METHYL BROMIDE QUARANTINE AND PRESHIPMENT
INTERIM NATIONAL MANAGEMENT STRATEGY
SUBMISSION BY THE UNITED STATES OF AMERICA
OCTOBER 30, 2009

1. Introduction

The United States is committed to the objectives of the Montreal Protocol. Finding effective alternatives to methyl bromide for quarantine use is a United States government priority. We are committed to our ongoing, vigorous research program to look for effective alternatives recognizing that the United States must be able to protect agriculture, forests and ecosystems for damaging exotic pests as well as meet phytosanitary requirements of importing countries, while protecting the ozone layer.

1.1 Overview of MP text and relevant decisions and regulatory authorities

At the seventh meeting (MOP 7) the Parties decided in Decision VII/5 on definitions for "quarantine applications" and "pre-shipment applications."

> *"a) Quarantine applications, with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:*
>
> *i. Official control is that performed by, or authorised by, a national plant, animal or environmental protection or health authority;*
>
> *ii. Quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled"*
>
> b) *Pre-shipment applications are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or existing phytosanitary or sanitary requirements of the exporting country;"*

The definition of "pre-shipment applications" was subsequently clarified in Decision XI/12 as:

> *"Pre-shipment applications are those non-quarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country. Official requirements are those which are performed by, or authorized by, a national plant, animal, environmental, health or stored product authority."*

The phrases in Decision VII/5, as agreed by the Parties to the Montreal Protocol, provide guidance to Parties regarding which categories of uses can be classified as "quarantine applications" and as "preshipment applications." The USA based its domestic regulatory program for QPS directly on the language in Decision VII/5 as agreed by the Parties.

The QPS program is administered through a combination of authorities in the United States, specifically through the programs that administer the Montreal Protocol, domestic pesticide regulations, and natural quarantine treatments.

The establishment of quarantine requirements and the implementation of actions to protect against invasive pests is the responsibility of both domestic state agencies and the national agency called the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA).

The US EPA, Office of Pesticide Programs (OPP) plays a role in managing QPS uses through its pesticide labeling program under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). OPP is developing specific methyl bromide quarantine and preshipment pesticide labels for soil fumigation to more clearly define where those uses are allowed. The OPP is developing new pesticide use requirements which will include lower maximum application rates, a fumigant management plan, good agricultural practices to reduce emissions, lower permeability films (lower mass transfer coefficients), and buffers between the treated area and habited structures, schools, hospitals, and day care centers as well.

The U.S. EPA's Office of Air and Radiation (OAR) is responsible for implementing provisions of the Montreal Protocol under the Clean Air Act and oversees the exemption to allow for production and import of methyl bromide to meet QPS needs.

OAR issued an interim final regulation for the QPS exemption in July 19, 2001. US EPA moved forward with finalizing the regulation during 2001 and published the final regulation on January 2, 2003. In both the interim final and the final regulation US EPA made reference to the guidance from TEAP and MBTOC regarding uses considered to be QPS, such as "treatment of land prior to export of crop" (i.e., for propagation material like strawberry runners).

Below are excerpts from US EPA's final regulation published January 2, 2003. The full explanatory text for the interim final regulation published on July 19, 2001, and the explanatory text for the final regulation published January 2, 2003, are attached in Annex…

"… the definition of quarantine applications is qualified by the scope of the exemption as stated in the Clean Air Act (US law). As passed by Congress, the Clean Air Act (CAA) specifically applies the quarantine and preshipment exemption to quantities of methyl bromide used to 'fumigate commodities entering or leaving the United States or any State (or political subdivision thereof)…' (CAA section 504(d)(5)). This language makes clear Congress's intent to apply the exemption only where there is the transport of goods from one distinct locality to another, and thus to prevent the potential for the geographic spread of pests. As a result, today's action adds the following sentence to the definition of quarantine applications: 'This definition excludes treatments of commodities not entering or leaving the United States or any State (or political subdivision thereof).'"

"With today's final action, [US] EPA is defining quarantine applications …as follows:"

"*Quarantine applications*, with respect to [methyl bromide], are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where: (i) Official control is that performed by, or authorized by, a national (including state tribal or local) plant, animal or environmental protection or health authority; (ii) quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled. This definition excludes treatments of commodities not entering or leaving the United States or any State (or political subdivision thereof)."

"As specified in the above definition, a quarantine application of methyl bromide must be 'performed by, or authorized by, a national (including state, tribal or local) plant, animal or environmental protection, or health authority.' In addition, as delineated in the above definition, quarantine applications must be directed at quarantine pests."

2. Overview of QPS Uses in the United States

2.1 Quarantine Uses

2.1.1 Import Uses and Recording Methyl Bromide for Phytosanitary Use (Decision XX/6(10)(d)

The Plant Protection and Quarantine (PPQ) division of the United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA APHIS) is responsible, as the designated National Plant Protection Organization (NPPO), for ensuring that invasive, threatening plant pests do not enter our borders. Pests that are not permitted to enter this country are categorized as Federal quarantine pests. In accordance with APHIS, PPQ regulations, regulated articles found to be or have the potential to be infested with Federal quarantine pests must be treated with an approved treatment before it may enter the country; otherwise, those items must be sent back to the port of origin or destroyed. Importers may be offered a choice of treatments, but they will choose that treatment which is the most effective expedient and cost-effective. Although physical treatments such as cold (refrigeration) treatment or irradiation are available for a variety of our imported commodities, the importer's treatment of choice for many of the commodities that enter our country is methyl bromide. This is due to its effectiveness, low cost, and speed of application. Sometimes the only available treatment is methyl bromide.

There are two possible scenarios when pests are detected upon entry: treat and release; or return or destroy. Allowing treatment upon entry, when appropriate, is keeping within the spirit of the World Trade Organization (WTO) SPS Agreement in that it is application of the least restrictive phytosanitary measure. Rejecting or destroying products in such situations would be very disruptive. Another option would be to require phytosanitary certification from the NPPO on the exporting side. This has the potential to just move the treatment to the exporting country. In addition, if quarantine pests are still found on certified commodities, it could result in more stringent measures such as mandatory treatment or prohibiting certain commodities.

Traditionally, APHIS, PPQ has collected usage data on all fumigations conducted for import uses. Consequently, we have the best usage data for this area of use pattern. Usage data is presented in Table 1.

Table 1. PPQ Quarantine and Preshipment Use of Methyl Bromide[1]

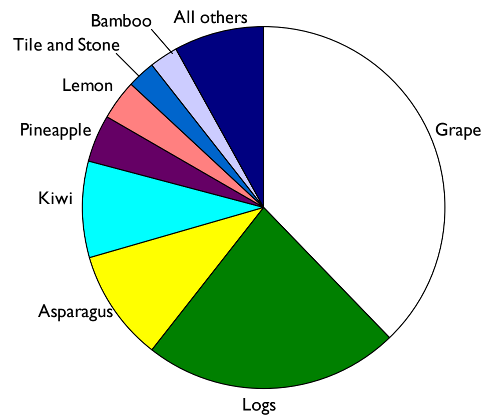
Treated commodity	2005 Tons	2005 %	2008 Tons	2008 %
All Fruits and Vegetables[2]	214.43	53.21	289.05	68.84
Grape	138.07	34.26	159.01	37.87
Asparagus	25.76	6.39	42.46	10.11
Kiwi	8.90	2.21	35.92	8.55
Pineapple	7.43	1.84	17.63	4.20
Lemon	2.47	0.61	14.85	3.54
Logs	160.39	39.80	94.94	22.61
Wood and lumber	1.16	0.29	1.46	0.35
Wood packaging and dunnage	1.06	0.26	0.07	0.02
Bamboo	4.06	1.01	9.85	2.34
Tile and Stone	11.30	2.80	10.94	2.61
Flowers, greenery, and plants	4.26	1.06	6.61	1.58
Cotton	1.64	0.41	3.21	0.76
Containers	0.18	0.04	1.11	0.26
Vehicles, Machinery and Equipment	0.28	0.07	0.68	0.16
Metal	0.29	0.07	0.05	0.01
Furniture and household goods	0.08	0.02	0.23	0.05
Glass	0.00	0.00	0.19	0.05
Pine Cones	0.08	0.02	0.20	0.05
Tobacco	0.25	0.06	0.05	0.01
Miscellaneous Cargo	0.29	0.07	0.66	0.16
Guar gum	2.66	0.66	0.00	0.00
Others[3]	0.56	0.14	0.50	0.12
Total Commodity Use	**403.01**		**419.90**	

[1]Data from PPQ 429 reports, which does not include preclearance use for imports to the U.S. or export fumigation conducted outside PPQ

[2]93% of fruit and vegetable use is for 5 commodities

[3]Includes 32 commodities with less than 0.1 ton use each

PPQ QPS Use of Methyl Bromide in 2008 by Commodity



2.1.2 Export Uses

Domestically-grown commodities destined for export to other countries must meet the importing countries' phytosanitary requirements in order to gain entry into the importing country. In many cases, the importing country requires that the commodity be certified as "pest-free". In many cases, the importing country specifically requires fumigation with methyl bromide in order to gain entry.

The United States cannot change another country's phytosanitary requirements. Exporters must treat their commodities in accordance with the importing country's regulations, so long as that treatment is available in the exporting country. Alternative treatments approved by APHIS, PPQ for imported commodities (e.g. irradiation, forced hot air, hot water) are not always readily available to treat domestic exports, unless that alternative treatment is approved by the importing country and documented in regulations or a bilateral agreement.

In the United States, treatments are monitored by Authorized Certification Officials (ACO) who assure that the fumigation is properly performed. These officials document that the consignment is "pest-free" by issuing a Federal Phytosanitary Certificate (PC). ACOs include both Federal and State/County officials. Even though sometimes a treatment is required to be documented on a PC, the total quantity of methyl bromide used to perform phytosanitary treatments of exported commodities is not a documented requirement. Therefore, the quantity of methyl bromide used to fulfill other countries' regulations is generally unknown to Parties.

2.2 Domestic Uses

2.2.1 Federal Domestic Quarantines

APHIS, PPQ is responsible, as our nation's NPPO, to prevent movement of quarantine pests that have already entered the country. For example, in 2006, a Federal quarantine soil pest, the potato cyst nematode, was identified in a locality within the State of Idaho. Articles that move into and out of quarantined fields are now regulated, and Idaho growers are now prohibited from planting potatoes and other host crops of the potato cyst nematode in field under Federal quarantine. However, in order to get the fields removed from Federal quarantine and approved for planting back to potatoes, one of that region's primary crops, the soil within the quarantine area must be fumigated yearly with methyl bromide, the most efficacious fumigant for eradicating the cyst stage of this quarantine pest.

