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EVALUATION OF CONTAINMENT AND CONTROL OPTIONS FOR METHYL BROMIDE IN COMMODITY TREATMENT

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CONVERSION FACTORS

Certain nonmetric units are used in this report for the reader's convenience. Readers more familiar with metric units may use the following factors to convert to that system.

Nonmetric	Multiplied by	Yields metric
atm	98.1	kPa
Btu/hr	0.293	W
cal	4.18	J
cfm	0.000472	m^3/s
°F	5/9(°F-32)	°C
ft	0.305	m
ft^2	0.0929	m^2
ft^3	0.0283	m^3
gal.	0.00379	m^3
hp	0.746	kW
in.	0.0254	m
in. WC	0.249	kPa
lb	0.454	kg
mil	0.0000254	m
psi	6.89	kPa
ton	907	kg

SECTION 1.0
INTRODUCTION

Methyl bromide (MeBr), with the chemical formula CH_3Br, also called bromomethane, is listed by the 1991 Montreal Protocol as an ozone depleting chemical similar to the other halogenated hydrocarbons such as the chlorofluorocarbons (CFCs). The U.S. Environmental Protection Agency's (EPA's) regulations authorized by the Clean Air Act (CAA) call for a phaseout of MeBr by the year 2001. This would mean an end to uses of MeBr where the material is emitted to the atmosphere. In some applications, there is no apparent, ready substitute for MeBr. Therefore, this study was undertaken to investigate possible means for MeBr recovery for reuse and for MeBr destruction to prevent atmospheric emissions if its limited use were still allowed. A summary discussion of the data sources used for this study is presented in Appendix A.

MeBr is widely used in United States agriculture as a fumigant.[1] A fumigant is a material that can exist as a gas in a concentration lethal to a pest organism. As a gas, it can penetrate the material being fumigated, and then diffuse away after the fumigation ends. MeBr is a very useful general fumigant since it is a permeating gas at ambient temperatures and pressures, and since it has a very desirable toxicity to many pest populations. Physical property data for MeBr are listed in Appendix B.

As Table 1 shows, the primary use of MeBr is in soil fumigation, where it is used to kill nematodes and soil insects prior to planting. According to Chemical Products Synopsis (CPS), approximately 75% of the 47 million lb of MeBr consumed in 1991 in the U.S. was for this application.[1] An additional 8% of MeBr consumption is as a chemical intermediate or as a solvent. The remaining 16% of MeBr consumption is used in space fumigation. Half of that space fumigation is structural fumigation, and half is for commodity fumigation. This report is concerned mainly with the 8%, or 3.8 million lb, of MeBr used in commodity fumigation.

The National Agricultural Pesticide Impact Assessment Program (NAPIAP) of the USDA also produced use numbers for MeBr that are different than the CPS numbers.[2] However, both sources show that approximately 4 to 5 million lb/yr of MeBr is used for commodity/agricultural harvest space fumigation. The

Table 1

Methyl Bromide Use (Million Pounds/Yr)

	1991 Use from Chemical Product Synopsis[1]	1990 Use from NAPIAP[2]
Total	47	64
Soil Fumigation	35	47
Chemical Intermediate	3.8	
Structural Space Fumigation	3.8	4 to 9
Commodity Space Fumigation	3.8	5

Chemical Manufacturer's Association has also produced a methyl bromide use report, but the report is not publicly available.

This study has gathered preliminary data that can be used to determine if some of the essential agricultural commodity fumigation applications for MeBr could be continued by the use of some emission control methods on those commodity fumigation applications.

Physical characteristics of methyl bromide emission sources in commodity treatment are discussed in Section 2. This includes statistics on end uses by purpose of fumigation and configuration for various applications. Section 3 discusses specifics of various commodity containment methods. This information is important in defining how recovery systems could be retrofitted or how fumigation systems might have to be modified to accommodate an emission control system. Basic design considerations for emissions control and technologies currently being considered are presented in Section 4. Current control research efforts are discussed in Section 5. Identification of remaining information gaps is the subject of Section 6, and Section 7 presents conclusions of the present study. Several appendices present supplementary information.

SECTION 2.0
PHYSICAL CHARACTERIZATION OF METHYL BROMIDE EMISSION SOURCES IN COMMODITY TREATMENT

This section briefly describes the general uses and physical details of each space fumigation application for commodity treatment. At this time, our information suggests that MeBr fumigation for commodities' treatment is limited to only a few of these specific configurations. However, since we have only a sampling of applications rather than a complete inventory, a broad range of applications is described. This information is fundamental for characterizing the sources in order to establish potentially feasible emission controls.

Space fumigation refers to a wide range of treatments in enclosed areas. The "enclosed areas" can range from air-tight fumigation chambers, to relatively air-tight structures such as sealed silos, to open structures such as warehouses. The "areas" may be buildings or structures that are infested themselves, and require structural fumigation to rid them of pests, such as termites. However, half of all space fumigation is conducted to treat harvested agricultural products with residual insect populations. Harvested materials may be stored in bulk, such as in grain silos, or may be in shipment containers, such as crates, bags, or boxes of fruit, nuts, or grain.

2.1 End Use Patterns

This section describes the specific areas of use, or "end use patterns" for methyl bromide fumigation. The purpose of each use is outlined, and quantified where possible. End uses are shown by purpose and by agricultural product.

2.1.1 End Use Patterns by Purpose

MeBr is used for three main purposes in commodity fumigation:

1. **Import/export quarantine fumigation** as required by the importing country. This use is usually to prevent entry of a pest that is not native to the import country; the application is a regulated and monitored process. An importing country often requires certain crops to be fumigated even if there is no visual indication of pests. This use is 416,000 lbs, or 11% of commodity fumigation.

2. **Long term bulk storage of agricultural products** to hold the products for off-season demand. Long-term in this case means a month or longer. Storage is often in stacks inside of warehouses specifically built to store the products. Fumigation for long term storage may occur in a chamber prior to placing the material into cold storage warehouses, or may occur under tarpaulin either outdoors or in a warehouse, where the tarp is left in place for the duration of storage. This use is estimated to be 3.0 million lbs/yr, or 80% of commodity fumigation.

3. **Potentially infested harvested crops** on their way to domestic markets. Fumigation in this case saves the harvest from destruction and prevents infestation of other products that the cargo may contact. This use is estimated to be 340,000 lb/yr, or 9% of commodity fumigation.

According to the Animal and Plant Health Inspection Services (APHIS), the agency that monitors the quarantine fumigations in the U.S., there were 416,685 pounds of MeBr used in the U.S. (Oct 1991 to Sept 1992) for quarantine fumigation. This represents only 11% of the 3.8 Mlb/yr commodity fumigation use, and 0.88% of total MeBr consumption in the U.S. for 1992.[2] This is a small portion of the MeBr commodity use, since much of the U.S. agricultural consumption is supplied domestically and there are relatively few imports requiring fumigation.

Of the products that do require fumigation, quarantine fumigation can occur in the exporting or in the importing country. Therefore not all of the U.S. import fumigation occurs in the U.S. Some shipments are fumigated in the transport containers during shipment. However, most quarantine fumigation has to be monitored, so it occurs at a fixed location.

APHIS representatives and USDA inspectors claim that approximately 90%+ of all quarantine fumigations are performed in temporary enclosures (under tarpaulin or other plastic-material sheets). The <10% exception is for some chamber fumigation of fruit exported to Japan from the west coast.[3]

The second use of MeBr for long term storage is estimated to comprise approximately 80% of the MeBr commodity use, and 6% of the total MeBr use nationally. However, this number is purely based upon an estimate of the use in bulk fumigation. No statistical data are yet available to validate this assumption.

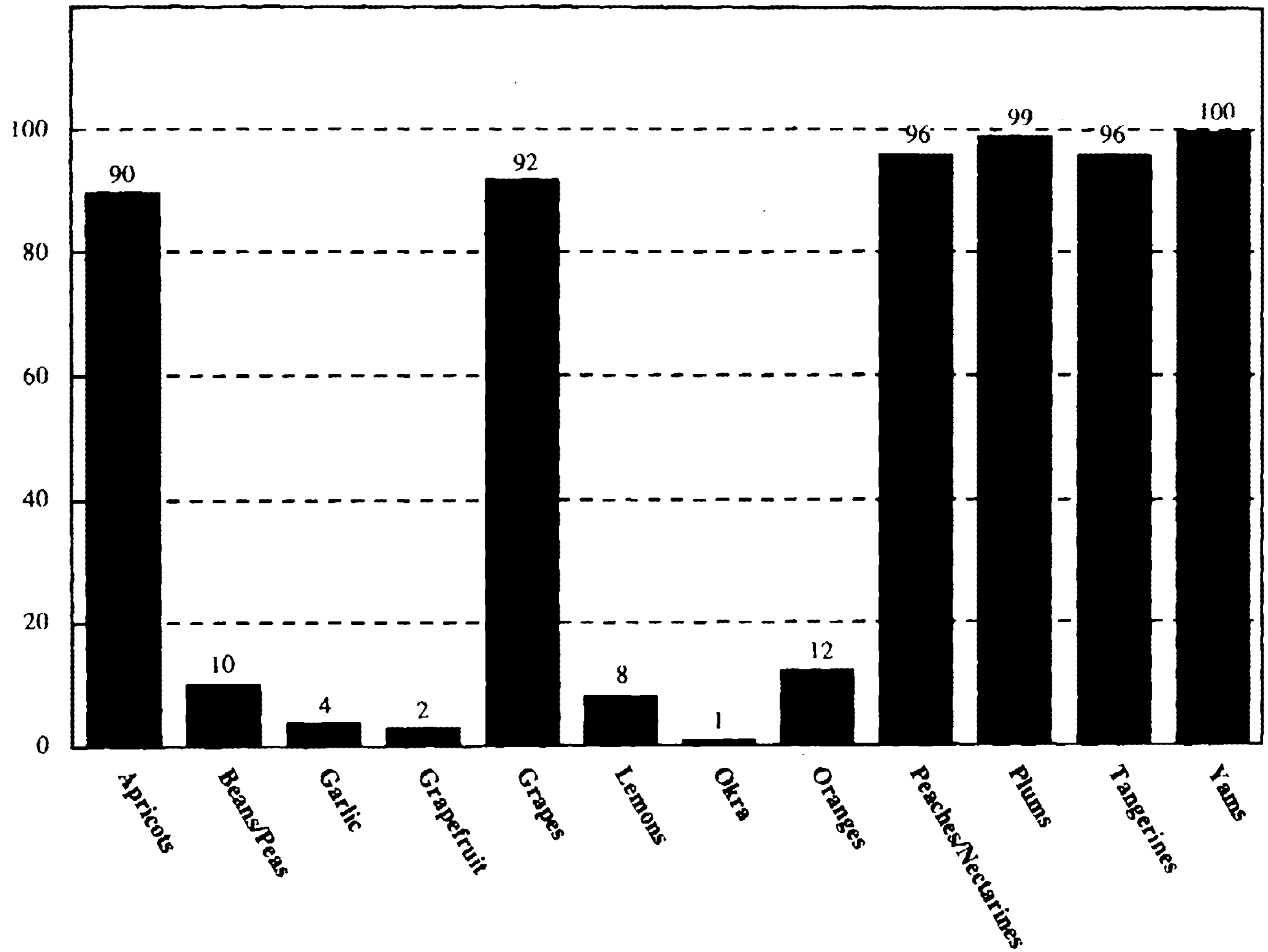
The third use for potentially infested crop harvests constitutes 9% of the MeBr commodity use and 0.7% of the total MeBr use nationally. It includes many MeBr applications, including fumigation prior to packaging and emergency fumigation of infested harvests or harvests with significant residual insect populations. This number is also based only upon the judgement that this is a small use nationally.

2.1.2 End Use Patterns by Agricultural Commodity

Commodity fumigation with MeBr is not performed on all agricultural crops. MeBr is not suitable for many sensitive harvests; it burns plums and pears, for example. Therefore, other fumigants are often preferred for specific applications. Conversely, MeBr works extremely well on many crops and insects; these crops receive a high amount of MeBr fumigation.

Data available from APHIS shows the percentage of various U.S. import crops that are fumigated with methyl bromide (see Figure 1).[2] Over 90% of all apricots, grapes, peaches, nectarines, plums, tangerines, and yams imported to the U.S. are fumigated. Figure 2 shows that the amount of imports fumigated is still a small percentage of the U.S. supply for most of those crops. Table 2 lists the numbers that Figures 1 and 2 were based upon.

Some additional specific data were available from the state of California. The following end-use analysis in Table 3 shows MeBr fumigation in California by product. This table was compiled from raw data on chemical use reports supplied by the California Department of Pesticide Regulations.[4]



Note: Fumigated imports of Brassica Dicracea and Kiwi were less than 1% of total imports in 1989/1990.

Figure 1. Percentage of Total U.S. Imports Fumigated with Methyl Bromide, 1989/1990

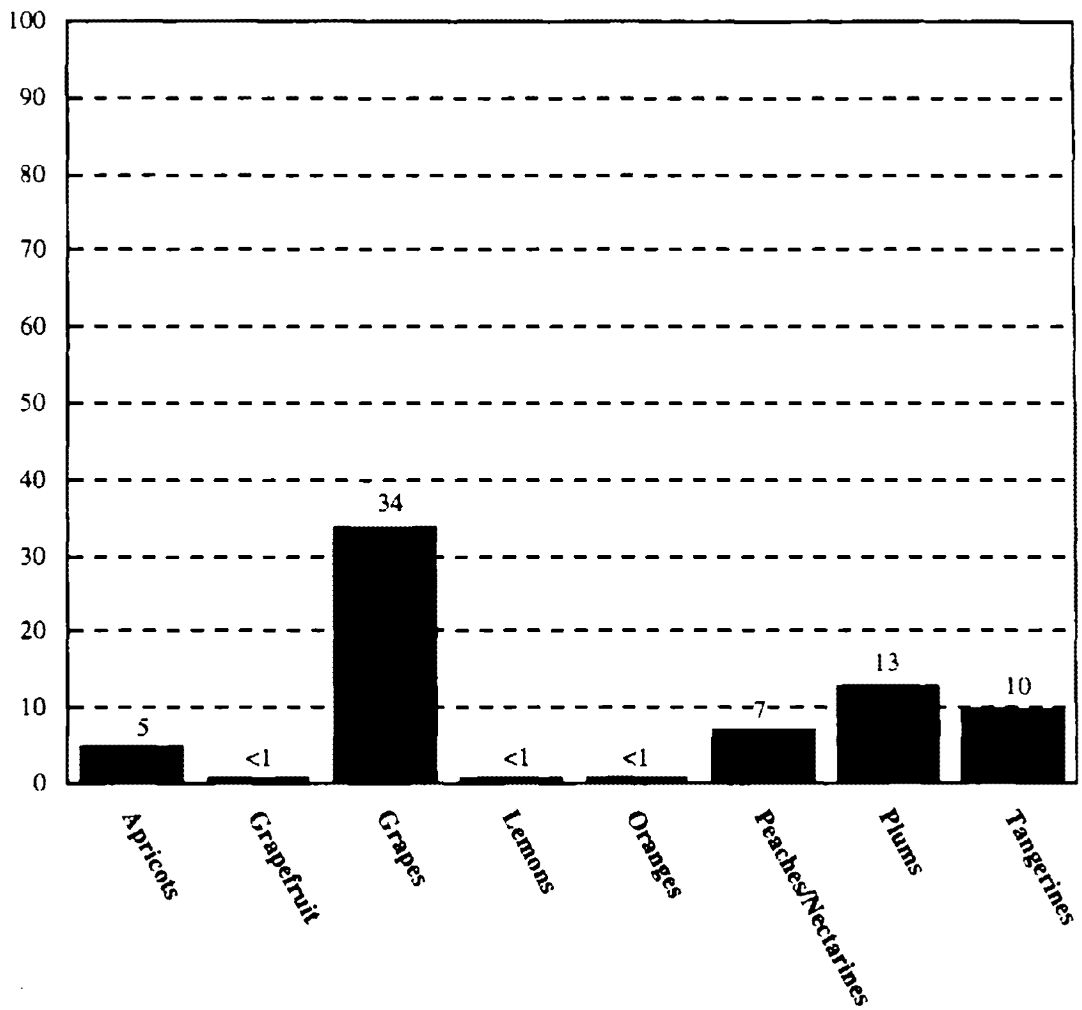


Figure 2. Imports Treated with Methyl Bromide as a Percentage of Annual U.S. Supplies, 1989/1990

Table 2

Trade Data for Fruit and Vegetable Imports Treated by Methyl Bromide Fumigation

Commodity	**Total Annual U.S. Imports (1989/1990 Average)**		**U.S. Imports Fumigated with MB (1989/1990 Average)**	
	(Metric Tons)	**($1000)**	**(Metric Tons)**	**($1000)**
Apricots	901	892	806	702
Beans/Peas	33,434	37,313	3,343	373
Brassica Oleracea	65,278	17,783	23	27
Garlic	17,309	15,747	645	1,345
Grapefruit	4,9455	879	159	28
Grapes	327,135	250,493	302,502	22,422
Kiwi	26,587	33,213	34	75
Lemons	8,556	1,281	651	250
Okra	18,484	4,919	185	49
Oranges	9,418	4,142	1,102	289
Peaches/Nectarines	47,968	31,578	46,024	29,999
Plums	22,052	14,036	21,740	13,844
Tangerines	12,617	4,191	12,134	3,859
Yam	18,169	10,769	18,169	10,769

Note: 1989/1990 Trade Data for Cipollino, Ethnog, Horseradish, Roselle, Thyme, and Tuna (fruit) was unavailable by country of origin.

Sources: Reference 5.

Table 3
California MeBr Use on Post-Harvest Products

Jan - Dec 1991 (lbs)

Post Harvest Product	Lbs of MeBr Applied	% of Commodity MeBr Use
Fruit	299080	46.7
Vegetables	8322	1.3
Nuts	155457	24.3
Grain	17795	2.8
Fibers	170	0.0
Other ag products	9210	1.4
Nursery Products (post harvest)	29105	4.5
Commodity (Non-Ag Product)	121840	19.0
TOTAL	640979	100.0

Source: Derived from Reference 4.

The California data in Table 4 also shows the split for other MeBr uses.

Table 4
California Total Use of MeBr

Use		Lbs	% of Total Use
1	Post Harvest Crop Fumigation	640979	3.4
2	Pre-Planting Soil Fumigation	14331057	76.7
3	Structural/Area Fumigation	3330834	17.8
4	Nursery-Greenhouse (Post-Harvest)	292698	1.6
53	Other	80275	0.4
TOTAL		18675843	100.0

The data in Tables 3 and 4 were assembled by manipulating the California data from Reference 4 (see Appendix C) using the following assumptions:

1. MeBr use attributed to an agricultural product, but with an acreage or square foot designation under "units treated" actually referred to pre-planting soil fumigation for that crop.

2. For MeBr use attributed to agricultural products, all other unit designations (pounds, Kilograms, Units, etc) referred to post harvest crop quantities.

These California percentages are slightly different than those reported in Chemical Products synopsis (CPS), cited in the Introduction. California has more structural fumigation (17.6% of total use) than the 8% reported for U.S. structural fumigation by CPS. This is not inconsistent with the CPS data, since the temperate climate of California allows pests such as termites to prosper all year and therefore requires additional structural fumigation of households and buildings. The soil fumigation number (77%) from the California data compares well to the CPS data of 75%.

The post harvest commodity and agricultural product fumigation that is the subject of this report includes categories 1 and 4. For California, this constitutes only 5.0% of total MeBr use, as compared to 8% suggested in CPS. If some of the greenhouse fumigation attributed to pre-planting were actually post harvest fumigation, then use in category 4 of Table 4 rises by 1.7 Mlbs/yr, or 9.1% of total MeBr use, and total commodity fumigation becomes 14.1% of total MeBr use in California.

2.1.3 End Use Patterns by Application Configuration

As is discussed in Section 2.2, Space Fumigation Applications, Technical Descriptions, there are many methods of applying the MeBr fumigant to the agricultural product. We have estimated the relative MeBr quantities for the various commodity fumigation applications, as shown in Table 5. The split was produced from estimates of populations and uses from various information sources.

Table 5
End Use Patterns By Application

Application	Population of Applications in the U.S.	Lbs/Yr of MeBr Use *
Vacuum Chambers using MeBr	Approximately 100 Chambers (69 Chambers are on the APHIS list of contract fumigation facilities) [a]	Assumed to be < 100,000
Atmospheric Chambers using MeBr	Approximately 100 Chambers (Only 8 Chambers are on the APHIS list of contract fumigation facilities, but there are many private chambers) [a]	Assumed to be < 100,000
Tarpaulin for all uses	122 Companies [a] 711 Ports of Entry (Quarantine) [a]	3,000,000 (Only 400,000 for quarantine)
Agricultural products inside Shipping Containers (Land/Sea Trailers, Ship Holds)	Number of containers unknown at this time	Unknown at this time
Grain Storage Warehouses (silos, elevators)	10,120 [b]	Assumed to be <100,000

[a] Reference 5.
[b] Reference 6.
* All quantities are based on engineering judgement.

2.1.4 End Use Trends

There has been some relocation of import product fumigation operations from the U.S. to the exporting country for economic and other reasons. For example, Nogales, Arizona used to use MeBr extensively, but all fumigation is now done in Sonora, Mexico, across the border. If MeBr standards in the U.S. under the Clean Air Act differ from those in other countries subject to the Montreal Protocol, there could be relocation of fumigation operations to countries with later MeBr phaseout dates.

Other fumigation applications shift from port to port in the U.S. depending on the current local environmental concerns. The Port of San Diego used to do fumigation, but most of that has shifted to the Port of Los Angeles. The Port of San Diego has installed a new cold storage facility (for post fumigation storage) and hopes to begin doing import fumigation again.

2.2 Space Fumigation Applications: Technical Descriptions

Most of the MeBr space fumigation applications in the U.S. do not have air emissions control equipment. Therefore any fumigant that is not consumed (hydrolyzed into the harvested commodity and insect population), will eventually be emitted into the atmosphere during or after completion of the fumigation process.

The general process for any space fumigation consists of several steps:

1. Enclosure of material to be fumigated,
2. Fumigation (exposure of material inside the enclosure to the fumigant gas),
3. Aeration (removal of the fumigant gas from the enclosure and the material),
4. Removal of the material from the enclosure.

The various space fumigation techniques have different designs and procedures for each of these steps.

