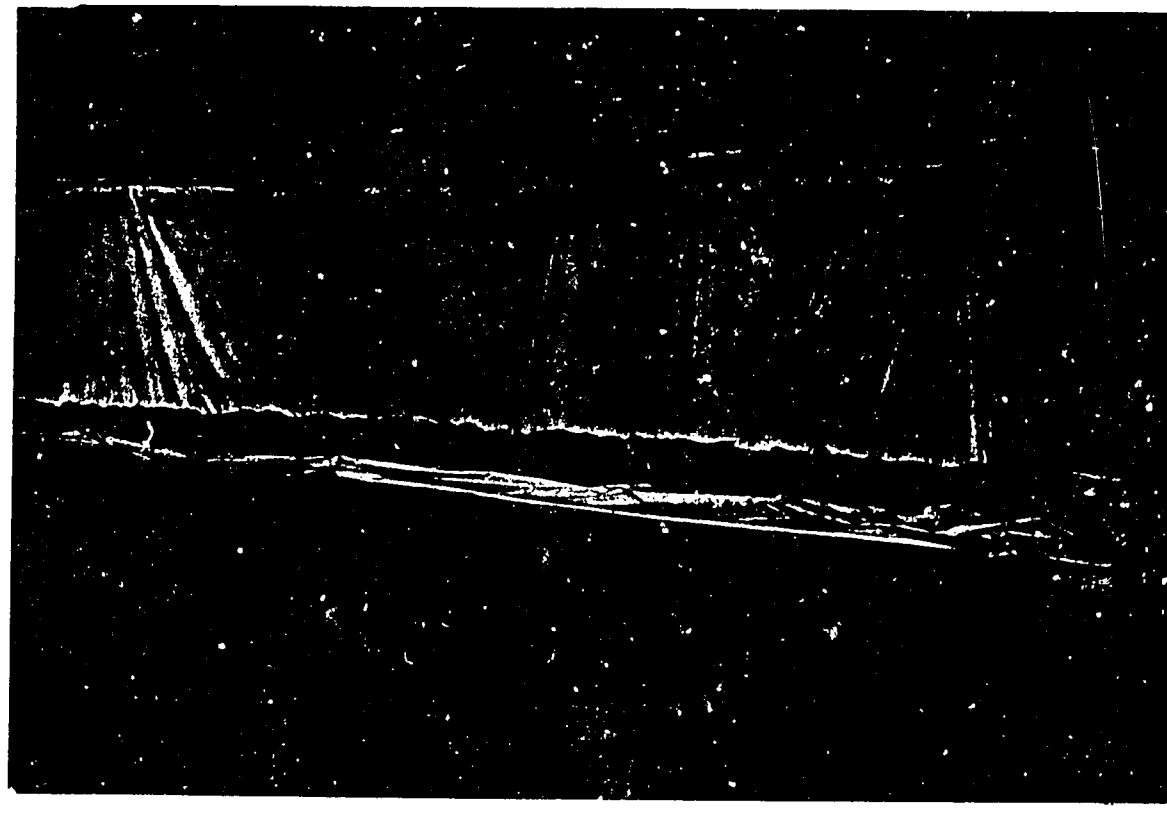

Figure 11. Loose earth placed on the suspended ends of the plastic sheets on the ground.

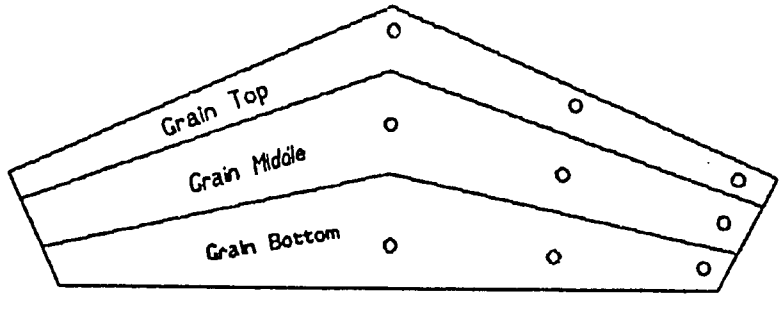

Figure 12. Cross-section of an open bulkhead showing the temperature monitoring points.