All methyl bromide fumigations performed on regulated articles (e.g. commodities, soil or field equipment that PPQ has reason to believe may be carrying Federal quarantine pests) to permit these articles to enter the chain of commerce are performed under the supervision of PPQ to ensure that they are performed in accordance with Federal regulations. The quantity of methyl bromide used to perform fumigations supervised by PPQ officials is always recorded.

Table 2. 2008 Use of Methyl Bromide in Emergency and Domestic Programs

Program	Tons
Potato Cyst Nematode	215.66
Golden Nematode	4.88
Witchweed	1.40
Total	**221.94**

2.2.2 State and Local Quarantines

States, localities, and tribal lands also protect their lands from domestic quarantine pests. These entities may have regulatory requirements that demand pest-free status of plants, plant products, or other regulated articles before they can come into their State or locality from another State or locality. Documentation indicating that the commodity or the soil in which the commodity has grown has received a methyl bromide fumigation, because of the extremely well-known efficacy of this chemical, is proof of a "pest-free" status. The majority of methyl bromide used under the QPS exemption in the United States is used to fulfill State or local quarantine requirements.

2.2.3 Pre-shipment Uses

Pre-shipment treatment with methyl bromide is applied with 21 days of export to meet official regulations. At present, the United States is not aware of any domestic uses of pre-shipment methyl bromide treatments.

3. Methyl Bromide Alternatives- Replacing Methyl Bromide Use (Decision XX/6 (10)(a))

3.1 Process for Approving Alternatives for Federal Quarantine Use

Once EPA approves a registration of a methyl bromide alternative chemical treatment, it cannot automatically be used in lieu of methyl bromide for APHIS, PPQ plant quarantine purposes. An EPA approval of an alternative pesticide is not equal to an APHIS determination that the product is acceptable for plant quarantine treatment purposes. APHIS must have data indicating that the alternative product is at least as effective, if not more so, than methyl bromide in removing a specific plant quarantine pest on a specific commodity.

The process of performing efficacy tests is lengthy. Research, often performed by the exporting country for review and approval by APHIS PPQ, must be performed for each commodity targeting the quarantine pests specific to that commodity. Official treatment rates are based upon the results of tests conducted on that commodity's pest complex, which may change with each import or export request since a pest complex depends upon the country of origin. If APHIS PPQ should determine that the treatment rate needed to effectively remove a specific quarantine pest from a specific commodity exceeds the label rate, then the test chemical may be unavailable for quarantine purposes. If APHIS, PPQ determines that the treatment rate needed to effectively remove a specific quarantine pests from a specific commodity is within the labeled treatment rates, then it must be determined whether that commodity remains marketable following treatment. For example, methyl bromide fumigation can damage or even destroy commodities at treatment rates necessary to kill the regulated pests, rendering the commodity safe to enter the country, but unmarketable. If the commodity is damaged or destroyed at a treatment rate needed to kill the quarantine pest, then that chemical would not be useful for quarantine purposes.

In the event that USDA develops or learns of an efficacious methyl bromide alternative chemical at a labeled treatment rate, and the commodity retains its marketability, there are further steps that must be taken to make it an APHIS-approved treatment.

For imports, the treatment must be added to the regulations in Title 7, Parts 300-399, of the Code of Federal Regulations (CFR), which is where APHIS' Plant Protection and Quarantine program codifies its import treatment requirements, among other things. A draft regulation must be developed, approved within the agency, and vetted within the Department of Agriculture. Prior to executing this step, APHIS must address numerous other Congressional mandates, to which all federal agencies engaged in rulemaking must adhere. Examples of such mandates that must be considered during rulemaking include the National Environmental Policy Act, the Endangered Species Act, and the Administrative Procedure Act. Formal consultation in accordance with section 7 of the Endangered Species Act may take up to one year; this can hold up promulgation of a regulation. In total, a typical time frame for most federal agencies to get new regulations added to the CFR , in this case, a new treatment, is typically two to four years.

For exports, research on methyl bromide alternative treatments is often performed by USDA's Agricultural Research Service, typically in conjunction with academia or a chemical company. If an alternative treatment is shown to be effective, a trade agreement must be made with the importing country such that the importing country agrees that the alternative treatment satisfies their phytosanitary standards. One example of such research is the low oxygen phosphine treatment to remove the Western flower thrips, a ubiquitous insect in California, but a quarantine threat to other countries. Taiwan has agreed to accept lettuce exported from the United States using this treatment, and exporters have been using this treatment successfully for at least two years. As with many other newly approved treatments, this treatment was developed because methyl bromide cannot be used on lettuce without affecting its marketability. Industry believes that Taiwan might accept this treatment for U.S. exports which are labeled for methyl bromide treatments, such as strawberries, grapes and asparagus. However, the U.S. Environmental Protection Agency has not approved the use of low oxygen phosphine on these commodities. Thus, this alternative treatment is not available for use on strawberries, grapes and asparagus which, together with lettuce, comprise the major agricultural exports to Taiwan.

APHIS approval of a methyl bromide alternative for specific commodities does not remove methyl bromide treatments from the list of available quarantine treatments. For a variety of reasons, APHIS may need to keep the methyl bromide treatment in the Treatment Manual as an effective alternate or back-up treatment. This may have to do with availability of alternative treatment (for example, few ports have access to irradiation facilities at this time,) an unexpected failure of a treatment, or it may have to do with the ambient temperature at the port where the commodity is treated. (Since fumigation efficacy is temperature-dependent, an alternative fumigant may not be as efficacious as methyl bromide at the ambient temperatures of the port where the commodity needs treatment.) If the alternate treatment is determined to be unavailable and the methyl bromide option has been removed, the APHIS has no recourse but to direct the importer to either destroy or re-export the commodity, actions which could have vast economic and trade consequences.

APHIS is thoroughly committed to adopting methyl bromide alternatives whenever and wherever possible and will continue to work with EPA to test newly-approved chemical alternatives. APHIS is also actively implementing regulations incorporating a wide variety of non-chemical quarantine treatments including cold treatment (mandatory time and temperature in refrigerated containers), hot water immersion treatment, forced hot air treatment, vapor heat treatment, steam treatment, and irradiation. The availability of these non-chemical treatments has allowed this nation to enjoy a wider variety of imported commodities, many of which were formerly unable to enter this country due to their inability to withstand fumigation treatment without compromising marketability. APHIS is also involved with approving ways to fumigate that involve less methyl bromide gas to be used as well as approving technology that will effectively capture and chemically destroy the methyl bromide gas.

While alternative research continues, there are some commodities for which non-chemical and alternative fumigant treatments have not proven to be successful. For these commodities, methyl bromide remains the only method of safeguarding the U.S. ecosystems from destructive quarantine pests and the only treatment that will provide Phytosanitary Certification for export.

3.2 Alternative Commodity Treatments

Some examples of alternative treatment regimes are provided below:

- Sulfuryl fluoride to treat domestic firewood potentially infested with emerald ash borer (EAB) to allow firewood to move outside of EAB quarantined areas of the United States. If this treatment were to replace all MB treatments, the use of MB in the U.S. may be reduced through this treatment.
- Vacuum/Steam treatment of imported bamboo to target beetles in the family Cerambycidae. This treatment has the potential of saving over 38 tons of MB over a five-year period, representing over 30,100 fumigations
- Vacuum/Steam treatment of durable goods (e.g. solid wood packing material, imported tiles, wool products, rugs) to target wood boring beetles and/or hitchhiker pests.
- Cold Treatment of cherries imported from Western Australia to target Queensland Fruit Fly. This treatment is being considered for implementation, based on recent research indicating that the standard regulatory treatment, consisting of a combination of cold treatment and methyl bromide treatment may no longer be necessary. Approval of this new treatment will reduce U.S. use of MB.

- Compressed cotton for export in lieu of MB fumigation. Some countries that import domestic cotton have been willing to accept compressed cotton in lieu of fumigated cotton if they agree that the compression is sufficient to kill all stages of the pink bollworm and boll weevil. PPQ does not have export data on MB usage so an estimate of the reduction in MB use cannot be ascertained.

- Fruit and Vegetable Irradiation: APHIS PPQ has approved the use of irradiation to target specific pests (e.g. fruit flies) of all fruits and vegetables. While irradiation can be used successfully for some pests, and may be already approved for certain phytosanitary treatments on many commodities that are traditionally treated with methyl bromide. Irradiation is very expensive and the technology is not developed to the point that large consignments may be treated in a reasonable amount of time compared to what can be accomplished using methyl bromide.

Research on a systems approach has produced treatments for cherries, further reducing our need for methyl bromide. A systems approach depends upon integrated technologies that are used throughout the growing season to control pests and eliminate the need for fumigation upon export. Such cherry production areas are now under consideration for acceptance by Japan as an alternative to methyl bromide fumigation of export cherries.

Compounds that have potential to replace methyl bromide for quarantine uses have been investigated for use on different commodities. Several potential fumigants were shown to have the technical potential to replace methyl bromide in quarantine treatments of walnuts. These potential treatments consisted of carbonyl sulfide, methyl iodide, sulfuryl fluoride, and propylene oxide. Phosphine in combination with compression has been shown to be effective in eliminating live Hessian flies and cereal leaf beetle from Timothy hay bound for Japan. This treatment can now be used on small or large compressed bales of the hay. Ozone was shown to be a useable replacement for methyl bromide in eliminating adult thrips from the navels of oranges being exported to Australia. Tests established the schedule needed to kill all thrips in a chamber designed to treat with ozone gas mixed with a low concentration of carbon dioxide. Tests are now underway to identify the types of waxes used on oranges that will help protect the orange from any phytotoxic effects caused by the ozone.

See the appendix to this document for additional descriptions of QPS research activities.

3.2.1 Alternative Treatments being Developed by APHIS.

The table below describes alternative treatments under consideration by APHIS.

Table 3: Quarantine Treatments Under Development by APHIS

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ

[1] **Note:** "Alternatives" may be followed by a mandatory MB fumigation, depending upon the pest complex and country of origin. Certain treatments alone do not target invasive surface or hitchhiker pests which will warrant a MB fumigation if detected upon inspection.