Most of the MeBr space fumigation applications are well known, having been used for many years and are as follows:[7]

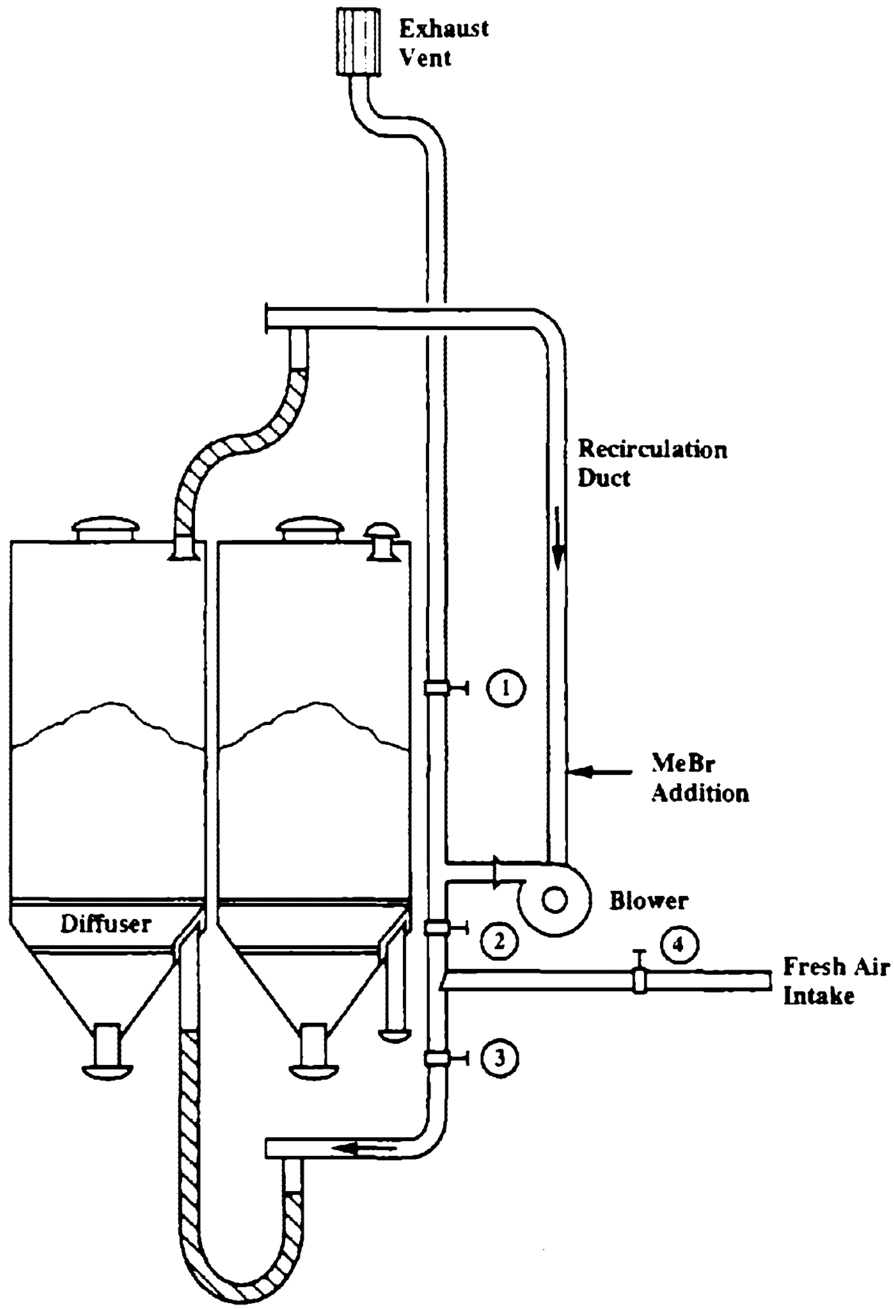
1. Bulk Grain Fumigation
2. Commodity Fumigation Chambers
3. Commodity Fumigation Under Sheets
4. Individual Package Fumigation
5. Field Fumigation Under Sheets
6. Fumigation of Full Cargo Spaces

Categories 1 through 6 are all fumigation of foodstuff or other agricultural products, which is estimated to be 8% of MeBr end use, or 3.8 million pounds per year. The 3.8 million pounds consumed in 1992 for commodity space fumigation are split among the 6 categories.

Each of the applications is described in more detail below.

2.2.1 Fumigation of Bulk Grain

Grain is stored in bulk in one of three structure types: 1) a vertical silo, 2) flat, horizontal storage, or 3) farm-type bins. However, there is great diversity even within a structure type. Silo storage can be constructed of many materials, and may or may not have a roof (see Figure 3). Silo storage can be made fairly air tight by application of a sealer to the interior surface of concrete or brick. Horizontal storage is also called "distress storage", and refers to temporary structures or freight cars or trucks. Naturally, many of these structures have open tops. Finally,



Fumigation Circulation: Valves 1 & 4 closed; valves 2 & 3 open
Aeration Venting: Valve 2 closed; valves 1,3, & 4 open

Figure 3. Permanent Installation for Fumigation of Grain in Silos by Recirculation

farm-type bins and storage units are used as permanent storage, but are often loosely constructed and not air tight.

Fumigation of grain in silos may skip some of the fumigation process steps listed above. Generally, the grain storage silo is the fumigation enclosure, so the grain is not removed after the fumigation. The fumigant may be introduced at one end of the silo and pulled up by aeration fans. Conversely, the grain may be directly fumigated as it is transferred into the bin. The MeBr usually vents directly to the atmosphere at the top of the silo.

2.2.2 Commodity Fumigation Chambers

Commodity fumigation chambers are vessels, one-room buildings, or sheds, constructed specifically for product fumigation. Most of the chambers are stationary, with large doors for easy loading and unloading of goods. The chambers are constructed to generally contain the gas and enclose the goods, but not all chambers are gas-tight. The chambers usually have ports for applying the fumigant, a fan circulation system to circulate and distribute the fumigant, and an exhaust fan system to vent the fumigant during aeration.

Chambers can be air-tight pressure vessels (as in the case of vacuum chambers) or can be any structure made of wood, masonry, plastic, or metal where sufficient effort has been made to seal leaks at joint locations and openings. The size of the chambers varies widely depending on the chamber use.

Reference 2 lists many suggested specifications for the construction of chambers for various purposes. However, there is no single standard, so the construction of actual chambers may or may not use this guideline. Enclosures used for quarantine do require certification, but this certification process does not ensure that the application is gas-tight.[3]

The different types of fumigation Chambers are:

- Atmospheric pressure,
- Vacuum, and
- Pressurized chambers.

Vacuum and pressurized chambers are not suitable for many tender fruits or other tender agricultural products.

Normal Atmospheric Pressure (NAP) Chambers

Most of these chambers are of the construction shown in Figure 4. These chambers have wide doors and can be tight or fairly leaky. There are some NAP chambers that are tent-type, barrel-type, or portable trailer fumigators, but these are few in number and do not constitute a significant use of MeBr.

An additional atmospheric pressure fumigation "chamber" is a greenhouse or glasshouse nursery, where the structure itself becomes the fumigation chamber. Usually, other fumigants are used in greenhouses because greenhouses are very leaky structures. However, if efforts are made to seal the leaks, MeBr can be used for disinfestation purposes.[7]

Vacuum Fumigation Chambers

These chambers have to withstand an atmosphere (1 atm) of full external pressure, so they are usually shaped cylindrically, and made of steel (see Figure 5). They are air-tight. The support equipment includes a vacuum pump (capable of pulling a vacuum in less than 15 minutes), an aeration fan, and doors that can also take a full vacuum. Vacuum chambers operate slightly differently than other chambers, pulling a vacuum to remove air before the fumigant introduction. This allows the fumigant to better penetrate into the stock when the fumigant is added. Another vacuum is pulled to remove the fumigant after the exposure is complete, expediting the MeBr removal prior to normal fan aeration at atmospheric pressure.

Vacuum chambers are expensive to construct and are usually used where quick turnover is a key economic issue. Vacuum fumigation has a more efficient permeation of fumigant than other techniques, and is therefore faster for the same target exposure/fumigant penetration. Typical vacuum fumigation is less than 4 hours, versus less than 24 hours for atmospheric fumigation.[7] Vacuum fumigation was originally developed when hydrogen cyanide (HCN) was the primary fumigant; the greater penetrating ability of MeBr has made vacuum fumigation less important for treatment of many commodities.

Pressurized Fumigation Chambers

Steel chambers capable of holding high pressures can be used to drive the MeBr into the commodity's void spaces by holding a pressure higher than atmospheric pressure. Although one such chamber is under construction at the

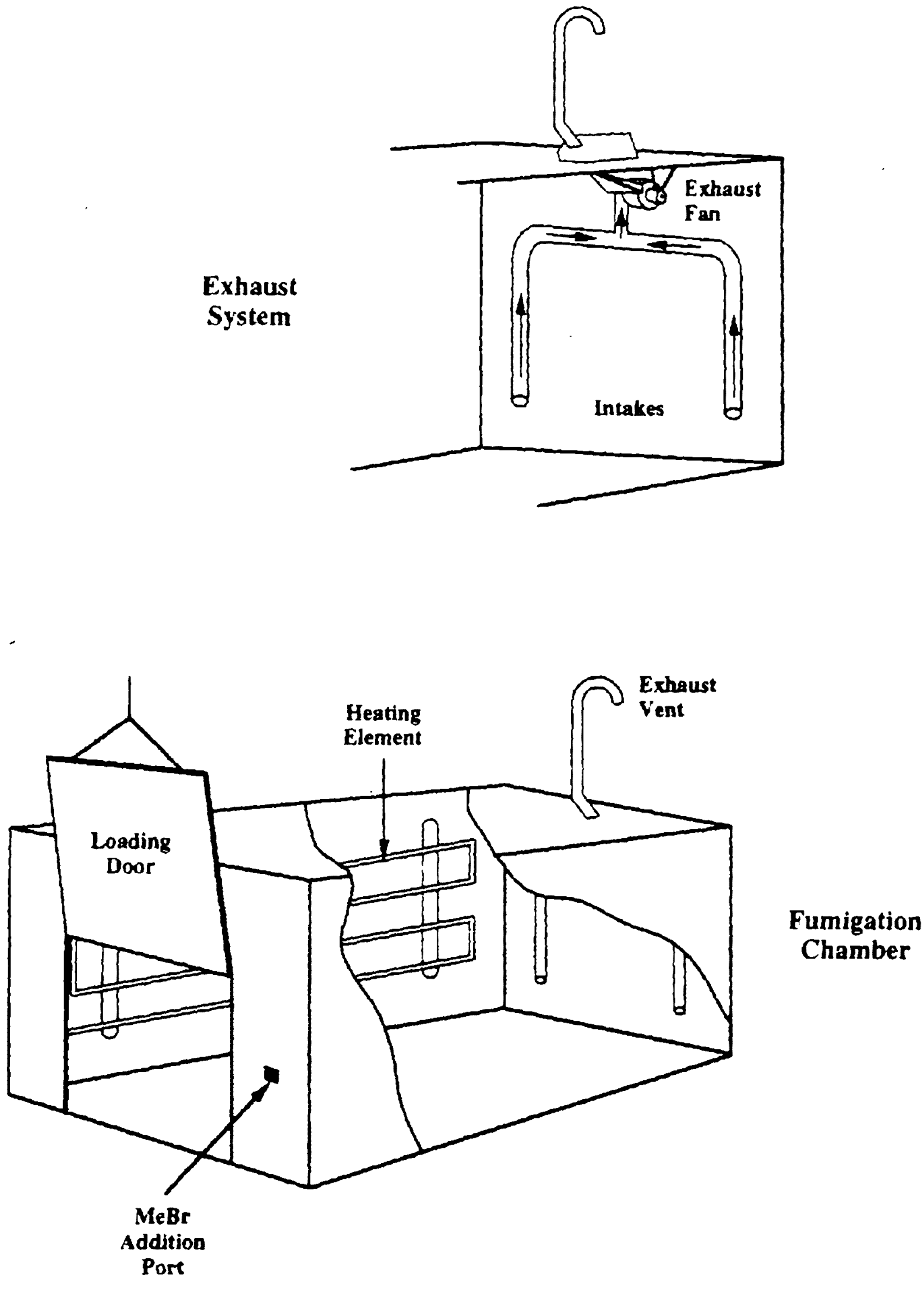


Figure 4. Generalized Plan of an Atmospheric Fumigation Chamber

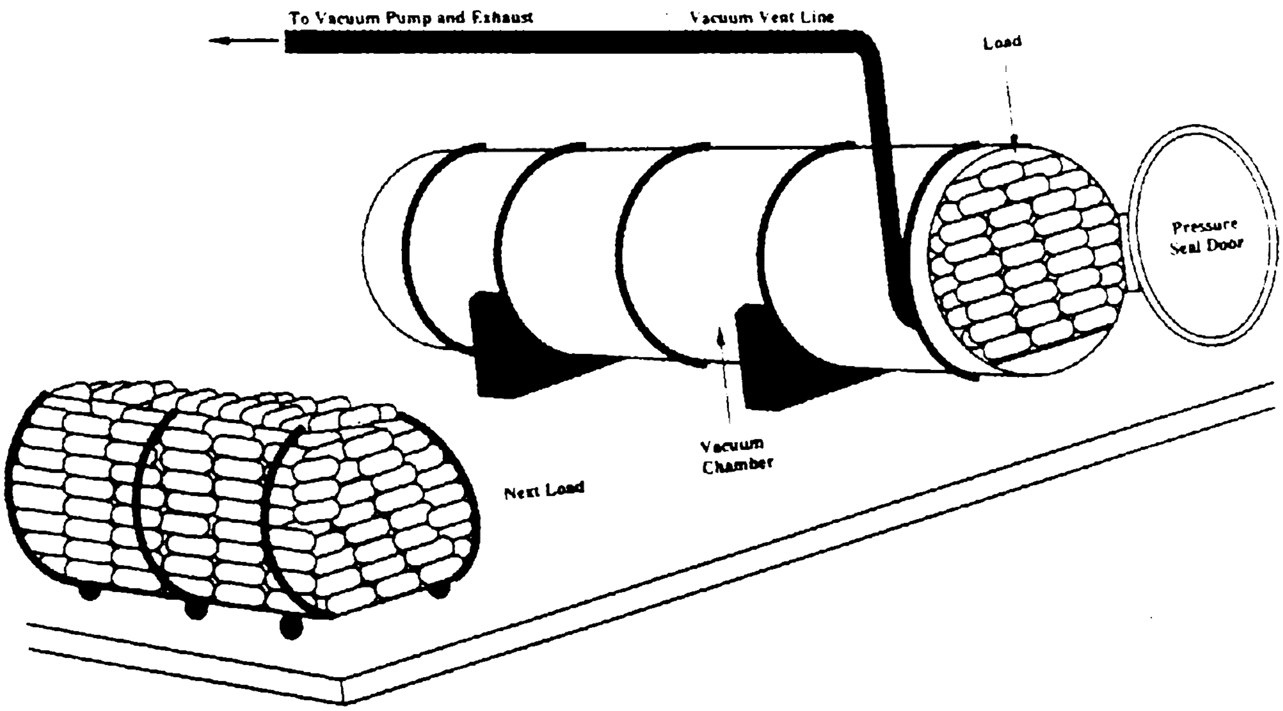


Figure 5. Vacuum Fumigation Installation

Port of Los Angeles, Radian could not locate any complete working examples of such chambers.

2.2.3 Commodity Fumigation Under Sheets (Tarpaulins)

This application is the single largest use of MeBr in commodity treatment, since it is the easiest to apply (facility requirements are minimal), and since it can be easily adapted to fit various size loads. Reference 7 states that most of the goods fumigated under sheets are cereals and other plant products in bags that are stacked many layers high.

Fumigation under sheets refers to construction of a temporary enclosure around a stack of agricultural products by laying sheets of polyethylene plastic across them (see Figures 6 and 7). The floor must be a solid surface, generally a cement foundation. However, the application may be indoors (inside a large warehouse) or outdoors. The edges of the plastic are "sealed" to the floor by sandbags, and sheets edges that meet one another on top of the stack are "sealed" to each other by rolling and clamping the interface. The pressure seal of this enclosure is generally weak.

Tarp applications usually have circulating fans and may or may not have exhaust fans attached through ducts made of tarp material. For applications with exhaust fans, the aeration step is vented through the exhaust duct. For those without, the aeration may simply be performed by quickly removing the sheets from the stack.

One of the largest tarpaulin applications is for long term storage at warehouses. For this application, the tarps are left in place for the full duration of storage, and the aeration step never occurs. The user intends to leave the fumigant inside the sheet seal as long as possible, to prevent reinfestation for as long as possible during storage. The entire MeBr charge is usually emitted by leakage if the load is stored for extensive time periods.

2.2.4 Individual Package Fumigation

This use covers emergency application such as direct treatment without an enclosure of small quantities of infested packages, as well as continuous uses such as packaging line treatments, i.e. fumigation in processes where the product is packaged for market. The processes covered are usually for dried fruits and vegetables, where fumigant is added to the individual plastic package before it is sealed. The package usually holds the fumigant just long

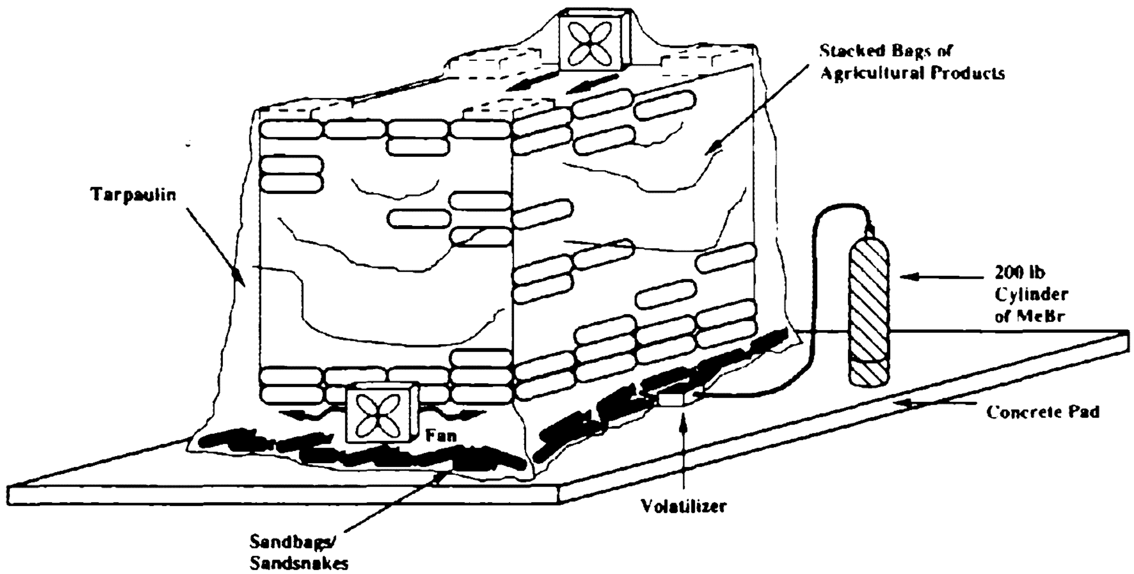


Figure 6. Fumigation of Bagged Grain Under Polyethylene Sheets Inside a Warehouse

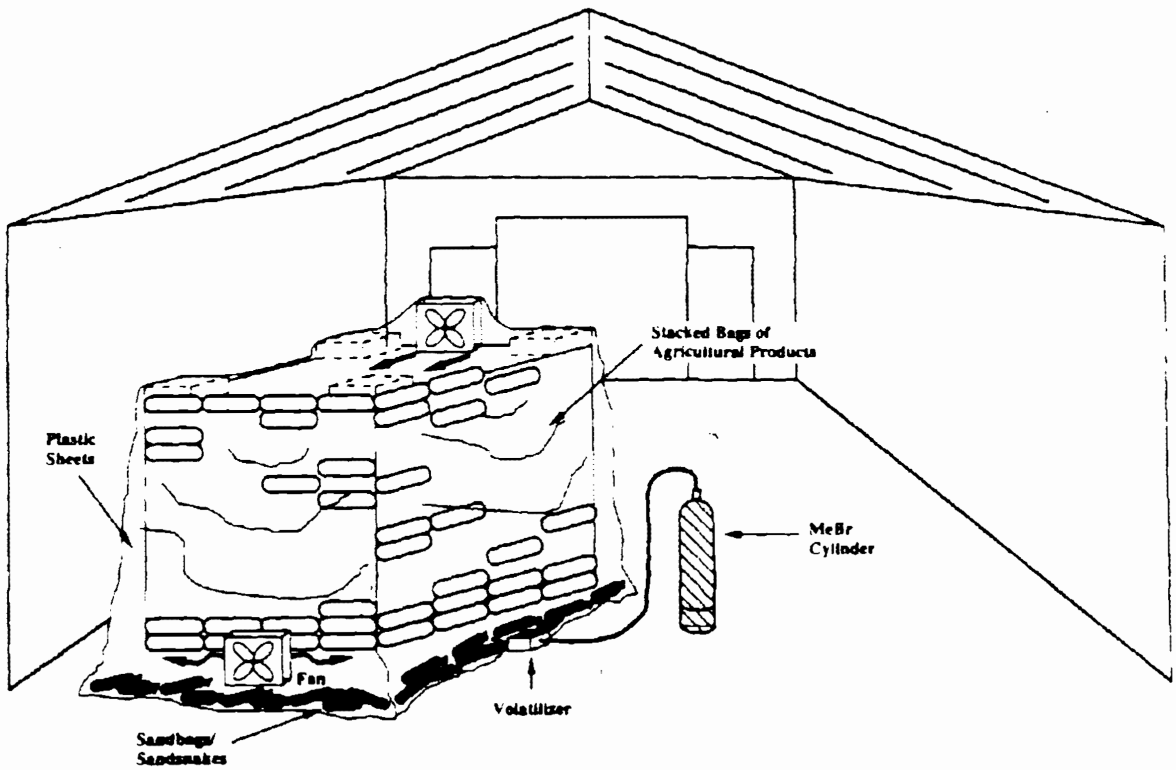


Figure 7. Outdoor Fumigation of Stacked Bags Under Sheets

enough to deliver an effective treatment. All of the fumigant is eventually leaked to the atmosphere. These uses are considered to be small consumers of MeBr.

2.2.5 Field Fumigation Under Sheets

Preharvest infested crops are sometimes treated in situ. Lightweight plastic sheets can cover a large area of land and hold the MeBr long enough to effect a treatment of soil or growing crop.[7] The best known application of this technique is for California strawberries, where large beds of strawberry plants infested with cyclamen mites are covered with sheets that are sealed at the edges with earth or sand bags. MeBr is introduced under the sheets through soaker hoses. Exposure is usually limited to a few hours, and all of the MeBr is released to the atmosphere by permeation through the weak seals and finally by removal of the sheets after exposure.