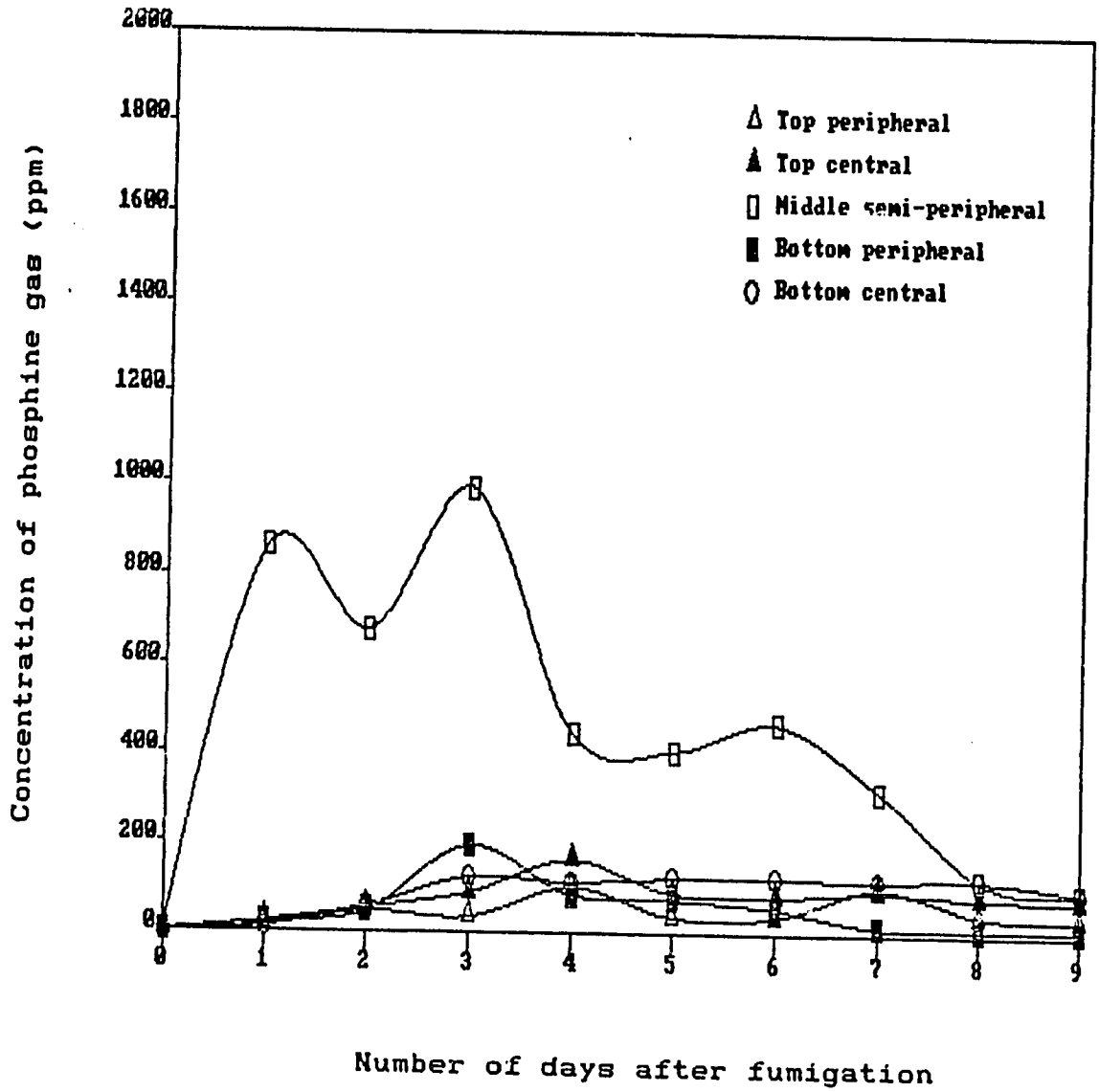

Figure 13. Graph showing the concentration of phosphine gas (ppm) over time when a compartment of the open bulkhead was fumigated according to the PASSCO method.