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ
Sweet Potato from Hawaii	Irradiation has replaced the need for methyl bromide entirely for this commodity	
Grape	Cold treatment for some fruit flies and false codling moth. Irradiation for most insects and *Brevipalpus chilensis* mites approved for all fruits.	
Grapes, stone fruit, clementine		Cold treatment for Bactrocera invadens (2009)
Asparagus	Irradiation for most insects including *Copitarsia decolora* in all vegetables.	
Kiwi	Cold treatment for some fruit flies. Irradiation for most insects and *Brevipalpus chilensis*.	
Pineapple	Vapor heat for some fruit types. Irradiation for most insects, currently used on fruit from Hawaii and Thailand.	
Lemon	Cold treatment alone for some fruit flies. Irradiation for most insects and *Brevipalpus chilensis*.	
Logs	Heat treatment for emerald ash borer and gypsy moth quarantine. Debarking and heat treatment for all imported logs.	Sulfuryl fluoride to target emerald ash borer to allow interstate movement of infested wood

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ
Mangoes from Florida		Vacuum Treatment (2009)
Propagative Dracaena and other canes; cut flowers of all types entering the Plant Inspection Stations		Sulfuryl Fluoride treatment to remove snails (2009)
Avocadoes		Packinghouse washing to remove armored scales (2009)
Wood Packing Material		Radiofrequency (2009)
Dried unroasted coffee beans from Central America shipped to Puerto Rico or Hawaii		Ozone (2009)

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ
Kaffir lime leaves		Washing to target Asian citrus psyllid (2009)
Citrus and citrus-related commodities		Performing a detailed risk analysis to see if we may eliminate need for MB treatment targeting Brevipalpus mites, a vector of citrus leprosis, by determining the likelihood of it's establishment on citrus commodities (2010)
Domestic stone fruit and other potential commodities		Attempting to stimulating industry's interest in using irradiation as a pnytosanitary treatment for export (2010)
Domestic grapes, stone fruit, and pome fruit		Phosphine for mealybugs on grapes and light brown apple moth on stone and pome fruit for export (2010)
Passionfruit from Colombia		Hot water to target Medfly *(2010)*

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ
Cut flowers from Colombia		Perform detailed pathway and risk analysis to eliminate the need for MB treatment to target Copitarsia by estimating likelihood of establishment (2010)
Cape gooseberries from Colombia		Perform detailed pathway and risk analysis to see if we can eliminate the need for MB to target fruit flies in Cape gooseberries from Colombia by investigating host status
Imported tile and stone		Vacuum steam, methyl iodide, and sulfuryl fluoride treatment to target invasive snail species
Equipment and containers entering the country, including military equipment brought in from overseas		Chlorine dioxide
Cherries from Western Australia		Cold treatment to target Queensland Fruit Fly is being considered for implementation, based on recent research indicating that the standard regulatory treatment (cold treatment + methyl bromide) treatment may no longer be necessary.

COMMODITY	ALTERNATIVE TREATMENTS IN THE APHIS PPQ TREATMENT MANUAL[1]	TREATMENTS UNDER DEVELOPMENT BY APHIS PPQ
Imported Bamboo		Vacuum/Steam treatment to target beetles in the family Cerambycidae. This treatment has the potential of saving over 38 tons of MB over a five-year period, representing over 30,100 fumigations.
Durable goods (e.g. solid wood packing material, imported tiles, wool products, rugs)		Vacuum/Steam treatment of to target wood boring beetles and/or hitchhiker pests
Cotton being exported to certain countries, including Peru	High density compression in lieu of fumigation to target pink bollworm and boll weevil (this is an export treatment and as such is not in the Treatment Manual)	

3.3 Barriers to Replacing Methyl bromide

There is a wide range of items that can serve as conveyances for exotic pests to invade new regions and countries including marble stone, military vehicles, agricultural commodities, used automobile tires, wooden packaging materials and many more. All these have served to bring a serious new pest into a previously uninfested country.

Finding replacements for methyl bromide in a major trading country with hundreds of ports of entry is complicated by many factors. They include:

3.3.1 Registration

Many of the potential alternatives will require EPA registration to be legally used. This is a requirement that ensures the protection of the environment, human and animal health. Registration of new alternatives incurs costs of many millions of dollars for the collection of required safety testing, the registration process and marketing. On the other hand, quarantine treatment fumigants, while vital to the health of the environment, agricultural and public lands as well as human and animal health, have a very small market when compared to the market for most agricultural pesticides.

3.3.2 Efficacy

Efficacy requirements for quarantine treatments are very high, many times higher than other types of pesticides because the goal of the treatment is not to reduce the level of the pest to an acceptable level but to completely rid the commodity of the pest. Many countries require quarantine treatments be effective at probit 9 levels (99.9968% kill) for the exotic pests that pose the most serious threats to their countries. Alternatives are rare that meet this level of efficacy and yet be able to pass stringent registration requirements related to safety for health and the environment.

3.3.3 Phytotoxicity

In addition to providing required efficacy in killing the target pest, the alternative must not cause unacceptable damage to the product being fumigated. Fruits and vegetables are particularly susceptible to phytotoxicity which damages or even renders the product unsalable. Few pesticides have the rare combination of features that include extreme toxicity to the pest but mild action of the commodity.

3.3.4 Difference in Quarantine Security

Countries vary in susceptibility to different invasive exotic species. Climate, crops grown, farming practices, types of forests, and many other factors contribute to the risk to a particular country that a pest might pose. Countries have taken note of this and allow countries to set their own level of quarantine security based on the many factors that contribute to the particular risk of any particular pest. The quarantine security level will determine the efficacy requirements of the quarantine treatment for that pest. Methyl bromide is a fumigant that provides broad spectrum efficacy equating to a very high level of quarantine security where as other common commodity treatments may not provide sufficient efficacy. Because countries have different levels of quarantine security, a particular quarantine might be suitable in one country but might not meet quarantine security requirements for that particular pest in another country with higher requirements. As a consequence, there can be no definitive list of quarantine treatments that can be assured to be acceptable across all countries and situations.

3.3.5 Bilateral Agreements

Quarantines relate to the unique situations in the exporting and importing countries. It is not surprising then that trade agreements dealing with quarantine situations are bilateral in nature arrived at by country to country negotiations where detailed discussions have occurred between the importing country and the exporting country to satisfy the importing country that their concerns about introduction of invasive pests have been satisfied. These discussions revolve around the security requirements of the importing country and the measures taken by the exporting country to assure that the commodity being moved in trade will present no risk of introduction of an invasive species. In many cases, a fumigation of comparable treatment will be specified as mandatory by the importing country in order to allow the commodity to entry. The importing country is the sole determinant of the suitability of any treatment proposed by the exporting country.

3.3.6 Logistics

Although some treatments of commodities entering the U.S. occur in the country of origin, thousands of treatments occur after the product has arrived at the port of entry and has been found by inspection to be infested with a quarantine pest. There are several hundred Ports of Entry in the United States and quarantine action may need to be taken at any of them if a quarantine pest is discovered in cargo entering at that Port of Entry. This requires an effective treatment that can be performed without specialized facilities—most generally a fumigant.

3.3.7 Specialized Facilities

Some treatments that may satisfy the United States or other country level of quarantine security for some commodities and situations have a disadvantage of requiring specialized facilities and trained staff to run them. Radiation treatments as well as cold and heat treatments are three such treatments. In the U.S. and many countries, actual quarantine treatments are conducted by private companies, not governmental agencies, and any specialized facilities would need to be provided by these businesses and in many situations they do just that. Heat treatment facilities to export papaya to the U.S. Mainland is an example where private enterprise has invested in facilities that provides the heat quarantine treatment to disinfest papaya grown in the state of Hawaii of fruit flies quarantined on the Mainland. These treatments for some pests can effectively replace methyl bromide treatments but the requirement for specialized equipment and trained staff, generally limit their use to the country of export where there may be sufficient through-put for long periods of time to justify the expense of building the facility and paying a trained staff to run it. At the country of origin, the volume of product being treated may justify these expenses but not at Ports of Entry.

4. Physically Reducing Methyl Bromide Emissions (Decision XX/6(10)(c))

4.1 Exploration of Gas Recapture Technology

The USDA APHIS uses methyl bromide (MB) fumigant for quarantine fumigations at ports of entry and domestic facilities. The Agency also supervises quarantine fumigations conducted internationally as part of preclearance programs. Since the negotiation of the Montreal Protocol in 1987, the USDA APHIS has been actively pursuing MB alternatives and recapturing techniques. One such technology is the charcoal absorber recapture technology. This device traps most of the MB gas, preventing its release into the atmosphere and reducing impacts on the ozone layer. In order for a recapturing unit to be considered for use by USDA APHIS, it must meet the specifications outlined in this section.

A system should:

- Accommodate a variety of enclosure types (portable chamber and fixed chamber)
- Accommodate MB monitoring sensors in the air flow (number and placement of sensors will depend on the size of the equipment)
- Accommodate the fumigant concentrations and temperature conditions listed in this (Treatment) manual
- Ensure that all untreated ventilation air is under negative pressure (in the event of a leak, ambient air will leak into the system instead of contaminated air escaping from the system)
- Leak-tight (includes valves, ducts, canisters)
- Provide a minimum adsorptive capacity of 1 pound of MB per 10 pounds of carbon (The quality of the carbon will determine the adsorptive capacity. A lower quality carbon could cause a ration of 1 pound of MB per 20-25 pounds of carbon.)
- Provide between 4 and 15 complete gas exchanges per hour
- Provide flow and pressure system monitoring

- Provide onsite installation, training, and continual technical support
- Reduce emissions of MB by at least 80%
- Retain approved fumigation and aeration times as mandated by the PPQ Treatment Manual
- Not exceed 500 ppm (2 oz/1000 ft3) MB gas released to the atmosphere and provide the ability to document MB concentration levels

Any recapturing system used in tandem with a PPQ-supervised fumigation must be approved by appropriate authorities.

PPQ has approved a gas recapture system which is being used at a single port in Texas. This port uses only small quantities of gas per year, as the system can only treat one or two containers at a time. The technology to use this system on a large scale has yet to be developed. While PPQ can test and approve gas-recapture technology, PPQ does not have authority under the Plant Protection Act to mandate its use. Such authority would have to come from a Federal, State, or local air quality agency.