The California data cited in earlier sections shows that 4.5 million lbs of MeBr was used on strawberries in 1991. This covers all types of applications including soil fumigation, post-harvest fumigation, and field use under sheets. Use on strawberries is significant, since 4.5 million pounds is 24.3% of all of California's MeBr use. However, no data are available on the amounts used for the individual applications on strawberries in the field.

2.2.6 Fumigation of Full Cargo Spaces

This application uses the cargo container as the fumigation chamber. These are the large holds of ships or barges, in land/sea trailers, and rail cars (the latter two applications being wheeled carriers). In some cases, the container may be covered with a tarp and a fumigation under tarpaulin is performed, but in most situations, the fumigation is more similar to an atmospheric chamber fumigation or a bulk grain storage fumigation. One major difference is that there is no controlled aeration step.

The application for cargo boxes introduces the MeBr to the interior after the cargo has been loaded and the doors to the cargo space closed. The structures can be leaky, especially at the doors. Generally, the aeration occurs simply by opening the doors. However, much of the MeBr may have escaped before this point.

As a final note, fumigation of empty structures such as Buildings/Mills, Ship Holds (Empty), and Wheeled Carriers (Empty) is significant, but is not considered as part of this commodity fumigation study.

The following section examines the implications of these various fumigation and containment methods from the point of view of potential control systems.

SECTION 3.0
CONTAINMENT METHODS

Containment refers to the method in which the fumigation area is enclosed or contained. Procedures for containment are just as important as the physical containment measures. Physical structure methods are discussed first, and then a discussion of containment procedures follows.

3.1 Physical Containment Methods

There are very few fumigation applications where a completely air tight structure is used. Therefore some MeBr is lost due to the inefficiency of the chamber seal. A fumigation vacuum chamber is the only ready example of an air tight chamber. One measure of structure tightness is the prolonged pressure differential that it will hold. A vacuum chamber can indefinitely handle pressure differentials up to 14.7 psi (33.9 feet of water) at full vacuum. In the case of vacuum chambers, the leak is from the outside to the inside, so there is no MeBr loss. MeBr is completely contained in these vessels, however, they represent a very small fraction of the MeBr commodity fumigation use.

Most structures and under-sheet uses are good barriers against mixing of outside air currents with the internal gas, but are relatively weak as total barriers or pressure seals. In fixed volume structures and chambers where methyl bromide is added, the pressure increases proportionally to the amount of MeBr added. The structure has atmospheric pressure inside when originally "sealed" at the beginning of fumigation, and then additional gas molecules of MeBr are added, slightly increasing the internal pressure. If all of the MeBr is to be contained, the enclosed area must expand in volume (which does not happen, since the structures have weight or are fixed), or the pressure must increase and hold. In reality, neither usually happens, since the gas is not completely contained. The pressure increase is leaked out of the chamber in the form of the internal air and MeBr mixture.

In fact, most fumigation areas can only hold minute positive pressure differentials (dP) of much less than two inches of water. Even for specially constructed atmospheric fumigation chambers, a suggested pressure leakage test starts at only 50 mm of kerosene manometer dP (approximately 1.6 inches of water, or 0.058 psi). Furthermore, the recommended procedure allows a drop of 45 mm kerosene (1.4 inches of water, or 0.052 psi) in only 22 seconds.[7] These are very small pressures and fast leak rates that represent a relatively weak seal. Therefore, most fumigation structures have some leakage.

Fortunately, the leakage is usually small. The increase in pressure and molecules due to the MeBr addition is low, since MeBr is only needed in part per million level to kill pests. For example, say a dose of 2 pounds of MeBr was added to a 10 foot cube (1000 ft^3 chamber) at atmospheric pressure. The chamber already contains 76 lbs of air (1000 ft^3) before the fumigation begins. The MeBr would only add 8.0 ft^3 of space, forcing a loss to the atmosphere of 8.0 ft^3 of MeBr/air mixture when the leaks return the chamber to atmospheric pressure. The air/MeBr mixture that is lost, however, may only contain 0.1 lbs of MeBr, which is less than 5 percent of the MeBr added. This assumes that the leaked material is not near the fumigant admission port.

In summary, most losses of MeBr in fumigation comes from the aeration-purge step following the fumigation, rather than from leaks during fumigation. A small amount of MeBr is lost due to inefficient chamber seals, but all of the remaining MeBr is then purged to the atmosphere once the fumigation is complete. Therefore, MeBr containment during fumigation is not a large issue, given any of the standard enclosed fumigation methods. Most recovery options must center on recovery of MeBr from the purge gas. The chamber seal efficiency may become an issue only if the chamber or the purge apparatus leaks during the purge operation.

The wide use of sheets to make any area into a temporary fumigation chamber implies that this might be the "worst case" and most leak prone containment system. In other words, any recovery/control operation that would work for the low pressure seal of sheet applications is likely to work for all applications.

3.2 Containment Procedures

Current procedures are usually set to effect an efficient cargo fumigation exposure while limiting fumigation time and personnel exposure. However, there are very few procedures that intentionally try to allow recovery of all MeBr. Many of the techniques discussed in section 3 had no means for collecting the MeBr since there was no single exit point for the MeBr; it leaked during the fumigation and then exited through multiple openings when the fumigation was finished.

As the following section will discuss, there are many ways that MeBr can be lost: during the fumigation, during the chamber aeration, or from inadequate removal (desorption) from the cargo. Physical systems must be in place to ensure that all MeBr exits through a single point to allow recovery, such as through a fumigation chamber's aeration exhaust fan stack, and procedures must ensure that this step is used every time. A sheet fumigation application that has an exhaust fan, for example, must use it to aerate rather than simply removing the sheets to aerate. Procedures that contain the MeBr are as important as the physical containment measures.

3.3 APHIS Methods and Procedures

The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) publishes a Plant Protection and Quarantine (PPQ) Manual for use by PPQ officers.[5] The manual lists methods and procedures specific to MeBr for tarpaulin fumigation, chamber fumigation, ship fumigation, and bulk storage fumigation of grain, spices, or flour (which APHIS calls "structure fumigation").

The following paragraphs outline the APHIS PPQ design and procedures for tarpaulin fumigations.

Design Considerations for Tarpaulin Applications

- Site Selection
  - Well-ventilated area,
  - Ability to heat area (to above 40°F), and
  - Impervious floor surface;

- Load/Stack Arrangements
  - Break-up bulk cargo,
  - Containers: limit of eight under one tarp and only loaded to 80% capacity each, and
  - Finely milled products: provide space every 5 feet in any direction;

- Distribution Fans
  - Throughput per minute should equal enclosure volume, using one fan (of 2500 cfm capacity) for every 2500 ft^3 of enclosure, and
  - For containerized cargo under tarps, add at least one additional fan of 2500 cfm at the top of the load;

- Tarpaulin Type
  - Minimum thickness is 4 mils, but must be 6 mils to be reused, and
  - Large enough to go 2 feet above and 1 foot beyond the sits of the commodity;

- Seal
  - Loose, wet sand, sand snakes, water snakes, adhesives, or a combination can be applied where the tarp touches the flooring surface.
  - Two rows of snakes on the side and three on the corners.
  - Snakes should overlap each other by one foot.
  - Use loose, wet sand in the areas where the gas introduction line and electrical cords extend under the tar.
  - 30 minutes after MeBr is introduced, test for leaks using a halide lead detector. Add sand to seal discovered leaks.

- Aeration

Aeration procedures for tarpaulin fumigation varies depending on the product and storage method. Table 6 lists some of the design criteria for tarpaulin aerations. Figure 8 depicts the physical configurations of the tarpaulin aeration operations.

As Table 6 shows, the outdoor tarpaulin PPQ fumigations do not use exhaust ducts. This procedure would have to be changed in order to allow recovery of MeBr during fumigation.

The APHIS PPQ manual also lists methods and procedures for chamber fumigation. Most of the text centers on dosage and aeration. The design and operation are not covered, since the reader is referenced to the chamber manufacturer's operating manual. Since all chambers have aeration fans, the PPQ manual simply lists appropriate aeration times:

- Normal Atmospheric Pressure Chambers:
  4-15 minutes (4 complete changes of air); and

Table 6

Tarpaulin Aeration System Design (USDA APHIS PPQ)[5]

Cargo Type	Minimum Exhaust Fan Requirements	Minimum Exhaust Duct Diameter Requirements	Minimum Air Introduction Fan Requirements	Aeration Time*
Nonsorptive, containerized (indoor or outdoor)	1 @ 5200 cfm	>16"	1 @ 3750 cfm plus a 12" duct	3 hours
Nonsorptive, noncontainerized (indoor)	1 @ 3500 cfm	Required, but no size specification	None specified	2 hours
Nonsorptive, noncontainerized (outdoor)	No exhaust method required since the tarps are simply removed for the aeration step.			
Fresh fruits, vegetables, cut flowers	2-3 @ 5000 cfm	36"	None specified	2 hours
Sorptive, noncontainerized (indoor)	1 @ 3500 cfm	Required, but no size specification	None specified	4 hours
Sorptive, noncontainerized (outdoor)	No exhaust method required since the tarps are simply removed for the aeration step.			
Sorptive, containerized (indoor)	1 @ 5200 cfm	≥16"	1 @ 3750 cfm plus a 12" duct	12 hours
Sorptive, containerized (outdoor)	No exhaust method required since the tarps are simply removed for the aeration step.			

*The aeration vent must read ≤5 ppm MeBr at the end of the venting period, or the procedure will continue.

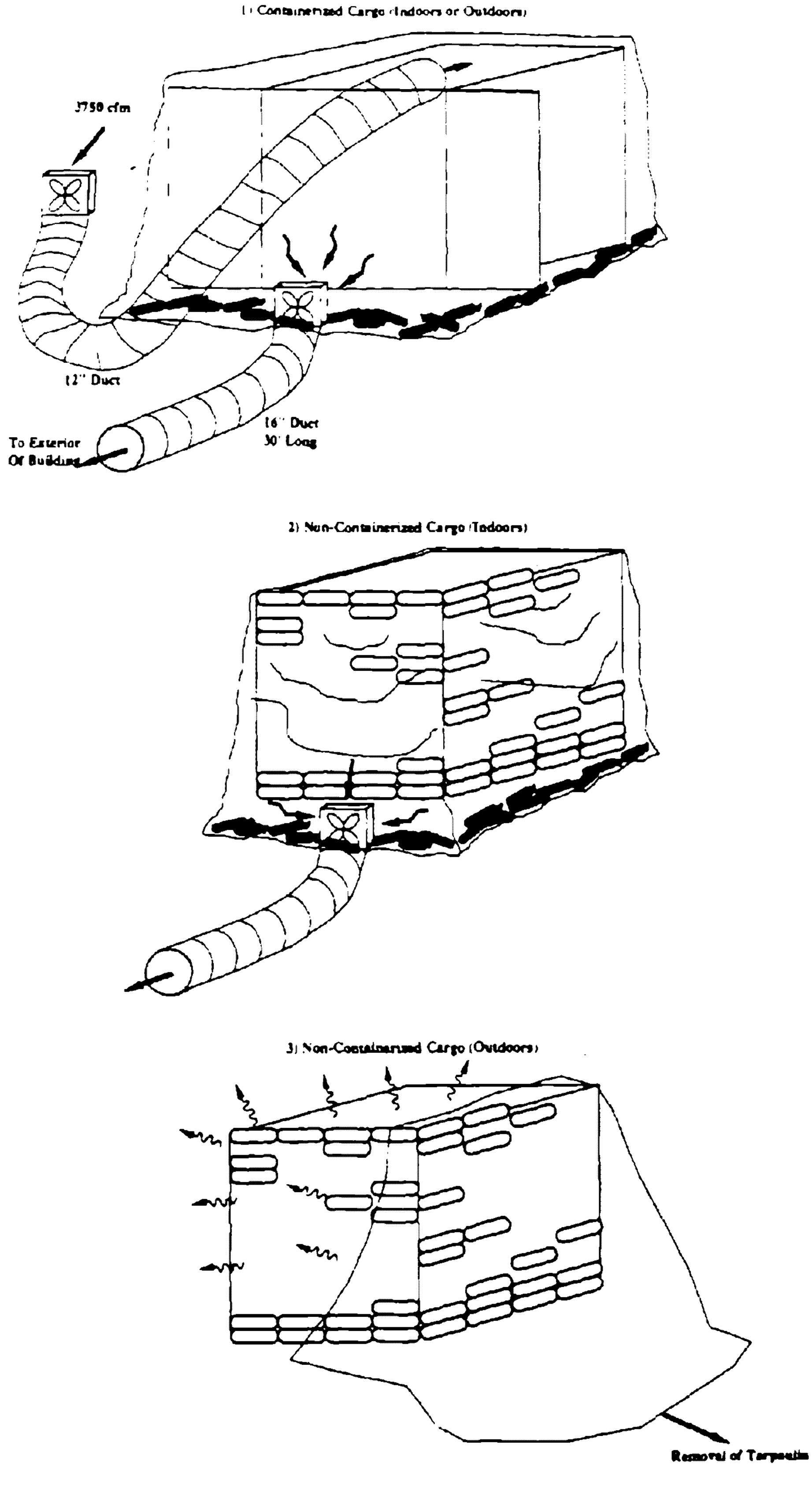


Figure 8. Tarpaulin Aeration Systems

- Vacuum Chambers:
  Draw a vacuum of 15" WC with the vacuum pump and release it by admitting air. Repeat four times.

Again, as with any fumigation, the gas concentration has to be ≤5 ppm to end the aeration.

The PPQ manual covers fumigation of commodities inside ships for storerooms and cargo holds. The rooms are treated as leaky NAP chambers, and an effort is made to locate and seal all openings. Circulation fans are also placed inside: at least two 1800 cfm fans in a storeroom, and 2500 cfm fans for cargo holds. As with tarpaulin application, a halide detector is used to test for leaks after all of the MeBr has been introduced.

Aeration of ship's holds does not always produce a single vent stream. Aeration occurs by either 1) using an outside blower to force fresh air through a portable duct and into the cargo space, or 2) using compressed air hoses to force fresh air into the bottom of the hold. The MeBr may exit via 1) a suction fan with an exit duct or 2) the ship's ventilation system. However, since the PPQ manual does not specify the fan and blower sizes, so an oversized blower and undersized suction fan may force some leakage from the chamber inside the ship.

The APHIS PPQ manual lists methods and procedures for bulk storage of grain, spices, or flour in various storage structures. Options for this fumigation are:

- Complete enclosure of structure under a tarpaulin; and
- Interior fumigation.

Interior fumigation is less desirable since the structures are rarely air-tight. However, they are treated as NAP chambers (similar to ship holds), and are made as air-tight as possible by sealing openings. Tarpaulin fumigations for bulk storage proceed very similarly to the tarp procedure listed earlier.

Aeration for tarpaulin applications is achieved by partially removing the tarp while using suction fans that exhaust through ducts to the outside. A minimum of one 2500 cfm fan should be used.

The reader should note that APHIS conducts a minority of the commodity fumigations in the U.S. Most fumigations are non-quarantine applications by private companies. Therefore, the design and method details described in this section may not be representative of all of the U.S. applications. It is, however, one of the few detailed references available.

SECTION 4.0
EMISSION CONTROL TECHNOLOGY CONSIDERATIONS

4.1 General Considerations

The control options for MeBr are basically:

- Collection, recovery and recycle;
- Collection and destruction; or
- Direct destruction.

These concepts are illustrated by the block diagrams in Figures 9, 10, and 11, respectively. Figure 9 illustrates a process for recycle which also shows destruction applied to a purge vent stream. Figure 10 shows a process without recycle where destruction is applied to the MeBr after it is collected, by activated carbon adsorption, for example. This would occur in a situation where, for some technical reason, recycle might not be possible. Figure 11 shows a process where destruction might be employed directly on the vent stream in a case where recycle is impossible. For all of these processes, the components of the individual process blocks and many of the design considerations are similar and are discussed in the subsequent pages of this section.

For design of such processes consideration must be given to each of the following:

- Stream characteristics;
- Process influences on recoverable MeBr;
- Fumigation vent stream capture;
- MeBr Collection;
- Intermediate MeBr storage; and
- MeBr destruction.

4.1.1 Stream Characteristics

A fundamental design consideration for a system are the characteristics of the stream being treated. Minimum information includes the following:

- Flow rate;
- Temperature;
- Pressure; and
- Composition (primarily MeBr and water vapor content).

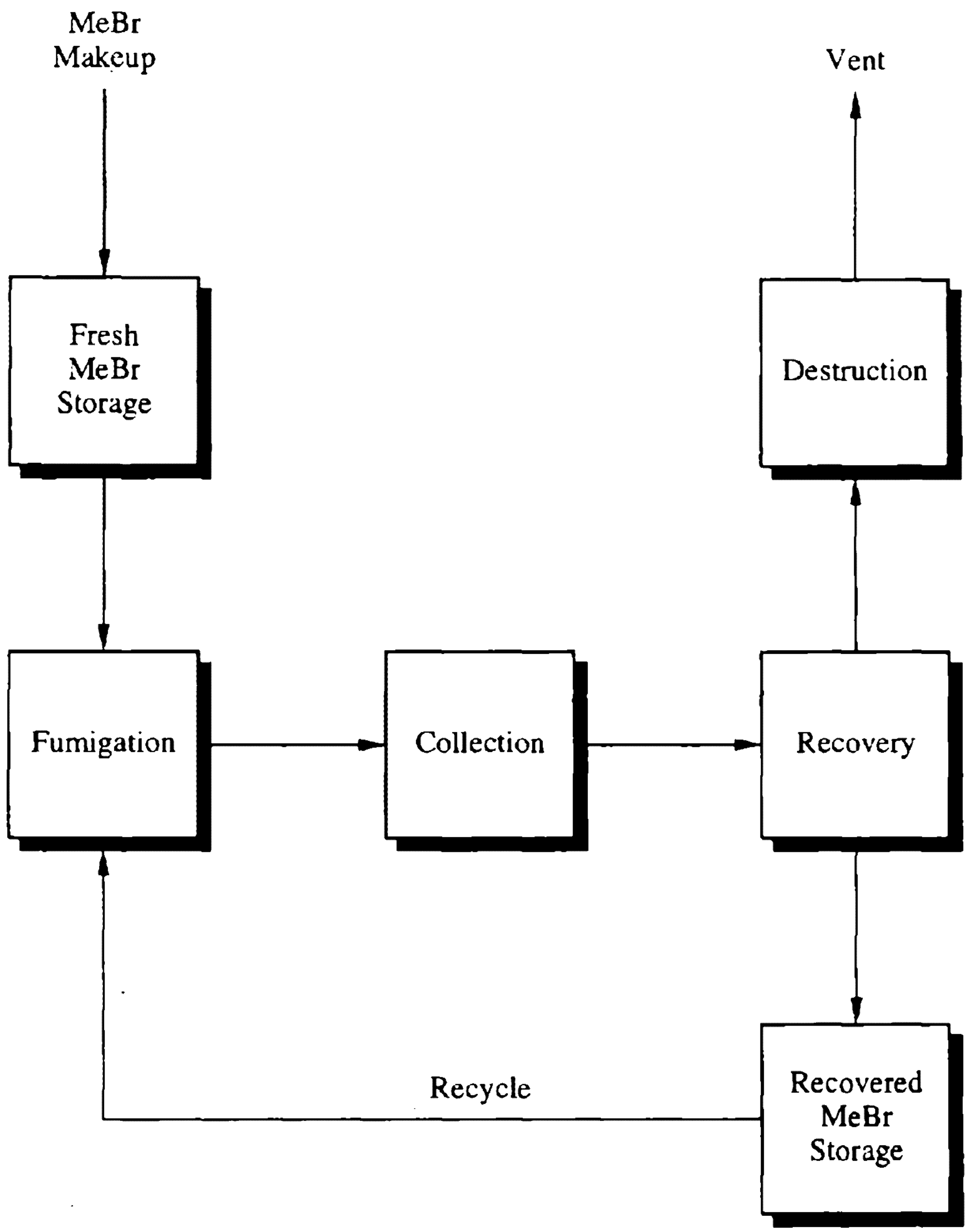


Figure 9. Process Concept for MeBr Recovery

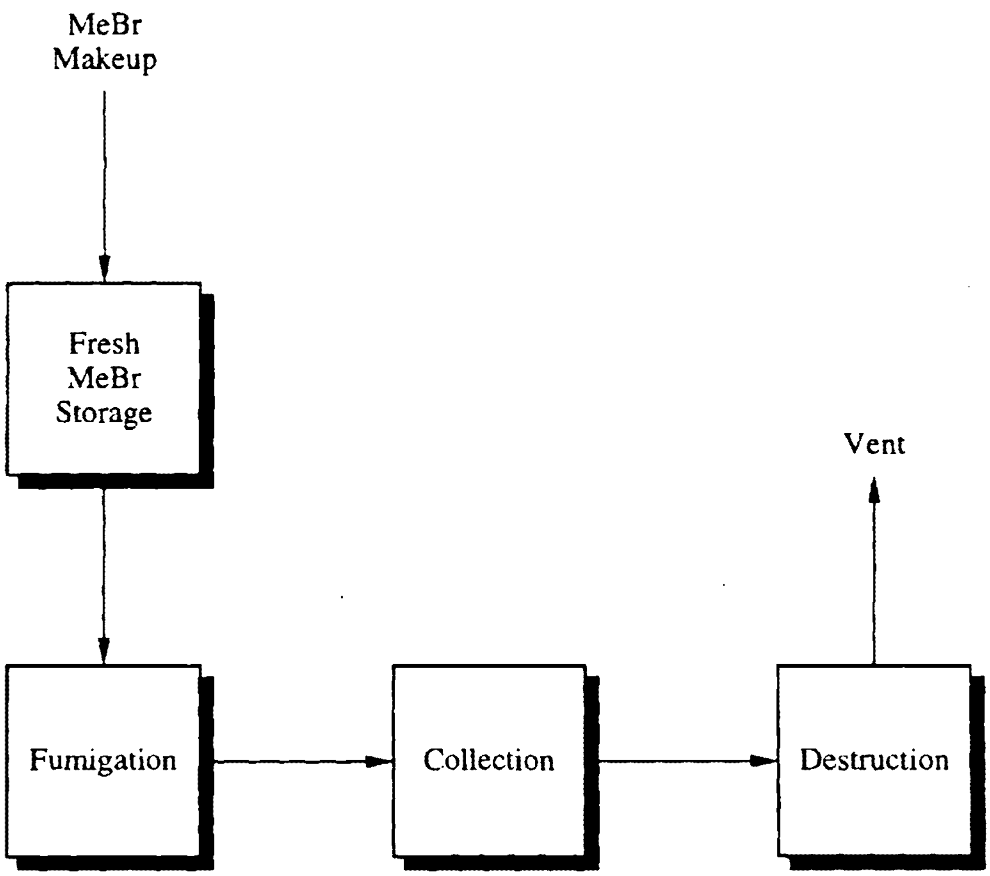


Figure 10. Process Concept for MeBr Collection and Destruction

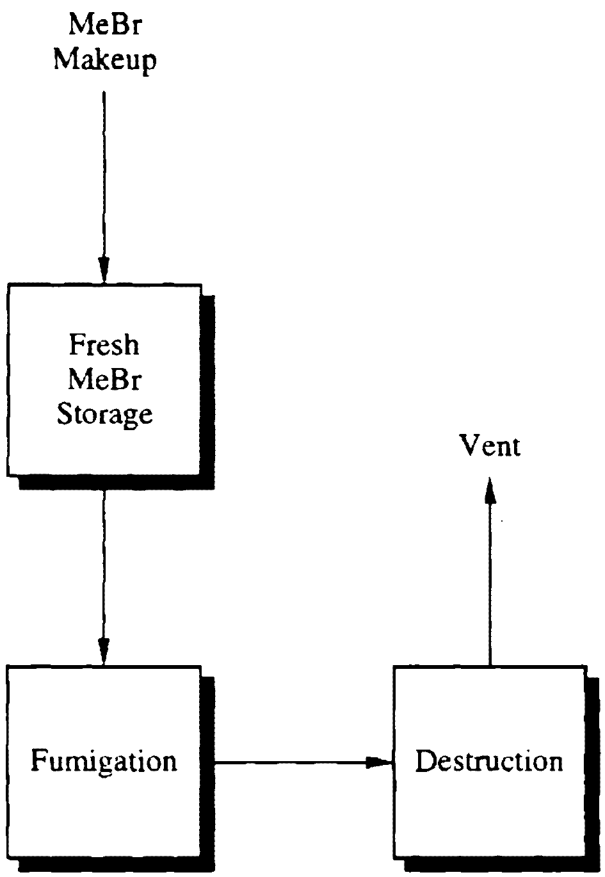


Figure 11. Process Concept for MeBr Direct Destruction

In addition, information on other chemical constituents in the air would be useful. This is especially important for adsorption processes.