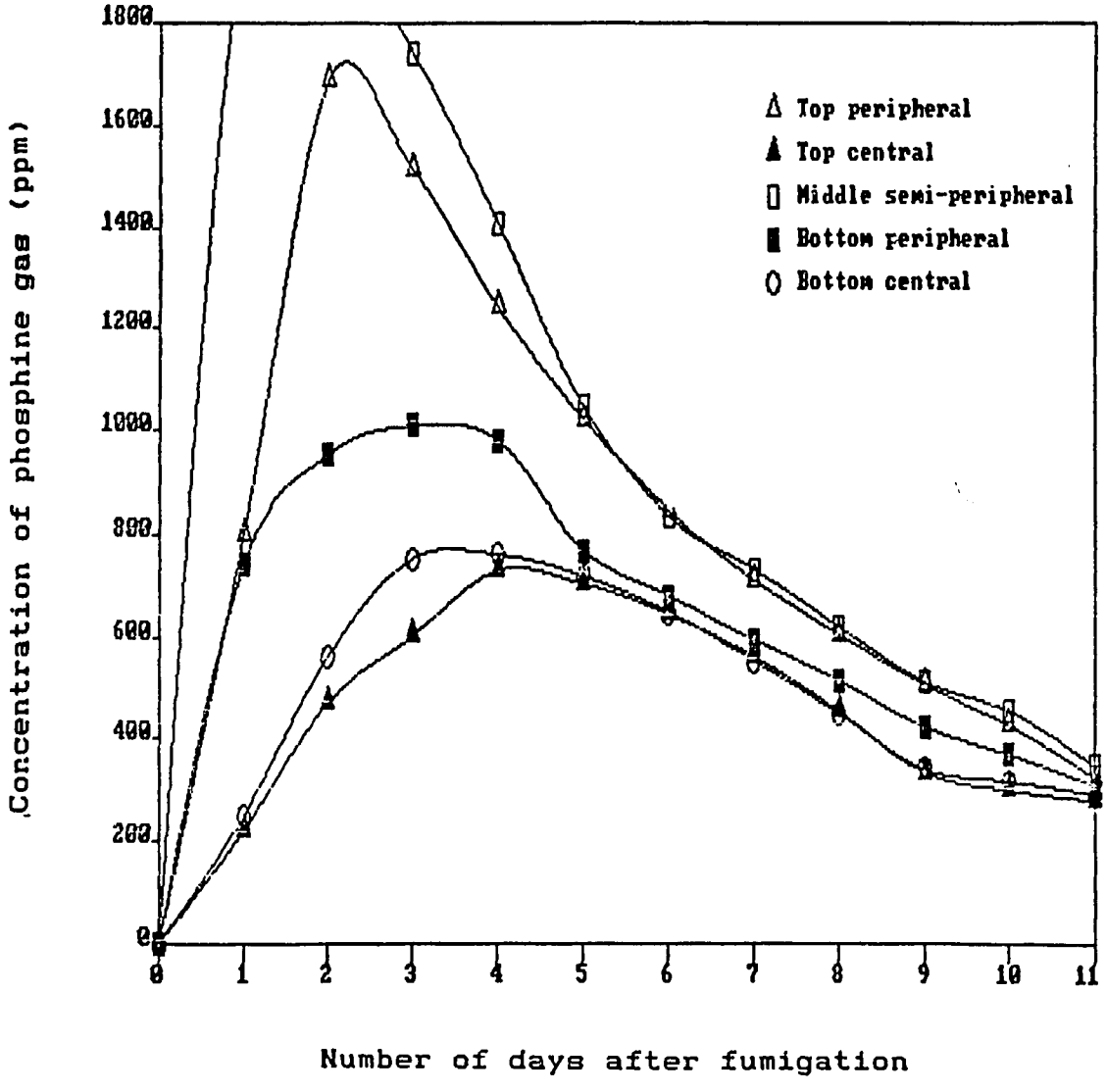

Figure 14. Concentration of phosphine gas (ppm) at different gas monitoring points in a bulkhead fumigated by inserting the AlP tablets with an applicator.