5. New Processes to Reduce Use & Emissions

5.1 Treated Logs - Reducing the Total Quantity Needed for Fumigation

PPQ is exploring alternative ways of treating logs such that less gas may be needed to accomplish the phytosanitary treatment required for export to China or the EU. Currently, logs are fumigated by introducing gas under a tarp covering log-filled containers that have been opened. Data are being collected to determine whether less gas is needed if the container remains closed, and the gas is added directly into the container. Due to the fact that containers are not air-tight, the containers will still be kept under a sealed enclosure, such as a tarp, to prevent leakage.

5.2 Impermeable Tarps

ARS with its University and commodity group collaborators have shown in actual field trials that emissions can be cut by 95% by use of impermeable tarps. In other words only 5% of the MB that was applied actually escaped to the air after fumigation, the rest was broken down in the soil. This compares to about 60% of the applied gas escaping to the soil when the soil is tarped by high density polyurethane. These tests were conducted on sandy loam soils in California and are about mid-range in the expected results--very sandy soils would have a somewhat higher emission rate and very reactive soils with high organic matter would have even lower emission rates. Earlier work indicated that treatment of the soil with sodium thiosulfate would reduce emissions similar to the levels seen using the impermeable films but required high level of thiosulfate to be effective--levels that far exceeded levels needed as a fertilizer and a level that potentially could be detrimental to the crop. ARS continues to run large tarp permeability trials in Florida to better characterize the release rate for different cropping methods and soil types.

6. Cooperation with Other Countries

The US works closely with other members of the International Plant Protection Convention (IPPC) to develop standards and guidelines for use by members. In 2008, the Commission on Phytosanitary Measures of the IPPC approved a “Recommendation” termed Replacement or Reduction of the Use of Methyl Bromide as a Phytosanitary Measure. This document provided practical advise for replacing and reducing the use of methyl bromide as we as for reducing emissions and recording usage (See CPM -3 report, 2008). The United States fully endorses these recommendations.

APPENDIX
ARS RESEARCH ACTIVITIES RELATED TO QPS

Controlled Atmospheres
Effective controlled atmospheres, containing ultra-low oxygen (ULO), were developed for control of lettuce aphid without injury to lettuce. This has resulted in greater efforts to find effective ULO treatments for control of other quarantined pests including western flower thrips and leafminer flies on lettuce. The lettuce industry has also shown great interest in ULO treatments for postharvest insect control. Controlled atmosphere treatments have been developed for the Mexican Fruit fly infesting grapefruit and have proved successful on a semi-commercial scale. Host status studies have shown that walnut husk fly, which is a native fruit fly, does not prefer peaches and nectarines, thus opening export markets, based on poor host status, for peaches and nectarines where none existed because of quarantine concerns for the fly.

Combination Systems
Sometimes by combining different techniques, a treatment can be developed that takes advantage of the attributes of each contributor to the combination. Development of a controlled atmosphere/temperature treatment system (CATTS) has been shown to be efficacious and non-injuring to fruit for disinfestation. CATTS technology has been tested both in the laboratory and in commercial settings and provides an viable potential alternative to methyl bromide for quarantine uses.

Physical Control (Heat, Cold and Irradiation)
In the production of exotic fruit and vegetables in Hawaii, studies in heat and cold treatment resulted in the export of litchi, longan and papaya to the mainland and foreign countries. Irradiation research has also resulted in treatments for these commodities plus mangos, rumbutan and sweet potatoes. Tests of irradiation as a quarantine treatment against the most tolerant stages of several insect species have shown that 400 Gy is a secure dose. Cold treatments have been developed for the above named commodities plus avocado and carambola. Forced hot air treatments for citrus have proven successful for eliminating live Mexican fruit flies from grapefruit and ohmic heat has proven promising to disinfest apples of the apple maggot.

Methyl bromide fumigation of fresh prune plums to eliminate codling moth has allowed the plum industry to ship plums to Japan. This quarantine schedule allows millions of dollars worth of plums to be exported from California where a large planting of the plums has resulted in an excess of the fruit. Up until now, the processors of postharvest commodities had only phosphine and methyl bromide to rely upon. With the information developed, they now know that several new potential fumigants exist and that they may be useful alternatives to methyl bromide in both control and quarantine fumigations. CATTS technology has provided the export fruit industry with a viable treatment system that avoids a chemical fumigation treatment while providing pest-free, quality fruit for export. With ozone, registration is not required because it is a GRAS compound, so oranges can now be fumigated to eliminate thrips from the commodity without using methyl bromide. Also, it has been shown that Timothy hay can be successfully treated for Hessian fly in compressed bales using phosphine along with compression. Thus, two new export treatments are now available for use on commodities. Success using controlled atmosphere technology to control insects on harvested leafy vegetables has been encouraging and might lead to treatments that are efficacious and maintain quality.

This success has shown vegetable export industry and scientific community the potential of controlled atmosphere technology to solve postharvest pest problems. In addition, by showing that walnut husk fly is unlikely to infest peaches and nectarines, a large market has been opened in Chile for exports of that stonefruit. Hawaiian commodities are often subject to quarantine treatments because of the fruit fly problems in Hawaii. Technology to replace methyl bromide as a quarantine agent has advanced in the areas of heat/cold and irradiation treatments of commodities from Hawaii resulting in the expansion of export markets for Hawaiian exotic fruits. Irradiation treatments have now been developed that will allow the U.S. to treat for apple maggot, plum curculio and oriental fruit moth in commodities being exported to such countries as Brazil. Finally, systems approach technology is now allowing the export of commodities such as cherries to markets previously only open to methyl bromide fumigated commodities.

Aerosol Space Treatments

ARS scientists have conducted research evaluating the efficacy of aerosol treatments against stored-product insect inside mills, processing facilities, and food storage warehouses. This research has focused on filling gaps in knowledge about efficacy of both current aerosol products and newer systems that can target specific areas within a facility. A series of recent trials inside commercial sites were conducted, using different aerosol products, to control red flour beetle and confused flour beetle larvae and adults.

The confused flour beetle was more tolerant to the evaluated aerosols, and systems that deliver a particle size of 15 to 20 microns seem to give more complete control. Results also show that application systems with separate timing systems for individual areas within a facility show potential for reducing the need for fumigations of the entire site.

Contact Insecticides

Contact insecticides are used as general surface treatments and as crack and crevice or spot applications to control insects in milling, processing, and warehousing facilities. New reduced-risk insecticides such as insect growth regulators (IGRs) can effectively control beetle and moth pests when used as surface treatments, and targeted controls to specific areas are being advocated as a possible alternative to whole-plant fumigations.

Heating of Facilities

Working with heat in facilities, it was found that heat treatments might alleviate the use of methyl bromide in mills and storage facilities. However, different insect species and life stages vary in their response to heat, and acclimation to heat during the heating cycle may be important in mortality. In lab studies where red and confused flour beetles were gradually exposed to temperatures ranging between 120 to 130°F, the time required to kill beetles decreased.

The results of ARS research show that aerosol application systems, particularly those that offer options for targeted control within specific areas, could replace some applications of methyl bromide. There are monitoring systems that can identify locations or sources of infestations, and aerosols can be used to eliminate areas of infestation before they spread to other locations within the facility. Many industrial sites have installed aerosol systems, and use of aerosols, along with other management tactics, show potential for inclusion into an overall management strategy that reduces the need for methyl bromide fumigations. Crack and crevice treatments may help reduce the number of whole-plant fumigations required in a processing plant or storage facility by keeping indigenous populations to a minimum. It may be rather easy to get registrations for some of these new control agents such as IGRs.

Behavioral Studies

The West Indian fruit fly, *Anastrepha oblique* is an exotic pest which on occasion is found in surveillance traps in the southern United States. This fly apparently attacks dooryard fruit such as guava, plum and rose-apple in subtropical areas of Florida and Texas. Because its host range is incompletely known, its detection triggers quarantine restrictions, including a requirement for methyl bromide fumigation. Studies of this species behavior concerning host selection and survival of eggs and larvae in citrus showed that under laboratory conditions only late season (after mid-April) red varieties of grapefruit allow any development of adults. Females will oviposit in grapefruit after color break but egg mortality is 100% until after mid April and normally after seeds in the fruit begin to sprout. Hence, host utilization of this species is so limited that it does not pose a significant threat to U.S. citrus.

Physical Controls

In California a new pest which attacks olives, the olive fruit fly, has become established in the coastal portions of southern California. A cold treatment of 0-1°C for 2 weeks was found to provide a high level of post-harvest pest control for these flies. It has also been found that the climate of the San Joaquin Valley is not conducive to the spread of the olive fruit fly into that area where olives are a major product in California. Work by ARS scientists has also shown that infestation by transported olives from growers to processing areas can be prevented by transporting in brine.

The new information on West Indian fruit fly host relations was used by APHISPPQ to support revision of the absolute quarantine placed on grapefruit during outbreaks. Cold temperature treatments of harvested olives provide a non-chemical alternative to methyl bromide fumigation. Major beneficiaries of this research are fruit producers and packers since there is a reduction in the quarantine actions, including methyl bromide fumigation, often required when the pests are detected.

Sterile Insect Release

The sterile insect technique (SIT) is used to suppress outbreak populations of the medfly. Improvements in this technology include the development of genetic sexing strains so that only males are released, the implementation of an aromatherapy strategy which enhances the competitiveness of the sterile males, and the advent of better lab diets that yield significant cost savings in the mass production of the sterile flies. Similarly, transgenic methods have been developed to produce male-only strains of lepidopteran fruit pests with similar benefits in efficacy and cost. Management techniques were developed and implemented based on knowledge of pest population dynamics allowing integration of biological control methods (such as SIT or augmentation of natural enemies) with pesticides. Among these advances was research which revealed the relationship between climate and population growth of the olive fly in California and the Mexican fruit fly in Texas. In Hawaii a pilot program demonstrated the effectiveness of integrated pest management programs against the fruit fly complex in melon and persimmon cropping systems.