All recovery applications except for vacuum fumigation have to deal with air and moisture that will be mixed with the recovered MeBr. Also, various organic vapors emitted from the commodities being fumigated may also be present.

As was discussed in the previous section, the main recovery goal is to collect the MeBr from the purge operation upon completion of fumigation. Many fumigation systems employ induced draft fans to purge the fumigation space by drawing outside air through the space after fumigation is complete. This is to dissipate the toxic MeBr concentration so that people can enter the work space.

4.1.2 Process Influences on Recoverable MeBr

Not all of the MeBr fed to the process will be available for final recovery. As was discussed in the previous section, under current practices, some MeBr is typically lost due to leaks because enclosures are not leak tight. Even without leaks, some MeBr is absorbed, hydrolyzed, or converted to other compounds from contact with the commodities being fumigated. Typically, the MeBr available for collection can be represented by:

$$\text{Collectable Mass} = \text{Inlet} - \text{Loss}_U - \text{Loss}_C - \text{Loss}_L - \text{Loss}_I$$

Where:

Inlet	=	Mass of MeBr input the fumigation space
Loss_U	=	Mass lost to unrecovered absorption/adsorption in the commodity
Loss_C	=	Mass lost due to chemical interaction with chemical constituents in the air or the commodity
Loss_L	=	Mass leaked to atmosphere
Loss_I	=	Mass lost due to inefficiencies in the recovery technique

Loss_U is a term that can be reduced by designing post-fumigation aeration to have sufficient volumes of exchange and time duration to allow the maximum efficient amount of MeBr to rediffuse back from the commodity. The commodity packaging and fill density in the fumigation chambers also affects this term. An extended aeration time does hurt many processes where fast turnover is a key economic issue. Expensive vacuum chambers, for example, were built to expedite turnover, but reduction of $Loss_U$ could extend the fumigation time requirements.

$Loss_C$ is a term that may not be easily controlled since it will happen no matter what the containment method or procedure. If the MeBr is chemisorbed or actually reacts with the commodity or air, it cannot be readily recovered.

$Loss_L$ can be easily reduced by using a tighter chamber. This may simply mean making an existing "chamber" tighter by an inexpensive sealing of leaks, or may involve an expensive switch to a new containment method.

$Loss_I$ refers to the efficiency of the recovery technology that is used to remove the MeBr from the aeration exit stream. A lower efficiency lowers the recoverable mass of MeBr by allowing some MeBr to escape. This can be controlled by careful selection of recovery technique.

Several sources[8,9] suggested that the typical MeBr loss was 20% per application, mostly lost to chemical reaction such as hydrolysis ($Loss_C$). One source on grain elevators suggests that the loss is 30% per application.[10,11] Other recovery vendor sources[12] have suggested that $Loss_C$ is much lower, and the 20% loss quoted is simply due to inadequate air turnovers that increase $Loss_U$. Regardless of the real loss number, any recovery system still requires a constant make-up of MeBr. Therefore, if all production of MeBr ceases, none of the fumigant recovery options will be viable if the current supply of MeBr is expended.

Radian Corporation had the opportunity to make measurements on an MeBr system in a previous program.[13] Data on losses from this work are shown in Table 7. These data show that some of the systems had no controlled aeration step, and that some of the systems had high leakage losses during fumigation.

4.2 Technology Descriptions

4.2.1 Capture of Methyl Bromide Vapors

For any of the process configurations, MeBr vapors vented from the fumigation equipment must be captured for conveyance to the control process. Capture devices may consist of hoods and ducting. Where the purge gas exits through a single duct, as occurs with some enclosed chamber systems, this is not a major design issue. For systems with multiple purge vents or sheet

Table 7

California Methyl Bromide Test Results[13]

Fumigation Type	Trailer Truck Land-Sea Container	Ambient Pressure (uncertified) Fumigation Chamber	Ambient Pressure (uncertified) Fumigation Chambers (3)	Ambient Pressure (uncertified) Fumigation Chambers (2)	Certified Vacuum Chambers (2)	Silo Chambers with Open Tops	Silo Chambers with Open Tops	Trailer Truck Land-Sea Container
Cargo	Dried prunes, dried fruit, packaged for shipment. (88k lbs)	Dried prunes (108k lbs)	Raisins (unknown lbs)	Raisins (unknown lbs)	Walnuts	Walnuts	Walnuts	Dried, unpackaged prunes
MeBr Added (lbs)	5	12 + 12	210 * 3	55,45	4.3 * 2	7.8 * 20	6.0 * 8	6
Duration of fumigation (hrs)	17	20	24	24	2	2	2	24
Chamber Volume (ft^3)	2200	15000	143,382 * 3	55000, 45000	1430 * 2	2600 * 2	2000 * 8	2200
Aeration Time (hrs)	2	6	24	24	2	6	0.5 to 0.75	2
Ideal Internal Equilibrium Concen-tration (ppmv)	9364	5509	6048	4173				11204
Actual Internal Measured (ppmv)	5300	108	3900, 7500, not available	280, 84000	No data	No data	No data	630, 21000
MeBr Emitted During Aeration (lbs)	No data	0.33	No data	No data	No data	No data	No data	No data
Minimum MeBr Lost or Consumed During Fumigation	2.3 lbs (47%)	11.67 lbs (97%)	74.6, 0.0 lbs (36%), (0%)	51.3, 0.0 lbs (93%), (0%)	No data	No data	No data	0.0, 5.6 lbs (0%), (94%)
Aeration Practice	Rear doors of trailer opened. No fan was used.	Exhaust fans turned on.	Portable exhaust fan connected to fumigation port. Fan run for 30 minutes, then doors to shed are opened while fans continue to run.	Chamber doors opened, then exhaust fans turned on.	A new vacuum is pulled (the addition of MeBr during the fumigation eliminates the first vacuum). Fans pulling the vacuum to 26" water exhaust to the atmosphere. Vents are then opened and air pulled through for 2 hours.	Vents are opened and fans pull air through for 2 hours.	Vents are opened and fans pull air through for 30-45 minutes.	Rear doors of trailer opened. Small house-hold fan turned on.
Aeration Exit	Rear doors	Exhaust fan stack	Exhaust stack on portable fan	Doors, exhaust fan stack	Fan exhaust stack	Silo top?	Silo top?	Rear doors

systems, application of a control device might require specialized capture system designs or modification of the fumigation enclosure itself.

4.2.2 Collection of Methyl Bromide

Potential collection technologies to separate the MeBr from the air stream in a manner suitable for easy recovery are:

- Adsorption;
- Condensation; and
- Membrane separation.

Adsorption. Differences in chemical properties between the air and the MeBr allow adsorption of the MeBr on a solid substrate while allowing the air to pass through the adsorption medium. Activated carbon adsorption is a common solid adsorption medium that has been tried experimentally for MeBr. Other adsorbents are also being considered, but carbon is inexpensive and a proven adsorption media with a high adsorptivity for many gases.

Another adsorption medium of interest is synthetic zeolites. The pore sizes in these zeolites are of a more consistent size than those in activated carbon, and the pore size can be "tailored" to the chemical to be adsorbed. These zeolites can also be designed to be less hydrophilic than activated carbon, which could reduce the costs of drying the regenerated solvent vapors before condensation.

Carbon beds in vessels are used. The honeycomb-like, porous internal structure provides an internal surface area of approximately 10,000 ft^2 per gram.[13] The effluent aeration gas stream from fumigation passes through carbon beds. The remaining air would flow to a destruction device or to the atmosphere depending on the residual MeBr concentration in the gas. The collection block illustrated in Figures 9, 10, and 11 might have a configuration similar to that shown in Figure 12.

The adsorbed MeBr on the bed is then desorbed via fresh hot air. In a standard configuration, used in other activated carbon applications, two parallel beds would be used. One bed would operate for adsorption, while the other was in the regeneration mode. For fumigation applications, where the process may be intermittent, a single bed might suffice. For direct reuse, the MeBr regenerant stream would be routed to the fumigation application or condensed first and temporarily stored. In the destruction scenario, the MeBr might be desorbed directly into a separate destruction system or condensed and temporarily stored for later destruction either on- or off-site.

For batch treatment, it might also be possible to "store" the MeBr on the activated carbon and do a pressure swing regeneration to desorb directly onto the next batch. This might work especially well with vacuum chambers.

Specific design criteria of a tested commercial system were not available. The needed data for a system would be:

- Flow rate of aeration gas; and
- Concentration profile of MeBr in the aeration gas.

In addition, data are needed on performance of the recovery system:

- Adsorption capacity for MeBr (adsorption isotherms);
- Affinity of activated carbon for MeBr (capacity to adsorb);
- Residence time required to adsorb;
- Space velocity limitations; and
- Desorption characteristics of various carbons.

Specific data regarding performance of carbon adsorption for MeBr have been generated, but little data appear to be published. One U.S. vendor of carbon bed recovery systems reports that they have installed commercial MeBr recovery systems for overseas fumigation chambers. The vendor claims to achieve nearly 100% recovery of MeBr in the vent stream, but has not published these results nor would they provide details to us for this report.[12] However, as stated earlier, not all of the original MeBr is available in the vent stream. Fumigation systems leaks and absorption and reaction in the agricultural product cause losses. The vendor claimed to have eliminated leaks, so that only 2-3% of the MeBr was unrecoverable as a result of absorption in the agricultural product.

Some technical papers on MeBr adsorption in carbon beds have been published. Two papers from the University of Queensland, Australia were published in the mid-1970's that described recovery of methyl bromide from grain silo fumigation by carbon adsorption.[10,11] The articles described laboratory tests of activated carbon and proposed a commercial scale truck-mounted carbon bed unit. They claimed a recovery of approximately 90% of the MeBr that was left after the fumigation step. The article claims that 30% of the total MeBr introduced to fumigation is "used" by reaction with the grain, decomposition in the air, or loss to leaks.

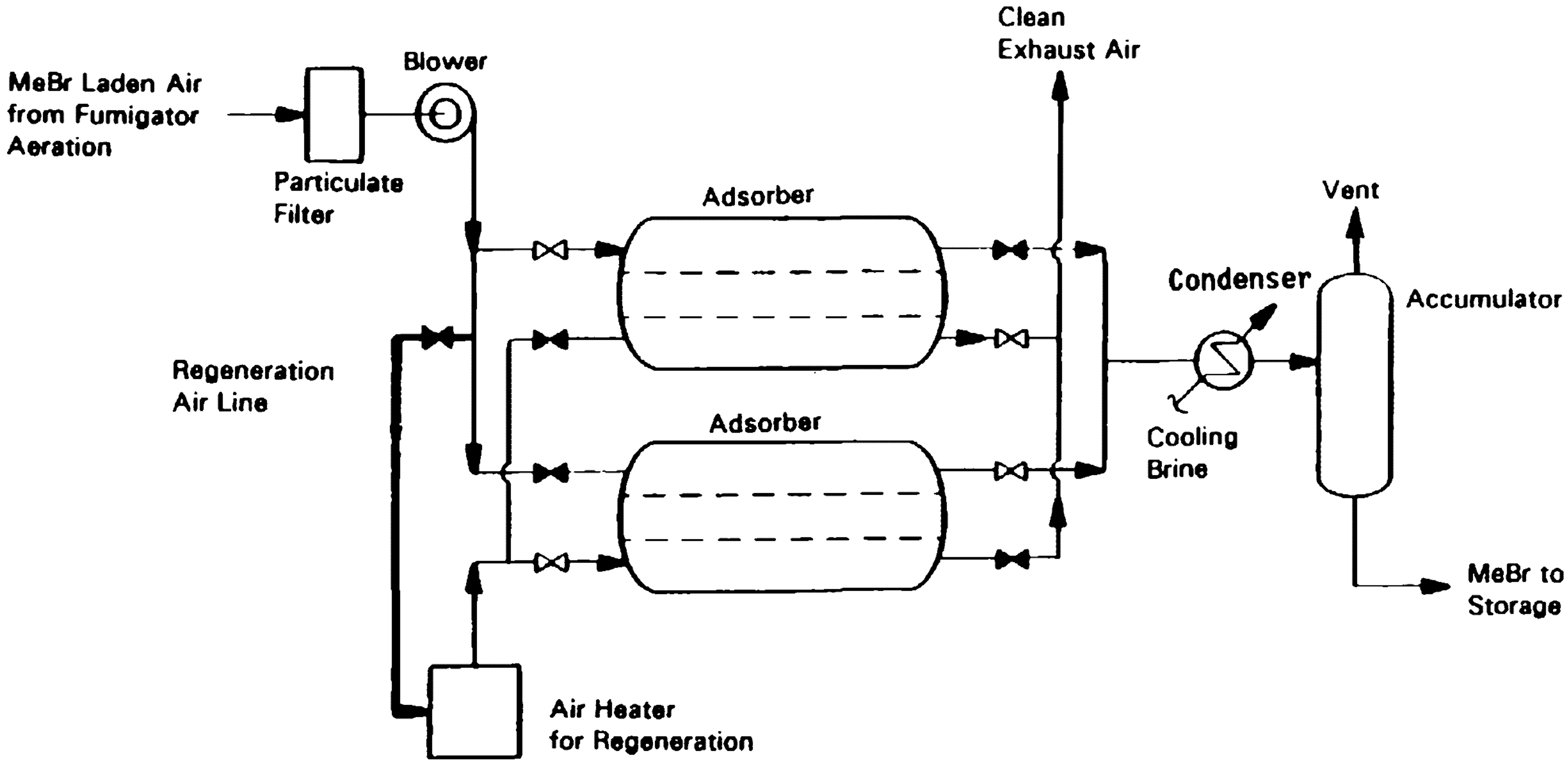


Figure 12. Typical Carbon Adsorption Configuration for MeBr Collection

The Australian data provided some information on carbon bed adsorptive capacity, up to 20% by weight of MeBr. The laboratory tests subjected the adsorbent to 30 cycles of adsorption/desorption without a measurable change in bed capacity. Figures 13 and 14 show the equilibrium capacity of MeBr on the carbon at various temperatures. Figures 15 and 16 show the adsorption and desorption run times on a pilot scale wheat "silo" that was 1.8 m tall, 0.15 m diameter, filled with 25 kg of wheat. These figures show the "breakthrough" curves.

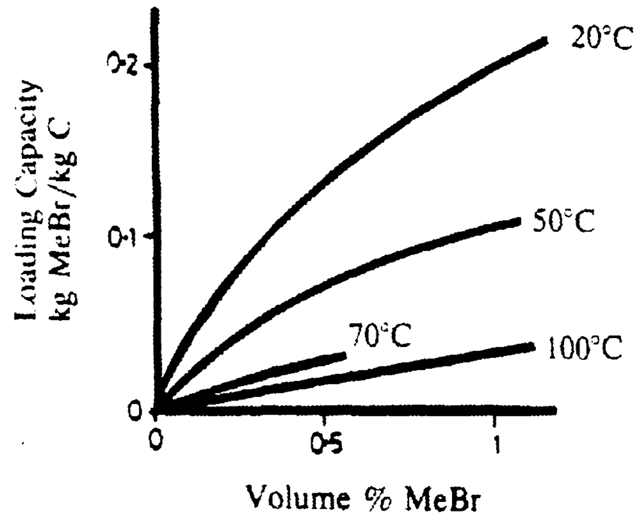


Figure 13. Equilibrium Capacity Curves of Methyl Bromide on Carbon Adsorbent Derived from Experimental Data at Various Temperatures

Source: Adapted from Reference 10

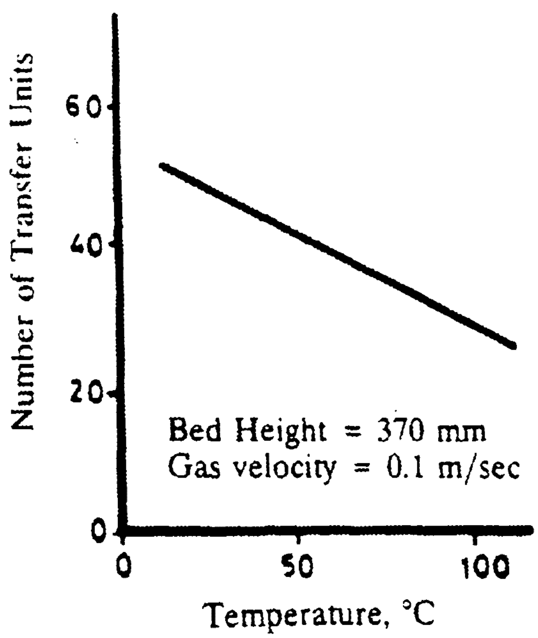


Figure 14. Adsorption Rate Function for Laboratory Adsorption Bed Derived from Experimental Data

Source: Adapted from Reference 10

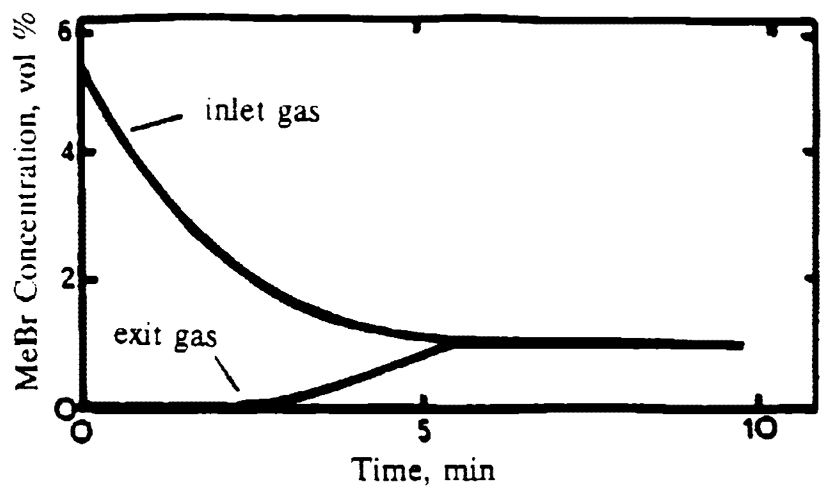


Figure 15. Inlet and Outlet Gas Concentration Curves Derived from Experimental Data for Adsorption of MeBr on a Wheat Column

Source: Adapted from Reference 10

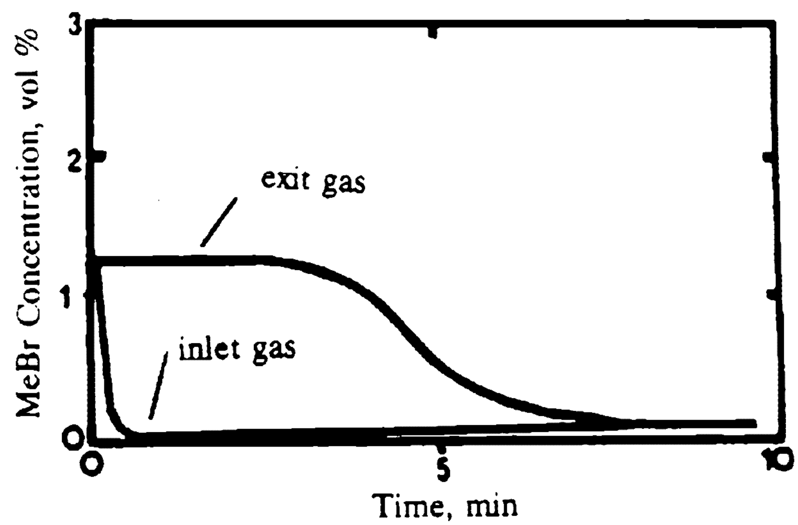


Figure 16. Inlet and Outlet Gas Concentration Curves Derived from Experimental Data for Desorption of MeBr on a Wheat Column