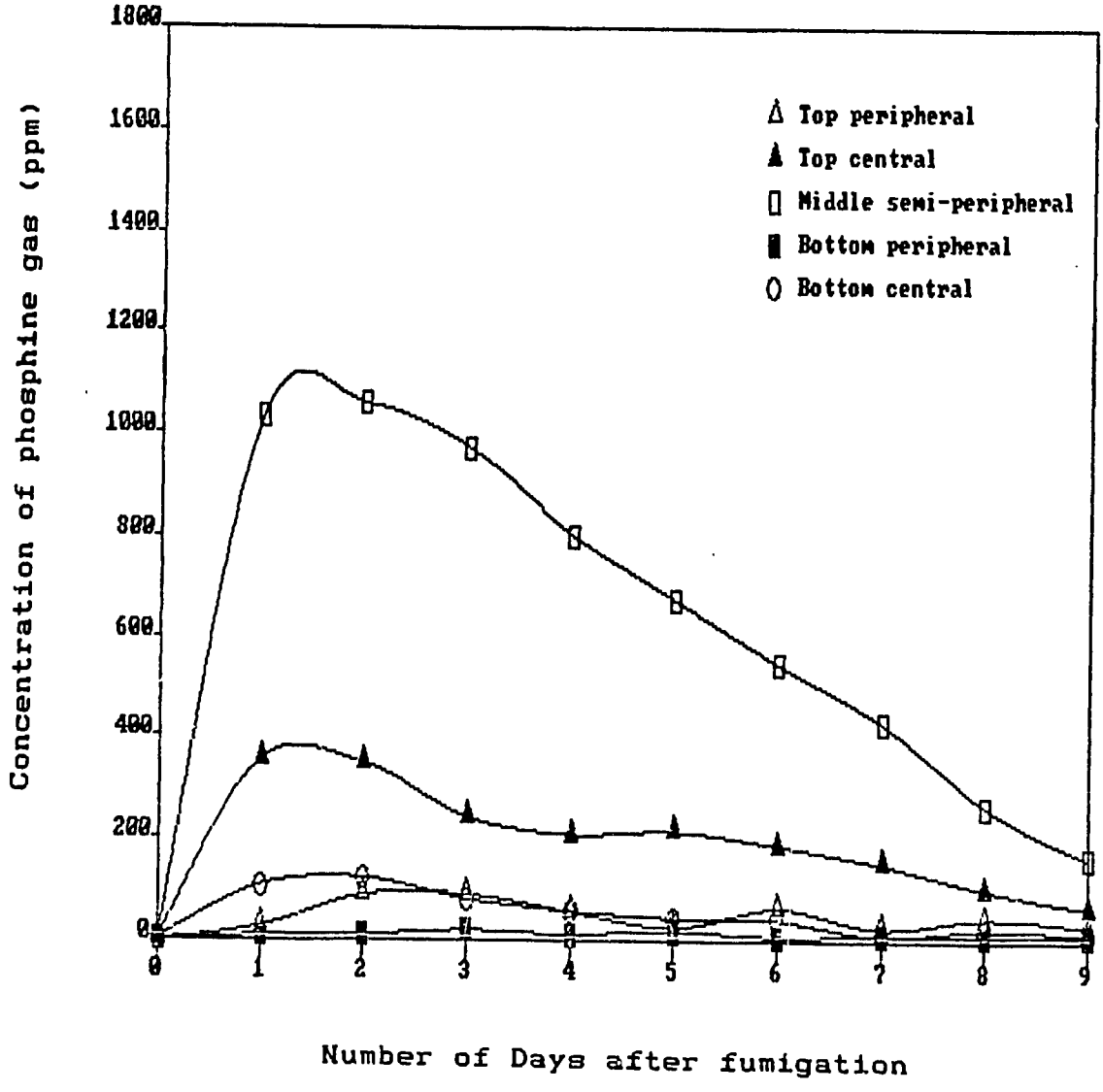

Figure 15. Concentration of phosphine gas (ppm) at different gas monitoring points in a bulkhead fumigated by inserting the AlP tablets with a tablet applicator but covering the grain surface with tarpaulins.