Insecticide Baits

Through a cooperative agreement with Dow AgroSciences, insecticidal bait was developed by ARS scientists using spinosad as the insecticide. This formulation (GF-120) is now registered for use in the U.S. and most fruit producing countries against tropical and temperate fruit flies. A modification of this bait was developed and was registered as organic by USDA and European certification agencies. This bait-spray system provides an alternative to malathion or other organophosphate based sprays for both emergency and management programs against fruit flies and can be used in organic production systems. Synthetic lures have been identified as substitutes for the liquid protein baits that are traditionally used in *Anastrepha* fruit fly traps. Field tests have determined the best combinations against different species while reducing non-target effects which impact operation and maintenance of the surveillance traps. Slow-release technologies have extended the life of attractant devices thus increasing their costeffectiveness.

Prohibition of Imports
Collaboration between ARS and APHIS-PPQ related to identification of risks associated with imported commodities documented that hot chili peppers (*Capsicum pubescens*) imported from Mexico were an uncontrolled pathway for Mexican fruit flies to the U.S. Certain varieties of hot peppers require shade and are intercropped with fruit trees, a factor contributing to their infestation risk. As a consequence, imports of these varieties have been prohibited.

The agricultural community, including research scientists, growers, and especially sterile fruit fly program officials, have several new weapons at their disposal to improve the efficacy and reduce costs of sterile insect releases and other eradication programs worldwide. In Hawaii, growers have completely taken over demonstration programs for fruit fly pest management in persimmon and melons. The new fruit fly suppression technologies have resulted in a drastic reduction in the use of organophosphate insecticides. Fruit fly outbreaks have been eradicated in Florida, Texas, and California using GF-120 in place of the malathion previously used. After forbidding the use of malathion sprays, Mexico and Guatemala have allowed the MoscaMed program to resume sprays over more than 300,000 hectares with GF-120. New improved trap-lure systems are currently being used by California, Florida and Texas action agencies for detecting invasive fruit fly species and by MoscaMed for fruit fly monitoring in Mexico and Guatemala. A patent for "attract and kill" devices has been filed.

Iodomethane
Iodomethane (methyl iodide) is recently approved fumigant that could potentially be used as a near "drop in" replacement for methyl bromide as both a soil fumigant and a commodity treatment. Iodomethane is marketed as a soil fumigant by Arysta Lifesciences under the trade name Midas. It is currently registered in 47 states; registration in CA and WA is still pending, and is not being pursued in NY. Iodomethane is similar to methyl bromide in level of efficacy and the range of pests that are controlled, but is not an ozone depleting chemical or greenhouse gas. It is registered for pre-plant soil fumigation for field grown ornamentals, peppers, strawberries, tomatoes, turf, stone fruits, tree nuts, grapevines, and nurseries to control broadleaf and grass weed seeds, plant-parasitic nematodes, soil-borne insects, and soil-borne diseases. In 2008, about 8000 acres in the U.S. were treated with iodomethane.

This fumigant is more expensive than methyl bromide at this point, but is effective at lower concentrations. Costs of iodomethane treatment on a per acre basis are still higher than methyl bromide, but the price is considered "competitive" by a company representative. Sydorovych et al. (2008) estimated that replacement of methyl bromide with iodomethane in tomato production resulted in $425/acre less profit relative to methyl bromide. Welker (2008) estimated that fumigation of strawberry fields with iodomethane was $130/acre more expensive than methyl bromide in product costs if virtually impenetrable film was used to cover the beds. Highly retentive films greatly reduce the amount of product needed, and 100 lbs/acre is the highest rate of Midas that can be used with these films. Midas was about $9/pound and methyl bromide was about $4.50/pound in this study. An important limitation for use is that the label requirements for iodomethane are much more restrictive than for methyl bromide. For example, no more than 40 acres can be treated in one day and buffer zones between the treatment areas and adjacent properties are required. However, the EPA has proposed new rules for the use of several soil fumigants, including methyl bromide, so they will have similar restrictions as iodomethane if the rules are finalized.

Soil Fumigation

Iodomethane has been reported to be highly effective against several parasitic nematodes including *Heterodera schachtii*, sugar beet cyst nematode. Therefore iodomethane could potentially be an alternative for methyl bromide in the Potato Cyst Nematode program. Scientists with the USDA-Agricultural Research Service are conducting greenhouse trials in Prosser, Washington to evaluate the efficacy of various fumigants against PCN in greenhouse trials. Iodomethane will be added as a treatment in these trials to determine its efficacy against PCN. APHIS will closely monitor these trials so that if iodomethane is effective, this fumigant could displace methyl bromide use in the PPQ PCN program in Idaho. Iodomethane is registered for use in Idaho but potatoes would have to be added to the label if a crop was planted after treatment. Currently the PCN infested fields are treated with methyl bromide once a year at a rate of 400 pounds/acre. If iodomethane is effective at 100 pounds/acre with highly retentive film, there could actually be a reduction in the cost of treatment, despite the higher price per pound. The application restrictions, especially the buffer zones, could be a barrier to switching to iodomethane until methyl bromide use becomes similarly restricted.

Logs

Iodomethane is also being evaluated as a commodity fumigant in Japan and New Zealand. Tests on logs in Japan have shown that iodomethane is effective against pine wood nematode, the Far East rusty long-horned beetle, and other forestry pests. One of the largest uses of methyl bromide in PPQ is for log fumigation, so research on iodomethane as a log fumigant could be very useful in reducing methyl bromide use. The names of foreign researchers that can be contacted for additional information and possibly cooperative methods development are in the next section.

Tile and Stone

Sulfuryl fluoride fumigant is currently being tested for this use. Iodomethane could be also be tested.

Edible commodities

ARS scientists conducted a fumigation test on lemons for phytotoxicity and control of red scale several years ago, but the only current food use is for chestnuts in Japan. Concerns about phytotoxicity and residue levels may be an issue for edible commodities.

Phosphine

Phosphine has been used extensively as an alternative to methyl bromide for commodity fumigation. Phosphine fumigant can be formulated as pellets or tablets that release phosphine gas, or can be applied directly from a gas cylinder. Disadvantages of this product include slow activity (particularly at low temperatures), poor efficacy on pathogens, and development of insect resistance.

Phosphine is currently labeled for use on a number of fruits and vegetables, nuts, processed foods, and nonfood commodities. These include lemons, logs, and bamboo, and a significant amount of PPQ methyl bromide fumigation is directed at these commodities. ECO_2FUME is a 2% phosphine/ 98% carbon dioxide gas product from Cytec Industries that is ready-to-use, non-flammable, and designed for fumigation in sealed storage applications. Residue testing for this product is currently being conducted on grapes. VAPORPH$_3$OS is a pure phosphine gas formulation that requires mixing with another gas on site.

Pests controlled by phosphine include a number of insects, including several moths, beetles, weevils, and fruit flies. Certain species and life stages (such as eggs) require higher exposure levels or treatment times to achieve full mortality, which can be a limitation. Labeled treatment rates of ECO$_2$FUME are 200-1000 ppm for a minimum of 1-6 days, with higher rates and exposure times required at low temperatures or with tolerant pests. Scientists with the PPQ Center for Plant Health Science and Technology (CPHST) have shown that fumigation treatments of 2000 ppm for 120 hours at 6°C provided complete control of eggs of *Copitarsia decolora*, a quarantine pest of asparagus (Scott Myers, 2008). Horn et al. (2005) have reported phosphine fumigation followed by cold treatment is effective against *Brevipalpus chilensis*, a quarantine pest on grapes, citrus, and kiwi. USDA-ARS scientists are investigating adding propylene oxide to phosphine fumigation for grapes to improve efficacy (Spencer Walse, personal communication).

Sulfuryl fluoride

Sulfuryl fluoride (SF) is widely used as a structural fumigant and can provide rapid control of stored product insects and pathogens. Profume (Dow Agrosciences) is a sulfuryl fluoride product that is labeled for use in commodity processing and storage facilities to control storage pests. It is also labeled for use on specific commodities including many grains, nuts, dried fruit, and beans.

SF has been tested extensively on wood products, and is considered to have considerable promise for this use. One limitation is that high concentrations are required to control insect eggs. Another disadvantage is that SF has recently been identified as a greenhouse gas (Journal of Geophysical Research-Atmospheres 114:D05306). SF may be combined with methyl isothiocyanate to improve efficacy. SF has been tested for control of pests in solid wood packing material, lumber and logs and has shown efficacy against pathogens and insects. CPHST has been involved in testing SF for quarantine fumigation of bamboo (Al Barak, personal communication) and tiles (Ron Mack, personal communication). There are PPQ-approved SF treatment schedules for wood borers and termites in certain wood products, including containers.

Ethyl Formate

Ethyl formate is registered in Australia and New Zealand for use on grains and fruits and vegetables as Vapormate (16.7% ethyl formate in CO_2). The mixture with CO_2 is non-flammable and has improved efficacy over pure ethyl formate. Ethyl formate breaks down to ethanol and formic acid and is considered to be safe for food use. Vapormate is registered for control of grain borer *Rhyzopertha dominica*, flour beetle *Tribolium castaneum*, rice weevil *Sitophilus oryzae*, and book lice at a dose of 420 g/m^3, with 6-24 hours exposure in grains. A 4-hour exposure is registered for fruit and vegetable use to control *Frankliniella occidentalis* (thrips), *Tetranychus pacificus* (mite), *Platynota stultana* (leafroller), aphids, and mealybugs (Haritos, 2006). The manufacturer, BOC Limited, is testing Vapormate for controlling mites and mealybugs on pineapples and bananas in the Philipines (Ryan, 2006).

Ethanedinitrile

Ethanedinitrile, also known as cyanogen, is being researched in Australia by CSIRO and industrial gas company BOC Limited as a grain and timber fumigant. Most reports about efficacy are conference presentations, and the efficacy data is reported for pests directly exposed to ethanedinitrile, not for pest infested commodities.

Controlled atmosphere
Controlled atmosphere treatments are generally slow, but do avoid the use of chemical fumigants and avoid chemical residues. They typically use reduced oxygen and/or elevated carbon dioxide to control pests, but can have adverse effects on quality. Table grapes exported from the U.S. bound for Australia and other overseas markets are fumigated with 6% CO_2 plus 1% SO_2 for 30 min at 15.6–20.6°C to control black widow spiders, but also undergo methyl bromide fumigation for other pests.

Irradiation
Irradiation doses for most insects and the mite *Brevipalpus chilensis* have been approved by PPQ for use on all fruits and vegetables. Irradiation is used in export programs to the U.S. from Mexico, Thailand, Vietnam, and India. This is relatively new technology, but irradiation programs are expanding. Research on irradiation in grapes to control *B. chilensis* showed that it was an effective treatment, but Chilean grapes are still being treated with methyl bromide. The Methyl Bromide Alternatives Information System (MBAIS, an Australian database) has a report of irradiation research being conducted on logs. There are published reports on control of wood pests that are directly exposed to irradiation, but not larvae in infested logs.