Source: Adapted from Reference 10

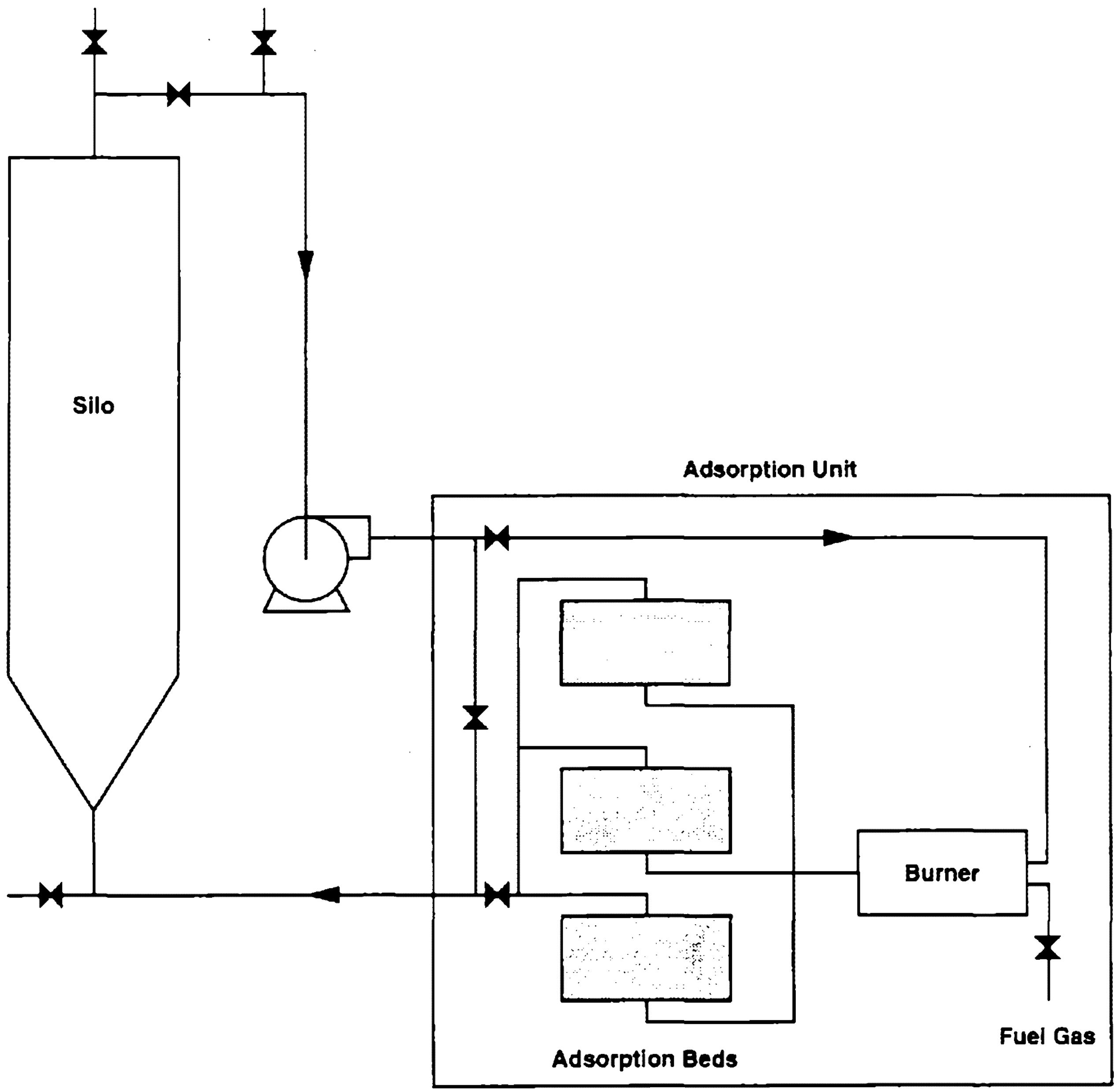


Figure 17. Attachment of Mobile Adsorption Unit to Silo
Source: Adapted from Reference 10

In addition to the lab tests, the Australians performed one silo test where gas from the silo was drawn continuously through the adsorbent for 24 hours. This test checked for effects of poisoning from impurities in the grain and from odorant (chloropicrin) used in full scale grain fumigations. The capacity of the carbon was not measurably altered after regeneration.

The full scale truck system was estimated to cost 20,000 A$ in 1975, which is equivalent to approximately 30,000 US $ in 1992. This is based upon 1975 and 1992 equipment cost indices from Chemical Engineering Magazine.[14,15] Design specifics are listed below:

- For a 2500 ton wheat silo, fumigated with 50-100 kg of MeBr:
  - Bed system operated in parallel
  - Air blower circulation of 1 m^3 per second
  - 50 mm WG pressure drop per bed
  - Charge: 2 m^3 of carbon (2/3 m^3 per bed)
  - Inlet MeBr concentration: 1.2% by volume in air (12000 ppmv)
  - Cycle time: Adsorption < 10 minutes, Desorption < 10 minutes
  - Fuel Use: 5 kg of LPG per silo

Desorption of MeBr and regeneration of the carbon was accomplished by heating the air entering the beds to 150°C. Adsorptive capacity is lower at higher temperatures, so the MeBr desorbs into the air stream. The air stream, which circulated through the grain, returned the MeBr to the silo for another fumigation cycle.

Desorption occurred quickly, and the article stated that all of the MeBr was desorbed before the first MeBr reached the top of the grain silo.

Usually the only equipment that must be added to a carbon bed recovery system in order to accomplish the recycling step is a heating system. This can be accomplished with any heating medium, but the Australian article recommended a LPG tank with a burner inside the circulating air path. Combustion of the circulating air could introduce PICs (products of incomplete combustion) to the recycle loop, and should be avoided.

<u>Condensation</u>. Cold temperatures can condense methyl bromide out of the effluent aeration air stream. At atmospheric pressure MeBr boils or condenses at 3.46°C (38°F), a refrigeration system that can cool the entire aeration

vent stream below 38°F will condense the MeBr. Appreciable quantities of MeBr will not condense until much lower temperatures are reached where the vapor pressure is very low. A very low temperature refrigeration system with temperatures in the range of -10 to -30°F may be required. Depending on the size of the overall recovery system, using delivered liquid nitrogen as a coolant may be more economical than a mechanical refrigeration system.

Unfortunately, cooling the aeration vent stream will also condense moisture (H_2O), and MeBr forms a voluminous crystalline hydrate with cold water[16] Therefore, condensing operations would require drying capability upstream of the condenser unit.

This can be an expensive and energy intensive operation, especially given the high flow rates of air that occur during the aeration step. Data from two chamber fumigation fans[3] and from one silo fumigation circulating fan[14] had the following flow rates:

- Chamber Fan: 320 ft^3/min
- Chamber Fan: 1985 ft^3/min
- Silo Blower: 2119 ft^3/min

Cooling 2000 ft^3/min of air from 100°F to 37°F consumes 531,000 calories/min, or 126,500 Btu/hr. This is based upon the heat capacity equation:

$$\text{Del } H - m * C_p * dT$$

where:

C_p - 0.237 Cal./g°C for air from reference 17, Table 3-180.

Dt - 63°F, or 35°C

m - 2000 ft^3, or 64030 grams (assuming ideal gas laws)

The process could be made more energy efficient by the integration of precooling feed/effluent exchangers, but those could add significantly to the capital cost of the option.

<u>Membrane Separation</u>. In recent years, advances in synthetic polymeric membrane technologies have made separation of certain components of gas streams feasible. It might be possible that a suitable membrane material could be found for separation of MeBr from air. At this time no data for such a system are available, and during the course of this study no one we talked to suggested that any work had been done with this technology.

Membrane pore size and differences in molecular size and relative diffusivities within the membrane pore structure determine selectivity. A membrane system relies on a pressure differential across the membrane as the primary driving force for mass transfer.

The pressure difference can be provided by a positive pressure applied to the upstream side of the membrane or a vacuum applied to the downstream side. For a process stream at essentially atmospheric pressure as would be the case for the commodity fumigation aeration stream, a vacuum system could be likely.

The separated MeBr vapor would then be condensed for recovery in the same manner as for other separation technologies.

4.2.3 **Recovery and Recycle**

A condensation collection system provides MeBr directly available for recycle. If a carbon adsorption system is used for collection, condensation would be used as an auxiliary step for condensing concentrated vapors resulting from carbon bed desorption. The condensed MeBr would then be recycled.

Recovery for reuse appears to be the most economically attractive, since it significantly reduces the net consumption of MeBr. It also fits well with the Montreal Protocol and the U.S. Clean Air Act phaseout of MeBr production, since recycling drastically reduces net consumption. However, recycling still requires make up MeBr, since some MeBr is lost, and therefore recycle cannot exist if all MeBr production stops. Recycling may also have some other limitations.

Recycling may trap and concentrate certain other undesired compounds along with the MeBr, such as various hydrocarbons (odor constituents) that are unacceptable on agricultural products. This may require that a treatment step be added to remove the other compounds, or that the recycled MeBr and hydrocarbon mixture be destroyed after a limited number of recycle uses. In fact, although MeBr is available as a pure chemical (99.5+%), manufacturers often deliver MeBr mixed with an odorant to allow easy detection of leaks. The odorant could build up during recycle steps if the recovery step is more efficient at capturing the impurity than at capturing MeBr. A common odorant mix with MeBr contains 2% of the pungent chemical chloropicrin (Cl_3CNO_2). Chloropicrin condenses at only 112°C (234°F), so it should be more easily recovered in a condensing operation than MeBr. No published data were found that quantified the buildup of odorants or other poisons during MeBr recycling operations.

It is unlikely that condensation can be used directly as a recovery technique because MeBr concentrations may not be high enough to provide for efficient condensation at reasonable temperatures. A refrigeration system would be required to provide a cold enough cooling medium for condensation of a dilute MeBr stream. An intermediate storage tank would be needed to hold the MeBr between fumigations. For a non-pressurized tank, maintaining temperatures below 38°F would be necessary. A heating system would be necessary to vaporize the condensed MeBr once a new fumigation begins.

4.2.4 Destruction

The final step in a MeBr control process is destruction. Destruction options for MeBr depend whether the MeBr has been recovered from the aeration stream, or is to be destroyed while still mixed with the aeration stream. In the latter case, the entire aeration stream containing MeBr can be burned in an incinerator or can be scrubbed with an appropriate chemically reactive solution, such as caustic soda. In the former case, MeBr might be collected and handled like other liquid hydrocarbon wastes, in waste drums for example.

Treatment in the Aeration Stream

Scrubbing with caustic solution is a direct treatment of the aeration stream that can remove and destroy MeBr. This method employs a contacting tower with a recirculating caustic solution to "scrub" the MeBr out of the air stream. One published Russian article describes scrubbing tests with various sodium solutions. The first test of 10-20% aqueous sodium sulfite (Na_2SO_3) neutralized the MeBr by forming the salts CH_3SO_3Na and NaBr, both of which are non-toxic to warm blooded animals, and are non-flammable.[18] The article also cited tests of a mixture of 7% ethylene diamine and 13% sodium carbonate (Na_2CO_3).

Operating commercial scale MeBr scrubbers could not be located during this study, nor any data regarding cost or design specifications. One scrubber was reported to have started up in the Los Angeles area, but an accident (explosion) shut the facility down.[9]

Incineration of the entire aeration stream could be accomplished by installation of a packaged incinerator on the aeration vent exit. This technology is very similar to that of incineration of pure MeBr, and is covered in the following section. No data were available to estimate the costs of such a system at this time.

Treatment after Recovery from the Aeration Stream

If destruction directly from the aeration stream were not practical, then recovery followed by destruction might be required. Such destruction would be useful for a system where recovery was being practiced anyway, and some disposal of a recycle purge stream was required.

Destruction technologies for halogenated hydrocarbons have been studied previously for recovered waste chlorofluorocarbons. Similar technologies might apply for MeBr. Destruction technologies are discussed in the UNEP Ozone Depleting Compounds (ODCs) Destruction Technologies Report.[19]

Destruction methods potentially applicable for MeBr include both on-line process technologies and off-site bulk treatment technologies in the following categories:

1. **Thermal Oxidation**
2. **Catalytic Processes**
3. **Chemical Destruction**
4. **UV Pyrolysis**
5. **Biological Processes**
6. **Supercritical Water Oxidation**
7. **Wet-air Oxidation**
8. **Plasma Destruction**
9. **High-Energy Radiation**
10. **Thermal Pyrolyses**

A brief description of each technology has been included in Appendix F. Appendix F also states the limitations and advantages of the application, along with the anticipated destruction efficiency for the method.

At this time, it appears that thermal oxidation (incineration) would be the most viable approach for fumigation applications, followed by scrubbing.

Oxidation/incineration uses high temperatures and oxygen to destroy organic compounds, producing CO_2, H_2O, HBr, and/or Br_2. Incomplete combustion products may also be produced. The exhaust's bromine gases, Hbr and Br_2, are acidic and very corrosive, and must be treated before discharge to the atmosphere. Therefore incineration may also require coupling with scrubbing.

Scrubbing with a caustic solution is the accepted method for this step. The addition of NaOH in water solution forms NaBr, a more easily handled solid. The general reactions are:

$$HBr + NaOH \longrightarrow NaBr + H_2O \text{ and}$$
$$Br_2 + 2\ NaOH \longrightarrow NaBr + NaBrO + H_2O$$

The addition of incineration with caustic scrubbing can add considerable expense to a small fumigation control application.

Most of the destruction techniques discussed in the UNEP report were bulk destruction techniques based upon hauling recovered liquid CFCs to a facility specially built for destruction or for another purpose where destruction could also be accomplished. None were applied directly to air streams containing the wastes, as would be the case for the fumigation aeration vent treatment. Therefore, use of these UNEP defined technologies implies that a separation and recovery of MeBr liquid from the aeration stream has already been accomplished. It also implies that spent MeBr would be stored temporarily prior to destruction. It suggests further that a central destruction facility might be employed that could receive contaminated MeBr from multiple fumigation facilities in a region.

4.2.5 Potential Technologies for Direct Vent Stream Control

Some of the destruction technologies ruled out by the UNEP report for bulk destruction of liquid halogenated hydrocarbons may be desirable for the smaller scale treatment of MeBr in fumigation vents. Recovery and recycle techniques even if used would likely require a destruction method because of impurity buildups in the MeBr from the treated commodities.

The only method that appears to have been tested commercially at this time is carbon bed adsorption. Other techniques have yet to be applied, show promise, and would require some bench and pilot-scale test work to be developed for application.

For example, one company has proposed a unique ultraviolet (UV) destruction technique for the aeration gas vent stream. This might be an acceptable method for a small scale application, even though UNEP rejected it for large scale commercial destruction options.

4.3 Control Costs

At this time, very little cost data specific to these systems, as applied to MeBr destruction, are available. The UNEP report on Destruction Technologies contained no cost data. Cost data from four recent MeBr recovery proposals to the Port of San Diego and from two papers[10,11] on recovery from grain fumigation were available.

The control methods with known cost and design data are summarized in Table 8. The range of control costs reported is quite wide.

In order to develop a rough estimate of economic feasibility of a MeBr recovery system, calculations were based on the conceptual design of Figure 9 and the stream variables presented in Table 9. The system uses collection by activated carbon adsorption, recovery by desorption and condensation, and has intermediate storage. It also includes MeBr destruction. In this case we selected a scrubber because of the likelihood that incineration would be uneconomical for a relatively dilute stream containing MeBr. The general specifications for major equipment are provided in Table 10. Costs were obtained from the technical literature and a factored estimate was prepared. The results of this estimate are presented in Table 11 which shows both the capital cost and the annual operating and maintenance costs for the system.

At this time these estimates should only be treated as very preliminary since no actual data were used in their preparation and they do not represent costs for an optimized system. The stream basis for design is based on assumed or approximate values, especially with regard to the MeBr composition.

Actual costs will depend greatly on the exact flow rate of the stream requiring treatment and the MeBr composition. They will also depend greatly on equipment details and especially materials of construction. These costs are useful, however, in focusing research needs in terms of defining key design variables and factors that drive the economic feasibility.

Table 8

Vendor Reported Control Cost Data

Control Option	Cost	Design Description
Carbon Absorption/Desorption (Recovery/Recycle)	$960,000 $ by Vendor 1	10,000 cfm air flow, 300-1000 lbs MeBr per application, tent application, 95+% recovery
	100,000 $ by Vendor 2	No design description available
Condensation (Recovery/Recycle)	Cost not defined by Vendor 3	2 stage compression to 1000 psi, intermediate water knockout, chamber application, pressurized storage, 95 +% recovery
Oxidizer and Scrubber (Recovery/Destruction)	Cost not defined by Vendor 4	Thermal oxidizer followed by limestone scrubber, 4643 cfm air flow, 300 lbs MeBr per application, 96% destruction efficiency

Source: Control installation proposals provided from Reference 9.

Table 9

Stream Design Basis for Example Recovery System Cost Estimate

Stream	Carbon Bed Inlet	Condenser Inlet	Vaporizer Inlet	Scrubber Inlet
Flow rate, ft^3/min	5,000	5,755	4,623	5,000
Temperature, °F	70	150	30	70
Pressure, atm	1	1		1
Composition MeBr (ppm) H_2O (R.H.)	 500 50	 250,000 50	 N.A. N.A.	 5,000 50

Table 10

Major Equipment List

Activated carbon adsorber - 3 ft. deep, 147 ft^3, carbon bed; FRP shell, 3.95 ft. diameter x 6 ft. length.
Condenser - shell and tube; process fluid shellside; chilled brine at -30°F, 1300 ft^2 tube area; shell material and tube material stress corrosion resistant stainless steel or other alloy.
Brine Cooler - 13 ton, packaged brine cooler system, glycol/water, capable of -30°F chilled brine temperature.
Storage Tank - 50 gallons; stress corrosion resistant stainless steel or other alloy; temperature rating 0°F; pressure rating 100 psig.
Vaporizer - 10 gallon; stress corrosion resistant stainless steel or other alloy pressure vessel; electrically heated; temperature rating 300°F; pressure rating 200 psig.
Scrubber - plastic packing packed bed; FRP shell, 10 ft total height, 6 ft. packed bed, 10 inches diameter.
Scrubber recirculation pump - centrifugal pump; flow rating 10 gpm at 20 psig total head; 0.5 Hp motor; plastic construction.

Table 11

Estimated Costs for MeBr Recovery System Example
(January 1993 dollars)

Total Capital Cost	$
Major purchased equipment cost	121,000
Installation materials and labor[a]	121,000
Engineering, contingencies, and construction fees[b]	121,000
Total	363,000
Annual Operating and Maintenance Costs[c]	$/yr
Operating labor and materials	900
Maintenance labor and materials	12,000
Electricity	100
Total	13,000

[a] Installation at 100% of purchased equipment cost.

[b] Engineering, contingencies, and construction fees at 50% of installed equipment costs.

[c] Based on operation of 40 hr/wk, 13 weeks/year.

SECTION 5.0
IDENTIFICATION OF CURRENT CONTROL RESEARCH EFFORTS

Many of the potential technologies for control are untested on either a development or commercial scale, since MeBr production phase-out under the Clean Air Act has only recently become a concern. Some of the control options have been tested on the bench or pilot scale. In fact, when the Port of San Diego recently issued a request for proposals to construct a MeBr recovery unit, eight of the twelve respondents only offered to study the matter further for the Port. Only four of the proposals actually proposed construction of a recovery unit, and several of those proposals were on technologies that had not been commercially tested.

Research efforts at control appear to have been very limited. Although there have been many conferences on MeBr phase-out, they have all centered on finding an alternative replacement for MeBr, rather than on recovery and emissions control. Examples of these technical meetings are:

- UNEP Methyl Bromide Technical Options Committee meetings (held around the world);
- USDA Workshop on Alternatives for Methyl Bromide, June 29 - July 1, 1993, Crystal City, VA; and
- Methyl Bromide Alternatives Conference, Sponsored by Alliance for Responsible CFC Policy, and the U.S. Environmental Protection Agency, March 8-9, 1993, Fresno, CA.

Currently, the California South Coast Air Quality Management District (SCAQMD) has just jointly funded recovery research work along with the Port of San Diego and one utility company. The project will perform a lab/bench scale demonstration of a selected recovery technology. The budget is reported to be approximately $50,000.[20] The UNEP Methyl Bromide Technical Options Committee has also sponsored a paper study on recycling options. Their data gathering study is due out in early 1994.[21] The data UNEP is gathering includes details of:

- Existing recovery installations;
- Proposed installations;
- Pilot testing of recovery or recycling technologies;
- Other research conducted on recovery or recycling technologies; and
- Proposed research on recovery or recycling technologies.

UNEP data gathered to-date were not available at the time this report was written.

Other than the government agency sponsored work alluded to above, research appears limited to small-scope proprietary work conducted at individual recovery process vendors. These vendors appear to be reluctant to release the details of their research at this time. With the exception of carbon bed absorption, no commercial scale installations appear to exist for MeBr, so most of the company research is on the laboratory or bench-scale.

The previous sections of this report have discussed research efforts on MeBr recovery (i.e., the specific technology for removing MeBr from the aeration stream). There has been very little work done on chamber or enclosure modifications required to reduce emissions during fumigation and thus increase the potential for MeBr recovery. In addition, some of the vendors of the recovery processes claim to have developed proprietary improvements to tarpaulin design and procedures that greatly reduce emissions. However, no general, published research was found that covered fumigation emissions reduction by better sealing systems.

SECTION 6.0
IDENTIFICATION OF REMAINING INFORMATION GAPS

The preceding sections of this report have discussed some of the major technical factors involved in controlling emissions of MeBr and surveyed the current status of work to find suitable controls. The feasibility of control depends on these technical factors in the context of any of several possible regulatory scenarios. These considerations are important as they influence both the technical and economic feasibility of control and, hence, the technologies that are viable for control.

Establishment of a viable control strategy and the corresponding technologies requires additional information and further research. This information and research can be defined by categories corresponding to the regulatory, technical, and economic factors that will ultimately determine feasibility.

6.1 Regulatory Issues

The exact regulatory scenario will have a direct bearing on the feasibility of MeBr controls. This derives from a fundamental fact: some MeBr losses will occur as a fundamental characteristic of the fumigation process itself; a total ban implies that the total inventory of MeBr will eventually be depleted if there is not more manufactured because of the ban. The rate of depletion will depend on the loss rate in each recycle, but eventually the MeBr inventory will run out. Therefore, collection and recycle technologies will have a limited life. In some applications, such as those where consumption reaches 30% per fumigation cycle, the use of MeBr will effectively be impractical, since consumption of inventory will be rapid. Complete makeup is required after only about 3 cycles. Therefore the fumigation process itself becomes impractical if there is no longer a supply of MeBr.

For lesser rates of losses it can be readily shown that the inventory would still be depleted relatively quickly, although it might take days, weeks, or months. Controls would not be practical.

Therefore, if substitutes cannot be found, and some use of MeBr is permitted, the exact permissible emission limits, equipment, or work practices specified by the regulations would become the critical factor in the feasibility of specific controls.