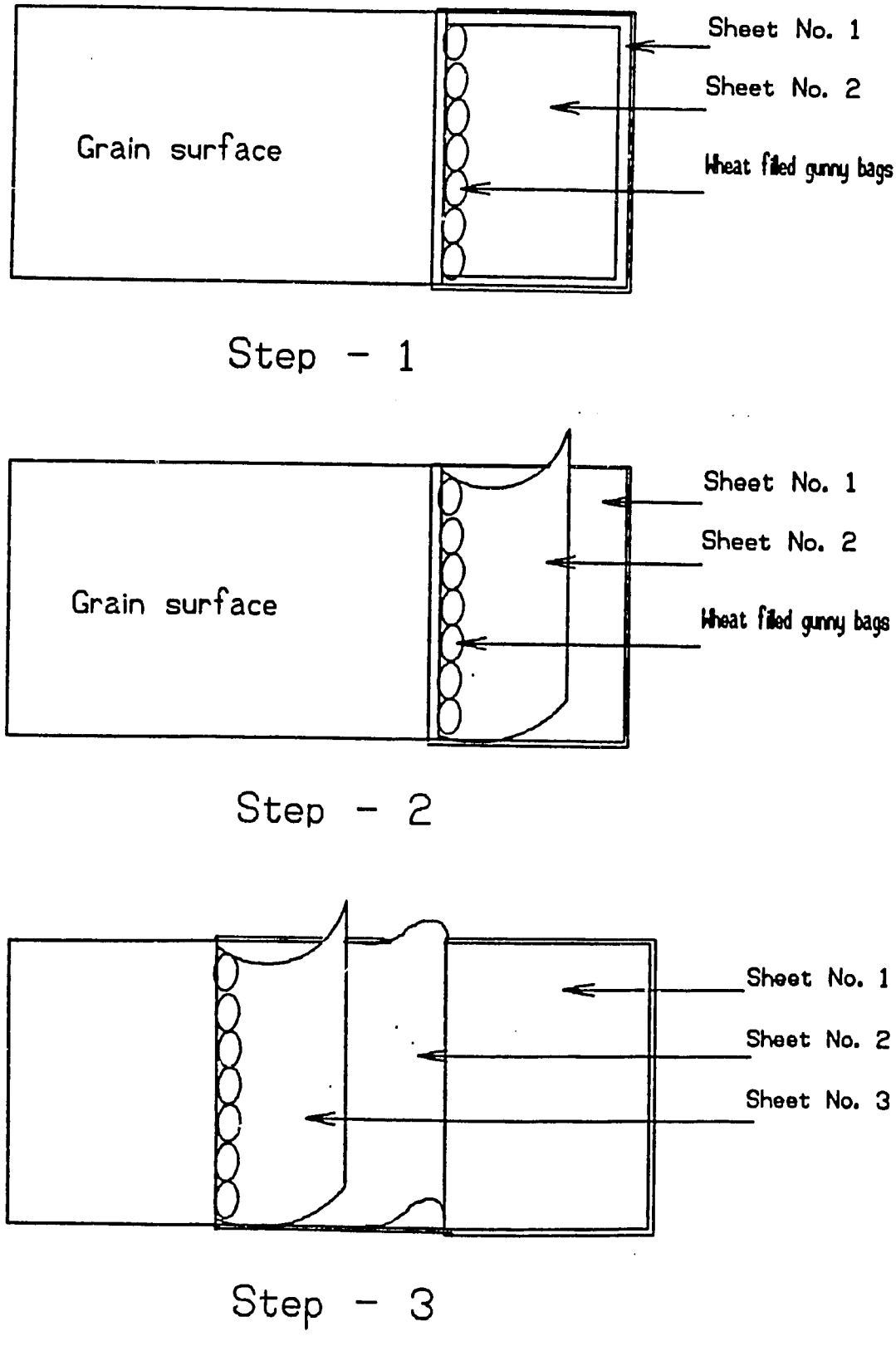

Figure 16. Various steps to cover the grain surface and make the bulkhead airtight with fiber-reinforced sheets.

SECTION III

RESULTS AND DISCUSSION

The use of grain protectants, at present, has a limited application in Pakistan because of the predominantly manual grain handling system in public-sector storage. Due to the introduction of an efficient bulk handling system by the STDT project, the use of grain protectants in bulk storage structures became feasible.

At the Manga Mandi open bulkhead, the compartment treated with Reldan was not a complete success. Table 1 shows live Rhizopertha dominica in all sampling zones of the grain which indicated the ineffectiveness of Reldan against this species. Reldan was, however, effective against Tribolium castaneum and Sitophilus oryzae, while partially effective against Trogoderma granarium. The effectiveness of Reldan against these species can be further confirmed by observing the pre-treatment insect data of other compartments filled at the same time (Table 2). The failure of Reldan to control Rhizopertha dominica has already been reported by McFarlane (1989); Ahmad et al., (1990); and Daglish (1991). The failure to control this species may be due to the development of resistance against organophosphorus compounds (McFarlane, 1989 and Alam, et al., 1991). Malathion and actellic (both belong to organophosphorus group) are two insecticides extensively used as a surface treatment in Pakistan, while Reldan has no history of any use in this country. Therefore, the ineffectiveness of Reldan against Rhizopertha dominica may be due to a high natural tolerance or cross-resistance. However, Table 1 shows that Reldan provided protection against Tribolium castaneum for a period of only three months. This confirms with earlier observations of Ahmad et al., (1990) against this species in hexagonal bins. The density of Trogoderma granarium was comparatively lower than other infesting species at the time of loading the bulkhead. The Trogoderma granarium encountered in the first sampling after treatment was found dead, indicating the effectiveness of Reldan against this species. However, grain samples taken after two months of treatment showed the re-appearance of the species in all three of the representative zones. This infestation may be due to the emergence of larvae from the eggs present in the grain which might have remained unaffected. The newly hatched larvae was not killed, probably due to the fast degradation of Reldan in wheat as observed in laboratory conditions by Masud and Perveen (1991). They noted an 87.56% loss in residue after two months at 35°C and 10% moisture content. The temperature recorded at different depths in present study ranged from 39 to 40°C, while the moisture content of the grain ranged from 9 to 10% throughout the experimental period (Table 3). Sitophilus oryzae was effectively controlled by Reldan throughout the experiment.

In the remaining three compartments of the bulkhead at Manga Mandi, three different phosphine fumigation procedures were tested. The effectiveness of these procedures was determined on the basis of the concentration and the retention pattern of phosphine gas in the grain bulk over a period of time. The same criterion proposed for successful fumigation by Mahmood et al., (1991a) was that a concentration of 200 ppm of phosphine gas should be maintained in the enclosure for more than 12 days.

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The fluctuating concentrations at about all gas sampling points may be attributed to two storms that occurred on day two and seven after application of the fumigant. In the second procedure (P-2), the fumigant was applied in horizontally laid perforated pipes. Above 200 ppm of gas was retained in the bottom central, top peripheral, and top central zone for 11 days. Such a retention pattern could not be achieved in the remaining two gas monitoring point (Table 4). At these positions, the gas could not be retained after the storm which occurred on seventh day of fumigation resulting in a continuous drop in the concentration of gas.