Microwave / Radiowave frequency heating
Debarking and heating to 71.1°C for 75 minutes is accepted alternative to methyl bromide for logs imported into the U.S., regardless of the method of heating. Microwave / radiowave frequency heating is an alternative to kiln heating of wood for phytosanitary treatment. Microwave heating uses less energy and achieves desired temperatures more quickly. However, the expensive equipment required is a limitation, and the heating can be uneven in the treated commodity. Additional research and possible use of radiofrequency heating in the future may address some of the quarantine issues. CPHST is conducting research to determine if radiofrequency heating can be used to control *Sirex* woodwasp in logs (Ron Mack, personal communication).

Dichloropropene
The fumigant 1, 3 Dichloropropene (Telone) is labeled for use as a soil fumigant to control nematodes, symphylans, and wireworms in soils to be planted with vegetable crops, field crops, fruit and nut crops, and nursery crops. Application rates range from 9-55 gallons/acre depending on the crop, soil type, and pest. There are numerous reports of the nematicidal activity of 1,3-D, and it has also been tested specifically against potato cyst nematode.

Chloropicrin
Chloropicrin is a pre-plant soil fumigant used for the control of soil-borne pests such as wireworms, nematodes and diseases (including certain species of *Phytophthora, Pythium, Fusarium* and *Verticillium*). It is labeled for use in floral crops, nursery crops, plant beds, seed beds, strawberries, tomatoes, peppers, tobacco and dozens of other crops. Labeled rates are 150-500 pounds/acre for most crops (1/3 less if tarped). It is less nematicidal than 1,3-D and is commonly used in combinations with other fumigants such as methyl bromide, 1,3-D, or iodomethane to improve the spectrum of biological activity, particularly for soil pathogen control.

Metam sodium/ Dazomet *(Methyl isothiocyanate [MITC] generators)*
Chemicals which generate MITC in soil are broad spectrum fumigants with activity against nematodes, weeds, oomycetes, and a variety of plant pathogenic fungi. They may be used with other fumigants to provide weed control. Metam sodium (Vapam) is labeled for all crops at 37.5-75 gallons/acre. Dazomet (Basamid) is only labeled for turfgrass and nursery crops at a rate of 260-530 pounds/acre. A disadvantage of these fumigants is the low mobility of MITC in soil, with the

result that careful application is necessary to ensure sufficient distribution in the soil for control. These chemicals control a variety of nematodes, and the Basamid label specifically cites the cyst nematodes *Heterodera schachtii*, *Heterodera goettingia*, and *Globodera rostochiensis*.

Dimethyl disulfide

Dimethyl disulfide (trade name Paladin) is a pre-plant soil fumigant for the treatment of weeds, soil-borne plant pathogens and nematodes in soils to be planted with vegetable and fruit crops where plastic-culture is used for fumigation. The new fumigant is not yet registered with EPA for use by the general public and may only be used under an experimental use permit. Commercial registration is expected in 2009.

Furfural

Furfural is an industrial chemical derived from a variety of agricultural byproducts. Illovo Sugar Ltd. (South Africa) markets a furfural fumigant derived from sugarcane fiber. Furfural was conditionally registered by the EPA in 2006 under the trade name Multiguard Protect, with an application rate of 45 pounds/acre up to 8 times per season. It is labeled as a nematicide/fungicide fumigant for use on nursery materials and non-food/non-feed commodities in greenhouses (no outdoor use). It is used commercially in South Africa on turfgrass.

Propargyl bromide

Propargyl bromide, used in the soil fumigant Trizone in the 1960s, is a potential chemical alternative. that is structurally very similar to methyl bromide, but has a low ozone-depleting potential. It has been shown to be effective in controlling certain nematodes and plant pathogens. However, PBr has never been registered as a commercial pesticide/fumigant. Additional toxicology information is needed for EPA registration.

Witchweed Control

The parasitic plant witchweed (*Striga asiatica*) is currently controlled in the U.S. by fumigation of infested soil with methyl bromide or by injection of ethylene into the soil to induce germination, followed by herbicide application to kill the sprouting plants. Metam sodium and dazomet are also potential fumigant alternatives.

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Phosphine

ECO_2FUME Application Manual. 2005. Cytec Industries.

http://www.cytec.com/specialty-chemicals/products/phosphine-gas.htm

Williams, P., G. Hepworth, F. Goubran, M. Muhunthan, and K. Dunn. 2000. Phosphine as a replacement for methyl bromide for postharvest disinfestation of citrus. Postharvest Biology and Technology 19:193-199.

A 48-h fumigation at 23°C with an initial phosphine concentration of 1.67 g/m³ resulted in 99.998% mortality of Bactrocera tryoni larvae in oranges.

Fields, P.G., and N.D.G. White. 2002. Alternatives to methyl bromide treatments for stored-product and quarantine insects. Annual Review of Entomology 47:331-359.

Glassey, K. 2005. Phosphine as an alternative to methyl bromide for the fumigation of pine logs and sawn timber, pp. 63-1 - 63-2 Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA.

The current specification of phosphine at 200 ppm for 10 days was shown to be effective in all life stages for insects (Cerambycidae, bark beetles, termites) associated with Pinus radiata logs in New Zealand; data suggested this specification could be lowered without compromising efficacy.

Horn, J., P. Horn, F. Horn, and J. Sullivan. 2005. Control of false Chilean mite (*Brevipalpus chilensis*) with a phosphine and cold storage. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA.

B. chilensis adults and eggs were controlled by a combination of fumigation with phosphine at 2500 ppm at 6°C for 72 hours, followed by a cold treatment of 10 days at 0°C. Each treatment alone did not provide sufficient control of the mites.

Myers, S., and J. Nydam. 2008. Efficacy of phosphine at low temperature for insects of quarantine significance, pp. 121-1 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL.

Fumigation treatments of 2000 ppm for 120 hours at 6°C provided complete control of Copitarsia decolora and Lymantria dispar eggs.

Liu, Y.-B. 2008. Low temperature phosphine fumigation for postharvest control of western flower thrips (Thysanoptera: Thripidae) on lettuce, broccoli, asparagus, and strawberrry. Journal of Economic Entomology 101:1786-1791.

Phosphine treatments at 250 ppm and 2°C for 18 hours achieved total control of thrips in jars. Thrips were also controlled in fumigated lettuce and broccoli treated at 1000 ppm for 24 hours. No phytotoxicity was observed in broccoli, lettuce, asparagus, or strawberry fumigated at low temperature.

Sulfuryl fluoride

Profume Gas Fumigant Label and Applicator Manual.. Dow Agrosciences http://www.dowagro.com/PublishedLiterature/dh_014b/0901b8038014b5d3.pdf?filepath=profume/pdfs/noreg/010-70687.pdf&fromPage=GetDoc

Woodward, R.P., and E.L. Schmidt. 1995. Fungitoxicity of sulfuryl fluoride to *Ceratocystis fagacearum* in vitro and in wilted red oak log sections. Plant Disease 79:1237-1239.

Ceratocystis fagacearum was eradicated from log sections treated with 280 g/m³ SF for 72 hours.

Schmidt, E.L., J. Juzwick, and B. Schneider. 1997. Sulfuryl fluoride fumigation of red oak logs eradicates the oak wilt fungus. Holz als Roh-und Werkstoff 55:315-318.

The oak wilt fungus can be killed throughout red oak logs after fumigation with SF treatment of 27,400 g h/m³ at 10-20°C. However, not all microorganisms were eliminated.

Dwinell, L.D., E. Thoms, and S. Prabhakaran. 2003. Effect of sulfuryl fluoride on the pinewood nematode in pine wood. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. pp. 94-1.

SF accumulated CxT dosages ranging from 997 to 1751 g/h/m³ completely controlled pinewood nematode in lumber.

Abe, Y., T. Itabashi, Y. Soma, H. Komatsu, and F. Kawakami. 2005. Methyl iodide and mixture gas of methyl isothiocyanate and sulfuryl fluoride fumigation as a quarantine treatment for solid wood packing material, pp.67-1 - 67-3. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, CA.

Complete mortality of pinewood nematode, Xyleborus perforans, X. pfeilii, Callidiellum rufipenne, and Cryphalus fulvus at 21/21 g/m³ of MITC/SF at 18-25°C in pine packing material. This mixture was registered in Japan for treatment of logs in 2004.

Soma, Y., H. Komatsu, Y. Abe, T. Itabashi, Y. Matsumoto, and F. Kawakami. 2006. Effects of some fumigants on mortality of the pine wood nematode, Bursaphelenchus xylophilus infesting wooden packages, 7: Fumigation schedules for pine wood nematode by mixture gas of methyl isothiocyanate and sulfuryl fluoride. Research Bulletin of the Plant Protection Service (Japan) 42:15-22.

Fumigation of pine packing material in a fumigation box with 21/21 g/m³ of MITC/SF at 10°C 18/18 g/m³ of MITC/SF at 15°C, and 15/15 g/m³ of MITC/SF at 25°C resulted in complete mortality of pine wood nematode.

Barak, A., Y. Wang, G. Zhan, Y. Wu, L. Xu, and Q. Huang. 2006. Sulfuryl Fluoride as a Quarantine Treatment for *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in Regulated Wood Packing Material. Journal of Economic Entomology 99:1628-1635.

SF treatments at a dose of at least 104 g/m³and above 15.6°C were recommended for control of Anoplophora glabripennis larvae and pupae in wood packing material.

Zhang, Z. 2006. Use of sulfuryl fluoride as an alternative fumigant to methyl bromide in export log fumigation. New Zealand Plant Protection 59:223-227.

One day direct exposure fumigation with SF controls of Arhopalus tristis eggs at 120 g/m³, Hylastes ater larvae and adults at 15 g/m³, and eight fungi at 30 g/m³. Not tested on infested logs.

Messenger, M., A. Barak, P. Neese, E. Thoms, and S. Prabhakaran. 2008. Sulfuryl fluoride as a quarantine treatment for the emerald ash borer in firewood, pp. 92-1 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL.

SF was effective in eliminating EAB larvae (the most tolerant life stage) in ash logs when treated for 24 hours at 15.6°C or above.