At this time, such policy issues cannot be established and the issues of technical feasibility take precedence. From practical considerations, the technical feasibility of various options must be considered in the context of assumptions about regulatory scenarios. The fundamental assumption at this time is that manufacturers would continue to meet industry needs even if the use of MeBr is restricted to only a few specialized applications.

The fundamental information requirements for MeBr emissions controls are the same as for any emissions control problem. These issues are discussed below.

6.2 Stream Characteristics

As discussed in this report, limited information is currently available on stream characteristics. These characteristics need to be established for each major category of fumigation application. The basic stream variables that need to be determined include typical flow rates, temperatures, pressures, and compositions of aeration streams for each type of fumigation application. Actual design for a given facility will require the corresponding site specific information.

6.3 Fumigation Commodity Containment Options

To maximize capture, and to reduce MeBr losses prior to the collection device, current designs and practices for fumigation may have to be altered. Fumigation applications for which add-on controls can be easily applied must be clearly distinguished from those which would have to be altered to accept control technologies. For example, current chamber applications might require essentially no modification. The control device would be attached by ducting directly to the outlet vent. Sheet applications might have to be abandoned, or a means devised to ensure complete capture of the vent stream from the vent opening. The practice of simply removing the tarp from the commodity container or stack after fumigation might no longer be possible. New temporary containment methods require investigation.

6.4 Achievable Recovery from Fumigation

The quantities of MeBr consumed directly by contact with various commodities must be established. Also, the pickup of organic vapors by the aeration stream must be defined for various commodities since this will influence the performance of MeBr controls for recovery and reuse when adsorption systems, either activated carbon or other adsorption systems, are used.

6.5 Technology Performance Characteristics

The fundamental performance characteristics for each potential recovery technology must be established. Removal efficiency from the aeration stream must be established. This information must be obtained for:

- Specific commodities and commodity classes;
- Different containment options and fumigation applications; and
- Different control technologies.

The most critical needs appear to be for adsorption systems, especially with regard to contaminant effects from organics picked up from the commodities themselves and with regard to partial decomposition of the methyl bromide on the adsorbent. In addition to activated carbon, data would be needed for zeolites and other adsorbents that might be candidates for adsorption.

Research on combustion and condensation would appear to be less critical, although the destruction efficiency at different flame temperatures and other combustion conditions would be required.

6.6 Economic Issues

Once appropriate design bases are adequately defined, the economics of control in different applications must be determined. This will be based on the costs of appropriate technologies for specific sizes of systems and type of application. Process economic constraints must be clearly defined. Since systems may in many cases be relatively small and used only intermittently, cost impacts of recovery and recycle could be substantial.

A significant consideration here will be the availability and cost of MeBr itself. Since commodity fumigation is a small fraction (ca. 8%) of methyl bromide use, a selective ban could reduce the market for MeBr by 90% or more. This would surely affect the economics of production and influence its price.

6.7 Availability of Substitutes

There is no single alternative to MeBr in all of the broad applications where it is used. However, there are many alternative chemicals and procedures for specific applications. Further identification and discussion of these alternatives can be found in references 22 and 23. The discussion of MeBr substitutes is a separate issue and not a part of this report on MeBr control.

SECTION 7.0
CONCLUSIONS

This section summarizes conclusions of this study. The conclusions are organized into the following subject areas:

- Methyl bromide uses and quantities;
- Emission source characteristics;
- Potential control technologies;
- Process economics;
- Current research and development activities; and
- Information gaps.

7.1 Methyl Bromide Uses and Quantities

Methyl bromide uses are relatively restricted, and MeBr can be viewed as a specialty fumigant. The consumption of MeBr for space fumigation of commodities represents about 8% of MeBr use. The primary use for MeBr in commodity fumigation is for fruits and nuts. In the treatment of these commodities, there are general commodity containment schemes which are common throughout the industry, although some details may vary with individual installations. The types of configurations for commodity containment are relatively limited.

Fumigation is carried out extensively at a few primary locations, mostly major sea ports. Two of the largest ports where MeBr is used are San Diego and Philadelphia. Other major ports include Seattle and Miami, but any port where fruit and nuts are imported is a candidate. Also, fumigation facilities are reported to be present at some airports and military facilities.

7.2 Emission Source Characteristics

Emissions sources are characterized in terms of physical configuration and emission stream characteristics.

Physical configurations are divided into two categories: sources with a duct, pipe, or stack outlet, and sources with multiple, irregular outlets. The former occur in chambers specifically built for holding the commodity during fumigation. The latter occur with sheet or tarpaulin fumigation or fumigation in vehicles where ordinary leakage or simply an open door is used to vent the MeBr when fumigation is complete.

The emissions arise when air is blown through the commodity to remove the MeBr. Currently the emissions are vented directly to the atmosphere.

Little data are currently available for stream characteristics. This is a key area for additional research. Information that is available suggests flow rates in the range of no more than a few thousand to a few tens of thousand of cubic feet per minute air flow with a MeBr content ranging from a few hundred to a few thousand ppm.

Currently few control systems exist for MeBr emissions. Likewise, research and development related to control system design has been extremely limited.

Various vendors have proposed control technologies for MeBr control, recovery and recycle. Few systems have been built. Currently, systems are being investigated and the Port of San Diego is installing a MeBr treatment system. Some systems have been installed overseas. Technical details of these systems are not readily available at this time, so that further work would be required to determine how extensively they control emissions and how effective they may be at recovery.

In general, conventional vapor control technologies, such as activated carbon adsorption systems appear to be applicable to MeBr emissions. However, in the context of minimum or even zero emissions, depending on the regulatory scenario, control systems must also provide for recovery. Conventional approaches using condensation and other methods appear to be applicable here. The fundamental technologies required appear to exist, but the specifics of the application of these technologies to the MeBr control issue require much more investigation and design data acquisition.

7.3 Process Economics

Process economics of MeBr control and recovery are not well defined. Scattered data on actual and possible costs of systems was skimpy. Because many components of a control system would appear to rely on existing technologies, costs and the corresponding economics do not appear to be difficult to estimate. Costs can be expected to be comparable to other vapor control systems for similar flow rates of gas streams.

Preliminary economics of a conceptual design prepared specifically for this report indicate that control will be relatively expensive. The relative expense compared with control systems of similar nature in other applications is because of the relatively small volumes of recoverable material that would be handled and the intermittent nature of many of the fumigation operations to which the control system would be applied. At this time, there are not sufficient data available on either design or costs to make a definitive statement.

A factor that might considerably influence the economics of MeBr control is the availability of future MeBr supplies. This will be influenced by the regulatory scenario. A total ban, but allowance of the use of existing MeBr inventories with recycle would, in effect make recycle impractical for technical reasons. Chemical reaction losses would quickly deplete the supply. On the other hand, a selective ban that would allow some manufacture of MeBr to continue might drive up the price, assuming a manufacturers were willing to continue manufacture, because the use volume would be sharply reduced. Unit manufacturing costs would increase sharply.

7.4 Current Research and Development Activities

Current research and development activities on the issues discussed in this report appear to be limited at the present time. Much of the current work appears to be under the auspices of various vendors of systems and equipment. Some government agencies and industrial groups are showing increasing interest in funding some research. UNEP has had a leading role in addressing some of these issues.

7.5 Information Gaps

In general, information gaps fall into two fundamental categories: 1) MeBr emission source characterization and 2) control technology characterization. The fundamental focus needs to shift beyond mere reduction of emissions and toward recovery and recycle. There also needs to be an effort to gather some fundamental performance data related specifically to fundamental stream characteristics. This is especially important because of the reported potential for the accumulation of various commodity chemical components picked up by the MeBr on each cycle of contact with the commodity being fumigated. Detailed economic evaluations based on existing data should be carried out early in order to better direct the research and maximize research efficiency.

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APPENDIX A

DATA COLLECTION

Data for this project was collected from a literature search and from telephone contacts with industry sources. The data search included an electronic search of the following bibliographic databases using keywords associated with methyl bromide and recovery:

1. Biosis Previews (Biological Abstracts),
2. Agricola (National Agricultural Library),
3. CAB Abstracts (Commonwealth Agricultural Bureau),
4. Food Science and Technology Abstracts,
5. CRIS/USDA Database,
6. AGRIS International,
7. Agribusiness USA,
8. CA Search (Chemical Abstracts),
9. Pollution Abstracts,
10. Enviroline,
11. Environmental Bibliography,
12. Water Resources Abstracts,
13. EI-Compendex Plus, and
14. Energy, Science, & Technology (DOE).

Few published articles were found.

Information in the area of general fumigation is well developed. Several key documents and texts were available that described the history of fumigant uses and general applications of various fumigants. In the area of fumigant recovery, however, Radian found very little published information. This may be because regulations requiring recovery are few, and the market for recovery is therefore small. For MeBr, there are a few older articles on recovery techniques, but most of the details of the techniques described in Section 4.0 have not been published.

Most of the data for this report was obtained from industry and government contacts. The contacts included:

1. Manufacturers of methyl bromide: Ethyl Corporation and Great Lakes Corporation,
2. Fumigation Operating Companies,
3. U.S. Government Agencies, including U.S. Environmental Protection Agency (EPA), Animal and Plant Health Inspection Services (APHIS), and U.S. Department of Agriculture (USDA),
4. United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee,
5. State pesticide experts,
6. Agricultural shipping ports, and

7. Vendors of recovery processes.

Some additional data were obtained from an earlier Radian report on methyl bromide fumigation emission measurements.

APPENDIX B

METHYL BROMIDE PHYSICAL PROPERTIES

Methyl Bromide Physical Properties
(From Reference 6 and 12)

Boiling Point: 3.46°C, (38.5°F)
Freezing Point: -94°C, (-137°F)

Vapor Pressure: 189.3 kPa @ 20°C

Flash Point: None
Autoignition Temperature: 998°F (at 10-16 mol% in air)

Solubility in Water: Low (1.34 g/100 ml @ 25°C)
Gas Density: 3.3 times heavier than air
Liquid Density: 14.4 lb/gal (specific gravity 1.732 @ 0°C)

Storage Methods: Stored as a liquefied gas in metal cylinders

Storage Grades: 1) Technical, pure (99.5% min)
2) Odorized (2% chloropicrin)

Effective Fumigation Temperature: > 40°F

APPENDIX C

CALIFORNIA CHEMICAL USE REPORT FOR METHYL BROMIDE

CHEMICAL / COMMODITY	NUMBER OF APPLICATION	POUNDS APPLIED	ACRES/UNITS TREATED	TYPE
N-GRNHS GRWN PLANTS IN CONTAINERS	1	.0010	760.00	S
N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL	2	.7800	7.00	A
N-OUTDR CONTAINER/FLD GRWN PLANTS	5	1.1392	57.00	A
N-OUTDR GRWN CUT FLWRS OR GREENS	•	3.1997	33.00	A
PUBLIC HEALTH PEST CONTROL	5	.0587	.00	J
STRUCTURAL PEST CONTROL	4	.8529	.00	U
* CHEMICAL TOTAL *	28	53.8595		
METHYL BROMIDE				
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	2	6,191.8850	95.00	A
ALMOND	615	630,087.5654	24,519.48	A
ALMOND	21	3,091.1110	1,858,888.00	C
ALMOND	1	4,187.4000	2,800.00	K
ALMOND	13	2,001.0000	5,255,295.00	P
ALMOND	9	468.5310	467,949.00	S
ALMOND	15	5,120.4120	15,088.50	T
ALMOND	381	86,410.7722	365,850.47	U
ANISE (SWEET ALICE)	1	19.8000	2.00	A
APPLE	17	63,819.0706	483.68	A
APPLE	1	120.0000	39,360.00	C
APPLE	1	4.0000	20,000.00	P
APPLE	1	79.8000	40.00	U
APRICOT	14	38,069.5100	173.46	A
APRICOT	1	50.0000	12,000.00	C
APRICOT	1	3.9800	38,828.00	P
APRICOT	10	280.2678	4,286.00	U
ASPARAGUS (SPEARS, FERNS, ETC.)	1	5,074.5000	17.00	A
ASPARAGUS (SPEARS, FERNS, ETC.)	5	11.1400	621.00	P
AVOCADO (ALL OR UNSPEC)	2	413.0000	28.00	A
AVOCADO (ALL OR UNSPEC)	1	8.4000	220.00	P
AVOCADO (ALL OR UNSPEC)	3	93.5500	2,690.00	U
BEANS (ALL OR UNSPEC)	2	3,988.8950	38.00	A
BEANS (ALL OR UNSPEC)	2	163.0000	105,400.00	C
BEANS (ALL OR UNSPEC)	5	175.9870	517,405.00	P
BEANS (ALL OR UNSPEC)	5	1,369.1300	9,563.00	T
BEANS (ALL OR UNSPEC)	6	542.0700	498,759.00	U
BEANS, DRIED-TYPE	3	292.5000	98,415.00	C
BEANS, DRIED-TYPE	2	74.8950	574,300.00	P
BEANS, DRIED-TYPE	9	3,515.0000	9,969.29	T
BEANS, DRIED-TYPE	1	418.7400	38,196.00	U
BEANS, SUCCULENT (OTHER THAN LIMA)	1	10.5000	780.00	P
BEEHIVES (ALL OR UNSPEC)	1	4.9000	2,880.00	C
BEEHIVES (ALL OR UNSPEC)	1	49.7500	4,000.00	U
BEVERAGE CROPS (ALL OR UNSPEC)	5	221.0000	139,878.00	C
BEVERAGE CROPS (ALL OR UNSPEC)	1	15.0000	215,952.00	P
BEVERAGE CROPS (ALL OR UNSPEC)	1	151.0000	12,677.00	U
BROCCOLI	31	46,192.0250	252.75	A
BRUSSELS SPROUTS	8	6,057.9800	21.52	A
CABBAGE	10	47.3500	66,800.00	P
CANTALOUPE	6	42,185.3000	224.00	A
CARROTS, GENERAL	200	1,294,670.3415	8,316.68	A
CAULIFLOWER	18	18,750.9575	118.20	A
CAULIFLOWER	4	497.5000	50,000.00	S
CELERY, GENERAL	8	22,490.4000	83.50	A
CHERRY	89	70,998.8702	643.79	A
CHERRY	1	100.3000	33,511.00	C
CHERRY	1	350.0000	270,000.00	P
CHERRY	1	2,498.0000	745.60	T
CHERRY	12	6,712.3792	18,617.00	U
CHESTNUT	3	14,790.6000	37.35	A
CHINESE CABBAGE (NAPPA, WON BOK, CELERY CABBAGE)	7	25.9100	86,850.00	P
CHINESE CABBAGE (NAPPA, WON BOK, CELERY CABBAGE)	1	19.0000	10.01	T
CHINESE GREENS, CHINESE LEAFY VEGETABLES	2	7,056.0000	18.00	A

CHEMICAL / COMMODITY	NUMBER OF APPLICATION	POUNDS APPLIED	ACRES/UNITS TREATED	TYPE
CHINESE RADISH/DAIKON (LOBOK, JAPANESE RADISH)	3	1.7500	7,200.00	P
CITRUS FRUITS (ALL OR UNSPEC)	21	66,368.4900	157.75	A
CITRUS FRUITS (ALL OR UNSPEC)	1	57.0000	20.00	U
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	1	1,700.0000	30.68	A
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	6	451.0000	143,405.00	C
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	1	27.8600	900.00	S
COMMODITY FUMIGATION	1	195.0000	144,500.00	C
COMMODITY FUMIGATION	207	121,644.8135	61,540.00	U
CORN (FORAGE - FODDER)	1	17.8200	.10	A
CORN, HUMAN CONSUMPTION	2	144.5000	291.50	T
COTTON, GENERAL	1	2,634.3900	7.00	A
COTTON, GENERAL	2	60.0000	19,840.00	C
COTTON, GENERAL	1	110.0000	19,500.00	U
CUCUMBER (PICKLING, CHINESE, ETC.)	4	1,248.2250	4.63	A
DATE	1	12.0000	19.00	A
DATE	2	6.0000	600.00	C
DATE	37	1,238.8800	6,176,469.00	P
DATE	13	7,078.4000	107,343.35	T
DATE	1	179.4600	837,200.00	U
DRIED FLOWERS	3	96.4800	38,197.00	C
DRIED FLOWERS	1	6.8000	20,317.00	P
EGGPLANT (ORIENTAL EGGPLANT)	30	65,256.6550	195.22	A
ENDIVE (ESCAROLE)	2	8.4500	260.00	P
FIG	2	199.0000	120.00	A
FIG	17	10,581.8700	8,221,100.00	C
FIG	7	7,263.0000	6,988.00	K
FIG	1	1,352.0000	67,600.00	P
FIG	2	619.5000	414,500.00	S
FIG	4	308.0575	1,582.50	T
FIG	3	103.0000	36.00	U
FLAVORING AND SPICE CROPS (ALL OR UNSPEC)	2	61.8550	1,332.00	C
FLAVORING AND SPICE CROPS (ALL OR UNSPEC)	1	5,000.0000	2,500.00	K
FLAVORING AND SPICE CROPS (ALL OR UNSPEC)	2	7.7000	400.00	P
FLAVORING AND SPICE CROPS (ALL OR UNSPEC)	6	312.5200	1,845.00	U
FOOD PROCESSING/HANDLING PLANT/AREA (ALL/UNSPEC)	1	25.5000	1.50	A
FOOD PROCESSING/HANDLING PLANT/AREA (ALL/UNSPEC)	1	4,156.0000	206,898.00	S
FORAGE - FODDER GRASSES (ALL OR UNSPEC) (HAY)	2	483.0000	128,358.00	C
FOREST TREES, FOREST LANDS (ALL OR UNSPEC)	12	14,132.8750	13,571.33	A
FOREST TREES, FOREST LANDS (ALL OR UNSPEC)	2	2,029.0000	1,353.00	U
FRUIT TREES (ORCHARDS)	1	19,800.0000	50.00	A
FRUITING VEGETABLES (ALL OR UNSPEC)	1	24.5000	1.00	A
FRUITS (ALL OR UNSPEC)	21	2,192.0000	1,538,111.00	C
FRUITS (ALL OR UNSPEC)	1	12,000.0000	8,000.00	K
FRUITS (ALL OR UNSPEC)	1	730.0000	464,000.00	P
FRUITS (ALL OR UNSPEC)	3	78.0000	7,480.00	S
FRUITS (ALL OR UNSPEC)	1	30.0000	80.00	T
FRUITS (ALL OR UNSPEC)	16	886.0000	39,955.00	U
FUMIGATION, OTHER	3	2,824.4400	26.80	A
FUMIGATION, OTHER	131	29,106.8470	368.00	U
GARLIC	4	9.9000	3,680.00	C
GARLIC	3	21.5000	8.00	U
GINGER (GINGER ROOT, COMMON GINGER)	2	20.0000	6,500.00	C
GINGER (GINGER ROOT, COMMON GINGER)	1	3.0000	34,020.00	P
GRAIN CROPS (ALL OR UNSPEC)	1	19.9000	18,000.00	S
GRAPEFRUIT	3	32,251.9300	76.30	A
GRAPES	128	907,423.7710	798,234.48	A
GRAPES	300	51,472.9900	21,800,334.90	C
GRAPES	21	55,599.1700	562,900.00	K
GRAPES	2	3,414.0000	6,775.00	P
GRAPES	3	1,809.0000	1,809,000.00	S
GRAPES	11	33,830.0000	24,092.00	T
GRAPES	7	932.8850	44,099.00	U
GRAPES, PROCESSED	97	571,572.0774	1,629.30	A
GRAPES, PROCESSED	3	1,394.5200	881,213.00	C

CHEMICAL / COMMODITY	NUMBER OF APPLICATION	POUNDS APPLIED	ACRES/UNITS TREATED	TYPE
GRAPES, PROCESSED	1	29.9100	108,200.00	P
GRAPES, PROCESSED	3	20.3768	21,000.00	S
GRAPES, PROCESSED	1	5,250.0000	3,500.00	T
GRAPES, PROCESSED	12	2,108.6188	1,908.00	U
GREENHOUSES (EMPTY) (ENVIRONS, BENCHES, ETC.)	1	98.0000	2,700.00	C
GREENHOUSES (EMPTY) (ENVIRONS, BENCHES, ETC.)	1	27.4400	2,750.00	S
GREENHOUSES (EMPTY) (ENVIRONS, BENCHES, ETC.)	1	9,828.2240	11,000.00	U
HORSERADISH (ALL OR UNSPEC)	7	3.0400	375.00	P
KIWI FRUIT	1	5.8800	4.00	A
KIWI FRUIT	1	1,448.0000	144,800.00	S
KIWI FRUIT	1	852.7150	879.00	U
LANDSCAPE MAINTENANCE	4	7,428.8800	38.27	A
LANDSCAPE MAINTENANCE	2	192.0350	14,888.00	S
LANDSCAPE MAINTENANCE	113	10,018.5877	.00	U
LEAFY VEGETABLES (ALL OR UNSPEC)	2	1.4924	2.00	A
LEAFY VEGETABLES (ALL OR UNSPEC)	1	4.4000	3,040.00	P
LEEK	2	4.2000	195.00	P
LEMON	9	48,087.2910	168.74	A
LEMON	1	39.2000	4,000.00	S
LEMON	1	12.0000	20.00	U
LETTUCE, HEAD (ALL OR UNSPEC)	29	79,105.9075	377.59	A
LETTUCE, HEAD (ALL OR UNSPEC)	1	14.0000	7,200.00	P
LETTUCE, LEAF (ALL OR UNSPEC)	20	78,177.5900	329.72	A
LETTUCE, LEAF (ALL OR UNSPEC)	2	11.4500	6,960.00	P
LIME (MEXICAN LIME, ETC.)	1	308.4500	310.00	U
MELONS	1	149.2500	1.00	A
MUSHROOMS	3	45.0000	22,778.00	C
N-GRNHS GRWN CUT FLWRS OR GREENS	433	130,656.9933	428.71	A
N-GRNHS GRWN CUT FLWRS OR GREENS	5	53.7500	17,620.00	C
N-GRNHS GRWN CUT FLWRS OR GREENS	8	1,232.0000	281.00	K
N-GRNHS GRWN CUT FLWRS OR GREENS	416	54,823.9819	5,328,868.74	S
N-GRNHS GRWN CUT FLWRS OR GREENS	2	114.0000	22,000.00	U
N-GRNHS GRWN PLANTS IN CONTAINERS	27	21,871.3088	31.48	A
N-GRNHS GRWN PLANTS IN CONTAINERS	48	445.1300	14,975.00	C
N-GRNHS GRWN PLANTS IN CONTAINERS	14	211.0200	57,277.01	S
N-GRNHS GRWN PLANTS IN CONTAINERS	5	28.6900	920.00	U
N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL	37	73,327.4000	265.82	A
N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL	100	8,154.8880	525,327.00	C
N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL	32	869.7500	112,971.50	S
N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL	18	910.0850	30,701.00	U
N-OUTDR CONTAINER/FLD GRWN PLANTS	219	1,140,780.1130	4,439.41	A
N-OUTDR CONTAINER/FLD GRWN PLANTS	64	27,849.2050	1,203,848.00	C
N-OUTDR CONTAINER/FLD GRWN PLANTS	2	147.0000	4.05	K
N-OUTDR CONTAINER/FLD GRWN PLANTS	85	8,924.7150	676,703.34	S
N-OUTDR CONTAINER/FLD GRWN PLANTS	19	249.9600	7,104.00	U
N-OUTDR GRWN CUT FLWRS OR GREENS	272	315,288.4740	1,015.01	A
N-OUTDR GRWN CUT FLWRS OR GREENS	1	12.0000	49,248.00	C
N-OUTDR GRWN CUT FLWRS OR GREENS	84	8,284.6695	927,331.00	S
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	125	218,745.6933	845.73	A
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	31	847.3120	53,112.00	C
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	117	15,058.3928	1,448,357.00	S
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	17	5,192.6907	35.00	U
NECTARINE	111	348,298.4137	1,564.50	A
NECTARINE	2	125.0000	24,000.00	C
NECTARINE	3	108.0000	108.00	P
NECTARINE	23	1,247.3771	97,732.00	U
NUT CROPS, NUT TREES (ALL OR UNSPEC)	3	9.5000	2,810.00	C
NUT CROPS, NUT TREES (ALL OR UNSPEC)	1	465.0000	750.00	T
NUT CROPS, NUT TREES (ALL OR UNSPEC)	1	4.5000	453.00	U
OATS, GENERAL	3	12,708.8300	31.50	A
ONION (DRY, SPANISH, WHITE, YELLOW, RED, ETC.)	7	10,603.2000	31.13	A
ONIONS (GREEN)	8	17,784.1000	61.00	A
ORANGE (ALL OR UNSPEC)	18	51,525.6250	223.53	A
ORANGE (ALL OR UNSPEC)	4	3,592.3850	4,407.90	S