In the third procedure (P-3), where perforated pipes were positioned vertically in the grain mass and fumigant applied by mixing it with grain, the gas distribution was comparatively more uniform than P-2 (Table 5). The required lethal concentration (200 ppm) of phosphine gas was retained for 11 days in the bottom central zone. It was recorded for seven days at other monitoring points. This method was partially successful as the required concentration could not be retained for more than 12 days in all parts of the grain bulk.

The fourth procedure (P-4) was a complete failure. The required concentration (> 200 ppm) of phosphine gas was retained for only seven days at the middle semi-peripheral zone of the grain bulk. This may be due to the continuous release of phosphine gas from the AlP tablets inserted above this region. The gas leaked out continuously from the top and peripheral regions so the required concentration could not be reached and retained at all other gas sampling points (Table 6). The graph in Figure 13 shows the gas concentration in various zones of the grain mass in this compartment.

All the fumigation procedures tested (P-2 to P-4) proved to be a failure or only partially successful because:

a. The gas distribution in all parts of the grain was not uniform.

b. The required lethal concentration of phosphine gas could not be retained for more than 12 days in all parts of the grain bulk.

c. The lethal level of phosphine (above 200 ppm) was better maintained in P-2 and P-3 as compared with P-4. The installation of pipes during the filling of bulkhead was a laborious job. This is impractical to use by bulkhead managers.

After this partial success, it was decided to try another method of fumigation of bulkheads which has already been tested successfully to fumigate bulk wheat in hexagonal bins (Mahmood, et al., 1991b). It was first tried in a bulkhead at Depalpur. AlP tablets were inserted half-way down the grain depth with the help of a tablet applicator. The monitoring of gas showed that the required lethal concentration of phosphine gas was retained in all parts of the bulk wheat for more than 12 days (Table 7). The maximum concentration of gas was monitored in the middle of the grain mass because the fumigant was deposited at that level (Figure 14). To confirm the results further, the method was tested in two more bulkheads located at Depalpur and Okara. The gas concentrations monitored over time in these bulkheads are given in Table 8 and 9, respectively. The gas was monitored only for nine days after the application of fumigant in each bulkhead.

It was found that after nine days, the gas was well above the 200 ppm level at all of the gas sampling points. The low gas leakage rate clearly indicated that gas can be retained in all parts of the grain mass for more than 12 days. The method is very simple to adopt for a regular fumigation program requiring no complicated technique before or during the loading operation.

In P-6, where the bulkhead was covered with a tarpaulin, the required lethal concentration of gas was maintained in the middle of the grain bulk for only seven days where AlP tablets were deposited (Table 10). At all other sampling points, negligible concentrations of phosphine gas were detected throughout the experiment (Figure 14). Table 10 clearly demonstrates the gas leaking pattern in the bulkhead. Gas being generated in the middle of the grain mass was leaking out through the tarpaulin, probably due to the convectional air currents and porosity of the tarpaulin. The tarpaulin cover is therefore not suitable for fumigation purposes as it cannot prevent phosphine gas from leaking. The continued use of a tarpaulin as cover for fumigation purposes is not only ineffective but also promotes the development of resistance in insects to phosphine gas.

Table 1. Number of different insect species per kg of wheat samples drawn each month from compartment No. 1 where the grain protectant Reldan was admixed with wheat.

Sampling Zones	Insect Species		Sampling Periods			
			06/20/90	07/27/90	08/28/90	09/30/90
Top	Rhizopertha dominica	Alive	3.25	0.51	0.10	0.10
		Dead	1.45	2.92	2.16	4.25
	Trogoderma granarium (L)	Alive	Nil	Nil	0.10	Nil
		Dead	Nil	Nil	0.11	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	Nil	Nil
		Dead	0.22	Nil	Nil	Nil
	Tribolium castaneum	Alive	Nil	Nil	Nil	0.36
		Dead	Nil	Nil	0.68	0.97
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	0.56	Nil	1.11	0.80
Middle	Rhizopertha dominica	Alive	2.72	0.27	Nil	Nil
		Dead	1.13	1.57	3.86	2.31
	Trogoderma granarium (L)	Alive	Nil	Nil	0.15	Nil
		Dead	Nil	Nil	0.15	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	Nil	Nil
		Dead	Nil	Nil	Nil	Nil
	Tribolium castaneum	Alive	Nil	Nil	Nil	0.11
		Dead	0.31	0.77	0.63	0.33
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	0.21	Nil	1.24	0.20
Bottom	Rhizopertha dominica	Alive	1.76	0.60	Nil	Nil
		Dead	0.51	3.49	1.14	4.48
	Trogoderma granarium (L)	Alive	Nil	Nil	0.41	Nil
		Dead	Nil	Nil	0.94	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	Nil	Nil
		Dead	Nil	Nil	Nil	Nil
	Tribolium castaneum	Alive	Nil	Nil	Nil	Nil
		Dead	0.21	Nil	0.21	0.40
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	Nil	Nil	0.10	0.30

A = Adult
L = Larvae

Table 2. Number of different insect species per kg of wheat samples drawn just after loading each compartment from three grain depths.