Tubajika, K. M. and A. V. Barak. Methyl Iodide and Sulfuryl Fluoride as Quarantine treatments for Solid Wood Packing Material. PPQ-CPHST Project Summary Report.

Control of Ceratocystis fagacearum in wood blocks with 24 hour fumigation with SF at 240 g/m^3.

Iodomethane (Methyl iodide)

Midas 98:2 Product Label. Arysta Lifesciences.
http://www.arystalifescience.com/default.asp?V_DOC_ID=1876

Aung, L., J. Leesch, and J. Jenner. 2004. Methyl iodide and forced aeration on the post-harvest quality of lemons. Postharvest Biology and Technology 33:45-50.

Dosage of 26 g/m^3 for 2 h combined with 24-h forced aeration post-fumigation could provide an effective quarantine treatment for lemon to control California red scale (Aonidiella aurantii).

Abe, Y., T. Itabashi, Y. Soma, H. Komatsu, and F. Kawakami. 2005. Methyl iodide and mixture gas of methyl isothiocyanate and sulfuryl fluoride fumigation as a quarantine treatment for solid wood packing material, pp.67-1 - 67-3. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, CA.

Complete mortality of the pine wood nematode and the Arhopalus rusticus longhorn beetle were attained at 84g/m^3 at 10°C, 60g/m^3 at 15°C, 64g/m^3 at 20°C, 48g/m^3 at 25°C, respectively, after a 24 hour fumigation of infested logs and lumber with methyl iodide.

Soma, Y., H. Komatsu, Y. Abe, T. Itabashi, Y. Matsumoto, and F. Kawakami. 2006. Effects of some fumigants on mortality of the pine wood nematode, *Bursaphelenchus xylophilus* infesting wooden packages 6. Mortality of pine wood nematode and longhorn beetles by methyl iodide tarpaulin fumigation. Research Bulletin of the Plant Protection Service (Japan) 42:7-13.

Complete mortality of pine wood nematode was attained at each of 84 g/m^3 at 10°C, 60 g/m^3 at 15°C, 64 g/m^3 at 20°C and 48 g/m^3 at 25°C. Complete mortality of larvae and pupae of longhorn beetle, Arhopalus rusticus and pine sawyer Monochamus alternatus was attained at each of 84 g/m^3 at 10°C, 60 g/m^3 at 15°C, and 36 g/m^3 at 25°C.

Ethyl Formate

Damcevski, K., G. Dojchinov, and V. Haritos. 2003. Vapormate, a formulation of ethyl formate with CO_2, for disinfestation of grain, p. 199-204, In E. J. Wright, et al., eds. Stored grain in Australia 2003. Proceedings of the Australian Postharvest Technical Conference, Canberra, Australia.

Ryan, R., P. Martin, N. Haines, R. Reddi, D. Beven, and A. Harvey. 2006. Vapormate: A niche methyl bromide alternative, pp 139-1 – 139-2. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL.

Haritos, V., K. Damcevski, G. Dojchinov, and R.F. Ryan. 2006. Vapormate: Update- a new fumigant for stored grain. Australian Postharvest Technical Conference.

The proposed new VAPORMATE label rates cover the complete control of all stages of R. dominica, T. castaneum, Psocids, storage moths (Ephestia spp., Plodia spp.), Trogoderma variabile, Orysoephilus spp., Collosobruchus spp., Bructus pisorum: In cereal grain and oilseeds: 660g/m³ held for 4 hours or 420g/m³ held for 24 hours. Complete control of rice weevil (Sitophilus oryzae) in cereal grains and oilseeds: 940g/m³ held for 72 hours.

Simpson, T., V. Bikoba, C. Tipping, and E. Mitcham. 2007. Ethyl Formate As a Postharvest Fumigant for Selected Pests of Table Grapes. Journal of Economic Entomology 100:1084-1090.

Ethyl formate concentrations up to 5% for 1-2 hours were effective against Frankliniella occidentalis (thrips), Pseudococcus maritimus (mealybug),Tetranychus pacificus (mite), and Platynota stultana (leafroller).

Ethanedinitrile

Smith, B.J., Y. Ren, and C.J. Waterford. 2003. Response of seed-borne fungi to fumigation with ethanedinitrile at various dosages, p. 217-220, In E. J. Wright, et al., eds. Stored grain in Australia 2003. Proceedings of the Australian Postharvest Technical Conference, Canberra, Australia.

Ethane dinitrile fumigation at 180 g/h/m³ controls Fusarium and Phytophthora fungi.

Ren, Y., H. Dowsett, Y.J. Wang, X. Wang, and A. Barak. 2005. Toxicity of ethanedinitrile (C_2N_2) to timber or wood related insect pests, pp. 86-1 - 86-3 Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA.

With direct exposure for 6 hours to C_2N_2 at 21-25°C, all the larval stages of A. glabripennis were completely killed at 11mg/L, workers of C. acinaciformis, C. brevis and M. darwiniensis were completely killed at 1.61mg/L, 3.0mg/L and 2.3mg/L respectively and the adult stage of R. dominica was completely killed at 1.0mg/L.

Ryan, R., P. Martin, N. Haines, R. Reddi, D. Beven, and A. Harvey. 2006. Sterigas & Cosmic: Update on proposed new fumigants, pp. 138-1- 138-2 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.

CSIRO in Australia is conducting efficacy trials on ethanedinitrile for BOC Limited. This fumigant, marketed as Sterigas, reportedly shows promise for soil and timber fumigation.
STERIGAS 1000 Draft Label Applications:

- *Devitalise grains & weed seeds + sterilise pathogens: 115g/m³ for 5 d exposure*
- *Timber and logs for export 50 g/m³, 6 h exposure*

Controlled Atmosphere

Mitcham, E., S. Zhou, and V. Bikoba. 1997. Controlled atmospheres for quarantine control of three pests of table grape. Journal of Economic Entomology 90: 1360-1370.

Treatment of grapes for 12 days at 0°C with 45% CO_2 and 1.5% O_2 controls Tetranychus pacificus spider mite, Platynota sultana moth, and Frankliniella occidentalis thrips.

Liu, Y., K. Daane, J. Tebbets, and L. Bettiga. 2008. Ultralow Oxygen Treatment for Control of *Latrodectus hesperus* (Araneae: Theridiidae) on Harvested Table Grapes. Journal of Economic Entomology 101:1515-1518.

Complete control of the black widow spiders was achieved in 24-h ULO treatments with 0.5% O_2 or lower at 1°C and in a 24-h low oxygen (2%) treatment at 15°C.

Irradiation

Morrell, J.J. 1995. Importation of unprocessed logs into North America: a review of pest mitigation procedures and their efficacy. Forest Products Journal 45:41-50.

This report reviews the efficacy of various mitigation procedures (e.g., heat, fumigation, and irradiation) in relation to controlling pests established deep in the wood. Except for heating, existing data on the mitigation procedures are inadequate to support their use to eliminate pests established beyond the surface of imported logs. Research needs for mitigating the risks of log imports are provided.

Lester, P., D. Rogers, R. Petry, P. Connolly, and P. Roberts. 2000. The lethal effects of gamma irradiation on larvae of the Huhu beetle, *Prionoplus reticularis*: a potential quarantine treatment for New Zealand export pine trees. Entomologia Experimentalis et Applicata 94:237-242.

Lethal dose (LD99) of gamma irradiation for Prionoplus reticlaris was 3677 Gy for 3 days or 2476 Gy for 10 days. No testing against larvae in wood. Wood moisture affected radiation penetration.

Castro, D., J. Espinsa, and M. Vargas. 2004. Ionising radiation as a quarantine treatment for controlling *Brevipalpus chilensis* (Acarina: Tenuipalpidae) in Thompson seedless grapes, In P. Loaharamu and T. W. Rubio, eds. Irradiation as a phytosanitary treatment of food and agricultural commodities. International Atomic Energy Agency, Vienna.

Irradiation of grapes at 300 Gy sufficient to stop reproduction of Brevipalpus chilensis, or 200 Gy with 15 days cold treatment.

Microwave/Radiowave frequency heating

Fleming, M., K. Hoover, J. Janowiak, Y. Fang, X. Wang, W. Liu, Y. Wang, X. Hang, D. Agrawal, and V. Mastro. 2003. Microwave irradiation of wood packing material to destroy the Asian longhorned beetle. Forest Products Journal 53:46-52.

Blocks of wood were artificially infested with Asian longhorned beetle larvae. Irradiation of 4 inch square blocks for 3 minutes at 900 watts killed all larvae and pupae.

Fleming, M., J. Janowiak, J. Kimmel, J. Halbrendt, L. Bauer, D. Miller, and K. Hoover. 2005. Efficacy of commercial microwave equipment for eradication of pine wood nematodes and cerambycid larvae infesting red pine. Forest Products Journal 55:227-232.

Batch irradiation resulted in 100% mortality of pinewood nematode and cerambycid larvae in 4x4x20 inch pine samples heated to 62°C or greater. Mortality at lower temperatures was achieved with continuous feed equipment.

Nzokou, P., S. Tourtellot, and D. Kamdem. 2008. Kiln and microwave heat treatment of logs infested by the emerald ash borer (*Agrilus planipennis* Fairmaire)(Coleoptera: Buprestidae). Forest Products Journal 58:68-72.

Kiln temperatures of 65°C were effective in sanitizing logs infested with EAB. Microwave treatments were not as effective, probably due to uneven heating and still need some improvement.

Dichloropropene

Telone II Soil Fumigant Label. Dow Agrosciences. http://www.cdms.net/LabelsMsds/LMDefault.aspx

Been, T., and C. Schomaker. 1999. Fumigation of marine clay soils infested with *Globodera pallida* and *G. rostochiensis* using 1,3-dichloropropene and additional top soil treatments. Nematology 1:3-14.

Fumigation with 1,3-D at 150 L/ha killed 48, 48, and 72% of the PCN in three fields, respectively.

Minnis, S., P. Haydock, and K. Evans. 2004. Control of potato cyst nematodes and economic benefits of application of 1, 3-dichloropropene and granular nematicides. Annals of Applied Biology 145:145-156.

Use of 1,3-D as part of an integrated approach to control potato cyst nematodes was effective in decreasing nematode populations.