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JANUARY THRU DECEMBER 1991

CHEMICAL / COMMODITY	NUMBER OF APPLICATION	POUNDS APPLIED	ACRES/UNITS TREATED	TYPE
ORANGE (ALL OR UNSPEC)	3	117.6000	35.00	U
ORCHARDS (FRUIT/NUT ETC)	1	2,437.7500	2,450.00	U
PEACH	352	872,881.4397	3,802.16	A
PEACH	2	165.0000	22,000.00	C
PEACH	5	257.2460	31,639.80	P
PEACH	1	86.5650	58.00	T
PEACH	97	20,664.6088	113,242.00	U
PEAR	3	2,054.7600	1,445.00	U
PEAS, GENERAL	6	1,243.1920	445,576.00	C
PEAS, GENERAL	3	203.2500	927,020.00	P
PEAS, GENERAL	1	251.2440	84,000.00	S
PEAS, GENERAL	1	765.0000	1,782.00	T
PEPPERS (CHILI TYPE) (FLAVORING AND SPICE CROP)	8	5,210.3100	18.75	A
PEPPERS (CHILI TYPE) (FLAVORING AND SPICE CROP)	1	.9800	100.00	S
PEPPERS (FRUITING VEGETABLE), (BELL,CHILI, ETC.)	30	146,659.5000	621.06	A
PERSIMMON	2	8,910.0000	22.00	A
PISTACHIO (PISTACHE NUT)	3	1,305.0420	716.00	A
PISTACHIO (PISTACHE NUT)	21	5,028.0000	2,287,357.00	C
PISTACHIO (PISTACHE NUT)	3	11.9400	2,880.00	S
PISTACHIO (PISTACHE NUT)	1	244.0000	980.00	U
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	66	278,906.6600	478.94	A
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	1	35.9100	2,400.00	S
POME FRUITS (ALL OR UNSPEC)	1	199.0000	.50	A
PRUNE	82	110,870.4822	2,848.83	A
PRUNE	47	7,714.2500	4,161,257.30	C
PRUNE	4	4,828.0000	3,256.00	K
PRUNE	1	10.0000	10.00	P
PRUNE	4	1,091.2250	197,190.00	S
PRUNE	19	613.0000	5,729.00	T
PRUNE	110	21,711.7053	115,143.00	U
PUBLIC HEALTH PEST CONTROL	14	16,573.1440	.00	U
PUMPKIN	1	2,924.8000	11.00	A
RADISH	9	4.2400	4,020.00	P
RANGELAND (ALL OR UNSPEC)	2	448.3500	2.00	A
RANGELAND (ALL OR UNSPEC)	1	30.0000	4,000.00	S
RASPBERRY (ALL OR UNSPEC)	4	3,731.5200	19.05	A
RASPBERRY (ALL OR UNSPEC)	6	279.9000	968.00	U
RECREATIONAL AREAS, TENNIS COURTS, PARKS, ETC.	1	348.2500	.50	A
REGULATORY PEST CONTROL	7	29,129.0000	.00	U
RICE (ALL OR UNSPEC)	21	3,852.0000	1,923,115.00	C
RICE (ALL OR UNSPEC)	1	13,283.0000	6,642.00	K
RICE (ALL OR UNSPEC)	4	40.5500	225,312.00	P
RICE (ALL OR UNSPEC)	1	6.0000	3,000.00	S
RICE (ALL OR UNSPEC)	2	10.5000	175.00	T
RICE (ALL OR UNSPEC)	1	2.0000	400.00	U
RIGHTS OF WAY	33	2,432.0450	.00	U
RUTABAGA (SWEDE, SWEDISH TURNIP)	2	.5000	250.00	P
RYE (ALL OR UNSPEC)	2	6,219.1800	18.49	A
SEEDS (AGRICULTURAL & ORNAMENTAL) (ALL OR UNSPEC)	5	17,184.7500	59.50	A
SEEDS (AGRICULTURAL & ORNAMENTAL) (ALL OR UNSPEC)	1	5.0000	2,400.00	C
SEEDS (AGRICULTURAL & ORNAMENTAL) (ALL OR UNSPEC)	1	16.0000	40,634.00	P
SILOS	1	11.9400	1,250.00	C
SMALL FRUITS (ALL OR UNSPECIFIED)	2	105.2000	9,411.00	A
SMALL FRUITS (ALL OR UNSPECIFIED)	1	4.8000	2,400.00	C
SMALL FRUITS (ALL OR UNSPECIFIED)	8	20,787.5000	51,462.00	U
SOIL APPLICATION (AG-CROP, ORN-PLANT SITUATIONS)	1	238.8000	24,200.00	S
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	213	614,075.5340	1,656.31	A
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	20	599.9400	1,279.35	C
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	8	1,755.4975	88,683.00	S
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	4	866.8240	971.00	U
SPINACH	2	8.7000	90.00	P
SQUASH (ALL OR UNSPEC)	6	5,585.5450	33.00	A
SQUASH (SUMMER)	1	234.5000	1.00	A
STONE FRUITS (ALL OR UNSPEC)	1	37.0000	15,400.00	C

CHEMICAL / COMMODITY	NUMBER OF APPLICATION	POUNDS APPLIED	ACRES/UNITS TREATED	TYPE
STONE FRUITS (ALL OR UNSPEC)	5	258.8910	57,468.00	U
STORAGE AREAS & PROCESSING EQUIPMENT (ALL/UNSPEC)	1	1,050.0000	61.00	A
STORAGE AREAS & PROCESSING EQUIPMENT (ALL/UNSPEC)	6	1,622.0000	189,573.00	C
STORAGE AREAS & PROCESSING EQUIPMENT (ALL/UNSPEC)	2	335.0000	167,000.00	S
STRAWBERRY (ALL OR UNSPEC)	1,224	4,536,075.4147	33,228.47	A
STRAWBERRY (ALL OR UNSPEC)	7	489.2500	177,300.00	C
STRAWBERRY (ALL OR UNSPEC)	6	874.2000	284,980.00	P
STRAWBERRY (ALL OR UNSPEC)	2	878.4375	76,379.25	S
STRAWBERRY (ALL OR UNSPEC)	1	374.4000	34,371.00	T
STRAWBERRY (ALL OR UNSPEC)	28	7,106.3625	581,236.00	U
STRUCTURAL PEST CONTROL	2	4,484.5000	17.00	A
STRUCTURAL PEST CONTROL	2,887	3,271,987.7835	.00	U
SWEET POTATO	57	190,707.8480	833.34	A
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	2	5,977.4100	14.00	A
TOMATO	88	211,654.6325	1,385.57	A
TOMATO	1	27.4400	4,800.00	S
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	102	435,477.9335	1,242.82	A
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	1	2.0100	150.00	C
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	4	354.4688	1,728.00	S
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	39	257,093.9891	738.02	A
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	9	45.0025	8,948.00	C
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	8	688.9150	54,600.00	S
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	1	10.4475	7.00	U
VEGETABLES (ALL OR UNSPEC)	7	3,906.8400	15.90	A
VEGETABLES (ALL OR UNSPEC)	2	5.0000	1,550.00	C
VEGETABLES (ALL OR UNSPEC)	1	3.9800	3,952.00	P
VERTEBRATE PEST CONTROL	15	3,044.0875	.00	U
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	238	281,931.4615	4,881.01	A
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	37	6,255.2735	3,337,418.00	C
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	6	1,741.3500	100,943.00	K
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	10	3,839.0000	3,780,705.00	P
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	4	341.6400	493,105.00	S
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	46	45,744.2970	159,273.74	T
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	150	23,151.9775	184,416.50	U
WATERMELONS	3	6,572.8000	35.00	A
WATERMELONS	1	.7500	180.00	C
WHEAT, GENERAL	5	14.5000	1,250.00	C
WHEAT, GENERAL	5	585.0800	4,135.00	T
* CHEMICAL TOTAL *	11,577	18,675,842.6285		
METHYL CELLULOSE				
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	13	21.6593	789.60	A
ALMOND	32	589.4121	3,474.00	A
APPLE	10	113.1227	550.86	A
APRICOT	1	.6840	5.00	A
CABBAGE	2	2.5659	15.00	A
CAULIFLOWER	30	52.2711	676.50	A
CELERY, GENERAL	1	2.0520	12.00	A
CHERRY	6	4.7454	63.00	A
CITRUS FRUITS (ALL OR UNSPEC)	3	6.1560	12.00	A
COLLARDS	30	42.6540	866.00	A
CORN (FORAGE - FODDER)	5	10.3898	199.00	A
CORN, HUMAN CONSUMPTION	5	7.4300	216.70	A
COTTON, GENERAL	4	9.5068	241.00	A
CUCUMBER (PICKLING, CHINESE, ETC.)	16	56.6101	555.00	A
GRAPES	138	354.4840	4,421.71	A
GRAPES, PROCESSED	10	15.4571	228.00	A
LANDSCAPE MAINTENANCE	7	1.1182	.00	U
LEMON	2	82.4405	42.00	A
N-OUTDR CONTAINER/FLD GRWN PLANTS	3	.7797	5.50	A
N-OUTDR GRWN CUT FLWRS OR GREENS	11	3.7981	48.53	A
NECTARINE	2	8.6741	42.00	A
OLIVE (ALL OR UNSPEC)	84	464.0999	2,253.00	A

APPENDIX D

OFFICIAL LIST OF GRAIN WAREHOUSES (UGSA)
BY STATE (SOURCE: USDA)

OFFICIAL LIST OF WAREHOUSES APPROVED
UNDER THE UNIFORM GRAIN STORAGE AGREEMENT
AS TRACKED BY THE USDA KANSAS CITY COMMODITY OFFICE
DATE: 5/3/93

1	AL	21
2	AR	171
3	AZ	9
4	CA	42
5	CO	170
6	DE	5
7	FL	7
8	GA	45
9	ID	202
10	IL	1395
11	IN	404
12	IO	1333
13	KN	33
14	KS	1134
15	LA	73
16	MD	13
17	ME	5
18	MI	151
19	MN	766
20	MO	353
21	MS	59
22	MT	182
23	NC	65
24	NE	775
25	NM	18
26	NV	1
27	NY	15
28	OH	469
29	OK	363
30	OR	96
31	PA	4
32	SC	29
33	SD	346
34	TN	41
35	TX	634
36	UT	6
37	VA	28
38	WA	472
39	WI	174
40	WV	1
41	WY	10
TOTAL U.S. COUNT		10120

APPENDIX E

FUMIGATION TREATMENT FACILITIES BY STATE (SOURCE: APHIS)

TREATMENT FACILITIES IN THE U.S. (Source: APHIS PPQ)

NAP–MB = Normal Atm Press – Methyl Bromide Use
VAC–MB = Vacuum Chamber – Methyl Bromide Use
Tarp = Tarpaulin Applications – Methyl Bromide Possible

State	No of Chambers NAP–MB	No of Chambers VAC–MB	No of companies Tarp
CA	2	10	9
AL			3
AZ		1	2
DE			2
FL	1	8	19
GA		2	7
HI	1	1	6
LA		2	5
MD		3	1
MA			3
IL			1
MI			1
MN			1
MS			6
MO			1
NJ		13	2
NY		3	4
NC	3	6	3
OH			2
OR			5
PR			6
RI			1
PA			4
SC			3
TN			2
TX		5	17
VA		14	2
WA	1		2
VI		1	1
WI			1
Total:	8	69	122

ALABAMA

Mobile

Commercial:

Tarpaulin
A&P Termite and Pest Control, 1704 Church Street
Atlas Exterminators, 106 N. Ann Street
Orkin Exterminating Co, Inc., 1764 S. Beltline Hwy

ARIZONA

Nogales

PPQ:

Dry heat
18" x 12" -- maximum 392°F

Hot water bath
36" x 18" x 9½"

Vac fumigation - MB
9' x 4' = 133 ft^3

Phoenix

Commercial:

Tarpaulin
Arizona Exterminating Co, 210 S 24th Street

Yuma

Commercial:

Tarpaulin
Truly Nolen, 840 South 5th Avenue

CALIFORNIA

Long Beach -- see Los Angeles

Los Angeles

Commercial:

NAP fumigation - MB
California Cotton Fumigation Co, Berth 155A, Wilmington
52' x 12.5' x 9.25' (two)
P.C. Fumigation, 909 Colon Street, Wilmington

Tarpaulin
Ag-Fume Services, Inc., 9722 Washburn Rd., Downey
California Cotton Fumigation Co. Berth 155A, Wilmington
Capricorn Fumigations, 7020 Marcelle Street, Paramount
Harbor Pest Control, 3388 Channel Way, San Diego
P.C. Fumigation, 909 Colon Street, Wilmington

Vac fumigation - CB, MB
7.2' x 4' x 5' = 144 ft^3
California Cotton Fumigation Co, Berth 155A, Wilmington
52' x 12.5' x 9.25' (two)
P.C. Fumigation, 909 Colon Street, Wilmington

Vac fumigation - MB
40' x 8' = 2,010 ft^3
8' x 8' x 50' = 3,200 ft^3
California Cotton Fumigation Co, Berth 155A, Wilmington

CALIFORNIA *(continued)*

Los Angeles *(continued)*

PPQ:

Dry heat
22½" x 19" x 18½" = 2.6 ft^3

Steam
38" x 20" x 20" = 8.73 ft^3 -- maximum 60 psi

Vac fumigation - MB
5'6½" x 2' x 3' = 34 ft^3
5'8" x 4' x 10'6" = 235.2 ft^3

San Diego

Commercial:

Dry heat
18' x 9' x 6' -- maximum 236°F
Equipped with automatic temperature recorder
San Diego Exterminating Co, 3645 India Street
Three ovens:
18" x 12" x 24" -- maximum 600°F (two)
18" x 12" x 24" -- maximum 2,000°F
Clarkson Lab and Supply, Inc. 1140 30th Street

Tarpaulin
Harbor Pest Control, 3388 Channel Way

PPQ:

Dry heat
14" x 15" x 25" -- maximum 550°F

Vac fumigation - MB
3'8" x 5' x 6'7" = 118.9 ft^3

E-4

CALIFORNIA *(continued)*

San Francisco

Commercial:

Tarpaulin
American Marine Fumigating and Warehouse Co, 6195 Coliseum Way, Oakland
Rose Extermination Co, 1512 East 12th Street, Oakland

PPQ:

Dry heat
19" x 23" x 19" -- maximum 392°F

Hot water
3" x 8" x 9½"

Vac fumigation - EO FR, MB
22" x 15½" = 2.4 ft^3

Vac fumigation - MB
6'7" x 3'8" x 5' – 120 ft^3

San Ysidro -- see San Diego

Wilmington -- see Los Angeles

E-5

CANADA

Quebec

Commercial:

Cold treatment One room
1665m³ (58,800 ft³)
JP and A Frappier Warehouse, Franklin Center
Operated by James Leahy and Sons

DELAWARE

Dover AFB

Commercial:

Tarpaulin
Dover AFB, Building 789

Wilmington

Commercial:

Tarpaulin
Wilmington Marine Terminal, Port of Wilmington, P.O. Box 1191, Warehouse B, Warehouse C

FLORIDA

Fernandina Beach -- See Jacksonville

Ft. Lauderdale

Commercial:

Tarpaulin
F & F Pest Control, 7880 NW 64th Street, Miami
G&PM Pest Control, 12232 SW 130 Street, Miami

Ft. Pierce

Commercial:

Tarpaulin
F & F Pest Control, 7880 NW 64th Street, Miami

Green Cove Springs -- See Jacksonville

Jacksonville

Commercial:

Tarpaulin
J.F. Yearty & Sons, Inc. 4717 Dellwood Avenue
Orkin Exterminating Co, Inc. Westside Branch, 529 W. Stuart Ln

Miami

Commercial:

Tarpaulin
F & F Pest Control, 7880 NW 64th Street
G&PM Pest Control, 12232 SW 130th Street
Orkin, 1960 NW 27th Avenue
Western Fumigation, 3541 W. Broward Blvd., Ft. Lauderdale

E-6

FLORIDA *(continued)*

Miami *(continued)*

PPQ:

Dry heat
18" x 18" x 23" -- maximum 500°F

Hot water
36" x 18" x 9½"

Steam
38" x 21" -- maximum 60 psi

Vac fumigation - MB
40" x 30" x 36" = 25 ft³ (two)
9'2" x 4' = 115 ft³ (two)
10' x 8' x 8' = 640 ft³

Orlando

Commercial:

Tarpaulin
Truly Nolen, 100 West Amelia Street

PPQ:

Dry heat
24" x 28" x 21" -- maximum 450°F

Vac fumigation - MB
8' x 8' x 10' = 640 ft³
5' x 5' x 5' = 125°F (two)

NAP fumigation - MB

17' x 8'6" x 11' = 1,590 ft³

FLORIDA *(continued)*

Port Canaveral

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

Port Manatee

Commercial:

Tarpaulin
Genesis Exterminator, Brandenton
Western Fumigation, 1-800-542-1542 (New Jersey)

Tampa

Commercial:

Tarpaulin
Genesis Exterminator, Brandenton
Western Fumigation, 1-800-542-1542 (New Jersey)

West Palm Beach

Commercial:

Tarpaulin
F&F Pest Control, 7880 NW 64th Street, Miami
G&PM Pest Control, 12232 SW 130th Street, Miami
PalmBeach Exterminating, P.O. Box 2788
Western Fumigation, 2800 NW 22nd Terrace, Pompano Beach

GEORGIA

Atlanta

Commercial:

Tarpaulin
Bizzy Bee Exterminators, P.O. Box 954, Covington
Terminiz International Co., LP, 5373 Riverdale Rd, College Park

Brunswick -- See Savannah

Savannah

Commercial:

Tarpaulin
Cargo Fumigations, Inc, 120 W Bay St, P.O. Box 1714
Degesch America Inc, 1233 Wilmington Island Road
Rid-A-Pest Exterminating Co, 506 E. Liberty Street
Town & Country Exterminating Co, Inc. 5106 Ogeechee Road
Yates Astro Termite Pest Control, 3007 Gibbons Street

State Facility:

Vac fumigation only - MB
77' x 9'6" x 10' - 7,315 ft³ (two chambers)
Georgia Ports Authority, P.O. Box 2406

E-8

HAWAII

Honolulu

Commercial:

<u>Tarpaulin</u>
Inter-Island Termite, Inc, 905C Kokea Street
Island Termite Inc, 905 Kokea Street
No Ka Oi Termite and Pest Control, Inc, 99-1272 Waihona St.
Terminix International, 920 Sheridan Street
Vet's Termite Control, 500 Alakawa Street, Suite 220
Xtermco, 1020 Auahi Street

PPQ:

<u>Dry heat</u>
18½" x 23" x 19" -- maximum 482°F

<u>Steam</u>
40" x 20" x 20" -- maximum 60 psi

<u>Vac fumigation - MB</u>
6'7" x 3'8" x 5' = 120 ft^3

<u>NAP fumigation - MB</u>
5.15' x 2.41' = 24.87 ft^3

Keaau -- See Hilo

ILLINOIS

Chicago

Commercial:

Tarpaulin
Marks Pest Control Company, 1057 W. Grand Avenue

PPQ:

Steam
12" x 20" x 2½"

LOUISIANA

Baton Rouge -- see New Orleans

New Orleans

Commercial:

Dry heat
Import Sterilization, Inc., 1000 Edwards Avenue, Harahan

Tarpaulin
Mr. B. Services, Inc., 900 Jefferson Hyw, Jefferson
Redd Pest Control, 3801 Florida Ave., Kenner
D & A Exterminating Co., 4533 Clearview Pkwy, Metairie
All Phase Pest Control, 2801 S. Carrollton Ave.
Degesch America, Inc., 512 Rosenwald, Reserve

E-9

LOUISIANA *(continued)*

New Orleans *(continued)*

PPQ:

Dry heat
2'6" x 1'6" x 2' -- maximum 550°F
1'3" x 1'2" x 1'6" -- maximum 536°F
1'7" x 1'11" x 1'7" -- maximum 437°F

Hot water
36" x 18" x 9½"

Steam
1'4" x 8" -- maximum 27 psi

Vac fumigation - MB
8'3" x 4' x 4' = 132 ft³
4' x 4' x 4' = 64 ft³

MARYLAND

Baltimore

Commercial:

Tarpaulin
Dundalk Marine Terminal, 2700 Broening Highway, Shed 3A

Vac fumigation - MB
7.2' x 5.7' x 24.02' = 985.78ft³

MARYLAND *(continued)*

Beltsville

PPQ:

Dry heat
14" x 18" x 19" -- maximum 212°F

Hot water
36" x 18" x 9½"

Steam
24" x 15½" -- maximum 15 psi

Vac fumigation - EO-FR
16" x 16" x 26" = 3.9 ft^3

Vac fumigation - MB
2.5' x 3' x 3.5' = 26 ft^3
4' x 5' x 6' = 120 ft^3

E-10

MASSACHUSETTS

Boston

Commercial:

Dry heat 10 ovens - various sizes to 2,250°F
6" x 12" to 5' x 10' x 5'
Lindberg Heat Treating Co, 475 Dorchester Avenue, South Boston, 268-9255, Mr. Jack Rourick

Tarpaulin
Bain Pest Central, 1320 Middlesex Street, Lowell
Safety Fumigation, 197 Beal Street, Hingham
Waltham Chemical, 817 Mordy Street, Waltham

Charleston - see Boston

MASSACHUSETTS *(continued)*

New Bedford

Commercial:

Cold treatment five rooms
Room 1--113,088 ft^3; Room 2--270,750 ft^3;
Room 3--274, 436 ft^3; Room 4--267,159 ft^3;
Room 5--950,400 ft^3 (West Terminal)
Maritime Terminal Incorporated, Whalers Wharf

MICHIGAN

Detroit

Commercial:

Tarpaulin
Rose Exterminating Company, 4862 Greenfield Rd., Dearborn

PPQ:

Dry heat
11" x 11" x 9" -- maximum 300°F

MINNESOTA

Duluth

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

MISSISSIPPI

Greenville

Commercial:

Tarpaulin
Orkin Pest Control, P.O. Box 5026
Terminix Service, P.O. Box 4672

Gulfport

Commercial:

Tarpaulin
Atlas Exterminators, 106 North Ann Street, Greenville
Orkin Pest Control, 178 Commission Road, Long Beach
Redd Pest Control, P.O. Box 2245

Jackson

Commercial:

Tarpaulin
Redd Pest Control, 108 E. Northside Drive

Pascagoula - see Gulfport

MISSOURI

St. Charles

Commercial:

Tarpaulin
Master Pest and Termite Control, 505 Cross Green Lane

NEW JERSEY

Bound Brook

Commercial:

Vac fumigation - EO
40" x 69" x 146" = 233 ft^3
58" x 67" x 209" = 470 ft^3
71" x 76" x 395" = 1,233 ft^3
Griffith Micro Science Inc., Central Jersey Industrial Park, 8E, Easy Street

Elizabeth

Commercial:

Cold treatment
Two rooms -- 77,774 ft^3 and 278,628 ft^3
Atalanta Corporation, Atalanta Plaza

Hoboken

PPQ:

Dry heat
19" x 23" x 19" -- maximum 430°F

Hot water
34" x 31" x 35" (two)
36" x 18" x 9½"

Steam sterilization
20" x 20" x 30" -- maximum 20 psi (autoclave)
6'3" x 2' x 4' -- maximum 20 psi (two)
5'6" x 4' x 5' -- maximum 20 psi
10' x 4' x 5' -- maximum 20 psi
16' x 5' x 5' -- maximum 20 psi

E-12

NEW JERSEY *(continued)*

Hoboken *(continued)*

PPQ: *(continued)*

Vac fumigation
6'3" x 2' x 4' = 50 ft^3 (two)
5'6" x 4' x 5' = 110 ft^3
10' x 4' x 5' = 200 ft^3
16' x 5' x 5' = 400 ft^3
23' 9½" x 6'11" x 6' = 987 ft^3

Linden

Commercial:

Cold treatment
One room--192,128 ft^3
Pig Tainer Express Corp., 340 South Stiles Street

Dry heat (two ovens)
15' x 6' x 2' = 180 ft^3 -- maximum 350°F
ETO Sterilization, Inc., 250 Brunswick Avenue

Vac fumigation - EO
80' x 10'6" x 7' = 5,880 ft^3
40' x 9' x 7' = 2,752 ft^3
40' x 5' x 7' = 1,400 ft^3
44' x 7' x 12' = 3,696 ft^3
ETO Sterilization, Inc., 250 Brunswick Avenue

Newark

Commercial:

Tarpaulin

Vanguard Pest Control Co., Inc., Port Authority, Building 122, Port Newark

NEW YORK

Albany

Commercial:

Tarpaulin
Terminex International, 10 Walker Way (Port Authority, Shed #5)

Brooklyn

Commercial:

Cold treatment
Two rooms -- 20,884 ft³ each (availability limited)
William Kopke, Jr., Inc., 676 Longfellow Ave., The Bronx

Tarpaulin
Red Hook Terminal, Pier 11

Bronx, The -- see Brooklyn

Buffalo

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

Jamaica

Commercial:

NAP fumigation - MB
88" X 90" X 474" = 2,160ft³
Agra-Services LTD, 221-20 147 Street, Spring Gardens

E-13

NEW YORK *(continued)*

Jamaica *(continued)*

PPQ:

Dry heat
25" x 19" -- maximum 500°F

Hot water
36" x 18" x 9½"

Steam
36" x 20" -- maximum 15 psi

Vac fumigation - MB
38" x 30" x 36" = 24 ft³ (two)

Vac fumigation - MB
127" x 48" x 68" = 240 ft³

Rochester

Commercial:

Tarpaulin
Sawyer, 201 Monroe Avenue

NORTH CAROLINA

Charlotte

Commercial:

Tarpaulin
Terminiz Service, 2001 South Tyron Street
Wilson Pest Control Co, P.O. Box 1398, Winston-Salem

NORTH CAROLINA *(continued)*

Morehead City

PPQ:

Tarpaulin as needed

State Facility:

Vac fumigation only - MB
82'5" x 10'1" x 10'10" = 9,000 ft³ (two)
North Carolina State Ports Authority

Wilmington

State Facility:

Tarpaulin - MB
North Carolina State Ports Authority -Wilmington State Port

Vac fumigation only - MB
76'8" x 9'6" x 10' = 7,284ft³ (two)
North Carolina State Ports Authority--Wilmington State Port

Wilson

Commercial:

NAP fumigation - MB
40' x 27' x 21' = 22,680ft³
40' x 62' x 21' = 52,080 ft³
40' x 97'8" x 21' = 82,034 ft³
Export Leaf Tobacco Co., P.O. Box 636, Old Stantonsburg Rd

Vac fumigation only - MB
10' x 10' x 40' = 4,000 ft³ (two)
Tobacco Processors, Inc., Storage Division, P.O. Box 1089, 2107 Old Black Creek Road

OHIO

Cleveland

Commercial:

Tarpaulin
Progressive Pest Control Co., 2883 Pasadena Drive

PPQ:

Dry heat
11¼" x 11" x 8 3/4" -- maximum 392°F

U.S. Navy:

Steam
23½" x 15 3/4" -- maximum 60 psi
U.S. Navy Finance, 2693 New Federal Building

Toledo

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

OREGON

Portland

Commercial:

Tarpaulin
DICO/Pacific Fumigation, 12011 NE 95th Street, Vancouver, WA
Larsen Pest Control, 5625 SE 85th
Orkin Exterminating Co., Inc., 4410 SW Beaverton-Hilldale Hwy
Paramount Pest Control, Inc., 5207 NE Portland Highway
PCO Services (Ardee Pest Control), 12013 NE Marx

PENNSYLVANIA

Philadelphia

Commercial:

Cold treatment One room (118,800 ft^3)
Holt Marine Terminal, 701 North Broadway

Dry heat
Stanford Seed Co., P.O. Box 320, Muddy Creek Rd, Denver, PA

Tarpaulin
Holt Marine Terminal, 701 North Broadway, Gloucester City, NJ
Tioga Marine Terminal, Tiogo Marine Terminal #2, Pier 84, Delaware Avenue
Broadway Terminal, North Broadway, Camden, NJ
Penn Terminal, Chester

E-15

PUERTO RICO

Ponce

Commercial:

Hot water
65' x 8' x 9½'
Fruits International, Bo. Coto Laurel

PUERTO RICO *(continued)*

San Juan

Commercial:

Tarpaulin
Antillas Exterminating Service, Calle O'Neil G-4, Hato Rey
Bazuka Exterminating Service, 1211 SB Roosevelt Avenue, Puerto Nuevo
New Systems Exterminating Service, P.O. Box 11017, Caparra Station
Oliver Exterminating Service, GPO Box 3888
Reina Exterminating Service, Corp. P.O. Box 394, Hato Rey
Pan American Exterminating, Inc., P.O. Box 2288, Bayamon

PPQ:

Dry heat (one airport)
18" x 14" x 14" -- maximum 400°F

RHODE ISLAND

Warwick

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

SOUTH CAROLINA

Charleston

Commercial:

Tarpaulin
Mooreguard Exterminating Company, 803-884-7162, Mt. Pleasant
National Exterminating Company, 803-766-1217
Willard Exterminating Company, 803-571-6909

TENNESSEE

Memphis

Commercial:

Tarpaulin
Taylor Enterprises, 5813 Leisure Lane
U.S. Pest Protection Co., Inc., Hendersonville

TEXAS

Brownsville

Commercial:

Tarpaulin
Abash Insect Control Service, 509 N. Commerce, Harlingen

PPQ:

Dry heat
23" x 19" x 19" -- maximum 437°F

Hot water
36" x 18" x 9½"

Vac fumigation - MB
6' x 4' x 5' = 120 ft^3
10' x 4' x 6' = 240 ft^3

E-17

Corpus Christi

Commercial:

Tarpaulin
Pest Fog, 1424 Bonita

TEXAS *(continued)*

Dallas

Commercial:

Tarpaulin
Industrial Fumigation Co, Wolfe City
Southwestern Fumigation Co., Desota

PPQ:

Dry heat
18" x 12" x 16" -- maximum 392°F

El Paso

PPQ:

Dry heat
19" x 19" x 23" -- maximum 392°F

Hot water
36" x 18" x 9½"

Vac fumigation - MB
9'1" x 4' = 144 ft^3

Galveston -- see Houston

Harlingen

Commercial:

Tarpaulin
Abash Insect Control Service, 509 N. Commerce
The Bug-Man System, 1017 W. Tyler

TEXAS *(continued)*

Hidalgo

Commercial:

Tarpaulin
Abash Insect Control Service, 509 N. Commerce, McAllen

State Facility:

Dry heat cast iron tray, with cover
16" x 25" x 4" 6 open gas burners
Texas Soil Lab, one-half mile East Highway, McAllen

Houston

Commercial:

Dry heat
12" x 12" x 18" -- maximum 392°F
Professional Services Industry, 6913 Hwy 225, Deer Park

Tarpaulin
Anchor Fumigation & Pest Control, Inc., 4209 Dahlia Lane, Deer Park
Coastal Fumigators, Inc. 1119 W. 34th St.
Degesch America, Inc., 14802 Park Almeda
International Fumigators, 9139 Becker
National Fumigation & Termite Service, 2103 Hazard
Orkin Exterminating Co., 6500 Long Drive

TEXAS *(continued)*

Houston *(continued)*

PPQ:

Dry heat
12" x 18" x 16" -- maximum 392°F
18" x 14" x 14" -- maximum 400°F
15" x 17½" x 19½" -- maximum 520°F

Hot water
36" x 18" x 19½"

Steam
10" x 15½" -- 45 psi

Vac fumigation - MB
4'6" x 9' x 6' = 243 ft³

Laredo

Commercial:

Tarpaulin
Asash Termite and Pest Control, Inc., 1102 Clark

PPQ:

Dry heat
16" x 18" x 12" -- maximum 392°F

Hot water
36" x 18" x 9½"

Vac fumigation - MB
6'7" x 5' x 3'8" = 120 ft³

E-19

TEXAS *(continued)*

McAllen -- see Hidalgo

Port Arthur

Commercial:

Tarpaulin
International Fumigators, 150 Marine St., Lake Charles, LA
Big State Pest Control, 1679 Lindbergh Dr., Beaumont, TX

Roma

PPQ:

Dry heat
12" x 16" x 18" -- maximum 392°F

San Antonio

Commercial:

Tarpaulin
ABC Pest Control, 10022 IH 35N

PPQ:

Dry heat
22" x 18" x 19" -- maximum 500°F

VIRGIN ISLANDS

St. Croix

Commercial:

Tarpaulin
Oliver Exterminating, 6x, Peter's Rest, Christainsted

VIRGINIA

Dulles International Airport

Commercial:

Tarpaulin -- can be arranged (no regular facility at present)

Newport News

Commercial:

Vac fumigation only - AN-CTC, MB
42' x 10' x 10' = 4,200 ft³ (two -- Chambers A & B)
67'3" x 5' x 9' = 3,026 ft³ (two Chambers 7 & 8)
Newport News Marine Terminal, 18th Street

Norfolk

Commercial:

Tarpaulin
129' x 19' x 14'6" = 35,539 ft³ (three) (other sizes can be arranged

Vac fumigation only - AN-CTC, HCN, MB
79' x 12' x 12' = 11,376 ft³ (six)
Lambert's Point Dock, Inc., Foot of Orapax Avenue
83' x 10'6" x 12' = 10,458 ft³ (two)
Norfolk International Terminal, 7737 Hampton Blvd.

Petersburg

Commercial:

Vac steam flow process only
5' x 13'8" x 5'6" = 375.8 ft³
Madin, Zimmer, McGill, Tobacco Co., P.O. Box 550

VIRGINIA *(continued)*

Portsmouth

Commercial:

Vac fumigation - AN-CTC
44' x 9'6" x 10'6" = 4,389 ft³ (two)
Portsmouth Marine Terminal, P.O. Box 7161

Richmond

Commercial:

NAP fumigation - Phosphine (PH 3)
15'8" x 31'3" x 68' = 33,291 ft³
Alleghany Warehouse #2, 12th & Gordon Streets

E-20

WASHINGTON

Longview see Portland, Oregon

Seattle

Commercial:

Cold treatment
24' x 100' x 120' = 288,000 ft³
Maritime Terminals Division, Port of Tacoma, P.O. Box 1837

NAP fumigation - MB
26' x 9'4" – 1,778 ft³
Paramount Pest Control, 423 Horton Street

Tarpaulin
Paramount Pest Control, 423 Horton Street
W.B. Sprague Co, 2139 S Fawsett Avenue, Tacoma

WASHINGTON *(continued)*

Seattle *(continued)*

PPQ:

Dry heat
18" x 14½" x 14" -- maximum 380°F

Hot water
20¼" x 27½" x 35"

Vac fumigation - EO-FR, MB
4.5' x 2.5' - 22.1 ft³

Tacoma

Commercial:

Cold treatment
24' x 100' x 120' – 288,000 ft³ (fruit treatment capacity limited
140,000 ft³

WISCONSIN

Milwaukee

Commercial:

Dry heat
Six ovens, various sizes from 2' x 2' x 2' to 8' x 8' x 6' -- maximum 500°F
Commercial Heat Treating Corp., 1952 So. First Street
Ten ovens, various sizes from 2' x 2' x 2' to 20' x 20' x 10' -- maximum 500°F

Steam
2' x 3' x 5' -- maximum 60 psi

Tarpaulin -- can be arranged (no regular facility at present)

APPENDIX 5–DIRECTORY OF TREATMENT FACILITIES

The following is a list of abbreviations used in the Appendix.

CB--Carboxide© which is a mixture of 10 percent ethylene oxide and 90 percent carbondioxide

EO-FR--A mixture of 10 percent ethylene oxide and 88 percent Freon®

MB--methyl bromide

NAP--normal atmospheric pressure

SF--sulfuryl fluoride which is registered under the name Vikane®

Vac Fumigation--vacuum fumigation (also approved for NAP)

Vac Fumigation only--not approved for NAP

ft^3--cubic feet

D--diameter

L--length

m--meters

m^3--cubic meters

psi--pounds per square inch

kg/cm^2--kilograms per square centimeter

kPa--kilopascals (6.894757 x psi)

/--volume is larger than figures indicate--includes external duct volume

F--Fumiscope® available

APPENDIX F

POTENTIAL DESTRUCTION TECHNOLOGIES
(SOURCE: REFERENCE 19)

APPENDIX F. POTENTIAL DESTRUCTION TECHNOLOGIES

General Category Name	Subcategory	DE	Recovery of By-products	Status	Recommend for Approval	Country	Source
A. Thermal Oxidation	1. Gaseous Liquid Thermal Oxidation/Hydrolysis						
	• Liquid Injection Incineration (On-Site or Off-Site Commercial)	≥99.99%	Occasionally	Commercial	Yes	Several	
	• Reactor for cracking CFCs/HCFCs/HFCs	≥99.99%	Yes	Commercial	Yes	Germany	Hoechst, AG
	• Gaseous/Fume Oxidation	≥99.99%	Occasionally	Commercial	Yes	Several	AK 20
	2. Rotary Kiln (On-Site or Off-Site Commercial)						
	• Hazardous Waste Incinerator	≥99.99%	Occasionally	Commercial	Yes	Several	
	3. Multipurpose (MSWI)						
	• Incineration of PUF with MSWI	≥99.99%	No	Full-scale testing	Yes	Several	Kernforschungszentrum
	4. Cement Kilns	≥99.99%	No	Commercial for other wastes	Yes	Several	
	5. Miscellaneous						
	• Fluidized Bed	Unknown	Unknown	Commercial for other wastes	No	USA	Ogden Environ. (Circul. Bed)
	• Waste Gasification	Not reported	No	Mobile demo unit	No	Austria	Voest-Alpine
	• Controlled Combustion (Burn Boxes)	Unknown	No	Commercial for other wastes	No	USA	MG Indst;CEMI
B. Catalytic Processes	1. Oxidation						
	• HDC Catalyst	≥99%	No	Commercial for other wastes	No	USA	Allied-Signal Industrial Catalyst
	• Direct Catalytic Oxidation	≥99%	No	Development	No	Japan	NIRE
	• Catalytic Decomposition	Approx. 100%	No	Lab Scale	No	Japan	Kyoto University
	• Catalytic Hydrolysis	Approx. 100%	No	Lab Scale	No	Japan	NIRE
	2. Hydrogenation						
	• Selective Hydrodechlorination	80-100%	Yes	Lab Scale	No	Japan	Hokkaido University
	• Direct Contact Hydrogenation	Unknown	Unknown	Bench Scale	No	USA	UOP
C. Pyrolysis	Rotary Kiln	Unknown	Possible	Unknown	No	Germany	FBD/BKMI
D. Chemical Destruction	1. Reaction with Elemental Metals						

General Category Name	Subcategory	DE	Recovery of By-products	Status	Recommend for Approval	Country	Source
	• Chemical Destruction of CFCs with Sodium	≥99%	Not presently	Lab Scale	No	Germany	Degussa
	• Reductive Destruction by Dehalogenation	≥99%	No	Lab Scale	No	Japan	Kyoto Institute of Technology
	• Steel Smelter	Unknown	No	Unknown	No	Germany	Dornier
	• Molten Iron Reactor	≥99.9999%	Yes	Bench Scale	No	USA	MMT, Inc. (Molten Metal Technology)
	• P-CIG (Molten Iron)	Unknown	No	Pilot plant/demo plant	No	Sweden	MEFOS
	2. Reaction with Metal Oxides						
	• Chemical-thermal destruction with $CaAl_2O_4$ or SiO_4	≥99-99.999-9%	Yes, HCI	Pilot plant	No	Germany	Nukem
	• Metal Oxide Conversion (pebble bed)	≥99.999%	No	Lab Scale	No	Australia	CSIRO
E. Supercritical Water Oxidation	1. Supercritical Water Hydrolysis	Approx. 100%	No	Lab Scale	No	Japan	NCLI
	2. Supercritical Water Oxidation	≥97%	No	No demo unit	No	USA	ABB Lummus-Crest/MODAR
F. Wet Air Oxidation	Wet Air Oxidation	≥99%	No	Commercial	No	USA	ZIMPRO
G. Plasma Destruction	1. Corona Discharge	Unknown	No	Pilot Scale	No	USA	US EPA
	2. Inductively-Coupled R.F. Plasma	≥99.9%	No	Pilot Scale	No	Japan	NIRE
	3. Thermal Plasma	Unknown	No	Lab Scale	No	Japan	Tokyo Institute of Technology
	4. Plasma Arc	Unknown	No	Pilot Scale	No	Australia	CSIRO
H. UV Photolysis	1. Photochemical Degradation	Unknown	No	Unknown	No	Japan	NCLI
	2. Decomposition by UV Irradiation	Approx. 100%	No	Lab Scale	No	Japan	Toshiba R&D
	3. (Photo-) Dechlorination	Approx. 100%	No	Lab Scale	No	Japan	Hosei University
	4. Photocatalytic Degradation	Unknown	No	Unknown	No	USA	Nutech & Sandia
	5. Photochemical Oxidation	≥95-99%	Unknown	Lab Scale	No	USA	Process Technologies, Inc.
I. Biological Processes	1. Degradation by Microbial Treatment	Approx. 100%	No	Lab Scale	No	Japan	NIES
J. High Energy Radiation	1. Conversion by Ionic Radiation	Unknown	Yes, HCFCs/-HFCs	Lab Scale	No	Japan	GIRIN

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16. ABSTRACT The report gives results of an investigation of means for methyl bromide (MeBr) recovery, reuse, and destruction to prevent atmospheric emissions if its limited use were still allowed. (NOTE: MeBr is an ozone-depleting chemical scheduled to be phased out by the Clean Air Act by the year 2001. For agricultural commodity fumigation, there is no ready substitute for MeBr.) Approximately 4-5 million lb/yr (1.8-2.3 million kg/yr) of MeBr is used for commodity/agricultural harvest fumigation. Commodity fumigation is carried out extensively at a few locations, mostly major seaports. Fumigation is conducted in chambers built for holding the commodity during fumigation and in temporary enclosures, such as under tarpaulins and in vehicles. The emissions are vented to the atmosphere. Few control systems exist for MeBr emissions. Likewise, control system research and development has been limited. Vendors have proposed control technologies for MeBr control, recovery, and recycle, but few systems have been built. Conventional vapor control technologies, such as activated carbon adsorption systems, appear to be applicable to MeBr emissions. These systems must also provide for recovery. Control will probably be expensive due to the small volumes of recoverable material and the intermittent nature of fumigation operations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fumigation	Pollution Control	13B	06F
Containment	Activated Carbon	Stationary Sources	14G	11G
Bromohydrocarbons		Methyl Bromide	07C	
Emission	Adsorption	Agricultural Commodities		
Agricultural Products			02D	
Bromides			07B	
Harvesting				

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