Sampling Zone	Species		P-1	P-2	P-3	P-4
Top	Rhizopertha dominica	Alive	3.25	5.20	17.30	18.68
		Dead	1.45	1.56	4.22	2.60
	Trogoderma granarium (L)	Alive	Nil	Nil	11.41	0.12
		Dead	Nil	Nil	0.93	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	0.52	Nil
		Dead	0.22	0.10	0.62	Nil
	Tribolium castaneum	Alive	Nil	1.11	4.77	2.09
		Dead	Nil	0.51	0.21	2.39
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	0.56	1.44	0.10	1.03
Middle	Rhizopertha dominica	Alive	2.72	5.35	18.16	3.59
		Dead	1.13	1.11	4.23	2.42
	Trogoderma granarium (L)	Alive	Nil	0.10	Nil	Nil
		Dead	Nil	Nil	Nil	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	Nil	Nil
		Dead	Nil	Nil	Nil	Nil
	Tribolium castaneum	Alive	Nil	0.91	1.32	2.09
		Dead	0.31	0.40	0.90	1.62
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	0.21	Nil	1.40	0.51
Bottom	Rhizopertha dominica	Alive	1.76	2.22	15.44	6.63
		Dead	0.51	3.15	5.75	2.45
	Trogoderma granarium (L)	Alive	Nil	Nil	4.54	0.43
		Dead	Nil	Nil	Nil	Nil
	Trogoderma granarium (A)	Alive	Nil	Nil	0.50	Nil
		Dead	Nil	Nil	2.62	0.22
	Tribolium castaneum	Alive	Nil	2.98	12.85	4.42
		Dead	0.21	1.05	2.76	0.76
	Sitophilus oryzae	Alive	Nil	Nil	Nil	Nil
		Dead	Nil	2.51	1.73	0.76

A = Adults
L = Larvae

Table 3. Average grain temperature and moisture content at three different grain depths in an open bulkhead during the experimental period.

Month	Grain Temperature (oC)			Moisture Content (%)		
	Grain Top	Grain Middle	Grain Bottom	Grain Top	Grain Middle	Grain Bottom
June	39.37	39.46	39.78	9.86	9.97	9.88
July	39.30	39.51	39.00	9.31	9.29	9.15
August	39.25	39.61	38.29	9.08	9.32	9.37
September	39.12	40.25	38.75	9.32	9.58	9.50
October	39.12	40.00	39.21	10.06	9.96	9.84

Table 4. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat bulk. The AlP tablets were applied inside the horizontal perforated pipes, buried in the grain mass.

Days After Initial Dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	230	37	134	331	197
2	363	407	202	574	261
3	413	340	338	730	497
4	112	397	179	692	900
5	207	386	291	649	913
6	340	408	371	698	788
7	314	402	343	772	674
8	155	145	175	476	692
9	97	387	--	377	581
10	--	331	--	290	469
11	--	248	--	267	369
12	--	192	--	205	251

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 5. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat bulk. The AlP tablets were applied inside the vertical perforated pipes, buried in the grain mass.

Days After Initial Dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	2000	2000	968	375	196
2	884	702	848	398	425
3	603	565	712	546	250
4	394	333	353	479	409
5	356	341	433	559	214
6	329	655	655	559	183
7	375	312	331	578	294
8	116	189	139	465	344
9	--	--	--	321	236
10	--	--	--	296	135
11	--	--	--	229	--

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 6. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat bulk. The AlP tablets were inserted in the grain mass about two feet deep by hand as per the PASSCO procedure.

Days After Initial Dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	22	11	862	14	22
2	45	46	678	58	53
3	194	34	990	122	88
4	85	102	445	113	162
5	74	36	408	122	88
6	55	37	468	123	83
7	15	101	320	118	93
8	9	44	122	122	82
9	13	34	96	96	77

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 7. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat in open bulkhead (No. 1) at Depalpur. The AlP3 tablets were inserted half way down the grain mass by using an AlP3 tablet applicator.

Days After initial dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	741	798	>2000	249	220
2	952	1690	>2000	563	471
3	1010	1514	1743	753	602
4	981	1244	1410	762	730
5	770	1023	1048	720	705
6	680	845	834	648	644
7	594	711	732	553	561
8	515	605	620	450	455
9	425	508	513	342	335
10	370	427	455	317	300
11	309	324	347	293	280

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 8. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat in an open bulkhead (No. 2) at Depalpur. The AlP tablets were inserted half way down the grain mass by using an AlP tablet applicator.