Chloropicrin

Nutrapic Fumigant Label. Arysta Lifesciences. http://www.cdms.net/LabelsMsds/LMDefault.aspx

Duniway, J. 2002. Status of chemical alternatives to methyl bromide for pre-plant fumigation of soil. Phytopathology 92:1337-1343.

Metam sodium/Dazomet

Vapam Product Label. Amvac Chemical Corporation.

Basamid Specimen Label. Certis USA, L.L.C.

http://www.cdms.net/LabelsMsds/LMDefault.aspx

Csinos, A.S., Sumner, D.R., Johson, W.C, Johnson, A.W., McPherson, R.M., and Dowler, C.C. 2000. Methyl bromide alternatives in tobacco, tomato, and pepper transplant production. Crop Protection 19: 39-49.

When applied in the fall of the year to nursery beds of bell pepper, tomato, and tobacco, metam sodium was similar to methyl bromide plus chloropicrin (98:2) in 76 out of 79 tested parameters which included crop vigor, winter annual weed control, soilborne fungal populations, nematode soil populations, and nematode injury ratings.

Duniway, J. 2002. Status of chemical alternatives to methyl bromide for pre-plant fumigation of soil. Phytopathology 92:1337-1343.

Iodomethane/Methyl Iodide

Midas 98:2 Product Label. Arysta Lifesciences. http://www.arystalifescience.com/default.asp?V_DOC_ID=1876

McMillan, R.T., Jr., and Bryan, H.J. 1996. Methyl iodide a replacement of methyl bromide as a soil fumigant for tomatoes. Proc. Fla. State. Hort. Soc. 109: 200-201.

Five soil fumigant, methyl bromide (250 lbs/acre), MC33 (67% methyl bromide + 33% chloropicrin, 250 lbs/acre), chloropicrin (75 lbs/acre), methyl iodide (375 lbs/acre), and methyl iodide plus chloropicrin were evaluated for the control of soilborne diseases, root knot nematode, yellow nutsedge weed control, and for fruit yield. Methyl bromide, MC33, methyl iodide +chloropicrin, and methyl iodide provided statistically significant control of corky brown rot (Pyrenochaeta lycopersici), root knot nematode (Meloidogyne incognita), and yellow nutsedge (Cyperus esculentus).

Becker, J.O., H.D. Ohr, N.M. Grech, M.E. McGiffen Jr, and J.J. Sims. 1998. Evaluation of methyl iodide as a soil fumigant in container and small field plot studies. Pesticide Science 52:58-62.

Iodomethane applied at a rate of 168 kg/ha controlled nematodes Meloidogyne incognita, Heterodera schachtii, and Tylenchulus semipenetrans as well as Pythium spp.

Hutchinson, C.M., McGiffen, M.E., Ohr, H.D., Sims, J.J., and Becker, J.O. 1999. Efficacy of methyl iodide soil fumigation for control of *Meloidogyne incognita, Tylenchulus semipenetrans*, and *Heterodera schactii*. Nematology 1(4): 407-414.

A comparison of the methyl bromide: methyl iodide ratios at the $EC(ED)_{90}$ *(effective dose required to control 90% of the nematode concentration) rates indicated that, averaged over all treatments, methyl iodide was 4.67 and 1.77 more potent than methyl bromide in laboratory and field experiments, respectively.*

Eayre, C.G., Sims, J.J., Ohr, H.D., and Mackey, B. 2000. Evaluation of methyl iodide for control of peach replant disorder. Plant Disease 84: 1177-1179.

Peach replant soils were fumigated with methyl bromide or methyl iodide at rates of 393 to 448 kg/ha. Plots fumigated with MI did not differ from plots fumigated with MB in trunk growth, weight of branch prunings, or reductions in population densities of the nematode Paratylenchus. MI and MB appeared to be equally effective in controlling replant disorder.

Schneider, S.M., Ajwa, H.A., Trout, T.J., and Gao, S. 2008. Nematode control from shank- and drip-applied fumigant alternatives to methyl bromide. HortScience 43(6): 1826-1832.

Iodomethane controlled citrus citrus nematode (Tylenchulus semipentrans) and/or the root-knot nematodes (Meloidogyne spp.) as well as methyl bromide/chloropicrin and was superior to other alternatives (1,3-D, metam sodium, propargyl bromide) in the depth of soil with nematode control.

Sydorovych, O., C.D. Safley, R.M. Welker, L.M. Ferguson, D.W. Monks, K. Jennings, J. Driver, and F.J. Louws. 2008. Economic Evaluation of Methyl Bromide Alternatives for the Production of Tomatoes in North Carolina. HortTechnology 18:705-713.

Chloropicrin applied at 15 gal/acre provided the greatest returns in tomato production with an additional return of $907/acre relative to MeBr. Telone-C35 provided an additional return of $848/acre and drip-applied metam sodium provided an additional return of $137/acre. The return associated with broadcast applied metam sodium was about equal to the estimated return a grower would receive when applying MeBr. Fumigating with a combination of chloropicrin and metam

sodium; shank-applied chloropicrin at 8 gal/acre; drip-applied chloropicrin, Midas, or InLine; and the nonfumigated soil treatment all resulted in projected losses of $156/acre, $233/acre, $422/acre, $425/acre, $604/acre, and $2133/acre, respectively, relative to MeBr.

Welker, R.M. 2008. Methyl Bromide Update [Online] http://www.smallfruits.org/CoAgentTraining/Nov2008Strawberry/5%20Welker-2008%20agent%20training.ppt#285,1,Methyl Bromide Update Rob Welker Department of Plant Pathology - NCSU (verified April 14).

The costs of various methyl bromide alternatives were compared. It was estimated that fumigation of strawberry fields with iodomethane was only $130/acre more expensive than methyl bromide in product costs if virtually impenetrable film (which requires lower application rates) was used to cover the beds.

Dimethyl disulfide

Coosemans, J. 2005. Dimethyl disulphide (DMDS): a potential novel nematicide and soil disinfectant. Acta Horticulturae 698:57-64.

At 0.3, 0.6 and 0.8 ml per dm^3 soil, DMDS reduced potato cyst nematode development and root-knot disease incidence on tomato as well as plant parasitic nematode soil population density (by 90% relative to the untreated control).

Olson, S.M., and Rich, J. 2007. Efficacy of Paladin (DMDS) as a soil fumigant for tomato and cantaloupe production, 68-1 to 68-4. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.

DMDS plus chloropicrin (Paladin 79:21; 549, 823 kg/ha) was evaluated for nutsedge and bacterial wilt (Ralstonia solanacearum) control in tomatoes and compared to methyl bromide/chloropicrin (67/33; 196 and 392 kg/ha). Paladin performed equally to MB when used in tomato production. In cantaloupe, Paladin (100%, 448 and 448 kg/ha) was compared to Telone II (170 kg/ha) and methyl bromide (98:2; 185, 269 kg/ha) for nutsedge control and yield and root gall index (Meloidogyne spp.). Methyl bromide gave the best nutsedge control and Paladin using virtually impenetrable film was not significantly different than methyl bromide. For root gall index, Paladin did not differ from the untreated control.

Furfural

Rodriguez-Kabana, R., J.W. Kloepper, C.F. Weaver, and D.G. Robertson. 1993. Control of plant parasitic nematodes with furfural- a naturally occurring fumigant. Nematropica 23:63-73.

Furfural at 0.1-1.0 ml/kg of soil in greenhouse experiments suppressed populations of Meloidogyne arenaria, M. incognita, Pratylenchus brachyurus, and Heterodera glycines. Nematode control was also demonstrated in microplot experiments at rates of 53-159 ml/m^2 soil.

Kokalis-Burelle, N. 2007. Multiguard ®: Effects on nematode populations and galling on tomato and pepper, pp.118-1 to 118-3. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Orlando, FL.

Greenhouse trials were conducted over three season on plant growth and root knot population and galling in tomato and pepper. As in the fall trials, the 452 kg/ha preplant Multiguard treatments significantly reduced galling on tomato. Post-plant applications did not significantly increase *nematode control over the 452 kg/ha preplant rate alone. Multiguard has an effect on either the host plant or the nematode that inhibits gall formation in tomato.*

Abdel-Rahman, F.H., Clark, S., and Saleh, M.A. 2008. Natural organic compounds as alternatives to methyl bromide for nematodes control. Journal of Environmental Science and Health. Part B: Pesticides, Food Contaminants, and Agricultural Wastes 43(8): 680-685.

Thirty-three organic acids and furfural metabolites were examined for their nematicidal activity against plant parasitic (Tylenchulus semipenetrans, Paratylenchus spp., Helicotylenchus spp., Criconemella spp., Rotylenchulus spp., Meloidogyne spp., Xiphinema spp., and Trichodorus spp.), free-living, and predacious nematodes. Furfural resulted in 87% mortality for all nematodes combined.

<u>Propargyl bromide</u>

Zasada, I.A., Elmore, C.L., Yakabe, L.E., and MacDonald, J.D. 2007. Evaluation of propargyl bromide as a soil fumigant. Hort Science 42(5): 1212-1216.

Propargyl bromide was applied to soil in large, buried containers at rates of 28, 56, 84, 112, and 168 kg/ha and compared to standard soil fumigants methyl iodide (168, 263 kg/h), methyl bromide/chloropicrin (364 kg/ha (87%:33%)), and metham sodium (358 kg/ha). The citrus nematode (Tylenchulus semipenetrans) and an isolate of Fusarium oxysporum were both controlled at the lowest rate of propargyl bromide tested (28 kg/h).

Duniway, J. 2002. Status of chemical alternatives to methyl bromide for pre-plant fumigation of soil. Phytopathology 92:1337-1343.

<u>Witchweed Control</u>

Sand, P.F., Eplee, R.E., and Westbrooks, R.G. 1990. Witchweed research and control in the United States. In Monograph Series on the Weed Science Society of America. No. 5, WSSA, Champaign, IL. Pp 56 – 117.

Witchweed germination was 97% and 93% for ethylene (ul/l) and ethephon (mg/l)when concentrations reached 10^{-1} *ul/l or mg/l, respectively. Witchweed germination was 0% and 95%, after 2 hours of exposure at* 10^{-3} *M ethephon concentration for soil with pH levels at 5.0 and 6.5, respectively. Metam sodium applied at 654 or 935 l/ha and disked twice resulted in 0% witchweed germination in 1980 APHIS field trial. Dazomet, disked twice and applied at 324 – 647 kg/ha had 0% witchweed germination at 52 days after application.*