Days After Initial Dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	187	475	342	43	190
2	437	590	522	92	793
3	546	706	668	215	782
4	549	672	649	400	769
5	572	728	700	490	800
6	595	739	716	556	826
7	676	781	729	627	709
8	490	694	667	595	704
9	418	578	563	578	565

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 9. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat in an open bulkhead at Okara. The AlP tablets were inserted half way down the grain mass by using an AlP tablet applicator.

Days After Initial Dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	676	936	216	313	438
2	1103	1464	570	472	860
3	1247	1522	764	683	1022
4	1163	1365	743	814	981
5	1140	1256	786	861	1002
6	1082	910	746	716	844
7	458	575	256	466	406
8	380	505	245	405	390
9	298	426	160	342	305

* BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

Table 10. Average concentration of phosphine gas (ppm) in air monitored at five different zones of wheat in an open bulkhead (No. 3) at Depalpur. The AlP tablets were inserted half way down in the grain mass by using an AlP tablet applicator. The bulkhead was covered with tarpaulins.

Days After initial dosing	Average Concentration (ppm) of Phosphine Gas in Wheat Bulk				
	BP*	TP*	MS*	BC*	TC*
1	9	27	1031	108	355
2	10	89	1058	123	349
3	19	90	971	81	243
4	11	56	802	57	209
5	18	25	672	44	215
6	7	63	545	40	187
7	11	24	429	9	151
8	9	45	265	23	102
9	8	29	163	12	65

*
BP Bottom Peripheral
BC Bottom Center
MS Middle Semi-peripheral
TP Top Peripheral
TC Top Center

SECTION IV

CONCLUSIONS

The following conclusions were drawn from this study.

1. Reldan provided protection against the rice weevil, Sitophilus oryzae, the khapra beetle, Trogoderma granarium, and the red flour beetle, Tribolium castaneum, for a short duration of time (less than three months). It was ineffective against the lesser grain borer, Rhizopertha dominica, as this species is known to have a high natural tolerance against organophosphorus compounds.

2. The present practice of fumigating the open bulkheads by placing the AlP tablets in the top grain layer proved to be unsuccessful. This is because phosphine gas could not be diffused uniformly in the grain mass.

3. Inserting the AlP tablets using a tablet applicator proved to be an effective and a practical method for a regular fumigation program for bulkheads.

4. The fiber-reinforced plastic cover was found to be more successful for retaining the phosphine gas than the tarpaulin.

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SECTION V

RECOMMENDATIONS

1. Fumigation of open bulkheads requires considerable effort, therefore, sufficient manpower should be available to complete the work rapidly enough to prevent excessive exposure to phosphine.

2. Fumigation should be done just after the completion of the filling operation. This will save energy and labor in removing and putting back the heavy plastic sheets.

3. Prepare AlP tablets at the dosage rate of two tablets per ton of wheat before fumigation.

4. Insert AlP tablets in the grain mass with a tablet applicator at about 2 m apart. This ensures even distribution of the fumigant in the grain mass.

5. Deposit 20 to 30 tablets at each insertion point at depths ranging from about 1 m in the periphery to 2.5 m towards the center of the bulkhead.

6. After application of AlP tablets, cover the bulkhead with fiber-reinforced plastic sheets. Normally five to six plastic sheets are needed to cover the entire grain surface. The appropriate way to spread these sheets is described below:

   a. Spread two sheets, one above the other, on the grain surface starting from one end of the bulkhead (Figure 16, Step No. 1).

   b. Place wheat filled gunny bags on the inner end of the whole width of the sheets (Figure 16).

   c. Lift the upper sheet and spread on-ward, on the grain top covering the filled bags (Figure 16, Step No. 2).

   d. Spread the third sheet above the second one and place the bags on the other ends. Again, lift the upper sheet and spread on the grain surface. By using this method, cover the whole grain surface (Figure 16, Step No. 3).

7. If the above mentioned method cannot not be adopted, place sand filled bags (sand snakes) on top of the overlapping sheets.

8. Clamp the loose ends of the sheets to the retaining walls. If some non-sealable gaps are noticed in the corrugated steel walls, drop and spread the loose ends of the plastic sheets on the ground and hold them with loose earth all around the bulkhead.

9. Close all the leakage points in the retaining wall or plastic sheets with PVC self-adhesive tape.

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10. Keep the bulkhead sealed as long as possible.

11. Spraying the bulkhead with some residual insecticide before and after storing the grain will help reduce the re-entry of insects from the surroundings.

SECTION VI

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